Food and Agriculture
Organization of the
United Nations

MAIN REPORT

THE STATE OF THE WORLD'S LAND AND WATER RESOURCES FOR FOOD AND AGRICULTURE 2021

Systems at breaking point

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Main report

Food and Agriculture Organization of the United Nations
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FOREWORD

The state of the world's land and water resources for food and agriculture 2021 (SOLAW 2021) provides new information on the status of land, soil and water resources, and evidence of the changing and alarming trends in resource use. Together, they reveal a situation that has much deteriorated in the last decade, when the first SOLAW 2011 report highlighted that many of our productive land and water ecosystems were at risk. The pressures on land and water ecosystems are now intense, and many are stressed to a critical point.

Against this background, it is clear our future food security will depend on safeguarding our land, soil and water resources. The growing demand for agrifood products requires us to look for innovative ways to achieve the Sustainable Development Goals, under a changing climate and loss of biodiversity. We must not underestimate the scale and complexity of this challenge. The report argues that this will depend on how well we manage the risks to the quality of our land and water ecosystems, how we blend innovative technical and institutional solutions to meet local circumstances, and, above all, how we can focus on better systems of land and water governance.

The interlinked actions and coalitions resulting from the 2021 United Nations Food Systems Summit provide an important entry to renew national and global priorities, and as a basis to advance the transformation of our agrifood systems to be more efficient, inclusive, resilient and sustainable.

A meaningful engagement with the key stakeholders – farmers, pastoralists, foresters and smallholders – directly involved in managing soils and conserving water in agricultural landscapes is central. These are nature's stewards and the best agents of change to adopt, adapt and embrace the innovation we need to secure a sustainable future.

I invite you to read the SOLAW 2021 report with a view to the fundamentals of all terrestrial agrifood production. Land degradation and water scarcity will not disappear. However, while the scale of the challenge is daunting, whether as cultivators of land or consumers of food, even small shifts in behaviours will see the much-needed transformation at the core of our global agrifood systems.

The new FAO Strategic Framework 2022-31 firmly commits the Organization to promote the sustainable management of our vital land and water ecosystems for better production, better nutrition, a better environment and a better life for all, leaving no one behind.

Dr Qu Dongyu
Director-General
Food and Agriculture Organization of the United Nations

PREFACE

Setting the scene

Human use of land and water for agriculture has not yet peaked, but all evidence points to slowing growth in agricultural productivity, rapid exhaustion of productive capacity and generation of environmental harm. Taking production that is more environmentally responsible and climate smart to scale can reverse trends in the deterioration of land and water resources and promote inclusive growth. This aligns with the aspirations of the FAO strategic framework: "better production, better nutrition, a better environment and a better life".

Taking production that is more environmentally responsible and climate smart to scale can reverse trends in the deterioration of land and water resources and promote inclusive growth.


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The past decade has seen the advent of several important global policy frameworks including the 2030 Agenda for Sustainable Development, the Paris Agreement on climate change, the Sendai Framework for Disaster Risk Reduction 2015–2030, the Small Island Developing States Accelerated Modalities of Action, the New Urban Agenda and the Addis Ababa Action Agenda on Financing for Development. The frameworks have introduced the Sustainable Development Goals (SDGs), nationally determined contributions and land degradation neutrality. In particular, there are dedicated SDGs for water, and targets for land and soil health. The frameworks are accompanied by global assessments of natural resources, including soils, forestry, biodiversity, desertification and climate. *The state of the world's land and water resources for food and agriculture 2021* (SOLAW 2021) report aims to take stock of the implications for agriculture and recommend solutions for transforming the combined role of land and water in global food systems.

The uncertainty of climate change and the complex feedback loops between climate and land present agriculture with amplified levels of risk that need to be managed. A global view points to a convergence of factors putting unprecedented pressure on land and water resources, leading to a set of human impacts and shocks in the supply of agricultural products, notably food. The SOLAW 2021 report argues that a sense of urgency needs to prevail over a hitherto neglected area of public policy and human welfare, that of caring for the long-term future of land, soil and water.


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Taking care of land, water and particularly the long-term health of soils is fundamental to accessing food in an ever-demanding food chain.

Shocks, including severe floods, droughts and the COVID-19 pandemic tend to divert attention away from development priorities. International finance institutions warn of the widening fault lines between developed and developing countries in meeting global goals while facing resurgent infections and rising death tolls from COVID-19. Recovery programmes offer opportunities to address urgencies and kick-start the process of change, including in land and water management.

Land, soil and water form the basis of the FAO commitment to the changes advocated in the 2021 United Nations Food Systems Summit. However, recognition and actions are needed to redirect the focus onto the land, on which 98 percent of the world's food is produced. Taking care of land, water and particularly the long-term health of soils is fundamental to accessing food in an ever-demanding food chain, guaranteeing nature-positive production, advancing equitable livelihoods, and building resilience to shocks and stresses arising from natural disasters and pandemics. They all start from land and water access and governance. Sustainable land, soil and water management also underpin nutritious, diverse diets and resource-efficient value chains in the shift to sustainable consumption patterns.

What SOLAW 2021 says

The SOLAW 2021 report comes at a time when human pressures on the systems of land, soils and freshwater are intensifying, just when they are being pushed to their productive limits. The impacts of climate change are already constraining rainfed and irrigated production over and above the environmental consequences resulting from decades of unsustainable use.

The SOLAW 2021 report builds on the concepts and conclusions given in the previous SOLAW 2011 report. Much has happened in the intervening years. Recent assessments, projections and scenarios from the international community paint an alarming picture of the planet's natural resources – highlighting overuse, misuse, degradation, pollution and increasing scarcity. Rising demands for food and energy, competing industrial, municipal and agricultural uses, and the need to conserve and enhance the integrity of the Earth's ecosystems and their services make the picture extremely complex and full of interlinkages and interdependencies.

The SOLAW 2021 report adopts the driver–pressure–state–impact–response approach. This is a well-established framework for analysing and reporting important and interlinked relationships among sustainable agricultural production, society and the environment. The approach provides a structure to report on cause–effect relationships to arrive at key policy recommendations and enable policymakers to assess the direction and nature of changes needed to advance sustainable management of land and water resources.

The **drivers** of demand for land and water resources are complex. By 2050, FAO estimates agriculture will need to produce almost 50 percent more food, fibre and biofuel than in 2012 to satisfy global demand and keep on track to achieve "zero hunger" by 2030. Progress made in reducing the number of undernourished people in the early part of the twenty-first century has been reversed. The number has risen from 604 million in 2014 to 768 million in 2020. While prospects for meeting the nutritional requirements of 9.7 billion people by 2050 at the global level exist, problems with local patterns of production and consumption are expected to worsen, with increasing levels of undernourishment and obesity among the steadily growing and mobile population.

Options to expand cultivated land areas are limited. Prime agricultural land is being lost to urbanization. Irrigation already accounts for 70 percent of all freshwater withdrawals. Human-induced land degradation, water scarcity and climate change are increasing the levels of risk for agricultural production and ecosystem services at times and in places where economic growth is needed most.

Most **pressures** on the world's land, soil and water resources derive from agriculture itself. The increase in use of chemical (non-organic) inputs, uptake of farm mechanization, and overall impact of higher monocropping and grazing intensities are concentrated on a diminishing stock of agricultural land. They produce a set of externalities that spill over into other sectors, degrading land and polluting surface water and groundwater resources.

The **impacts** from accumulating pressures on land and water are felt widely in rural communities, particularly where the resource base is limited and dependency is high, and to a certain extent in poor urban populations where alternative sources of food are limited. Human-induced deterioration of land, soil and water resources reduces production potential, access to nutritious food and, more broadly, the biodiversity and environmental services that underpin healthy and resilient livelihoods.

A central challenge for agriculture is to reduce land degradation and emissions and to prevent further pollution and loss of environmental services while sustaining production levels. Responses need to include climate-smart land management attuned to variations in soil and water processes. Management options are available to increase productivity and production levels if innovation in management and technology can be taken to scale to transition to sustainable agrifood systems. However, none of this can go far without planning and managing land, soil and water resources through effective land and water governance.

> Human-induced land degradation, water scarcity and climate change are increasing the levels of risk for agricultural production and ecosystem services at times and in places where economic growth is needed most.

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Increasing land and water productivity is crucial for achieving food security, sustainable production and SDG targets. However, there is no "one size fits all" solution. A "full package" of workable solutions is now available to enhance food production and tackle the main threats from land degradation, increasing water scarcity and declining water quality.


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Injecting a sense of urgency into making the necessary transformations in the core of the global food system is essential.

The SOLAW 2021 report indicates how **institutional and technical responses** can be packaged to address the challenges of increasing water and food security within land, soil and water domains, and, more widely, across agriculture and food systems. It stresses the importance of integrated approaches in managing land and water resources. Sustainable land management, sustainable soil management and integrated water resources management are all examples of such approaches, which can be blended with technology innovation, data and policies to accelerate improvement in resource-use efficiency, raise productivity and align progress with SDGs.

An important point to recognize is that many agents of change in the landscape remain excluded from the benefits of technical advances. This applies to disproportionately poorer and socially disadvantaged groups, with most living in rural areas. While technical solutions to specific land and water challenges may be within grasp, much will depend on how land and water resources are allocated. **Inclusive forms of land and water governance** will be adopted at scale only when there is political will, adaptive policymaking and follow-through investment. A primary focus on land and water governance is essential in creating the transformative changes needed to achieve patterns of sustainable agriculture that can enhance income and sustain livelihoods while protecting and restoring the natural resource base.

Significant complementary efforts will also be needed in food systems beyond the farm to maximize synergies and manage trade-offs in related sectors, particularly energy production. For this to happen, changes in policy, institutional and technical domains that disrupt "business as usual" models may prove necessary.

Time is of the essence. Current trends in natural resource depletion indicate production from rainfed and irrigated agriculture is operating at or over the limit of sustainability. Injecting a sense of urgency into making the necessary transformations in the core of the global food system is essential.

Chapter 1 of this report provides a base from which to examine the socioeconomic trends in Chapter 2 and the demand projections for land and water resources and attendant risks in Chapter 3. These assessments provide a rationale for resource planning and management in Chapter 4 and for implementing institutional adaptation and technological innovation to increase crop production and productivity while conserving natural resources in Chapter 5. Finally, Chapter 6 presents the conclusions drawn from the report and offers overall recommendations and action in four key areas.

METHODOLOGY – GLOBAL DATASETS

The global datasets used to assess environmental change have advanced since the first edition of *The state of the world's land and water resources for food and agriculture* (SOLAW) report in 2011. Annual "snapshots" of land-cover classifications are now derived from higher-resolution imagery under the European Space Agency's Climate Change Initiative using the FAO land-cover classification scheme. The Global Forest Resource Assessment provides an up-to-date account of net global forest loss. Continental coverage of monthly water consumption by growing vegetation is available in the FAO Water Productivity Open-access Portal. In addition, the development of the Global Agro-Ecological Zones (GAEZ) version 4 (v4) data portal now consolidates the global distribution of land and agroclimatic resources at high resolution (~1 km) to analyse the distribution of crop production for reference years and the potential for crop production under climate change.

Translating these changes in land cover and associated energy balances into land and water use for agricultural production is possible. Trends in agricultural production derived from national statistics are attributed to the land where agroclimatic conditions and available soil moisture are adequate for crop growth. Accordingly, the spatial frame of reference for this edition of the SOLAW 2021 report is the set of agroclimatic and land data compiled for GAEZ v4 and is an update of the GAEZ v2/3 used in the compilation of SOLAW 2011.

There are two baseline or reference years for GAEZ: 2000 and 2010. Reported agricultural production in these reference years is distributed across 12 main land-use/land-cover shares in each 5 arcminute cell. These shares are for: artificial surfaces, cropland, grassland, tree-covered areas, shrub-covered areas, herbaceous vegetation (aquatic or regularly flooded), mangroves, sparse vegetation, bare soil, snow and glaciers, water bodies and cropland equipped with full control irrigation. These are the major land-class layers in GAEZ to which the FAO Statistical Database (FAOSTAT) national crop production data are distributed (downscaled) through reference to land cover (FAO Global Land Cover Share) and land equipped for irrigation (FAO Global Map of Irrigated Areas v5).

The GAEZ v4 unit of analysis is the 30 arcsecond pixel used to compile its reference grid. This represents approximately 900 m at the equator and 600 m at the poles. The compilation of climate, soil, land-cover and water source data at this resolution allows GAEZ to depict a nominal "state" of land and related water resources in a set of land-use types that conform with FAO's Global Information System on Water and Agriculture (AQUASTAT) and FAOSTAT production data (i.e. they can accommodate reported harvested areas, yield and cropping intensity).

The AQUASTAT database has been regularly updated since 2011, providing up-to-date information on water resources for agriculture at the global level. It plays a crucial role in collecting data and monitoring achievement of Sustainable Development Goal (SDG) 6: “ensure availability and sustainable management of water and sanitation for all”, and in particular indicators of SDG target 6.4 on water stress and water-use efficiency. The AQUASTAT method for collecting data has evolved since 2018, relying on a network of AQUASTAT national correspondents who ensure data collection and quality. This allows AQUASTAT to align with the country-led and country-owned processes promoted through the SDGs for gathering data.

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Stockholm International Water Institute

Thünen Federal Research Institute for Rural Areas, Forestry and Fisheries

World Overview of Conservation Approaches and Technologies

ABBREVIATIONS AND ACRONYMS

AEZ	agroecological zoning
2030 Agenda	2030 Agenda for Sustainable Development
AQUASTAT	FAO's Global Information System on Water and Agriculture
BAU	business as usual
CBD	Convention on Biological Diversity (United Nations)
CFS	Committee on World Food Security
CO_2-eq	carbon dioxide equivalent
CRC	conflict resolution committee
ENS	ensemble
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	FAO Statistical Database
FFS	farmer field school
FLW	food loss and waste
FOFA	future of food and agriculture
GAEZ	Global Agro-Ecological Zones
GDP	gross domestic product
GEF	Global Environment Facility
GHG	greenhouse gas
GIAHS	Globally Important Agricultural Heritage Systems
GIS	Geographic Information System
GLADIS	Global Land Degradation Information System
GLC-SHARE	Global Land Cover Share

GLOSIS	Global Soil Information System
GMIA	Global Map of Irrigated Areas
GSP	Global Soil Partnership
HWSD	Harmonized World Soil Database
ICT	information and communications technology
IFI	international financing institution
IIASA	International Institute for Applied Systems Analysis
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IRWR	internal renewable water resources
IUCN	International Union for Conservation of Nature
IWRM	integrated water resources management
JRC	Joint Research Centre (European Commission)
KJWA	Koronivia Joint Work on Agriculture
LADA	Land Degradation Assessment in Drylands
LandPKS	Land Potential Knowledge System
LDN	land degradation neutrality
LRP	land resources planning
MARS	Monitoring Agricultural Resources
MEWS	monitoring and early warning system
NAEZ	national agroecological zoning
NbS	nature-based solution
NDC	nationally determined contribution
NDVI	normalized difference vegetation index
NGO	non-governmental organization
OECD	Organisation for Economic Co-operation and Development
PES	payments for ecosystem services
RCP	Representative Concentration Pathway

REDD+	Reducing Emissions from Deforestation and Forest Degradation in Developing Countries
REWAS	Real Water Savings
RUSLE	Revised Universal Soil Loss Equation
SAMIS	Strengthening Agro-climatic Monitoring and Information Systems
SDG	Sustainable Development Goal
SDS	sandstorm and dust storm
SI	suitability index
SIP	Strategic Investment Programme
SLM	sustainable land management
SOC	soil organic carbon
SOLAW	*The state of the world's land and water resources for food and agriculture*
SOM	soil organic matter
SPI	Science-policy Interface (United Nations Convention to Combat Desertification)
SRL	sustainable rural livelihoods
SSP	Shared Socioeconomic Pathway
SSS	stratified societies
TSS	towards sustainability
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VGGT	*Voluntary guidelines on the responsible governance of tenure of land, fisheries and forests in the context of national food security*
WaPOR	Water Productivity Open-access Portal
WOCAT	World Overview of Conservation Approaches and Technologies
WPI	water productivity index
WUA	water user association

KEY MESSAGES OF SOLAW 2021

The state

- **The interconnected systems of land, soil and water are stretched to the limit.** Convergence of evidence points to agricultural systems breaking down, with impacts felt across the global food system.
- **Current patterns of agricultural intensification are not proving sustainable.** Pressures on land and water resources have built to the point where productivity of key agricultural systems is compromised and livelihoods are threatened.
- **Farming systems are becoming polarized.** Large commercial holdings now dominate agricultural land use, while fragmentation of smallholder concerns concentrates subsistence farming on lands susceptible to degradation and water scarcity.

The challenges

- **Future agricultural production will depend upon managing the risks to land and water.** Land, soil and water management needs to find better synergy to keep systems in play. This is essential to maintain the required rates of agricultural growth without further compromising the generation of environmental services.
- **Land and water resources will need safeguarding.** There is now only a narrow margin for reversing trends in resource deterioration and depletion, but the complexity and scale of the task should not be underestimated.

Responses and actions

- **Land and water governance has to be more inclusive and adaptive.** Inclusive governance is essential for allocating and managing natural resources. Technical solutions to mitigate land degradation and water scarcity are unlikely to succeed without it.
- **Integrated solutions need to be planned at all levels if they are to be taken to scale.** Planning can define critical thresholds in natural resource systems, leading to the reversal of land degradation when wrapped up as packages or programmes of technical, institutional, governance and financial support.
- **Technical and managerial innovation can be targeted to address priorities and accelerate transformation.** Caring for neglected soils, addressing drought and coping with water scarcity can be addressed through the adoption of new technologies and management approaches.
- **Agricultural support and investment can be redirected towards social and environmental gains derived from land and water management.** There is now scope for progressive multiphased financing of agricultural projects that can be linked with redirected subsidies to keep land and water systems in play.

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STATUS OF AND TRENDS IN LAND, SOIL AND WATER RESOURCES

Key messages

Land used for crop production increased by 208 million ha (15 percent) between 1961 and 2019. Land used for irrigated cropping increased by 110 percent, while rainfed cropping increased by only 2.6 percent, over the same time period. Permanent pastures for livestock rearing markedly declined from a peak area of 3 400 million ha in 2000 to a level nearer to 3 200 million ha by 2019. This decline, together with global population growth, reduced available agricultural land use per capita for crops and livestock rearing by 20 percent between 2000 and 2019. Agricultural land per capita is now less than 0.64 ha.

Pressures on productive land and water resources are pushing the productive capacity of agricultural ecosystems to the limit. Land degradation, drought and related water scarcity are compromising agricultural production and intensifying poverty and malnutrition in all regions.

The loss of soil organic carbon (SOC) is accelerating. Agriculturally managed soils contain 25 percent to 75 percent less SOC compared to soils in undisturbed or natural ecosystems. This is due to changing land use and land management. Soils under conventional agriculture continue to be a source of carbon dioxide emissions.

Land and soils are degrading due to the spread and intensification of agriculture. Estimates suggest human-induced degradation affects 34 percent of cropland and pasture. The demand for more calories to satisfy population and income growth is constrained as cropping extends into marginal lands and existing land suffers erosion and depletion of carbon, nutrients and soil biodiversity. Estimates suggest over 3.2 billion people are directly affected by soil/land degradation.

Water scarcity is becoming endemic. The local impact of physical water scarcity and freshwater pollution is spreading and accelerating. The first sign of scarcity is increasing use and severe depletion of groundwater – the ultimate source of water for most of the world. The global Sustainable Development Goal (SDG) target 6.4 on water scarcity reached 18 percent in 2018, but this masks significant regional variations. Non-conventional water use in agriculture, such as water/effluent reuse and desalination, is growing, particularly in areas where water scarcity is most acute.

Accessible, high-quality groundwater is diminishing. Globally, groundwater accounts for over 30 percent of freshwater withdrawals for irrigated agriculture and continues to grow at around 2.2 percent per year. Approximately 70 percent of groundwater withdrawals are used to irrigate food, fibre and industrial crops, and for livestock. More is used in arid and semi-arid regions. Agricultural production is constrained where groundwater storage is depleted or degraded. Intensive exploitation in many principal continental aquifers and saline intrusion along highly productive coastal plains are evident. This level of groundwater exploitation is considered responsible for the loss of aquifer storage of 250 km^3/year, and more importantly, loss of aquifer function and utility to farmers as groundwater levels drop.

Water pollution is a rising global crisis that directly affects health, economic development and food security. Agriculture is the dominant source of water pollution (mainly diffuse or non-point pollution from agricultural land), but other human activities such as urbanization and industry are also major contributors. Degrading water quality is a significant threat to food safety and food security.

Climate change is driving processes that cause productive land to be lost. Although anticipated temperature changes may bring new land into production, opportunities for sustainable expansion and intensification are severely limited. Climate change increases evapotranspiration from cropped land, and alters the quantity and distribution of rainfall. This leads to changes in land/crop suitability and reduced yields where temperature stresses attenuate carbon assimilation. Long-term temperature increases can be anticipated across productive land, but rainfall intensities, duration and frequency are harder to predict. Greater variations in river flows and groundwater recharge are expected and will adversely affect irrigated agriculture in particular. Land-cover distribution over thermal climates and trends indicate increases in grasslands and artificial surfaces, while tree-covered areas and bare areas show significant declines.

Land and water productivity gains over the past decade have enabled crop and livestock production to match demand but at a cost. Land now produces more than 95 percent of the global food supply for a human population estimated at over 7.7 billion. Unsustainable agricultural intensification has increased environmental impacts that limit agricultural production capacity and damage a wide range of environmental services. Intersectoral competition for land and water resources is intense, and the scope to sustainably extend irrigation areas and convert new land to agriculture is limited.

1.1 Introduction

Pressures on land and water resources are pushing the productive capacity of land and water systems to the limit. These concerns are reflected in global environmental and scientific assessments, notably the Intergovernmental Panel on Climate Change (IPCC) special report on climate change and land (IPCC, 2019), the sixth edition of the United Nations Environment Programme (UNEP) global environmental outlook (UNEP, 2019), the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) assessment report on land degradation and restoration (IPBES, 2018) and the United Nations Convention to Combat Desertification (UNCCD) global land outlook (UNCCD, 2017).

What are the implications for the global food system and the food security of the 2.37 billion people facing moderate or severe food insecurity? The latest report on *The state of food security and nutrition in the world 2021* (FAO *et al.*, 2021) recognizes the severity of external drivers including conflict and COVID-19 containment measures, which constrain human engagement with productive land. This is land that produces more than 95 percent of the global food supply when measured in kilograms per capita per year (FAO, 2020a). However, the land and water systems at risk identified in the first report of the Food and Agriculture Organization of the United Nations (FAO) on *The state of the world's land and water resources for food and agriculture 2011* (SOLAW 2011; FAO, 2011) are now seeing the growth in land and water productivity stagnate. Global datasets reflect a decline in per capita natural resource availability.

This chapter provides a global overview of the current state of land, soil and water resources concerning agricultural production, building on the analysis in SOLAW 2011. The purpose is to describe the state of land and water resources at the global level using the best available global datasets to establish a baseline up to 2019 for land and 2018 for water data according to the status of the FAO land and water databases in 2021. Many of the global datasets on related environmental data were not established in 2010 when SOLAW 2011 was compiled, and these have been shown as distributed data, where appropriate, to provide a contemporary picture of land and water resources aggregated at the continental regional and subregional levels used for SOLAW 2011 (see the annex).


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1.2 Emissions from land and the changing climate

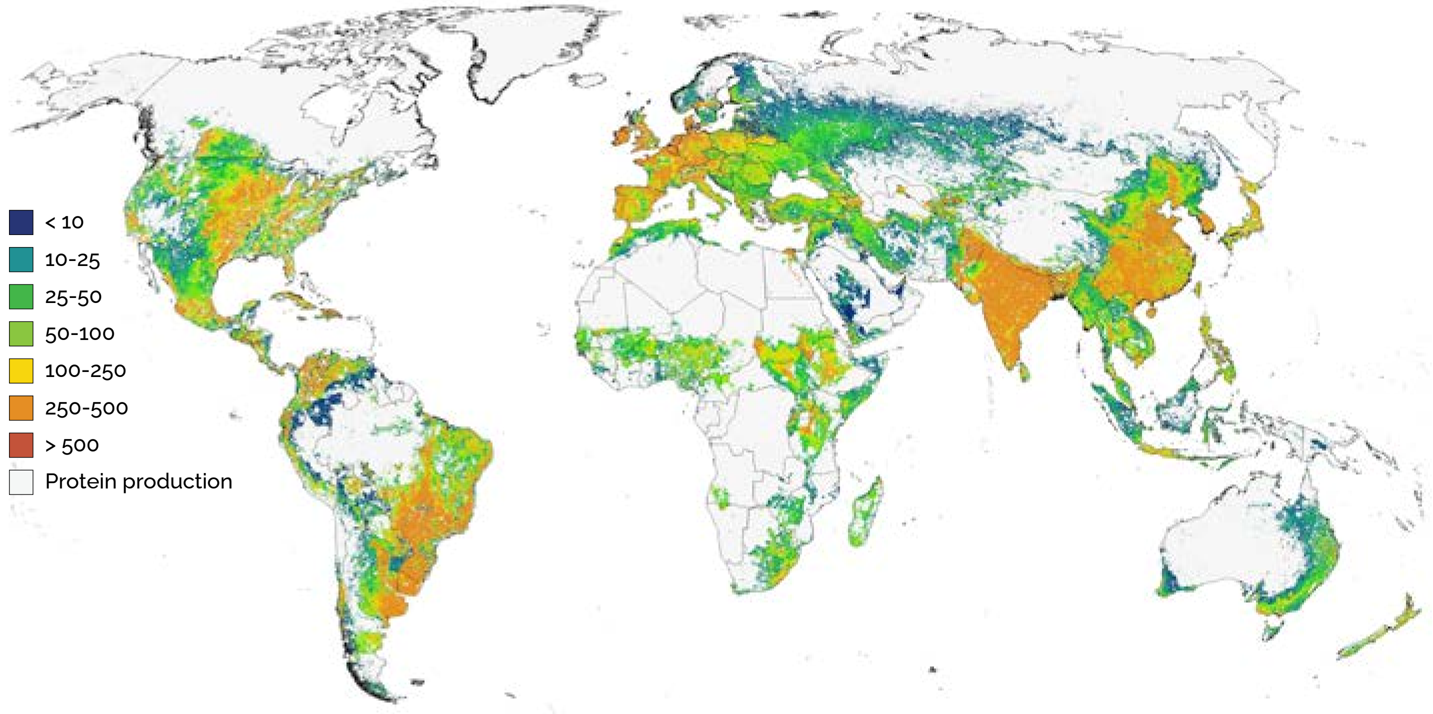
In 2019, global anthropogenic greenhouse gas (GHG) emissions, from all economic sectors including land use, land-use change and forestry, totalled 54 billion tonnes of carbon dioxide equivalent (CO_2-eq), and emissions from agrifood systems (including food processing and supply chain emissions) amounted to some 17 billion tonnes CO_2-eq or 31 percent of total global emissions (FAO, 2021a). Emissions from agrifood systems increased globally by 16 percent between 1990 and 2019, despite their share in total emissions decreasing from 40 percent to 31 percent, as did the per capita emissions, from 2.7 to 2.1 tonnes CO_2-eq.

The 2019 total agrifood system GHG emissions are composed of 7.2 billion tonnes CO_2-eq (13 percent of total global emission) from activities on agricultural land (at the farm gate), 3.5 billion tonnes CO_2-eq (7 percent) from land-use change processes such as deforestation and peatland degradation, and 5.8 billion tonnes CO_2-eq (11 percent) from pre- and post-production processes. These processes include energy use in fertilizer manufacturing, food processing, retail, transport and household consumption. Map 1.1 shows the global distribution of GHG emissions intensity from land in 2012.

The trends in these emissions over the past 30 years show the significance of the growth in the pre- and post-production processes (Figure 1.1), while emissions from agricultural land and land-use change have remained relatively stable. Nonetheless, agricultural land and land-use change are estimated to contribute 20 percent of global GHG emissions. Reductions in those land-related emissions through changes in agricultural practice and land management are desirable in the global effort towards achieving net-zero GHG emissions.

However, climate change is already affecting the human relationship with land and water. While some climate-induced shocks, such as intense periods of heat or flood events that surpass previous experience, are apparent immediately, the slower-onset phenomena, such as elevated night-time temperatures, have impacts on agricultural production that are more incremental in nature. The IPCC sixth assessment report *Climate change 2021: The physical science basis* attributes detectable changes in the global water cycle since the middle of the twentieth century to human-induced climate change (IPCC, 2021). Land and water management has played a significant part in triggering these changes through modified carbon and nutrient cycles, GHG emissions, and control over the distribution of freshwater across and within the Earth’s crust.

MAP 1.1 **GREENHOUSE GAS EMISSIONS INTENSITY PER UNIT OF LAND (TONNES CO_2-EQ PER KM^2)**



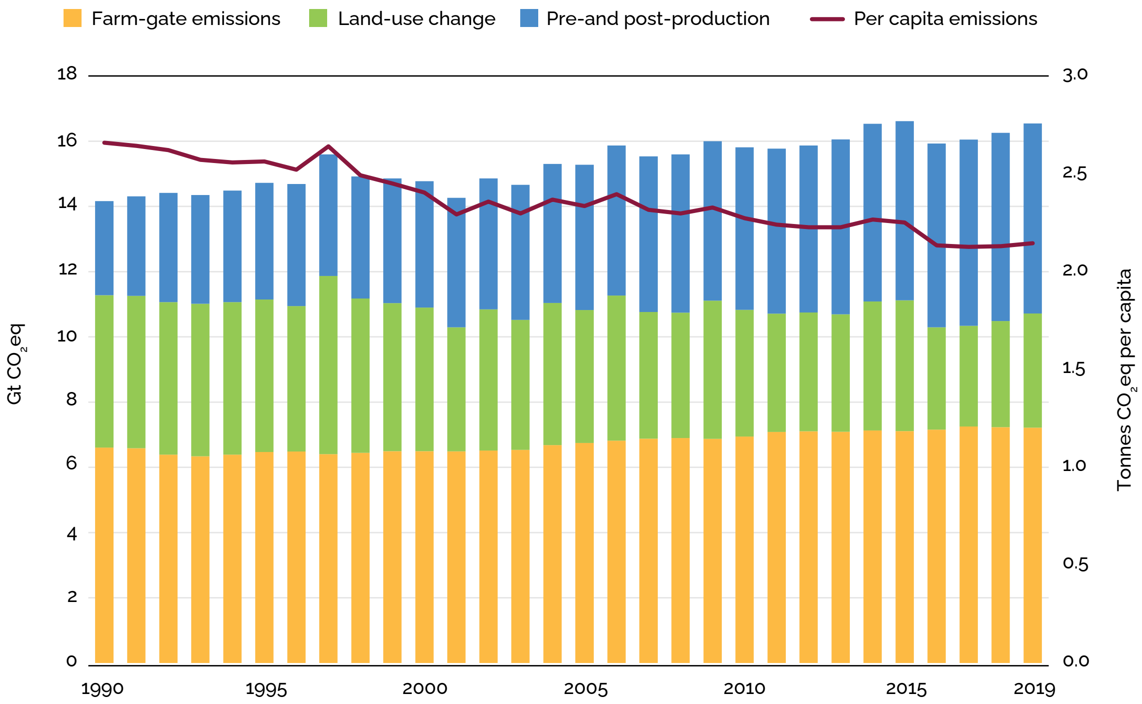
Source: **FAO**. 2013. *Tackling climate change through livestock: A global assessment of emissions and mitigation opportunities*. Rome.
www.fao.org/3/i3437e/i3437e.pdf

Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

FIGURE 1.1 GLOBAL AGRIFOOD SYSTEM GREENHOUSE GAS EMISSIONS BY LIFE-CYCLE STAGE AND PER CAPITA EMISSIONS, 1990–2019



Source: **FAO**. 2021. *The share of agri-food systems in total greenhouse gas emissions: Global, regional and country trends 1990–2019*. FAOSTAT Analytical Brief Series No. 31. Rome. www.fao.org/3/cb7514en/cb7514en.pdf

The results of the IPCC sixth assessment report and the special report on climate change and land point to the anticipated evolution of the complex feedback between the atmosphere, oceans and land (IPCC, 2019, 2021, 2022). The reports find climate change affects the rate and magnitude of some land degradation processes and introduces new degradation patterns. Climate models predict increasing frequency, intensity and amount of heavy precipitation as the climate changes. Rainfall that is more intense but with fewer events is combining to increase the risk of landslides, extreme erosion events and flash floods. The IPCC special report on climate change and land notes tropical cyclones are already shifting towards the poles, and the speed at which they move is slowing. Increased exposure of coastal areas to intense and long-duration storms is expected to lead to further land degradation and to affect coastal forest structure and composition. Sea-level rise already affects coastal erosion and salinization, leaving such areas vulnerable to catastrophic weather events.

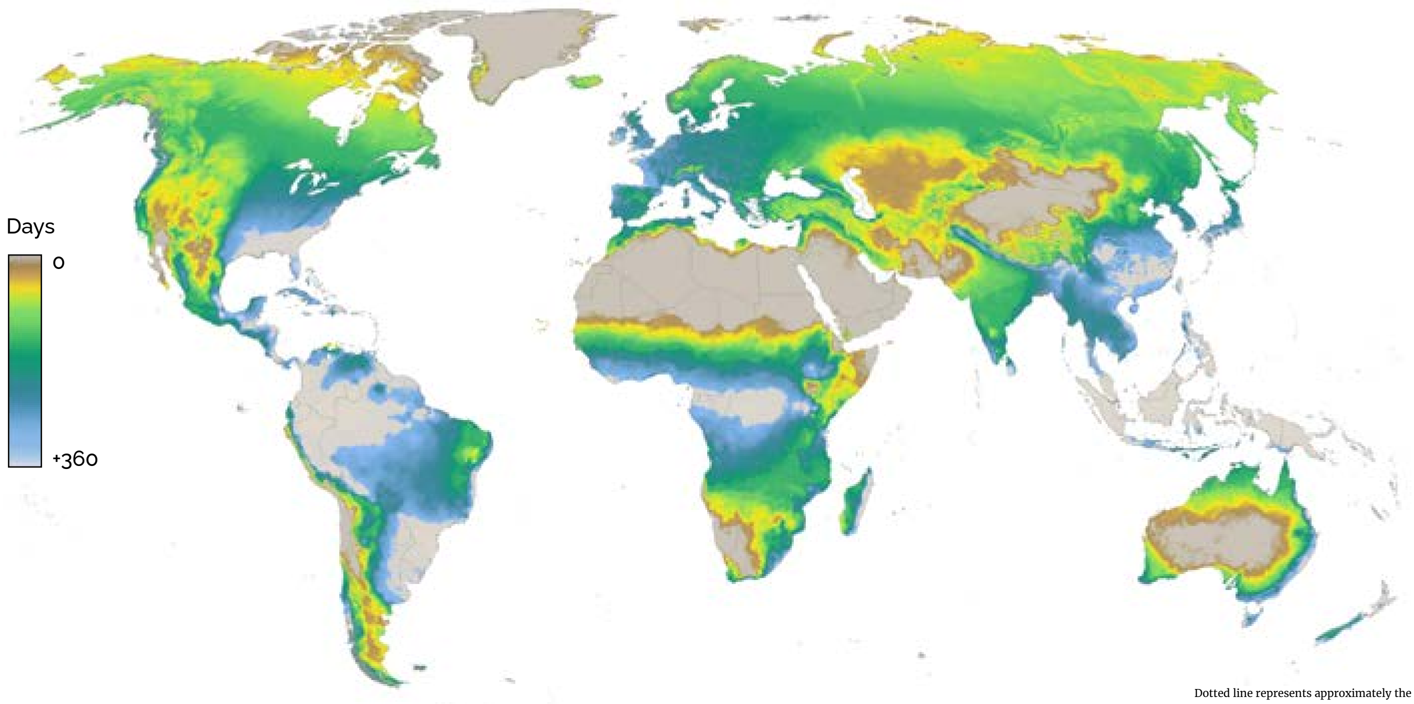
These short-term impacts of climate change need to be considered in combination with long-term changes in land use and land management. Cropland soils are estimated to have only 20–60 percent of their potential stocks before cultivation (Lal *et al.*, 2018), and soils under conventional agriculture continue to be a source of carbon dioxide emissions. Peatland soil degradation and drainage release large amounts of carbon through decomposition, and fires in drained peatlands accounted for about 4 percent of global fire emissions between 1997 and 2016. Agricultural practices also cause soils to emit other GHGs in addition to carbon dioxide, and climate change exacerbates these emissions. Soils emit nitrous oxide when organic and inorganic fertilizers are applied and when nitrogen-fixing crops are planted. They also emit methane when flooded for rice cultivation. Hence, there is interest in land management and conservation agriculture techniques that can halt, and, in some instances even reverse, the loss of SOC and reduce emissions of methane and nitrous oxide (e.g. reduced tillage with nitrogen-fixing plants in crop rotations, improved water management/irrigation, agroforestry and soil erosion control structures) (IPCC, 2022).

1.2.1 Land and temperature changes

At the Earth's surface, temperatures largely determine what crops can be grown in any given locality. Plants have specific heat requirements to complete their growth cycle, which can be calculated by accumulating temperatures above a specific threshold. The reference length of the growing season is therefore an important baseline to establish for crop production (Map 1.2).

However, the agroclimatic context is changing rapidly given the mean temperature changes observed over the past 60 years (Map 1.3). Farming enterprises are adapting to new thermal regimes that have upset crop growth stages and their supporting soil ecologies, with specific implications for spreading crop disease and pests. Fundamental changes to the water cycle, particularly the patterns of rainfall and periods of drought, are forcing adjustment of rainfed and irrigated production in particular. Under climate change, growing periods may become longer in boreal and arctic regions, but shorter in areas affected by extended drought periods, when compared with current reference lengths.

MAP 1.2 REFERENCE LENGTH OF THE GROWING PERIOD , AVERAGE FOR PERIOD 1981–2010 (DAYS)



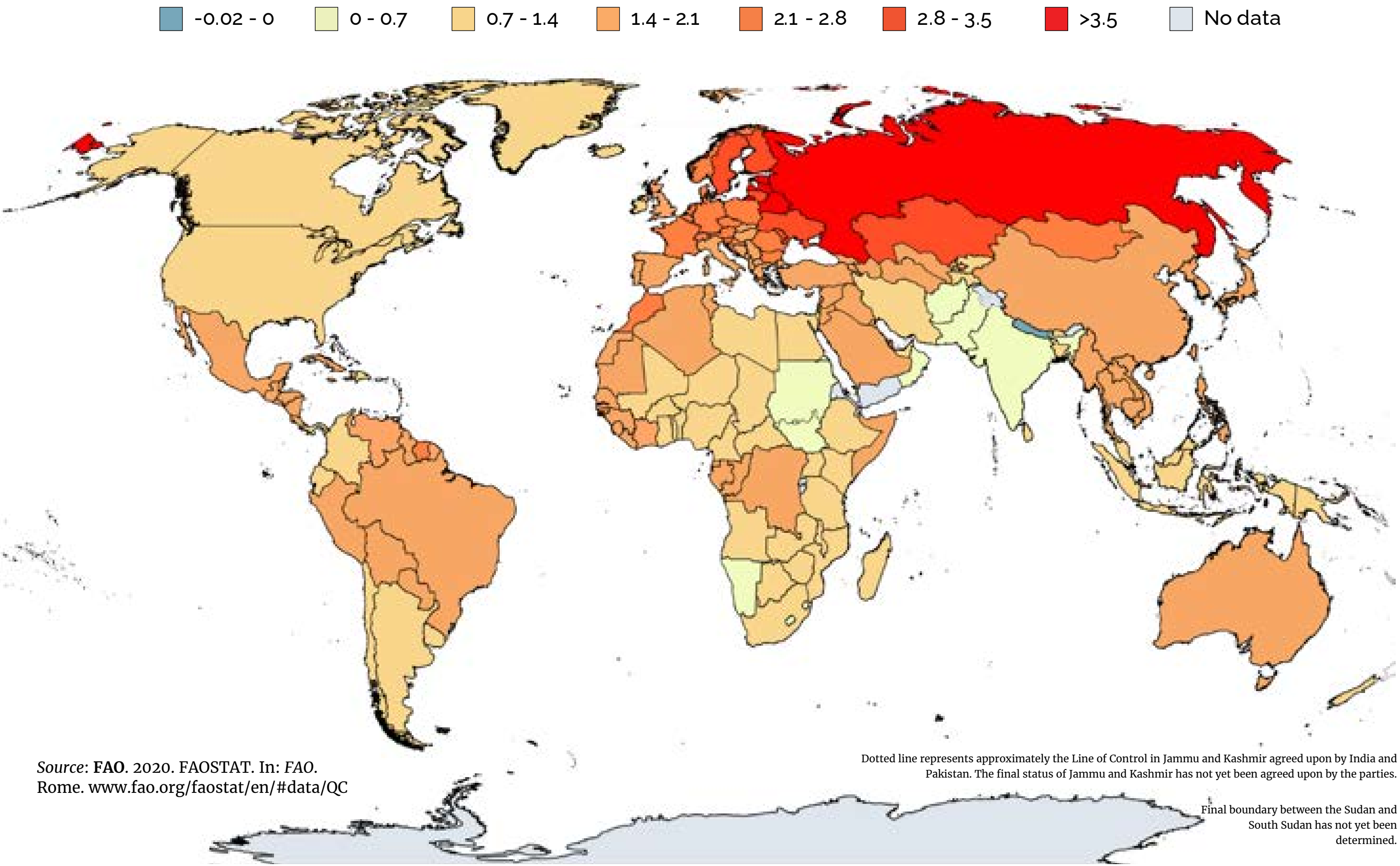
Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

Source: **FAO & International Institute for Applied Systems Analysis**. 2021. *Global agro-ecological zones v4.0 – Model documentation*. Rome. www.fao.org/nr/gaez/publications/en

Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

MAP 1.3 MEAN TEMPERATURE CHANGE, 1961–2020 (°C)



Source: **FAO**. 2020. FAOSTAT. In: *FAO*. Rome. www.fao.org/faostat/en/#data/QC

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

Final status of the Abyei area is not yet determined

Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

1.2.2 Impact of weather events on land, soil and water resources

The direct impact of weather events on cropping, grazing and forest systems and soil health is difficult to separate from the overall environmental outcome of land and water management practices. Reduced or erratic rainfall and more frequent and severe drought periods extend soil moisture deficits on some soils but extend periods of water-logging on others. Heavier rains are likely to increase the risk of soil erosion on cultivated lands, on moderate to steep slopes where runoff rates are high, and where the land has inadequate vegetative cover. Intensified and shorter rainfall events combined with higher evaporation and transpiration rates will lead to increased erosion from water and raindrop impacts, and accelerated runoff and strong winds will reduce soil moisture available for plant growth. In turn, increased incidence of windstorms will accelerate soil loss. Higher soil surface temperatures will increase the mineralization rate of soil organic matter (SOM) and impair the soil's capacity to sequester carbon and retain water and to ultimately support plant growth. Higher temperatures will increase evaporation and soil salinization, particularly in arid and semi-arid climates.

Soils in all regions are important regulators of climate change by virtue of their ability to absorb and store heat, moisture and carbon. Many soil types are affected by climate change and influence climate change through positive feedback loops. Soil physical properties affect how soils respond to climate change and determine the soil's capacity to maintain and deliver soil functions for agriculture and sequester carbon to reduce GHGs (FAO, 2017a). Two important soil types are permafrost soils and peatlands. Permafrost soils, which cover 25 percent of the northern hemisphere, are in danger of thawing and may exacerbate warming by releasing methane, which is an active GHG. Thawing will increase soil erosion, as permafrost lends stability to barren arctic slopes (Turetsky, 2019), and threatens industrial infrastructure, with risks of oil spills and soil contamination. Peatlands cover a modest 3 percent of the Earth's ice-free landmass, yet they contain 30 percent of the world's SOC. Changes in the state of peatlands resulting from fires and drainage contribute at least 5 percent of GHG emissions (Tubiello *et al.*, 2014).

The impacts of climate change on the water cycle and renewable freshwater resources are expected to significantly alter the agricultural output and the environmental performance of productive land and water systems recognized in SOLAW 2011 (FAO, 2011). Climate models predict decreases in renewable water resources in some regions (mid-latitude and dry subtropical regions) and increases in others (mainly high-latitude and humid mid-latitude regions). Even where increases are projected, there may be short-term shortages due to changing streamflows caused by greater variability in rainfall. The decreases in renewable surface water and groundwater resources in dry subtropical regions will intensify competition for water among different users.

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The long- and short-term impacts of climate change and related weather phenomena may transcend the prospects for remediation of land and water systems that are under pressure from the level of human demand for food, fibre and biofuel. While the implications for any specific point on the Earth's surface may be uncertain, the continuation of a "no-regrets" approach to more sustainable land management and agricultural practices in the face of such uncertainty is expected to be adopted at the global scale.

1.3 Land-cover status and trends

1.3.1 Status

The global land area, including inland waters and permanent snow and glaciers, amounts to 14 706 million ha. Table 1.1 presents 11 land-cover classes for years 2010 to 2019, together with the baseline data for 1992 using the land-cover classification of the European Space Agency Climate Change Initiative. The statistics do not include coastal water bodies and intertidal areas. Land cover upon which crops are cultivated (herbaceous crops, woody crops and wetlands used for cultivation) or available for animal husbandry (grassland) amounted to 4 132 million ha in 2019, approximately 28 percent of the global land area.

TABLE 1.1 **LAND-USE CLASS CHANGE, 1992 AND 2000–2019 (MILLION ha)**

LAND-COVER CLASS	1992	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Artificial surfaces (including urban and associated areas)	26	48	49	51	52	54	55	56	57	58	60
Grassland	1 773	1 796	1 799	1 800	1 801	1 802	1 802	1 801	1 801	1 810	1 813
Herbaceous crops	1 877	1 910	1 909	1 909	1 908	1 907	1 907	1 904	1 905	1 905	1 904
Woody crops	178	222	223	224	224	224	223	222	220	221	222
Shrubs and/ or herbaceous vegetation, aquatic or regularly flooded	202	189	189	190	190	189	189	189	189	191	193
Shrub-covered areas	1 615	1 595	1 597	1 598	1 599	1 599	1 600	1 597	1 597	1 601	1 605
Tree-covered areas	4 347	4 291	4 286	4 282	4 281	4 281	4 280	4 287	4 288	4 278	4 270
Sparsely natural vegetated areas	905	886	888	889	888	887	887	888	888	887	890
Terrestrial barren land	1 950	1 935	1 932	1 930	1 930	1 929	1 929	1 927	1 926	1 920	1 915
Inland water bodies	381	381	381	381	381	382	382	382	382	382	383
Mangroves	18	18	18	18	18	18	18	18	18	18	18
Permanent snow and glaciers	1 437	1 437	1 437	1 437	1 437	1 437	1 437	1 434	1 434	1 434	1 434
Total land cover	14 709	14 709	14 709	14 709	14 709	14 709	14 709	14 706	14 706	14 706	14 706

Source: **FAO**. 2020. FAOSTAT. In: *FAO*. Rome. www.fao.org/faostat/en/#data/QC; using European Space Agency Climate Change Initiative Land Cover statistics, containing annual land-cover area data for the period 1992–2019 produced by the Catholic University of Louvain Geomatics as part of the Climate Change Initiative of the European Space Agency (version 2.0, Climate Change Initiative University of Louvin Geomatics, 2017) and lately updated to version 2.1 under the European Copernicus programme.

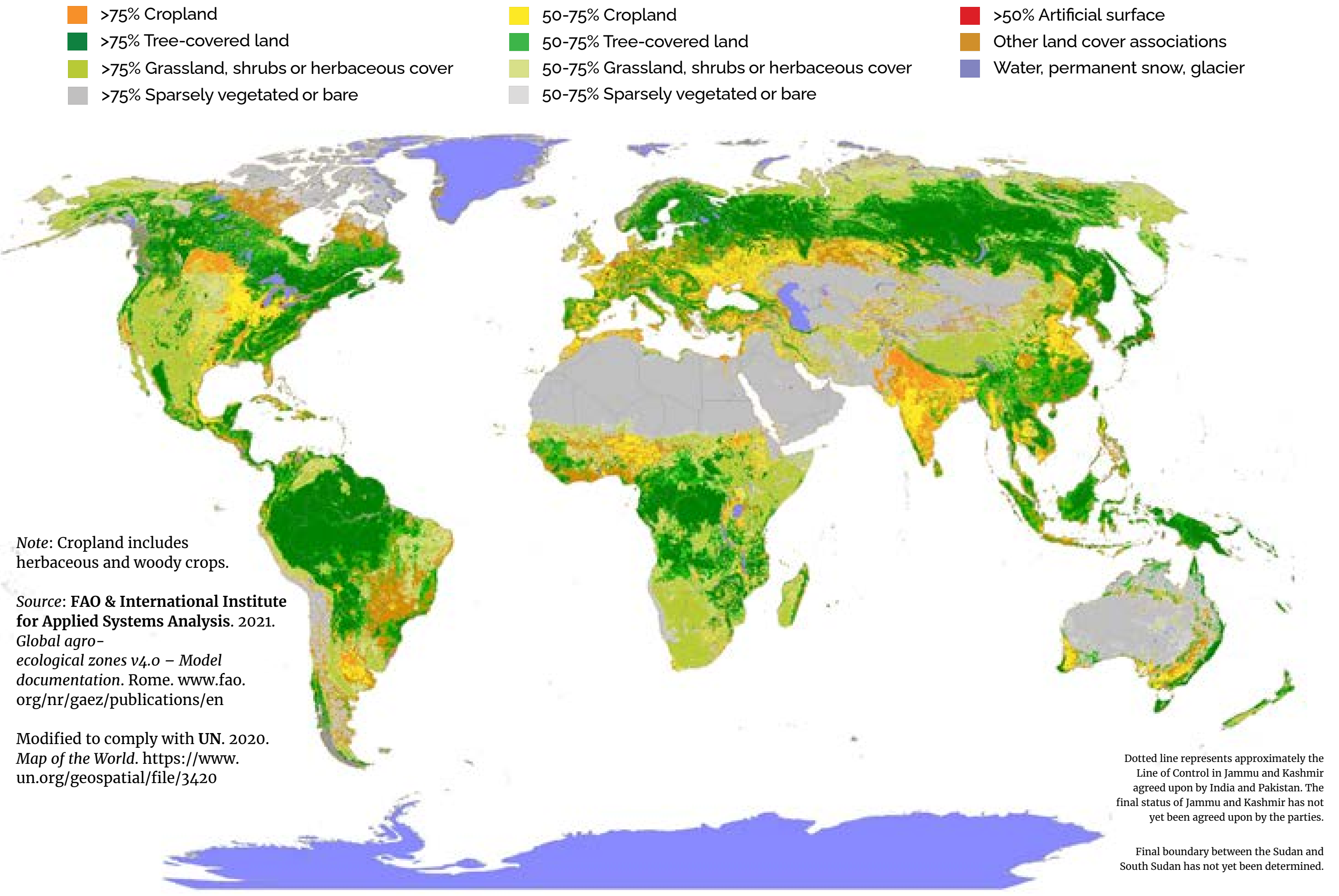
Map 1.4 illustrates the global distribution of dominant land-cover classes by FAO region using Global Land Cover Share (GLC-SHARE) data. Figure 1.2 shows the breakdown of these dominant land-cover classes by SOLAW region.

1.3.2 Trends

Since 1992, artificial surfaces (notably urban areas and paved highways/airports) have continued to expand, doubling from 30 million ha in 2000 to almost 60 million ha in 2019 (Figure 1.3). Tree-covered areas declined significantly from almost 4 347 million ha in 1992 to 4 270 million ha in 2019. Herbaceous crop cover peaked in 2004, then declined and plateaued from 2010 at 1 905 million ha. Woody crops also plateaued from 2010, stabilizing at around 220 million ha. Grassland cover has expanded since 1992 and appears to have stabilized at around 1 800 million ha by 2015, before showing a significant increase from 2017 to around 1 813 million ha in 2019.

In contrast, shrub-covered areas and barren lands contracted from 2000, although shrub-covered lands recovered from 2010. Wetlands used for cultivation (shrubs and or herbaceous vegetation aquatic or regu-

MAP 1.4 DOMINANT LAND-COVER CLASSES, GLOBAL LAND COVER SHARE DATA, 2010



Note: Cropland includes herbaceous and woody crops.

Source: **FAO & International Institute for Applied Systems Analysis**. 2021. *Global agro-ecological zones v4.0 – Model documentation*. Rome. www.fao.org/nr/gaez/publications/en

Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

larly flooded)[1] contracted from around 203 million ha in 1992 to 190 million ha in 2019. Sparsely vegetated land and barren land also contracted over the same period.

The global tree-covered area was estimated at just over 4 269 million ha in 2019, some 30 percent of the total land area. The net annual forest-cover loss between 2010 and 2020 is estimated at 4.7 million ha/year compared with 5.2 million ha/year between 2000 and 2010 and 7.8 million ha/year between 1990 and 2000 (FAO, 2020b). While this trend takes account of forest expansion through regeneration and afforestation (Figure 1.4), recent national accounts of deforestation rates for conversion to grassland or cropland are expected to reduce global cover statistics. Indeed, most forest-cover loss is linked to expanding newly cultivated arable land, while forest-cover gain is attributed to afforestation and natural forest regeneration on abandoned arable land (FAO, 2020b). More than 90 percent of the deforestation is taking place in the tropics. Between 2010 and 2020, of the SOLAW regions, sub-Saharan Africa lost the largest area to deforestation, surpassing Southern America (the previous regional leader). Deforestation of primary rainforest is occurring mainly in the Amazon and Congo basins.

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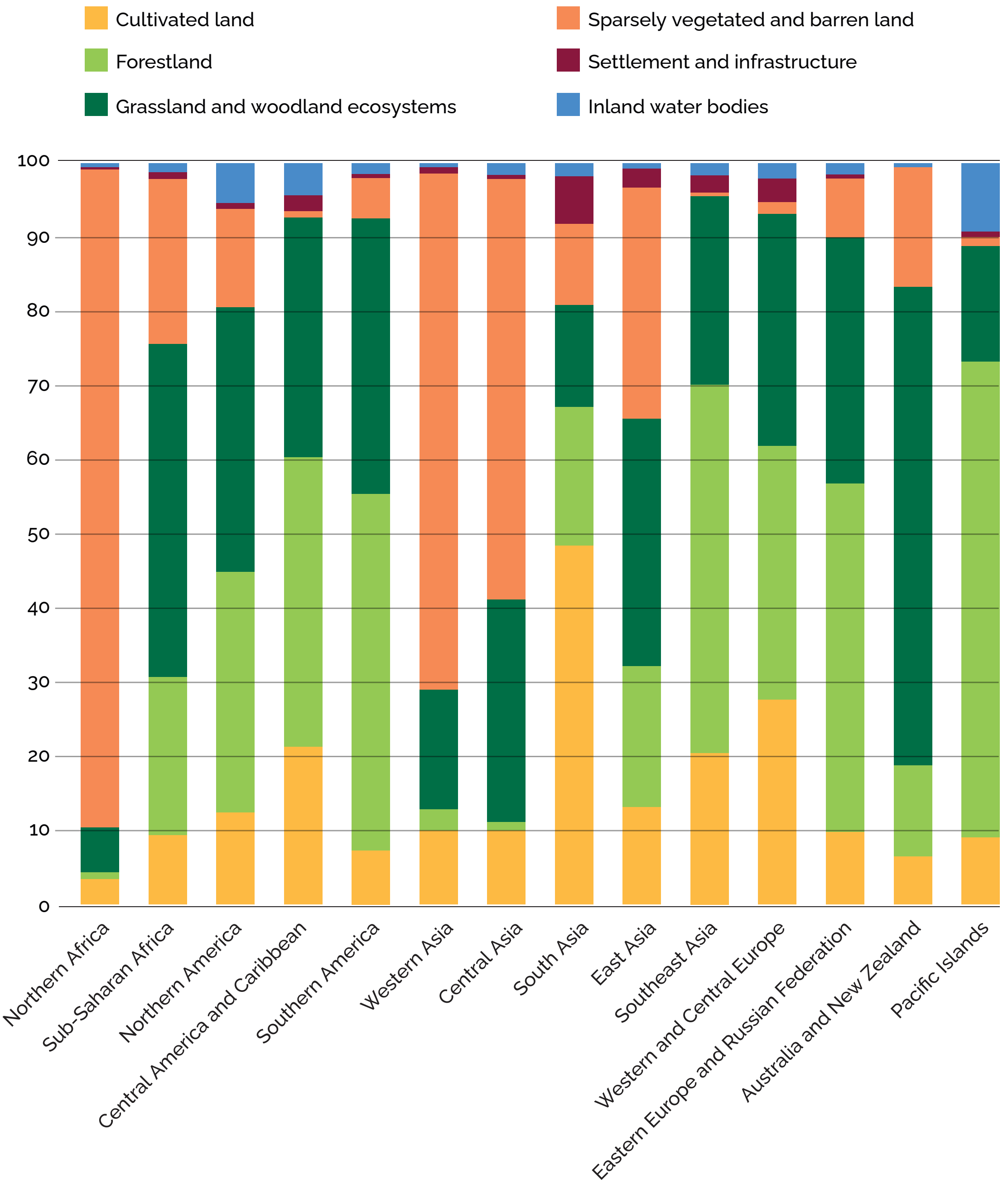
[1] FAO defines wetlands used for cultivation as areas having free water at or on the surface for at least most of the growing season. The water is sufficiently shallow to allow the growth of a wetland crop or of natural vegetation rooted in the soil. This includes lowland paddy and “bas fonds” in western Africa.

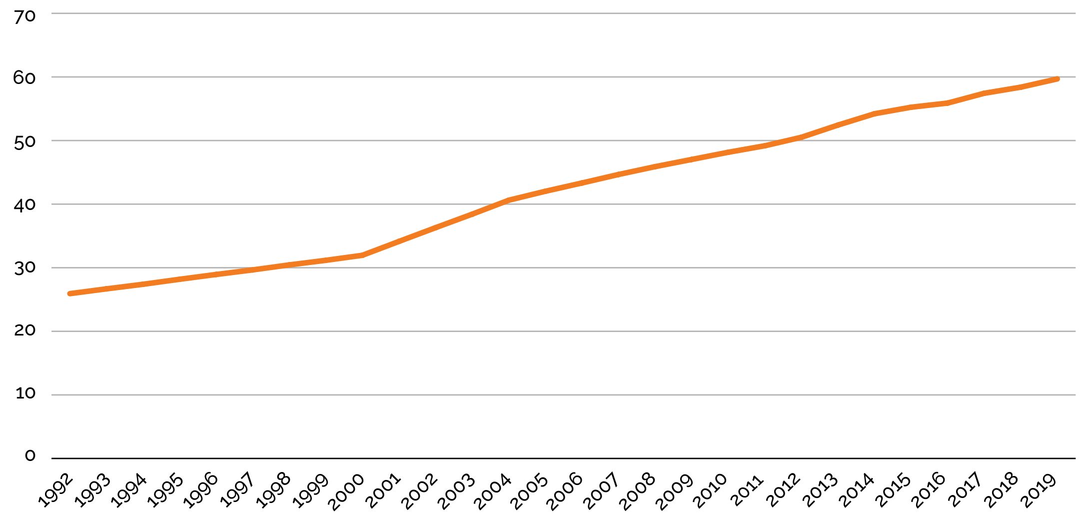
FIGURE 1.2 REGIONAL DISTRIBUTION OF DOMINANT LAND-COVER CLASSES (%)



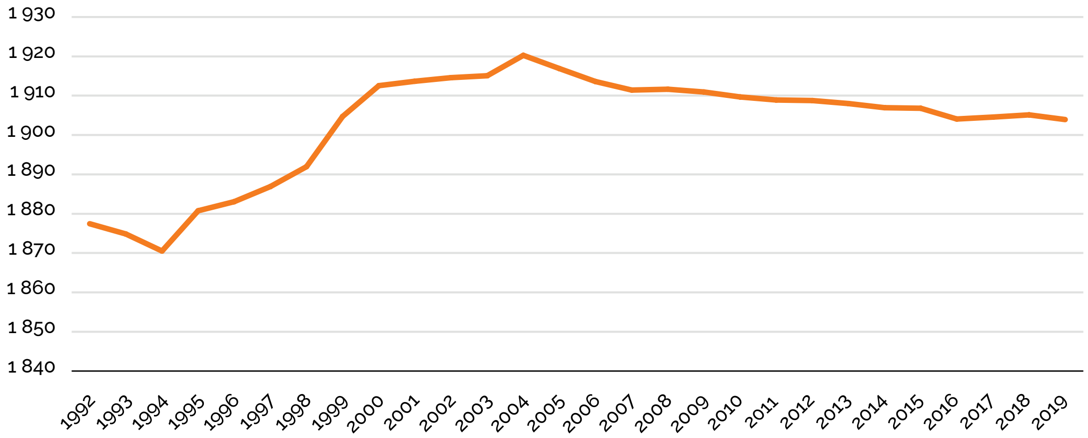
Sources: Based on land-cover information in **FAO & International Institute for Applied Systems Analysis**. 2021. *Global agro-ecological zones v4.0 – Model documentation*. Rome. www.fao.org/nr/gaez/publications/en; and SOLAW regional subdivisions in **FAO**. 2011. *The state of the world's land and water resources for food and agriculture: Managing systems at risk*. Rome, FAO and London, Earthscan. www.fao.org/3/i1688e/i1688e.pdf

FIGURE 1.3 LAND-COVER TRENDS, 1992–2019 (MILLION ha)

Artificial surfaces (including urban and associated areas)



Area of herbaceous crops



Area of woody crops

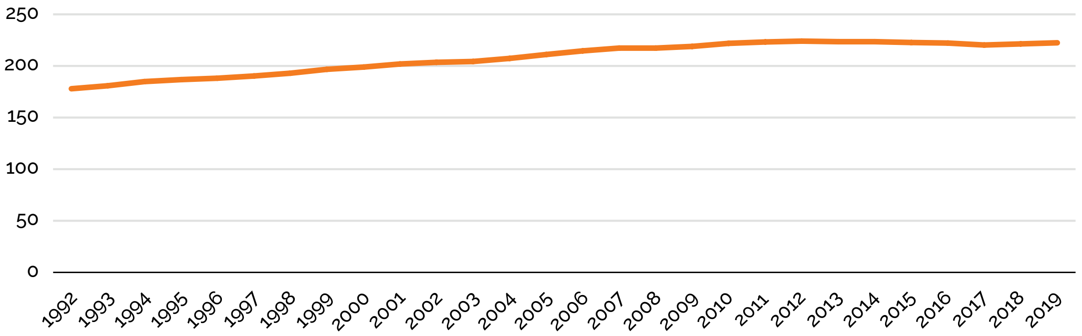
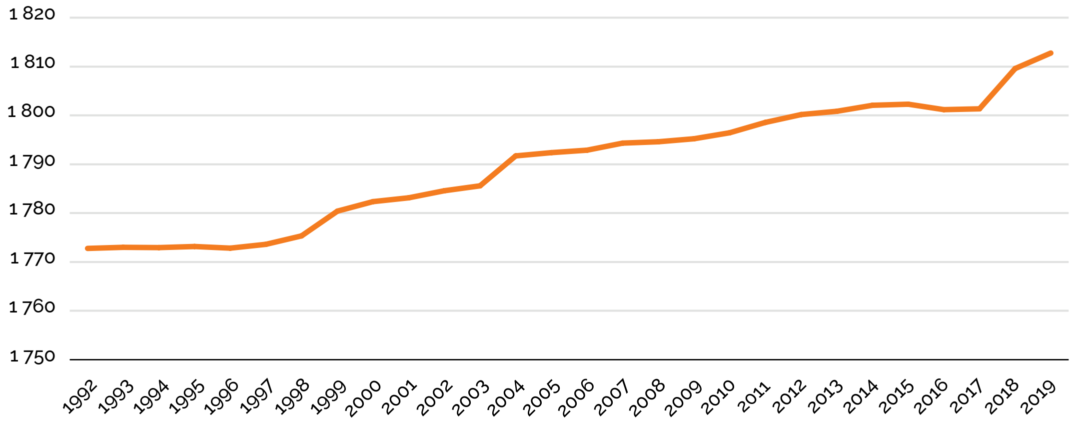
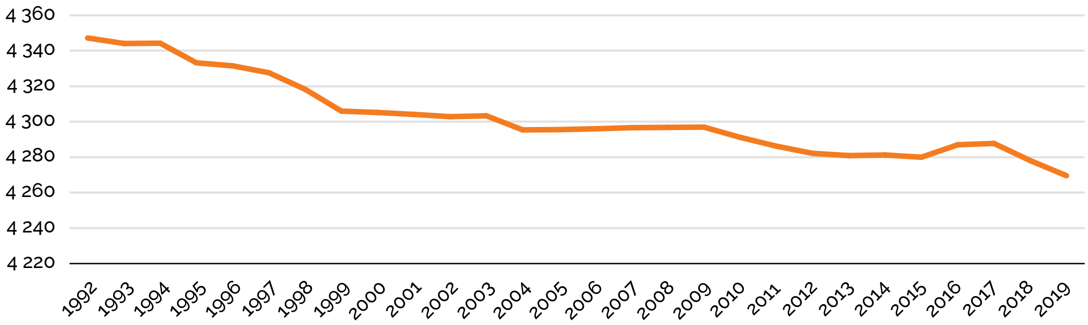


FIGURE 1.3 (CONTINUED)

Area of grassland



Area of tree-covered areas



Area of shrub-covered areas

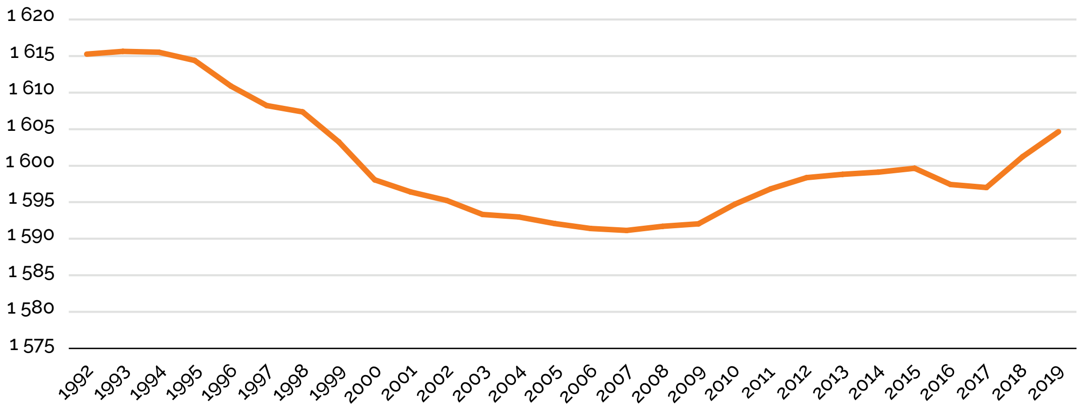
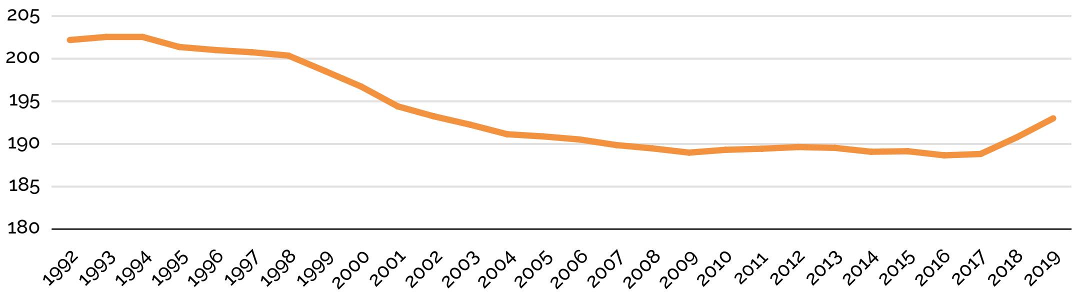
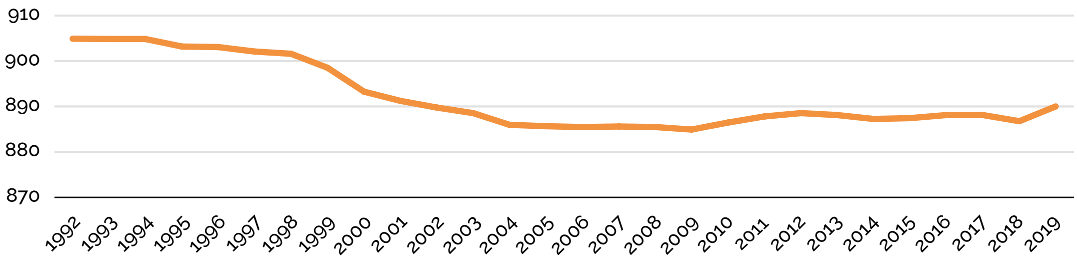


FIGURE 1.3 (CONTINUED)

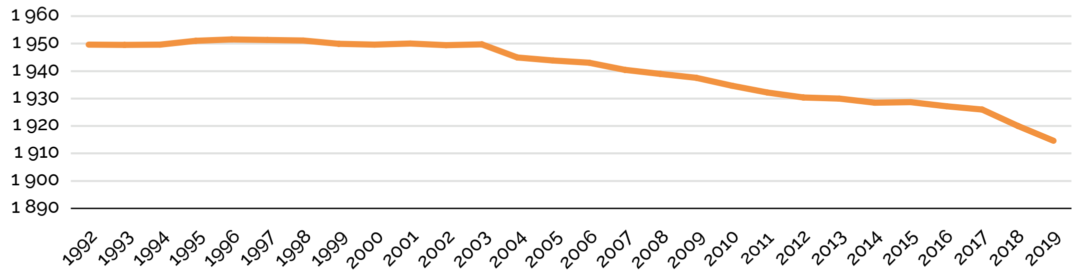
Area of shrubs and/or vegetation, aquatic or regular flooded



Area of sparsely natural vegetated areas



Area of terrestrial barren land



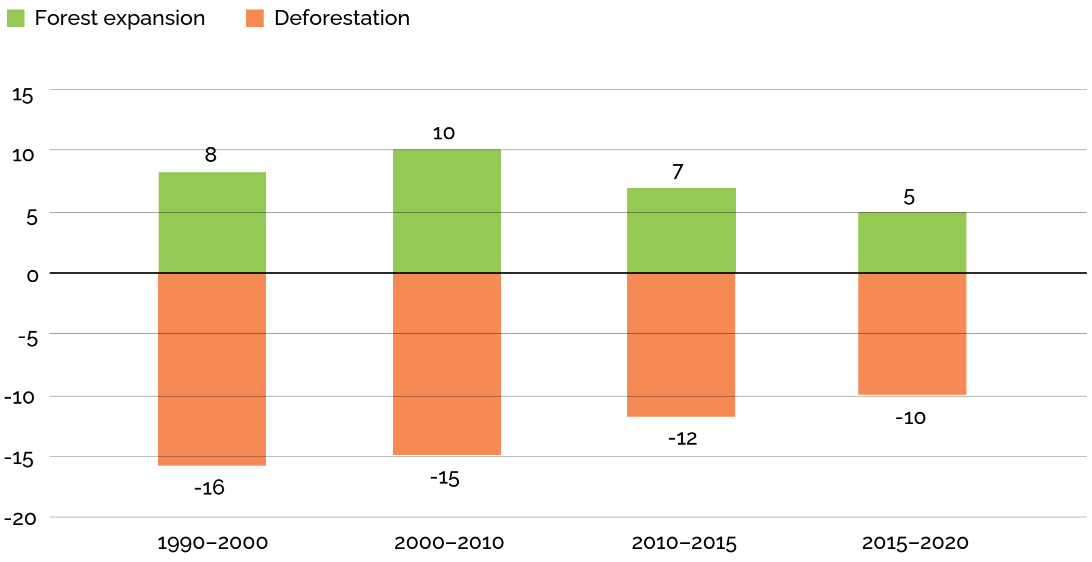
Source: **FAO**. 2020. FAOSTAT. In: *FAO*. Rome. www.fao.org/faostat/en/#data/QC

1.4 Land-use trends

Land used for all agricultural uses was about 4 752 million ha in 2019. This reflects an overall decline in land use since 2000 (Figure 1.5), mainly attributed to a decline in permanent pastures and meadows used for livestock husbandry.

Table 1.2 lists the land-use categories that are used to capture land productivity at the global level. These categories are reported at the national level and compiled in the FAO Statistical Database (FAOSTAT) to form the statistical framework for reporting agricultural statistics. Land-use classes conform with the mapping land-use types used in Global Agro-Ecological Zones (GAEZ) v4.

FIGURE 1.4 FOREST-COVER TRENDS, 1990–2020 (MILLION ha PER YEAR)

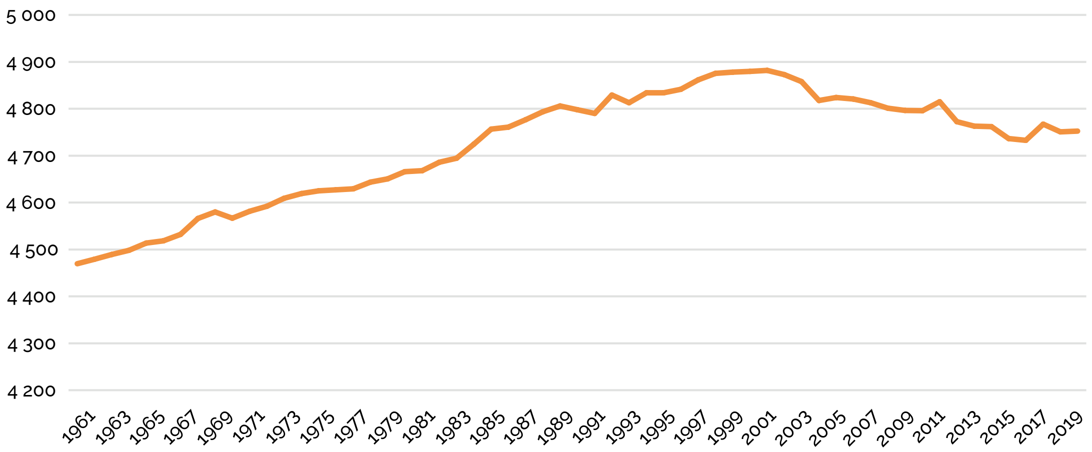


Source: **FAO**. 2020. *Global forest resources assessment 2020: Key findings*. Rome. https://doi.org/10.4060/ca8753en

Land-cover classifications (specifically GLC-SHARE) and areas equipped for irrigation (Global Map of Irrigated Areas; GMIA v5) guide the distribution in order to downscale the production statistics. For cropped land, the production area statistics are based on reported production volumes, cropping intensities and yields to derive harvested areas for specific crops under rainfed or irrigated conditions.

The overall distributions of land use and farming systems identified in SOLAW 2021 remain broadly the same as those compiled for SOLAW 2011 at global level (Map 1.5), and the land-use statistical trends to 2019 are given in Figure 1.6. Since 2000 when the original farming system descriptions were compiled, aggregate land use for all forms of agriculture (except aquaculture) has

FIGURE 1.5 AGRICULTURAL LAND-USE TRENDS, 1961–2019 (MILLION ha)



Source: **FAO**. 2020. FAOSTAT. In: *FAO*. Rome. www.fao.org/faostat/en/#data/QC

TABLE 1.2 GLOBAL LAND-USE CLASS EXTENT, 1992, 2000, 2010–2019 (MILLION ha)

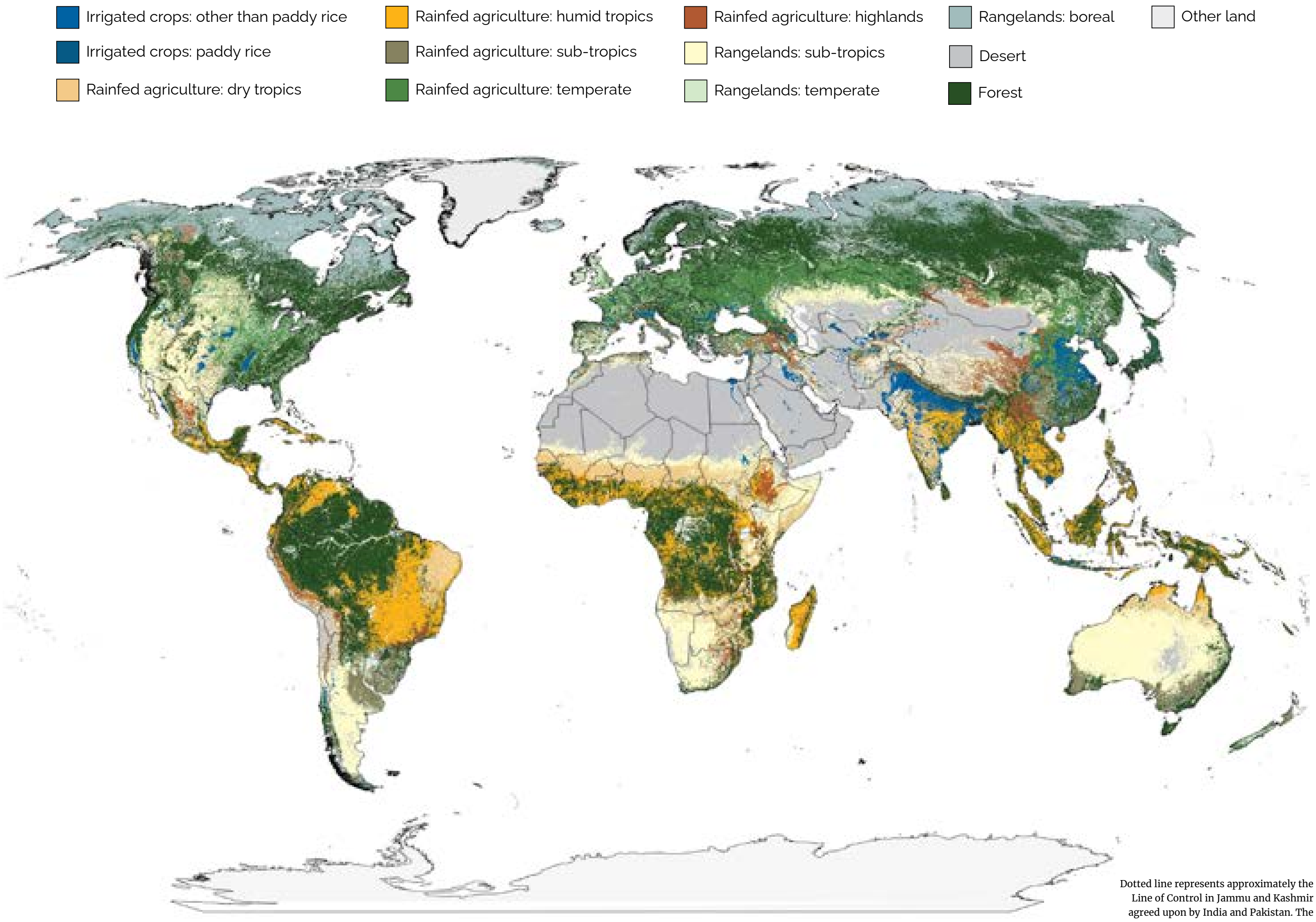
LAND-USE CLASS	1992	2000	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Country area	13 435	13 437	13 461	13 459	13 462	13 486	13 487	13 487	13 487	13 487	13 487	13 497
Land area	12 997	13 005	13 009	13 019	13 019	13 018	13 018	13 020	13 028	13 028	13 028	13 030
Land under permanent meadows and pastures	3 343	3 387	3 301	3 268	3 258	3 247	3 247	3 223	3 219	3 247	3 234	3 196
Arable land	1 368	1 493	1 361	1 370	1 378	1 380	1 381	1 383	1 387	1 396	1 395	1 383
Land under permanent crops	118	134	158	161	163	164	164	165	166	170	170	170
Cropland	1 486	13 437	1 520	1 534	1 544	1 546	1 547	1 551	1 556	1 568	1 568	1 556
Agricultural land (total of cropland and permanent Pasture)	4 829	4 880	4 820	4 802	4 801	4 793	4 795	4 774	4 775	4 815	4 801	4 752
Land area equipped for irrigation	264	289	322	325	329	332	333	335	337	338	339	342
Inland waters	435	430	450	437	437	438	437	436	428	429	428	427
Forestland	4 221	4 158	4 106	4 102	4 097	4 093	4 088	4 084	4 081	4 074	4 069	4 064
Naturally regenerating forest	4 033	3 937	3 834	3 825	3 817	3 809	3 801	3 792	3 787	3 778	3 771	3 763
Planted forest	187	220	271	275	278	282	286	290	292	294	297	299
Other land	3 947	3 968	4 060	4 102	4 102	4 103	4 098	4 138	4 138	4 111	4 133	4 188

Source: **FAO**. 2020. FAOSTAT. In: *FAO*. Rome. www.fao.org/faostat/en/#data/QC

remained stable at around 4 800 million ha. But this masks a significant decline in permanent meadows and pastures since 2000 (net loss of 191 million ha) and the continued increase in cropland (temporary and permanent crops) of some 100 million ha over the same period. The net forested area continues to decline (by about 94 million ha since 2000), although there have been slight increases in the planted forest.

At the global level, changes in overall land use appear small, but at country and local levels, shifts in land use and agricultural practices are significant. These changes trigger losses in soil structure and fertility and affect how soils respond hydrologically. Notably, the proportion of land equipped for irrigation to cropped land rose from 19.4 percent in 2000 to almost 22 percent in 2018. The conversions of forested land to cropped land in the Amazon and Congo basins are notable examples of the scale of change. The aggregate impact of local changes in oil palm plantations or draining organic soils to convert wetland to cropped land in Southeast Asia can be masked by classification shifts. For example, plantation development can register as a gain in forested land and permanent crops. Also the land registered as equipped for irrigation does not

MAP 1.5 MAJOR AGRICULTURAL SYSTEMS IN 2010



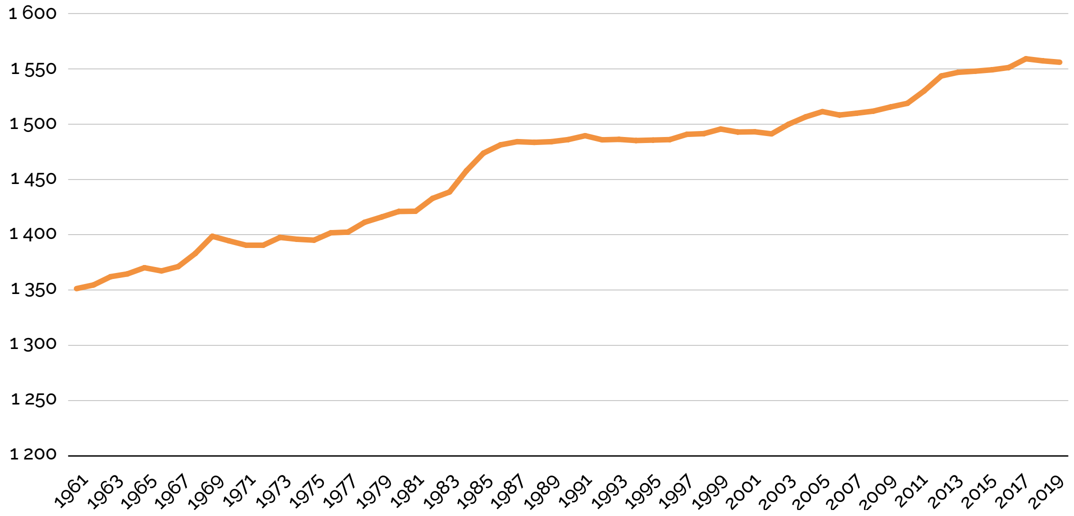
Source: **FAO**. 2011. *The state of the world's land and water resources for food and agriculture: Managing systems at risk*. Rome, FAO and London, Earthscan. www.fao.org/3/i1688e/i1688e.pdf
Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

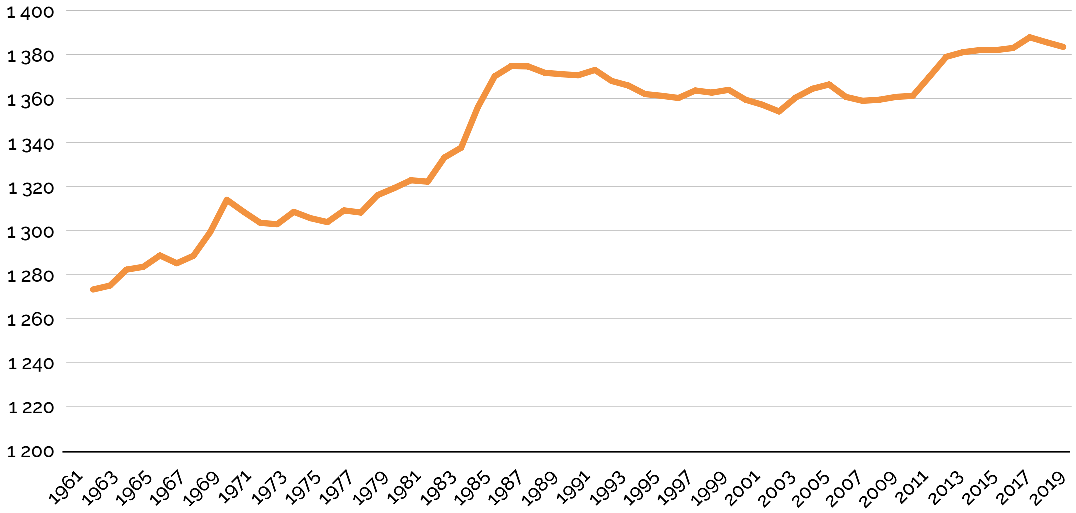
Final boundary between the Sudan and South Sudan has not yet been determined.

FIGURE 1.6 LAND-USE TRENDS (MILLION ha)

Cropland area



Arable land area



Agricultural land area

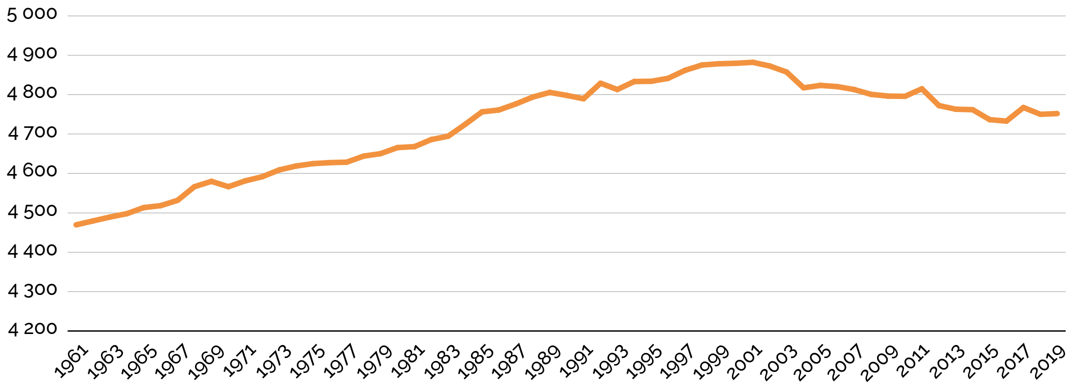
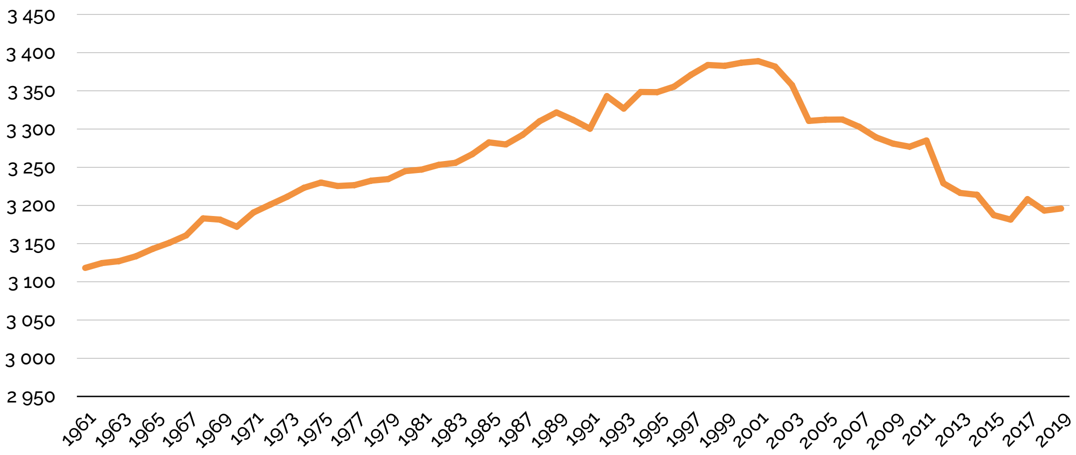
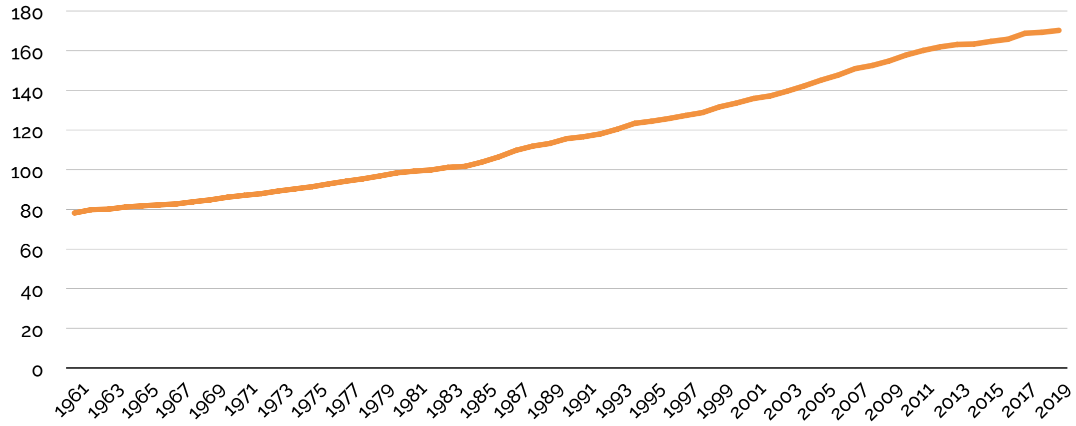


FIGURE 1.6 (CONTINUED)

Land under permanent meadows and pasture areas



Land under permanent crops area



Forestland area

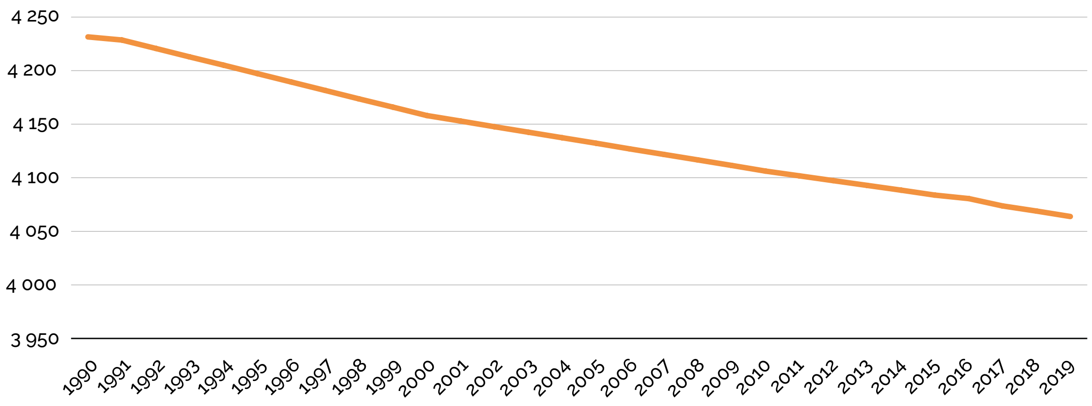
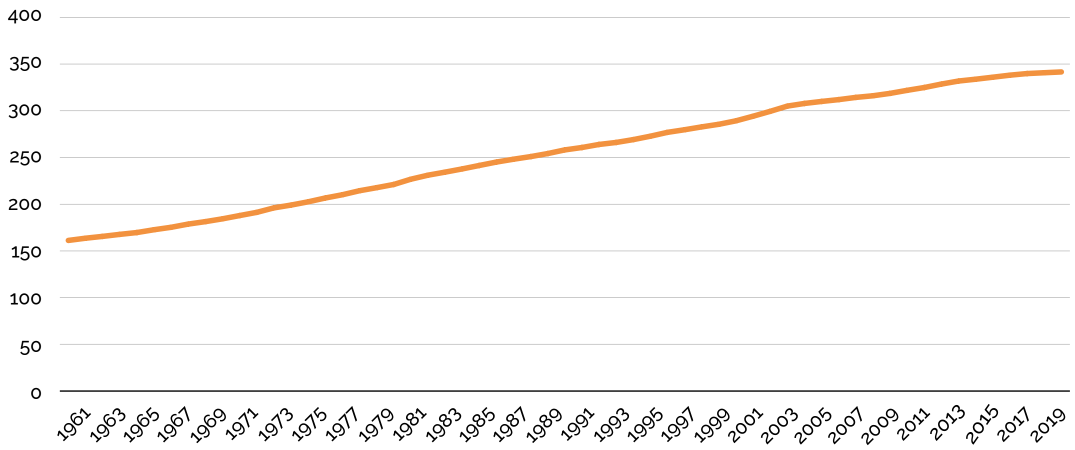


FIGURE 1.6 (CONTINUED)

Land area equipped for irrigation



Source: **FAO**. 2020. FAOSTAT. In: *FAO*. Rome. www.fao.org/faostat/en/#data/QC

imply this is the irrigated land area that will be recorded as the harvested area in any one calendar year as this is a function of cropping intensity.

1.4.1 Rainfed agriculture and the impact of drought

Rainfed agriculture is the predominant agricultural production system worldwide. Strictly defined, it depends exclusively on rainfall for crop production, with no permanent source of irrigation. In 2018, the world cultivated area was 1 557 million ha, of which 1 221 million ha (78 percent) was rainfed, producing about 60 percent of global crop output in a wide variety of production systems.

The areal extent of productive rainfed cropland has not changed significantly since the middle of the twentieth century, but this masks the extent to which land newly converted from forests and grasslands to arable farming has replaced degraded and abandoned land. The risks of resource degradation are high during periods of drought when SOC can be mineralized, although some land may not be permanently degraded and can be brought back into cultivation after long periods of fallow. National data on the extent of rainfed farming systems affected by land degradation are limited; it is therefore difficult to estimate the precise areas involved.

The most productive rainfed cropping occurs in the temperate zones of Northern America and Europe, and in the subtropics and humid tropics. Rainfed cropping in highland areas and the dry tropics tends to be relatively low yielding, with low-input practices associated with subsistence farming. Trends in rainfed areas differ regionally. In sub-Saharan Africa, where 97 percent of staple production is rainfed, the area of cereals has doubled since 1960. In Central America and the Caribbean, rainfed cultivation has expanded by 25 percent in the last 40 years.

The focus on dryland systems at the end of Chapter 4 discusses the combination of drought impacts in dry lands where, even during regular seasonal cycles, increases in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livestock traffic and cropping intensities can lead to rapid deterioration in soil fertility, biodiversity and soil structure, leaving large swathes of semi-arid subtropical land prone to degradation.

1.4.2 Irrigated agriculture

Irrigation plays a significant role in securing food supplies and supporting economic development in many countries. Its importance is likely to grow, given the impacts of climate change. Irrigated production is responsible for approximately 40 percent of agricultural output (FAO *et al.*, 2018). Land equipped for irrigation can stabilize the production of high-value crops, particularly eliminating the risk of unreliable rainfall, but, more importantly, delivering adequate soil moisture at the right time to maximize yield response. Irrigation in combination with drainage offers an important adaptation strategy to combat drought and flooding risk as the climate changes.

Land area equipped for irrigation[2] (including all full water control irrigation systems, equipped wetlands and spate irrigation) has almost doubled over the past 60 years, from 139 million ha in 1961 to over 328 million ha in 2018, with groundwater-sourced irrigation accounting for some 108 million ha, 33 percent of the equipped area (Table 1.3). Over the same period, land equipped for irrigation has increased from 10 percent of the total cultivated land to 21 percent. Since 2010, equipped areas have exhibited little or no growth in reported statistics, even as the global production of irrigated crops continues to increase. This may be due to changes in the pattern of production such as: increased cropping intensities and yields on existing continuously irrigated areas; infilling of gaps between equipped areas and actually irrigated areas (areas harvested); and production from areas not registered in national statistics as "equipped for irrigation". The latter may reflect informal and temporary irrigation systems or simply land that is equipped and not reported. This is particularly the case in the Near East and Arabian Peninsula subregions, which have experienced dramatic increases in livestock production derived from irrigated fodder and the expansion of vegetable and citrus production under protected cover, including temporary and permanent shade and greenhousing. Downscaling national statistics is improving due to the use of higher-resolution and calibrated remote-sensing techniques, such as the moderate-resolution imaging spectroradiometer platform using the normalized difference vegetation index (NDVI).

In 2018, the Asian continent had 70 percent of the world's area equipped for irrigation, mainly in the South Asia and East Asia subregions, and 32 percent of the cultivated area (Table 1.3, Figure 1.7 and Figure 1.8). Africa, particularly sub-Saharan Africa, had the smallest equipped area in 2018, accounting for only 3 percent of global irrigated land. Irrigation is essential in Northern Africa, representing 27 percent of the cultivated area. Countries with the largest land area equipped for irrigation were China (70 million ha), India (70 million ha), the United States of America (27 million ha) and Pakistan (20 million ha).

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[2] The area equipped for irrigation refers to the area equipped to provide water – via irrigation – to crops. It includes areas equipped for full control irrigation and partially controlled irrigation (equipped lowland areas and areas equipped for spate irrigation).

Figure 1.9 illustrates trends in irrigated areas as a percentage of cultivated area in 2000, 2012 and 2018.

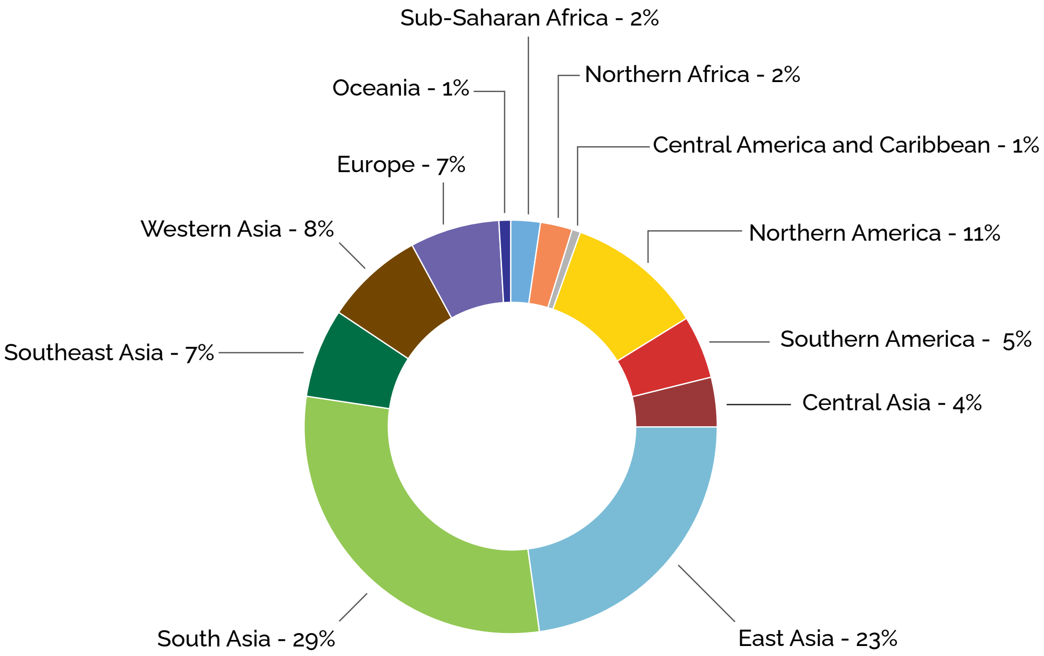
In the 1960s and 1970s, the push to intensify under the Green Revolution was primarily responsible for a 2 percent annual increase in the land area equipped for irrigation. By the 1980s, this slowed to less than 1 percent. As a percentage of the cultivated area, irrigation increased in almost all regions, mainly where irrigated agriculture dominated, such

TABLE 1.3 AREAS EQUIPPED FOR IRRIGATION, 1961, 2012 AND 2018

CONTINENT, REGION	EQUIPPED AREA (MILLION ha)			EQUIPPED AREA AS A PERCENTAGE OF CULTIVATED AREA (%)			GROUNDWATER IRRIGATION (2018)	
YEAR	1961	2012	2018	1961	2012	2018	AREA EQUIPPED (MILLION ha)	PERCENTAGE OF TOTAL IRRIGATED AREA (%)
Africa	**7.4**	**15.2**	**15.8**	**4.4**	**5.6**	**5.7**	**3.0**	**19.0**
Northern Africa	3.9	7.3	7.6	17.1	25.5	26.3	2.3	31.0
Sub-Saharan Africa	3.5	7.9	8.2	2.4	3.2	3.3	0.7	9.0
Americas	**22.6**	**51.3**	**53.6**	**6.7**	**14.0**	**14.5**	**22.0**	**41.0**
Central America and Caribbean	17.4	2.1	2.2	6.7	14.4	14.7	0.4	20.0
Northern America	0.6	33.6	35.2	5.5	15.2	15.9	20.2	57.0
Southern America	4.7	15.5	16.2	6.8	11.9	12.3	1.5	9.0
Asia	**95.6**	**231.8**	**232.9**	**19.6**	**39.9**	**39.4**	**79.0**	**34.0**
Central Asia	9.6	13.5	12.7	16.2	29.3	27.3	0.9	7.0
East Asia	7.2	73.8	74.8	13.4	50.5	51.4	19.7	26.0
South Asia	36.3	96.6	97.2	19.1	45.2	45.4	47.8	49.0
Southeast Asia	34.5	22.6	22.9	29.7	19.8	18.6	0.9	4.0
Western Asia	8.0	25.3	25.4	11.7	42.0	41.3	9.5	38.0
Europe	**12.3**	**22.0**	**23.0**	**3.6**	**7.6**	**8.0**	**3.2**	**14.0**
Eastern Europe and Russian Federation	8.7	6.3	6.3	5.8	3.9	3.8	0.5	8.0
Western and Central Europe	3.6	15.6	16.7	1.9	12.3	13.4	2.8	17.0
Oceania	**1.1**	**3.0**	**3.2**	**3.2**	**9.1**	**9.3**	**1.1**	**6.0**
Australia and New Zealand	1.1	3.0	3.0	3.2	9.3	9.5	1.1	6.0
Pacific Islands	0.0	0.0	0.0	0.2	0.5	0.6	0.0	12.0
World	**139.0**	**323.3**	**328.3**	**10.2**	**20.9**	**21.1**	**108.3**	**33.0**
High income	26.7	53.9	55.2	6.9	15.3	15.6	22.2	40.3
Low and middle income	66.6	269.4	273.2	23.6	22.6	22.7	85.1	31.2

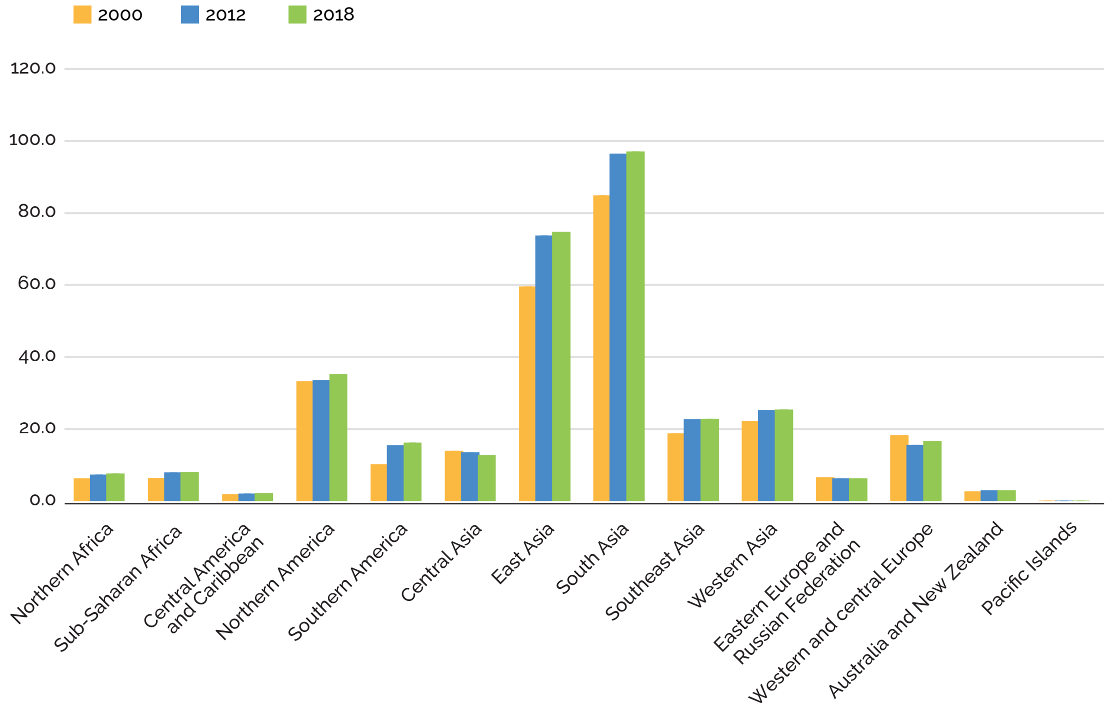
Source: **FAO**. 2021. AQUASTAT – FAO's Global Information System on Water and Agriculture. In: *FAO*. Rome. www.fao.org/aquastat/en

FIGURE 1.7 GLOBAL DISTRIBUTION OF IRRIGATED SURFACES BY GEOGRAPHICAL REGION, 2018



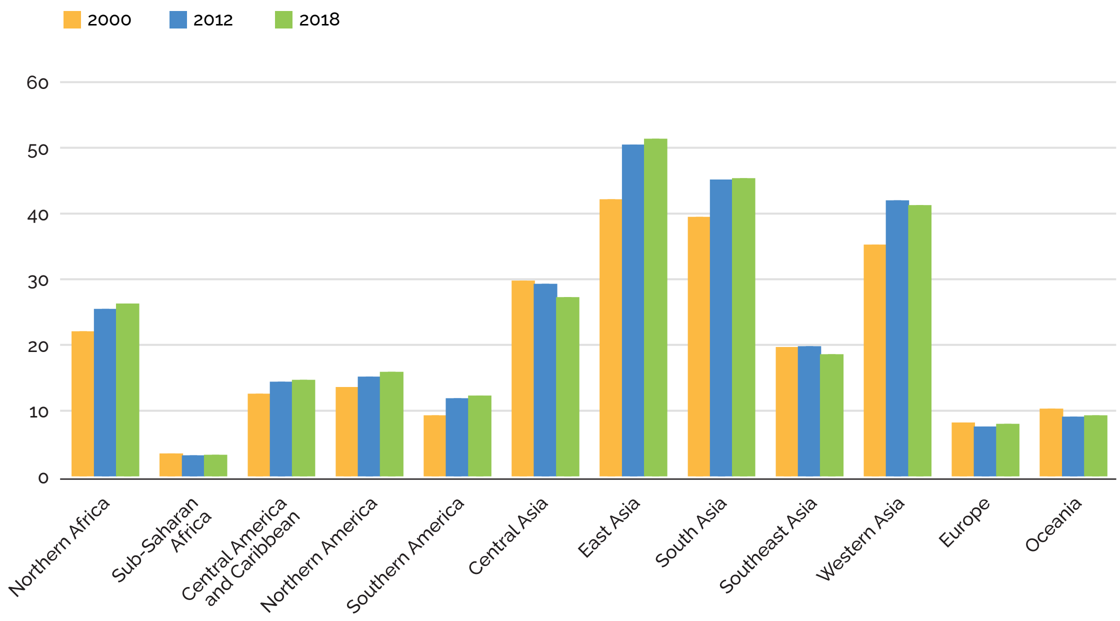
Source: **FAO**. 2021. AQUASTAT – FAO's Global Information System on Water and Agriculture. In: *FAO*. Rome. www.fao.org/aquastat/en

FIGURE 1.8 AREA EQUIPPED FOR IRRIGATION BY GEOGRAPHICAL REGION, 2000, 2012 AND 2018 (MILLION ha)



Source: **FAO**. 2021. AQUASTAT – FAO's Global Information System on Water and Agriculture. In: *FAO*. Rome. www.fao.org/aquastat/en

FIGURE 1.9 IRRIGATED AREA AS A PERCENTAGE OF CULTIVATED AREA, 2000, 2012 AND 2018 (%)



Source: **FAO**. 2021. AQUASTAT – FAO's Global Information System on Water and Agriculture. In: *FAO*. Rome. www.fao.org/aquastat/en

as Northern Africa, South Asia and East Asia. Globally, the annual growth rate has slowed to less than 0.5 percent, but this is based on reported statistics only. The development of new irrigated areas is evident from imagery and moderate-resolution imaging spectroradiometer data (FAO Water Productivity Open-access Portal (WaPOR); FAO, 2022a), particularly the growth of centre pivot installations, with each pivot reach averaging 50 ha. This recent expansion of centre pivot installations is apparent mainly in the Nile basin and Arabian Peninsula where high demand for irrigated fodder is concentrated (Alhumaid, 2020).

Some of the reasons for the overall decline in growth rates include increasing irrigation development costs, reduced government support and financing, ageing infrastructure and lack of maintenance. But increasing water demand for municipal and industrial uses, declining freshwater sources and growing concerns for the aquatic environment are also constraining growth. A contributing factor in the 1980s was the loss of many large schemes in Eastern Europe and the former Soviet Union that proved unprofitable, and which were unable to adapt and meet the requirements of commercial new market-oriented private commercial farming (Siebert and Döll, 2007).

Since 2000, investments have moved from developing large irrigation infrastructure, including dams, reservoirs and large irrigation systems, to improving on-farm irrigation systems and including microirrigation methods and more effective management practices. The area equipped for micro-irrigation (drip lines and sprinklers) in 2018 covered almost 70 million ha (21 percent)


©FAO/Sheam Kaheel

of the total equipped area. The adoption of precision irrigation is associated with the uptake of protected cropping in industrial-scale glasshouses and areas of shade netting, particularly for high-value horticultural crops. Many of these installations are visible on satellite imagery in the Mediterranean basin and the Near East.

Existing irrigation schemes contend with salinity and pollution build-up generated by decades of maladapted drainage and soil management practices. Options to manage salinity are becoming limited in areas where aridity is increasing (see section 1.5.3 on soil salinization).

In addition to water scarcity, the availability of suitable land for irrigation expansion is another constraint as urban areas expand and encroach on land previously dedicated to irrigated production. Fragmentation of land holdings and increases in land prices also inhibit the development of contiguous areas of formal production (Lowder, Sánchez and Bertini, 2019).

Irrigated agricultural crops typically yield at least twice that of nearby rainfed crops. Rainfed cereals yield on average 1.5 tonnes/ha in the developing countries, whereas irrigated cereals yield on average 3.3 tonnes/ha. Irrigated cropping intensities are typically higher, with two crops per year in most of Asia. Irrigation continues to stabilize agricultural output, raising cropping intensity and encouraging farmers to grow high-value crops (Fuglie *et al.*, 2020).

In the baseline year of 2012, some 346 million ha of irrigated production was harvested on 261 million ha of land equipped for irrigation, indicating a global cropping intensity of 130 percent (FAO, 2018a). Cereals accounted for over 60 percent of the harvested area, vegetables for 10 percent, fodder for 7 percent, oil crops for 7 percent, fruit for 6 percent, fibre for 5 percent and sugar for 4 percent.[3] However, proportions are changing in response to increasing demands for different products, particularly animal protein.

Land and water productivity under irrigation presents a mixed picture. Figure 1.10 illustrates the impact of irrigation on vegetable yields by region based on production statistics compiled in 2012.

Map 1.6 shows economic water productivity for rice. In Asia, subtropical climates and short growing seasons favour higher cropping intensities.

Map 1.7 illustrates economic water productivity for wheat. For instance, productivity is low in Punjab, India, because of the large volumes of water required to grow wheat. This contrasts with high productivity in Western Europe, where water consumption is lower, and fertilizer and pesticide inputs are relatively high.

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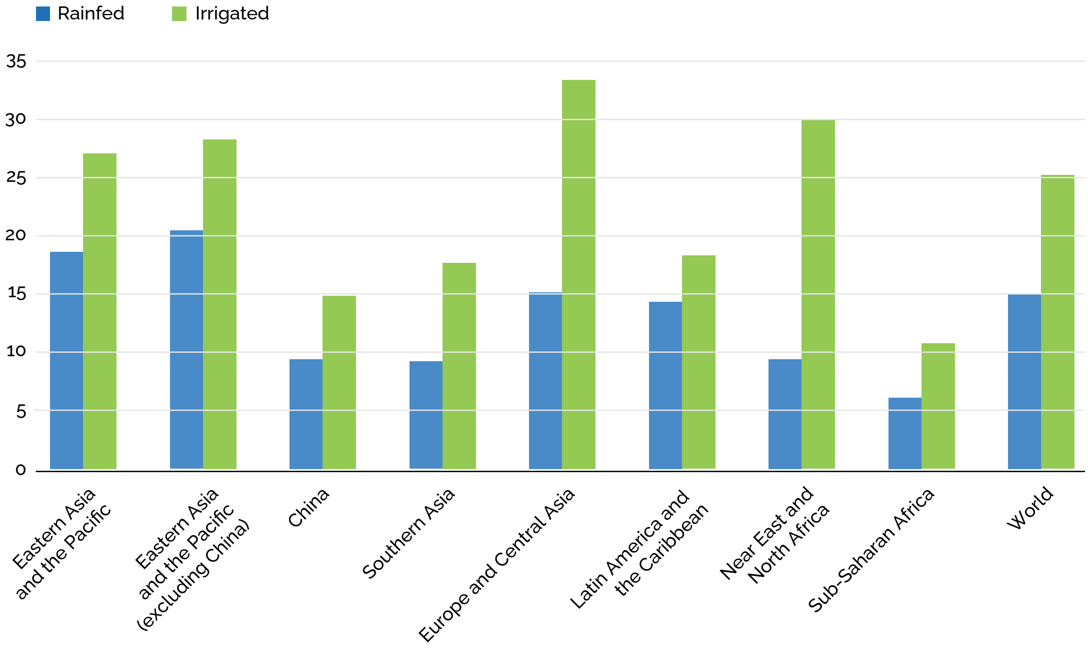
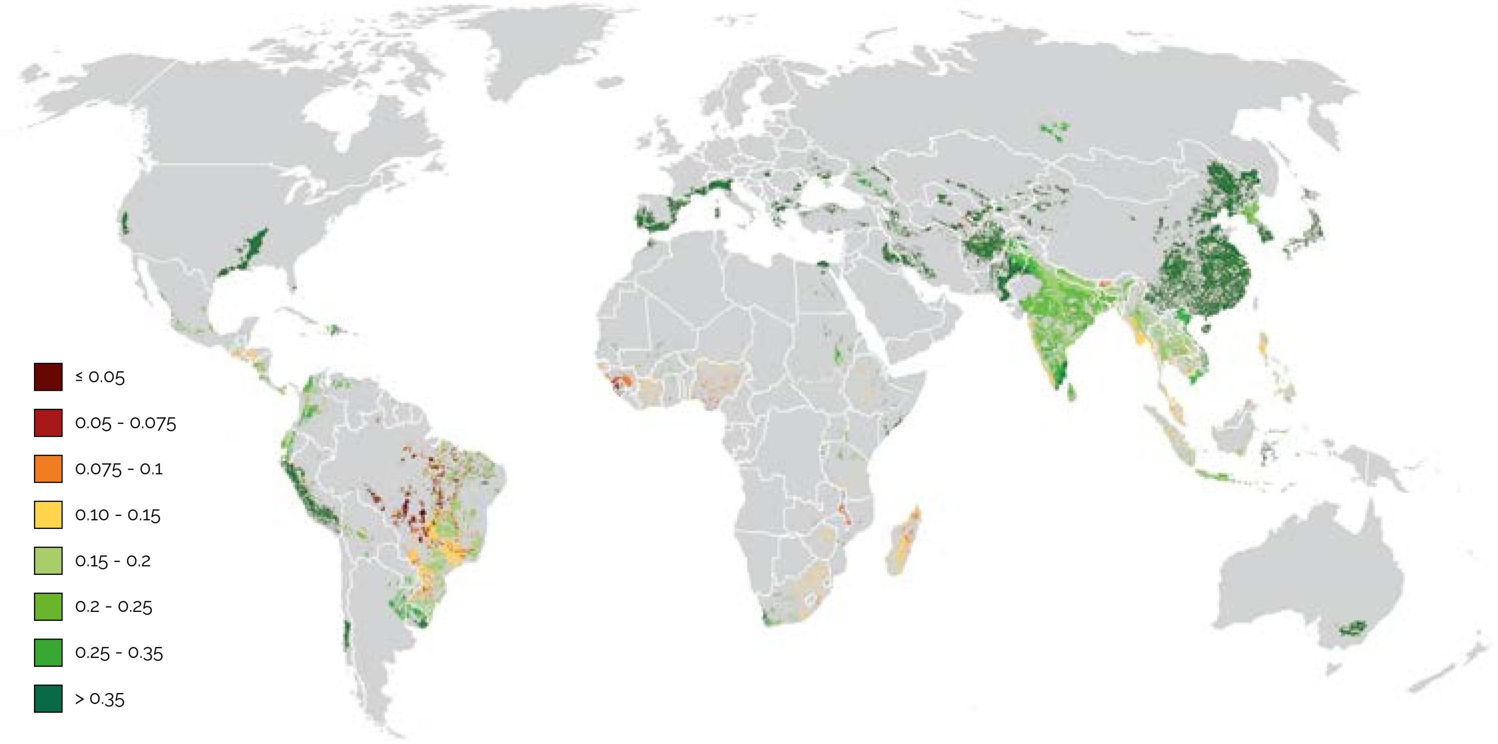
[3] Note that FAOSTAT (FAO, 2020a) data show crop production and may differ from the FAO Global Information System on Water and Agriculture (AQUASTAT) data (FAO, 2021b). In some regions, the same area is harvested twice in the same year and so some areas are counted twice. Also, the actual area irrigated must tally with production data and is always less than the area equipped for irrigation as given in AQUASTAT.

FIGURE 1.10 VEGETABLE YIELDS BY REGION, 2012 (TONNES/ha)



Source: **FAO**. 2020. *The state of food and agriculture 2020. Overcoming water challenges in agriculture.* Rome. https://doi.org/10.4060/cb1447en

MAP 1.6 ECONOMIC WATER PRODUCTIVITY FOR RICE, AVERAGE 1996–2005 (USD/m³)



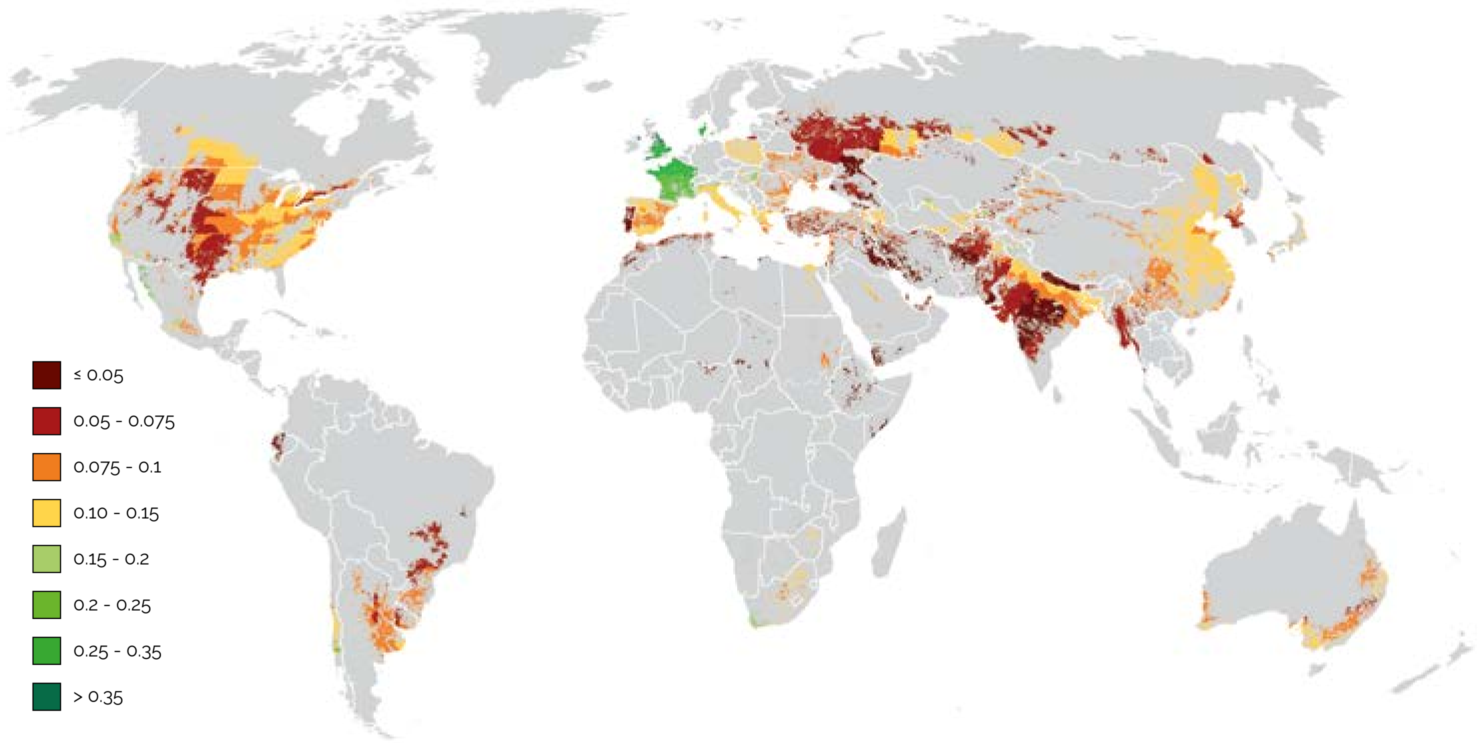
Note: Economic water productivity is defined as crop USD value per unit of water consumed (total evapotranspiration over the crop growing season). Values are converted from physical water productivity (kg/m³) to economic water productivity (USD/m³) using the average global price of each crop from FAOSTAT, average for period 1981–2010 (days).

Source: **FAO**. 2020. *The state of food and agriculture 2020. Overcoming water challenges in agriculture*. Rome. https://doi.org/10.4060/cb1447en. Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

MAP 1.7 ECONOMIC WATER PRODUCTIVITY FOR WHEAT, AVERAGE 1996–2005 (USD/m^3)



Note: Economic water productivity is defined as crop USD value per unit of water consumed (total evapotranspiration over the crop growing season). Values are converted from physical water productivity (kg/m^3) to economic water productivity (USD/m^3) using the average global price of each crop from FAOSTAT.

Source: **FAO**. 2020. *The state of food and agriculture 2020. Overcoming water challenges in agriculture*. Rome. https://doi.org/10.4060/cb1447en. Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

The most productive areas equipped for irrigation are in broad alluvial plains, deltas and coastal margins in subtropical climates with high evaporation rates, monsoonal rainfall, inundation and susceptibility to salinization. In these irrigated systems, the annual crop production cycle is highly conditioned by climatic volatility – prolonged periods of drought and higher-frequency intensified rainfall and associated flooding. The land's ability to recover from flooding to maintain cropping calendars is an important element of the resilience of irrigated farming systems. In the Indus basin, the July–September flood event in 2010 inundated at least 3.7 million ha of productive irrigated floodplain, disrupting rice food systems and industrial crops such as cotton, well into 2011 (NASA, 2011). The 2018 drought in southern Australia affected large areas, but even with reduced water allocations, productivity levels on irrigated land were sustained (Hatfield-Dodds *et al.*, 2018).

1.4.3 Land for livestock production

The rapid expansion of animal protein consumption in the latter half of the twentieth century is a feature of global food production assessments (FAO, 2017a, 2020c). Global land use dedicated to livestock production (permanent pastures and meadows) peaked around 2000 at 3.4 billion ha, and has since declined to around 3.2 billion ha in 2019 (Figure 1.11). The increase in animal protein consumption in the twentieth century is reflected in the expansion of pasture before 2000. The subsequent decline reflects the increase in livestock productivity and stocking intensity including growth in zero-grazing feedlots (FAO, 2019a).

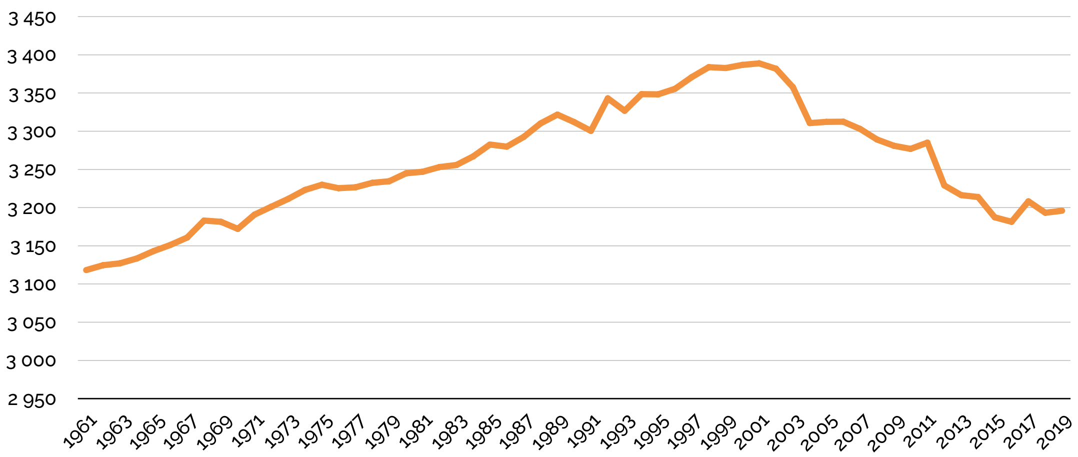
Livestock production (including pasture, rangeland and cropland for feed) represents almost 80 percent of all agricultural land, with feed production taking up roughly one-third of total cropland. Yet, the grassland and shrub-covered areas used to graze animals or as sources of fodder have significantly declined by 191 million ha over two decades to an area of 3 196 million ha in 2019, due to pressures of converting to cropland. Moreover, 13 percent of the grassland area has degraded due to high anthropogenic pressures, and 34 percent has reduced biophysical status, notably due to overgrazing and inadequate livestock mobility causing soil compaction and erosion, thus affecting soil function, plant growth and hydrological services.

Intensive livestock production has grown rapidly to meet expanding meat demand in middle- to high-income countries. This places pressure on *in situ* water resources and soil resources for intensive feed and forage production. Some 12 percent of irrigation water withdrawals is attributable to fodder crops (FAO, 2019a). Concentrating inputs and animal waste have resulted in energy use from fossil fuels, methane emissions and point-source water pollution from nutrients and antibiotics. Livestock and forest options also need analysing for a complete land-use scenario development for future production systems.

Rural communities living in dry lands have developed agricultural systems and practices that are adapted to arid, semi-arid and subhumid conditions and drought risk over generations of experience. These populations that depend on limited land potential and water resources have developed mixed crop–livestock systems based on short-season drought-resilient crops and receding floodwaters alongside wetlands and river plains. They can provide lessons for countries recently experiencing water shortage and drought due to climate change.

Overgrazing is also degrading grasslands, and erosion rates are increasing where over-

FIGURE 1.11 GLOBAL LAND USE UNDER PERMANENT MEADOWS AND PASTURES, 1961–2019 (MILLION ha)



Source: **FAO**. 2020. FAOSTAT. In: *FAO*. Rome. www.fao.org/faostat/en/#data/QC

grazing occurs (Pimentel and Burgess, 2013). Protecting and conserving grasslands require the fostering of crop rotations and seeded pastures in cropped grassland areas and improvements in grazing management.

The declining trend in land use for livestock production may flatten out as limits to productivity are approached in some regions, and demand for animal protein is saturated (FAO, 2018b). Land used for livestock production (including pastureland, rangeland and cropland) represents almost 80 percent of all agricultural land, with feed and fodder production taking up roughly one-third of total cropland (FAO, 2018b).

Intensive livestock production is apparent where higher livestock densities occur and feed and water inputs are concentrated, placing pressure on *in situ* water resources (notably groundwater) and soil resources for higher forage production rates. Adopting zero-grazing or feedlot systems in semi-arid and humid zones has reduced soil compaction and poaching from grazing livestock. However, concentrated inputs and animal waste have resulted in higher point-source water pollution from nutrients and antibiotics. Additional demand for imported feed and forage production is significant, particularly for high-protein feed crops such as soya. Estimates suggest that up to 12 percent of irrigation water withdrawals may be attributed to fodder crops (Mekonnen and Hoekstra, 2012). However, in practice, national reporting of fodder crop production has proved so unreliable and inconsistent that FAOSTAT no longer reports fodder production.

Projected grassland soil carbon sequestration is significant. Estimates suggest improved grazing management practices could sequester 409 million tonnes CO_2-eq of carbon annually on pastureland. A further 176 million tonnes CO_2-eq of sequestered emissions (net of increased nitrous oxide emissions) annually would be possible by sowing legumes in some grassland areas. Thus, a combined mitigation potential of 585 million tonnes CO_2-eq is estimated, representing about 8 percent of livestock supply-chain emissions (FAO, 2013a).

The current pattern of dryland management is responsible for losing significant amounts of carbon, driven mostly by increasing human and livestock pressures. Dryland soils tend to be low in carbon due to limited replenishment and loss to mineralization of humic complexes when dehydrated. Thus, they are susceptible to degradation by mechanical erosion (wind and water), but their potential to sequester carbon may be high. Estimates suggest that by 2030, improved rangeland management has the biophysical potential to sequester 1.3–2.0 billion tonnes CO_2-eq worldwide (Tennigkeit and Wilkes, 2008).

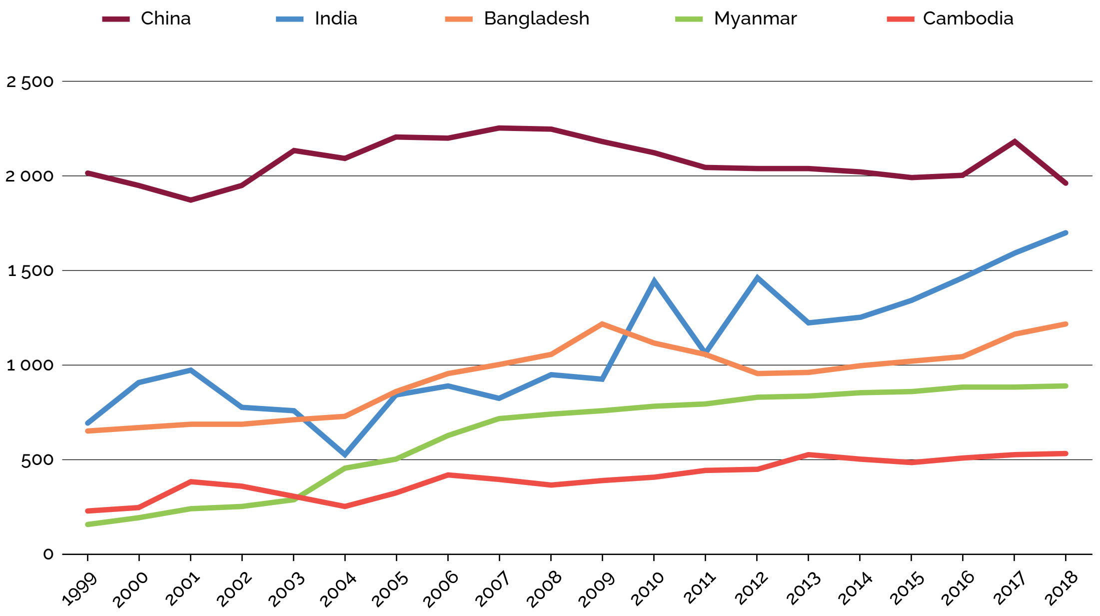
1.4.4 Inland fisheries and aquaculture

The growth in freshwater fish capture and aquaculture as the dominant form of fish production is significant, signalling the conversion of freshwater habitats with some using saline–alkaline water to raise marine species (FAO, 2020d). Significant regional differences in production levels reflect the distribution of freshwater habitats and geographical gradients in climate, geology, land use, biodiversity, human population density and economic activity. Figure 1.12 exhibits the growth in fish capture production by producers in South Asia and East Asia. Map 1.8 presents the distribution of inland fish capture in relation to major river basins.

Inland fisheries are subject to impacts from a range of human-induced drivers

FIGURE 1.12

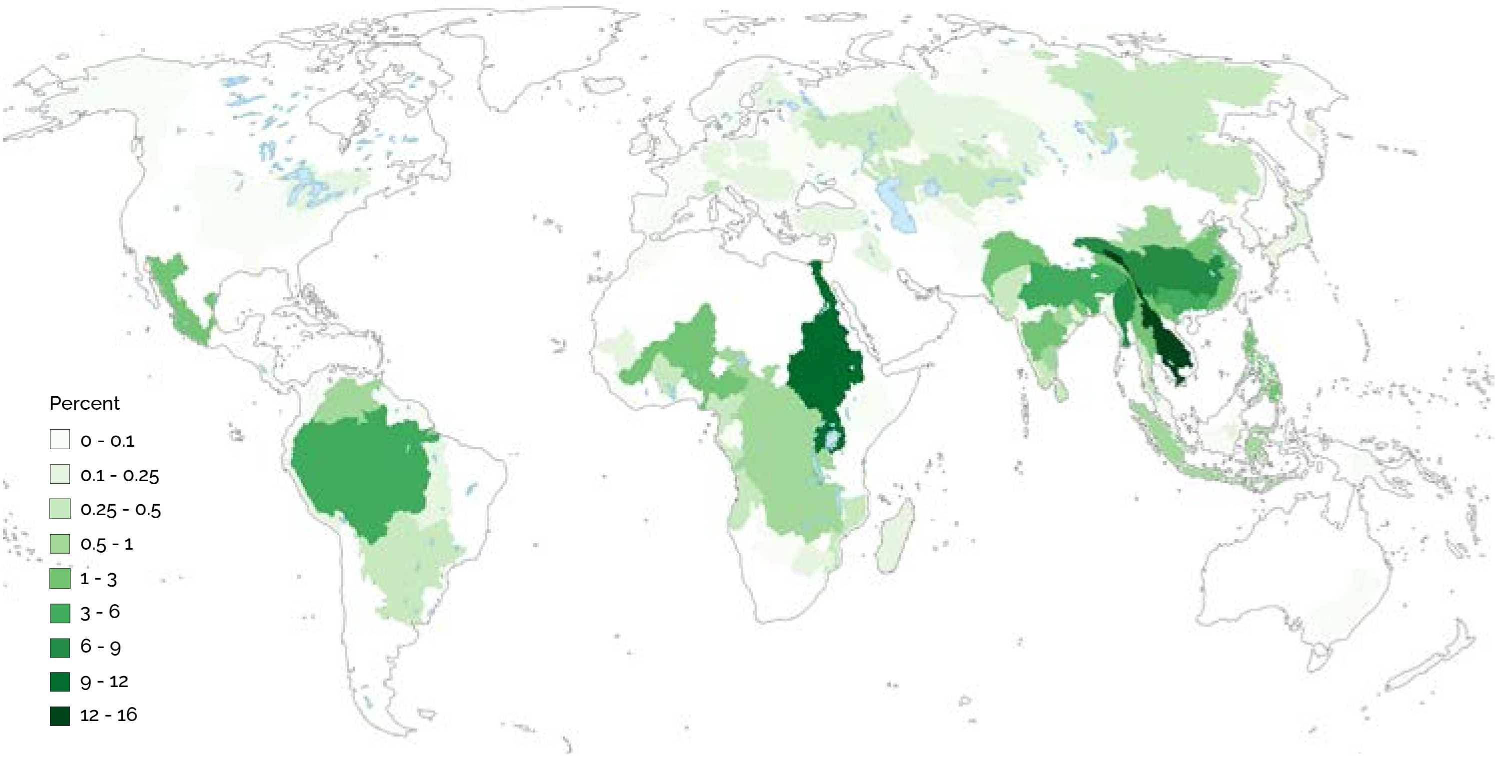
TOP FIVE INLAND WATERS FISH CAPTURE PRODUCING COUNTRIES, 1999–2018 (THOUSAND TONNES)



Source: **FAO**. 2020. *The state of world fisheries and aquaculture: Sustainability in action*. Rome. https://doi.org/10.4060/ca9229en

MAP 1.8

ESTIMATED INLAND FISHERY CATCH AS A PERCENTAGE OF THE GLOBAL INLAND 2007–2016 CATCH



Legend: White = no significant catch; lightest green = < 0.1 percent and darkest green = 12–16 percent of the global total inland fishery catch.
Note: Retained recreational catches are not included.

Source: **FAO**. 2020. *The state of world fisheries and aquaculture: Sustainability in action*. Rome. https://doi.org/10.4060/ca9229en
Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420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including competition for freshwater from irrigation and agriculture and impacts on habitat connectivity caused by water control infrastructure. This includes dams and flood protection, water regulation and pollution caused by runoff and drainage. Pekel *et al.* (2016) note that between 1984 and 2015, 90 000 km^2 of permanent water bodies has vanished altogether and over 72 000 km^2 has transitioned from permanent water bodies to seasonal waterbodies disconnected for periods of the annual water cycle. This disruption of natural surface water area and connection has diminished the potential for fish capture and aquaculture, while pollution from land-based source nutrients and pesticides has resulted in eutrophication of fish habitats and high rates of fish mortality (Funge-Smith, 2018).

Inland capture fisheries produce some 12 million tonnes of fish annually (12.5 percent of the total global capture fishery production), which is sufficient to meet the animal protein requirements of more than 160 million people (FAO, 2020d). More than 40 percent of the world's inland fish capture harvest comes from 50 low-income food-deficit countries. Inland fish provide nutritional quality to diets that are otherwise poor in nutrients, minerals and vitamins. Emissions of GHGs associated with inland capture fisheries are relatively small compared to livestock and rice production, as most fish harvested are consumed or sold locally, and fishing activities rely on manual labour and low transportation costs (Welcomme *et al.*, 2016).

Inland aquaculture increased from less than 1 million tonnes of annual live weight production globally in 1950 to 51.3 million tonnes in 2018. It contributes 62.5 percent of the world fish production (FAO, 2020d). Rice–fish culture, often operating at a family scale with renovated paddy fields, has expanded rapidly among rice farmers in China in recent decades. In 2008, an estimated 1.5 million ha of rice fields was used for aquaculture (FAO, 2020a). Cage aquaculture in freshwater lakes and rivers has flourished in many countries as an efficient non-consumptive use of freshwater. Asia (especially China) has the greatest freshwater aquaculture production in terms of land and water surface area. Fish production in coastal and offshore marine environments offers alternative and new aquaculture opportunities when freshwater and land become scarce (Kapetsky, Aguilar-Manjarrez and Jenness, 2013).

1.4.5 Forestland

The 4 060 million ha of forest cover assessed in 2020 comprises tropical (45 percent), boreal (27 percent), temperate (16 percent) and subtropical (11 percent) forests (Map 1.9) (FAO, 2020c). About 1 150 million ha is managed primarily for producing wood and non-wood forest products. Since 1990, the area of multiple forest use has declined by 71 million ha, to 749 million ha in 2015. Multiple use includes crop production, which has been relatively stable since 1990. The total carbon stock in forests declined from 668 billion tonnes in 1990 to 662 billion tonnes in 2020, while carbon density increased slightly over the same period, from 159 tonnes/ha to 163 tonnes/ha. Most forest carbon is in the living biomass (44 percent) and SOM (45 percent), with the remainder in dead wood and litter.

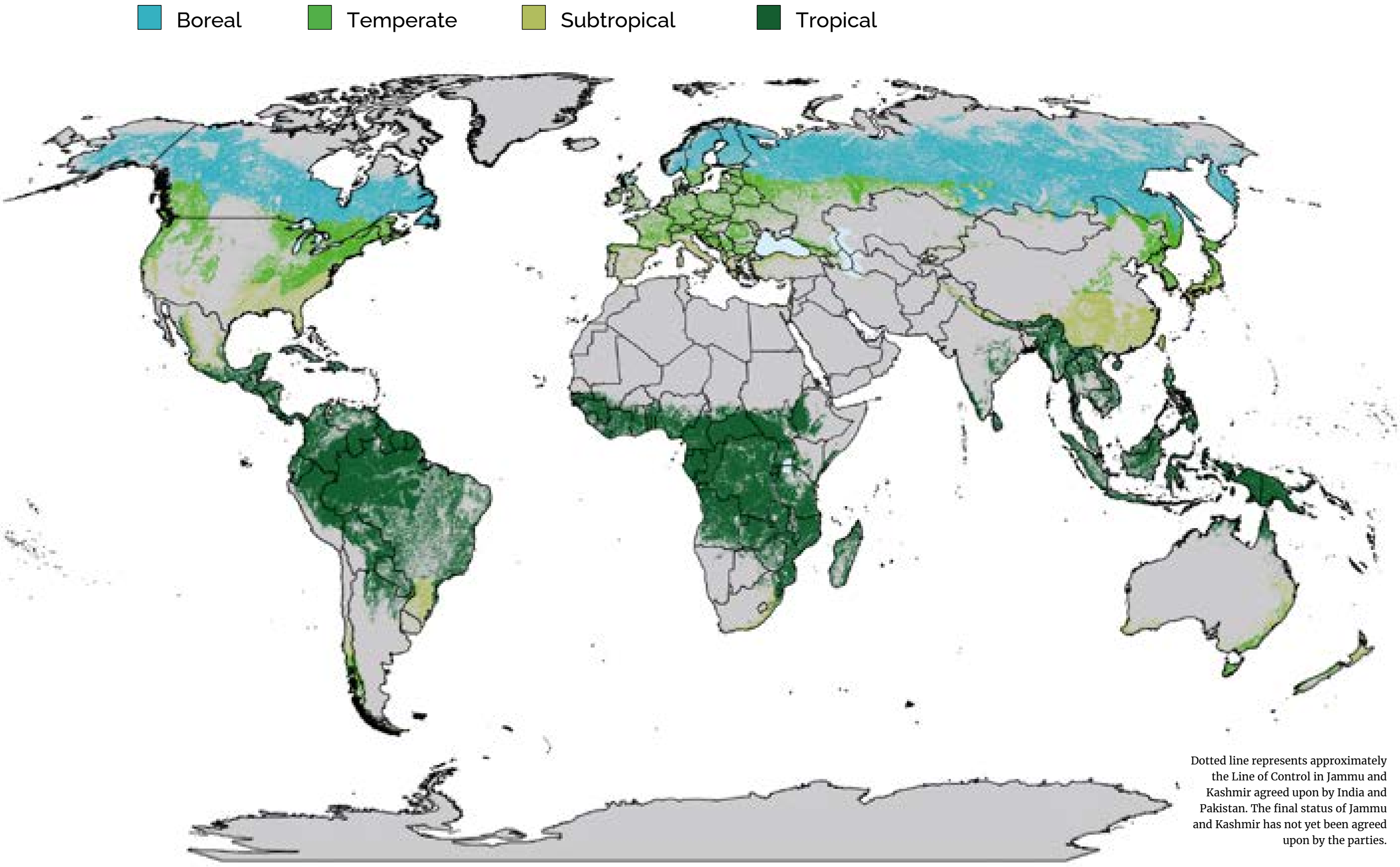
Since 1990, the net decline in forest area has amounted to some 420 million ha by 2020. Between 2015 and 2019, forest loss was 10 million ha/year compared with

12 million ha/year between 2010 and 2014. Between 2010 and 2019, the highest net forest loss rates occurred in Africa (3.9 million ha/year) and Southern America (2.6 million ha/year). Taking account of forest expansion through regeneration and afforestation, the overall net annual decline between 2010 and 2020 was 4 million ha/year, compared with 5.2 million ha/year between 2000 and 2009 and 7.8 million ha/year between 1990 and 2000 (Figure 1.13 and Figure 1.14).

The area of primary forest decreased by 81.3 million ha between 1990 and 2019. The average annual rate of loss of primary forest was 3 410 million ha in 1990–2000 and 3 450 million ha in 2000–2010; the rate dropped substantially in the latest decade, to 1 270 million ha. The biggest average annual loss of primary forest area in 2010–2019 was in Africa, at 849 thousand ha, up from 611 thousand ha in 1990–1999 and 585 thousand ha in 2000–2009. The increase since 2010 is due largely to the Democratic Republic of the Congo, where the average annual rate of loss was 723 thousand ha in 2010–2019, up from 442 thousand ha in 1990–2009.

Primary forest covers only 1 110 million ha, natural regeneration covers 3 750 million ha and plantation forest covers 131 million ha. Regional variations are significant in relation to the Amazon and Nile/Congo basin hydrology and the primary forest function of sequestering carbon and absorbing carbon dioxide. The global trend can also mask significant increases at the country level. For instance, the slowing rate of loss of Amazon forest cover in the Legal Amazon region of Brazil observed after 1990 has been reversed, from some 4 600 km²/year in 2012 to 13 200 km²/year in 2021 (TerraBrasilis, 2022).

MAP 1.9 GLOBAL DISTRIBUTION OF FORESTS BY CLIMATE DOMAIN, 2020

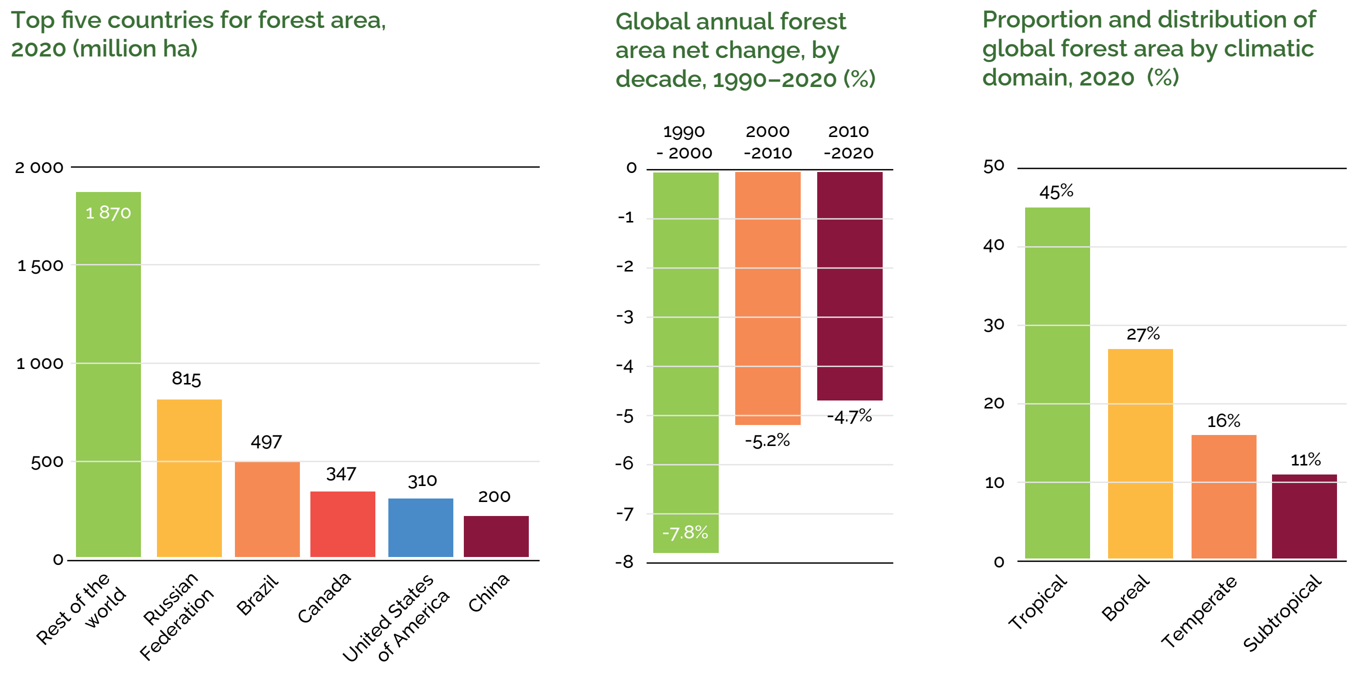


Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

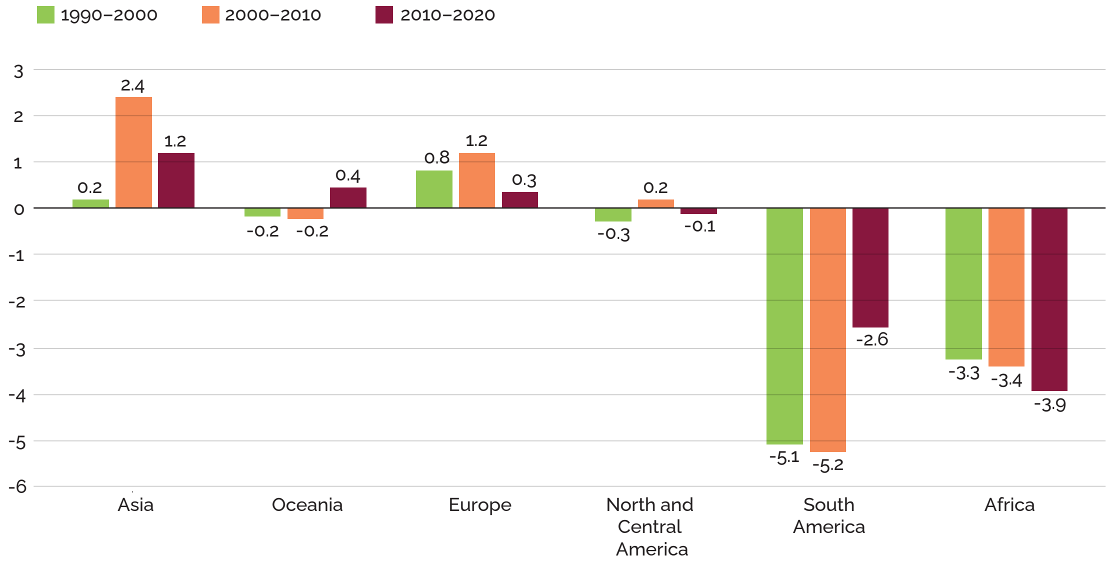
Source: **FAO**. 2020. *Global forest resources assessment 2020: Key findings.* Rome. https://doi.org/10.4060/ca8753en
Modified to comply with UN. 2020. *Map of the World.* https://www.un.org/geospatial/file/3420/

FIGURE 1.13 GLOBAL FOREST AREAS IN 2020 AND NET CHANGES BY DECADE, 1990–2020



Source: **FAO**. 2020. *Global forest resources assessment 2020: Key findings*. Rome. https://doi.org/10.4060/ca8753en

FIGURE 1.14 ANNUAL FOREST AREA NET CHANGE BY DECADE AND REGION, 1990–2020 (MILLION ha/YEAR)



Source: **FAO**. 2020. *Global forest resources assessment 2020: Key findings*. Rome. https://doi.org/10.4060/ca8753en

1.4.6 Per capita land availability

Global trends in agricultural land use (for cultivating crops and animal husbandry) show significant variation. Between 2000 and 2019, agricultural land per capita declined by 22 percent worldwide. Significant declines occurred in Africa, Western Asia, Australia and New Zealand, and the Pacific Islands. There were slight declines in Eastern Europe and the Russian Federation (Table 1.4).

Farm holdings in 179 countries are estimated to total 608 million (Lowder, Sánchez and Bertini, 2021); 70 percent are smaller than 1 ha and account for only 7 percent of agricultural land. Farms with an area greater than 1 thousand ha represent only 0.03 percent of holdings but account for almost 40 percent

TABLE 1.4 AGRICULTURAL LANDS (CROPLAND, PERMANENT MEADOWS AND PASTURES) PER CAPITA, 2000, 2010 AND 2017

REGION	AGRICULTURAL LAND PER CAPITA (ha/CAPITA) 2000	AGRICULTURAL LAND PER CAPITA (ha/CAPITA) 2010	AGRICULTURAL LAND PER CAPITA (ha/CAPITA) 2017	PERCENTAGE CHANGE 2000–2017
Northern Africa	1.33	1.12	0.92	-31
Sub-Saharan Africa	1.40	1.11	0.95	-32
Northern America	1.52	1.37	1.28	-16
Central America and Caribbean	0.79	0.67	0.63	-20
Southern America	1.56	1.44	1.36	-13
Western Asia	1.48	1.17	1.02	-31
Central Asia	5.30	4.65	4.12	-22
South Asia	0.23	0.18	0.17	-26
East Asia	0.44	0.40	0.39	-10
Southeast Asia	0.21	0.21	0.21	0
Western and Central Europe	0.41	0.42	0.41	-2
Eastern Europe and Russian Federation	1.28	1.31	1.31	2
Australia and New Zealand	20.61	14.62	13.06	-37
Pacific Islands	0.25	0.23	0.20	-22
World	0.80	0.70	0.64	-20
High income	1.22	1.07	1.11	-9
Middle income	0.87	0.61	0.51	-41
Low income	0.58	0.73	0.84	45
Low income and food deficit	0.55	0.47	0.41	-25
Least developed	1.18	0.98	0.80	-32

Source: **FAO**. 2018. *The future of food and agriculture: Alternative pathways to 2050. Summary version*. Rome. www.fao.org/3/CA1553EN/ca1553en.pdf of agricultural land. About 70 percent of agricultural land comprises farms greater than 50 ha. This skewed distribution of land holdings is significant for designing and deploying agricultural programmes to mitigate land degradation processes and water scarcity. To treat 7 percent of agricultural land needs an outreach to more than 400 million farm holdings, while treating 40 percent of land requires outreach to some 163 thousand holdings only.

Southeast Asia has made remarkable progress in terms of improving food security. In the early 1990s, its undernourishment rates were the world's highest at 31 percent, but these rates have now fallen below 10 percent. Agricultural land use has increased by more than 50 percent between 1980 and 2014 in Cambodia, Indonesia, Lao People's Democratic Republic, Myanmar and Viet Nam. However, limits on agricultural land use are being reached. Agricultural production in Southeast Asia remains centred around rice. But the contribution of rice to the total gross agricultural production value has fallen since the early 1990s, from 40 percent to 30 percent in 2013. Competition comes mainly from oil palm (Malaysia) and meat/fruit/vegetable production (Myanmar). There has been a significant increase in fertilizer and mechanization use in East and South Asia, mainly in the last 30 years.

1.4.7 Agricultural intensification

The current level of land use is expected to continue with few options to set aside or convert large areas of agricultural land other than through general urbanization. Although marine food resources account for almost 10 percent of the protein content in global food supply, they make up less than 5 percent of global food supply when measured in terms of quantity and even less in terms of fat and kilocalories (FAO, 2020a).

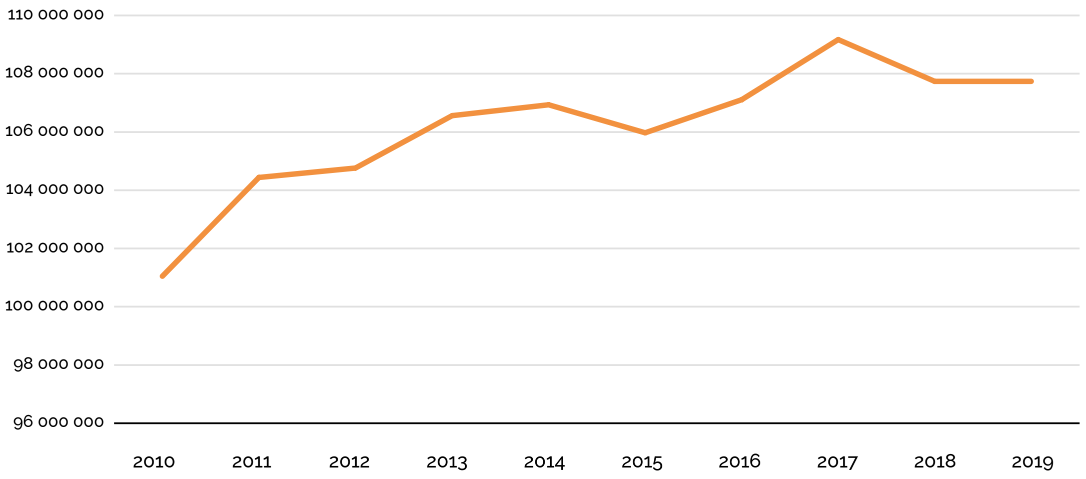
Trends in land use and agricultural production point to continued intensification from a combination of high-yielding cereal grain varieties, expanded irrigation systems, improved management practices, and increased farmer access to hybridized seeds, synthetic fertilizers and pesticides. Global application of fertilizer (nitrogen, phosphorus and potassium) peaked in 2017 at 192 million tonnes/year (Figure 1.15), and overall pesticide use has remained stable at around 4 million tonnes/year (Figure 1.16). Farm mechanization is extending from large commercial concerns to smallholder production in response to demand for higher productivity levels and as a reaction to limited labour availability. Mechanized cultivation for land treatment and conservation, seed drills and low-pressure trafficking/harvesting vehicles is expanding into new markets that previously relied on animal traction. The increasing uptake of plastic cloches and glasshouses/polytunnels is now marked and visible on time-lapsed satellite imagery.

Productivity in aquaculture has increased through intensifying production methods. In Asia, farmed fish and crustacean production, which mainly relies on additional feed, has replaced small-scale traditional pond aquaculture. Key drivers have raised land prices and the prices paid for farmed fish, which makes feed affordable.

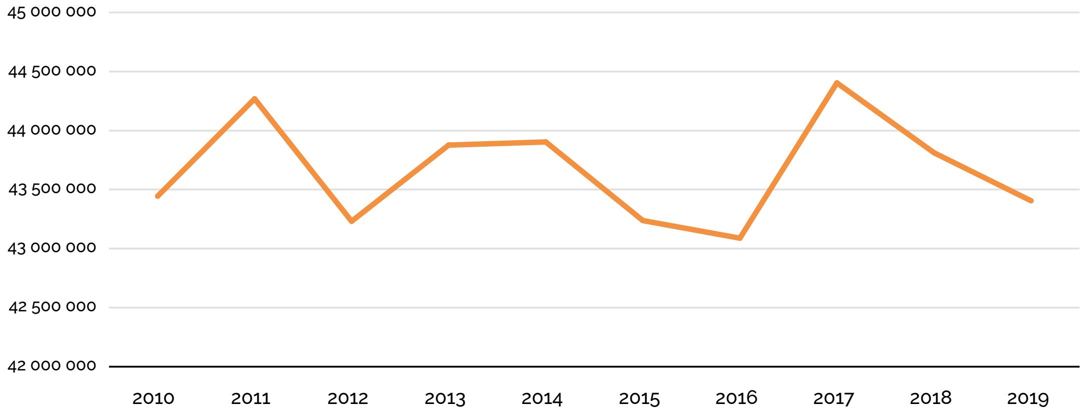
To meet the increasing demand for food, the Organisation for Economic Co-operation and Development (OECD)/FAO outlook for 2021 (OECD and FAO, 2021) expects crop yield growth to account for 88 percent of crop production increases to 2030, to come from yield improvements based on improvement of genetic material, higher inputs and investments in production technology. Some 7 percent of the projected increase could come from increasing the number of harvests on the same land (cropping intensity) and 6 percent from a modest expansion of cropland area.

FIGURE 1.15 **GLOBAL FERTILIZER INPUTS, 2010–2019 (TONNES)**

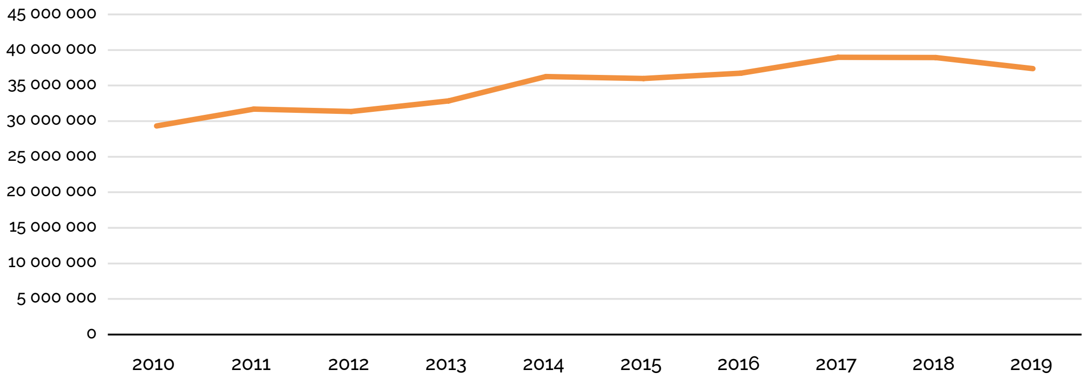
Nutrient nitrogen N (total) Agricultural use in World + (Total)



Nutrient phosphate P_2o_5 (total) Agricultural use in World + (Total)

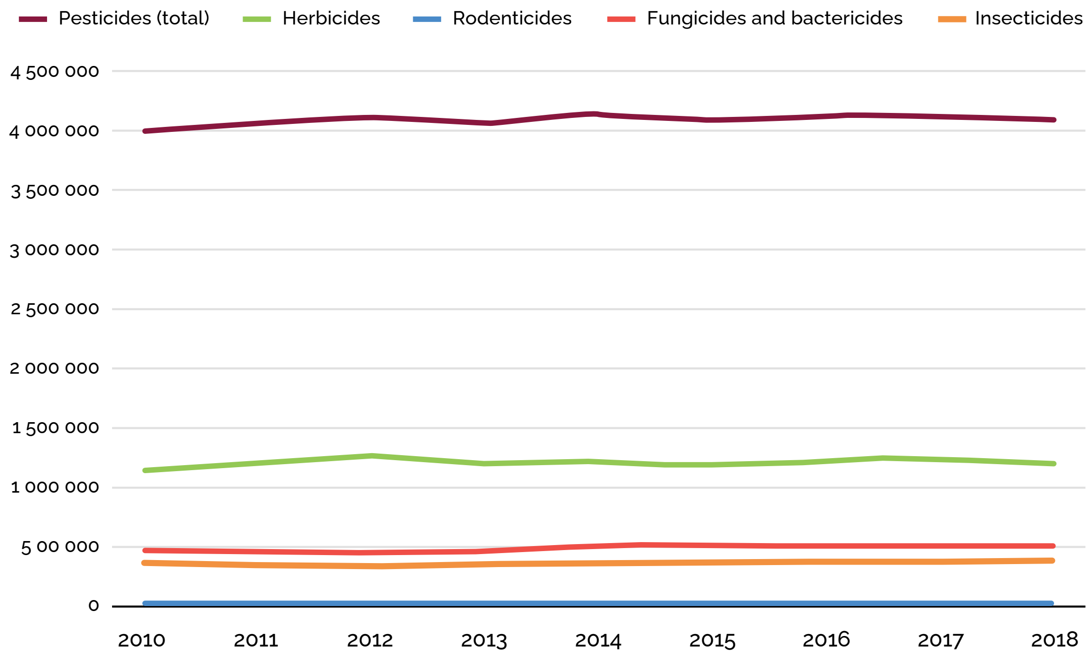


Nutrient potash K_2o (total) Agricultural use in World + (Total)



Source: **FAO**. 2020. FAOSTAT. In: *FAO*. Rome. www.fao.org/faostat/en/#data/QC

FIGURE 1.16 GLOBAL CROP PROTECTION INPUTS, 2010–2019 (TONNES/YEAR)



Source: **FAO**. 2020. FAOSTAT. In: *FAO*. Rome. www.fao.org/faostat/en/#data/QC

Selective breeding of new crop varieties still has the potential to boost yields. New varieties that better exploit local conditions and are more resistant to pests, diseases and drought, are more readily adopted than new management practices and are often cheaper for farmers and extension organizations (Fischer, Byerlee and Edmeades, 2014). Since the Green Revolution, crop breeding has been responsible for about half of all crop yield gains. Progress has accelerated since 2000. It will become increasingly important in the future since agriculture has already exploited other solutions, such as adding more water, using agrochemicals and introducing basic machinery (Searchinger *et al.*, 2019).

Although crop breeding has contributed to meeting increasing food demand, increasing privatization and domination of plant breeding and seed supply by a limited number of agribusiness multinationals has also contributed to the massive loss of crop species and varieties grown worldwide (OECD and FAO, 2021). *The state of the world's biodiversity for food and agriculture* report (FAO, 2019b) highlights the drastic loss of biodiversity that underpins food systems. Of some 6 000 plant species cultivated for food, fewer than 200 contribute substantially to global food output, and only 9 account for 66 percent of total crop production. Thus, governments need policies that address biophysical and structural drivers of biodiversity loss by enhancing crop diversity and varieties for growers, including those developed using the latest technologies and through participatory plant breeding by farmers.

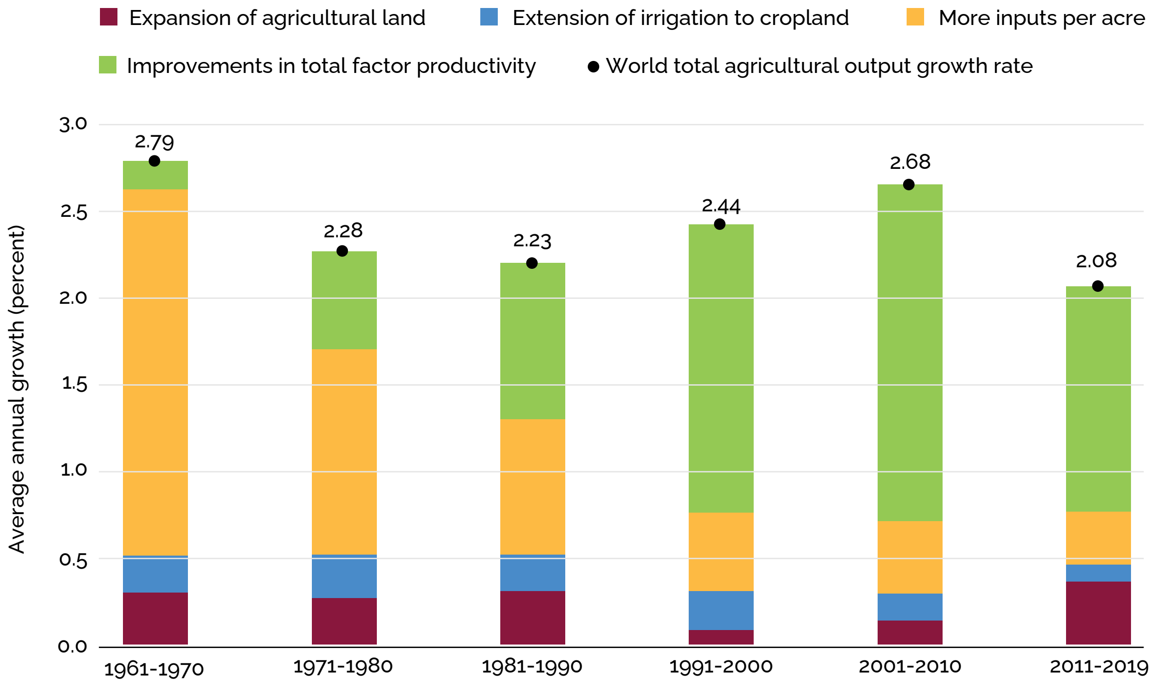
The production growth is expected mainly in the emerging and developing economies where most population growth is anticipated. However, this raises serious concerns about the negative environmental and social impacts that will be created.

Future climate change scenarios point to the need for changing cropping patterns and management practices to adapt to changes in crop/land suitability. Agricultural systems are already adapting, with more precise use of technology and inputs, partly as a response to climate change, but mainly as a response to the more sophisticated demands of the global food system. Owing to these innovative measures, the traditional measures of land and water productivity have seen their significance decline as more factors of production are taken into account.

Therefore, while growth in agricultural land use and irrigated areas has stagnated, total factor productivity in agriculture has increased. It grew from an average of 0.2 percent per year between 1961 and 1970 (when total agricultural output growth peaked at 2.79 percent per year) to almost 2.0 percent between 2001 and 2010 (Figure 1.17). This increase has occurred as growth of inputs and land factors has slowed significantly, reflecting greater overall efficiency in the use of all agricultural inputs and replacing intensification of inputs on land as the primary source of growth in global agriculture output (Figure 1.17) (Fuglie, Jellife and Morgan, 2021). In 2011–2019, growth rates slowed to an average of about 2 percent, while expansion of agricultural land has been marked (Figure 1.17) and is attributed largely to slowing agricultural productivity in developing countries including Brazil, China and India (Fuglie, Jellife and Morgan, 2021).

This pattern of agricultural growth highlights the impact of human-induced climate change in slowing agricultural productivity (Ortiz-Bobea *et al.*, 2021) and the imperative for sustainable use of existing land and efficient use of water resources and associated nutrient and carbon cycling. While the use of agricultural inputs has intensified to meet

FIGURE 1.17 TOTAL FACTOR PRODUCTIVITY GROWTH IN WORLD AGRICULTURE, 1961–2019



Source: **United States Department of Agriculture**. 2021. International agriculture productivity. In: *USDA Economic Research Service*. Washington, DC. www.ers.usda.gov/data-products/international-agricultural-productivity current demand, the resulting environmental impacts have accumulated to the point where a wide range of environmental services are affected, limiting agriculture's capacity to respond. At the same time, intersectoral competition for land and water resources is intense, so that while rainfed production has been able to expand since 2011 through conversion of forested land (Figure 1.14), the scope to extend irrigated has been extremely constrained.

1.5 Soils under pressure

Human pressures on soil resources underpinning agricultural land use are reaching critical limits. Conservation agriculture techniques are now applied to conserve soil structure and fertility on a large scale, such as in southern Brazil. But the overall picture is continued land degradation through human-induced erosion, compaction and loss of structure through agricultural practice. The *Status of the world's soil resources* report (FAO and ITPS, 2015) found most of the world's soil resources are in only fair, poor or very poor condition, with 33 percent of land being moderately to highly degraded due to the erosion, salinization, compaction, acidification and chemical pollution of soils.

The *Status of the world's soil resources* report (FAO and ITPS, 2015) also identified ten main threats to soil functions leading to soil degradation: erosion, SOC loss, nutrient imbalance, acidification, contamination, waterlogging, compaction, sealing, salinization and loss of soil biodiversity. Soil threats occur in specific soils under all types of agricultural land uses, including wetlands and urban soils. Land-use changes, such as deforestation and urbanization, are also increasing the rate of soil degradation.

Climate change exacerbates soil degradation. Higher temperatures and extreme weather events such as droughts, floods and storms affect soil quantity and fertility, reduce soil moisture and deplete the layers of nutrient-rich topsoil. This section describes the key soil processes, and section 1.6 discusses their effects on land degradation.

The Intergovernmental Technical Panel on Soils defines soil health as "the ability of the soil to sustain the productivity, diversity, and environmental services of terrestrial ecosystems". Restoring soil services, of which agriculture is the primary beneficiary, requires tackling all aspects of soil degradation (FAO *et al.*, 2020). Sustainable soil management is now recognized as a fundamental solution for addressing the interlinked problems of land degradation, climate change and biodiversity loss, and financing of related initiatives is indicated across all regions (FAO *et al.*, 2020).

1.5.1 Declining soil organic carbon and biodiversity

Soil organic carbon is the main component of SOM and the principal indicator of soil health. It is responsible for many soil functions that provide essential ecosystem services and plays a crucial role in the global carbon balance. It regulates dynamic biogeochemical processes and mitigates the impacts of climate change by limiting the main carbon-based gases in the atmosphere (FAO, 2019c). Soil organic carbon constitutes the largest terrestrial carbon pool, approximately 694 million tonnes of carbon in the top 300 mm of soil (Ciais *et al.*, 2013). Land-use change and unsustainable management practices translate into total SOC depletion of 115–154 million tonnes of carbon (Lal *et al.*, 2018).

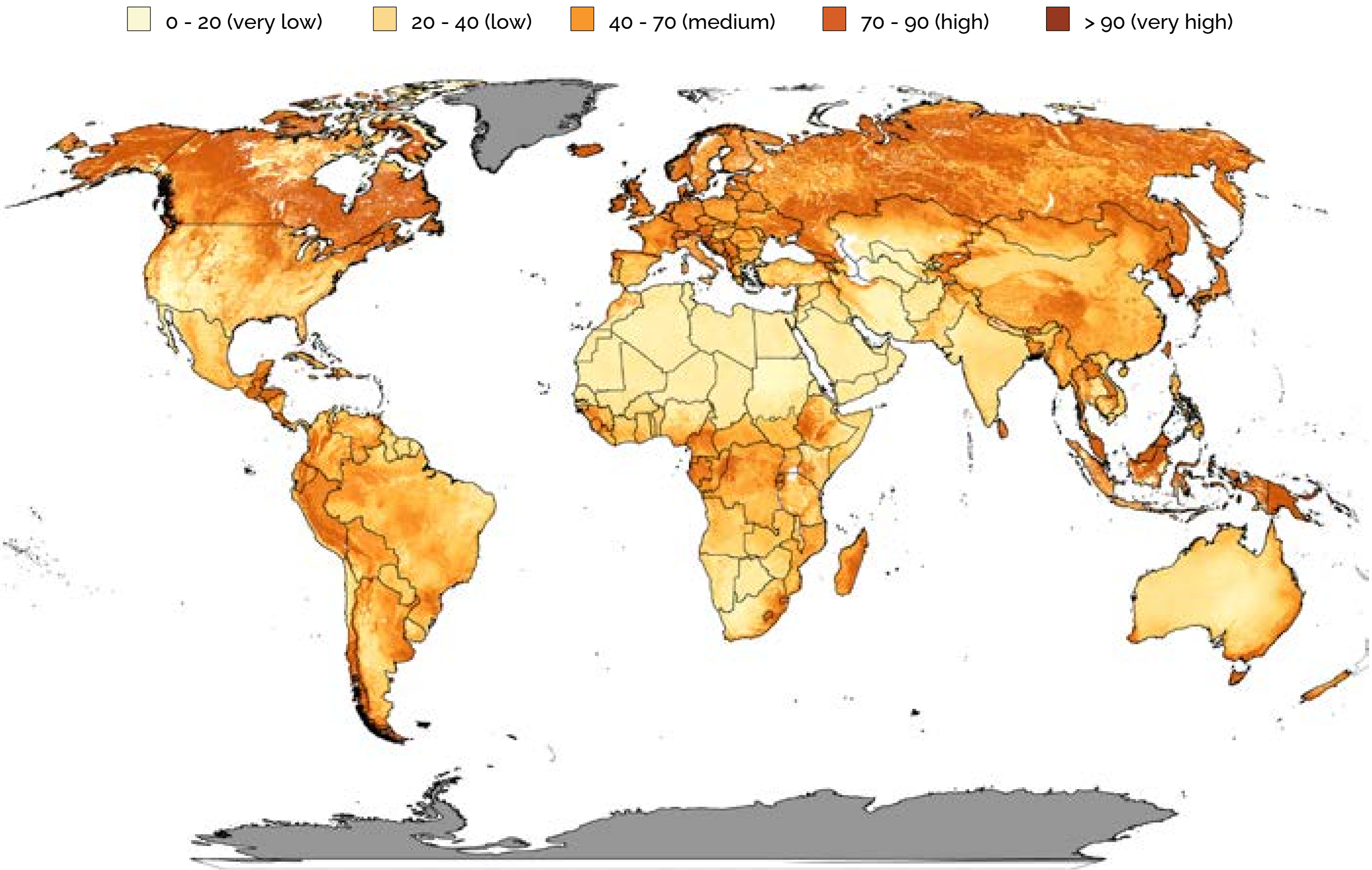
The Global Soil Organic Carbon Map (Map 1.10) is the first global SOC assessment produced at the national level. It enables estimates of SOC stock in the top 300 mm of soil and establishes a framework for compiling and sharing georeferenced data on SOC. Continuing improvements are expected to increase accuracy and resolution.

According to the Global Soil Organic Carbon Map, 65 percent of global SOC is concentrated in ten countries, highlighting their importance in managing terrestrial carbon stocks sustainably. More than one-third of SOC stock is undercultivated land in China and Kazakhstan. The Democratic Republic of the Congo and Indonesia have significant SOC stock under forest-covered land.

Soil organic carbon stocks are susceptible and responsive to land-use changes from a natural state to an agricultural ecosystem and from forestland to cropland (Map 1.11). Loss of SOM results in a reduction of nutrient levels, soil structure and biodiversity, and the overall effect is to release GHGs, further reducing the soil's capacity to help regulate climate change.

In the northern hemisphere, the permafrost (permanently frozen soil) regions contain twice as much carbon as in the atmosphere. Most of the SOC stocks in Canada and the

MAP 1.10 **GLOBAL SOIL ORGANIC CARBON, 2019 (TONNES/ha)**



Note: The three largest SOC stocks were found in boreal moist regions (130.5 Pg of carbon) followed by cool temperate moist regions (98.8 Pg of carbon) and tropical moist regions (80.4 Pg of carbon).

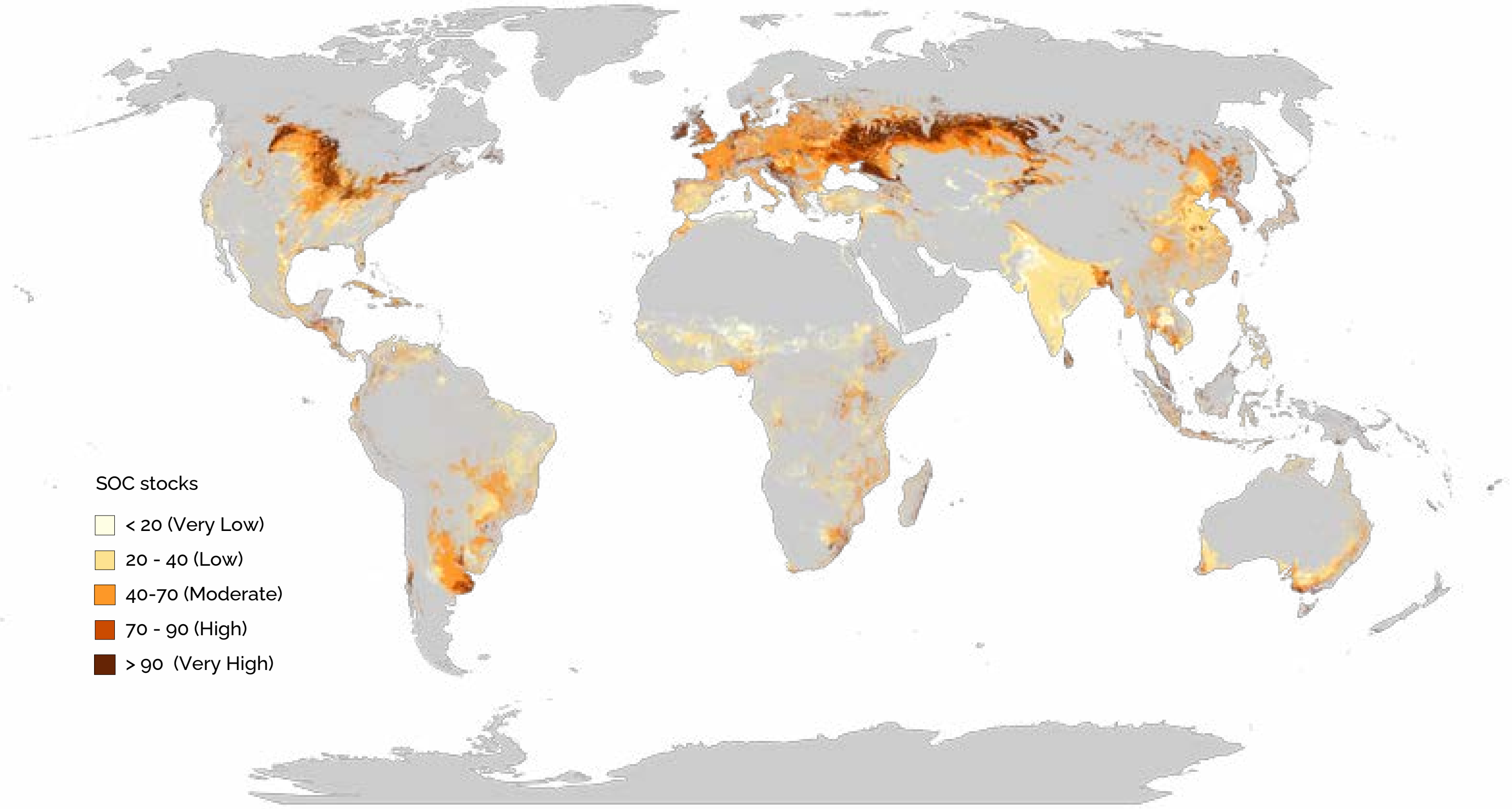
Source: **FAO**. 2019. GLOSIS - GSOCmap (v1.5.0). Global soil organic carbon map. Contributing countries. In: *FAO*. Rome. http://54.229.242.119/GSOCmap/. Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

Final status of the Abyei area is not yet determined

MAP 1.11 SOIL ORGANIC CARBON STOCKS IN CROPLANDS, 2019 (TONNES/ha)



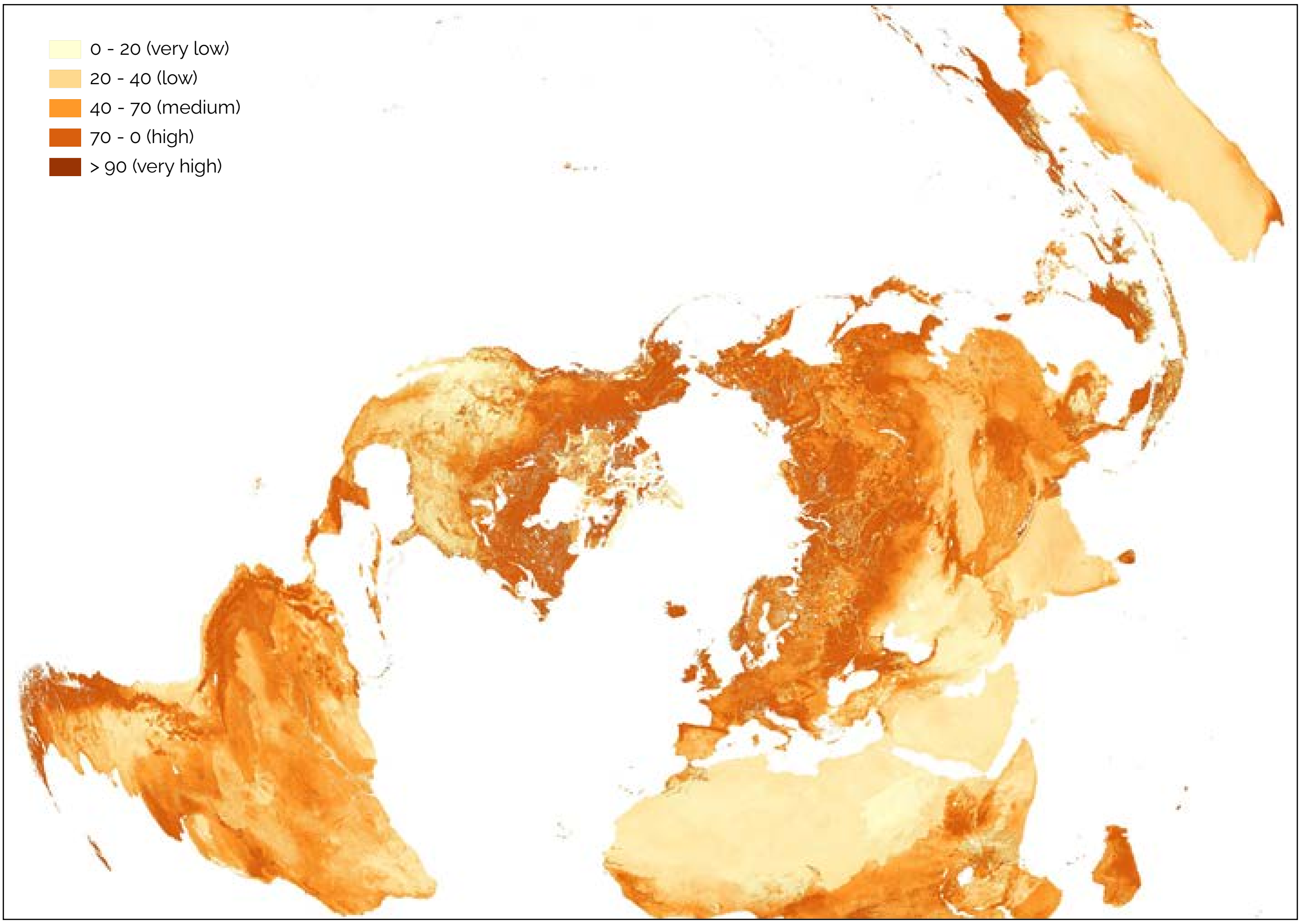
Source: **FAO**. 2019. GLOSIS - GSOCmap (v1.5.0). Global soil organic carbon map. Contributing countries. In: *FAO*. Rome. http://54.229.242.119/GSOCmap. Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

Russian Federation are under boreal forests and grasslands, which correspond to sparsely populated areas (Map 1.12).

Upland soils usually experience lower temperatures and higher precipitation and have higher SOC stocks than soils at lower altitudes (FAO, 2019d). Mountain soils with permafrost contain approximately 66 Pg of SOC, 4.5 percent of the global pool. High-elevation and high-latitude soils are experiencing warmer air temperatures and a thickening of the active weathering layer (Bockheim and Munroe, 2014), and are becoming more sensitive to change.

Organic soils cover only 3 percent of the global land area but store up to 20 percent of the total global SOC stock: 600–644 billion tonnes of carbon (Leifeld and Menichetti, 2018). This exceeds the carbon stored in the Earth's vegetation and may equal the carbon in the atmosphere (Turetsky *et al.*, 2015). Intact peatland ecosystems are carbon sinks, but when drained and degraded, they turn into long-term sources of GHGs (FAO, 2020e). Drainage-based land-use systems have often provided short-term gains in mined organic material (peat) or crops (from rice to oil palm) in exchange for long-term losses of ecosystem services (Sumarga *et al.*, 2016). Globally, 11–15 percent of peatland has been drained for cropping, forestry, grazing and energy use (FAO, 2020e). The largest drained areas are in Europe and Southeast Asia (Crump, 2017).

MAP 1.12 SOIL ORGANIC CARBON IN THE CIRCUMPOLAR REGION, 2019 (TONNES/ha)



Source: **FAO**. 2019. GLOSIS - GSOCmap (v1.5.0). Global soil organic carbon map. Contributing countries. In: *FAO*. Rome. http://54.229.242.119/GSOCmap
Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

Draining and clearing peat forests for plantations with fertilizer use and land clearing by burning have led to a dramatic loss of SOC (Parish *et al.*, 2008). Constant subsidence combined with rising sea levels will increase the risk of regular, and in some cases permanent, flooding in large coastal peatland areas (Sumarga *et al.*, 2016).

Continual anthropogenic pressures are compromising the critical role of soil biodiversity in ecosystem functioning and ecosystem service delivery. Pressures come from deforestation, urbanization and agricultural intensification, loss of SOM/SOC, soil compaction, surface sealing, soil acidification, nutrient imbalance, pollution, salinization, sodification, desertification, wildfires, erosion and landslides. Co-occurring drivers of environmental change can have synergistic effects and may pose particular threats to soil organisms and ecosystem functions. Deforestation and fires particularly affect soil biodiversity negatively.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Changes in land use, such as forest or natural grassland to pastureland or cropland, remove biomass, disturb soils, lead to loss of SOC and other nutrients, and change soil properties and soil biodiversity. However, the reverse is also true. Afforestation on abandoned cropland can increase SOC and nutrients. However, land use that does not change the cover, such as forest harvest and regrowth or increasing grazing intensity, can degrade soil properties (FAO and ITPS, 2015).

1.5.2 Soil nutrient loss

The nutrient status of soil, or soil fertility, is defined as the ability of soils to support and sustain plant growth, including making nitrogen, phosphorus and other nutrients available for plant uptake. The introduction of mineral/synthetic fertilizers since the 1950s has produced greater biomass production and yield increases. However, SOM has still declined in many regions, and buffer capacity has been lost, resulting in overall nutrient loss. In most cultivated soils, extensive use of mineral fertilizers has resulted in atmospheric pollution, GHG emissions (carbon dioxide and nitrous oxide), water eutrophication and risks to human health (Galloway *et al.*, 2008).

The soil atlas of Latin America and the Caribbean illustrates significant soil diversity with contrasting situations. Naturally fertile soils represent only 10 percent of the region's surface, such as the inter-Andean valleys and the dark and deep soils characteristic of the Argentine Pampas. However, there is a growing weakness in the region's ability to produce staple foods, most of which are exported (Gardi *et al.*, 2014).

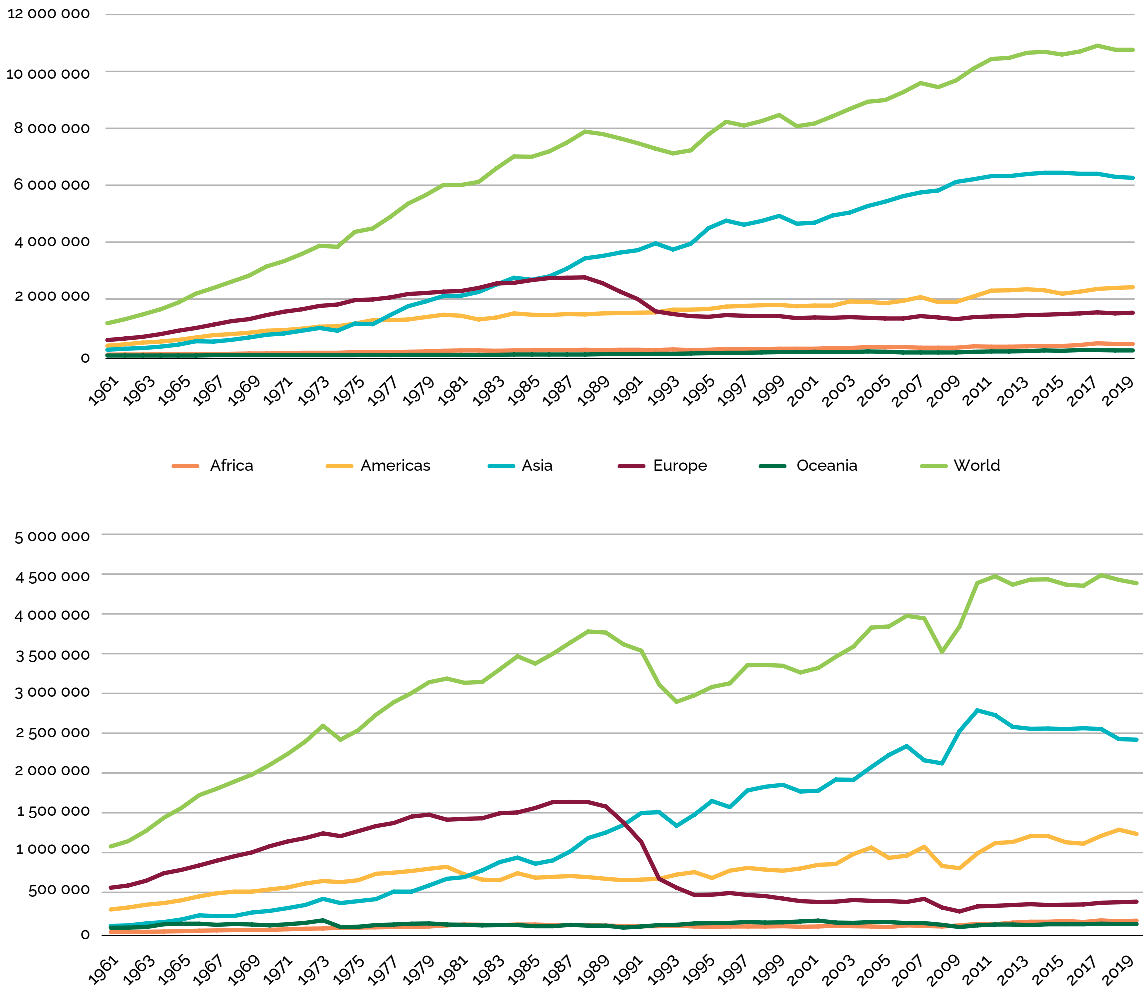
In most African countries and other least developed countries, continuous depletion of soil nitrogen, phosphorus and potassium, coupled with low crop production levels, threatens agricultural sustainability and food security. Human-induced soil fertility problems are expected to continue (Tan, Lal and Wiebe, 2005) including soil micronutrient deficiency caused by the lack of nutrients in the geological material and poor soil management practices. For example, boron, molybdenum and zinc deficiencies are present in 50 percent, 30 percent and 15 percent of arable soils worldwide, respectively. Yet, soil micronutrient deficiencies can be closely associated to livestock and human health issues (von Braum *et al.*, 2021).

In some countries, nutrient removal in harvested crops substantially exceeds inputs through natural replacement or fertilizer application. Negative soil nutrient balances have been reported in 15 agroclimatic regions of India (Tandon, 1992). Agricultural intensification can also deplete soil nutrients, as crop residues are not returned to the soil to prevent pests and weeds. Higher biomass production and yield increases have relied on mineral/synthetic fertilizers since the 1960s (Figure 1.18). This has led to declining SOC in agricultural soils and replacing macronutrients and micronutrients with mineral fertilizers. Between 1961 and 2002, global nitrogen fertilizer use increased 7.4-fold and phosphorus 2.3-fold (FAO, 2019e). Excessive use of mineral fertilizers can result in nutrient loss through leaching and runoff, polluting groundwater and eutrophying surface water bodies. Microbial activity can also transform excess nitrogen into nitrous oxide, which is one of the GHGs responsible for global warming as it contributes to depleting the stratospheric ozone layer. Mineral fertilizers are also sources of trace elements, increasing the soil's toxic compound burden (FAO, 2019f).

The sustained upward trends in nitrogen use and phosphorus use on cropland since 1997 to counter soil nutrient loss and boost yields are expected to continue (FAO, 2019f). The global demand for fertilizer has grown steadily by 1.6 percent each year and reached over 200 million tonnes in 2018. The treatment of soils with inorganic fertilizers has significantly affected soil health and freshwater pollution induced by runoff and drainage.

Soil nutrient budgets depend on local socio-economic conditions, market prices for farm inputs and government policies. In Western Europe, rising fertilizer costs and strengthening environmental policies have reduced

FIGURE 1.18 GLOBAL AND CONTINENTAL NITROGEN (TOP) AND PHOSPHORUS (BOTTOM) FERTILIZER USE, 1961–2019 (TONNES/YEAR)



Source: **FAO**. 2020. *The state of food and agriculture 2020. Overcoming water challenges in agriculture*. Rome. https://doi.org/10.4060/cb1447en nitrogen and phosphorus inputs into farmland. This trend is expected to continue. Dwindling phosphorus resources and climate change may further affect soil nutrient balances in managed and natural ecosystems (FAO and ITPS, 2015).

Farmers practising irrigation often appreciate access to low-quality wastewater because it contains macronutrients and micronutrients. However, the nutrient content is not often accurately measured and balanced with the inputs of synthetic and organic fertilizers. Although a benefit for some, wastewater can also negatively affect crop productivity, the soil, and human and environmental health.

1.5.3 Soil salinization

Soil salinization and sodification are major soil degradation processes threatening ecosystem services as identified in the *Status of the world's soil resources* report (FAO and ITPS, 2015). They are among the most important problems facing agricultural production, food security and sustainability in arid and semi-arid regions. Salt-affected soils refers to soils with a salt content that affects soil properties, crop growth and yield (Daliakopoulos *et al.*, 2016). They include saline soils, saline–sodic soils and sodic soils, depending on the salt content, type(s) of salt present, amount of sodium present and soil alkalinity/pH. Saline soils are known for containing excessive amounts of soluble salts, mainly calcium and magnesium. Sodic soils, with abundant sodium salts such as sodium chloride and sodium sulphate, usually have low permeability and a high pH of 8.2 and above (FAO and ITPS, 2015).

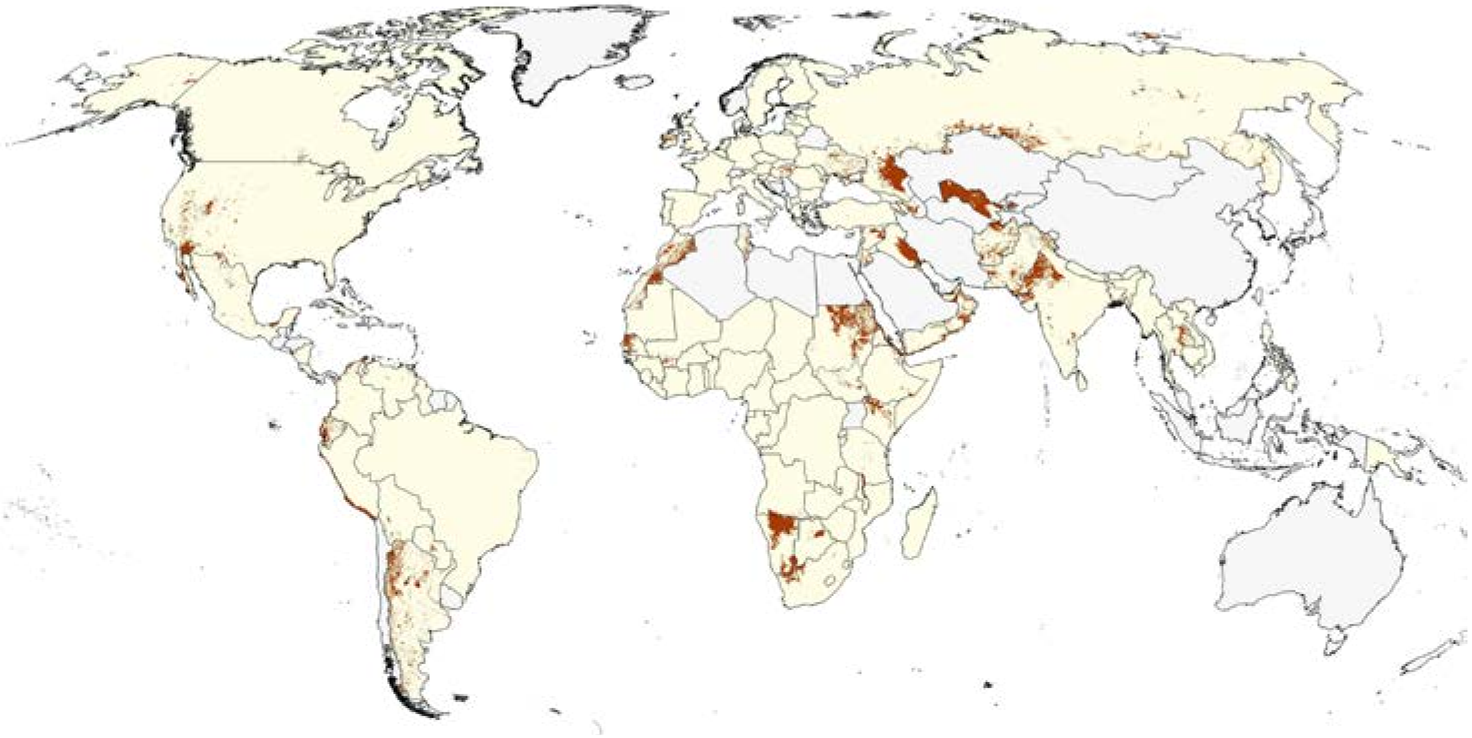
Soil salinization is a significant problem worldwide (FAO and ITPS, 2015). It is estimated to take 0.3–1.5 million ha of farmland out of production each year and reduce productivity for a further 20–46 million ha. According to the United States Department of Agriculture, approximately 10 million ha of arable land annually drops out of agricultural use due to salinization, sodification and desertification. In 1990, the annual cost of degraded salt-affected soils was estimated at USD 264/ha. The total cost for 2013 was equivalent to USD 441/ha, adjusting for inflation (Qadir *et al.*, 2014). Some 380 million ha of salt-affected soils could be restored for agriculture (Lambers, 2003).

Human-induced salt-affected soils are widespread. They exist around the Aral Sea and in the Islamic Republic of Iran. There is potential salinity due to permafrost melting, and saline intrusion occurs in in many coastal aquifers and critically in small islands with thin freshwater lenses (FAO, 2022b). The legacy of deforestation in southeastern Australia continues to compromise agricultural production as shallow groundwater rises into salt-laden aeolian soils and mobilizes damaging soil water salinity levels. This is a continuing risk to agricultural production affecting some 1 million ha in southeastern Australia (Department of Primary Industries and Regional Development, Government of Western Australia, 2021). Groundwater rise threatens an additional 2.8–4.5 million ha of low-lying or valley floor soils, despite recent periods of prolonged drought (Hatfield-Dodds *et al.*, 2018).

The distribution of salt-affected soil (Map 1.13) reflects a build-up of human-induced soil water processes. The Global Map of Salt-affected Soils represents the spatial distribution of salt-affected soils with electrical conductivity > 2 dS/m and/or exchangeable sodium percentage > 15 percent and/or pH > 8.2 at two depth intervals (0–30 cm and 30–100 cm). The Global Map of Salt-affected Soils v1.0 indicates that more than 424 million ha of topsoil (0–30 cm)

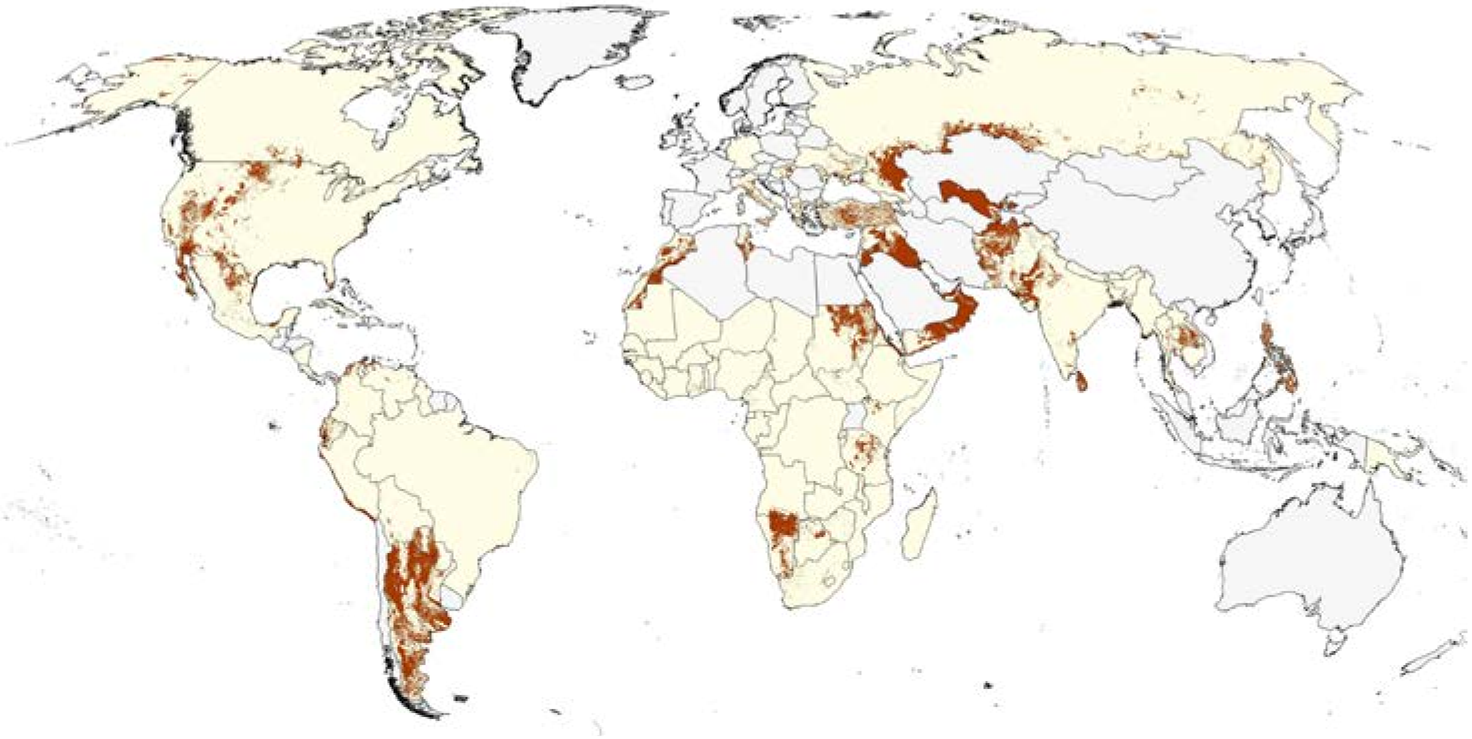
MAP 1.13 GLOBAL MAP OF SALT-AFFECTED SOILS (GLOBAL SALT-AFFECTED AREAS) V1.0: (TOP) TOPSOIL (0–30 cm) AND (BOTTOM) SUBSOIL (30–100 cm)

Topsoil (0-30cm)



🟥 Salt-affected soils ⬜ None ⬜ No data

Subsoil (30-100cm)



Source: **FAO**. 2022. Global map of salt-affected soils (GSASmap). In: *Global Soil Partnership*. Rome. Cited 9 February 2022. www.fao.org/global-soil-partnership/gsasmap/en.
Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.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and 833 million ha of subsoil (30–100 cm) are salt affected. These estimates, based on the submitted data (118 countries covering 73 percent of the global land area), show that more than 4.4 percent of topsoil and more than 8.7 percent of subsoil of the total land area is salt affected. Soil salinity is estimated to take up to 1.5 million ha of cropland out of production each year. Higher rates of evapotranspiration are expected to exacerbate the accumulation of salts in the surface horizons, but the extent of subsoil salinity at the 30–100 cm depth range is much more pronounced.

1.5.4 Soil compaction

Soil compaction is caused by livestock trampling, heavy agricultural machinery and inappropriate soil management practices such as tillage. It affects almost all physical, chemical and biological soil properties and functions. It also affects crop quality and yield as plants cannot retrieve sufficient nutrients, gases and water, and cannot adequately develop their root systems (Soane and Van Ouwerkerk, 2013). Soil compaction also increases waterlogging, soil erosion and GHG emissions, reduces soil biodiversity and inhibits groundwater recharge (Radatz *et al.*, 2012). Increasing mechanization, livestock and intensification exacerbate soil compaction in croplands and rangelands.

Soil and crop management practices can help to provide a favourable environment for soil organisms and their biological activity, such as reducing soil disturbance and maintaining plant cover. Earthworms are well known for enhancing soil structure and porosity, and microorganisms stimulate nutrient cycling, such as symbiotic nitrogen-fixing bacteria for legumes and arbuscular mycorrhizal fungi, which assist host plants to transport bio-available phosphate. Yet, soil biodiversity management is in its infancy; despite huge advances due to genetic technology, knowledge remains in the research arena and not in the field.

Monocropping and repetitive tillage in many crops and environments threaten soil health and biodiversity and increase pests and weed infestation. In contrast, mixed-cropping systems and agroforestry improve soil quality, soil biodiversity and nutrient cycling, especially when practised with conservation agriculture to maintain cover through rotations and cover crops and to minimize tillage and traffic.

Conservation tillage, with crop rotations that improve SOM, and organic inputs reduce carbon dioxide losses and enhance soil carbon sequestration. Even in dry lands, where SOM is low, combined soil–crop–water approaches that increase biomass and minimize burning can sequester substantial amounts of carbon in extensive agropastoral and rangelands.

1.5.5 Soil erosion

Human activity and related land-use change accelerate soil erosion. This has substantial implications for nutrient and carbon cycling, land productivity and socioeconomic conditions. Removing forests to create cropland and pasture is often followed by intensive soil erosion (Pimentel and Burgess, 2013). Between 1985 and 2013, croplands and pasture areas increased by 279 million ha (Borrelli *et al.*, 2017).

The most likely range of annual global soil erosion (natural and human-induced) by water is now considered to be 33–40 million tonnes. Given uncertainties in the estimates of soil erosion rates, modelling with a Revised Universal Soil Loss Equation (RUSLE), Borrelli *et al.* estimated annual average potential soil erosion amounts of 35 million tonnes and 36 million tonnes for the 2001 and 2012 baselines, respectively (Borrelli *et al.*, 2017).

Agriculture accounts for about three-quarters of soil erosion globally (FAO and ITPS, 2015). This significantly affects crop yields and the soil's ability to store and cycle carbon, nutrients and water. Annual cereal production losses due to topsoil erosion are estimated to be of the order of 7.6 million tonnes.

Upland and mountain soils are intrinsically vulnerable and sensitive to degradation processes such as water erosion and loss of chemical and physical quality (FAO, 2015) (see the focus on mountain agriculture at the end of this chapter). It should be noted that annual soil erosion due to tillage alone amounts to almost 5 million tonnes (FAO and ITPS, 2015), indicating the relative scale of human-induced land degradation.

Regional and global estimates of soil loss rates differ substantially, depending on the method used to derive them. Generally, mean annual soil loss estimates from field plots are considerably higher (8 tonnes/ha to almost 50 tonnes/ha) than those from regional and global models (2–4 tonnes/ha). However, any estimate of erosion must also be placed in the context of the tolerable rate of loss, which depends on the soil formation rates. These vary significantly: early studies report rates of 0.05–0.50 mm/year, while the most referenced studies suggest 1.4–2 tonnes/ha annually (Verheijen *et al.*, 2009). According to OECD, the annual soil loss rate of 11 tonnes/ha is considered critical for crop losses (Borrelli *et al.*, 2020). The ranges for soil loss and tolerable soil loss demonstrate the need for site-specific estimates to reflect different sensitivities to eroding surface soil (FAO, 2019d).

1.5.6 Soil pollution

Information about the extent of soil pollution at the global level is sparse, mainly due to the technical complexity of measuring the pool of contaminants present in agricultural soils and their spatial variability (FAO and UNEP, 2021). On agricultural land, contaminants are derived from synthetic and mineral fertilizers that frequently contain significant concentrations of trace elements, mostly cadmium and radionuclides (El-Bahi *et al.*, 2017). These can reduce soil organisms, plant growth and food quality, and affect human health. Organic fertilizers such as manure or sewage sludge often contain veterinary drugs and other pharmaceuticals, trace elements, and persistent organic contaminants and microplastics (Lwanga *et al.*, 2017).

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The legacy of polluted soils worldwide is significant (Rodriguez-Eugenio *et al.*, 2018). Thousands of chemicals are introduced into the environment every year, a high percentage of which are hazardous to human health and the environment (EEA, 2019). Most soil contaminants come from industrial processes, chemical production and waste products. These include: mineral extraction and processing; agrochemical use, synthetic and organically derived from manure, sewage sludge or biosolids; irrigation using wastewater; transport and urban activities; and military activities and armed conflicts. In Northern America, Southern America, Europe, Central Asia and some East Asian countries, the primary sources of soil pollution are intensive agriculture and livestock production. In sub-Saharan Africa and Pacific region countries, the main concerns are uncontrolled local and imported waste accumulation. In Northern Africa and the Near East, oil extraction and armed conflicts are the major polluting activities (FAO and UNEP, 2021).

Pesticide use has increased by over 34 percent globally since 2000. In South America, it has increased by 105 percent, in Oceania by 84 percent and in the Caribbean by 69 percent. Many pesticides and their by-products persist in the environment. They persist in the soil and can be leached into groundwater and transported by runoff to surface water bodies due to their chemical structure, half-life and affinity with other organic compounds. Pesticides deposited in soils and surface water can be transported to places far from where they were released. Soil organic carbon content, texture, mineralogy, pH, microorganisms and climate conditions will determine their persistence, bioavailability and mobility. In addition, some pesticides are sources of trace elements, such as copper-based fungicides applied in vineyards and orchards or fungicides and pesticides containing arsenic, copper, manganese and zinc used in the past to protect fruit crops.

Plastic cloches, mulch film and agroplastics (e.g. agricultural product containers, irrigation hoses, bags, and fruit and vegetable protection screens) are increasingly found in agricultural soils (Gao *et al.*, 2019). Large pieces of plastic can break into smaller pieces by photo-oxidation, microbial degradation and erosion, or can be physically damaged by agricultural machinery, becoming microplastics and nanoplastics. The tiny particles are incorporated into the soil structure, and, due to their hydrophobicity and lipophilicity, can retain other organic contaminants and form stable bindings with SOM (Boots, Russell and Green, 2019). Microplastics can also be ingested by soil-dwelling organisms and enter the food chain.

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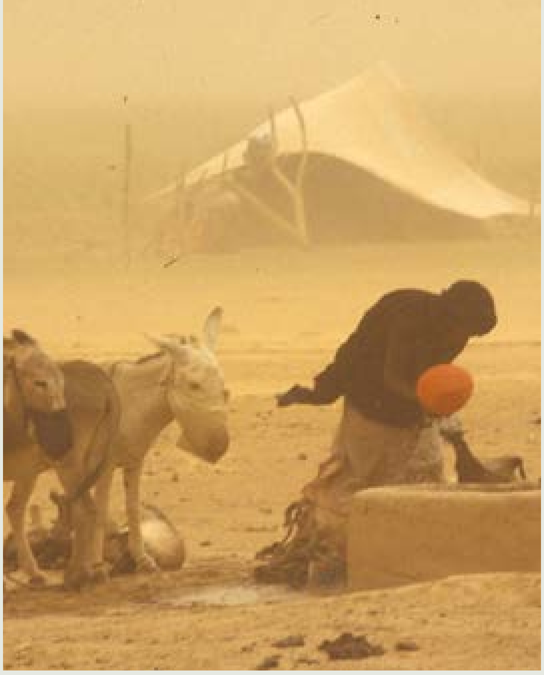
1.5.7 Sandstorms and dust storms

Approximately 430 million ha of dry lands, comprising 40 percent of the Earth's surface, is susceptible to wind erosion (FAO and ITPS, 2015), but erosion rates are highly uncertain. Estimates of the total dust mobilized on arable land place an upper limit of about 2 million tonnes/year (Yue *et al.*, 2009). However, wind mobilizes dust and coarser soil particles (sand), implying much higher total wind erosion rates.

Sandstorms and dust storms (SDSs) are responsible for eroding and depositing dryland soils. They can cause widespread scouring of fine soil particles in the cold (periglacial) and warm (desertic) climatic regimes (UNCCD, 2022). They can also cause accumulation of aeolian soils such as loess. Global warming is expected to increase the distribution, intensity and frequency of SDS events, including local meso-climatic events such as tornados and local microevents such as "dust devils". The issue is gaining attention because of transboundary impacts on human and animal health in particular (Mu *et al.*, 2013; Middleton and Kang, 2017; UNEMG, 2022; WMO, 2022a).

Sandstorms and dust storms depend on meteorological conditions such as surface wind speed and precipitation, and surface properties including vegetation cover, sediment availability and soil surface crusting. The main driving force is strong winds from thunderstorms or cyclones sweeping across large areas of bare or sparsely vegetated arid and semi-arid lands that lift huge quantities of soil particles into the atmosphere. Human activity accelerates this process, notably land clearing, unsustainable agricultural practices and mining, which cause vegetation depletion and associated hydrological changes, loss of biodiversity and soil surface disturbance during cultivation. Some 40 percent of aerosols in the troposphere (the lowest layer of the Earth's atmosphere) are dust particles from wind erosion (Middleton and Kang, 2017). Storms may transport sand and dust particles hundreds to thousands of kilometres. The frequency of SDSs is increasing, and climate change will be a significant potential driver of future wind erosion risk. The main areas affected are the arid regions of Northern Africa, the Arabian Peninsula, Central Asia and China. Australia, South Africa and the United States of America are also affected but to a lesser extent. Global estimates of dust emissions, mainly derived from simulation models, vary between 1 billion tonnes and 3 billion tonnes per year.

Sandstorms and dust storms adversely affect agriculture. They reduce crop and animal production, bury crop seedlings, cause loss of plant tissue, reduce photosynthesis and increase soil erosion. Indirect dust deposits fill irrigation canals, impede transport routes, and affect river and stream water quality. Sustainable agricultural and land management practices, such as conservation agriculture, agroforestry and other land management practices, can reduce the risks, extent and severity of SDSs.



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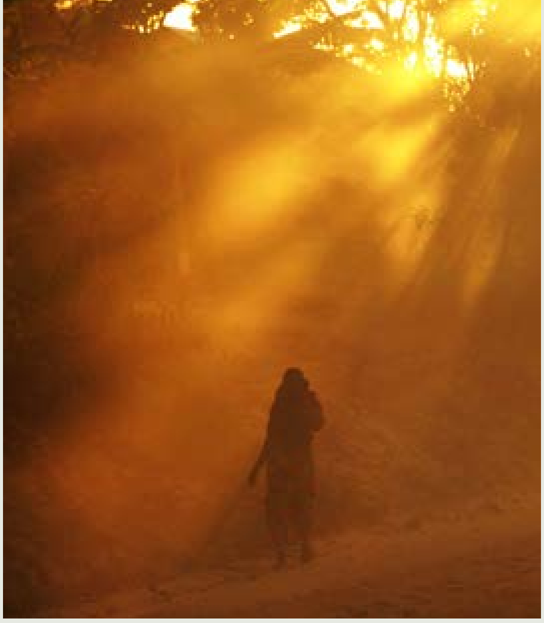

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Nonetheless, SDSs can bring interregional long-term and large-scale benefits, as surface dust deposits are a source of micronutrients for continental and maritime ecosystems. For example, Saharan dust is thought to fertilize the Amazon rainforest, and dust transporting iron and phosphorus benefits marine biomass production in parts of the oceans.

The impacts of SDSs on the climate, human health, the environment and many socioeconomic sectors have increasingly been recognized over recent decades. The World Meteorological Organization's Sand and Dust Storm Warning Advisory and Assessment System, launched in 2007, has three regional centres covering: Asia; the Americas (led by the United States of America); and Northern Africa (led by China), the Middle East (led by the United States of America) and Europe (led by Spain). The centres are supported *inter alia* by decisions of the UNCCD Conference of the Parties and the UNCCD Science-policy Interface (SPI).

Economic losses from single SDS events indicate the magnitude of their impacts. In China, between 2010 and 2013, dust storms caused losses estimated at USD 964 million. In the Sistān region of the Islamic Republic of Iran, between 2000 and 2005, dust storms led to estimated losses of USD 125 million.

1.6 Land degradation – human pressures on land resources

Human-induced land degradation is affecting sustainable food production and agriculture, livelihoods and the fight against poverty. Degradation results from complex local biophysical factors and socioeconomic drivers, including agricultural expansion, deforestation, fire, grazing density, population density and invasive/native species ratio. The IPBES global land degradation and restoration assessment refers to land degradation as the many processes that drive the decline of biodiversity, ecosystem functions or ecosystem services (Fisher, Montanarella and Scholes, 2018).

Although land degradation may be apparent at the field level, it cannot be measured directly or monitored with Earth observation techniques because it combines local biophysical factors and socioeconomic drivers and depends on the subjective perception of local populations and stakeholders (FAO, 2013b; Fisher, Montanarella and Scholes, 2018). Consequently, the Land Degradation Assessment in Drylands (LADA) programme has defined land degradation as a process that reduces the land's capacity to provide ecosystem goods and services over time for its beneficiaries and stakeholders (FAO, 2013b).

In addition to the negative impacts of climate change, the human pressures on land and water resources are pushing the productive capacity of land and water systems to the limit. These concerns are reflected in global environmental and scientific assessments, notably the IPCC special report on climate change and land (IPCC, 2019), the sixth edition of the

UNEP global environmental outlook (UNEP, 2019), the IPBES assessment report on land degradation and restoration (IPBES, 2018), and the UNCCD global land outlook (UNCCD, 2017). The land and water systems at risk identified in SOLAW 2011 are now seeing their overall changing land and water productivity gains stagnate. Global datasets reflect a decline in per capita natural resource availability.

1.6.1 Biophysical status, trends and pressures

For this report, the state of human-induced land degradation was assessed at the global level using an adapted Global Land Degradation Information System (GLADIS) methodology (Box 1.1). This methodology compiles the changes in the biophysical status of land elements over time at the national level and translates socioeconomic drivers (population density) into pressures. Biophysical status and drivers cover key environmental, social and economic variables, and the baseline is taken to represent pre-degradation conditions. As most global geospatial datasets do not date back further than the 1980s, evaluation of the status and trend of land degradation and the responsible drivers is constrained by long-term data availability. Nevertheless, integrating status, trends and drivers generates additional information about the distribution, causes and land degradation processes.

A multi-index approach blends biophysical status, trend and cumulative pressure from anthropogenic drivers and is used together with available high-resolution global datasets, to derive a global distribution of the extent of human-induced land degradation (Coppus, 2022) for a 2015 baseline. The term "degradation" is therefore used in this analysis only when associated with high pressures from anthropogenic drivers. All other declines in biophysical status, not related to such high pressures, are defined as "deterioration".

Additionally, the "convergence of evidence" concept, developed for the *World atlas of desertification* (Cherlet *et al.*, 2018), was adapted and applied for direct anthropogenic drivers of degradation. The approach assumes that a combination of pressures induced by human activities is indicative of environmental change. For example, when rangeland is burned to produce fresh forage for livestock, three direct anthropogenic drivers of land degradation may coincide: fire, grazing and invasion of exotic species. The sum of these pressures is referred to as the cumulative pressure by anthropogenic drivers.

Map 1.14 illustrates the biophysical status of land based on nine input layers compiled around the year 2015. The input layers are: soil nutrient availability, soil carbon content, water erosion, wind erosion, groundwater recharge, water stress, native species richness, above-ground biomass and artificial or built-up land cover. The grade of biophysical status, from high to low, is significant. With soil and wind erosion and water stress, high erosion or stress rate implies a low status, while the remaining layers have a positive impact and contribute towards a high score. A high score implies a high status.

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BOX 1.1

GLOBAL LAND DEGRADATION ASSESSMENT USING THE ADAPTED GLOBAL LAND DEGRADATION INFORMATION SYSTEM METHOD

Overall biophysical status and trend indices are determined using an adapted GLADIS methodology. This applies a Geographic Information System (GIS) approach to calculate separate biophysical status and trend indices for six components – biomass, soil health, water quantity, biodiversity, economic services and cultural services. It combines them to give an overall status index and a trend index. Trends refer strictly to changes over time (Table 1.5).

TABLE 1.5 INPUT LAYERS FOR OVERALL BIOPHYSICAL STATUS, OVERALL TREND AND CUMULATIVE PRESSURE BY DRIVERS

ITEM	SOIL	WATER	VEGETATION	DEMOGRAPHY
Status	Nutrient availability Soil carbon content Water erosion Wind erosion	Groundwater recharge Water stress	Native species richness Above-ground biomass	Built-up cover
Trend	Soil erosion change Soil protection change	Freshwater change Water stress change	Change in land productivity Forest biomass change	Population density change
Driver	Agricultural expansion, deforestation, fire, grazing density, population density and ratio of invasive/native species			

The maps for overall biophysical status, trend and cumulative pressure represent three different dimensions of land degradation. When combined, they give insight into the relationships among the patterns, processes and their causes. Regions at risk occur when the overall status and trend are combined. Areas with a low biophysical status and exposure to deterioration are at risk of ending in a degraded state. Areas with high biophysical status and exposed to substantial deterioration are also likely to be at risk. Integrating pressure from human activities with biophysical status and trends is a first step to distinguishing natural from human-induced degradation.

Maps published in peer-reviewed journals provide the input layers. The criteria for selecting these include availability, readiness to be used, relevance according to the literature and date of publication.

The **biophysical status** of land resources is based on nine input layers that reflect their present (or most recently known) biophysical condition. These include soil nutrient availability, SOC, water erosion rate, wind erosion, groundwater recharge, water stress, native species richness, above-ground biomass and artificial land cover (urban and infrastructure).

The **trend** is based on seven input layers that indicate changes in soil, water, vegetation and population density; they include changes in soil erosion, soil protection, freshwater, water stress, land productivity and forest biomass. The time factor varies between 10 and 20 years.

Direct anthropogenic **drivers** are used to estimate pressure exerted by human activities: agricultural expansion, deforestation, fire extent and frequency, grazing density, population density and ratio of invasive/native species (Barger, Gardner and Mahesh, 2018).

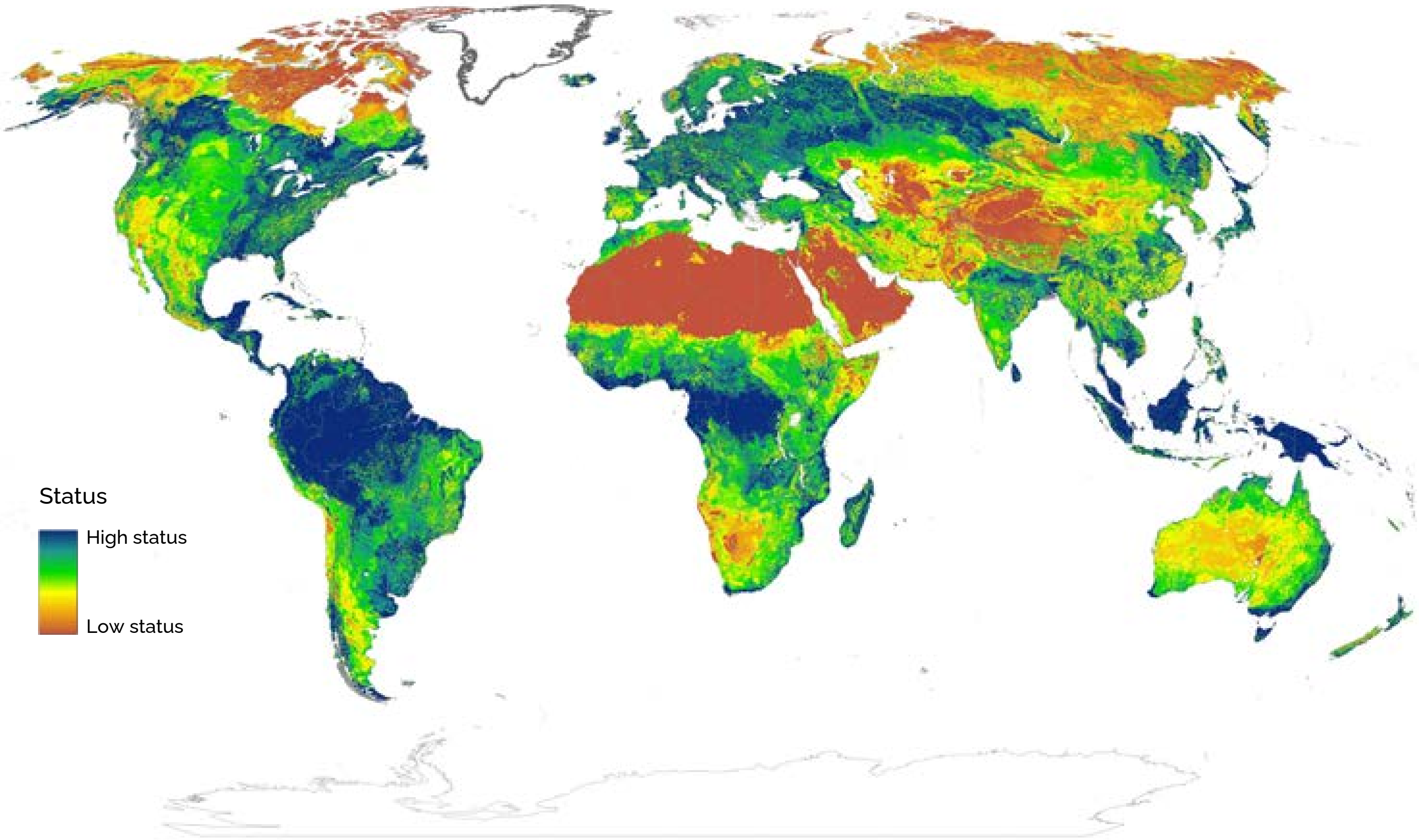
Regions at risk are large contiguous areas with low biophysical status and subject to strong or light deterioration. Regions with substantial deterioration and interspersed high and low biophysical status are also at risk. Stable or improving areas are presently not at risk.

Land degradation classes are defined based on the trend of land deterioration and the presence of anthropogenic drivers. A highly negative trend coinciding with high pressure is characteristic of substantial human-induced land degradation. The land's resilience (ability to withstand anthropogenic pressures) also plays a role, for instance, when strong anthropogenic drivers do not coincide with negative trends.

Source: **Nachtergaele, F., Petri, M., Biancalani, R., van Lynden, G., van Velthuizen, H. & Bloise, M.** 2011. *Global Land Degradation Information System (GLADIS) - An information database for land degradation assessment at global level.* LADA Technical Report 17. Rome, FAO.

Low values for biophysical status are found in dry lands, cold zones (with potential evapotranspiration of less than 400 mm/year) and steep terrain, and appear to be related directly to climate and geomorphology. Most of the land with a moderate biophysical status is also situated in arid to subhumid, cold or mountainous environments. Flat and humid areas with a moderate biophysical status are located throughout Europe, West Africa, the northern and southern parts of the Congo basin, the Paraná basin in southwest Brazil, Paraguay and north Argentina and the southwest coast of the United States of America. High biophysical status is located in the remaining flat and humid regions of the world and the dry Gran Chaco in the southeast of the Plurinational State of Bolivia and northwest Paraguay. Mountainous areas with high biophysical status are situated in the upper Amazon basin at the foot slopes of the Andes, the western Canadian Rockies, the south coast of Quebec, the most northern main island of Hokkaido in Japan, the mountain ranges in Borneo and Papua New Guinea, and the Australian Alps. The highest status is located in the lowland rainforests of the Amazon basin and the Guianas, the Choco region along the northern coast of Ecuador, and the Pacific coast of Colombia and eastern Panama, from the southern Gulf of Guinea to the Congo basin, and in the south part of the Malay Peninsula, on Borneo, Papua New Guinea and Sumatra.

MAP 1.14 BIOPHYSICAL STATUS OF LAND, 2015



Note: Overall status, where status is defined as the capacity to provide ecosystem services and goods. Nutrient availability, soil carbon content, water erosion, wind erosion, groundwater recharge, water stress, native species richness, above-ground biomass and built-up cover served as input layers to assess overall status.

Source: **Coppus, R.** 2022. *Global distribution of land degradation*. Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en. Modified to comply with **UN.** 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

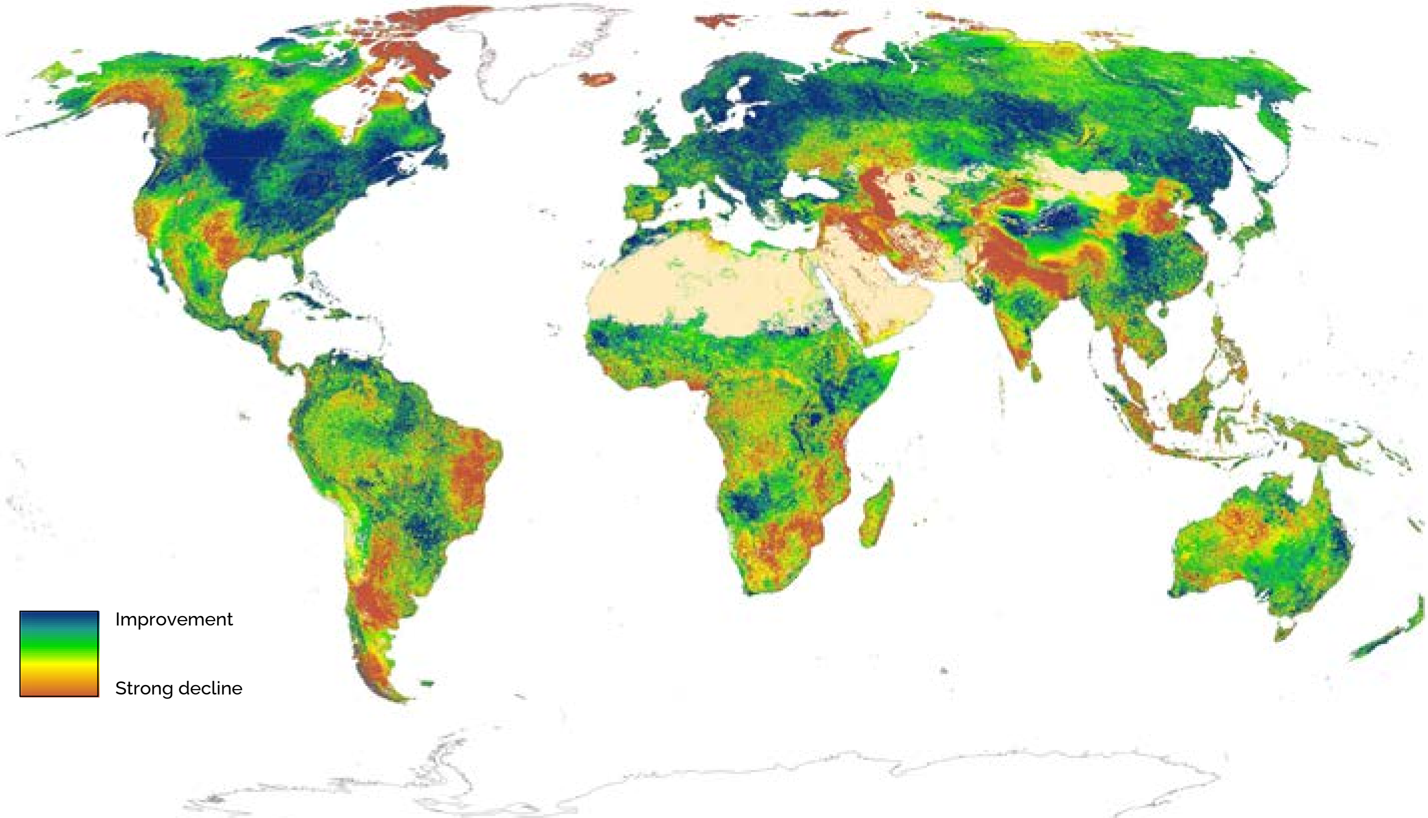
Map 1.15 presents the trend in biophysical status to illustrate where there has been a declining status or where the status is broadly stable or even improving, based on a set of GIS layers in which change is detected (soil erosion, soil protection, water stress, land productivity, forest biomass and population density).

In general, an overall decline in biophysical status has resulted from various negative trends together with the combinations of indices varying per affected area. The trend analysis reveals that even the few remaining regions with large, contiguous tropical rainforests are subject to decline. Only some areas in the core of the Amazon, the eastern part of the Congo basin and isolated patches in Borneo are stable or improving. For most rainforests, decreasing forest biomass and increasing population result in a negative trend, but locally decreasing soil protection and increasing erosion rates also contribute.

Map 1.16 presents drivers of land degradation, with the index based on six input layers of direct anthropogenic drivers: deforestation, accessibility, agricultural expansion, fire, invasive species and grazing. Low values correspond to low intensities or pressure and high values correspond to high pressure.

At the global level, there are some regions where many drivers converge, resulting in extensive areas with high pressure on soil, water and vegetation resources. These include the east coast of the United States of America, including the Great Lakes area and the Mexican Gulf coast states; Western, Central and

MAP 1.15 **TREND IN BIOPHYSICAL STATUS, 2015**



Note: Overall trend, where trend is defined as a change in status (the capacity to provide ecosystem services and goods). A negative trend is referred to as decline, a positive trend is referred to as improvement and a trend with a value near zero is referred to as stable.

Source: **Coppus, R.** 2022. *Global distribution of land degradation*. Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en. Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

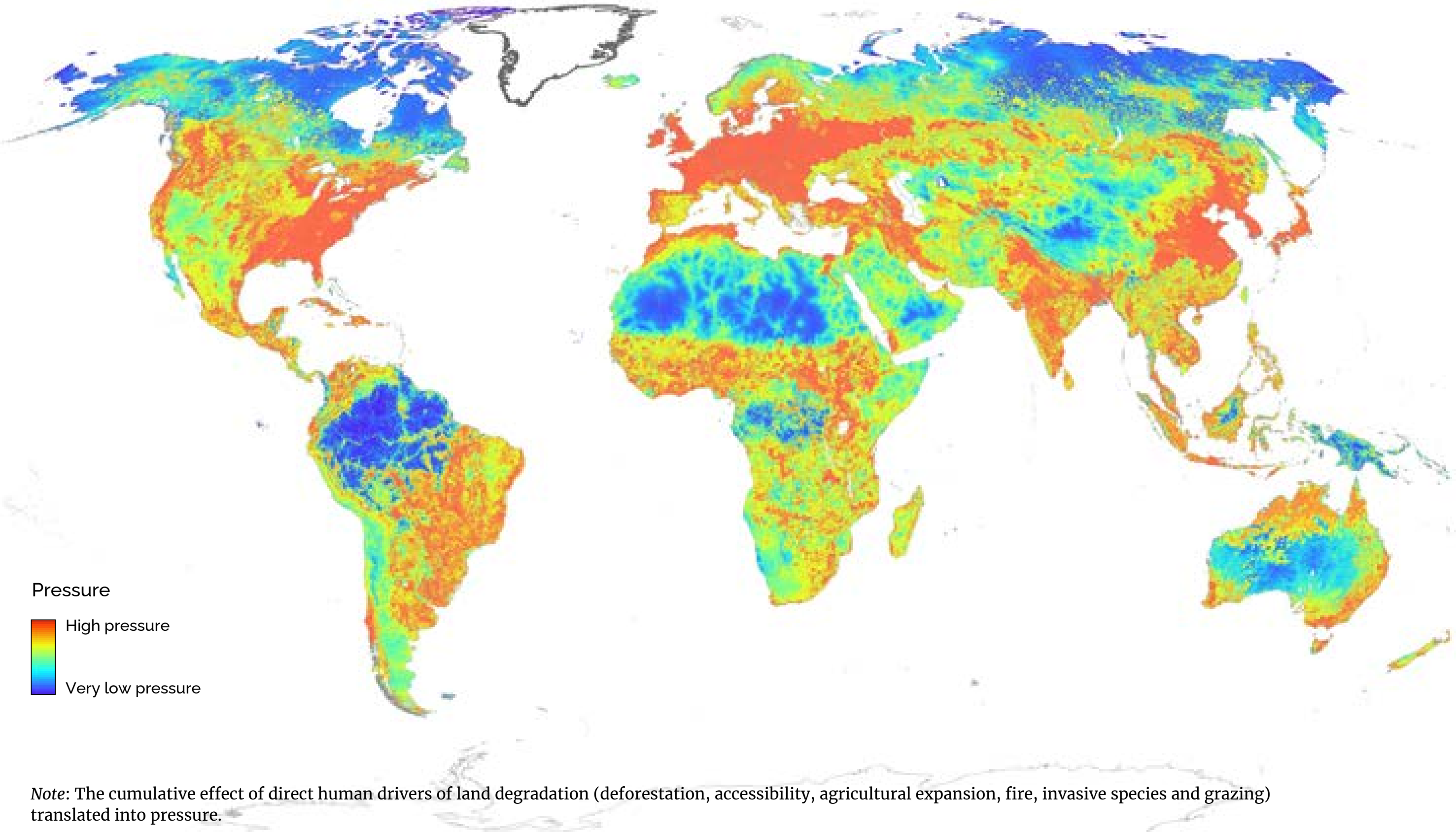
Eastern Europe, and the adjacent Volga basin in the Russian Federation; east Pakistan, India and Bangladesh; and the Democratic People's Republic of Korea, the Republic of Korea, central east China and Japan.

Map 1.17 presents the dominant drivers of land degradation. The main driver is dominant relative to the other drivers in terms of pressure but not necessarily responsible for human-induced land degradation because low and moderate pressures were also included in the analysis. Grazing and agricultural expansion are common in large parts of the United States of America, while invasive species and deforestation dominate in Alaska, northern Canada, Northern Europe and Siberia. Invasive species also dominate in Europe. In the Asian steppe, the most frequent drivers are fire and grazing, and in South and Southeast Asia, population density and deforestation are common. Australia is exposed to fire, and New Zealand is subject to high grazing densities. In Africa, fire and grazing are common, and in the Southern America region, grazing and deforestation dominate.

1.6.2 A global perspective

At the global level, in 2015, areas affected by human-induced land degradation covered 1 660 million ha, of which 850 million ha was subject to strong degradation, and 810 million ha was subject to light degradation (Table 1.6). Degrading areas were relatively evenly distributed over dry lands and humid areas, although humid areas had a higher share of light degradation (Map 1.18). Human-induced land degradation occurred in 11 percent of dry lands and 15 percent of humid areas.

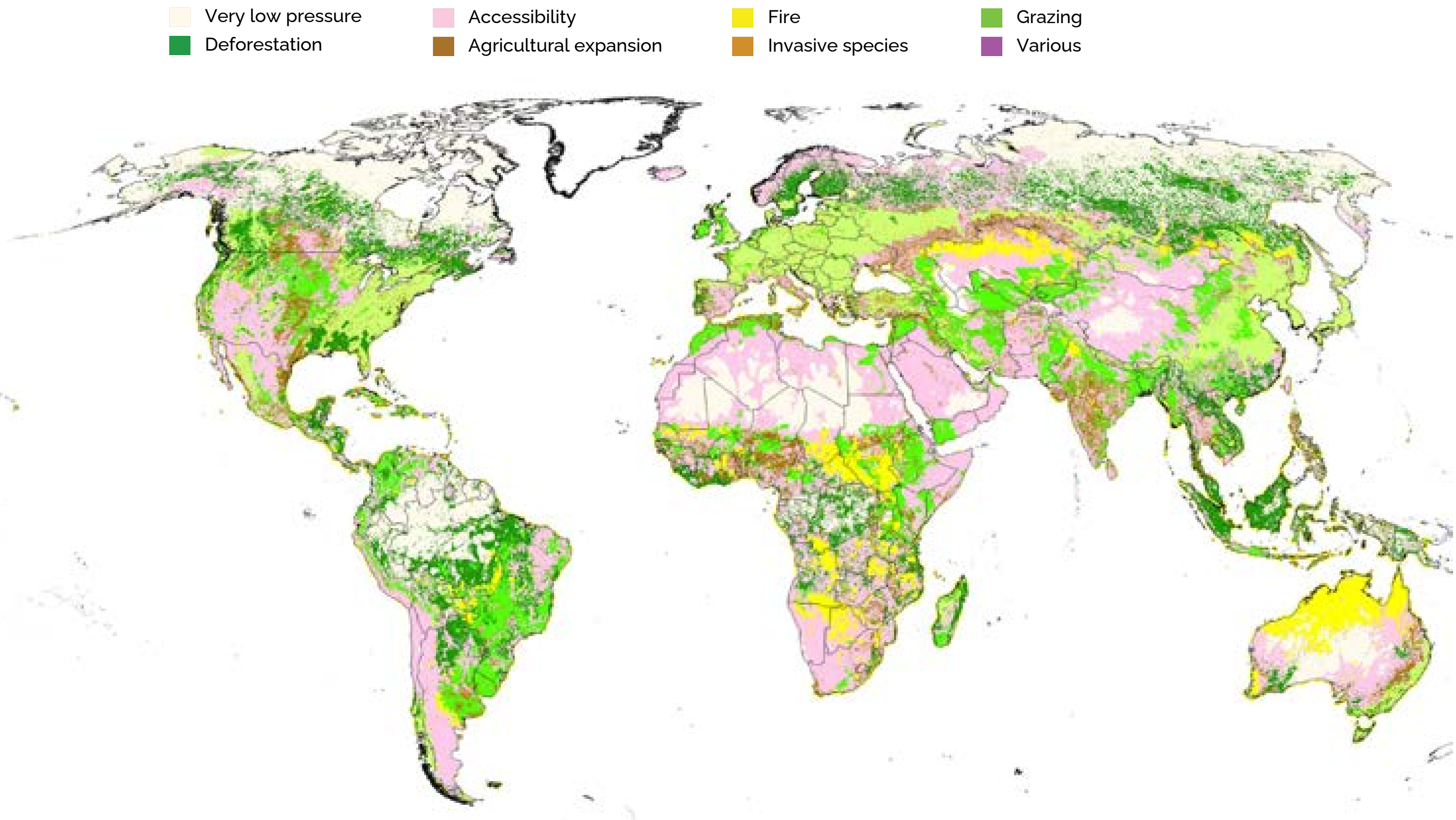
MAP 1.16 LAND DEGRADATION PRESSURES, 2015



Note: The cumulative effect of direct human drivers of land degradation (deforestation, accessibility, agricultural expansion, fire, invasive species and grazing) translated into pressure.

Source: **Coppus, R.** 2022. *Global distribution of land degradation*. Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en. Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

MAP 1.17 DOMINANT DRIVERS OF LAND DEGRADATION, 2015



Note: Global distribution of the dominant direct human drivers per area. The dominant driver is defined as the driver that exerts the highest pressure in a given area.

Source: **Coppus, R.** 2022. *Global distribution of land degradation*. Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en. Modified **UN.** 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

High pressure does not necessarily lead to human-induced land degradation. The trend analysis shows 3 576 million ha of land was under high pressure from human activities in 2015, of which slightly less than half (1 660 million ha) was subject to human-induced land degradation (Table 1.7). This implies more than half of the areas under high pressure are stable. Comparing the land degradation map with the status layer reveals 82 percent of these areas have high status, suggesting favourable land conditions impede degradation processes.

At the global level, the status of 5 670 million ha of land was declining in 2015, of which 1 660 million ha (29 percent) is attributed to human-induced land degradation. The remaining 71 percent is classified as deterioration caused by natural processes or which has an anthropogenic origin. Comparing deteriorated areas with status reveals that about half have low status. Areas with low status are likely to be more sensitive to degradation processes than areas of high status. Moderate pressures may suffice to trigger human-induced land degradation. A closer look at areas with low status subject to deterioration shows 656 million ha is under moderate pressure, equal to 12 percent of the overall global decline. Most of these areas are probably affected by human-induced land degradation, which means that approximately 41 percent of global decline can be attributed to human-induced land degradation.

TABLE 1.6 EXTENT OF HUMAN-INDUCED LAND DEGRADATION, 2015 (MILLION ha)

DEGRADATION	GLOBAL	DRYLANDS	HUMID AREAS
Total	1 660	733	927
Strong	850	418	432
Light	810	315	495

Note: Antarctica, Greenland and land with more than 90 percent bare cover (the great deserts) are excluded. For humid areas, the cold zone where potential evapotranspiration > 400 mm is also excluded.

Source: **Coppus, R.** 2022. *Global distribution of land degradation*. Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en

TABLE 1.7 EXTENT OF LAND DEGRADATION, 2015 (MILLION ha)

LAND DEGRADATION STATUS	EXTENT
Negative trend	5 670
High cumulative pressure	3 576
Human-induced land degradation	1 660

Source: **Coppus, R.** 2022. *Global distribution of land degradation*. Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en

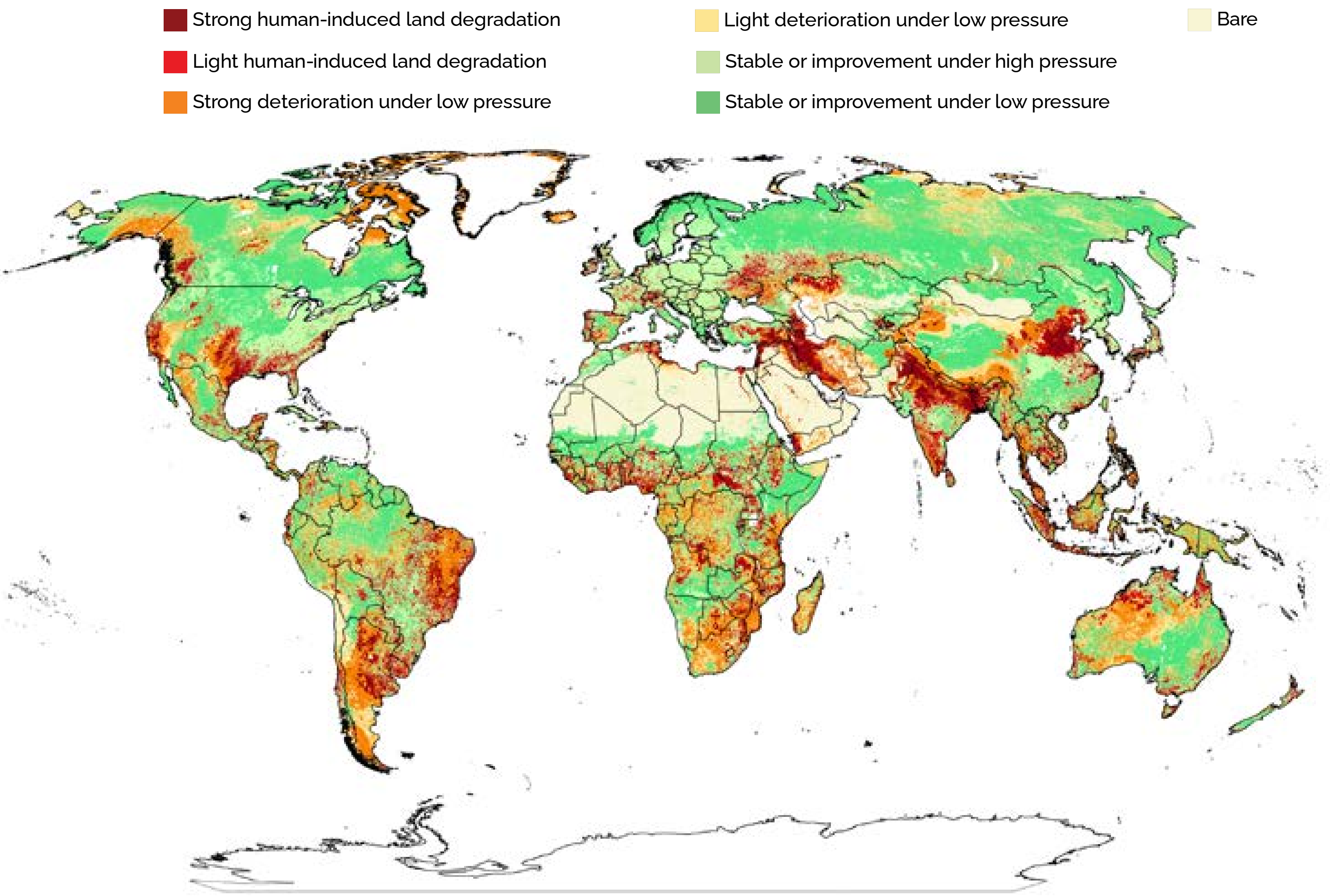
In 2015, a fifth of human-induced degraded land was in sub-Saharan Africa, followed by Southern America with 17 percent (Table 1.8). Northern America is about five times the size of South Asia, but both regions contributed 11 percent to global degradation. In relative terms, South Asia was the most affected region, with 41 percent of its area suffering from human-induced degradation, of which 70 percent was strongly degraded. Southeast Asia follows with 24 percent, of which 60 percent was severe, and Western Asia had 20 percent, of which 75 percent was strongly affected. Deserts are not included in these estimates.

There are three regions severely affected by human-induced land degradation over large contiguous areas: the arc in northern Western Asia, stretching from Israel and Jordan to southeast Turkey into Mesopotamia and western Islamic Republic of Iran; the Indo-Gangetic plain south of the Himalaya on the Indian subcontinent; and northern China, from the Loess Plateau to the Yellow River basin and the Bohai Sea region. However, almost all inhabited parts of the world are subject to some form of human-induced land degradation, and 52 degrading regions have been identified with an optimized analysis undertaken for this report (Coppus, 2022).

Global warming, causing ice sheet loss and melting glaciers, is responsible for a substantial decrease in available freshwater in the eastern arctic region of Canada and the stretch from southern Alaska to southwest Yukon. Groundwater depletion and drought have led to a substantial decrease in freshwater availability in California and adjacent Nevada (Rodell *et al.*, 2018). In Texas, soil, water and vegetation resources are in sharp decline due to a combination of drought, grazing, population pressure and expanding agriculture. Soil protection decline, high soil erosion rates and water stress characterize the fragile conditions in the Sierra Madre Occidental in Mexico.

MAP 1.18

LAND DEGRADATION CLASSES BASED ON THE SEVERITY OF HUMAN-INDUCED PRESSURES AND DETERIORATING TRENDS, 2015



Note: Global distribution of land degradation. Overall trend combined with cumulative pressure by direct human drivers. Human-induced land degradation refers to a negative trend, which is caused by human activity. Deterioration refers to a negative trend caused by natural phenomena or by humans in case status is low.

Source: **Coppus, R.** 2022. *Global distribution of land degradation*. Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en. Modified **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

Parts of Spain face increasing water stress and groundwater depletion. Drought in west Kazakhstan has led to deterioration of the Caspian Sea and Aral Sea. Large parts of Western Asia are at risk because of severe groundwater depletion, drought and population increase. East Pakistan and north India are exposed to groundwater depletion and population pressure, whereas water stress and agricultural expansion are the main issues in southeast India. The semi-arid area from the Loess Plateau in northern China to the Bohai Sea region is coping with severe groundwater depletion and population pressure. Arid west Australia receives low rainfall, which is combined with a decline in land productivity and large, frequent fires.

The eastern Maghreb is exposed to agricultural expansion and decreasing freshwater availability. The northern Nile valley is subject to high-intensity grazing, population

TABLE 1.8 HUMAN-INDUCED LAND DEGRADATION, 2015

REGION	AREA AFFECTED BY HUMAN-INDUCED DEGRADATION (MILLION ha)	TOTAL LAND AREA OF REGION (MILLION ha)	PERCENTAGE OF REGION AFFECTED (%)	STRONGLY DEGRADED (MILLION ha)	SLIGHTLY DEGRADED (MILLION ha)
Sub-Saharan Africa	330	2 413	14	149	181
Southern America	281	1 778	16	153	128
South Asia	180	439	41	126	54
Northern America	177	2 083	8	82	95
East Asia	156	1 185	13	84	72
Western Asia	123	615	20	92	31
Southeast Asia	122	501	24	74	48
Australia and New Zealand	94	796	12	34	59
Eastern Europe and Russian Federation	83	1 763	5	21	62
Western and Central Europe	56	489	11	12	44
Central Asia	31	456	7	12	19
Northern Africa	22	579	4	9	13
Central America and Caribbean	11	76	14	5	5
Pacific Islands	0.14	7	2	0.11	0.03
World	1 660	13 178	13	850	810
High income	393	3 817	10	175	218
Upper middle income	621	5 604	11	326	295
Lower middle income	428	2 207	19	241	187
Low income	220	1 520	14	107	112
Low income and food deficit	283	2 062	14	133	149
Least developed	288	2 097	14	134	154

Note: Percentage of region extent refers to the portion of the total regional extent that is degraded. Antarctica, Greenland and land with more than 90 percent bare cover (the great deserts) are excluded.

Source: **Coppus, R.** 2022. *Global distribution of land degradation*. Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en

pressure and increasing water stress. In the Ethiopian Highlands, soil erosion caused by intensive grazing and agricultural expansion is a significant issue. The southern half of Sudan is coping with agricultural expansion and increasing water stress. The western part of South Sudan is affected by large and recurrent fires and is also subject to massive forest biomass loss and increasing water stress. Southern Africa faces increasing water stress and a decline in land productivity. Eastern Brazil has been affected by a recent drought that caused increased water stress and decreased land productivity. Similar effects are found in central Argentina, where precipitation is decreasing and large areas are being burned.

Stable or improving regions with low biophysical status are located in the western arctic zones of Northern America and Eurasia and at the edges of the great deserts, such as the Sahara (the Sahel), the Karakum in Central Asia, the Gobi in East Asia and the Kalahari in Southwest Africa. The arid and semi-arid regions of the Taklamakan desert, the Tibetan plain, southeast Australia and the Horn of Africa show low resistance to degradation. Stable or improving regions with high biophysical status are located throughout southern Canada and the northern and central east part of the United States of America. The stable or improving regions stretching from Central and Southeast Europe to the Eurasian taiga and from eastern Mongolia to Manchuria also have high biophysical status. Low biophysical status occurs in dry lands and mountains and seems to be related to climate and geomorphology. However, this could be the result of severe degradation in historical times, which has reached a new equilibrium and appears to be under natural conditions. Unfortunately, there is no technique to identify such areas with current datasets (Fischer and van Velthuizen, 2018).

1.6.3 Productive areas at risk

Table 1.9 presents a summary of the spatial relationship between land degradation and the global land-use/-cover classes derived from GAEZ v4 for indicators compiled around the year 2015. In 2015, human-induced land degradation primarily affected cropland (FAO and IIASA, 2021). Although cropland covered only 15 percent of the analysed area, it accounted for 29 percent of all degraded areas. Almost one-third of rainfed cropland and nearly half of irrigated land are subject to human-induced land degradation.

In Northern Africa, Western Asia and South Asia, more than 60 percent of the irrigated areas are degraded. The largest areas are in the northern hemisphere, except for Southeast Asia. Globally, only 38 percent of irrigated land is stable, the lowest of the land covers analysed.

In Western Asia, agricultural expansion, grazing and accessibility drive degradation, while in the densely populated areas of East Asia and South Asia, good accessibility and high grazing density are exerting high pressures on irrigated fields. Grazing, accessibility and deforestation drive environmental change in irrigated cropland in Southeast Asia. Grazing, accessibility and agricultural expansion contribute most to the pressure on irrigation in the eastern United States of America.

The decline in status in East Asia and Western Asia is mainly due to decreasing freshwater availability, increasing water stress, reducing soil protection and increasing population. Similar degradation processes occur in South Asia. Major degradation processes in Southeast Asia are increasing erosion rates, rapidly decreasing forest biomass and increasing population. In the eastern United States of America, a decline in available freshwater and loss of soil protection are the main degradation processes. Problems are similar in the western United States of America, but rising population density brings additional pressure.

TABLE 1.9 EXTENT OF LAND DEGRADATION CLASSES FOR GLOBAL LAND COVER, 2015

LAND COVER	TOTAL AREA (MILLION ha)	DEGRADATION (MILLION ha)	DETERIORATION (MILLION ha)	STABLE (MILLION ha)	DEGRADED (%)	DETERIORATED (%)	STABLE (%)
Cropland	1 527	479	268	780	31	18	51
Rainfed	1 212	340	212	660	28	17	54
Irrigated	315	139	57	120	44	18	38
Grassland	1 910	246	642	1 022	13	34	54
Trees	4 335	485	1 462	2 388	11	34	55
Shrubs	1 438	218	584	636	15	41	44
Herbs	203	16	51	136	8	25	67
Sparse vegetation	1 034	85	499	450	8	48	44
Protected area	980	76	361	443	9	41	50

Note: The term degradation refers to high pressures from anthropogenic drivers. All other declines in biophysical status are defined as deterioration.

Source: **Coppus, R.** 2022. *Global distribution of land degradation*. Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en

The expansion of areas at risk is indicative of declining ecosystem services as Map 1.19 illustrates. Biophysical status is given as much importance as trend, and no distinction is made between anthropogenic and natural causes. Consequently, areas with a low status and strong decline are considered to be at risk. Areas with a high status and slight decline are not considered to be at risk. Neither are stable nor improving areas. Based on this analysis, the extent of cropland at risk (Table 1.10) is similar to the extent of degraded croplands in 2015. Combining status and trends indicates areas at risk in 2015 amounted to some 3 866 million ha. The distribution of irrigated and rainfed cropland at risk matches the degraded areas.

Croplands at risk tend to be areas recently brought into production and which are subject to limited freshwater availability and where population density is increasing. Most grasslands at risk are exposed to decreasing freshwater availability. The exceptions are in Southern America and sub-Saharan Africa, where decreasing land productivity and soil protection account for declining ecosystem services. In Asia, increasing water stress also contributes to the grasslands at risk. In sub-Saharan Africa, grasslands are prone to frequent and intense fires. Forestland at risk is prone to deforestation, and in sub-Saharan Africa also to frequent and severe fires. Forests at risk are affected by decreasing freshwater, loss of soil protection and decreasing forest biomass. The biophysical status of most regions at risk is characterized by low SOM and low plant species biodiversity.

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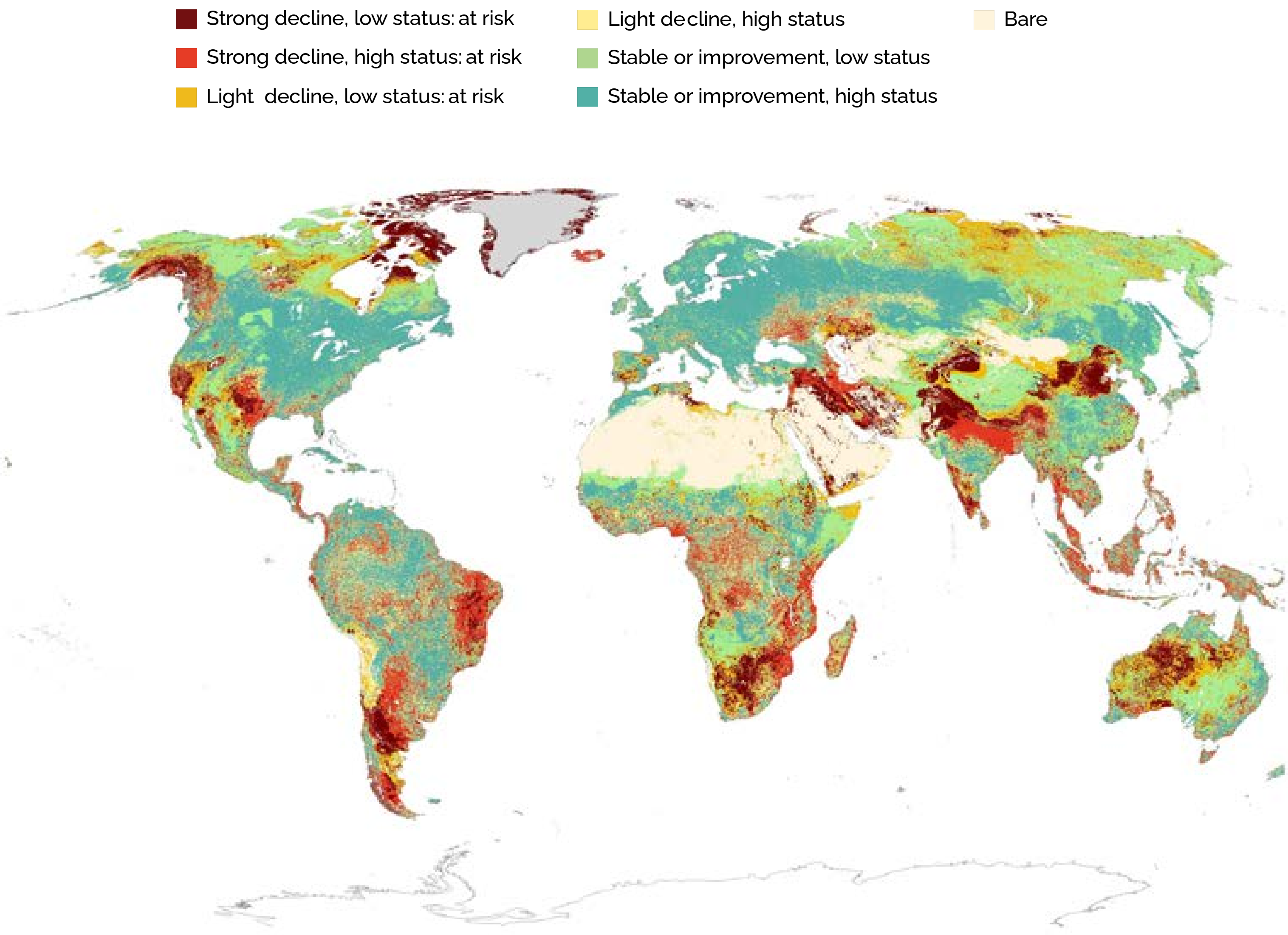
TABLE 1.10 AREAS OF AGRICULTURAL LAND AND FOREST AT RISK, 2015

LAND COVER	TOTAL AREA (MILLION ha)	AREA AT RISK (MILLION ha)	AREA AT RISK (%)
Cropland	1 527	472	31
Rainfed	1 212	322	27
Irrigated	315	151	48
Grassland	1 910	660	35
Forestland	4 335	1 112	26

Source: **Coppus, R.** 2022. *Global distribution of land degradation*. Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en

MAP 1.19 REGIONS AT RISK BASED ON STATUS AND TRENDS OF LAND RESOURCES, 2015



Note: Overall biophysical risk combined with overall trend.

Source: **Coppus, R.** 2022. *Global distribution of land degradation*. Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en. Modified **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

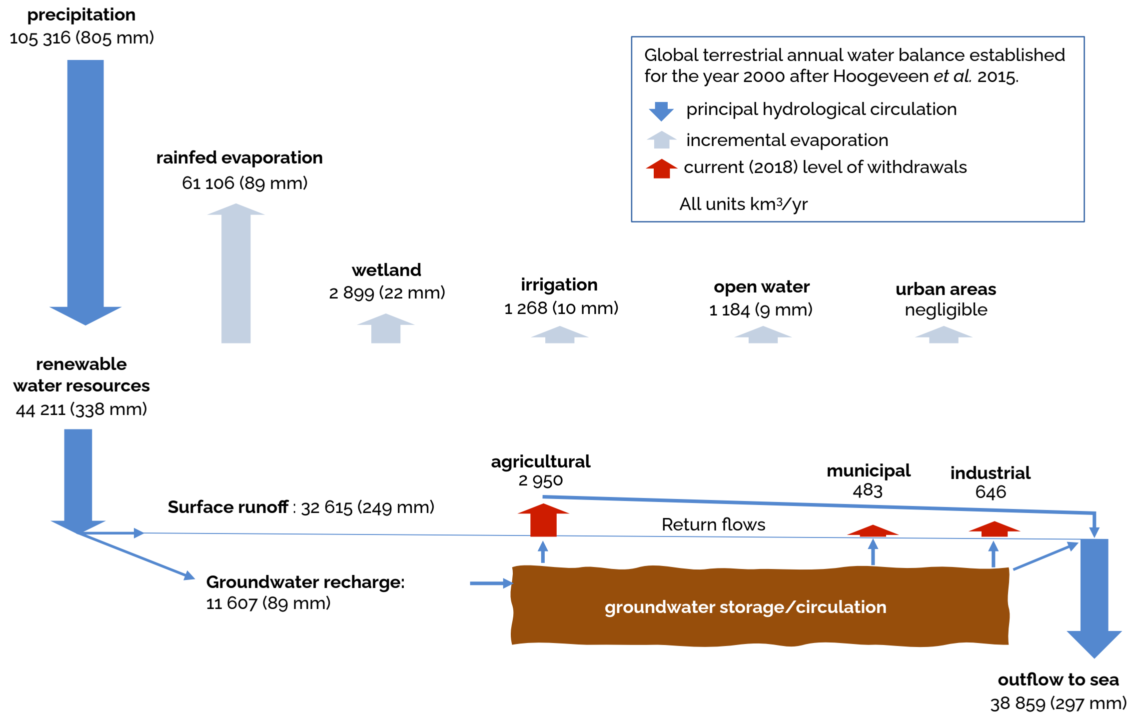
1.7 Water scarcity

1.7.1 Structural changes within the global water balance

The global water budget is under pressure. The long-term internal renewable water resources (IRWRs) derived from rivers, lakes and shallow aquifer circulation are estimated to amount to 44 211 km³/year (Figure 1.19). Estimated withdrawals for all sectors exceeded 4 000 km³/year in 2018, almost 10 percent of IRWRs. The global freshwater water balance estimated for 2000 (Figure 1.19) is still valid for long-term means of precipitation and outflows, but structural changes to storage volumes in snowpacks, glaciers and aquifers have since occurred across many of the large continental river basins.

Direct measurement of changes in surface water body "cover" with high-resolution satellite sensors have been available since 1984 (Pekel *et al.*, 2016; EC, 2020, 2021). These data reveal that 0.9 million ha of detectable water bodies has disappeared, and 7.3 million ha has transitioned from a permanent state to a seasonal state between 2000 and 2019. Over the same period, 18.4 million ha of new permanent water bodies was created in areas that were not previously covered. Natural surface water bodies are expanding due to accelerated runoff/snowmelt, as on the Tibetan Plateau. The measurable change in permanent and seasonal surface water bodies on irrigated and rainfed cropland is significant. Table 1.11 and Table 1.12 present the regional breakdowns for water cover on irrigated land and rainfed cropland for 2019 and the changes established with respect to a 2000–2004 baseline. For irrigated land and rainfed cropland, the global aggregate

FIGURE 1.19 ANNUAL GLOBAL WATER BALANCE, 2000



Source: **Hoogeveen, J., Faurès, J.M., Peiser, L., Burke, J. & Van De Giesen, N.** 2015. GlobWat – A global water balance model to assess water use in irrigated agriculture. *Hydrology and Earth System Sciences*, 19(9): 3829–3844.

increases in areas are positive, with irrigated land registering nearly 5 percent gain in permanent cover and rainfed cropland registering 2.5 percent gain (Table 1.12). The largest regional gains in permanent cover are in the South Asia and East Asia regions, while the largest losses occur in Eastern Europe. Permanent water bodies occupy about 10 percent of the combined areas equipped for irrigation (342 million ha) and rainfed (1 556 million ha) based on FAOSTAT data in 2019.

The volume of artificially stored surface water is significant. The Global Reservoir and Dam Database monitors the rate of change in large dam reservoir storage greater than 100 million m^3 (GDW, 2022), and Figure 1.20 summarizes version 1.3 of the database. Total built storage as of 2016 was estimated to be of the order of 7 500 km^3. Although large dam construction has declined over the past two decades, reservoir size and relative magnitude of river flows impounded have increased. Reservoir storage is approximately half of total freshwater withdrawals, and the impact on wetlands and free-flowing rivers is significant (Schneider *et al.*, 2017; Grill *et al.*, 2019). Annual evaporation from impounded reservoirs is estimated to be approximately 350–400 km^3 (FAO, 2020a). In the International Commission on Large

TABLE 1.11 PERMANENT AND SEASONAL WATER COVER ON IRRIGATED LAND, 2019 AND 2000–2004 CHANGES (ha)

REGION	PERMANENT EXTENT, 2019	SEASONAL EXTENT, 2019	TOTAL WATER EXTENT, 2019	PERMANENT CHANGES SINCE 2000–2004 BASELINE	SEASONAL CHANGES SINCE 2000–2004 BASELINE
Australia and New Zealand	8 812	9 382	18 194	−3 425	−2 416
Central America and Caribbean	11 251	11 733	22 984	1 541	2 607
Central Asia	155 033	757 795	912 828	2 138	380 195
Eastern Europe	106 557	56 956	163 513	−13 373	13 233
Northern Africa	60 475	61 757	122 232	347	17 762
Northern America	238 594	1 016 245	1 254 838	15 950	319 488
Pacific Islands	0	0	0	0	0
Southern America	73 096	108 213	181 309	−1 371	−9 251
South Asia	456 204	4 358 549	4 814 754	−9 923	914 729
East Asia	1 419 312	2 305 217	3 724 529	128 047	−62 124
Southeast Asia	196 888	1 977 423	2 174 311	−7 634	−396 565
Sub-Saharan Africa	52 910	128 216	181 126	434	62 473
Western Asia	217 788	603 638	821 427	31 014	438 097
Western and Central Europe	143 547	156 048	299 595	9 201	65 676
Total/net change on irrigated land	3 140 468	11 551 172	14 691 639	152 945	1 743 903

Sources: Data from **European Commission**. 2020. Global surface water explorer. In: *European Commission*. https://global-surface-water.appspot.com/#data; **European Commission**. 2021. *Index of /ftp/jrc-opendata/GSWE*. https://jeodpp.jrc.ec.europa.eu/ftp/jrc-opendata/GSWE/

TABLE 1.12 **PERMANENT AND SEASONAL WATER COVER ON RAINFED CROPLAND, 2019 AND 2000–2004 CHANGES (ha)**

REGION	PERMANENT EXTENT, 2019	SEASONAL EXTENT, 2019	TOTAL WATER EXTENT, 2019	PERMANENT CHANGES SINCE 2000–2004 BASELINE	SEASONAL CHANGES SINCE 2000–2004 BASELINE
Australia and New Zealand	191 057	440 394	631 451	-39 310	-48 526
Central America and Caribbean	185 889	164 666	350 555	8 872	32 014
Central Asia	705 919	1 319 492	2 025 411	19 112	702 853
Eastern Europe	1 860 830	1 359 806	3 220 636	-96 620	221 401
Northern Africa	51 381	32 954	84 334	10 281	11 623
Northern America	1 480 520	1 542 198	3 022 717	142 060	506 394
Pacific Islands	1 000	1 724	2 724	46	1 124
Southern America	3 176 202	3 372 214	6 548 416	-82 183	184 092
South Asia	726 382	2 993 642	3 720 024	61 018	1 004 399
East Asia	1 874 842	2 093 807	3 968 650	307 681	265 463
Southeast Asia	1 136 326	2 842 313	3 978 639	24 318	185 560
Sub-Saharan Africa	1 955 850	2 413 382	4 369 232	-50 706	835 436
Western Asia	345 662	323 305	668 967	47 240	158 534
Western and Central Europe	702 146	232 021	934 168	13 822	46 298
Total/net change on rainfed land	14 394 006	19 131 918	33 525 924	365 632	4 106 666

Sources: Data from **European Commission**. 2020. Global surface water explorer. In: *European Commission*. https://global-surface-water.appspot.com/#data; **European Commission**. 2021. *Index of /ftp/jrc-opendata/GSWE*. https://jeodpp.jrc.ec.europa.eu/ftp/jrc-opendata/GSWE/

Dams world register of dams, of the 58 713 registered dams, 13 580 are dedicated to irrigation as single-purpose dams and a further 6 278 irrigation dams are registered as being multipurpose.

The impact of small-scale hydraulic structures on surface storage is less certain, but the areal contribution of small reservoirs and tanks in agricultural areas with prolonged dry seasons such as Eastern Africa and peninsular India is indicated by surface water dynamics (Pekel *et al.*, 2016).

The adverse impact of water storage sediment flows is particularly important for the long-term evolution of deltas, which support irrigated production and aquaculture. Reduced sediment flows into deltas combined with land subsidence (from compaction and groundwater withdrawals) are estimated to result in an average relative sea-level rise of 6.8 mm/year (Tessler *et al.*, 2018). Impacts of planned dams and dams under construction are estimated to increase the relative sea-level rise by up to 1 mm/year in some deltas progressively starved of sediment. Sediment flows have been estimated to decrease by up to 60 percent in the Danube basin and 20 percent in the Ganges–Brahmaputra–Meghna system (Tessler *et al.*, 2018), with implications for the high population concentrations associated with deltas (Tellman *et al.*, 2021). Higher rates of fluvial erosion downstream of large dams releasing sediment-hungry water also threaten previously productive alluvial terraces (Kondolf *et al.*, 2014).

Changes in the volumes of water withdrawn also point to shifts in the pattern of withdrawals. Agriculture continues to be the primary water user at the global level, and accounted for some 2 950 km^3 (72 percent) of total water withdrawals in country reporting in 2018 (Table 1.13). This compares with an estimated total of 2 703 km^3 in 2006, which indicates annual growth rates of about 0.8 percent per year. Approximately 483 km^3 (12 percent) was withdrawn for municipal use and 646 km^3 (16 percent) for industry (Table 1.13). However, these figures vary significantly by region. In Europe, agriculture withdraws only 30 percent, municipalities 26 percent and industry 45 percent. In South Asia, agriculture withdraws 91 percent, municipalities 7 percent and industry 2 percent. High-income regions, such as Northern America and Europe, have proportionally lower withdrawals for agriculture compared with low-income countries. Residual flows retained in-stream or returned to shallow groundwater and draining to the marine environment still represent 88 percent of renewable water resources at the global level, but this masks significant variation at the regional level. Withdrawals and dam storage are estimated to account for an overall reduction in natural pre-development flows (Pekel *et al.*, 2016; Schneider *et al.*, 2017; Tessler *et al.*, 2018).

The overall change in per capita distribution of freshwater resources is significant as populations grow. The decline in global per capita IRWRs was about 20 percent between 2000 and 2018 (Figure 1.21). The change was greater in countries with the lowest per capita IRWRs, such as sub-Saharan Africa (41 percent), Central Asia (30 percent), Western Asia (29 percent) and Northern Africa (26 percent). The region with the lowest percentage change was Europe (3 percent). On the demand side, the regions with the largest water withdrawals per capita were Northern America and Central Asia.

Total water withdrawals per capita remained flat or declined from 2000 to 2018, except in Central America and the Caribbean, Southern America and Southeast Asia (Figure 1.22). These trends are expected to persist as populations grow, partly due to overall increases in water productivity, including agriculture, and partly due to the prevalence of water scarcity induced by extended periods of aridity in areas of high population density.

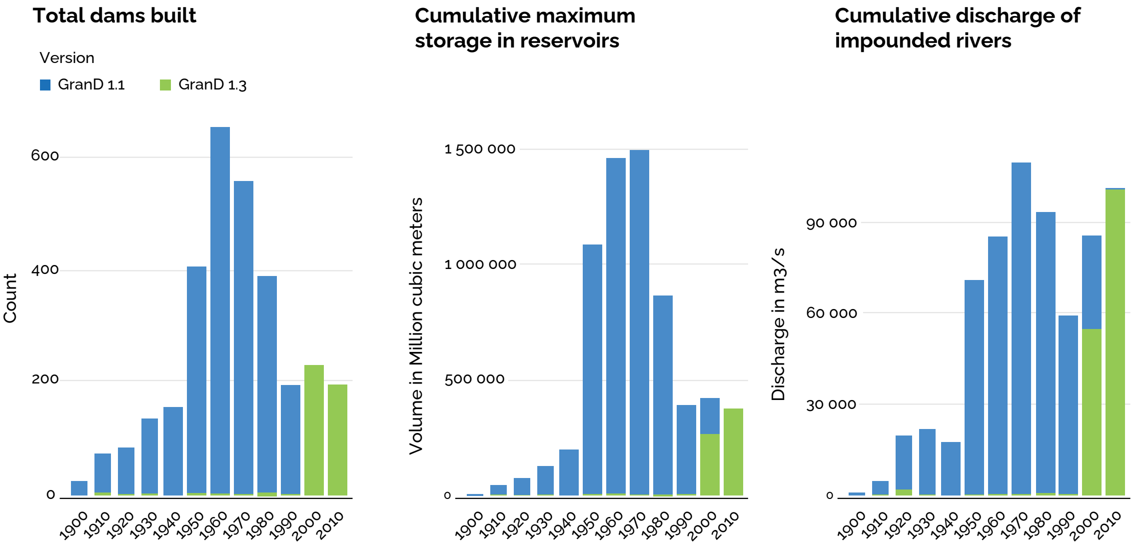
1.7.2 Droughts and scarcity

Droughts are among the most complex and severe climate-related hazards encountered, with wide-ranging and cascading impacts across societies, ecosystems and economies. They are recurrent, can last from a few weeks to several years, and affect large areas and populations around the world. Droughts have occurred throughout history, due to natural climate variability (UNDRR, 2021).

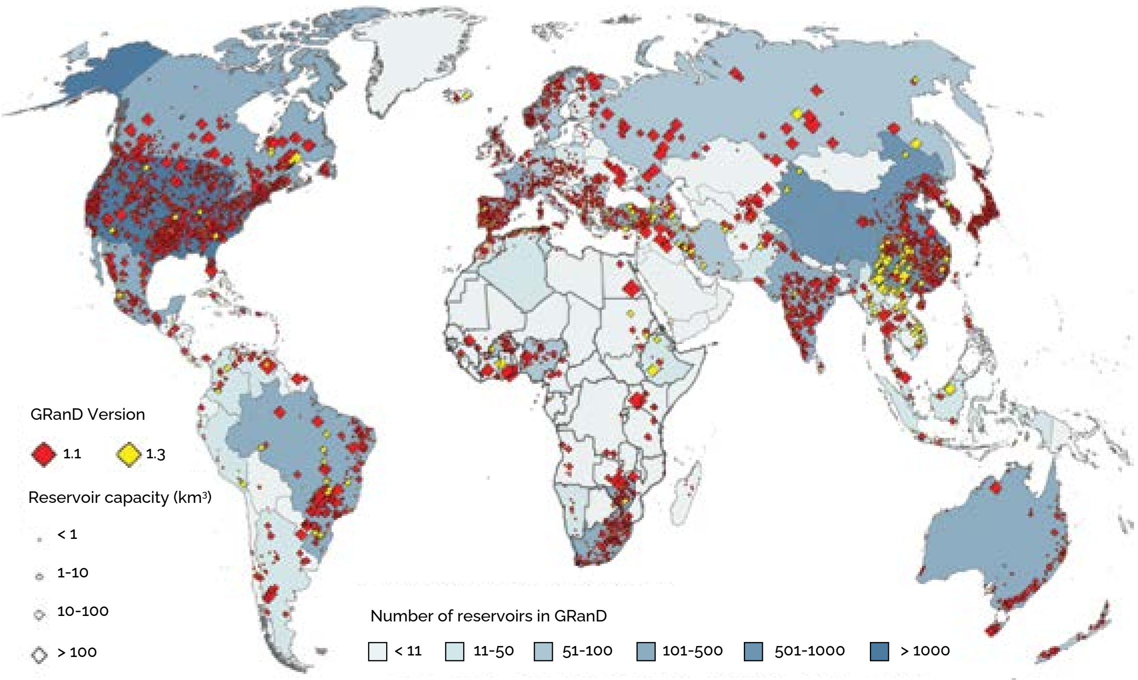
> Drought is a prolonged dry period in the natural climate cycle that can occur anywhere in the world. It is a slow on-set phenomenon caused by a lack of rainfall. Compounding factors, such as poverty and inappropriate land use, increase vulner-

FIGURE 1.20 GLOBAL DISTRIBUTION OF LARGE DAMS AND RESERVOIRS, 2016

GRanD v1.1 and v1.3 contain the locations and characteristics for 7,320 dams and reservoirs across the planet. GRanD dams are snapped to the HydroSHEDS river network, which facilitates research on the size of rivers being dammed.



When focusing on reservoirs with storage greater than 100 million cubic metres (MCM), large dam and reservoir construction peaked between 1960 and 1969. Cumulative volume of water impounded peaked later, between 1970 and 1979. Large reservoir construction slowed considerably after these peaks. Though dam and reservoir construction has not returned to rates seen over the middle of the 20th century, the size of rivers being dammed has increased. Fewer dams with large reservoirs were built between 2000 and 2016, but the cumulative discharge of rivers being impounded by large dams nearly reaches that of the much more active decade between 1970 and 1979, indicating that recent dams are increasingly built on larger rivers.



Source: **Global Dam Watch**. 2022. Research using core global dam datasets. In: *Global Dam Watch*. http://globaldamwatch.org/our-research

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

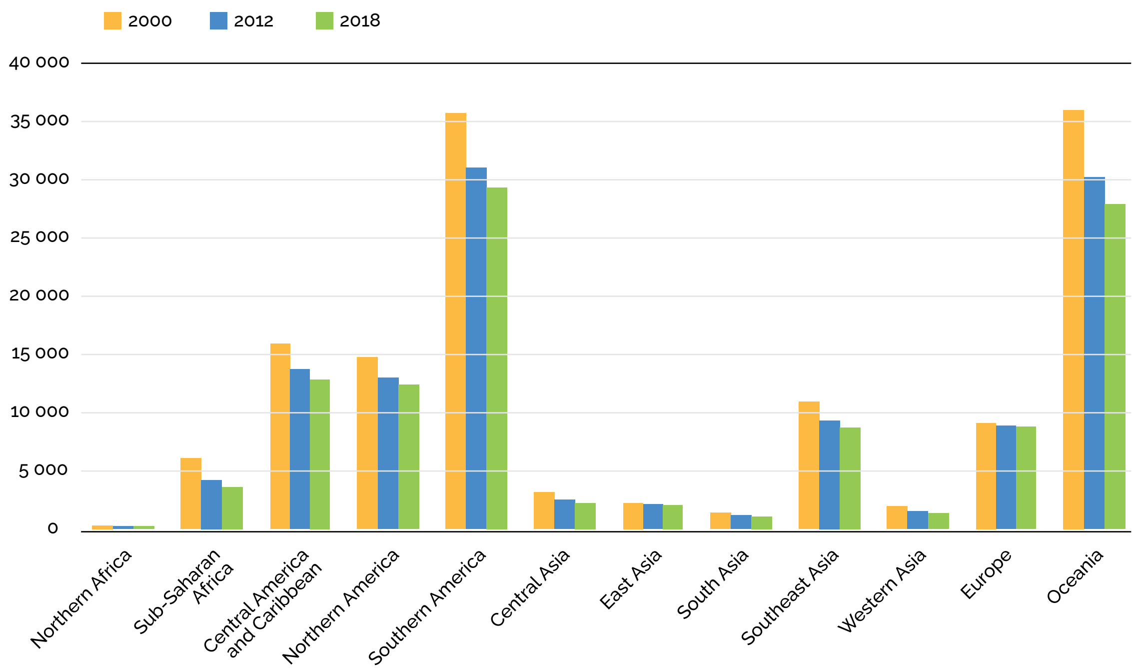
TABLE 1.13 TOTAL WATER AND TOTAL FRESHWATER WITHDRAWALS FOR HUMAN USE, AND PERCENTAGE OF TOTAL WATER WITHDRAWALS, 2018

REGION	AGRICULTURAL WATER WITHDRAWAL		MUNICIPAL WATER WITHDRAWAL		INDUSTRIAL WATER WITHDRAWAL		TOTAL WATER WITHDRAWAL	TOTAL FRESHWATER WITHDRAWAL	IRWR
	km³/YEAR	%	km³/YEAR	%	km³/YEAR	%	km³/YEAR	km³/YEAR	km³/YEAR
Africa	186	79	36	15	15	6	237	222	3 935
Northern Africa	85	79	17	16	6	6	108	94	46
Sub-Saharan Africa	101	78	19	15	9	7	129	128	3 889
Americas	500	56	120	13	274	31	894	896	19 673
Central America and Caribbean	24	63	8	20	7	17	38	35	1 209
Northern America	246	43	76	13	246	43	569	569	6 077
Southern America	230	80	36	13	22	7	287	292	12 387
Asia	2 162	82	249	9	223	8	2 634	2 518	11 865
Central Asia	131	88	8	5	10	7	149	148	242
East Asia	462	65	102	14	150	21	714	709	3 410
South Asia	913	91	70	7	20	2	1 003	899	1 935
Southeast Asia	429	85	43	8	34	7	506	507	5 794
Western Asia	227	87	26	10	8	3	262	255	485
Europe	86	30	76	26	130	45	291	286	6 576
Eastern Europe and Russian Federation	23	30	20	26	34	44	78	77	4 414
Western and Central Europe	63	29	55	26	96	45	213	209	2 163
Oceania	15	67	3	14	4	19	23	22	915
Australia and New Zealand	15	68	3	14	4	19	23	21	819
Pacific Islands	0	59	0	30	0	11	0	0	96
Total general	2 950	72	483	12	646	16	4 079	3 944	42 964

Notes: IRWR = internal renewable water resources generated on country areas. Total water withdrawal includes use of desalinated water, direct use of treated municipal wastewater and direct use of agricultural drainage water. Total freshwater withdrawal is defined as the sum of surface water withdrawal extracted from rivers, lakes and reservoirs, and groundwater withdrawal extracted from aquifers. It does not include non-conventional waters.

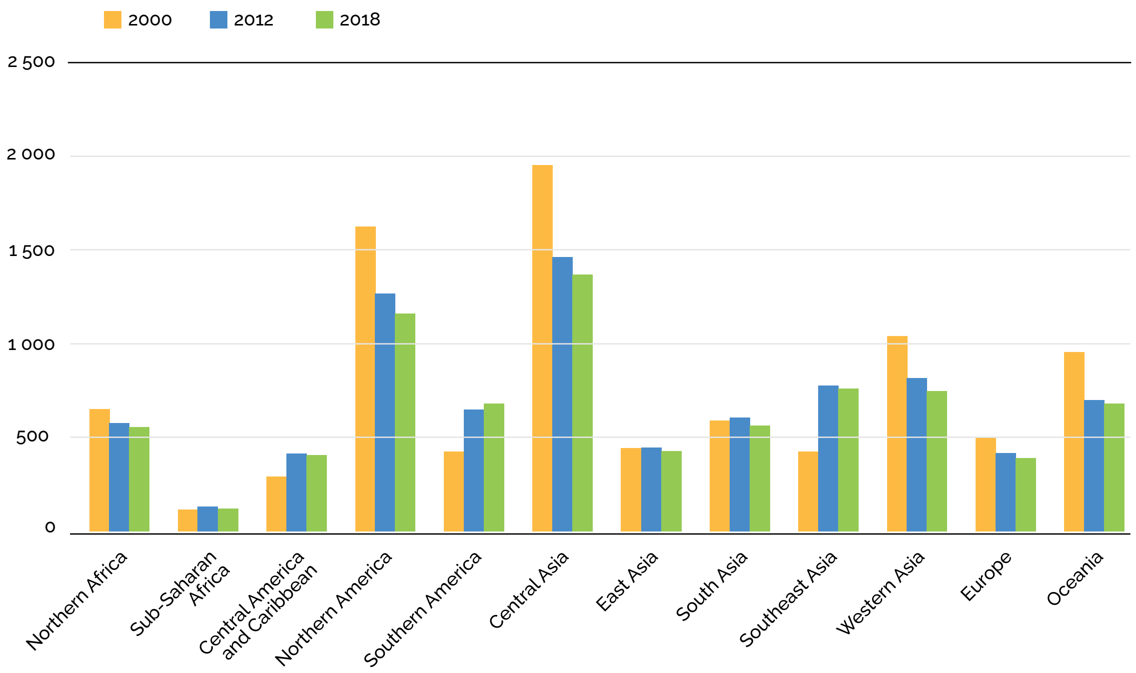
Source: **FAO**. 2021. AQUASTAT – FAO's Global Information System on Water and Agriculture.
In: *FAO*. Rome. www.fao.org/aquastat/en

FIGURE 1.21 TOTAL ANNUAL INTERNAL RENEWABLE WATER RESOURCES PER CAPITA BY GEOGRAPHICAL REGION, 2000, 2012 AND 2018 (m³/CAPITA)



Source: **FAO**. 2021. AQUASTAT – FAO's Global Information System on Water and Agriculture. In: *FAO*. Rome. www.fao.org/aquastat/en

FIGURE 1.22 TOTAL ANNUAL WATER WITHDRAWALS PER CAPITA BY GEOGRAPHICAL REGION, 2000, 2012 AND 2018 (m³/CAPITA)



Source: **FAO**. 2021. AQUASTAT – FAO's Global Information System on Water and Agriculture. In: *FAO*. Rome. www.fao.org/aquastat/en

> ability to drought. When drought causes water and food shortages, there can be many impacts on the health of the population, which may increase morbidity and result in death. In recent years, most drought-related mortality has occurred in countries also experiencing political and civil unrest. In the period from 1970 to 2012, drought caused almost 680 000 deaths, due to the severe African droughts of 1975, 1983 and 1984. (WMO, 2022b)

Drought needs to be distinguished from aridity. Drought is an immediate risk and can affect all regions and is not confined to drier regions only. Occurrences of drought are unpredictable, but they come to an end, while aridity does not. In simple terms, a drought is a period when rainfall is less than "normal" or "expected", and there is not enough water to meet the demands of human activities and sustain environmental services. However, not all droughts cause problems or become crises; this depends on where and when they occur. "Agricultural drought" is usually the first visible sign of drought. It can be short lived, reduce crop yields, affect rangeland and forest productivity, and increase fire hazards. "Hydrological drought" follows, adversely affecting aquatic ecosystems, wetlands and river flows, leading to domestic water shortages. Finally, "socioeconomic drought" affects most aspects of life, including public health and economic growth, with impacts lasting many months and even years, beyond the time when the meteorological drought is over and forgotten about. In rural areas, reduced crop productivity can lower farm incomes and increase food prices, unemployment and migration. In vulnerable communities, farm incomes can take many years to recover after drought.

Climate change increases drought risk by increasing the frequency and magnitude of extreme weather events. It changes the average climate conditions and climate variability and generates new threats in regions that have little experience of dealing with drought. As with climate change, drought is slow to develop and not easily recognized at first but can quickly become a crisis when severe and damaging impacts emerge.

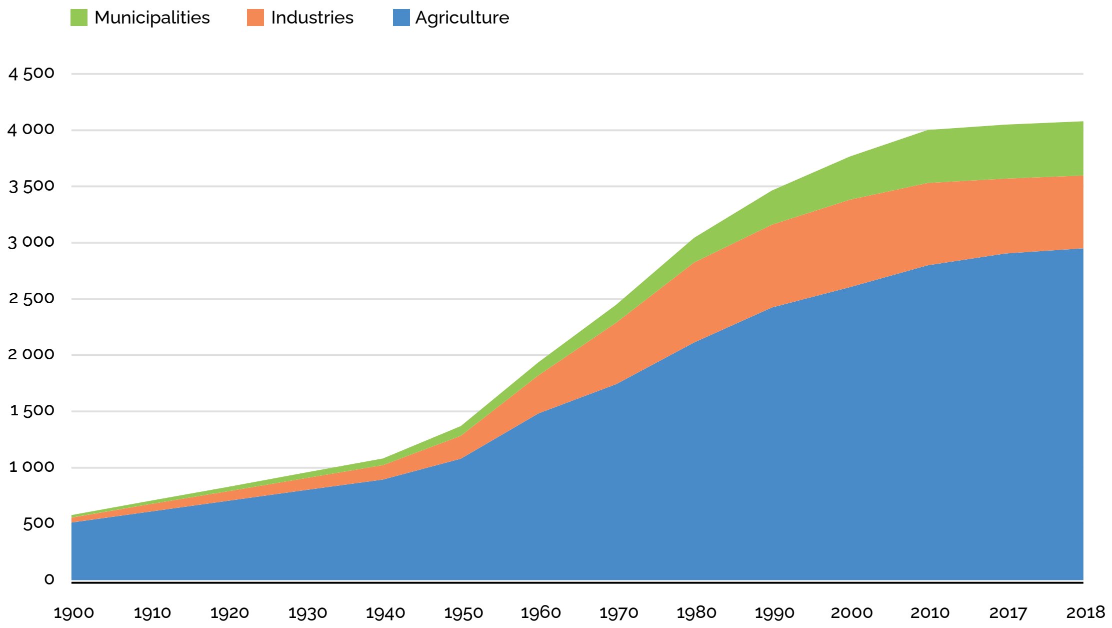
FAO surveyed the drought characteristics and management practices covering 2003–2013 in 48 developing countries in Latin America, Africa and Asia, and found that agriculture takes the brunt, absorbing over 80 percent of the economic losses. Crop production was most affected, accounting for 42 percent, and livestock for 36 percent. FAO has published detailed reports from this survey for the Caribbean (FAO, 2016), Central Asia and Turkey (FAO, 2017b) and the Near East and North Africa (FAO, 2018c).

1.7.3 Water withdrawals flatten but consumption increases

Increasing global population and economic growth have been driving water withdrawals. The annual rate of increase peaked in the 1960s and has since been slowing, particularly during the 2000s (Figure 1.23). From 2010 to 2018, municipal withdrawals increased by 3 percent, while agricultural withdrawals increased by 5 percent, representing 72 percent of total withdrawals. Industrial withdrawals decreased by 12 percent from 2010 to 2018, reflecting reductions in withdrawals for thermal power production as cooling processing has become more water efficient.

In 2012, irrigation accounted for 90 percent of all evaporation (consumptive use) induced by human activities (Hoogeveen *et al.*, 2015). Estimated crop water requirements in 2012

FIGURE 1.23 EVOLUTION OF GLOBAL TOTAL WATER WITHDRAWALS, 1910–2018 (km³/YEAR)



Source: **FAO**. 2021. AQUASTAT – FAO's Global Information System on Water and Agriculture. In: *FAO*. Rome. www.fao.org/aquastat/en

accounted for 1 507 km³ of total agricultural withdrawals (2 872 km³ in 2012). Evaporation from irrigated land increased from 1 268 km³ in 2004 to 1 285 km³ in 2012 (Hoogeveen *et al.*, 2015) and continues to place the most significant pressure on river basin balances. In some cases, total withdrawals and reduced return flows result in basin closure (Molle and Wester, 2009), indicating the sensitivity of hydrological circulation in subtropical zones in particular. Combined with anticipated impacts of climate change and rapid increases in demand from a predominantly urban population, the pressure or stress on freshwater resources is set to continue. Patterns of agricultural water withdrawals have changed since 2003, in response to increased demand for calories and changing dietary demands, notably the growth in consumption of animal protein (FAO, 2017a).

Non-conventional water sources (including reclaimed wastewater and desalinated water) account for only 0.12 percent of consumptive irrigation use. The use of treated wastewater for irrigation is still small, but it is growing as the marginal cost of treatment declines. The estimated volume of treated wastewater from urban areas used for irrigation is 5 km³/year, and is concentrated in Southern America, the Near East and China. Estimates suggest 10 percent of the global irrigated land area receives untreated or partially treated wastewater, more than 30 million ha in 50 countries (FAO, 2020f). Wastewater used for irrigation is one of the significant drivers of diffuse soil pollution. Even treated wastewater still contains residues of contaminants not removed by modern technologies.

There were approximately 18 thousand desalination plants worldwide at the end of 2015, with a total installed annual produc-

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tion capacity of 31 km³. Some 13.6 km³ (44 percent) was in the Near East and North Africa (IWA, 2016), which is expected to grow by 7–9 percent annually. Desalination is also likely to increase in Southern America, the United States of America and Asia. Modest amounts only are used directly for irrigation, mostly on high-value horticultural crops. However, desalinated water forms a high percentage of urban wastewater in the Near East and the Arabian Peninsula and is reused for irrigation.

In 2021 the global desalination operating capacity was estimated at 28.6 km³/year (78 349 678 m³/day) and 10 209 180 m³/day of desalination contracted capacity in 183 countries in the world (IDA, 2021). The global installed desalination capacity has been increasing steadily at the rate of about 7 percent per annum since 2010 to the end of 2019. Mega-plants are few in number, but they supply most of the global desalination capacity (Eke *et al.*, 2020). The seawater and brackish water desalination capacity has had a great increase of 6.4 million m³/day of new capacity in 2019 as a result of numerous mega-projects in the Gulf and Israel. Desalination capacity is increasing across the Middle East, but there are also a number of large-scale projects in India. In the United States of America, seawater desalination is slowly increasing (IDA, 2021). There is a sharp rise in the desalination capacities in regions that did not have desalination in the past, including Africa and Europe.

1.7.4 Regional variations in water stress

The SDG aggregate indicator 6.4.2 on water stress[4] assesses the level of stress that human activities are considered to exert on natural freshwater resources (FAO and UN-Water, 2021). This is an aggregate (all-sector) indicator and is taken as an overall measure of physical water scarcity. At the global level, SDG indicator 6.4.2 reached an average of 18 percent in 2018, but this masks substantial regional variations (Figure 1.24). In 2018, Europe experienced a low stress level of 8.3 percent. In comparison, the stress levels in East Asia and Western Asia were about 45 percent and 70 percent, respectively. In Central Asia and South Asia, they were over 70 percent, while in Northern Africa, they were above 100 percent.

The SDG indicator 6.4.2 accounts for all freshwater withdrawals relative to total freshwater resources, including environmental flow requirements for ecosystem services. A withdrawal rate above 75 percent of renewable water resources represents high water stress, and more than 100 percent is critical. High water stress can have devastating consequences for the environment and hinder or even reverse economic and social development.

There are concerns that SDG indicator 6.4.2, although useful as a broad aggregate indicator, can mask the recirculation of water use in river basins and aquifers (Vanham *et al.*,

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[4] SDG indicator 6.4.2 measures the level of water stress and is defined as the ratio of total freshwater withdrawn by all major sectors (agricultural, industrial and municipal) to total renewable freshwater resources, after considering environmental flow requirements. The ratio between 0 and 25 percent indicates no stress; 25–50 percent indicates low stress; 50–75 percent indicates medium stress; 75–100 percent indicates high stress; and more than 100 percent indicates critical stress.

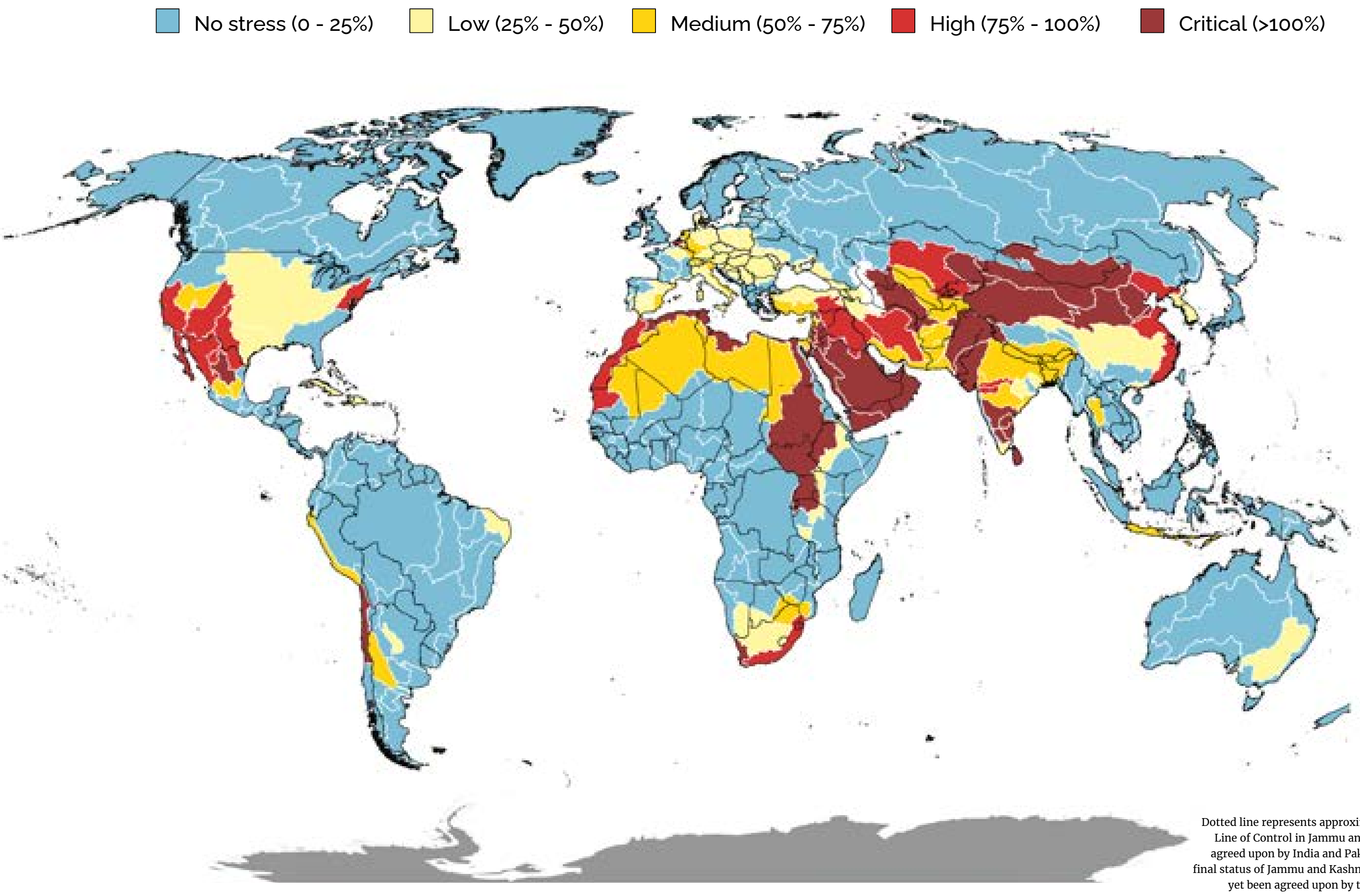
FIGURE 1.24 LEVEL OF WATER STRESS BY GEOGRAPHICAL REGION, 2006, 2009, 2012, 2015 AND 2018

Source: **FAO**. 2021. AQUASTAT – FAO's Global Information System on Water and Agriculture. In: *FAO*. Rome. www.fao.org/aquastat/en

2018). Indices of stress that are more complex are being developed to account for more variables and sectors (e.g. the World Resources Institute AQUEDUCT indices; WRI, 2022) (Qin *et al.*, 2019). The method of calculation in this report is somewhat different from that used for SOLAW 2011, which expressed agricultural water stress as the ratio of irrigation consumption to river basin renewable water resources (Hoogeveen *et al.*, 2015) and not the ratio of water withdrawals to renewable water resources as used for SDG indicator 6.4.2. The Hoogeveen *et al.* (2015) stress criterion considers water stress to be substantial when the incremental evaporation due to irrigation exceeds 10 percent of the generated water resources in a river basin. A ratio exceeding 20 percent indicates critical stress.

The SDG indicator 6.4.2 on water stress has been calculated at country level and aggregated following the SOLAW regional groupings. A different picture appears when aggregating the indicator by river basin (Map 1.20). Water stress is high in all those basins with intense irrigated agriculture, as well as in those including densely populated cities (e.g. Cape Town), which compete with the agricultural sector for the use of water, and where there is less volume of available freshwater resources due to climatic conditions. Countries are encouraged to disaggregate at the sub-basin level to give a more detailed picture of the distribution of water stress. Basins affected by high or critical water stress are located in regions of

MAP 1.20 LEVEL OF WATER STRESS OF ALL SECTORS BY MAJOR BASIN, 2018



Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

Source: **FAO & UN-Water**. 2021. *Progress on level of water stress: Global status and acceleration needs for SDG indicator 6.4.2*. Rome. https://doi.org/10.4060/cb6241en. Modified **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

high water stress, such as Northern America, the west coast of Central America, Northern Africa, and South and Central Asia.

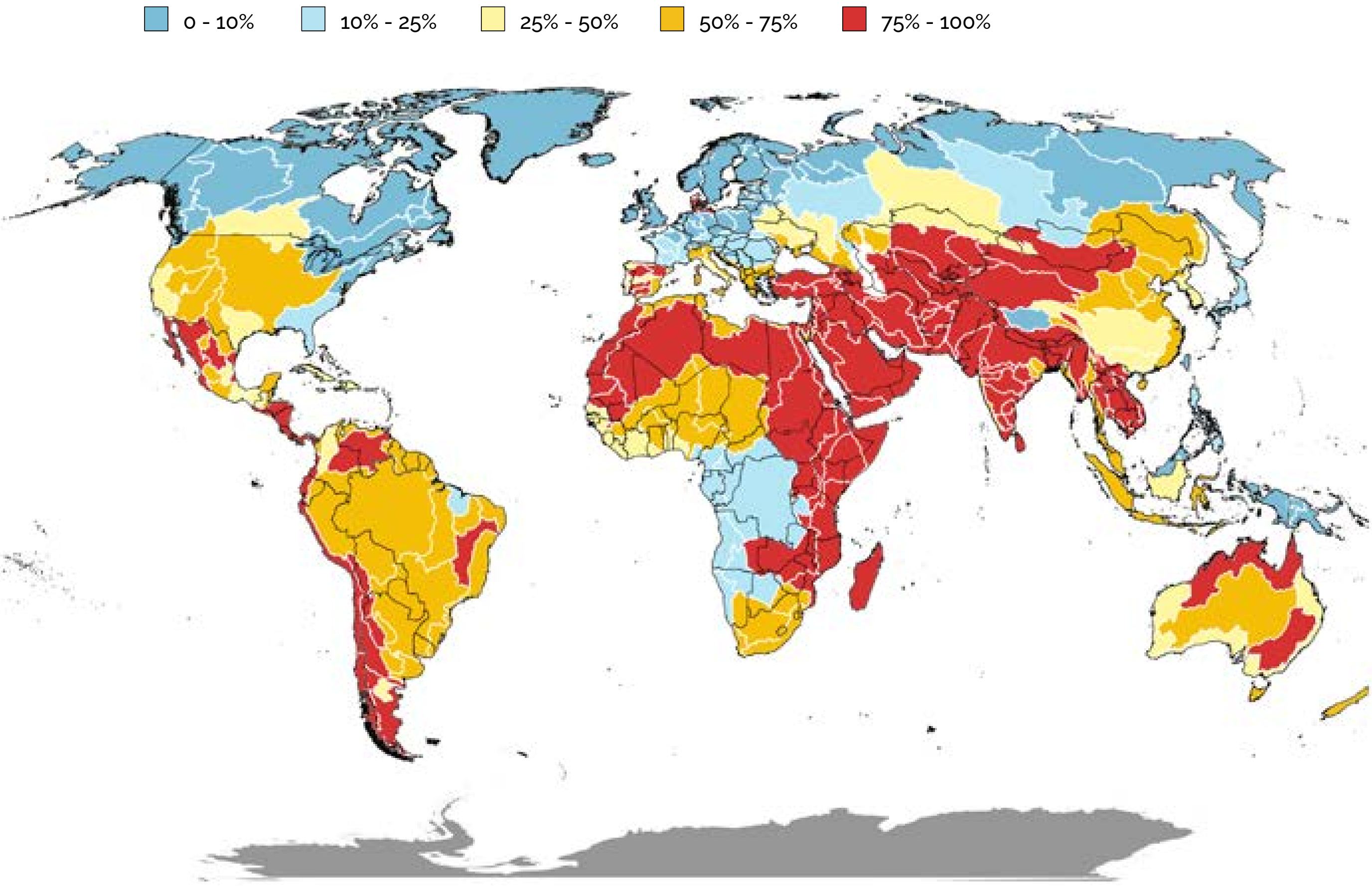
Agriculture makes a significant contribution to water stress in countries with high levels of water stress. Agricultural withdrawals account for a significant part of total withdrawals in Northern Africa, the Middle East–Western Asia and Central Asia. Water stress due to agricultural withdrawals at the water basin level shows the critical nature of the Nile River basin and river basins in the Arabian Peninsula and South Asia (Map 1.21).

1.7.5 Keeping groundwater systems in play

Many countries are concerned about increasing dependence on groundwater for domestic, industrial and agricultural supply, as withdrawals are exhausting their recoverable groundwater storage. Depletion of non-renewable groundwater resources continues in the arid zones of Northern America, Northern Africa, the Near East and Arabian Peninsula, and Central Asia, where irrigated agriculture dominates total withdrawals. Recent reviews of large, irrigated basins point to the growing role of

MAP 1.21

LEVEL OF WATER STRESS DUE TO THE AGRICULTURE SECTOR BY BASIN, 2018



Note: The contribution of the agriculture sector to water stress is defined as the ratio between total freshwater consumed by the agricultural sector and total renewable freshwater resources, after considering environmental flow requirements. The SDG water stress indicator 6.4.2 measures the contribution of the agriculture sector to water stress at the major basin level as follows: no stress – when the proportion of agricultural water withdrawal is between 0 percent and 25 percent; low stress – between 25 percent and 50 percent; medium stress – between 50 percent and 75 percent; high stress – between 75 percent and 100 percent; and critical stress – more than 100 percent.

Source: **FAO & UN-Water**. 2021. *Progress on level of water stress: Global status and acceleration needs for SDG indicator 6.4.2*. Rome. https://doi.org/10.4060/cb6241en. Modified **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

groundwater exploitation for irrigation and the complex water management implications in sustaining the quantity and quality of groundwater (e.g. Lytton *et al.*, 2021).

Global groundwater withdrawals for irrigated agriculture were estimated at 820 km^3/year based on aggregate country-level reporting for 2018, and crop water requirements were over 33 percent of the total global area equipped for groundwater irrigation (see Table 1.3). For 2018, the crop water requirement to withdrawal ratio is assumed at 65 percent, reflecting lower conveyance losses associated with groundwater-sourced irrigation (Siebert *et al.*, 2010). This level of withdrawal represents a 19 percent increase relative to 2010, when an estimated 688 km^3/year was withdrawn for irrigated agriculture, and indicates annual growth rate of 2.2 percent.

Margat and van der Gun (2013) identified local and regional aquifers with severe storage

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depletion, mainly associated with agricultural withdrawals for irrigation. Notable depletions occurred on continental aquifers associated with agricultural plains and coastal margins. Localized depletion in minor alluvial, coastal and island aquifers has been attributed to agricultural withdrawals, leading to groundwater scarcity, pollution and saline intrusion, which threatens potable water supply and limits agricultural production on coastal aquifers. The impact of agricultural withdrawals of groundwater presents a complex picture. As more groundwater is pumped to surface water evaporation and runoff to sea or saline sinks, withdrawals can exceed the natural rates of groundwater recharge and aquifer recovery. The result is a net gain to the atmosphere and oceans, possibly accelerating sea-level rise (Wada, Van Beek and Bierkens, 2012). However, for some aquifers, recharge patterns are changing as groundwater drawdown is opening opportunities for higher recharge rates (Konikow, 2013).

Despite the range of individual aquifer studies, there is no consistent reporting of groundwater withdrawals and their relative contribution to economic activity on land, particularly for conjunctive use. Where high-quality groundwater information is collected, the detail of these shifts becomes apparent. For example, across the United States of America, some 117 km^3 of groundwater was withdrawn from principal aquifers in 2015. Agriculture accounted for 83 km^3, of which 79 km^3 was withdrawn for irrigation and livestock and 4 km^3 was for aquaculture (USGS, 2018). But at state level in California, while surface water was the primary source of irrigation water from 1950 to 2009, groundwater became the main source of supply between 2010 and 2015 as severe drought reduced surface water withdrawals by 64 percent (USGS, 2018).

This evolution of conjunctive use may not be managed or planned, but it indicates a global expansion of groundwater use in agriculture to service irrigation expansion, and, more significantly, intensification within existing surface command areas as in South Asia (Shah, 2009). Recent updates of agricultural groundwater use, including those of the United States Department of Agriculture (USDA National Agricultural Statistics Service, 2019) and India's 5th Census of Minor Irrigation Schemes (MoWR RD and GR, 2017), all point to continued irrigation expansion in which the proportion of irrigated land using surface and groundwater sources conjunctively can be expected to increase.

Local and regional groundwater models incorporating land-use changes and estimates of withdrawals and recharge can be used to track groundwater depletion (Konikow, 2013). However, verifying the scale and magnitude of depletion trends using remote sensing by monitoring water storage changes in the Earth's crust (the National Aeronautics and Space Administration Gravity Recovery and Climate Experiment satellite mission) has proved challenging (Famiglietti, 2014). This is largely due to the coarse resolution of the gravity anomalies used to infer storage changes (Vishwakarma *et al.*, 2021). Modelled estimates suggest that between 2000 and 2009, global groundwater depletion for all uses was of the order of 113 km^3/year (Döll *et al.*, 2014), while other models suggest volumes of the order of 304 km^3/year for 2010, of which 228 km^3/year (75 percent) was attributed to agriculture (Wada, Van

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Beek and Bierkens, 2012). Estimates of the depletion attributed to irrigated production (Dalin *et al.*, 2017) indicate this increased from almost 195 km^3/year in 2000 to just over 241 km^3/year in 2010.

In practice, quantifying aquifer storage depletion at the global scale remains conjectural when pre-development states are not documented and when aquifer systems are being actively pumped. Boundary and leakage conditions are continually changing, and recharge capture is variable, so categoric distinctions between renewable and non-renewable groundwater storage are often not possible without detailed hydrochemical and isotope verification. However, models now include measured piezometric heads as a valuable indicator of storage depletion and are available for many local and regional aquifers (e.g. Haacker, Kendall and Hyndman, 2016).

The trends in groundwater storage and the risks of groundwater depletion must be taken together with the build-up of aquifer pollution from anthropogenic sources and the migration of geogenic pollution, notably arsenic and fluoride. By 2018, in China, only 63 percent of groundwater was considered potable. In Southeast Asia, arsenic and fluoride were the most common geogenic pollutants. However, fertilizers and pesticides remain some of the main sources of anthropogenic pollution. In Europe, nitrate pollution was the most common cause of poor groundwater quality, with 23 percent of groundwater bodies exceeding European Union groundwater nitrate standards (FAO and IWMI, 2018).

1.7.6 Deteriorating water quality

At the global level, agriculture remains the dominant source of water pollution (mainly diffuse or non-point pollution from agricultural land), followed by human settlement and industry. For 2010 it was estimated that all annual non-consumed water (2 250 km^3) was discharged into the environment as urban wastewater (330 km^3), industrial wastewater including cooling water (660 km^3) and agricultural drainage (1 260 km^3) (FAO and IWMI, 2018). But agriculture is also a victim of the deterioration of water quality. Saline water significantly decreases agricultural productivity, with major implications for global and local food security. Recent estimates indicate that food losses caused by the presence of saline water in soils and groundwater is equivalent to the annual food requirements of 170 million people (Damania *et al.*, 2019). Under climate change, the consequences of rainfall variability and increased temperature are expected to translate into further deterioration of water quality.

The capacity of soils to store, buffer and degrade water-borne contaminants is being exceeded by anthropogenic treatment of soils on cropland and pasture to the point where elevated levels of nitrogen, salinity and biological oxygen demand in freshwater are widespread (Map 1.22).

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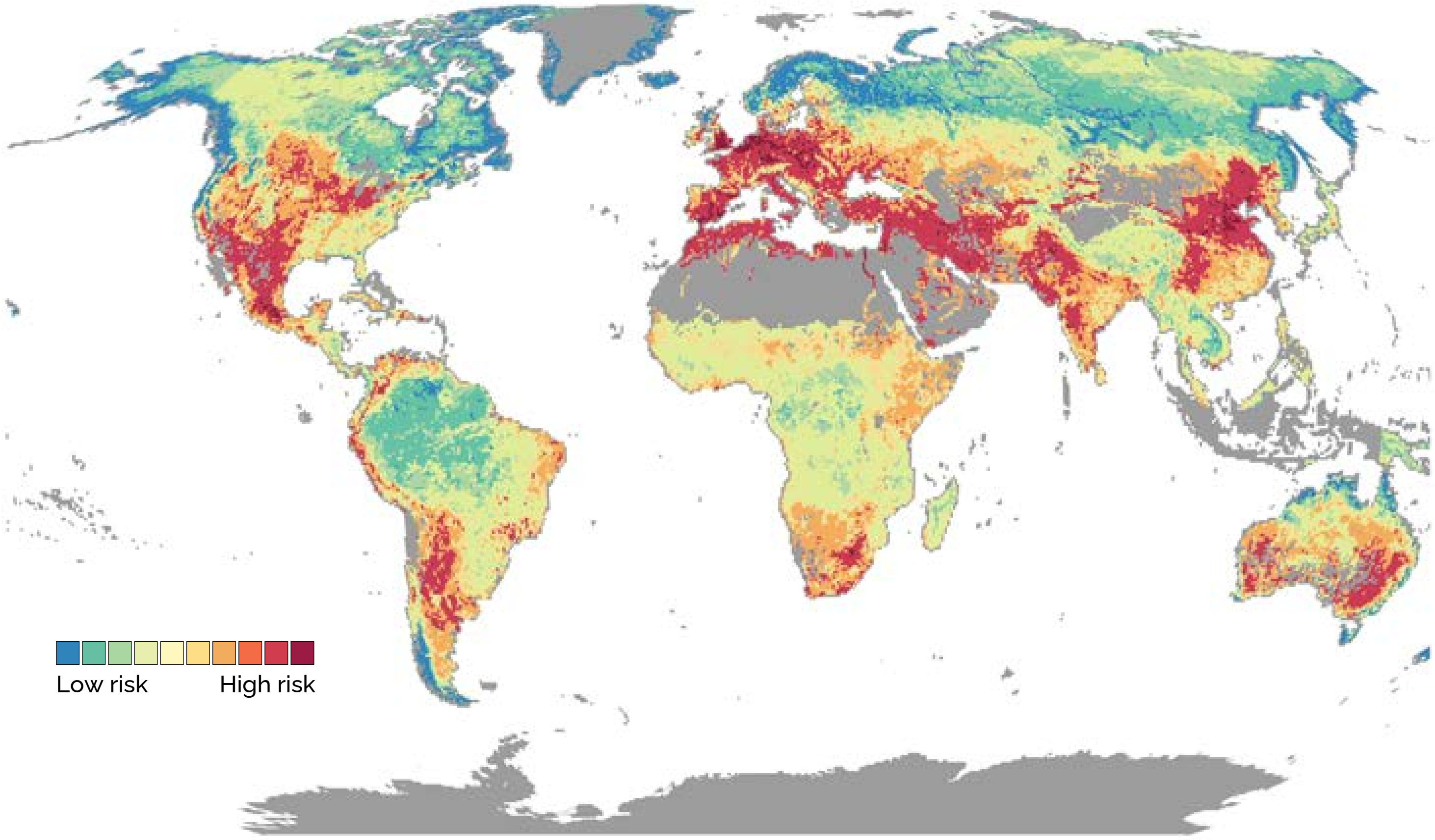
Agricultural use of reactive nitrogen has continued to increase since 2000, from almost 81 million tonnes to a peak of 110 million tonnes in 2017, with signs of a slight decline in 2018. Industrial fertilizer production and biological fixation of nitrogen in agriculture account for 80 percent of anthropogenic nitrogen fixation (Stevens, David and Storkey, 2018). In agricultural systems, reactive nitrogen is a major threat to water quality (eutrophication of surface water), soil quality (soil acidification, changes in SOM content and loss of soil biodiversity), plant biochemistry, insects (i.e. pollinators), functional composition of vegetation communities and mammal herbivores (grazing animals) (Sutton *et al.*, 2011; Stevens, David and Storkey, 2018). It was estimated that the annual cost of the environmental impacts of nitrogen pollution in the European Union was between EUR 70 billion and EUR 320 billion in 2012 (EC, 2013).

The global growth rate of phosphorus use in agriculture is modest, from 32 million tonnes in 2000 to a peak of 45 million tonnes in 2016 (Figure 1.18 and Map 1.23). Nutrient phosphate is one of the essential nutrients required for plant growth and development, but when leached from cultivated soils, it

MAP 1.22 **GLOBAL WATER QUALITY RISK FOR THREE SUSTAINABLE DEVELOPMENT GOAL 6.3.2 INDICATORS (NITROGEN, ELECTRICAL CONDUCTIVITY AND BIOLOGICAL OXYGEN DEMAND), MODELLING OF THE GLOBAL FRESHWATER QUALITY DATABASE DATA 2000–2010 AT 50 km RESOLUTION**



Note: This figure maps a water quality index summarizing global predictions for biological oxygen demand, electrical conductivity and nitrogen. Each value is scaled to a common support for comparability, then summed together. Average values for 2000–2010 are displayed. Grey areas have no data for one or more parameters.

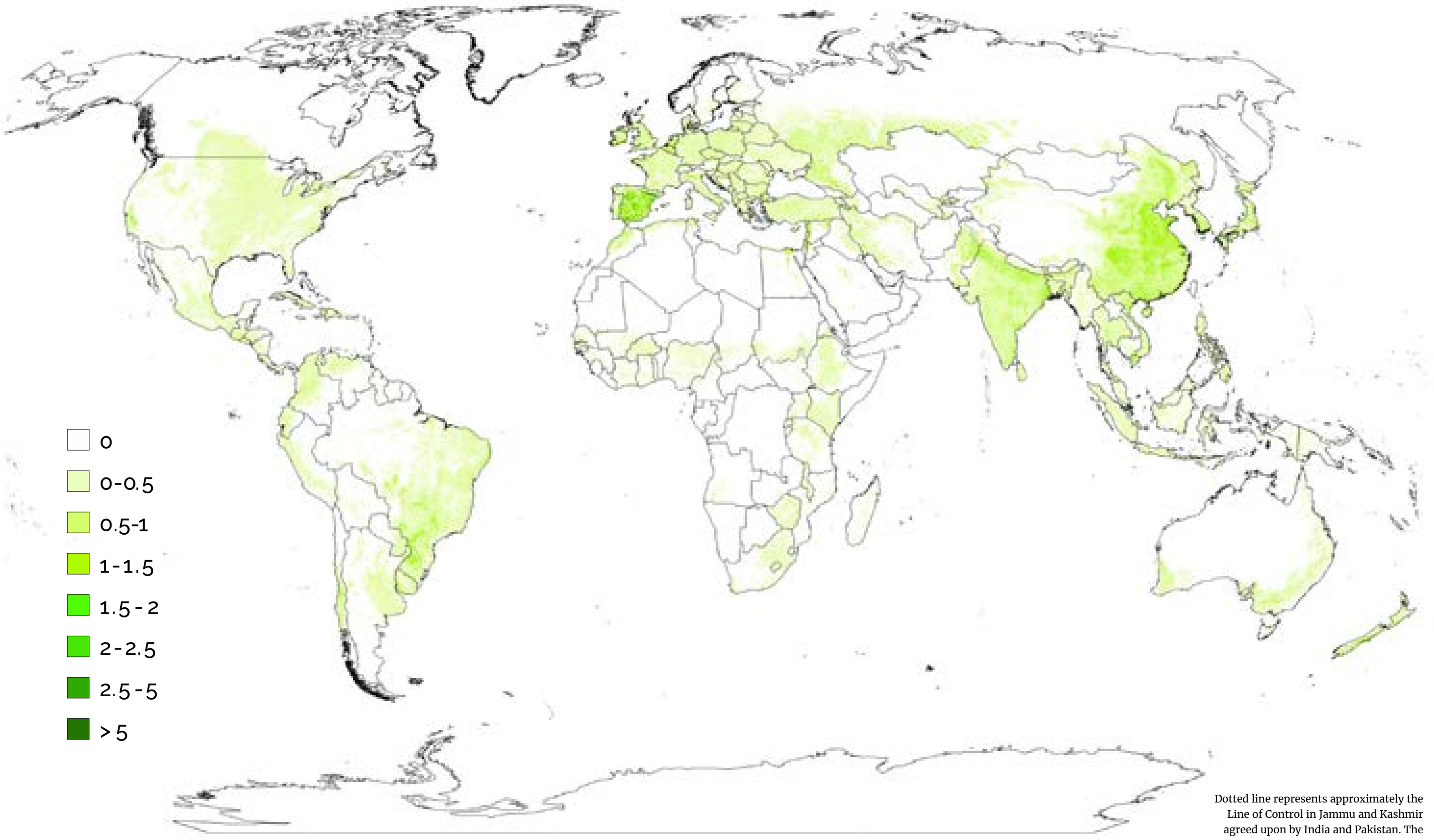
Source: **World Bank Group.** 2019. *Quality unknown: The invisible water crisis*, R. Damania, S. Desbureaux, A.-S. Rodella, J. Russ & E. Zaveri, eds. Washington, DC. https://openknowledge.worldbank.org/bitstream/handle/10986/32245/9781464814594.pdf?sequence=8&isAllowed=y. Modified **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420 can cause freshwater eutrophication (FAO and IWMI, 2018). Estimates indicate that the total phosphorus input to water bodies from anthropogenic sources is about 1.5 million tonnes annually, with 62 percent from point sources (domestic and industrial) and 38 percent from diffuse sources (agriculture) (Mekonnen and Hoekstra, 2018). There has also been a significant increase in the annual atmospheric deposition of nitrogen since the 1900s, from 1.9 Tg of nitrogen in 1900 to 3.8 Tg of nitrogen in 2000, of which 63 percent was deposited on agricultural land (Sutton *et al.*, 2011).

Agricultural use of potash rose from 22 million tonnes in 2000 to a peak of almost 39 million tonnes in 2018. The impact on freshwater eutrophication is not marked, as it is for nitrogen and phosphorus, although it contributes to runoff salinity.

The global trend in the intensification of agricultural production is also testing the capacity of the receiving freshwater to dilute pollutants, some of which are highly persistent and resistant to breakdown. The global distribution of the water pollution threat from human activities including nitrogen loading, phosphorus loading, mercury deposition, pesticide loading, organic loading, salinization, acidification and sediment loading has been summarized by Sadoff *et al.* (2015). Of particular concern

MAP 1.23

ANNUAL ANTHROPOGENIC PHOSPHORUS INPUTS INTO FRESHWATER SYSTEMS FROM AGRICULTURE, INDUSTRIAL AND DOMESTIC SECTORS, 2002–2010 (kg P/ha)



Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

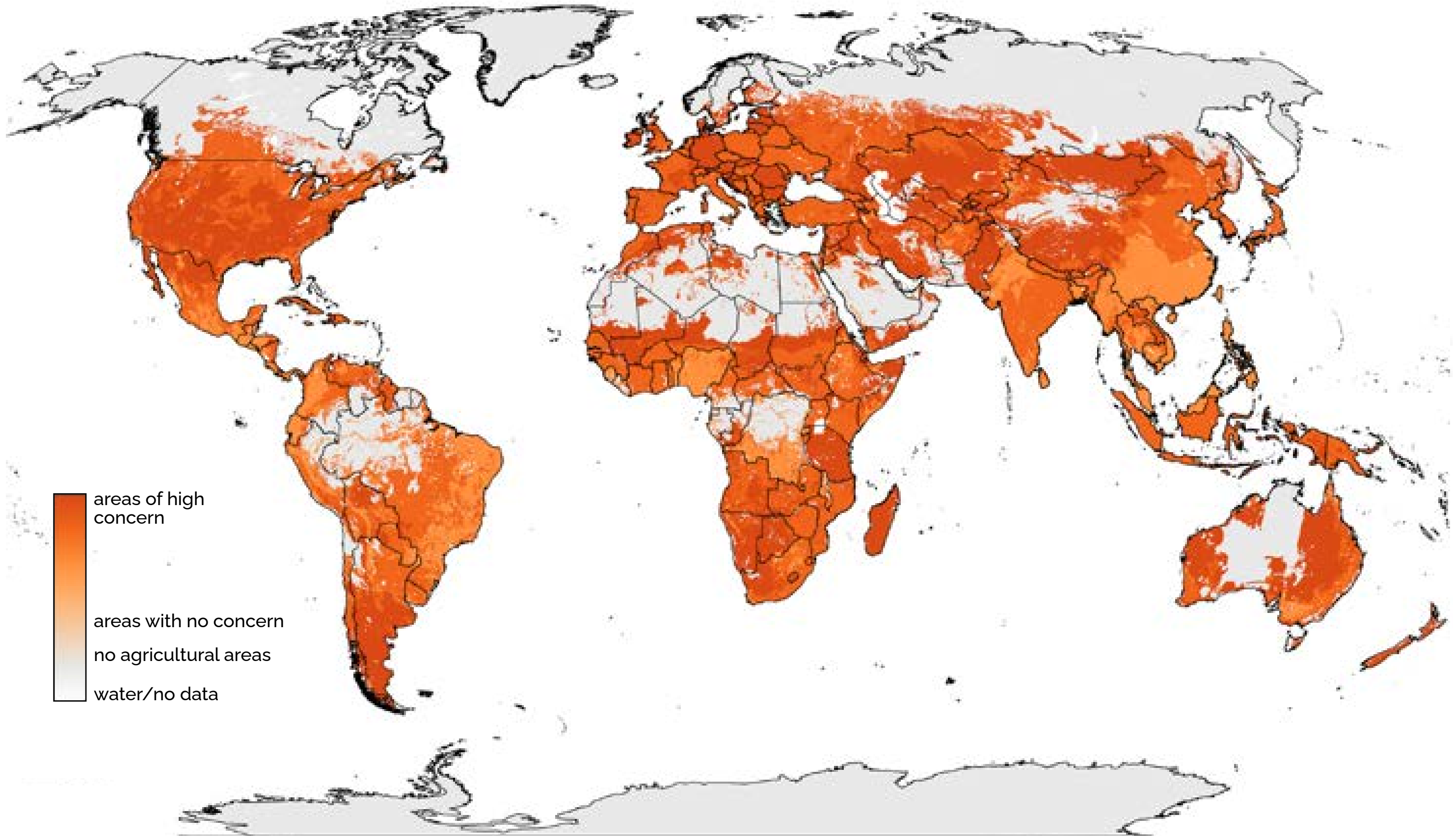
Source: **Mekonnen, M.M. & Hoekstra, A.Y.** 2018. Global anthropogenic phosphorus loads to freshwater and associated grey water footprints and water pollution levels: A high-resolution global study. *Water Resources Research*, 54(1): 345–358. Modified **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420 is pollution caused by emerging chemical contaminants, including pesticides, livestock pharmaceuticals and plastics, for which there is currently little regulation or monitoring. Recent compilation of gridded data for active ingredients (Maggi *et al.*, 2019) has allowed the accumulation of active ingredients in pesticides to be mapped at the global level (Tang *et al.*, 2021) (Map 1.24).

The use of wastewater for irrigation, if not well managed, also has the potential of causing health issues and environmental degradation and groundwater pollution. Large areas of irrigated fields rely on the same surface water sources of urban areas without wastewater treatment capacity. A study using GIS-based modelling found that 65 percent (35.9 million ha) of downstream irrigated croplands is located in catchments with high levels of dependence on urban wastewater flows. Of these croplands, 29.3 million ha is located in countries with low levels of wastewater treatment exposing 885 million urban residents to health risks (Thebo *et al.*, 2017).

1.7.7 Environmental continuity at breaking point

The global environment outlook report (UNEP, 2019) and the United Nations System of Environmental Economic Accounting

MAP 1.24 GLOBAL REGIONS OF CONCERN (GLOBAL AREAS SUSCEPTIBLE TO PESTICIDE POLLUTION), 2010



Sources: **Tang, F.H.M., Lenzen, M., McBratney, A. & Maggi, F.** 2021. Risk of pesticide pollution at the global scale. *Nature Geoscience*, 14(4): 206–210; data from **Tang, F.H.M., Lenzen, M., McBratney, A. & Maggi, F.** 2021. Global pesticide pollution risk data sets. In: *figshare*. https://figshare.com/articles/dataset/Global_pesticide_pollution_risk_data_sets/10302218/1
Modified **UN.** 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

Final status of the Abyei area is not yet determined

(SEEA, 2022) for natural resource accounting confirm trends in the loss of environmental services and biodiversity as natural landscapes are lost to cultivated land. Freshwater withdrawals and drainage from agricultural land (including irrigation return flows) place the most significant sectoral pressure on river basin water balances (FAO and IWMI, 2018). As this plays out in specific river basins, the hydraulic continuity of downstream wetlands and associated ecosystem services is compromised. The patterns of surface water flows and aquifer recharge have been disrupted to such an extent that some basin freshwater systems are now considered "closed" (Molle and Wester, 2009).

Estimates suggest only 37 percent of rivers longer than 1 000 km remain free-flowing over their entire length, and only 23 percent flow uninterrupted to oceans (Grill *et al.*, 2019). For all other river reaches with modified magnitude, frequency and flow duration can expect to adversely affect suites of aquatic habitats and ecosystem processes. The disruption to reservoir storage and flow diversion for agricultural purposes, as opposed to hydropower, cooling water and municipal uses, can be assessed only at individual catchment or basin levels. The International Commission on Large Dams database of registered large dams confirms almost 50 percent of large dams (13 580 dams) are dedicated to irrigation and 24 percent (6 278 dams) of multipurpose dams have irrigation functions.

Estimates suggest that the decline of groundwater level (piezometric head) (de Graaf *et al.*, 2019) need only to be less than 1.0 m before a prescriptive limit of daily flow alterations of not more than 10 percent is reached in many aquifers servicing irrigated areas. Flow disruption of more than 10 percent is presumed to remove a high level of ecological protection (Gleeson and Richter, 2018). The presumptive standard proposed by Gleeson and Richter (2018) is that a high level of ecological protection is provided when daily streamflow alterations are no greater than 10 percent.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Estimates suggest the world has lost 70 percent of natural wetlands over the past century, including significant losses of freshwater species (Gardner *et al.*, 2015), and decline in food security and nutrition (e.g. Turyahabwe *et al.*, 2013). Of the 29 500 freshwater-dependent species so far assessed for the International Union for Conservation of Nature (IUCN) Red List, 27 percent are under threat of extinction (Lausche, 2019; Tickner *et al.*, 2020a).

The impact of agricultural practices on freshwater ecosystems has long been recognized at all scales from the Azraq oasis in eastern Jordan to the Aral Sea in Central Asia. In practice, the impacts on water quantity and water quality can be hard to untangle and attribute definitively, as each downstream impact may have multiple causes. Nonetheless, the conversion of wetlands to rice paddy is expected to have made a significant contribution to the 40 percent decline in inland and coastal wetlands between 1970 and 2008 (Leadley *et al.*, 2014), with the overall decline in natural wetlands noted in a Ramsar Convention on Wetlands briefing note (Gardner *et al.*, 2015). The impact of irrigation technology has also been highlighted

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with respect to maintaining desired environmental flows (Linstead, 2018), but attributing in-stream flow volumes and timing to specific water-conservation measures is restricted to specific basins.

The term "environmental flows" is now commonly used to refer to a flow regime designed to maintain a river or stream in some agreed ecological condition (IRF, 2007). Recent reviews of environmental flow concepts, methods and tools are available (Acreman, 2016; Poff, Tharme and Arthington, 2017; World Bank Group, 2018). The desired environmental flows have been established at the country level for compiling SDG indicator 6.4.2 on water stress (Sood *et al.*, 2017). However, comprehensive analysis of environmental flow implementation and its impact across representative scales and types of river basins still requires more research (Tickner *et al.*, 2020b).

1.8 Conclusions

This chapter has established the global state of land, soil and water resources and trends in their use, in response to the pressures and drivers as demands change and increase. Most of the additional growth in agricultural production since SOLAW 2011 has been derived from intensification, particularly on prime agricultural land combined with irrigation. By contrast, rainfed systems in the tropics and mountain regions have exhibited slower increases in productivity but have proved more vulnerable to food insecurity and poverty. Many uses of land and water systems are continuing to impose negative impacts on ecosystem services.

World food demand is expected to increase by 50 percent over the next 30 years, with the greatest needs in developing countries. While it is expected that production will respond to rising demand, this will not be the only measure of success. The environmental sustainability of the main land and water systems and their capacity to satisfy the livelihood requirements of urban and rural populations will be essential criteria.

Trade-offs between production and the environment should be important for policymakers. Such trade-off decisions will require sound data and information to fully understand the consequences of socioeconomic outcomes and environmental impacts. Decisions taken will need to include ways of reducing the risks and their impacts to avoid further degrading natural resources while maintaining food security and poverty targets.

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In focus: Fragile mountain agriculture

Mountains[5] host important upland ecosystems that support the livelihoods of an estimated 1.1 billion people. They are often referred to as the "water towers" of the world for their role in generating high volumes of orographic rainfall and also providing over-year storage of freshwater in glaciers and snowpacks. Their steep environmental gradients and climatic conditions are hosts to unique ecosystems comprising a wide range of biomes. As the impacts of climate change take hold, the sensitivity of their hydrology and related biomes has become apparent as they experience glacier retreat and higher rates of erosion, compromising the capacity of downstream reservoirs.

Mountain agriculture is linked to water availability. In the Andes, the mountains provide water to over 75 million people in the region and a further 20 million people downstream. Most of the water is used for agriculture, but also for hydropower and other industries. During dry periods, about 800 000 people depend on glacial water for 25 percent of their water needs (Alfthan *et al.*, 2018).

Glacier and snowpack meltwater baseflows are increasing, yet these are essential during the dry season for agriculture and other human needs (Biemans *et al.*, 2019). Water availability for 1.9 billion people living in or directly downstream of mountainous areas is vulnerable to climatic and socioeconomic changes (Immerzeel, Lutz and Andrade, 2019).

Mountain agriculture is characterized by small and fragmented plots of land with low carbon footprints and time-consuming and labour-intensive cultivation. Agricultural practices aid ecosystem conservation and restoration, and it is essential to protect soils against avalanches and floods. Farming is predominantly carried out by families and is based on relatively high agrobiodiversity, producing nutritious and diversified foods. In comparison to plain regions, mountains contain more diversity: altitude changes and varied landscapes have created a multitude of ecological zones, with highly genetically variable agricultural crops and farm animals (FAO, 2019g).

Mountain communities are preserving many of the rarest crop varieties, and have developed valuable traditional knowledge and techniques in crop cultivation, livestock production and water harvesting that help to sustain entire ecosystems. Terracing is widely practised; if properly planned and maintained, it helps to stabilize the land, reduces soil erosion and prevents nutrients from being washed away.

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[5] For a definition of mountains, see Mountain Partnership (2015).

Upland soils are poorly developed, skeletal, shallow, acidic and relatively infertile (FAO, 2015). As elevation increases, soils become shallower and less fertile because of soil erosion and low temperatures that limit biological activities. They are often degraded due to nutrient leaching and water and wind erosion in exposed areas. As a result, mountain soils are often less productive than lowland soils. Globally, 45 percent of the world's mountain areas are either unsuitable or marginally suitable for growing crops, raising livestock or forestry (FAO, 2015). In cold mountain areas, freeze–thaw cycles reduce the aggregation of soils and consequently affect their stability, fertility and water retention.

Production systems

Under the mountain environment, a range of farming systems have developed to cope with variations in climate, slope and elevation, which could be classified into five systems (see the box).

Arable crops and permanent fruit crops are usually grown at low altitudes, while permanent grassland and animal grazing are more common at higher altitudes. For example, pastoral livestock production continues in the Tibetan steppe above 4 000 m (Sheehy, Miller and Johnson, 2006). In the Indian Garhwal region, more than 40 crops are cultivated between 300 m and 3 000 m above sea level (FAO, 2015).

FIVE MOUNTAIN PRODUCTION SYSTEMS

Pastoral livestock production systems: These are grazing-based production systems whereby livestock are fed on natural vegetation and rangelands that include grasses, legumes, shrubs and other vegetation to provide forage throughout the year. Excessive grazing may cause degradation of rangelands, soil erosion and loss of biodiversity. Rangeland degradation is increasing; it is crucial to halt and reverse this process globally.

Agropastoral livestock production systems: These are integrated crop–livestock–rangeland production systems that include: different types of livestock; natural pastures and various field crops such as barley, forage crops, shrubs and trees; and by-products of field crops, contributing to food security and nutrition in the mountain area. These integrated systems involve a socioeconomic and policy environment in addition to a market component that incorporates different factors to ensure an efficient and productive integrated livestock–rangeland–crop production system.

Rainfed agriculture production systems, including fruit trees: In tropical and non-tropical areas, rainfed agriculture occurs in areas that receive more than 400 mm of rain during the rainy season. Worldwide, rainfed agriculture is often used as a conservation agriculture approach, meaning minimum soil disturbance or zero tillage, stubble retention and crop rotation. Conserving soil moisture and reducing soil erosion in rainfed agriculture production systems is crucial to ensure the sustainability of soil productivity, soil conservation and water conservation.

Irrigated agriculture production systems, including fruit trees: Irrigated agriculture systems are practised in arid and semi-arid mountain areas, where annual rainfall is less than 350 mm. The sources of irrigation water are deep artesian wells, surface water from rivers or harvested rainwater in macro and micro water catchments and dams. Farmers using irrigated mountain agriculture production systems tend to diversify production to ensure food security with high-value crops including vegetables, fruit trees and ornamentals.

Forestry or agroforestry production systems: These are important sources of livelihoods in mountain areas and provide essential environmental goods and services, such as timber, fuelwood, carbon storage and other products that improve the lives of people living in mountain communities.

Source: **FAO**. 2019. Forests: Nature-based solutions for water. *UNASYLVA*, 70(251).

Mountain agriculture in Brazil, Afghanistan and Armenia


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Soil degradation

Mountain soils are intrinsically vulnerable and sensitive to degradation processes such as water erosion and chemical and physical quality loss (FAO, 2015).

Soil erosion is common, and a destructive consequence of development. In Nepal, degraded red-soil sites are responsible for 40 percent of the sediment load in rivers and for clogging irrigation canals and local streams, thus increasing flood events (FAO, 2015). Agriculture is just one of many development activities that accelerate soil erosion; road building, trail use, excavation, extractive activities and construction also contribute (Harden, 2001).

Terracing is a frequently used means of reducing erosion. The method has been used for many centuries across the world (Moreno-de-las-Heras *et al.,* 2019). However, the most efficient approach is to maintain soil cover. Annual erosion rates of less than 1 tonne/ha were recorded for rice crops compared to over 80 tonnes/ha for cassava or bare soil terraces. Intermediate annual values, between 10 tonnes/ha and 40 tonnes/ha, were found on terraces with weeds, ginger or mixed rainfed cropping (Arnáez *et al.,* 2015).

In some mountain areas, mostly in marginal areas with difficult access, cultivated terraces are being abandoned due to socioeconomic and technological changes. Although they are no longer being maintained and are losing their soil-conservation function, they are being colonized by vegetation, effectively controlling erosion.

Mountain systems, generally characterized by lower temperatures and higher precipitation than other landscapes, have higher SOC stocks compared to lower-altitude systems (FAO, 2019h). Mountain soils with permafrost contain approximately 66 Pg of SOC, which is 4.5 percent of the global pool. High-elevation and high-latitude soils are experiencing warmer air temperatures and permafrost and a thickening of the active layer (Bockheim and Munroe, 2014), and are highly endangered by climate change.

References

Acreman, M. 2016. Environmental flows—basics for novices. *Wiley Interdisciplinary Reviews: Water, 3(5): 622–628.*

Alfthan, B., Gjerdi, H., Puikkonen, L., Andresen, M., Semernya, L., Schoolmeester, T. & Jurek, M. 2018. *Mountain adaptation outlook series: Synthesis report.* Nairobi and Vienna, United Nations Environment Programme and Arendal, Norway, GRID-Arendal. www.grida.no/publications/426

Alhumaid, N. 2020. *KSA water report: Building a better food and water balance.* Food & Agribusiness Report. Farrelly & Mitchell.

Arnáez, J., Lana-Renault, N., Lasanta, T., Ruiz-Flaño, P. & Castroviejo, J. 2015. Effects of farming terraces on hydrological and geomorphological processes. A review. *CATENA, 128: 122–134.*

Barger, N., Gardner, T. & Mahesh, S. 2018. *Chapter 3: Direct and indirect drivers of land degradation and restoration. In: A. Montanarella, L. Scholes & R. Brainich, eds.* The IPBES assessment report on land degradation and restoration. Bonn, Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Science. https://ipbes.net/assessment-reports/ldr

Biemans, H., Siderius, C., Lutz, A.F., Nepal, S., Ahmad, B., Hassan, T., von Bloh, W. *et al.* 2019. Importance of snow and glacier meltwater for agriculture on the Indo-Gangetic Plain. *Nature Sustainability,* 2(7): 594–601.

Bockheim, J. & Munroe, J. *2014. Organic carbon pools and genesis of alpine soils with permafrost: A review. Arctic, Antarctic, and Alpine Research, 46(4): 987–1006.*

Boots, B., Russell, C.W. & Green, D.S. *2019. Effects of microplastics in soil ecosystems: Above and below ground. Environmental Science and Technology, 53(19): 11496–11506.*

Borrelli, P., Robinson, D.A., Fleischer, L.R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K. *et al.* *2017. An assessment of the global impact of 21st century land use change on soil erosion. Nature Communications, 8(2013).*

Borrelli, P., Robinson, D.A., Panagos, P., Lugato, E., Yang, J.E., Alewell, C., Wuepper, D., Montanarella, L. & Ballabio, C. *2020. Land use and climate change impacts on global soil erosion by water (2015-2070). Proceedings of the National Academy of Sciences of the United States of America, 117(36): 21994–22001.*

Cherlet, M., Hutchinson, C., Reynolds, J., Hill, J., Sommer, S. & von Maltitz, G. *2018. World atlas of desertification. Luxembourg, Publications Office of the European Union.* https://publications.jrc.ec.europa.eu/repository/handle/JRC111155

Ciais, P., Sabine, C., Bala, G., Bop, L., Brovkin, V., Canadell, J., Chhabra, A. *et al.* *2013. Carbon and other biogeochemical cycles. In: T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex & P.M. Midgley, eds. Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK, Cambridge University Press.* www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter06_FINAL.pdf

Coppus, R. *2022. Global distribution of land degradation. Thematic Background Report for SOLAW 2021. Rome, FAO.* www.fao.org/land-water/solaw2021/en

Crump, J. *2017. Smoke on water: Countering global threats from peatland loss and degradation. Nairobi, United Nations Environment Programme, and Arendal, Norway, GRID-Arendal.*

Daliakopoulos, I.N., Tsanis, I.K., Koutroulis, A., Kourgialas, N.N., Varouchakis, A.E., Karatzas, G.P. & Ritsema, C.J. *2016. The threat of soil salinity: A European scale review. Science of the Total Environment, 573: 727–739.*

Dalin, C., Wada, Y., Kastner, T. & Puma, M.J. *2017. Groundwater depletion embedded in international food trade. Nature, 543(7647): 700–704.*

Damania, R. Desbureaux, S., Rodella., A., Russ J. & Zaveri E. *2019. Quality unknown: The invisible water crisis. Washington, DC, World Bank.* https://elibrary.worldbank.org/doi/abs/10.1596/978-1-4648-1459-4

de Graaf, I.E.M., Gleeson, T., (Rens) van Beek, L.P.H., Sutanudjaja, E.H. & Bierkens, M.F.P. *2019. Environmental flow limits to global groundwater pumping. Nature, 574(7776): 90–94.*

Department of Primary Industries and Regional Development, Government of Western Australia*. 2021. Dryland salinity in Western Australia. In: Agriculture and Food. South Perth. Cited 9 February 2022.* www.agric.wa.gov.au/soil-salinity/dryland-salinity-western-australia-0

Döll, P., Schmied, H.M., Schuh, C., Portmann, F.T. & Eicker, A. *2014. Global-scale assessment of groundwater depletion and related groundwater abstractions: Combining hydrological modeling with information from well observations and GRACE satellites. Water Resources Research, 50(7): 5698–5720.*

EC (European Commission)*. 2013. Nitrogen pollution and the European environment: Implications for air quality policy. Science for Environment Policy Series. Brussels.* https://ec.europa.eu/environment/integration/research/newsalert/pdf/IR6_en.pdf

EC*. 2020. Global surface water explorer. In: EC.* https://global-surface-water.appspot.com/#data

EC*. 2021. Index of /ftp/jrc-opendata/GSWE.* https://jeodpp.jrc.ec.europa.eu/ftp/jrc-opendata/GSWE/

EEA (European Environment Agency)*. 2019. The European environment — state and outlook 2020: Knowledge for transition to a sustainable Europe. Luxembourg, Publications Office of the European Union.* https://doi.org/10.2800/96749

Eke, J., Yusuf, A., Giwa, A. & Sodiq, A. *2020. The global status of desalination: An assessment of current desalination technologies, plants and capacity. Desalination, 495: 114633.*

El-Bahi, S.M., Sroor, A., Mohamed, G.Y. & El-Gendy, N.S. *2017. Radiological impact of natural radioactivity in Egyptian phosphate rocks, phosphogypsum and phosphate fertilizers. Applied Radiation and Isotopes, 123: 121–127.*

Famiglietti, J.S. *2014. The global groundwater crisis. Nature Climate Change, 4: 945–948.*

FAO. *2011. The state of the world's land and water resources for food and agriculture: Managing systems at risk. Rome, FAO and London, Earthscan.* www.fao.org/3/i1688e/i1688e.pdf

FAO. *2013a. Tackling climate change through livestock: A global assessment of emissions and mitigation opportunities. Rome.* www.fao.org/3/i3437e/i3437e.pdf

FAO. *2013b. Land degradation assessment in drylands. Rome.* www.fao.org/3/a-i3241e.pdf

FAO. *2015. Understanding mountain soils: A contribution from mountain areas to the International Year of Soils 2015. Rome.* www.fao.org/3/a-i4704e.pdf

FAO. *2016. Drought characteristics and management in the Caribbean. FAO Water Reports 42. https://reliefweb.int/sites/reliefweb.int/files/resources/Drought%20characteristics%20and%20mgmt%20in%20the%20Caribbean.pdf.*

FAO. *2017a. The future of food and agriculture: Trends and challenges. Rome.* www.fao.org/3/a-i6583e.pdf

FAO. *2017b. Drought characteristics and management in Central Asia and Turkey. FAO Water Reporst 44. Rome.* www.fao.org/3/a-i6738e.pdf

FAO. *2018a. The future of food and agriculture: Alternative pathways to 2050. Summary version. Rome.* www.fao.org/3/CA1553EN/ca1553en.pdf

FAO. *2018b. World livestock: Transforming the livestock sector through the Sustainable Development Goals. Rome.* https://doi.org/10.4060/ca1201en

FAO. *2018c. Drought characteristics and management in North Africa and the Near East. FAO Water Report 45. Rome. www.fao.org/3/CA0034EN/ca0034en.pdf*

FAO. *2019a. Water use in livestock production systems and supply chains: Guidelines for assessment (Version 1). Rome.* www.fao.org/3/ca5685en/CA5685EN.pdf

FAO. *2019b. The state of the world's biodiversity for food and agriculture, J. Bélanger & D. Pilling, eds. Rome, FAO Commission on Genetic Resources for Food and Agriculture Assessments.* www.fao.org/3/CA3129EN/CA3129EN.pdf

FAO. *2019c. Measuring and modelling soil carbon stocks and stock changes in livestock production systems: Guidelines for assessment (Version 1). Rome.* www.fao.org/3/ca2934en/ca2934en.pdf

FAO. *2019d. Soil erosion: The greatest challenge for sustainable soil management. Rome.* www.fao.org/3/ca4395en/ca4395en.pdf

FAO. *2019e. Fertilizers archive. Consumption of total fertilizers between 1961 and 2002. In: FAOSTAT. Rome.* www.fao.org/faostat/en/#data/RA

FAO. *2019f. Pesticides use. Total pesticides use in agriculture from 2000 to 2017. In: FAOSTAT. Rome.* www.fao.org/faostat/en/#data/RP

FAO. *2019g. Mountain agriculture: Opportunities for harnessing zero hunger in Asia. Bangkok.* www.fao.org/3/ca5561en/CA5561EN.pdf

FAO. *2019h. GLOSIS - GSOCmap (v1.5.0). Global soil organic carbon map. Contributing countries. In: FAO. Rome.* http://54.229.242.119/GSOCmap/

FAO. *2020a. FAOSTAT. In: FAO. Rome.* www.fao.org/faostat/en/#data/QC

FAO. *2020b. Global forest resources assessment 2020: Key findings. Rome.* https://doi.org/10.4060/ca8753en

FAO. *2020c. The state of the world's forests 2020: Forests, biodiversity and people. Rome.* https://doi.org/10.4060/ca8642en

FAO. *2020d. The state of world fisheries and aquaculture: Sustainability in action. Rome.* https://doi.org/10.4060/ca9229en

FAO. *2020e. Peatland mapping and monitoring: Recommendations and technical overview. Rome.* https://doi.org/10.4060/ca8200en

FAO. *2020f. The state of food and agriculture 2020. Overcoming water challenges in agriculture. Rome.* https://doi.org/10.4060/cb1447en

FAO. *2021a. The share of agri-food systems in total greenhouse gas emissions: Global, regional and country trends 1990–2019. FAOSTAT Analytical Brief Series No. 31. Rome.* www.fao.org/3/cb7514en/cb7514en.pdf

FAO. *2021b. AQUASTAT – FAO's Global Information System on Water and Agriculture. In: FAO. Rome.* www.fao.org/aquastat/en

FAO. *2022a. WaPOR, remote sensing for water productivity. In: FAO. Rome. Cited 9 February 2022.* www.fao.org/in-action/remote-sensing-for-water-productivity/en

FAO. *2022b. International Network of Salt-affected Soils. In: Global Soil Partnership. Rome.* www.fao.org/global-soil-partnership/insas

FAO & IIASA (International Institute for Applied Systems Analysis). *2021. Global agro-ecological zones v4.0 – Model documentation. Rome.* www.fao.org/nr/gaez/publications/en

FAO & ITPS (Intergovernmental Technical Panel on Soils). *2015. Status of the world's soil resources: Main report. Rome.* www.fao.org/3/i5199e/i5199e.pdf

FAO & IWMI (International Water Management Institute). *2018. More people, more food, worse water? A global review of water pollution from agriculture, J. Mateo-Sagasta, S. Marjani & H. Turral, eds. Rome.* www.fao.org/3/ca0146en/ca0146en.pdf

FAO & UNEP (United Nations Environment Programme). *2021. Global assessment of soil pollution: Report. Rome.* https://doi.org/10.4060/cb4894en

FAO & UN-Water. *2021. Progress on level of water stress: Global status and acceleration needs for SDG indicator 6.4.2. Rome.* https://doi.org/10.4060/cb6241en

FAO, Intergovernmental Technical Panel on Soils, Global Soil Biodiversity Initiative, Convention on Biological Diversity & European Commission. *2020. State of knowledge of soil biodiversity: Status, challenges and potentialities. Report 2020. Rome, FAO.* https://doi.org/10.4060/cb1928en

FAO, International Fund for Agricultural Development, United Nations Children's Fund, World Food Programme & World Health Organization. *2018. The state of food security and nutrition in the world 2018. Building climate resilience for food security and nutrition. Rome.* www.fao.org/3/i9553en/i9553en.pdf

FAO, International Fund for Agricultural Development, United Nations Children's Fund, World Food Programme & World Health Organization. *2021. The state of food security and nutrition in the world 2021. Transforming food systems for food security, improved nutrition and affordable healthy diets for all. Rome, FAO.* https://doi.org/10.4060/cb4474en

Fischer, G. & van Velthuizen, H. *2018. Climate change impacts on suitability of main crops in the DECCMA study areas in Ghana and in South Asia. Deltaic environments, vulnerability and climate change: The role of mitigation as an adaptation and its policy implications (DECCMA). GCP/GLO/546/USH. Laxenbourg, Austria.*

Fischer, T., Byerlee, D. & Edmeades, G. *2014. Crop yields and global food security. Monograph No. 158. Canberra, Australian Centre for International Agricultural Research.*

Fisher, J., Montanarella, L. & Scholes, R. *2018. Chapter 1: Benefits to people from avoiding land degradation and restoring degraded land. In: L. Montanarella, R. Scholes & A. Brainich, eds. The IPBES assessment report on land degradation and restoration. Bonn, Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.* https://ipbes.net/assessment-reports/ldr

Fuglie K., Jellife J. & Morgan, S. *2021. Slowing productivity reduces growth in global agricultural output. In: Amber Waves. 28 December 2021. United States Department of Agriculture Economic Research Service.* www.ers.usda.gov/amber-waves/2021/december/slowing-productivity-reduces-growth-in-global-agricultural-output

Fuglie, K., Gautam, M., Goyal, A. & Maloney, W.F. *2020. Harvesting prosperity: Technology and productivity growth in agriculture. Washington, DC, International Bank for Reconstruction and Development / The World Bank.* https://openknowledge.worldbank.org/bitstream/handle/10986/32350/9781464813931.pdf?sequence=6&isAllowed=y

Funge-Smith, S.J. *2018. Review of the state of world fishery resources: Inland fisheries. FAO Fisheries and Aquaculture Circular No. 942, Rev. 3. Rome, FAO.* www.fao.org/3/ca0388en/CA0388EN.pdf

Galloway, J.N., Townsend, A.R., Erisman, J.W., Bekunda, M., Cai, Z., Freney, J.R., Martinelli, L.A., Seitzinger, S.P. & Sutton, M.A. *2008. Transformation of the nitrogen cycle: Recent trends, questions, and potential solutions. Science, 320(5878): 889–892.*

Gao, H., Yan, C., Liu, Q., Ding, W., Chen, B. & Li, Z. *2019. Effects of plastic mulching and plastic residue on agricultural production: A meta-analysis. Science of the Total Environment, 651: 484–492.*

Gardi, C., Angelini, M., Barceló, S., Comerma, J., Cruz Gaistardo, C., Encina Rojas, A., Jones, A. *et al.* *2014. Atlas de suelos de América Latina y el Caribe. Luxembourg.*

Gardner, R.C., Barchiesi, S., Beltrame, C., Finlayson, C.M., Galewski, T., Harrison, I., Paganini, M. et al. *2015. State of the world's wetlands and their services to people: A compilation of recent analyses. Ramsar Briefing Note No. 7. Gland, Ramsar Convention on Wetlands Secretariat.* https://doi.org/10.2139/ssrn.2589447

GDW (Global Dam Watch). *2022. Global Reservoir and Dam Database (GRanD). In: GDW.* https://globaldamwatch.org/grand

Gleeson, T. & Richter, B. *2018. How much groundwater can we pump and protect environmental flows through time? Presumptive standards for conjunctive management of aquifers and rivers. River Research and Applications, 34(1): 83–92.*

Grill, G., Lehner, B., Thieme, M., Geenen, B., Tickner, D., Antonelli, F., Babu, S. *et al*. *2019. Mapping the world's free-flowing rivers. Nature, 569(7755): 215–221.*

Haacker, E.M.K., Kendall, A.D. & Hyndman, D.W. *2016. Water level declines in the high plains aquifer: Predevelopment to resource senescence. Groundwater, 54(2): 231–242.*

Harden, C.P. *2001. Soil erosion and sustainable mountain development: Experiments, observations and recommendations from the Ecuadorian Andes. Mountain Research and Development, 21(1): 77–83.*

Hatfield-Dodds, S., Hughes, N., Cameron, A., Miller, M. & Jackson, T. *2018. Analysis of 2018 drought: 26 October 2018. ABARES Insights 2. Canberra, Australian Bureau of Agricultural and Resource Economics and Sciences.* https://doi.org/10.25814/5bceb32574707

Hoogeveen, J., Faurès, J.M., Peiser, L., Burke, J. & Van De Giesen, N. *2015. GlobWat – A global water balance model to assess water use in irrigated agriculture. Hydrology and Earth System Sciences, 19(9): 3829–3844.*

IDA (International Desalination Association). *2021. The IDA – Desalination & reuse handbook 2021-2022. Oxford.* www.globalwaterintel.com/products-and-services/market-research-reports/ida-desalination-reuse-handbook

Immerzeel, W., Lutz, A. & Andrade, M. *2019. Importance and vulnerability of the world's water towers. Nature, 577: 364–369.*

IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services). *2018. The IPBES assessment report on land degradation and restoration, L. Montanarella, R. Scholes & A. Brainich, eds. Bonn.* https://ipbes.net/assessment-reports/ld

IPCC (Intergovernmental Panel on Climate Change). *2019. Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Geneva.* www.ipcc.ch/srccl

IPCC. *2021. Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud et al., eds. Cambridge, UK, Cambridge University Press.* www.ipcc.ch/report/ar6/wg1/#TS

IPCC. *2022. Climate change 2022: Mitigation of climate change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, Set al., eds. Cambridge, UK and New York, USA. Cambridge University Press.*

IRF (International River Foundation). *2007. The Brisbane Declaration. Conference presentation at 10th International River symposium and International Environmental Flows Conference.* http://riverfoundation.org.au/wp-content/uploads/2017/02/THE-BRISBANE-DECLARATION.pdf

IWA (International Water Association). *2016. Desalination – past present and future. In: IWA. London.* https://iwa-network.org/desalination-past-present-future

Kapetsky, J., Aguilar-Manjarrez, J. & Jenness, J., *eds. 2013. A global assessment of offshore mariculture potential from a spatial perspective. Rome, FAO.* www.fao.org/3/i3100e/i3100e.pdf

Kondolf, G.M., Gao, Y., Annandale, G.W., Morris, G.L., Jiang, E., Zhang, J., Cao, Y. *et al.* *2014. Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents. Earth's Future, 2(5): 256–280.*

Konikow, L.F. *2013. Groundwater depletion in the United States (1900–2008). United States Geological Survey Scientific Investigations Report 2013–5079.* https://pubs.usgs.gov/sir/2013/5079/SIR2013-5079.pdf

Lal, R., Smith, P., Jungkunst, H., Mitsch, W., Lehmann, J., Nair, P.K., McBratney, A. *et al.* *2018. The carbon sequestration potential of terrestrial ecosystems. Journal of Soil and Water Conservation, 73(6): 145A–152A.*

Lambers, H. *2003. Introduction: Dryland salinity: A key environmental issue in Southern Australia. Plant and Soil, 257: 5–7.*

Lausche, B. *2019. Integrated planning: Policy and law tools for biodiversity conservation and climate change. Bonn, International Union for Conservation of Nature.* https://doi.org/10.2305/IUCN.CH.2019.EPLP.88.en

Leadley, P., Krug, C., Alkemade, R., Pereira, H., Sumaila, U.R., Walpole, M., Marques, A. *et al.* *2014. Progress towards the AICHI biodiversity targets: An assessment of biodiversity trends, policy scenarios and key actions. Technical Series No. 78. Montreal, Canada, Secretariat of the Convention on Biological Diversity.* www.cbd.int/doc/publications/cbd-ts-78-en.pdf

Leifeld, J. & Menichetti, L. *2018. The underappreciated potential of peatlands in global climate change mitigation strategies. Nature Communications, 9(1).*

Linstead, C. *2018. The contribution of improvements in irrigation efficiency to environmental flows. Frontiers in Environmental Science, 6: 1–6.*

Lowder, S.K., Sánchez, M. V & Bertini, R. *2019. Farms, family farms, farmland distribution and farm labour: What do we know today? FAO Agricultural Development Economics. Rome, FAO.* www.fao.org/3/ca7036en/ca7036en.pdf

Lowder, S.K., Sánchez, M. V. & Bertini, R. *2021. Which farms feed the world and has farmland become more concentrated? World Development, 142: 105455.*

Lwanga, E.H., Vega, J.M., Quej, V.K., de los Angeles Chi, J., del Cid, L.S., Chi, C., Segura, G.E. ***et al.*** *2017. Field evidence for transfer of plastic debris along a terrestrial food chain. Scientific Reports, 7(1).*

Lytton, L., Ali, A., Garthwaite, B., Punthakey, J.F. & Basharat, S. *2021. Groundwater in Pakistan's Indus basin: Present and future prospects. Water Global Practice. International Bank for Reconstruction and Development / The World Bank.* https://openknowledge.worldbank.org/handle/10986/35065

Maggi, F., Tang, F.H.M., la Cecilia, D. & McBratney, A. *2019. PEST-CHEMGRIDS, global gridded maps of the top 20 crop-specific pesticide application rates from 2015 to 2025. Scientific Data, 6(1): 1–20.*

Margat, J. & van der Gun, J. *2013. Groundwater around the world: A geographic SYNOPSIS. Boca Raton, USA, Taylor & Francis Group.* www.un-igrac.org/sites/default/files/resources/files/Groundwater__around__world.pdf

Mekonnen, M.M. & Hoekstra, A.Y. *2012. A global assessment of the water footprint of farm animal products. Ecosystems, 15(3): 401–415.*

Mekonnen, M.M. & Hoekstra, A.Y. *2018. Global anthropogenic phosphorus loads to freshwater and associated grey water footprints and water pollution levels: A high-resolution global study. Water Resources Research, 54(1): 345–358.*

Middleton, N. & Kang, U. *2017. Sand and dust storms: Impact mitigation. Sustainability, 9(6): 1053.*

Molle, F. & Wester, P., eds. *2009. River basin trajectories: Societies, environments and development. Comprehensive Assessment of Water Management in Agriculture Series. Wallingford, UK, CAB International.* www.iwmi.cgiar.org/Publications/CABI__Publications/CA__CABI__Series/River__Basin__Trajectories/9781845935382.pdf

Moreno-de-las-Heras, M., Lindenberger, F., Latron, J., Lana-Renault, N., Llorens, P., Arnáez, J., Romero-Díaz, A. & Gallart, F. *2019. Hydro-geomorphological consequences of the abandonment of agricultural terraces in the Mediterranean region: Key controlling factors and landscape stability patterns. Geomorphology, 333: 73–91.*

Mountain Partnership. *2015. Mountains. In: Definitions. Rome.* www.fao.org/mountain-partnership/about/definitions/en

MoWR RD (Ministry of Water Resources, River Development) & GR (Ganja Rejuvenation). *2017. Report of 5th Census of Minor Irrigation Schemes, pp. 120–159.*

Mu, H., Otani, S., Shinoda, M., Yokoyama, Y., Onishi, K., Hosoda, T., Okamoto, M. & Kurozawa, Y. *2013. Long-term effects of livestock loss caused by dust storm on Mongolian inhabitants: A survey 1 year after the dust storm. Yonago Acta Medica, 56(1): 39–42.*

NASA (National Aeronautics and Space Administration). *2011. Heavy rains and dry lands don't mix: Reflections on the 2010 Pakistan flood. In: Earth Observatory.* https://earthobservatory.nasa.gov/features/PakistanFloods

OECD (Organisation for Economic Co-operation and Development) & FAO. *2021. OECD-FAO agricultural outlook 2021-2030. Paris, OECD Publishing.* https://doi.org/10.1787/19428846-en

Ortiz-Bobea, A., Ault, T.R., Carrillo, C.M., Chambers, R.G. & Lobell, D.B. *2021. Anthropogenic climate change has slowed global agricultural productivity growth. Nature Climate Change, 11(4): 306–312.*

Parish, R., Sirin, F., Charman, A., Joosten, D., Minayeva, H., Silvius, T. & Stringer, M. *2008. Assessment on peatlands, biodiversity and climate change: Main report. Kuala Lumpur, Global Environment Centre and Wageningen, Wetlands International.* www.imcg.net/media/download_gallery/books/assessment_peatland.pdf

Pekel, J.F., Cottam, A., Gorelick, N. & Belward, A.S. *2016. High-resolution mapping of global surface water and its long-term changes. Nature, 540(7633): 418–422.*

Pimentel, D. & Burgess, M. *2013. Soil erosion threatens food production. Agriculture, 3(3): 443–463.*

Poff, N.L.R., Tharme, R.E. & Arthington, A.H. *2017. Evolution of environmental flows assessment science, principles, and methodologies. In: Water for the environment: From policy and science to implementation and management, pp. 203–236.* https://doi.org/10.1016/B978-0-12-803907-6.00011-5

Qadir, M., Quillérou, E., Nangia, V., Murtaza, G., Singh, M., Thomas, R.J., Drechsel, P. & Noble, A.D. *2014. Economics of salt-induced land degradation and restoration. Natural Resources Forum, 38(4): 282–295.*

Qin, Y., Mueller, N.D., Siebert, S., Jackson, R.B., AghaKouchak, A., Zimmerman, J.B., Tong, D., Hong, C. & Davis, S.J. *2019. Flexibility and intensity of global water use. Nature Sustainability, 2(6): 515–523.*

Radatz, A., Lowery, B., Bland, W. & Hartemink, A. *2012. Groundwater recharge under compacted agricultural soils, pine and prairie in central Wisconsin, USA. Agrociencia Uruguay Special issue, 16(3): 235–240.*

Rodell, M., Famiglietti, J.S., Wiese, D.N., Reager, J.T., Beaudoing, H.K., Landerer, F.W. & Lo, M.H. *2018. Emerging trends in global freshwater availability. Nature, 557(7707): 651–659.*

Rodriguez-Eugenio, N.R., McLaughlin, M.J. & Pennock, D.J. *2018. Soil pollution: A hidden reality. Rome, FAO.* www.fao.org/3/i9183en/I9183EN.pdf

Sadoff, C., Hall, J., Grey, D., Aerts, J.C.J., Ait-Kadi, M., Brown, C., Cox, A. *et al.* *2015. Securing water, sustaining growth. Report of the GWP/OECD Task Force on Water Security and Sustainable Growth. Oxford, UK, University of Oxford.* www.gwp.org/globalassets/global/about-gwp/publications/the-global-dialogue/securing-water-sustaining-growth.pdf

Schneider, C., Flörke, M., De Stefano, L. & Petersen-Perlman, J.D. *2017. Hydrological threats to riparian wetlands of international importance – A global quantitative and qualitative analysis. Hydrology and Earth System Sciences, 21(6): 2799–2815.*

Searchinger, T., Waite, R., Hanson, C., Ranganathan, J. & Dumas, P. *2019. Creating a sustainable food future: A menu of solutions to feed nearly 10 billion people by 2050. Washington, DC, World Resources Institute.* https://research.wri.org/sites/default/files/2019-07/WRR_Food_Full_Report_0.pdf

SEEA (System of Environmental Economic Accounting)*. 2022. What is the SEEA? In: SEEA. New York. Cited 9 February 2022.* https://seea.un.org

Shah, T. *2009. Taming the anarchy: Groundwater governance in South Asia. Washington, DC, Resources for the Future.*

Sheehy, D., Miller, D. & Johnson, D. *2006. Transformation of traditional pastoral livestock systems on the Tibetan steppe. Sécheresse, 17(1–2): 142–151.*

Siebert, S. & Döll, P. *2007. Irrigation water use – A global perspective. In: J.L. Lozán, H. Graßl, P. Hupfer, L. Menzel & C. Schönwiese, eds. Global change: Enough water for all?, pp. 104–107. University of Hamburg/GEO.*

Siebert, S., Burke, J., Faures, J.M., Frenken, K., Hoogeveen, J., Döll, P. & Portmann, F.T. *2010. Groundwater use for irrigation – A global inventory. Hydrology and Earth System Sciences, 14(10): 1863–1880.*

Soane, B. & Van Ouwerkerk, C. *2013. Soil compaction in crop production. Amsterdam, Elsevier.*

Sood, A., Smakhtin, V., Eriyagama, N., Villholth, K., Liyanage, N., Wada, Y., Ebrahim, G. & Dickens, C. *2017. Global environmental flow information for the Sustainable Development Goals. Colombo, IWMI.*

Stevens, C.J., David, T.I. & Storkey, J. *2018. Atmospheric nitrogen deposition in terrestrial ecosystems: Its impact on plant communities and consequences across trophic levels. Functional Ecology, 32(7): 1757–1769.*

Sumarga, E., Hein, L., Hooijer, A. & Vernimmen, R. *2016. Hydrological and economic effects of oil palm cultivation in Indonesian peatlands. Ecology and Society, 21(2): 52.*

Sutton, M.A., Billen, G., Bleeker, A., Erisman, J.W., Grennfelt, P., van Grinsven, H., Grizzetti, B., Howard, C.M. & Leip, A. *2011. Technical summary. The European Nitrogen Assessment, pp. xxxv–lii. Cambridge, UK, Cambridge University Press.* https://doi.org/10.1017/CBO9780511976988.003

Tan, Z.X., Lal, R. & Wiebe, K.D. *2005. Global soil nutrient depletion and yield reduction. Journal of Sustainable Agriculture, 26(1): 123–146.*

Tandon, H. *1992. Assessment of soil nutrient depletion. FADINAP seminar: Fertilization and the environment. Thailand, Chiang Mai.*

Tang, F.H.M., Lenzen, M., McBratney, A. & Maggi, F. *2021. Risk of pesticide pollution at the global scale. Nature Geoscience, 14(4): 206–210.*

Tellman, B., Sullivan, J.A., Kuhn, C., Kettner, A.J., Doyle, C.S., Brakenridge, G.R., Erickson, T.A. & Slayback, D.A. *2021. Satellite imaging reveals increased proportion of population exposed to floods. Nature, 596: 80–86.*

Tennigkeit, T. & Wilkes, A. *2008. An assessment of the potential for carbon finance in rangelands. ICRAF Working Paper No 68. Beijing.* http://apps.worldagroforestry.org/downloads/Publications/PDFS/WP15892.pdf

TerraBrasilis. *2022. Amazon forest cover. In: TerraBrasilis. Cited 9 February 2022.* http://terrabrasilis.dpi.inpe.br/app/dashboard/deforestation/biomes/legal_amazon/rates

Tessler, Z.D., Vörösmarty, C.J., Overeem, I. & Syvitski, J.P.M. *2018. A model of water and sediment balance as determinants of relative sea level rise in contemporary and future deltas. Geomorphology, 305: 209–220.*

Thebo, A.L., Drechsel, P., Lambin, E.F. & Nelson, K.L. *2017. A global, spatially-explicit assessment of irrigated croplands influenced by urban wastewater flows. Environmental Research Letters, 12(7): 074008.*

Tickner, D., Opperman, J.J., Abell, R., Acreman, M., Arthington, A.H., Bunn, S.E., Cooke, S.J. ***et al.*** *2020a. Bending the curve of global freshwater biodiversity loss: An emergency recovery plan. BioScience, 70(4): 330–342.*

Tickner, D., Kaushal, N., Speed, R. & Tharme, R. *2020b. Editorial: Implementing environmental flows: Lessons for policy and practice. Frontiers in Environmental Science, 8(August): 1–3.*

Tubiello, F., Salvatore, M., Cóndor Golec, R., Ferrara, A., Rossi, S., Biancalani, R., Federici, S., Jacobs, H. & Flammini, A. *2014. Agriculture, forestry and other land-use emissions by sources and removals by sinks 1990-2011 analysis. FAO Statistics Division Working Paper Series ESS/14-02. Rome, FAO.* www.fao.org/3/i3671e/i3671e.pdf

Turyahabwe, N., Kakuru, W., Tweheyo, M. & Tumusiime, D.M. *2013. Contribution of wetland resources to household food security in Uganda. Agriculture & Food Security, 2: 5.*

Turetsky, M.R. *2019. Permafrost collapse is accelerating carbon release. Nature, 569: 32–34.*

Turetsky, M.R., Benscoter, B., Page, S., Rein, G., van der Werf, G.R. & Watts, A. *2015. Global vulnerability of peatlands to fire and carbon loss. Nature Geoscience, 8(1): 11–14.*

UNCCD (United Nations Convention to Combat Desertification). *2017. Global land outlook. Bonn.* https://knowledge.unccd.int/glo/GLO_first_edition

UNCCD. *2022. Sand and dust storms. In: UNCCD. Bonn.* www.unccd.int/actions/sand-and-dust-storms

UNDRR (United Nations Office for Disaster Risk Reduction). *2021. GAR special report on drought 2021. Geneva.* www.undrr.org/publication/gar-special-report-drought-2021

UNEMG (United Nations Environment Management Group). *2022. UN coalition to combat sand and dust storms. In: UNEMG. Geneva.* https://unemg.org/our-work/emerging-issues/sand-and-dust-storms

UNEP (United Nations Environment Programme). *2019. Global environment outlook: GEO-6: Healthy planet, healthy people. Nairobi.* www.unep.org/resources/global-environment-outlook-6

USDA (United States Department of Agriculture) National Agricultural Statistics Service. *2019. 2017 census of agriculture. 2018 irrigation and water management survey. Volume 3, Special Studies, Part 1.* www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Farm_and_Ranch_Irrigation_Survey/fris.pdf

USGS (United States Geological Survey). *2018. Estimated use of water in the United States in 2015. Circular 1441, Water Availability and Use Science Program. Virginia.* https://pubs.usgs.gov/circ/1441/circ1441.pdf

Vanham, D., Hoekstra, A.Y., Wada, Y., Bouraoui, F., de Roo, A., Mekonnen, M.M., van de Bund, W.J. et al. *2018. Physical water scarcity metrics for monitoring progress towards SDG target 6.4: An evaluation of indicator 6.4.2 "Level of water stress". Science of the Total Environment, 613–614 (February): 218–232.*

Verheijen, F.G.A., Jones, R.J.A., Rickson, R.J. & Smith, C.J. *2009. Tolerable versus actual soil erosion rates in Europe. Earth-Science Reviews, 94(1–4): 23–38.*

Vishwakarma, B.D., Bates, P., Sneeuw, N., Westaway, R.M. & Bamber, J.L. *2021. Re-assessing global water storage trends from GRACE time series. Environmental Research Letters, 16(3).*

von Braum, J., Afsana, K., Fresco, L.O. & Hassan, M., eds. *2021. Science and Innovation for Food Systems Transformation and Summit Actions. Papers by the Scientific Group and its partners in support of the UN Food Systems Summit. Science Group of the UNFSS. https://sc-fss2021.org/wp-content/uploads/2021/07/Scientific-Group-Strategic-Paper-Science-for-Transformation-of-Food-Systems_August-2.pdf*

Wada, Y., Van Beek, L.P.H. & Bierkens, M.F.P. *2012. Non-sustainable groundwater sustaining irrigation: A global assessment. Water Resources Research, 48(6).*

Welcomme, R.L., Baird, I.G., Dudgeon, D., Halls, A., Lamberts, D. & Mustafa, M.G. *2016. Fisheries of the rivers of Southeast Asia. Freshwater Fisheries Ecology (December 2017): 363–376.*

WMO (World Meteorological Organization). *2022a. Sand and dust storms. In: WMO. Geneva.* https://public.wmo.int/en/our-mandate/focus-areas/environment/SDS

WMO. *2022b. Drought. In: WMO. Geneva.* https://public.wmo.int/en/our-mandate/water/drought

World Bank Group. *2018. Good practice handbook: Environmental flows for hydropower projects – Guidance for the private sector in emerging markets. Washington, DC.* https://doi.org/10.1596/29541

WRI (World Resources Institute). *2022. Aqueduct: Using cutting-edge data to identify and evaluate water risks around the world. In: WRI. Washington, DC.* www.wri.org/aqueduct

Yue, X., Wang, H., Wang, Z. & Fan, K. *2009. Simulation of dust aerosol radiative feedback using the Global Transport Model of Dust: 1. Dust cycle and validation. Journal of Geophysical Research Atmospheres, 114(D10).*

2

SOCIOECONOMIC SETTINGS

Key messages

Demographic growth, economic growth and urbanization are changing patterns in food demand. These changes are placing unprecedented pressures on ecosystems and limited renewable land, soil and water resources. Higher incomes and urban lifestyles are changing food demand towards more resource-intensive consumption of animal proteins, fruits and vegetables. The world's population is expected to grow from 7.7 billion in 2019 to 9.7 billion in 2050 (26 percent). The fastest growth will be in the poorest countries, such as those in sub-Saharan Africa, where the population is expected to double by 2050.

Globally, 80 percent of the extreme poor live in rural areas, mostly in the developing world, and 64 percent of the extreme poor are employed in agriculture. It is key to increasing food security, reducing poverty and achieving multiple SDGs, but is highly exposed to current and future climate risks.

Uncontrolled urbanization threatens sustainable resources management. By 2050, two out of three people will be living in towns and cities, with most urban growth occurring in the less-developed regions of Africa and Asia. Urban dwellers consume 80 percent of all food produced globally. "Industrial" foods dominate and bring alarming health consequences – the triple burden of malnutrition comprising undernutrition, overweight and obesity – and micronutrient deficiencies.

Increasing population reduces the natural resources available per capita. In sub-Saharan Africa, which has the fastest demographic growth, water availability per capita declined by 40 percent over the past two decades, and agricultural land declined from 0.80 ha/capita to 0.64 ha/capita between 2000 and 2017.

Increasing concentration of farmland among larger farms as economies grow brings increasing inequality in agriculture. All types of farms and the entire value chain, from producers to consumers, need to consider ways of transforming food systems to address SDGs.

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Ensuring equitable access to land and water resources is key for promoting inclusive rural transformation. The lack of adequate access and user rights and increasing disparities in capacities to take advantage of natural capital are underlying drivers of overuse of resources to meet short-term needs.

Social, agricultural and environmental policies can be mutually reinforcing in order to reconcile competition over land and water. Opportunities to change or modify national policies exist, supported by United Nations Decades that focus on ecosystems, water, SDGs and family farming, and which encourage agroecological approaches and harmonized decisions by parties to the multilateral environmental conventions.

2.1 Introduction

Chapter 1 established the challenges of water scarcity, land and soil degradation, and the uncertainties from climate change that reinforce the need to adapt and integrate sectoral policies to ensure wise use of limited resources for people and the environment. The management of land and water resources for agriculture, forestry and other uses is driven as much by socioeconomics and governance as by biophysical and technical factors. Trade-offs between competing social and economic demands and desired environmental outcomes become inevitable in setting a path towards sustainable land and water management.

Land and water are crucial assets for livelihoods and well-being among rural communities and farming households. The multidimensional role of these assets and their sustainable management require different kinds of institutions. Rural communities are the custodians of natural resources. Their local decision-making is affected by decision-making at national, regional and international levels. Such decision-making influences the governance of natural resources in rural settings. Local decision-making is also affected by markets and linkages of rural areas to urban centres, which creates employment but additional pressures on limited resources. The scale of farms, whether smallholdings less than 2 ha in extent or large-scale commercial concerns, determines the type and effectiveness of land and water governance needed.

In 2013, household surveys indicated that 80 percent of the extreme poor living on less than USD 1.90 per day is in rural areas (World Bank, 2016; Castañeda *et al.*, 2018). Most live in low-income food-deficit countries, and their livelihoods are highly dependent on agriculture. The performance of all types of agriculture in such countries is key to reducing poverty and food insecurity and achieving SDGs. However, agriculture is highly exposed to land degradation and water scarcity, in addition to climate risk. Responding to these risks by improving land and water access and management is an essential part of enhancing the resilience of rural livelihoods and sustaining ecosystem services. Access to land, water and associated biological diversity is essential for most rural households, but it is vital for the rural poor.


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This chapter describes the main socioeconomic and governance drivers that affect land and water availability and use. It also discusses the socioeconomic trends that will influence future land and water strategies and planning, and how they are expected to affect the state of land and water resources and their associated farming systems.

2.2 Socioeconomic transitions – implications for land and water management

Population growth, economic growth and urbanization are the principal socioeconomic variables driving demand for land and water resources. In addition, migration of human populations, adoption of new forms of communication and exchange of information are transforming the character of rural economies and the mobility of the rural workforce. At the same time there is continuous adaptation to climate change in all regional and agricultural subsectors. Pressures placed on limited land, soil and renewable water resources are therefore unprecedented. Higher incomes and urban lifestyles are also steering food demand towards more resource-intensive consumption.

2.2.1 Population growth

Demographic growth drives the demand for food and agricultural products, putting unprecedented pressure on renewable but limited water and land resources. Projections suggest the world's population will grow from 7.7 billion in 2019 to 8.5 billion by 2030 (10 percent increase), to 9.7 billion by 2050 (26 percent) and to 10.9 billion by 2100 (42 percent) (United Nations, 2019) (Figure 2.1). The fastest growth is in the poorest regions, including sub-Saharan Africa where the population will double by 2050, thus creating immense challenges to achieving SDGs, in particular, SDG 1 (no poverty), SDG 2 (zero hunger), SDG 6 (clean water and sanitation) and SDG 15 (life on land).

2.2.2 Food insecurity, malnutrition and poverty

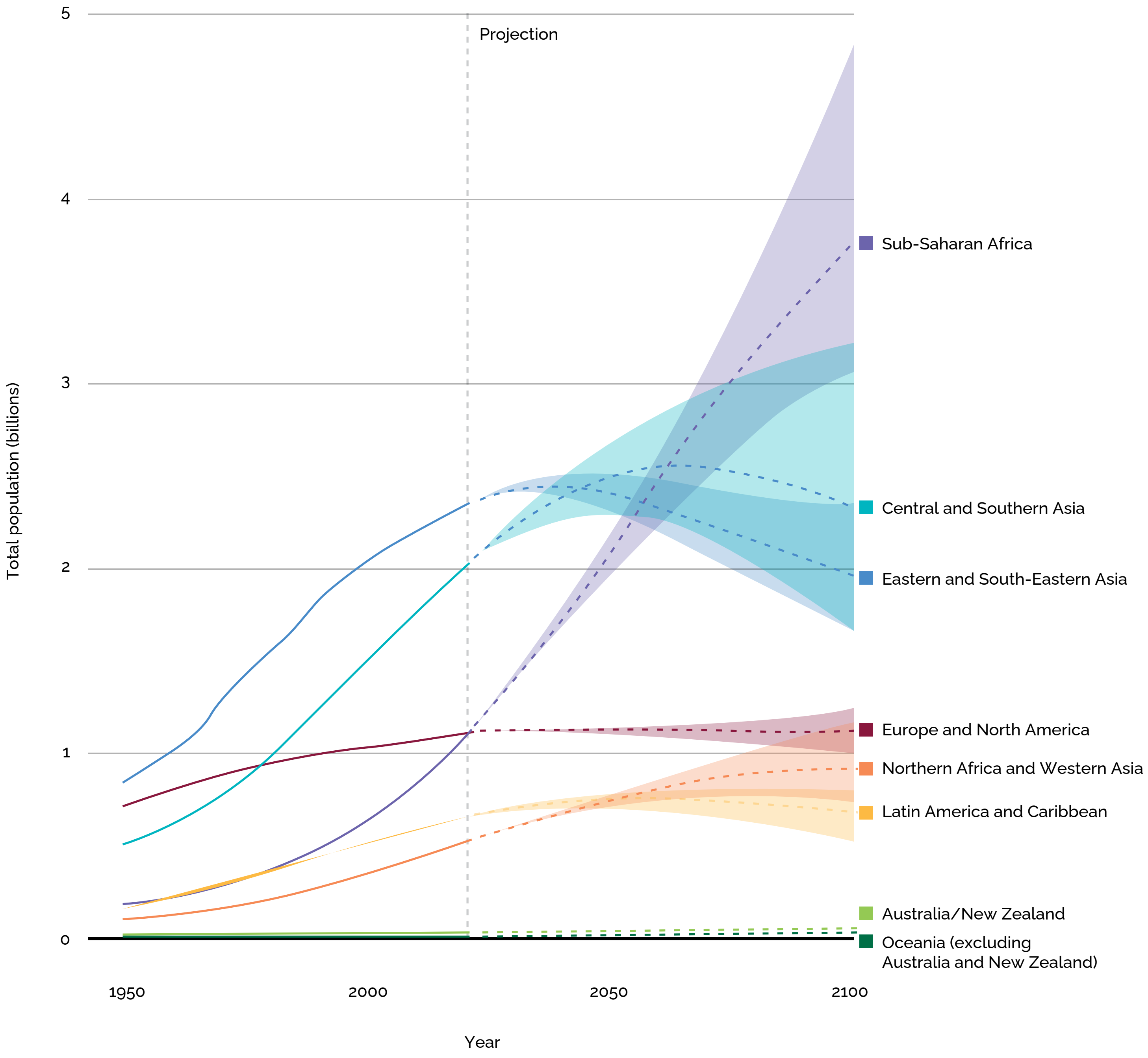
Agricultural production more than trebled between 1960 and 2015 (HLPE, 2017). Diets are changing, and numerous local, national and multinational food-related enterprises have emerged, providing livelihoods for millions. However, global hunger is rising again, and climate change and the effects of the COVID-19 pandemic are making matters worse. According to *The state of food security and nutrition in the world 2021* report (FAO *et al.*, 2021), the world is not on track to eradicate hunger, food insecurity and all forms of malnutrition by 2030. Efforts will need redoubling, given the challenges brought by COVID-19. Between 720 million and 811 million people faced hunger in 2020, about 118 million more than in 2019. More than half were in Asia (418 million) and more than a third were in Africa (282 million). Projections suggest that by 2030 there will be 660 million people undernourished, in part due to the lasting effects of COVID-19 on global food security. The COVID-19 pandemic has therefore exposed the vulnerabilities within poor populations and the global food system as a whole. The World Bank estimates the COVID-19 pandemic pushed an additional 119 million to 124 million people into extreme poverty in 2020 (Lakner *et al.*, 2021).

Climate variability and extreme weather events, such as droughts, floods and extremes of heat, together with territorial conflicts and economic downturns are crucial drivers of food insecurity and malnutrition (FAO *et al.*, 2021) and have highlighted the close relationship with land and water. The number of low- and middle-income countries exposed to climate extremes increased from 76 countries in 2000–2004 to 98 in 2015–2020 (FAO *et al.*, 2021).

Climate extremes can also intensify other drivers of food insecurity, such as conflicts, loss of livelihoods, poverty and increased inequality. According to the World Bank, extreme poverty increased in 2020 for the first time in over 20 years (World Bank, 2020). The poor are predominantly rural, young and undereducated. Half of those in poverty are children and women. In 2018, four out of five people below the international poverty line lived in rural areas, although the rural population accounted for only 48 percent of the global population. Indeed, poverty became more rural between 2015 and 2018, and increased by more than 2 percent (World Bank, 2020). Climate change is expected to drive 68 million to 132 million into poverty by 2030.

FIGURE 2.1

POPULATION BY SUSTAINABLE DEVELOMENT GOAL REGION: ESTIMATES, 1950–2020 AND MEDIUM-VARIANT PROJECTION WITH 95 PERCENT PREDICTION INTERVALS, 2020–2100



Source: **United Nations**. 2019. *World population prospects 2019: Highlights*. ST/ESA/SER.A/423. New York, Department of Economic and Social Affairs, Population Division. https://population.un.org/wpp/Publications/Files/WPP2019_Highlights.pdf

Dry lands often include a disproportionate share of poor people. This is especially the case in Africa, where dry lands are home to 50 percent of the population and account for 43 percent of the region's land surface, of which 75 percent is used for agriculture. In 2010, the World Bank reported that about 171 million people living in African dry lands depended on agriculture, including 26 million pastoralists and 105 million agropastoralists. They were exposed to weather shocks, especially drought, due mainly to the poor performance of the agriculture sector. Moreover, dry lands could expand by 20 percent under some climate scenarios, with population growth bringing even more people into a challenging environment. The negative trends identified in human-induced land degradation raise concerns about the adverse impacts on land productivity, reducing farm incomes and increasing vulnerability and stress (Cervigni *et al.*, 2016).

Political economy factors affecting resilience, especially the uneven distribution of wealth and power, can marginalize many dryland groups. This can skew the distribution of social services for human health and education. Targeted adaptive interventions could help reduce the impact of droughts by about half, keeping 5 million people each year out of danger in some of Africa's poorest zones (Cervigni *et al.*, 2016).

In June 2021, the World Bank reported that COVID-19 plunged sub-Saharan Africa into its first recession in over 25 years (with activity contracting by nearly 5 percent on a per capita basis, exacerbating high public debt). This disproportionately affects vulnerable groups, such as the poor, informal sector workers, women and youth, thus reducing opportunities and access to social safety nets. Up to 40 million people could be pushed into extreme poverty, erasing at least five years of progress.

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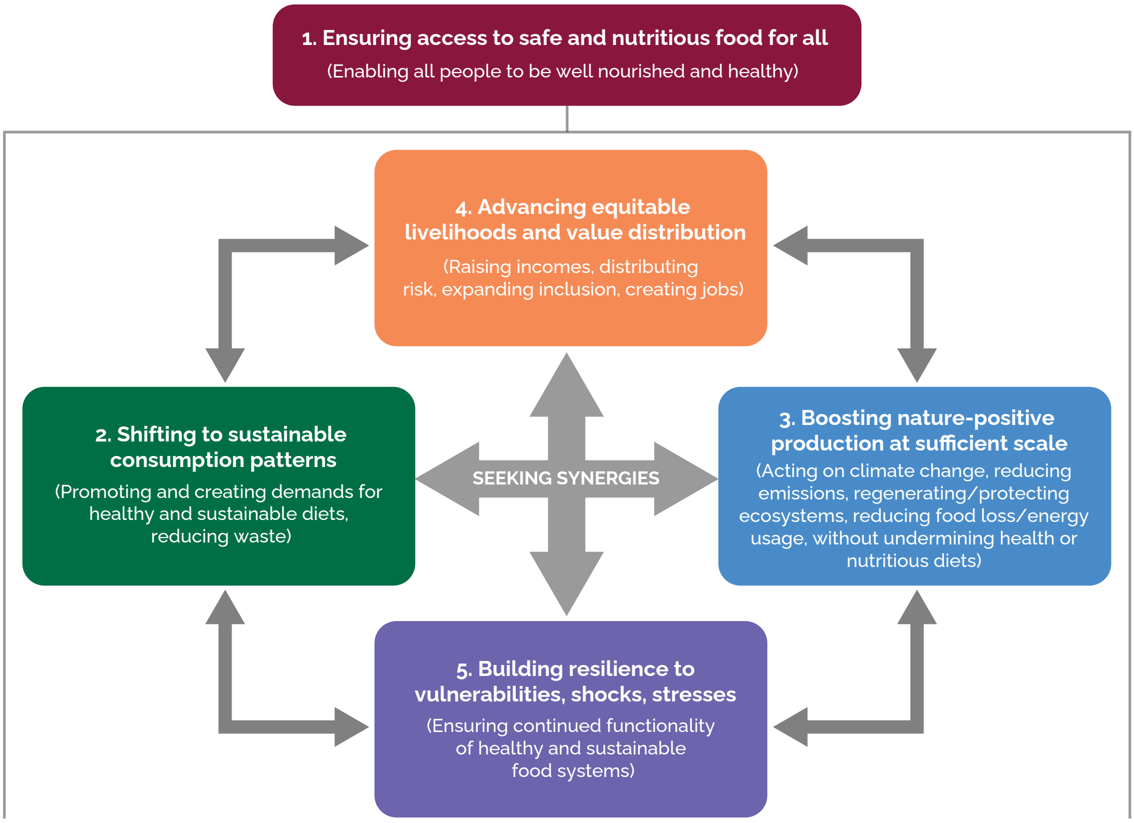
Suggested interventions include policy support and investment to improve natural resources management practices and technologies for pastoral and agropastoral livestock keepers and crop producers in rainfed and irrigated systems. Other options include reducing trade barriers to make food more available and affordable, and strengthening integrated landscape management to reverse degradation trends and enhance ecosystem health and function (Cervigni *et al.*, 2016). Chapter 5 develops these response options in more detail.

The FAO framework on extreme rural poverty recognizes that conservation and restoring natural resources should directly benefit the rural extreme poor, particularly those living in remote marginal areas. This is linked to promoting responsible governance of the tenure of resources. Recognizing the legitimate tenure rights of people to use, manage and control land, water, biodiversity, forests and fisheries is fundamental to helping the rural extreme poor adapt to climate change (FAO, 2019).

As identified in the Action Tracks for the 2021 United Nations Food Systems Summit, "advancing equitable livelihoods and value distribution" and "building resilience to vulnerabilities, shocks and stresses" are essential and interlinked components of shifting to sustainable production and consumption patterns at scale, and ensuring access to safe and nutritious food for all (Figure 2.2).

FIGURE 2.2 ACTION TRACKS IN A FOOD SYSTEM



Source: **von Braun, J., Afsana, K., Fresco, L., Hassan, M. & Torero, M.** 2021. *Food systems – definition, concept and application for the UN Food Systems Summit*. A paper from the Scientific Group of the UN Food Systems Summit. www.un.org/sites/un2.un.org/files/scgroup_food_systems_paper_march-5-2021.pdf

2.2.3 Urbanization and changing consumption patterns

It is estimated that 55 percent of the world's population now lives in urban areas (United Nations, 2018a). By 2050, two out of three people are expected to live in towns and cities, with most growth in the less-developed regions of Africa and Asia. Urban dwellers consume 80 percent of all food produced.

Food demand is expected to increase by 50 percent between 2013 and 2050 (FAO, 2017). The main drivers are population growth, urbanization and rising incomes. Higher incomes and urban lifestyles are changing food demand towards more resource-intensive animal proteins, fruits and vegetables. Animal production relies mainly on rainfed systems (Heinke *et al.*, 2020), while intensive and concentrated industrial production units represent the largest share of resource consumption (HLPE, 2016). The rising consumption of processed foods, particularly meat products, is associated with urbanization. Meat consumption is increasing annually by 1.4 percent globally, and grew by 58 percent over 20 years to 2018, reaching 360 million tonnes. Per capita meat consumption has increased as consumer preferences change, particularly for poultry.

Consumption is growing fast in Africa and the Near East, but China is the world's largest meat consumer. Since 2009, China has turned from a net exporter of corn to a net importer to meet the demand for feed grain.

Managing the rural–urban transition is a significant challenge for large cities and the growing network of small- and medium-sized emerging towns competing for limited land and water resources. It requires paying attention to the types of farms and the types of food supply chains, and providing support through rural–urban public policies that are inclusive in terms of avoiding concentration and large-scale industrial value chains.

Urbanization concentrates food demands and trends; it requires renewed attention to land planning to manage the demand for green spaces and quality water (greener cities) and to bring about a transition to more sustainable patterns of food production and distribution. Addressing spatial and social inequalities will require differentiated policies focusing on strengthening regional and local food systems and changing waste management towards a circular economy (Chapter 5).

In cities, processed foods are part of a broad dietary transition and bring alarming health consequences: the triple burden of malnutrition, comprising undernutrition, overweight and obesity, and micronutrient deficiencies. The spread of small- or medium-sized food distribution stores supplying processed "fast" food with low nutritive value and its spin-off in reduced capacity and interest to cook at home are a new threat to public health. These trends compete with locally produced, good-quality and diversified food that provides rural livelihoods, including income for many women engaged in food crafting. In some countries, small- and medium-sized stores are increasingly spreading industrially processed food in rural areas, thus affecting local markets, diets and health.

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Urban-based farming accounts for a limited land area worldwide, but it involves a significant share of the agricultural population: 3–7 percent. Urban farming remains marginal in terms of overall production, but the COVID-19 crisis has revealed the importance of local systems, close to consumers and based on trust regarding food quality and safety. The linkages with organic agriculture and water waste recycling are assets expected to contribute to sustainable development in the coming decades.

Cities and municipal governance are becoming increasingly important agents of change for sustainable rural development, including policies and actions to improve natural resources sustainability and access to healthy diets (Neufield, Hendriks and Hugas, 2021). The FAO Green Cities Initiative focuses on improving the urban environment, strengthening rural–urban linkages, increasing the availability of green spaces through urban and peri-urban forestry and improving access to healthy diets.

In Africa, urbanization is increasing the population density in small- and medium-sized towns, thus creating conurbations in many subregions, such as the Mediterranean coast, from the Gulf of Guinea coast to the Sahel region, in the East African Highlands and in the Great Lakes region (Chatel, Imbernon and Moriconi-Ebrard, 2016). This brings opportunities for rural family farms by developing local food markets for millions of consumers and developing alternative and complementary income sources as local economies diversify (Mainet and Edouard, 2017; Agergaard *et al.*, 2019). Population growth in Africa calls for renewed land-use policies to enable sustainable agricultural development to boost productivity and diversification and innovative marketing channels to reach consumers and encourage sustainable diets. In restoring 100 million ha of degraded lands, the Great Green Wall for the Sahel and Sahara Initiative (see Chapter 4) includes efforts to promote urban and peri-urban agriculture, to facilitate market development for commodities at national and regional levels and create 10 million "green" jobs in rural areas (Cunningham and Abasse, 2005).

2.2.4 Migration

Seasonal migration for pastoral communities and farm labour has always been part of the evolution and development of agrarian societies. However the acceleration of migration of internally displaced communities and transboundary migration has increased significantly over the past two decades. It has now become a global issue of the twenty-first century and is high on the political agendas of many countries. Estimates indicate that in 2020, the number of international migrants increased to 281 million (3.5 percent of the global population) from 173 million in 2000 (United Nations, 2020). Between 2000 and 2019, the number of refugees increased from 14 million to nearly 26 million, and the number of internally displaced persons increased from 21 million to just over 41 million (IOM, 2019).

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Migration is closely related to the challenges affecting rural communities including food insecurity, limited income-generating activities, and lack of employment and decent working conditions. Rural–urban inequality has also pushed people to migrate to cities to find better jobs and living conditions and to access education, health services and social protection. Migrants have diverse socioeconomic profiles and expectations according to their economic, political and cultural circumstances, which change over time. Migration may be temporary or permanent. Family mobility, including the "walking assets" of herders and pastoralists, is part of a livelihood and way of living.

There is growing evidence that environmental change and disasters aggravated by climate change amplify international and national human movements and displacement (FAO, 2018a). Climate- and water-related disasters were responsible for displacing over 23 million people in 2016. In Somalia, drought is causing increased malnutrition, food insecurity and competition for limited resources, especially among farmers and pastoralists. Some 25 thousand people were displaced because of drought in 2018 (IOM, 2019). The World Bank estimated water shortages were linked to a 10 percent increase in total migration within countries between 1970 and 2000, and adversely affected the skills and educational levels of migrants (World Bank, 2020). Those who leave countries because of drought usually have lower academic grades and skills than other migrant workers, implying lower wages and poorer access to essential services at their destination.

Migrants affect land and water use in rural areas in their homeland, during transit and at their destination. Migration among youth and young men can lead to poor land management as responsibilities are left to female heads of family who face depleted family and community labour. Communities that generate a flow of migrants limit the develop-


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ment or maintenance of water harvesting and improved land management practices. The use of child labour may also increase. Water insecurity is one of the main vulnerabilities suffered by forcibly displaced people and their host communities. However, migration also has positive impacts. Sending remittances home to rural communities enables families to secure their basic social needs and invest in better equipment to reduce drudgery, improve productivity and create better links to markets. Remittances increased from USD 126 billion in 2000 to USD 689 billion in 2018 (IOM, 2019), with about 40 percent going to rural areas (IFAD, 2017).

Migration policies and strategies vary according to their context. Some policies try to reduce the risk of water insecurity in the countries of origin by investing in water storage infrastructure, irrigation, early warning systems and agricultural adaptation. This approach can alleviate economic imperatives to make migration a choice. Other policies focus on promoting the integration of migrants at their destination, promoting growth in cities and incentivizing mobility.

There have been substantial developments in global migration governance in recent years, but there is not yet an overarching framework that provides policy guidance on migration and environmental stressors including climate change. Policy developments include the United Nations Framework Convention on Climate Change (UNFCCC) climate negotiations and the Global Compact for Safe, Orderly and Regular Migration that addresses with varying emphasis the mobility aspects of environmental degradation and climate change (IOM, 2019).

2.2.5 Innovation through digital technologies

Digital technologies are transforming the way land and water resources are managed, making agriculture more resilient, innovative and efficient. They are changing the way farmers work in the field and in the market for agricultural produce. The advent of affordable mobile phones and the expansion of mobile networks have spurred adoption of just-in-time application of field inputs, including machinery, and the operation markets and crop/livestock processing beyond the farm gate. The volume and quality of customizable farming information available to farmers now allows near real-time adjustment of farming practices from large-scale commercial operations to those operating small hectare-level plots for high-value crops. Mobile internet and Global Positioning System services for tractors and harvesters are now standard, giving much more precision to land treatment, including automated laser levelling, fertilizer application and seed drilling.

The Internet of Things, data analytics, cloud computing and blockchain systems offer new capabilities to analyse, manage in real time, predict and minimize risks. Freely available satellite imagery can now reduce the cost of monitoring agricultural activities, including land and water management. For pastoralists, mobile phones and information systems can help to better manage natural resources, such as access to pastures and related water sources, to better manage animal movement/transhumance routes, and to provide information on market prices to get a better value for products (Lawali and Idrissa, 2015). While facilitating trading, information technologies can also increase security by connecting people during emergencies and build social capital among farmer groups.

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However, the adoption of digital technologies and communications faces challenges, including obsolete infrastructure and lack of investment in operation and maintenance. Some 4.5 billion people had internet access in 2020 (ITU, 2022), although there are still significant differences in connectivity, access and broadband speed between the wealthiest countries and the rest of the world, and between urban and rural areas. The "digital divide" or the technological gap between countries and between rural and urban areas can widen the development gap within and among countries. Some 40 percent of the global population remains unconnected, and the latest data indicate women are more likely to be unconnected than men. Addressing this unbalanced distribution and lack of access is critically important in achieving food systems that are more sustainable, resilient and inclusive.

2.2.6 Impacts of climate change in rural communities

Climate change is an important global trend that has key implications for land and water resources. The effects of climate change on land and water resources (Chapter 1) exacerbate the pressures arising from population growth, urbanization and dietary changes. Climate change will increase the risks to livelihoods of rural communities, and to food security and nutrition among rural and urban populations. The rural poor are the most vulnerable and are likely to be disproportionately affected. A recent FAO report suggests disasters happen three times more often today than in the 1970s and 1980s, and agriculture absorbs a disproportionate 63 percent share of their impacts, compared to other sectors such as tourism, commerce and industry (FAO, 2021).

Important impacts of climate change are increasing rainfall variability and water scarcity. Rainfall variability is responsible for an annual net loss of food production equivalent to feeding 81 million people every day. Worsening droughts are projected to affect about 700 million people by the end of this century, and to disproportionately affect developing countries. In addition to affecting agricultural yields, rainfall variability is also responsible for cropland expansion, thus placing much pressure on forested areas (Damania *et al.*, 2017). However, not all the changes are detrimental. In the Sahel, the wetter trend leading to increased intensity of rain events in recent years (Fiondella, 2013) has enhanced natural regeneration of critical tree cover to protect and restore cultivated soils. This process was subsequently scaled out to reverse degradation and desertification trends, and to adapt to climate change.

The projected impacts of climate change are diverse, among and within countries. Policymaking often struggles to integrate farm diversity, especially for family farms (Kansiime, van Asten and Sneyers, 2018). Climate action and the SDGs of the 2030 Agenda for Sustainable Development (2030 Agenda) are closely connected. It will be difficult, if not impossible, to eradicate poverty, end hunger or ensure access to water without building resilience and mitigating the impacts of climate change in smallholder agricultural production systems (Poláková *et al.*, 2013) and even beyond sector policies (Alpha and Fouilleux, 2018) through more integrated strategies.

Policy innovation for climate change and, in particular, dealing with land and water management in agriculture has so far been limited. Many agriculture and land and water planning documents do not yet consider the anticipated effects of climate change; even if they do, there is a lack of commitment, capacity, financing and tools for effective implementation. In many cases, conventional policy instruments have been relabelled as instruments for climate change adaptation, but need additional policy support to scale up adoption and enhance resilience.

From the mid-2000s onwards, under UNFCCC, countries began formulating National Adaptation Plans and nationally determined contributions (NDCs) that include efforts in the agriculture sector to identify medium- and long-term adaptation needs and to develop strategies. By 2020, 125 of the 154 developing countries had undertaken activities related to formulating and implementing National Adaptation Plans, of which 55 were supported by the Green Climate Fund (UNFCCC, 2020). FAO analysis of the intended NDCs in 2016 noted agricultural sectors are still not developed and prioritized enough in NDCs. Nevertheless, agricultural sectors and land and water management will need to and are expected to play a significant role in national responses to climate change. This is particularly important for developing countries where agriculture and natural resources management are critical for rural livelihoods, food security and nutrition (FAO, 2016a). Responses are needed at a national level, strategies need to be implemented at provincial and municipal levels, and plans and actions need to be implemented by farmers and rural communities. This requires intersectoral coordination and support for land and water management and agriculture and food systems.

Many initiatives are guiding climate change adaptation. These include supporting research and innovation, setting up information systems, and fostering and publishing regular reporting processes at different levels. However, implementation requires adjustment to specific contexts. For example, in the livestock sector, policies and instruments are needed to differentiate among diverse farming systems (Robinson *et al.*, 2014) to assess and understand resource consumption and its impact on climate change.

Climate change adaptation needs to include the “farming system dimension” at the territorial level. This also requires a “food system” perspective to consider the impacts of climate change, including the value chain down to the consumers. Understanding the timeline for interventions is crucial to avoid the inherent mismatch between short-term and long-term benefits. For a farmer, the financial and economic horizon is generally short (seasonal) to medium term (one to five years), or longer (up to ten years) if tree crops or large investments are concerned, allowing time to adapt to market fluctuations and climate variability to some extent. However, climate action requires a larger-scale landscape and ecosystems perspective and a longer-term collective adaptation process to cope with forecasted changes over two or more decades and to achieve results in terms of improving food security and reducing malnutrition and poverty. Farmers therefore need greater tenure security and intergenerational planning at the territorial level for sustainable development under climate change.


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2.3 Diminishing per capita water resources availability

The reduction in per capita water resource availability (supply) and its relation to withdrawals (demand) is evaluated at the macro level with the derivation of SDG indicator 6.4.2 on water stress (Chapter 1). Arguably, this is the most salient consequence of economic growth and climate change, and is felt by all types of farming communities as large swathes of productive land are subject to drought and reduced surface water allocations. The reaction of many smallholders and commercial farmers has been to turn to groundwater as a "lender of last resort", which, in turn, has unleashed another set of social and environmental externalities.

2.3.1 Water scarcity as a driver

As population increases, IRWRs per capita are declining (Chapter 1). At a regional level, Southern America has the most water available annually, with 29 357 m³/capita, followed by Oceania with 27 903 m³/capita. In contrast, Northern Africa has only 237 m³/capita and Western Asia 1 379 m³/capita. These are both less than the annual level of 1 700 m³/capita that is considered to reflect "water stress" and which compromises a nation's ability to meet water demand for food and from other sectors. An annual level of 500–1 000 m³/capita denotes "water scarcity" and an annual level less than 500 m³/capita denotes "absolute water stress", with serious impacts for the environment and socioeconomic development (Falkenmark, Lundqvist and Widstrand, 1989).

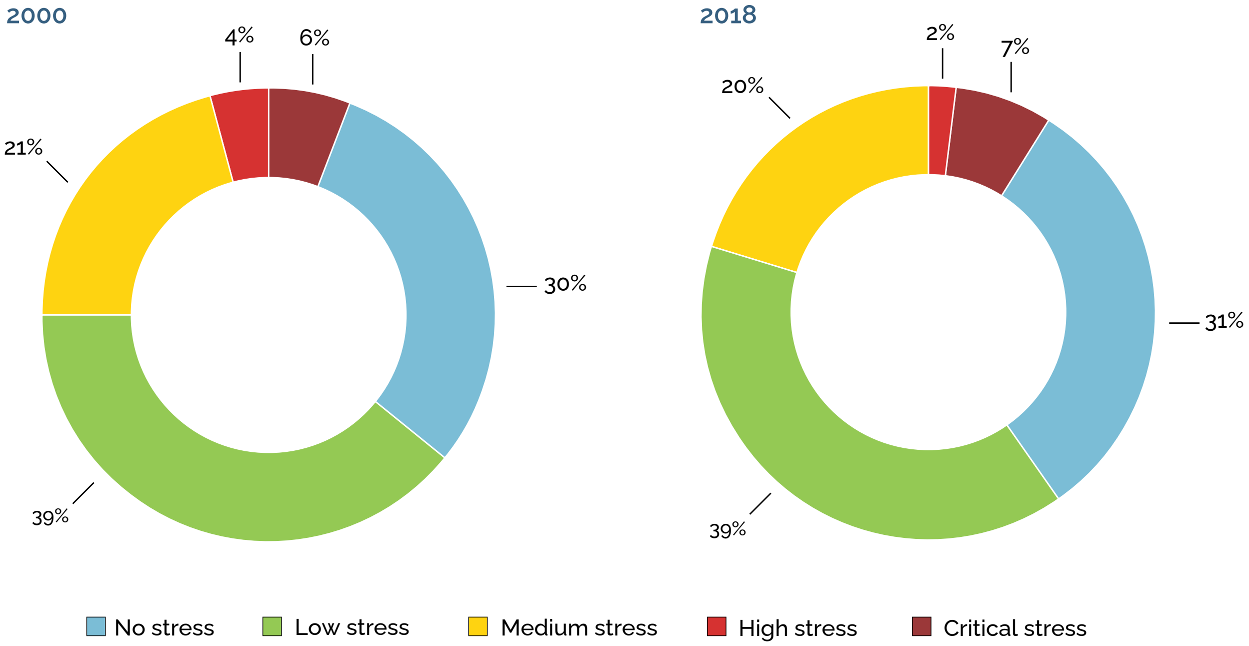
In many countries, surface and groundwater resources may be plentiful but unevenly distributed and difficult to access. The metadata for SDG target 6.4.2 give classes for water stress based on water availability, where low stress is 25–50 percent, medium stress is 50–75 percent, high stress is 75–100 percent and critical stress is >100 percent of freshwater withdrawals relative to total freshwater resources, taking account of environmental flow requirements.

In 2018, Central Asia had significant annual water withdrawals reaching 1 370 m³/capita and Northern America had 1 159 m³/capita. Since 2000, the global population has increased eight times faster than per capita water withdrawals. But, withdrawals per capita have mostly declined as the global population has continued to grow. Since 2000, only Central America and the Caribbean, Southern America and Southeast Asia have seen increases in per capita withdrawals (Chapter 1).

More than 733 million people live in countries with high (70 percent) and critical (100 percent) water stress areas, accounting for almost 10 percent of the global population in 2018. Between 2018 and 2020, the number of people living in areas under critical water scarcity increased from 6 percent to 7 percent, but in high water scarcity areas, numbers have decreased from 4 percent to 2 percent (Figure 2.3). Population density is higher in critical and high water-stressed basins (Figure 2.4).

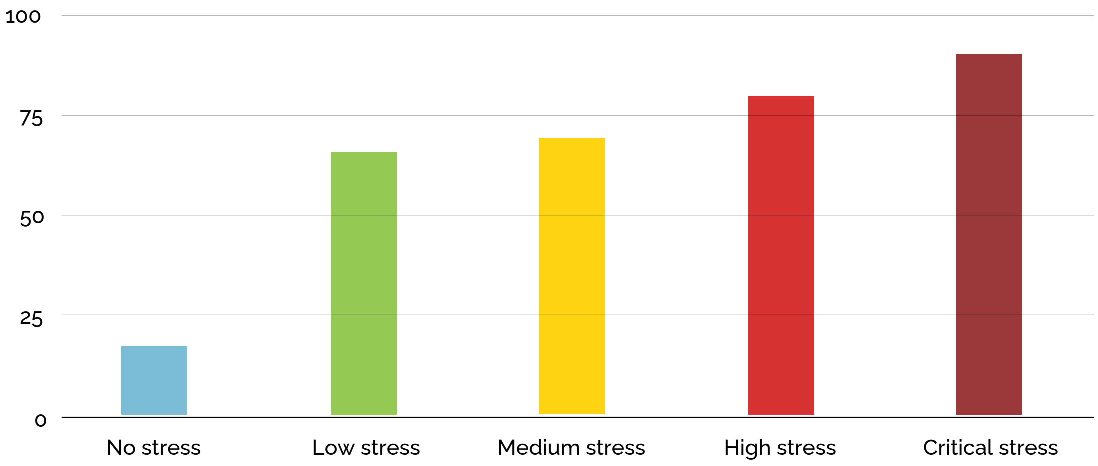
The evolution of large-scale irrigation schemes, such as those found in the Indus, Mekong and Nile basins, has seen the

FIGURE 2.3 POPULATION DISTRIBUTION ACCORDING TO COUNTRY THRESHOLD WATER STRESS, 2000 (LEFT) AND 2018 (RIGHT)



Source: **FAO & UN-Water**. 2021. *Progress on level of water stress: Global status and acceleration needs for SDG indicator 6.4.2*. Rome. https://doi.org/10.4060/cb6241en

FIGURE 2.4 POPULATION DENSITY MEAN (PEOPLE/km²) BY WATER STRESS CLASS AT MAJOR BASIN LEVEL, 2018 (%)



Source: **FAO & UN-Water**. 2021. *Progress on level of water stress: Global status and acceleration needs for SDG indicator 6.4.2*. Rome. https://doi.org/10.4060/cb6241en

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development of irrigated areas outstrip the available supply from surface flows. The environmental externalities resulting from the scale of demand on river flows and built storage are all too apparent (Molle and Wester, 2009). The hydraulic adjustment to changing demands for irrigation and drainage services has lagged behind rising demand or failed to adjust through institutional rigidity. The resulting inequity in timing and duration of surface water allocations and the political economy of farmer and irrigation organization adaptation has been well recognized (Chambers, 1988).

2.3.2 Entrenched groundwater dependency

The social reaction to apparent water scarcity or lack of water service has been profound. Many countries are now concerned about increasing dependence on groundwater for domestic, industrial and agricultural use. Scarcity of surface water resources and the availability of affordable pumping equipment combined with energy subsidies have driven demand from smallholder irrigators for groundwater as an alternative to unreliable surface supplies, primarily because of the convenience and control over on-farm abstractions. Groundwater irrigation has been triggered in many semi-arid regions since the 1960s by a combination of easily accessible pumping and irrigation technologies, promoted by public policies through subsidies for equipment and energy inputs (Molle, Shah and Barker, 2003). This was referred to as the "silent revolution", which quickly turned into a form of "anarchy" that threatened long-term groundwater access and water quality (Shah, 2009). This pattern of exploitation is becoming more complex as solar-powered pumps increase in popularity and high-value crops offer sufficient financial rewards. Meanwhile, unsustainable levels of pumping continue and are increasing (FAO, 2018b).

These global trends have been documented in many semi-arid and arid regions, such as in Algeria, Australia, China, India, Mexico, Morocco, Spain, Tunisia and the United States of America, where scarcity of renewable surface water supplies has made groundwater a strategic resource for irrigation (Margat and van der Gun, 2013). Increases in groundwater use are anticipated in sub-Saharan Africa, where food insecurity is a principal driver, and easier access to pumping technology combined with the occurrence of shallow groundwater circulation offer expanded opportunities for smallholder farming.

Access to land and water relies mainly on informal arrangements in which access by farmers to production factors and markets can be highly informal (López-Gunn, Rica and van Cauwenbergh, 2012; Kuper *et al.*, 2016). Formalizing tenure and responsibility for groundwater abstraction and aquifer pollution has proved challenging (FAO, 2020a), primarily due to the wide range of local groundwater governance arrangements practised among competing users (Blomquist, 1992).

Despite the concerns of overexploitation, many countries continue to use public policies to subsidize wells and boreholes, energy costs and land policies allowing the development of newly irrigated areas. While the negative impacts of groundwater-based irrigation have been apparent in all economies (Steenvorden and Endreny, 2004), many countries remain tolerant because of the political and economic stability offered by continued access and the compelling nature of groundwater tenure (FAO, 2020a).

The impact of soil and land management on groundwater quality through application of nutrients and pesticides is pervasive, and the tainting of water recharge to shallow aquifers affects all users and communities. Groundwater pollutants are easily embedded in aquifer fabrics and are extremely difficult or impossible to remove. Competition for groundwater quality can be as intense as competition for groundwater quantity among urban and rural communities at all scales (Barraqué, 2011). Serious impacts on human health from the use of polluted groundwater resources contaminated with arsenic or other heavy metals and chemical or biological contaminants are increasingly being reported.

2.4 Patterns of landholding

2.4.1 Landholdings and farm size

Statistical analysis of agricultural census data from 129 countries estimates that there are now over 608 million farm holdings on agricultural land (Lowder, Sánchez and Bertini, 2019; Figure 2.5). Some 43 percent of the holdings are located in East Asia and Oceania, including China (34 percent) and South Asia (30 percent). The size of individual holdings is highly skewed. Farms smaller than 1 ha account for 70 percent of all farm holdings but operate on only 7 percent of agricultural land, while land holdings larger than 50 ha operate on more than 70 percent of the world's farmland.

Approximately 80 percent of farms smaller than 2 ha (nominally "smallholders") are in low- and middle-income countries mainly in sub-Saharan Africa, South Asia, Southeast Asia and East Asia (Figure 2.6). Only 40–50 percent of farms smaller than 2 ha are in upper middle-income and higher-income countries (mainly in Central America and the Caribbean and the Near East and North Africa), and the research also indicates a trend towards large farms in higher-income regions compared with low- and middle-income countries (Lowder, Sánchez and Bertini, 2021). In other regions, the 2 ha share decreases as average income levels rise (Lowder, Sánchez and Bertini, 2019). In Central America and the Caribbean, small farms represent only about 35 percent of holdings. Much of the land (about 90 percent) is operated by 8 percent of farms larger than 50 ha. In Europe, Northern Africa, East Africa, the Near East and Central Asia, 60–70 percent of all farms are smaller than 2 ha, but more than half of the land is farmed by holdings larger than 10 ha.

Between 1960 and 2010, the average farm size decreased in nearly all low and lower middle-income countries with data available, although in some countries, there was a slight increase in average farm size between 2000 and 2010. Farm size increased in a third of middle-income countries and nearly all high-income countries. Food system transformation may affect farm size and income. For example, the number of small farms producing food consumed close to the source and the expansion of organic agriculture increased as local famers used local markets supplying the urban populations (Lowder, Sánchez and Bertini, 2019).

An upper limit of 2 ha is typically identified as the cropland area of a smallholding. Another measure is the number of livestock

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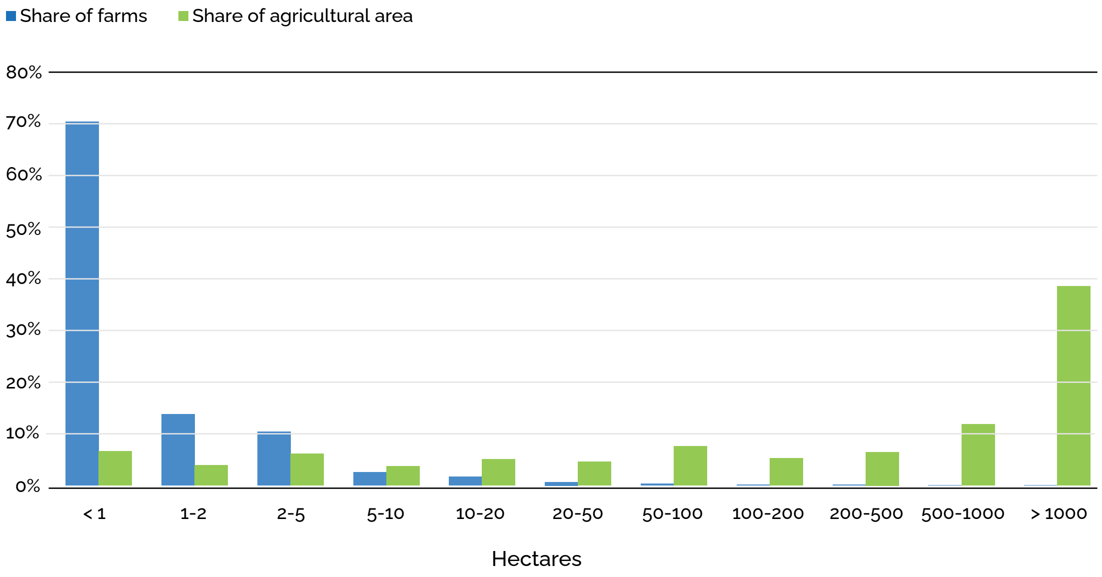
FIGURE 2.5

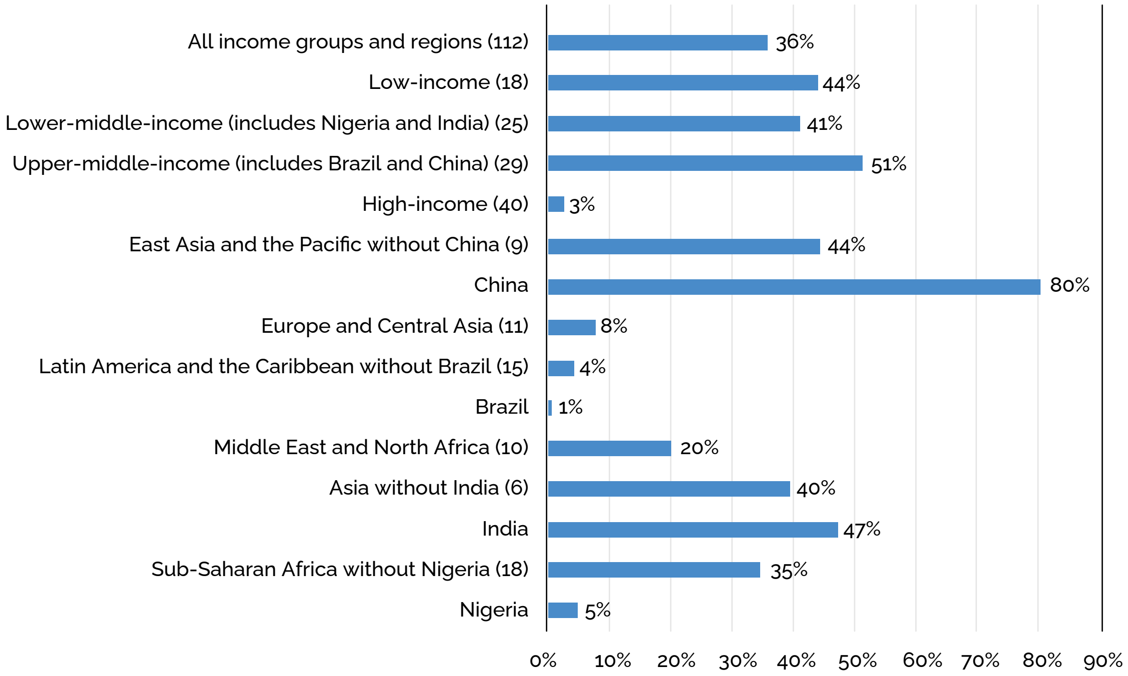
WORLDWIDE DISTRIBUTION OF FARMS AND FARMLAND, BY LAND SIZE CLASS, 2010 CENSUS DATA FOR 129 COUNTRIES AND TERRITORIES



Source: **Lowder, S.K., Sánchez, M.V. & Bertini, R.** 2021. Which farms feed the world and has farmland become more concentrated? *World Development*, 142: 105455.

FIGURE 2.6

SHARE OF VALUE OF FOOD PRODUCTION FROM SMALLHOLDERS (<2 ha), BY REGION AND INCOME GROUPING, 2010 CENSUS DATA FOR 129 COUNTRIES AND TERRITORIES



operated or owned by individual farmers and their families (Thapa, 2009). However, the land area threshold varies greatly across national statistical authorities, and smallholdings can be defined according to various criteria: endowment of land, labour and technology; type of management of the holding and degree of family involvement; market orientation; and/or economic terms such as value of production. Some smallholders may specialize in one activity but not to the exclusion of other options for food and income. The tendency is to diversify and develop complex livelihood systems using family labour and available resources.

At the other extreme, large commercial landholdings dedicated to agribusiness present a distinct governance target upon which regulation of land and water management can achieve impacts at scale. However, the spatial arrangement may be complex, with smallholder subsistence agriculture practised side by side with plantation operations.

2.4.2 Farming systems

Despite the polarization of land holdings, the global farming systems described by Dixon, Gulliver and Gibbon (2001) are becoming more diverse in response to changing market conditions and climate change. Farming systems can still be classified generally between rainfed and irrigated systems (FAO, 2020b). The application of freshwater over and above naturally occurring rainfall or occult precipitation still marks a sharp dividing line between methods of cultivation and application of inputs. Within those broad categories, individual farming systems are demonstrating a high degree of diversity as they adapt to changing market conditions and changing climates. The wide-ranging irrigated systems have diverse sources of water, equipment and infrastructure. Rainfed systems distinguish between cropland, including tree and fodder crops, and pastureland for grazing, while mixed crop–livestock (agropastoral) and agroforestry systems are mutually supporting in terms of inputs and resources management.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This "macro approach" to farming systems helps analyse resource use and impacts. Some systems use large quantities of resources (including non-renewable fossil fuels) and contribute to land and water pollution and GHG emissions. This is particularly the case for intensive livestock-raising (Herrero *et al.*, 2009), where industrial-scale animal-raising concentrates most of the negative impacts on the environment and resource use.

Smallholder farming systems coexist with off-farm work and migration. Although this trend is not new, over the past 20 years, off-farm work and remittances from family migrants (not limited to cash transfer) have grown in importance. According to the World Bank database, remittances represent up to a third of their external inflows. In Africa, they represent up to 22 percent of gross domestic product (GDP) (Dridi *et al.*, 2019). The COVID-19 crisis has demonstrated how dependent some highly productive intensified farming systems are on migrant workers and how rural households rely on remittances from migrants.

The FAO Globally Important Agricultural Heritage Systems (GIAHS) programme aims to identify and promote outstanding agricultural systems that have evolved over generations in specific sites in all ecoregions to provide aesthetic landscapes that combine agricultural biodiversity, resilient ecosystems and valuable cultural heritage (Box 2.1).

BOX 2.1
GLOBALLY IMPORTANT AGRICULTURAL HERITAGE SYSTEMS

Through conservation, ecological knowledge systems and adapted biodiverse agricultural practices, GIAHS generate food and livelihoods in rural areas and also deliver public goods by shaping and modelling biocultural landscapes. FAO has designated 62 systems in 22 countries in all regions as GIAHS since 2005, with most being in Asia and the Pacific. Building on local knowledge and experiences and the profound relationship between people and nature, they sustainably provide multiple goods and services and ensure food and livelihood security for millions of small-scale farmers and local communities. However, they represent only a limited share of all the families involved in farming systems that are able to adapt to continuous change.

Extensive knowledge of the environment and biodiversity allows these farming populations to farm and manage territories with strong environmental constraints and risks such as mountain areas (see the in-focus section at the end of Chapter 1) and dry lands (see the in-focus on dryland systems at the end of Chapter 4), where corporate farming is unlikely to substantively invest. Unfortunately, many factors threaten these agricultural systems, including climate change and increased competition for natural resources. They are also dealing with migration due to low economic viability, remoteness and lack of adequate support and investment, which has, in some cases, resulted in traditional farming practices being abandoned and the loss of endemic species and breeds. Increasing recognition of the small-scale and family farmers' roles in maintaining the landscape and managing land and water resources is expected to bring in more support for the sustainable evolution of such heritage systems and their biodiversity, landscapes and cultures.

Source: **FAO & Globally Important Agricultural Heritage Systems**. 2022. Globally important agricultural heritage systems. In: *FAO*. Rome. www.fao.org/giahs/en

2.4.3 The smallholder challenge

Smallholders with land holdings less than 2 ha may occupy only 12 percent of agricultural land but are nevertheless responsible for diverse and unique farming systems. Smallholders seek security in a diverse set of activities, including harvesting wild plants, hunting and fishing, exploiting non-renewable natural resources and off-farm activities. Specialization is a risky way to develop and is not usually the dominant pathway for smallholders (Bonnal *et al.*, 2018). Smallholders no longer live in a world where they are isolated, producing for their subsistence and looking reluctantly at the monetary economy. Most are fully involved in market-driven activities even if providing enough food for the family remains a proven and efficient safety net. Usually, development agencies focus on downstream markets that serve as outlets for smallholders' products and services.

Nevertheless, smallholders also engage in upstream markets where they can acquire specific inputs (and technologies). They use family labour to engage in diverse labour markets locally or through migration. Smallholders are also part of the general market for consumer goods. In addition, land markets are part of the daily life of smallholders, where they may rent, buy or sell land. They are also engaged in financial markets (including informal lenders) to acquire capital to cover operations costs and investments. Smallholders are fully part of the market economy, even in remote places. The challenge is about improving the conditions that govern their participation in markets, which are rarely favourable (HLPE, 2013).

Although size is a common feature, smallholders face different challenges in different socioeconomic settings, have different farm sizes, and manage land and water resources in different ways. Smallholders produce a significant share of food and traded commodities in world markets (e.g. coffee, cocoa, natural rubber and rice). Yet, they are rarely recognized as the backbone of agricultural development (Rafflegeau *et al.*, 2015; Samberg *et al.*, 2016). Most manage their natural resources and have limited resources to invest in resource improvement, except through their labour. Several assessments have demonstrated how smallholders use their skills, knowledge and family labour to produce food and manage natural resources, often in harsh environments (Sourisseau, 2015; Wada *et al.*, 2016; Guiomar *et al.*, 2018). The sustainable rural livelihoods (SRL) framework is suitable for analysing the livelihoods of smallholders and family farmers. It relies on access to a number of livelihood resources (e.g. human, natural, social and economic assets). This framework also considers a range of formal and informal institutions that influence the livelihoods of smallholders and family farmers (Box 2.2).

Smallholders are part of a multiple and complex set of local solutions available to restore and improve the quality of the diverse ecosystem in which they live and work. The challenge lies in mainstreaming policies, programmes and support to enhance their productive and entrepreneurial capacities

BOX 2.2
THE SUSTAINABLE RURAL LIVELIHOODS FRAMEWORK

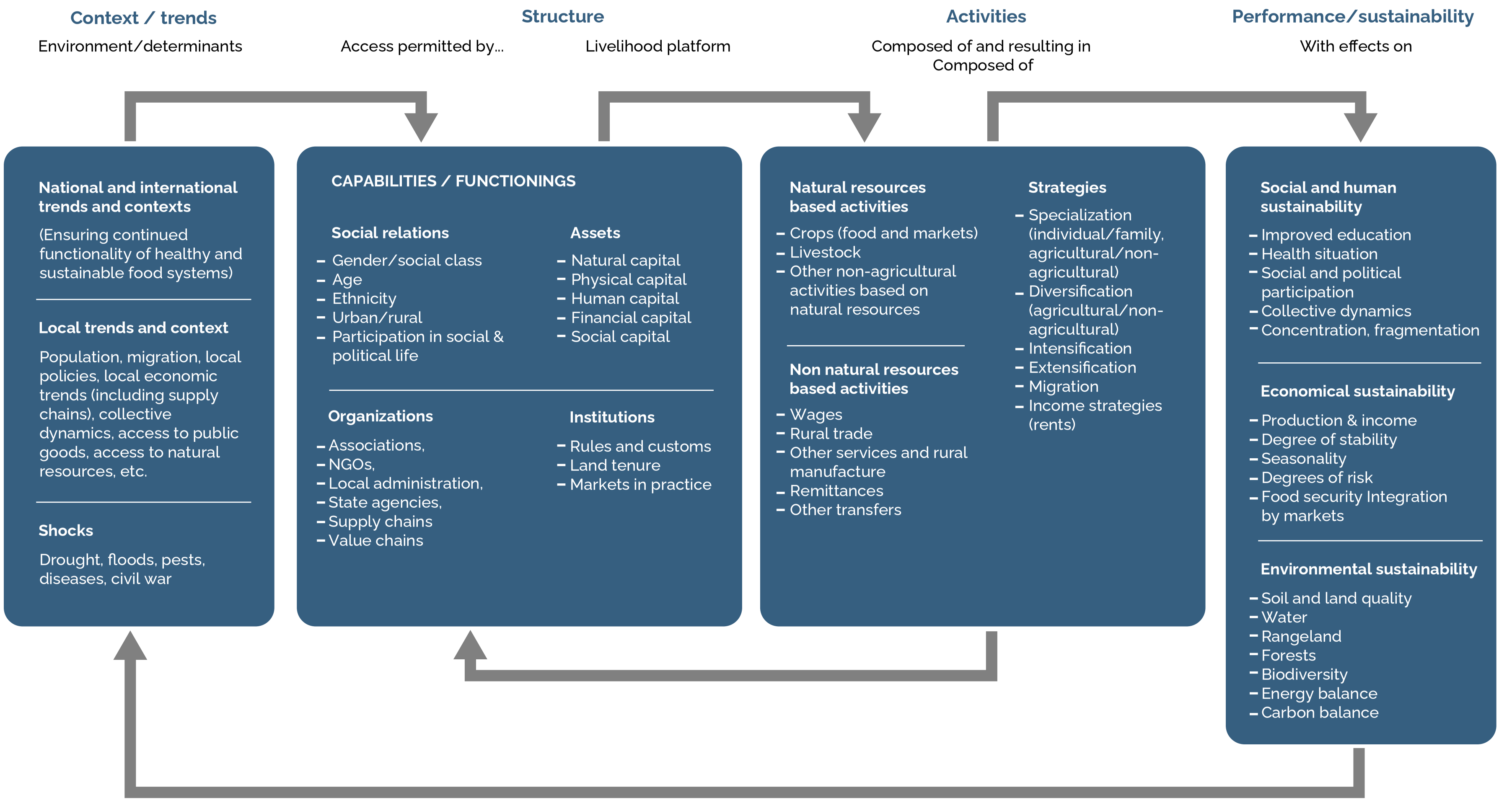
The SRL framework (Scoones, 2009) describes the situation of most smallholders and family farmers (Bosc *et al.*, 2014; Bonnal *et al.*, 2018). It relies on human, natural, social, physical and financial assets, and accounts for different types of capital and the institutions and organizations that make these investments possible. Activities can be socially or market oriented, which corresponds to the situation of most smallholders.

The SRL framework considers natural resources as natural capital given by local resources endowment that is also a product of human actions (Figure 2.7). Thus, investments in natural capital imply access and security conditions that do not necessarily mean private property (Ciriacy-Wantrup and Bishop, 1975; Oakerson, 1992; Ostrom, 1992). Investment in natural capital may also involve collective action. In such cases, this will depend on coordinating capacities at the territorial level involving individual, customary and local authorities and collective stakeholders. Inequality of access or lack of access for the most vulnerable may require public action to redistribute or allocate land through agrarian reforms.

The SRL framework helps to identify the different levels of investments that directly influence or improve the capacity of smallholders to invest, increasing their capabilities through social relations, institutions and organizations that provide increased opportunities to individuals. This includes several types of collective investments: (i) in landscapes and resources management, (ii) in improving access to markets through cooperatives and associations, (iii) in self-help groups (socially oriented), (iv) in corporate and private stakeholders upstream and downstream and (v) in public goods. This framework is valid for households and families and takes account of organizations and institutions. It also replaces the household/family level in an environment that considers national and international trends, shocks and other unpredictable events.

BOX 2.2 (CONTINUED)

FIGURE 2.7 ANALYSING SMALLHOLDINGS AND FAMILY FARMS THROUGH THE SUSTAINABLE RURAL LIVELIHOODS FRAMEWORK



Context / trends

Environment/determinants

Access permitted by...

Structure

Livelihood platform

Activities

Composed of and resulting in
Composed of

Performance/sustainability

With effects on

National and international trends and contexts

(Ensuring continued functionality of healthy and sustainable food systems)

Local trends and context

Population, migration, local policies, local economic trends (including supply chains), collective dynamics, access to public goods, access to natural resources, etc.

Shocks

Drought, floods, pests, diseases, civil war

CAPABILITIES / FUNCTIONINGS

Social relations

- Gender/social class
- Age
- Ethnicity
- Urban/rural
- Participation in social & political life

Assets

- Natural capital
- Physical capital
- Human capital
- Financial capital
- Social capital

Organizations

- Associations,
- NGOs,
- Local administration,
- State agencies,
- Supply chains
- Value chains

Institutions

- Rules and customs
- Land tenure
- Markets in practice

Natural resources based activities

- Crops (food and markets)
- Livestock
- Other non-agricultural activities based on natural resources

Non natural resources based activities

- Wages
- Rural trade
- Other services and rural manufacture
- Remittances
- Other transfers

Strategies

- Specialization (individual/family, agricultural/non-agricultural)
- Diversification (agricultural/non-agricultural)
- Intensification
- Extensification
- Migration
- Income strategies (rents)

Social and human sustainability

- Improved education
- Health situation
- Social and political participation
- Collective dynamics
- Concentration, fragmentation

Economical sustainability

- Production & income
- Degree of stability
- Seasonality
- Degrees of risk
- Food security Integration by markets

Environmental sustainability

- Soil and land quality
- Water
- Rangeland
- Forests
- Biodiversity
- Energy balance
- Carbon balance

Source: **Bosc, P.-M., Sourisseau, J.-M., Bonnal, Gasselin, P., Valette, E. & Bélières, J.-F.** 2014. *Diversity in family farming : Theoretical and empirical approaches to its many forms.* Rethinking Development Working Paper Series No. 2014/2. University of Pretoria. https://doi.org/10.13140/RG.2.1.4444.8409

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and result in positive potential implications on the state of the resources they manage.

Despite the important role of smallholders in food production and landscape management, they tend not to be the ones receiving attention as part of ongoing investments in land and water, nor do they receive policy support to formalize the allocation of their land- and water-use rights. The current context of climate change even further accentuates the importance of access to water for smallholder and family farmers.

2.5 Access to land and water

The rules of access, regulation, competition and conflict resolution defined by governance shape how natural resources are managed over time and define the conditions for restoring and improving renewable resources, including investments, incentives and disincentives. These require understanding and capacities within communities, local authorities and higher levels of governance to interact effectively to address issues affecting sustainable resource use.

2.5.1 Power asymmetries over land

Local authorities and communities face power asymmetries, either within communities or with external entities or individuals. In Central America and the Caribbean, Oxfam reports that women and youth often have limited access to smaller and poor-quality plots of land and insecure tenure rights (Oxfam, 2016). Indigenous people often have difficulties obtaining recognition and registration of their legitimate tenure rights at the same pace as private operators. Even when their rights are acknowledged and granted, they may face difficulties in preventing encroachment. There is also an imbalance between the rights of first settlers granted unsecured access rights and new groups willing to settle or use part of the resources controlled by the early comers. The same applies with pasture rights threatened by farmers extending and enclosing their cropped area and questioning the customary post-harvest pasture rights when their own needs for fodder develop.

The recent Land Inequalities Initiative (Anseeuw and Baldinelli, 2020) suggests traditional land inequalities analysis, based on the Gini coefficient for land distribution, underestimated inequalities by omitting criteria such as multiple ownership of plots, land values and landless population. In 17 countries, analysis showed 10 percent of the largest landowners accumulated 40–60 percent of the land value while the bottom 50 percent of small landowners accumulated only 6–10 percent (Bauluz, Govind and Novokmet, 2020). The analysis also showed land inequalities increased when landless persons engaged in agriculture were considered in countries with landless populations.

Increased concentration of farmland among larger farms in countries with higher income levels is occurring in most of the larger European countries (except Spain), in Brazil and in the United States of America. There is increased inequality with an apparent re-emergence of small farms, while the share of farmland on the largest holdings has increased. In 2010, the average farm size was 1.3 ha in low-income countries, 17 ha in lower middle-income countries, 23.8 ha in upper middle-income countries (excluding China) and 53.7 ha in high-income countries (Lowder, Sánchez and Bertini, 2019).

Investments in large-scale land acquisition can bring prosperity, but may adversely affect local communities and smallholders if not adequately planned. Investors target irrigated lands for their potential as they seek to secure their capital and get a good return on investment. This is a complex activity with diverse actors, contracts and practices around land tenure and water rights, often within incomplete and inconsistent legal frameworks.

Since the first land matrix report, large-scale land acquisitions continue to be a significant issue globally, with differentiated impacts across regions and countries (Anseeuw *et al.*, 2012). Africa ranks first with 10 million ha acquired, representing 37 percent of the global acquired area, principally along the main rivers in East Africa. The picture varies among other target countries, with the top five being Indonesia, Ukraine, Russian Federation, Papua New Guinea and Brazil (Nolte, Chamberlain and Giger, 2018).

Acquisitions are increasingly becoming operational and can threaten the livelihoods of rural people, who are not always part of the negotiation process (only 60 percent of 180 recorded cases). More than half deal with lands already under cultivation in regions with relatively high population densities, forest zones used by communities and marginal lands with less-populated areas but crucial for pastoralism. More than half of acquisitions belonged to communities, and only 30 percent received compensation.

Since 2000, African investors from non-agricultural backgrounds and farmers wishing to increase their holdings have accounted for a significant number of medium-scale acquisitions (5–100 ha). In Ghana, they accounted for about 50 percent of national cropped land (Jayne *et al.*, 2019).

In Africa, large- and medium-scale acquisitions have been facilitated by commodifying rural land markets, leading to the privatization of public and customary land. In Central America and the Caribbean, there are documented trends in land concentration (Baquero and Gómez, 2014) due to growing interest in large-scale lease schemes for the annual production of soya and corn in the Southern Cone and through large-scale land ownership for all type of production in the rest of the region (Bres, 2017). In many countries across the world, these recent trends reinforce historical dualistic polarized agrarian structures.

2.5.2 Inequalities in access to water resources

Equitable access to water and land will worsen with the increasing scarcity of land and water and the impacts of climate change. Estimates suggest 77 percent of small-scale farms in low- and middle-income countries are located in water-scarce regions, and less than a third of these have access to irrigation systems. The greatest disparities in irrigation coverage between small-scale and medium- and large-scale farms are in Central America and the Caribbean, sub-Saharan Africa and South Asia (Ricciardi *et al.*, 2020). In view of climate change impacts, poor access to irrigation can become a major constraint for rural livelihoods, particularly in arid regions. Sustainable resources management and improved access to natural resources and services can mitigate the adverse effects.

Irrigation investments have increased crop yields and irrigated areas and induced changes in cropping patterns, including from single-cropping to double-cropping systems. Studies have found crops show significant yield increase when cultivation shifts from rainfed to surface irrigation in semi-arid regions. Notably, studies generally illustrate the potential for infrastructure investments to decouple economic growth from rainfall variability. Irrigation can benefit poor consumers by reducing food prices. Groundwater irrigation has fostered a groundwater economy. It has helped to alleviate poverty, boost economic growth and transform rural economies in many countries in the Americas and Europe, in Asia through the Green Revolution, and more recently, in Northern Africa. Irrigation also brings many indirect benefits such as: (i) increased labour demand, particularly during planting and harvest periods, (ii) improved nutrition and health and (iii) economy-wide multiplier effects. Smallholders that irrigate can increase their farm income by growing higher-value crops and increasing the availability of vegetables, fruits and cash crops. Examples include Ethiopia and the United Republic of Tanzania (Passarelli *et al.*, 2018) and countries in Northern Africa (Dugué *et al.*, 2014).

Smallholder and family farmers in many countries have developed systems of informal irrigation. Only a minority of the world's small-scale users of water hold a legally sanctioned water right. Small-scale irrigation is not accounted for in official national statistics, and water users are often reluctant to register their water use due to fear of water fees being imposed. Yet, the informality of small-scale irrigation may increase the risk of water insecurity (United Nations, 2018b). In addition, the apparent success of groundwater irrigation for smallholders is creating resources problems as local aquifers are drawn down and degraded by migration of low-quality groundwater or saline intrusion.

Irrigation impacts on poverty vary greatly depending on farm size and location within an irrigation system and structural issues related to the overall institutional and socio-economic environment related to gender, caste and class. For example, irrigation effects on employment may benefit the landless poor, but inequalities may also widen as the increase in production may depress market prices, which disadvantages rainfed farmers. Irrigation may increase poverty if all legitimate tenure rights are not recognized, particularly those affecting the most vulnerable. This can lead to poor households losing rights and converting marginal and poor farmers to landless labourers. Mechanization and the use of herbicides can also replace labour on big production units.

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Irrigation development can have off-site environmental impacts that are particularly important for the poor. Irrigation is often associated with soil salinization and heavy uses of fertilizers and pesticides; it may reduce environmental service provision upon which the poor rely, such as inland and marine fisheries. There is growing evidence that links groundwater irrigation expansion with increasing socioeconomic inequalities as water tables decline and cropping changes.

2.5.3 Gender inequalities

Access and management of land and water have strong gender and equality dimensions. Women play a key role in ensuring food security and managing natural resources. They often have responsible roles across all agricultural subsectors including forestry and fisheries, while providing water, food and energy to their households. Globally, women comprise over 37 percent of the world's rural agricultural workforce, rising to 48 percent in low-income countries. They account for about 50 percent of the world's small-scale livestock managers and about half of the labour force in small-scale fisheries. These


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percentages are likely to underestimate women's full contribution to agriculture as their work, often unpaid, is not always adequately captured in official statistics.

Women are often marginalized and vulnerable to land tenure and water insecurity, and are less resilient to climate shocks. Compared to men, they have less access and control of assets to increase their resilience to climate and economic shocks (e.g. infrastructure, and land and water rights), and less access to irrigation and opportunities. Women often have limited participation in decision-making and do not usually benefit from land and water investments.

Land and water management investments can be gender blind, and fail to respond to the specific needs of women or address the issues constraining women farmers' empowerment. Land and water tenure insecurity can come from discriminatory laws and practices at national, community and family levels. For example, fewer than 50 countries have laws or policies that specifically mention women's participation in rural sanitation and water resources management (UN-Water, 2021).

National and global data on women's access to land and water that would enable them to monitor and enforce their rights are lacking. Land and water tenure are often linked. While contemporary water laws tend to decouple water rights from land tenure, the land–water nexus persists and has important impacts on realizing and securing water rights, particularly traditional customary water tenure among rural communities. A more integrated rights-based approach to tenure could unpack the relationship between rights to water, land and other terrestrial resources, and help to identify gaps and synergies across sectoral legislation (FAO, 2020a).

Human rights mechanisms and United Nations entities recognize that ensuring women's land and water rights are essential for achieving substantive equality and eradicating many forms of discrimination against women. This is a fundamental precondition to realizing rights to an adequate standard of living, including food and housing, health, well-being, work, cultural identity and participation in civil and political life, particularly when land and water management infrastructure is being planned and developed (United Nations OHCHR and Heinrich-Böll-Stiftung, 2018). The 2030 Agenda recognizes women's land and water rights as an explicit cross-cutting catalyst to ending poverty (SDG 1), seeking to achieve food security and improved nutrition (SDG 2), ensuring clean water and sanitation for all (SDG 6) and achieving gender equality and women's empowerment (SDG 5).

Investment in women and girls can be a catalyst to accelerate progress in agriculture, rural development and, ultimately, food security and nutrition. This should integrate the gendered implications of land and water investments, such as the appropriateness of technologies, governance arrangements and financing mechanisms, to ensure effective targeting of poor and vulnerable groups. Women are not a homogeneous group, and social dimensions such as age and ethnicity play a role in determining multiple forms of marginalization and exclusion.

2.6 Competition for land and water – an issue of governance

FAO defines governance as formal and informal rules, organizations and processes through which public and private actors articulate their interests and make and implement decisions. Governance issues arise in various public and private settings, from local communities, farms and cooperatives, business organizations and large-scale enterprises, to local, regional, national and international contexts. It includes social, political and economic dimensions, traditional authorities, and customary laws and norms (UNDP and EC, 2007; Bruch, Muffett and Nichols, 2016; FAO, forthcoming).

Governance over land and water resources relates to the enabling environment in which land and water management actions take place at multiple levels of decision-making: the overarching policies, strategies, plans, finances and incentive structures that concern or influence land and water resources; the relevant legal and regulatory frameworks and institutions; and planning, decision-making and monitoring processes. Effective governance promotes responsible actions and measures to protect and ensure the sustainability of resources for current and future generations and optimize the services and benefits obtained from those resources.

There has been a shift from focusing on promoting "good governance" principles – from participation (including the rule of law, transparency, responsiveness, consensus orientation, equity, inclusion, effectiveness, efficiency and accountability (United Nations ESCAP, 2009)), to establishing a formal normative set of institutional, financial and organizational procedures for regulating natural resources. These include informal and operational approaches that address the complex policy bottlenecks, political conflicts and local organizational realities that impede effective decision-making and land and water governance in practice (FAO, 2021).


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The focus has also shifted towards a more pragmatic agenda committed to bottom-up problem-solving approaches that recognize the development process as being deeply rooted in established socioeconomic, cultural and political relationships at national and local levels (Gonzalez Fischer and Garnett, 2016; FAO, 2021). Indeed, land and water resources generate revenues and drive economic growth. Yet, the way institutions operate and cooperate, and the relative power and capabilities of different actors, strongly shape outcomes and welfare distribution. Strengthening governance is therefore about enabling effective and efficient problem solving and decision-making in ways that stakeholders regard as legitimate.

2.6.1 Adoption of land tenure guidelines

In building the capacities of countries to improve the governance of land tenure, FAO has developed technical guides for a range of actors that provide practical mechanisms, processes, good practices and tools for the design of policy and reform processes, for investment projects and for guiding implementation of the *Voluntary guidelines on the responsible governance of tenure of land, fisheries and forests in the context of national food security* (VGGT; CFS and FAO, 2012). The technical guide on governing tenure rights to commons (FAO, 2016b) provides recommendations and calls on States to meet their obligations to secure legitimate tenure rights.

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The Committee on World Food Security (CFS) country members and stakeholders negotiated and adopted the VGGT. The guidelines promote secure legitimate tenure rights and equitable access to land, fisheries and forests as a means of eradicating hunger and poverty, supporting sustainable development and enhancing natural resources management. They set out principles and internationally accepted standards or practices for the responsible governance of tenure that States can use when developing their own strategies, policies, legislation, programmes and activities. They allow governments, civil society, the private sector and citizens to judge whether their proposed actions and the actions of others constitute acceptable practices.

2.6.2 Emergence of water tenure

The VGGT focus on land tenure, and did not initially include water tenure because of its complexity as a transboundary resource beyond the scope of national sovereignty alone. However, because of its fundamental importance for effective water allocation and management and for agriculture and food security, in 2014, FAO adopted a framework for systematic engagement in water governance to address: (i) the linkages among agriculture, water and related key sectors and elements such as food, land, energy, natural resources, societal goals and major drivers of change; (ii) a moving intervention scale from management to governance of water in agriculture, pointing to underlying issues that management approaches alone cannot solve; and (iii) governance issues of access, rights and tenure from the perspective of sustainability, inclusiveness and efficiency. The FAO Council and committees on food security and agriculture are kept informed of advances in land tenure and water tenure, and address the crucial links with agriculture and food security.

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Agriculture, which accounts for 70 percent of all water withdrawals, is increasingly required to "make its case" for its share of water to enable food production and ensure food security. The sustainability of agricultural water use is increasingly under scrutiny. There is an urgent need to consider how best to address control over, competition for and access to water resources while also ensuring efficient and effective management. In many places, water governance regimes have not kept pace with growing competition for water and are not conducive to its efficient and equitable management. Mechanisms to reflect values in conditions of resource scarcity and increase resource-use efficiency are generally lacking. Moreover, the water-use rights held by farmers are often not protected by law or formally registered.

FAO is developing the concept of water tenure to better assist Members in making the institutional, legal and political adjustments needed for successful water management (FAO, 2016b, 2020a). This includes governance of water in river basins and watersheds, groundwater governance, governance of irrigation, governance of water for pollution control and water quality management, and management and putting food security at the centre of the international water debate. In view of the fundamental importance also for human health, increasing emphasis is needed on governance for sustaining water quantity and quality.

Efforts have intensified to support effective water governance through international initiatives such as the OECD water governance principles (OECD, 2015) and the report on implementation, which took stock of progress and proposed two tools – an indicator framework, and 50+ concrete practices (OECD and FAO, 2018) and World Water Week – which have helped advance knowledge and promote more effective governance. Target 6.5 of SDG 6 provides an agreed global target on water governance: the implementation of integrated water resources management (IWRM) at all levels based on principles of social equity, economic efficiency and environmental sustainability.

For the land and water governance agenda, lessons can also be learned from measures and best practices in other sectors, notably the development of farmers' rights[6] over genetic resources (Lowder, Sánchez and Bertini, 2019) and an inventory of national measures, best practices and experiences of the United Nations Convention on Biological Diversity (CBD) through the Nagoya Protocol on Access and Benefit-sharing from the utilization of genetic resources.

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2.6.3 Conflicts over land and water resources

The potential for conflict is increasing as populations compete for resources in land- and water-stressed areas. Conflicts continue to grow in areas such as: the Horn of Africa and the Near East, where conflict exists between Israel and Palestine in Gaza and the Golan Heights; Eritrea and Ethiopia over land; and Egypt and Ethiopia over River Nile water resources. Water conflicts have intensified over the past decade, according to the Pacific Institute. However, tensions do not always lead to conflicts and wars; they can lead to negotiations and improved cooperation (Yoffe, Wolf and Giordano, 2003; Michel, 2020).

Disagreements over water allocation among countries that share river systems are a common source of political conflict, especially where demands outgrow the available resources. Water scarcity may well increase transboundary conflicts if political discussion and appropriate governance arrangements fail to prevent them. About 40 percent of the world's population lives in transboundary river basins, which cover about half of the Earth's land surface. Globally, more than 300 watersheds and over 360 aquifers cross the political boundaries of two or more countries, highlighting the need for effective transboundary governance arrangements among countries and local populations.

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[6] Farmers' rights developed under the International Treaty on Plant Genetic Resources for Food and Agriculture and the Commission on Genetic Resources for Food and Agriculture, which covers biological diversity for food and agriculture.

Concerns over national sovereignty pervade shared resources management, but this does not stop international cooperation on planned development of large dams on transboundary rivers, even when there is a long-standing history of mistrust among neighbouring States. The experience of international cooperation over shared aquifers is more limited and finds more application in national jurisdictions with federated territories. In all transboundary resource negotiations, the burden of proof on land-use impacts on water quantity and quality is perhaps the most demanding. This is particularly the case in shared aquifers where the effects of land management practices are highly distributed and are expensive to monitor and control over the required periods of time.

The tension between farming communities and pastoralists has become marked. Pastoralism has often developed in territories where land is marginal or not suitable for crop production, as the best land-use option. Another perspective is that pastoralism is also a means of taking the best of harsh environments marked by a high climatic variability, by managing resources (fodder and water) that are randomly spread over vast territories. Pastoralism is often combined with some type of seasonal cropping, which generally has "very low productivity" from an agronomic perspective but is important for nutrition and diet.


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Conflict sensitivity should be integral to any interventions involving land and water. Participatory and inclusive approaches should be central to strengthen buy-in, transparency and sustainability. Despite agreement on important component principles, there is no consolidated and agreed set of principles for joint land and water management nor an agreed international integrated framework. Cooperation should be a means to sustainable use of transboundary water resources.

2.7 Conclusions

Demographic and economic growth are driving food demand, placing unprecedented pressures on ecosystems and limited renewable land, soil and water resources. Socioeconomic trends, including urbanization, migration and technological change, will continue to drive the distribution of these pressures on available natural resources. Higher incomes and urban lifestyles are changing food demand towards more resource-intensive consumption of animal proteins, fruits and vegetables. At the same time, malnutrition persists among the urban and rural poor who are disconnected from markets or access to productive land through poverty or geography.

Globally, 80 percent of the extreme poor live in rural areas. Most live in the developing world, and their livelihoods are disproportionally dependent on agriculture, which is highly exposed to current and future climate risks. Ensuring equitable access to land and water resources is key for promoting inclusive rural transformation. The lack of adequate access and user rights and increasing disparities in capacities to take advantage of natural capital are underlying drivers of overuse of resources to meet short-term needs.

Underneath the patterns of economic growth, competition for land and water resources is intensifying. Increasing population is reducing the natural resources available per capita. More than 733 million people live in countries with high (70 percent) and critical (100 percent) water stress areas, accounting for almost 10 percent of the global population in 2018. Over the past decade, sub-Saharan Africa experienced a 40 percent reduction in water availability per capita, and a decline in agricultural land from 0.80 ha/capita to 0.64 ha/capita between 2000 and 2017. Northern, Western and Southern Africa have less than 1 700 m^3/capita, a level that compromises a nation's ability to meet water demand for food and for other sectors.

The social and economic structure of most populations is still finely tuned to natural resources access, even as populations concentrate in urban areas. Large-scale commercial holdings dominate agricultural land use to supply global food systems, while land tenure patterns restrict and concentrate up to 500 million smallholdings of less than 2 ha in subsistence farming on lands susceptible to degradation and water scarcity.

Governance over land and water resources requires an enabling environment in which land and water management actions take place at multiple levels of decision-making. Social, agricultural and environmental policies need to be harmonized mutually reinforcing if they are to reconcile competition over land and water. There is progress in land tenure initiatives, but land and water allocation adjustments will be possible only when explicit instruments are joined up and resource management decision-making become inclusive. Integrated land water resources planning is urgently needed to guide land and water use, not just to promote sustainable resource management but to establish the realistic scope for reducing emissions.

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Case study: Gender empowerment resolves water-related conflict in Yemen

In Yemen, disputes over land and water are endemic and often violent, claiming thousands of lives each year, destroying valuable crops, delaying investment and inhibiting social and economic development. FAO is helping farmers resolve such conflicts and gain access to water resources by improving opportunities for women and youth, who represent over 60 percent of the agricultural workforce, to play an influential role in decision-making.

Yemen is one of the Arab world's poorest nations and is among the world's most water-stressed countries (SDG indicator 6.4.2, level of water stress, is 170 percent). Yemeni farmers have long coped with their harsh environment and water scarcity, and developed indigenous water management practices to regulate water allocation. However, because of the unequal power relations between the genders, women are not usually involved in managing natural resources. Indeed, Yemen ranks last out of the 144 countries listed in the 2016 World Economic Forum's Global Gender Gap Index, a position it has held for the last ten years.

Woman providing water for cattle in a Yemeni smallholding – Al Hudaydah, Yemen

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The war in Yemen began in 2014; it is a complex mix of politics, socioeconomics and history connected to resource scarcity and has inflicted severe damage to the country's water infrastructure. As men were drawn into the conflict, many women became heads of households and key family decision-makers.

Women learn about the many interconnections influencing water sustainability – Al Hudaydah, Yemen

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In response, FAO developed a project to rehabilitate community water supplies. This included encouraging and training women to take a more prominent role in water management, facilitating and mitigating resource conflicts through mediation, and discussions at the household level.

FAO helped to establish water user associations (WUAs), comprising women's water user groups and also conflict resolution committees (CRCs), in which women would participate on equal terms with men. Women were empowered to lead in conflict resolution and mobilize community members to support agreed resolutions. Under the current management system, all WUAs choose their board members through elections, and 30 percent of the seats are for women.

As a result, 27 165 farmers improved their access to irrigation water. Some 1 083 people (294 women; 789 men) from low-income and vulnerable households increased income through cash for work because of the increased water availability. This improved local food production and increased the economic prospects for vulnerable families when the population was facing severe food insecurity.

Conflict over water supplies from the Sana'a Queen Dam storage is an example of farmers' issues. Built in 2002 and designed to benefit 350 farmers, a dispute led to a ban on using 170 000 m^3 of stored water annually to irrigate 34 ha. FAO worked with the community to resolve the dispute and empowered women to take an active role. In partnership with Al-Malakah WUA in Bani Al-Harith District, a CRC was formed (two women and two men) to analyse the dispute, the reasons behind it and its impact. FAO and Al-Malakah CRC were supported by village youth and women to dispel deep-seated mistrust and misunderstandings among the communities. They then agreed to construct shallow wells that would connect with the water stored in the dam. Participatory negotiations resolved a 17-year-old dispute that had prevented farmers from using water rather than leaving it to evaporate.

This project demonstrated that when women and youth play prominent roles in WUAs, they can bring innovative ideas to mitigate many resource-based disputes. It was possible to resolve water conflicts in a peaceful, participatory and equitable manner and improve secure access to natural resources. Training in conflict management offers a significant opportunity to develop human and social capital. However, training alone is unlikely to address all societal disputes. Socioeconomic and political factors may require appropriate reform of policy, legislation and institutions to provide an enabling environment.

Sources: **FAO.** 2017. FAO support provides water sustainability for farmers while empowering women. In: *Resilience*. www.fao.org/resilience/news-events/detail/en/c/1045903; **FAO.** 2018. FAO innovative approach to resolve land and water conflict in Yemen. In: *La resiliencia*. Rome. www.fao.org/resilience/multimedia/videos/video-detalle/es/c/1151119

References

Agergaard, J., Tacoli, C., Steel, G. & Ørtenblad, S.B. 2019. Revisiting rural–urban transformations and small town development in sub-Saharan Africa. *European Journal of Development Research*, 31(1): 2–11.

Alpha, A. & Fouilleux, E. 2018. How to diagnose institutional conditions conducive to inter-sectoral food security policies? The example of Burkina Faso. *NJAS: Wageningen Journal of Life Sciences*, 84(1): 114–122.

Anseeuw, W. & Baldinelli, G. 2020. *Uneven ground. Land inequality at the heart of unequal societies*. Rome, International Land Coalition. https://oi-files-d8-prod.s3.eu-west-2.amazonaws.com/s3fs-public/2020-11/uneven-ground-land-inequality-unequal-societies.pdf

Anseeuw, W., Boche, M., Breu, T., Giger, M., Lay, J., Messerli, P. & Nolte, K. 2012. *Transnational land deals for agriculture in the Global South: Analytical report based on the Land Matrix Database*. Bern, Centre for Development and Environment, Montpelier, University of Bern/Centre de coopération Internationale en Recherche Agronomique pour le Développement and Hamburg, German Institute of Global and Area Studies. https://landmatrix.org/documents/82/Analytical_Report_I_LMI_English_2012_xP1xzqu.pdf

Baquero, F. & Gómez, S., eds. 2014. *Reflexiones sobre la concentración y extranjerización de la tierra en América Latina y el Caribe*. Rome, FAO. www.fao.org/3/i3075s/i3075s.pdf

Barraqué, B., ed. 2011. *Urban water conflicts*. United Nations Educational, Scientific and Cultural Organization International Hydrological Programme and CRC Press.

Bauluz, L., Govind, Y. & Novokmet, F. 2020. *Global land inequality*. WID.world Working Paper No. 2020/10. https://wid.world/document/global-land-inequality-world-inequality-lab-wp-2020-10

Blomquist, W. 1992. *Dividing the waters: Governing groundwater in southern California.* San Francisco, ICS Press Institute for Contemporary Studies.

Bonnal, P., Sourisseau, J.M., Bosc, P.M., Gasselin, P., Bélières, J.F. & Valette, É., eds. 2018. *Diversity of family farming around the world. Existence, transformations and possible futures of family farms.* Cham, Springer.

Bosc, P.-M., Sourisseau, J.-M., Bonnal, Gasselin, P., Valette, E. & Bélières, J.-F. 2014. *Diversity in family farming: Theoretical and empirical approaches to its many forms.* Rethinking Development Working Paper Series No. 2014/2. University of Pretoria. https://doi.org/10.13140/RG.2.1.4444.8409

Bres, A. 2017. Challenge and opportunities for the VGGT implementation in Latin America and the Caribbean. Paper presented at *2017 World Bank conference on land and poverty*, Washington, DC.

Bruch, C., Muffet, C. & Nichols, S.S., eds. 2016. *Governance, natural resources, and post-conflict peacebuilding*. Routledge.

Castañeda, A., Doan, D., Newhouse, D., Nguyen, M.C., Uematsu, H. & Azevedo, J.P. 2018. A new profile of the global poor. *World Development*, 101: 250–267.

Cervigni, R., Morris, M., Scandizzo, P. & Savastano, S. 2016. Vulnerability in drylands today. In: R. Cervigni & M. Morris, eds. *Confronting drought in Africa's drylands: Opportunities for enhancing resilience*. Washington, DC, World Bank. https://openknowledge.worldbank.org/handle/10986/23576

CFS (Committee on World Food Security) & FAO. 2012. *Voluntary guidelines on the responsible governance of tenure of land, fisheries and forests in the context of national food security*. Rome, FAO. www.fao.org/3/i2801e/i2801e.pdf

Chambers, R. 1988. *Managing canal irrigation. Practical analysis from South Asia*. Cambridge, UK, Cambridge University Press.

Chatel, C., Imbernon, J. & Moriconi-Ebrard, F. 2016. *Megacities and archipelagos: An emerging urban framework*. HAL open science. https://hal-univ-paris.archives-ouvertes.fr/hal-01713844/document

Ciriacy-Wantrup, S.V. & Bishop, R.C. 1975. Common property as a concept in natural resources policy. *Natural Resource Journal*, 15(4): 713–727.

Cunningham, P.J. & Abasse, T. 2005. Reforesting the Sahel: Farmer managed regeneration. In: A. Kalinganire, A. Niang & A. Kone, eds. *Domestication des especes agroforestieres au Sahel: Situation actuelle et perspectives.* ICRAF Working Paper 5, pp. 75–80. Nairobi, World Agroforestry Centre. https://fmnrhub.com.au/wp-content/uploads/2013/09/Cunnigham-Abasse-2005-Reforesting-the-Sahel.pdf

Damania, R., Desbureaux, S., Hyland, M., Islam, A., Moore, S., Rodella, A., Russ, J. & Zaveri, E. 2017. *Uncharted waters: The new economics of water scarcity and variability*. Washington, DC, International Bank for Reconstruction / The World Bank. https://openknowledge.worldbank.org/handle/10986/28096

Dixon, J.A., Gibbon, D.P. & Gulliver, A., eds. 2001. *Farming systems and poverty: Improving farmers' livelihoods in a changing world*. Rome, FAO. www.fao.org/3/y1860e/y1860e.pdf

Dridi, J., Gursoy, T., Perez-Saiz, H., Bari, M., Berg, C., Chami, R., Kebhaj, S. *et al.* 2019. *The impact of remittances on economic activity: The importance of sectoral linkages*. IMF Working Paper WP/19/175. International Monetary Fund.

Dugué, P., Lejars, C., Ameur, F., Amichi, F., Braiki, H., Burte, J., Errahj, M., Hamamouche, M. & Kuper, M. 2014. Recompositions des agricultures familiales au Maghreb: Une analyse comparative dans trois situations d'irrigation avec les eaux souterraines. *Revue Tiers Monde*, 220(4): 99–118.

Falkenmark, M., Lundqvist, J. & Widstrand, C. 1989. Macro-scale water scarcity requires micro-scale approaches: Aspects of vulnerability in semi-arid development. *Natural Resources Forum*, 13(4): 258–267.

FAO. 2015. *Mapping the vulnerability of mountain peoples to food insecurity*. Rome. www.fao.org/3/i5175e/i5175e.pdf

FAO. 2016a. *The agriculture sectors in the intended nationally determined contributions: Analysis*. Environmental and Natural Resources Management Working Paper 62. Rome. www.fao.org/3/i5687e/i5687e.pdf

FAO. 2016b. *Governing tenure rights to commons*. Rome. www.fao.org/3/a-i6381e.pdf

FAO. 2017. *The future of food and agriculture: Trends and challenges*. Rome. www.fao.org/3/i6583e/i6583e.pdf

FAO. 2018a. *The state of food and agriculture: Migration, agriculture and rural development*. Rome. www.fao.org/3/I9549EN/i9549en.pdf

FAO. 2018b. *Progress on water-use efficiency: Global baseline for SDG indicator 6.4.1*. Rome, FAO and UN-Water. www.fao.org/3/CA1588EN/ca1588en.pdf

FAO. 2019. *FAO framework on rural extreme poverty: Towards reaching target 1.1 of the Sustainable Development Goals*. Rome. www.fao.org/3/ca4811en/ca4811en.pdf

FAO. 2020a. *Unpacking water tenure for improved food security and sustainable development*. Land and Water Discussion Paper 15. Rome. https://doi.org/10.4060/cb1230en

FAO. 2020b. *The state of food and agriculture 2020. Overcoming water challenges in agriculture*. Rome. https://doi.org/10.4060/cb1447en

FAO. 2021. *The impact of disasters and crises on agriculture and food security: 2021*. Rome. https://doi.org/10.4060/cb3673en

FAO. (forthcoming). *Governance assessment guidance*. Rome.

FAO, International Fund for Agricultural Development, United Nations Children's Fund, World Food Programme & World Health Organization. 2021. *The state of food security and nutrition in the world 2021. Transforming food systems for food security, improved nutrition and affordable healthy diets for all*. Rome, FAO. https://doi.org/10.4060/cb4474en

Fiondella, F. 2013. A wetter Sahel, but will it last? In: *Columbia Climate School International Research Institute for Climate and Society*. https://iri.columbia.edu/news/a-wetter-sahel-but-will-it-last

Gonzalez Fischer, C. & Garnett, T. 2016. *Plates, pyramids and planets. Developments in national healthy and sustainable dietary guidelines: A state of play assessment*. Rome, FAO and Oxford, University of Oxford. www.fao.org/3/I5640E/i5640e.pdf

Guiomar, N., Godinho, S., Pinto-Correia, T., Almeida, M., Bartolini, F., Bezák, P., Biró, M. ***et al.*** 2018. Typology and distribution of small farms in Europe: Towards a better picture. *Land Use Policy*, 75: 784–798.

Heinke, J., Lannerstad, M., Gerten, D., Havlík, P., Herrero, M., Notenbaert, A.M.O., Hoff, H. & Müller, C. 2020. Water use in global livestock production—Opportunities and constraints for increasing water productivity. *Water Resources Research*, 56(12).

Herrero, M., Thornton, P.K., Gerber, P. & Reid, R.S. 2009. Livestock, livelihoods and the environment: Understanding the trade-offs. *Current Opinion in Environmental Sustainability*, 1(2): 111–120.

HLPE (High Level Panel of Experts on Food Security and Nutrition). 2013. *Investing in smallholder agriculture for food security.* A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. HLPE Report No. 6. Rome, FAO. www.fao.org/3/i2953e/i2953e.pdf

HLPE. 2016. *Sustainable agricultural development for food security and nutrition: What roles for livestock?* A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. HLPE Report No. 10. Rome, FAO. www.fao.org/3/i5795e/i5795e.pdf

HLPE. 2017. *2nd note on critical and emerging issues for food security and nutrition*. A note by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome, FAO. www.fao.org/fileadmin/user_upload/hlpe/hlpe_documents/Critical-Emerging-Issues-2016/HLPE_Note-to-CFS_Critical-and-Emerging-Issues-2nd-Edition__27-April-2017_.pdf

IFAD (International Fund for Agricultural Development). 2017. *Sending money home: Contributing to the SDGs*. Rome. www.ifad.org/documents/38714170/39135645/Sending+Money+Home+-+Contributing+to+the+SDGs%2C+one+family+at+a+time.pdf/c207b5f1-9fef-4877-9315-75463fccfaa7

IOM (International Organization for Migration). 2019. *World migration report 2020*. Geneva. https://publications.iom.int/system/files/pdf/wmr_2020.pdf

ITU (International Telecommunications Union). 2022. *ITU*. https://www.itu.int

Jayne, T.S., Muyanga, M., Wineman, A., Ghebru, H., Stevens, C., Stickler, M., Chapoto, A., Anseeuw, W., Westhuizen, D. van der & Nyange, D. 2019. Are medium-scale farms driving agricultural transformation in sub-Saharan Africa? *Agricultural Economics*, 50(S1): 75–95.

Kansiime, M.K., van Asten, P. & Sneyers, K. 2018. Farm diversity and resource use efficiency: Targeting agricultural policy interventions in East Africa farming systems. *NJAS: Wageningen Journal of Life Sciences*, 85(1): 32–41.

Kuper, M., Faysse, N., Hammani, A., Hartani, M., Marlet, S., Hamamouche, M.F. & Ameur, F. 2016. Liberation or anarchy? The janus nature of groundwater use on North Africa's new irrigation frontiers. In: A.J. Jakeman, O. Barreteua, R.J. Hunt, J.-D. Rinaudo & A. Ross, eds. *Integrated groundwater management concepts: Approaches and challenges*, pp. 583–615.

Lakner, C., Yonzan, N., Gerszon Mahler, D., Castaneda Aguilar, R.A. & Wu, H. 2021. Updated estimates of the impact of COVID-19 on global poverty: Looking back at 2020 and the outlook for 2021. In: *World Bank.* Washington, DC. Cited 17 September 2021. https://blogs.worldbank.org/opendata/updated-estimates-impact-covid-19-global-poverty-looking-back-2020-and-outlook-2021

Lawali, S. & Idrissa, I. 2015. *Roles and impacts of ICT in the reduction of vulnerability in rural households in Niger: The case of Maradi*. ICTs for Agriculture Series. CTA Working Paper 15/10. https://cgspace.cgiar.org/bitstream/handle/10568/89993/1873_PDF.pdf

López-Gunn, E., Rica, M. & van Cauwenbergh, N. 2012. Taming the groundwater chaos. In: L. De Stefano & M. Famón Llamas, eds. *Water, agriculture and the environment in Spain: Can we square the circle?*, pp. 227–240. Boca Raton, CRC Press. https://rac.es/ficheros/doc/00935.pdf

Lowder, S.K., Sánchez, M. V & Bertini, R. 2019. *Farms, family farms, farmland distribution and farm labour: What do we know today?* FAO Agriculture Development Economics Working Paper 19-08. Rome, FAO. www.fao.org/3/ca7036en/ca7036en.pdf

Lowder, S.K., Sánchez, M. V. & Bertini, R. 2021. Which farms feed the world and has farmland become more concentrated? *World Development*, 142: 105455.

Mainet, H. & Edouard, J.-C. 2017. The role of small and medium sized towns in Eastern Africa mountains: New opportunities or challenged position? In: *Rural-urban dynamics in the East African mountains*, pp. 27–45. Dar es Salaam, Mkuki Na Nyota and Nairobi, IFRA Publishers.

Margat, J. & van der Gun, J. 2013. *Groundwater around the world: A geographic synopsis*. Leiden, CRC Press/Balkema.
www.un-igrac.org/sites/default/files/resources/files/Groundwater_around_world.pdf

Michel, D. 2020. Water conflict pathways and peacebuilding strategies. *Peaceworks*, 14. United States Institute of Peace. www.usip.org/publications/2020/08/water-conflict-pathways-and-peacebuilding-strategies

Molle, F. & Wester, P., eds. 2009. *River basin trajectories: Societies, environments and development.* Comprehensive Assessment of Water Management in Agriculture Series, vol. 8. Wallingford, CAB International. www.iwmi.cgiar.org/Publications/CABI_Publications/CA_CABI_Series/River_Basin_Trajectories/9781845935382.pdf

Molle, F., Shah, T. & Barker, R. 2003. *The groundswell of pumps: Multilevel impacts of a silent revolution*. Paper prepared for the International Commission on Irrigation and Drainage Asia meeting.

Neufield, L., Hendriks, S. & Hugas, M. 2021. *Healthy diet: A definition for the United Nations Food Systems Summit 2021*. A paper from the Scientific Group of the UN Food Systems Summit. https://sc-fss2021.org/wp-content/uploads/2021/04/Healthy_Diet.pdf

Nolte, K., Chamberlain, W. & Giger, M. 2018. *Transactions foncières internationales dans le domaine de l'agriculture. Nouvelles perspectives offertes par Land Matrix*. Bern, Centre for Development and Environment, Montpelier, Centre de coopération Internationale en Recherche Agronomique pour le Développement, Hamburg, German Institute of Global and Area Studies and Pretoria, University of Pretoria. https://doi.org/10.7892/boris.107739

Oakerson, R.J. 1992. Analyzing the commons: A framework. In: D.W. Bromley, ed. *Making the commons work. Theory, practice and policy*, pp. 41–59. San Francisco, Institute for Contemporary Studies.

OECD (Organisation for Economic Co-operation and Development). 2015. *OECD principles on water governance*. Paris. www.oecd.org/cfe/regionaldevelopment/OECD-Principles-on-Water-Governance.pdf

OECD & FAO. 2018. *OECD-FAO agricultural outlook 2018-2027*. Paris and Rome. https://doi.org/10.1787/agr_outlook-2018-en

Ostrom, E. 1992. *Crafting institutions for self-governing irrigation systems.* San Francisco, Institute for Contemporary Studies Press.

Oxfam. 2016. *Desterrados: Tierra, poder y desigualdad en América Latina*. Oxfam International. www.oxfam.org/sites/www.oxfam.org/files/file_attachments/desterrados-full-es-29nov-web_0.pdf

Passarelli, S., Mekonnen, D., Bryan, E. & Ringler, C. 2018. Evaluating the pathways from small-scale irrigation to dietary diversity: Evidence from Ethiopia and Tanzania. *Food Security*, 10(4): 981–997.

Poláková, J., Farmer, A., Berman, S., Naumann, S., Frelih-Larsen, A. & von Toggenburg, J. 2013. *Sustainable management of natural resources with a focus on water and agriculture*. Science and Technology Options Assessment. Brussels, European Union. https://doi.org/10.2861/27324

Rafflegeau, S., Losch, B., Daviron, B., Bastide, P., Charmetant, P., Lescot, T., Prades, A. & Sainte-Beuve, J. 2015. Contributing to production and to international markets. In: *Family farming and the worlds to come*, pp. 129–144. Dordrecht, Springer. https://doi.org/10.1007/978-94-017-9358-2_8

Ricciardi, V., Wane, A., Sidhu, B.S., Godde, C., Solomon, D., McCullough, E., Diekmann, F. *et al.* 2020. A scoping review of research funding for small-scale farmers in water scarce regions. *Nature Sustainability*, 3(10): 836–844.

Robinson, T.P., Wint, G.R.W., Conchedda, G., Van Boeckel, T.P., Ercoli, V., Palamara, E., Cinardi, G., D'Aietti, L., Hay, S.I. & Gilbert, M. 2014. Mapping the global distribution of livestock. *PLoS ONE*, 9(5): 13 (e96084).

Samberg, L.H., Gerber, J.S., Ramankutty, N., Herrero, M. & West, P.C. 2016. Subnational distribution of average farm size and smallholder contributions to global food production. *Environmental Research Letters*, 11(12): 124010.

Scoones, I. 2009. Livelihoods perspectives and rural development. *The Journal of Peasant Studies*, 36(1): 171–196.

Shah, T. 2009. *Taming the anarchy: Groundwater governance in South Asia*. Washington, DC, Resources for the Future and Colombo, International Water Management Institute.

Sourisseau, J.-M., ed. 2015. *Family farming and the worlds to come*. Dordrecht, Springer.

Steenvorden, J. & Endreny, T., eds. 2004. *Wastewater re-use and groundwater quality*. IAHS Publication No. 285. Wallingford, International Association of Hydrological Sciences.

Thapa, G. 2009. *Smallholder farming in transforming economies of Asia and the Pacific: Challenges and opportunities*. Discussion paper prepared for the side event organized during the thirty-third session of IFAD's Governing Council, 18 February 2009. Rome, International Fund for Agricultural Development.

UNDP (United Nations Development Programme) & EC (European Commission). 2007. *Governance indicators: A user's guide*. New York and Luxembourg. www.un.org/ruleoflaw/files/Governance%20Indicators_A%20Users%20Guide.pdf

UNFCCC (United Nations Framework Convention on Climate Change). 2020. *Progress in the process to formulate and implement national adaptation plans*. FCCC/SBI/2020/INF.13. https://unfccc.int/sites/default/files/resource/sbi2020_inf13.pdf

United Nations. 2018a. *World urbanization prospects: The 2018 revision*. ST/ESA/SER.A/420. New York, Department of Economic and Social Affairs, Population Division. https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf

United Nations. 2018b. *Sustainable Development Goal 6: Synthesis report 2018 on water and sanitation*. New York. https://www.unwater.org/publications/sdg-6-synthesis-report-2018-on-water-and-sanitation/

United Nations. 2019. *World population prospects 2019: Highlights*. ST/ESA/SER.A/423. New York, Department of Economic and Social Affairs, Population Division. https://population.un.org/wpp/Publications/Files/WPP2019_Highlights.pdf

United Nations. 2020. *International migration 2020 highlights.* ST/ESA/SER.A/452. New York, Department of Economic and Social Affairs, Population Division. www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/undesa_pd_2020_international_migration_highlights.pdf

United Nations ESCAP (Economic and Social Commission for Asia and the Pacific). 2009. *What is good governance*? www.unescap.org/sites/default/d8files/knowledge-products/good-governance.pdf

United Nations OHCHR (Human Rights Office of the High Commissioner) & Heinrich-Böll-Stiftung. 2018. *The other infrastructure gap: Sustainability*. Human Rights and Environmental Perspectives. Geneva and Berlin. www.ohchr.org/Documents/Publications/TheOtherInfrastructureGap_FullLength.pdf

UN-Water. 2021. *The United Nations world water development report 2021: Valuing water*. United Nations Educational, Scientific and Cultural Organization. https://unesdoc.unesco.org/ark:/48223/pf0000375724

Wada, Y., Flörke, M., Hanasaki, N., Eisner, S., Fischer, G., Tramberend, S., Satoh, Y. *et al.* 2016. Modeling global water use for the 21st century: The Water Futures and Solutions (WFaS) initiative and its approaches. *Geoscientific Model Development*, 9(1): 175–222.

World Bank. 2016. *Poverty and shared prosperity 2016: Taking on inequality.* Washington, DC. https://openknowledge.worldbank.org/handle/10986/25078

World Bank. 2020. *Poverty and shared prosperity 2020: Reversals of fortune*. Washington, DC. https://openknowledge.worldbank.org/bitstream/handle/10986/34496/9781464816024.pdf

Yoffe, S., Wolf, A.T. & Giordano, M. 2003. Conflict and cooperation over international freshwater resources: Indicators of basins at risk. *Journal of the American Water Resources Association*, 39(5): 1109–1126.

3

RISKS TO LAND AND WATER RESOURCES RUN DEEP

Key messages

Pressures on land and water systems risk compromising agricultural productivity. This is occurring precisely at times and in places where growth is most needed to meet global food security targets. Human-induced land degradation and water scarcity are increasing the risk levels for agricultural production and ecosystem services.

By 2050, FAO estimates agriculture will need to produce almost 50 percent more food, fibre, livestock feed and biofuel than in 2012. Agricultural production in sub-Saharan Africa and South Asia will need to at least double (increase of 112 percent) to meet estimated calorific requirements. The rest of the world will need to produce at least 30 percent more.

Meeting future demand will require support measures and interventions that complement the sustainable intensification of agriculture. These include substantially improving productivity along the food value chain, reducing food loss and waste (FLW), and addressing human dietary health.

Climate change adds uncertainty to the agroclimatic risks that producers are facing, particularly those who are least able to buffer shocks and are food insecure. Climate volatility and extreme hydrological and thermal events will affect all producers, but risks are greater in areas with minimal resource endowments, growing populations and limited economic powers to adapt local food systems or find substitutes.

Increasing competition for land, soil and water for agriculture and food production adds to the pressures on limited resources. It increases the risks to sustainable agriculture and food production and broader goals such as zero hunger and eliminating poverty. Annual cereal production growth rates remain below 1 percent. Limits on the global food system must be recognized, and alternative approaches planned and implemented, to avoid, mitigate or manage risks.

The land degradation risk caused by agricultural production is significant. However, it is rarely considered until cropland soils and pastures are significantly depleted or lost because of human-induced erosion, salinization and pollution. Climate change is expected to adversely affect growing conditions for crops and natural ecosystems in subtropical developing countries. In contrast, warming in temperate latitudes could extend growing seasons for some cereals. Sustainable land and water management across all agroclimatic zones will become a priority if GHG emissions are to be controlled and food production increased.

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Water scarcity increases agricultural production risks as water availability, storage and conveyance systems reach their design limits. In many areas of high water stress, farmers manage their production risks by abstracting shallow groundwater for irrigation, and in some cases, by using non-renewable groundwater. Competition for diminishing quantities of high-quality groundwater is intensifying as many aquifers suffer from overabstraction and saline intrusion plus a combination of agricultural and industrial pollution.

Water pollution from agriculture is proliferating. New and emerging pollutants and antimicrobial resistance in the environment are adding to clean-up costs and challenging technological and management solutions on land, water, and lacustrine and nearshore marine environments. Although plastic pollution is primarily land based, a significant amount of it travels via rivers and threatens marine life and human health.

The operational question for agriculture is complex. The sector needs to review if the overall risk to food production can be avoided or mitigated by changing agricultural and land management practices while reducing impacts on livelihoods, human health and ecosystem services.


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3.1 Introduction

The risk to agricultural production is rooted in the state of land, soil and water resources, the effects of human use and their systemic interaction with the climate. The climatic regime in each GAEZ primarily sets the risk and determines the specific frequency and magnitude of temperature and precipitation events. Competition for land and access to water compound the natural resource risk as freshwater is depleted and soil resources degraded. These affect impoverished communities, whose food security and livelihoods depend directly upon land and water (Chapter 2). The scale and intensity of current land and water use for agriculture are not sustainable at the global level (Gerten *et al.*, 2020). In addition, climate change introduces uncertainty and takes the agroclimatic context into ranges beyond standard probabilities. Climate change projections illustrate how temperature changes can exacerbate production risks by extending the magnitude of climate events beyond the normal or historical distributions of agroclimatic regimes (Kummu *et al.*, 2021).

This chapter assesses land, soil and water resources as systems under human pressure and risks to future agricultural production as the demand for limited natural resources intensifies. The previous edition of this report (SOLAW 2011) identified a wide range of risks to production, but this chapter now focuses on those that are most prominent: climate change, land and soil degradation, and overall freshwater scarcity, including groundwater depletion and deteriorating water quality. The purpose is to assist in identifying the preventive measures necessary to protect stable systems and the proactive measures required to reverse negative trends and move towards sustainable food and agricultural production as discussed in Chapters 4 and 5. The central concern is the risk to agricultural production presented by internal factors (e.g. the environmental impact of agricultural practice on land and water) and external factors (including the intersectoral competition for land and water resources).

The main socioeconomic drivers of demand for land and water resources are population growth, rapid urbanization, increased mobility, and the effects of increased income level dietary changes – leading to higher demand for meat, dairy products and ultraprocessed foods. However, poverty, unplanned urban expansion, civil strife, migration and insecurity of tenure lead to localized pressures on resources as current agricultural production systems adapt, and, in some cases, result in unsustainable resource management practices. Over the past decade, land-use changes and pressures on productive land and water systems have steadily increased to the point where some systems can no longer provide or maintain former ecological function levels and agricultural production. Some evidence is immediately visible, such as erosion in deforested land, but many issues are less apparent. One example is increased water and soil pollution levels from agricultural land, leading to land salinization and eutrophication of surface waters.

Climate change is generating additional pressures, compounding agroclimatic risks associated with agricultural systems and introducing a level of uncertainty at a global scale, with faster warming translating into specific impacts across all regions (IPCC, 2021). Rising temperatures and changes in the hydrological cycle amplify the frequency and severity of extreme flood and drought events. There is evidence that hydrologic regimes and weather systems are causing significant shifts in agricultural production zones and cropping patterns. Agricultural practices, such as draining organic soils, are accelerating GHG emissions, and the shifting seasonal availability of local water resources affects rural livelihoods, particularly those of smallholder families with no access to water storage or irrigation services.

This chapter offers a brief analysis of risks generated by current patterns and practices of land and water management. Unlike total crop water requirements, which are predictable to 2050 with and without climate change, it is not yet possible to predict the impacts of climate change on land degradation. Thus, land degradation risk can be assessed only in the broader multi-index approach used in Chapter 1. These issues set the agenda for the policy and management responses in Chapters 4 and 5.

3.2 Looking into the future

3.2.1 Climate change and land degradation

The risks to agricultural production from the impacts of climate change (drought, rainfall events and temperature extremes) are already being experienced across rainfed agricultural land. Historically, irrigation has been the prime adaptation to variations in climate, deployed when soil moisture deficits in rainfed land have become intolerable. However, within the current distribution of rainfed and irrigated land (Chapter 1), land degradation processes have intensified to the point where major soil groups are exhibiting declining structure and fertility. These changes are less apparent than the immediately visible impacts of mechanical erosion from rainfall, runoff and aeolian processes, but are nevertheless significant.

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It has proved difficult to classify, with any degree of consistency, the extent and severity of human-induced land degradation in the past (Gibbs and Salmon, 2015). But the compilation of contemporary datasets illustrates converging evidence to set a baseline for 2010–2012 (Coppus, 2022; see Chapter 1).

In 2018, IPBES published a thematic assessment of land degradation and restoration to establish the effect of degradation on biodiversity, ecosystem services and human welfare (IPBES, 2018). The findings were elaborated in the 2019 IPCC special report on climate change and land (IPCC, 2019). Both reports found land degradation affects people and ecosystems in all regions. Patterns of land use and management are estimated to produce almost 23 percent of global GHG emissions (IPCC, 2019). Taking into account post-harvest processing, storage and transport increased the overall contribution of the global food system to 35 percent in 2015 (Muntean *et al.*, 2018). Agriculture absorbs 26 percent of the economic impact of climate disasters, rising to 83 percent for drought in developing countries. With climate change expected to push 122 million more people, mainly farmers, into extreme poverty by 2030, leveraging the adaptation and mitigation potential simultaneously across agricultural landscapes is vital in meeting emissions reduction targets.


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Climate change and land degradation are interrelated. Extremes of heat and high rainfall intensities exacerbate land degradation. Land degradation processes accelerate GHG emissions and reduce carbon sequestration in ecosystems. Although carbon cycle stability is crucial for soil fertility and biodiversity, estimates suggest that between 20 and 60 percent of carbon stocks, historically stored in SOM as active components, has been lost since soil cultivation began (IPCC, 2019). This is attributed to changes in land use and land management practices (see Chapter 1).

Climate change will affect the rate and magnitude of some degradation processes and introduce new degradation patterns (IPCC, 2019). Climate models predict increasing frequency, intensity and amount of heavy rainfall, raising the risk of landslides, erosion events and flash floods. Tropical cyclones are already shifting towards the poles, and the speed at which they move is slowing. Increasing exposure of coastal areas to intense and long-duration storms will lead to land degradation and affect coastal forest structure, composition and resilience. Sea-level rise will increase coastal erosion and saline intrusion, leaving coastal areas vulnerable to catastrophic weather events.

Heat stress from rising global temperatures is already affecting agricultural productivity, the suitability of some areas for commodity crops (see Chapter 4, section 4.2.7) and livestock rearing. Prolonged droughts reduce vegetation cover and make soil prone to erosion, nutrient depletion and biodiversity loss. Heat stress is also altering wildfire regimes in many parts of the world. Some ecosystems have already adapted to specific fire regimes and produce changes in vegetation and soil properties that ultimately affect biodiversity, carbon stocks, albedo and fire–atmosphere–vegetation feedbacks, among other impacts (IPCC, 2019).

The impacts of climate change on land degradation are difficult to separate from other impacts given the diversity of social, economic and political settings, but there is little doubt about the risk to production. As risk multipliers, climate change and land degradation will interact to affect poverty, food security, conflict and migration, with the main burden falling on communities whose access to land and water is limited or excluded.

3.2.2 Future of food and agriculture foresight scenarios

Anticipating the future of agriculture is a central concern for FAO Members, particularly those experiencing high levels of food insecurity. The FAO global outlook exercise "The future of food and agriculture: Trends and challenges" (FOFA) (FAO, 2018) produced a single projection of the future but without explicit consideration of climate change or possible mitigation pathways. To test possible climate futures and the implications for land and water resource availability under rising demand for food and fibre, FAO developed three climate-based scenarios (Box 3.1) based on a range of assumptions about the future to 2050 (FAO, 2018). They build upon the Shared Socioeconomic Pathways (SSPs) established for the IPCC fifth assessment report (IPCC, 2014; O'Neill *et al.*, 2017).

Two economic models provide quantitative projections for the scenarios: the FAO Global Agriculture Perspectives System, which focuses on the relationships between production and consumption of food and agricultural goods, and food security and nutrition, and the Environmental Impact and Sustainability Applied General Equilibrium model.

BOX 3.1
FAO FUTURE OF FOOD AND AGRICULTURE SCENARIOS FROM A LAND-AND WATER-USE PERSPECTIVE

Business as usual (BAU): Climate futures, Representative Concentration Pathway (RCP) 6.0 and SSPs 2/3 ("middle of the road")

Arable land (the physical area under temporary and permanent agricultural crops) expands at faster annual rates than in the last decades, and land degradation is only partially addressed. Land intensity, the quantity of land per unit of output, decreases as crop and animal yields increase, but these achievements require the progressive use of chemicals. Deforestation and unsustainable raw material extraction continue while water efficiency improves, but the lack of significant changes in technology leads to the emergence of more water-stressed countries.

Towards sustainability (TSS): Climate futures, RCP 4.5 and SSP 1 ("the green road")

Low-input processes lead water intensity to decrease substantially and energy intensity to improve substantially against the levels seen under the BAU scenario. Land-use intensity, the quantity of land per unit of output, drops compared to current levels, thanks to sustainable agricultural intensification and other practices to improve resource efficiency. This helps to preserve soil quality and restore degraded and eroded land. Agricultural land is no longer substantially expanded, and land degradation is addressed. Water abstraction is limited to a smaller fraction of available water resources.

Stratified societies (SSS): Climate futures, RCP 8.5 and SSP 4 ("a road divided")

The world suffers further deforestation. New agricultural land is used to compensate for increased degradation and satisfy additional agricultural demand, which is left unmanaged. The quantity of land per unit of output decreases for commercial agriculture but remains stable or increases for family farmers, who increasingly suffer from crop losses fuelled by extreme climate events. Water use is not sustainable in many regions, and there is little investment towards water-use efficiency. Climate change exacerbates water and land constraints.

Notes

Harvested areas and yield differentials for each cropping system (irrigated and rainfed)

Data on harvested areas are used to calculate the shares of irrigated and rainfed production systems by crop and yield differentials between the two systems in the base year. The FAO and the International Institute for Applied Systems Analysis (IIASA) GAEZ data portal includes geospatial datasets consistent with country-level FAOSTAT data on harvested areas, yields and crop production. These are derived by disaggregating ("downscaling") country-level FAOSTAT production data for the period 2009–2011 to pixel level using an iterative rebalancing approach that ensures matching country totals. The assignment of crops and crop systems to each pixel is based on FAO GLC-SHARE (Latham *et al*., 2014), which provides high-resolution land-cover data, geospatial data on land equipped for irrigation (GMIA, available at https://www.fao.org/aquastat/en/geospatial-information/global-maps-irrigated-areas (Siebert *et al*., 2013)) and other datasets.

Land areas

Data on land cover are used to estimate the amount of suitable land available in the future under alternative climate scenarios. The GAEZ data portal includes pixel-level data on protected areas, based on a recent version of the World Database of Protected Areas (available at https://www.unep-wcmc.org/resources-and-data/wdpa) a comprehensive global dataset of marine and terrestrial protected areas that includes those under IUCN, such as nature reserves and national parks, protected areas with an international designation status, such as World Heritage and Ramsar Wetland areas, and those with national protection status. The land-suitability assessment does not account for land productivity changing over time due to natural or human-induced degradation and may overestimate potential land availability.

Source: Adapted from **FAO**. 2018. *The future of food and agriculture: Alternative pathways to 2050.* Summary version. Rome. www.fao.org/3/CA1553EN/ca1553en.pdf

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3.2.3 Implications of the scenarios for land and water

The FOFA foresight scenarios for cropland (arable land and land under permanent crops) apply a set of technical improvements (yield growth and cropping intensities) and climate change drivers to arrive at harvested areas of crop production to satisfy food balance sheets in 2030 and 2050. The projections for harvested areas on rainfed and irrigated land generate demand for land and water resources under the three FOFA scenarios (FAO, 2018). Under the BAU scenario, irrigated areas would need to increase their contribution to total production value from 42 percent in 2012 to 46 percent by 2050 (FAO, 2018).

When harvested area projections for irrigated and rainfed production are converted to arable land requirements, globally the cultivated area under the BAU scenario would need to grow from 1 567 million ha in 2012 to 1 690 million ha by 2030 and 1 732 million ha by 2050 (FAO, 2018). This growth projection is based on expected yield growth and higher cropping intensities required to meet the anticipated demand in 2050.

While it is possible to project land suitability under climate change scenarios (Chapter 4, section 4.2.7), it is not possible to predict how production scenario projections will be distributed in detail across agroecological zones. Some expansion to new agricultural land can be expected, together with conversion from non-agricultural uses, preparation of fallow land and restoration of abandoned land through consolidation/land banking (FAO, 2017). Land substitution through intensification is factored in through cropping intensity assumptions, but conjectural projections such as land required to substitute animal protein with plant-based protein are not included.

In 2017, FAO projected the global area equipped for irrigation might increase at a low annual growth rate of 0.1 percent, reaching 337 million ha by 2050 (FAO, 2017). In 2012, the area equipped for irrigation was 323.3 million ha, and in 2018, the reported area had reached 328.3 million ha, indicating annual growth rates of the order of 0.3 percent. The FOFA foresight BAU scenario expects the global land area equipped for irrigation to expand to 498 million ha by 2050 (FAO, 2018), indicating an annual growth rate of only 0.14 percent. This represents a significant slowdown, compared to that for 1961 to 2009, when the global area under irrigation grew at an annual rate of 1.6 percent and more than 2 percent in the poorest countries. Most expansion of irrigated land is likely to take place in low-income countries.

The water resource implications for this growth in irrigated harvested areas were modelled with an FAO global water balance model, GlobWat (Hoogeveen *et al.*, 2015), for the three FOFA climate change scenarios (FAO, 2018). Keeping the same set of cropping calendars (seasonality), the changes in temperature and precipitation under the respective RCP scenarios drive crop water requirements on irrigated land purely through incremental evapotranspiration due to the import of irrigation water into each irrigated cell in the model. In addition, the specific water requirements for land preparation in paddy irrigated areas are held constant since residual soil moisture that is not evaporated is assumed to drain to groundwater.

From a 2012 baseline used in the FOFA analysis (FAO, 2018) in which some 407 million ha of irrigated land was harvested (on an equipped area of approximately 305 million ha), the growth in harvested areas was calculated for the three scenarios with and without climate change. The model indicates that total crop water requirements (incremental evapotranspiration due to irrigation plus land preparation, leaching requirements and maintenance of rice paddy) would increase from 1 507 km³/year in 2012 to almost 1 761 km³/year by 2050 without considering climate change and to almost 1 952 km³/year with climate change under the BAU scenario (Table 3.1). The spread between the with climate scenarios is not that wide, from 1 816 km³/year under "sustainability" assumptions to 1 993 km³/year under "stratified society" assumptions.

Taking account of conveyance losses from the point of withdrawal to the point of consumption, the BAU assumptions would push annual gross agricultural withdrawals from 2 673 km³/year in 2012 towards 3 500 km³/year in 2050 on the basis of current crop water requirement to withdrawal ratios (FAO, 2021a) assumed at a global average of 0.56. In general, these withdrawal ratios can be expected to improve (i.e. become more "efficient") as the proportion of pressurized irrigation systems increases with the adoption of more precision agriculture. Section 3.4 examines the risks associated with this level of withdrawal and consequent soil/water pollution impacts in more detail.

3.2.4 Scenario areas of concern

The foresight scenarios set out possible food and agricultural production futures in broad macroeconomic terms (FAO, 2017) and explore alternative pathways (FAO, 2018). They indicate arable land availability and expected crop yield growth and cropping intensities under the climate scenarios. The increases in evapotranspiration with the climate futures factored in are striking. For all scenarios, the increase in water consumption due to climate change above the 2012 baseline reaches 8–9 percent by 2030 and 12–16 percent by 2050. When taken with the additional water volumes required for land preparation and maintenance of rice paddy, total crop water requirements are even higher (Table 3.1).

The expected agricultural future hinges on the continued availability of suitable land, soil and water resources. However, the risks of failure of current production patterns are immediate. Thresholds are already exceeded for some land and water systems, where land degradation and water scarcity combine to affect food security and associated livelihoods (Gerten *et al.*, 2020). Abrupt socioeconomic transitions are taking place in degraded landscapes that need targeted policy and management interventions.

Climate change increases drought risk by increasing the frequency and magnitude of extreme weather events. It changes the average climate conditions and climate variability and generates new threats in regions with little experience of dealing with drought. Droughts develop slowly and are not easily recognized at first, but can have deep and widespread impacts on societies, ecosystems and economies (UNDRR, 2021) (Chapter 4).

Rainfed systems

Seasonal rains and temperature progressions have immediate impacts on rainfed farming systems (Map 3.1). The drought frequency in main cereal-producing regions, such as central United States of America, the Punjab state in India, Ukraine and eastern Australia, is cause for concern, particularly where irrigation is not an option. The FAO FOFA scenarios, which exclude protected areas (615 million ha) and land-cover classes used for other purposes, limit suitable areas for rainfed crop production expansion to approximately 400 million ha. More than two-thirds of this suitable land is in low- and middle-income countries, half in sub-Saharan Africa (29 percent) and Latin American countries (21 percent).

TABLE 3.1 ANTICIPATED INCREASES IN CROP WATER REQUIREMENTS INDUCED BY DEMAND AND CLIMATE FORCING TO 2050

REGION	BASELINE			BAU				TSS				SSS			
	Area irrigated (ha)	ET irrigation (million m³)	Total CWR (million m³)	Total CWR 2050 (million m³)	Total CWR 2050 cc (million m³)	Δ (%)	Δ cc (%)	Total CWR 2050 (million m³)	Total CWR 2050 cc (million m³)	Δ (%)	Δ cc (%)	Total CWR 2050 (million m³)	Total CWR 2050 cc (million m³)	Δ (%)	Δ cc (%)
Northern Africa	6 336 576	61 750	62 969	60 682	66 194	−4	5	50 404	55 396	−20	−12	61 099	70 089	−3	11
Sudano-Sahel	2 607 514	17 297	19 193	19 888	23 127	4	20	21 407	25 147	12	31	19 612	23 736	2	24
Gulf of Guinea	585 938	2 303	3 015	5 078	4 851	68	61	6 688	6 359	122	111	4 888	4 918	62	63
Central Africa	121 634	221	319	488	497	53	56	635	647	99	103	479	498	50	56
Eastern Africa	619 385	3 367	3 603	6 211	5 640	72	57	8 332	7 452	131	107	5 869	5 378	63	49
Southern Africa	2 060 468	8 871	9 046	17 530	19 804	94	119	15 643	17 938	73	98	16 795	20 525	86	127
Indian Ocean islands	1 074 645	2 233	4 046	6 507	7 069	61	75	8 263	9 287	104	130	6 374	7 096	58	75
Northern America	29 470 830	99 007	101 101	140 448	131 006	39	30	132 546	124 269	31	23	168 901	168 774	67	67
Mexico	6 778 510	29 260	29 306	44 815	44 249	53	51	44 063	44 065	50	50	42 557	44 567	45	52
Central America	509 032	4 525	4 742	6 455	6 906	36	46	7 610	8 162	60	72	6 056	6 654	28	40
Antilles	1 295 871	2 503	3 565	4 663	4 991	31	40	4 276	4 774	20	34	4 374	5 021	23	41
Guyanas	190 128	428	708	859	1 067	21	51	971	1 201	37	70	843	1 020	19	44
Andes	4 330 560	22 938	26 039	37 786	37 090	45	42	44 399	43 186	71	66	36 084	36 544	39	40
Brazil	4 431 697	27 568	30 336	40 405	47 277	33	56	47 588	55 025	57	81	37 735	49 810	24	64
Southern America	4 022 088	23 845	24 912	38 109	44 722	53	80	43 578	52 085	75	109	38 671	48 983	55	97
Arabian Peninsula	2 458 827	17 455	17 455	20 257	20 796	16	19	17 771	18 294	2	5	21 127	22 337	21	28
Caucasus	2 130 901	3 512	3 516	4 457	5 487	27	56	3 802	4 791	8	36	4 269	5 703	21	62

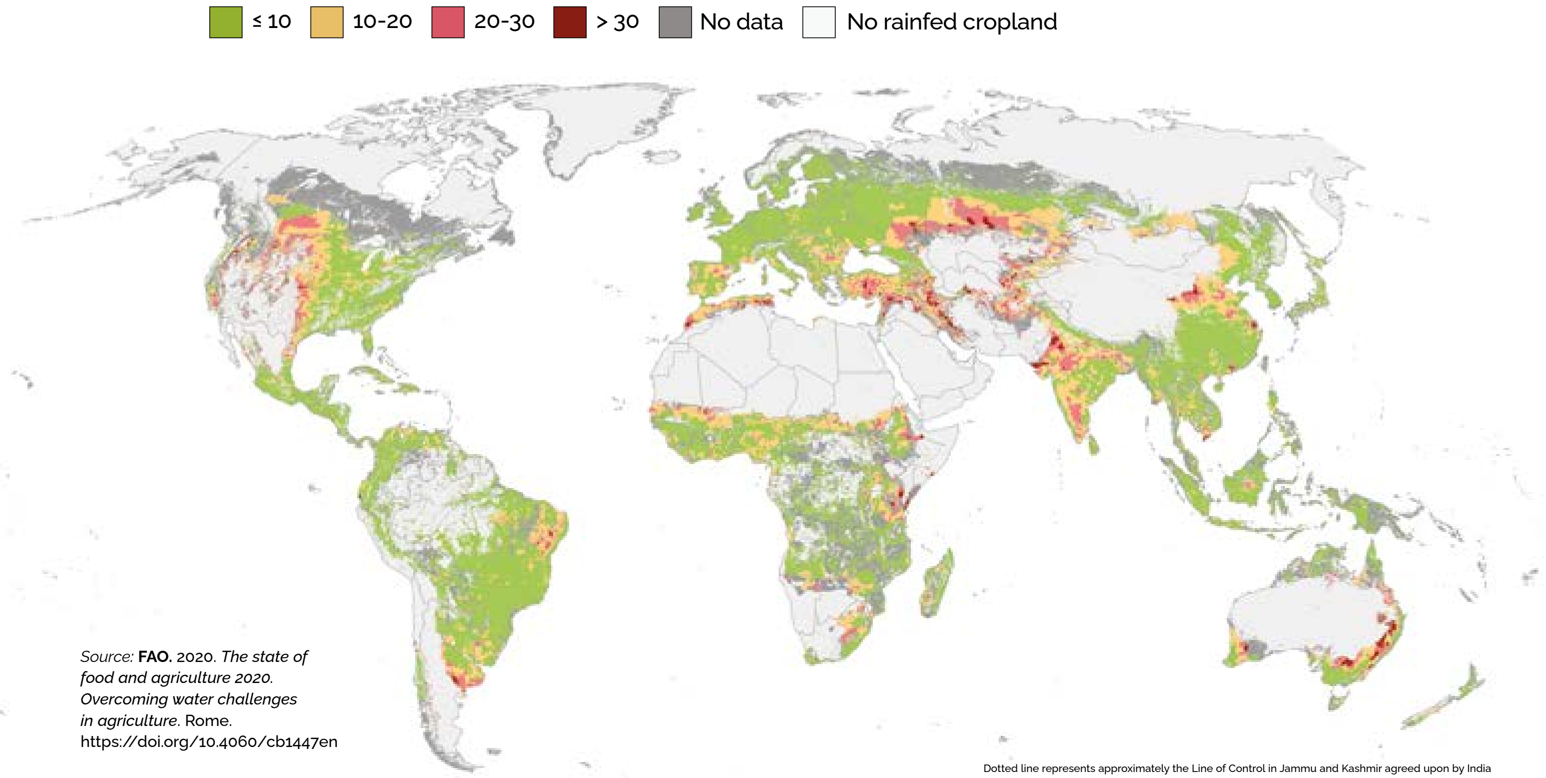
TABLE 3.1 (CONTINUED)

REGION	BASELINE			BAU				TSS				SSS			
	Area irrigated (ha)	ET irrigation (million m^3)	Total CWR (million m^3)	Total CWR 2050 (million m^3)	Total CWR 2050 cc (million m^3)	Δ (%)	Δ cc (%)	Total CWR 2050 (million m^3)	Total CWR 2050 cc (million m^3)	Δ (%)	Δ cc (%)	Total CWR 2050 (million m^3)	Total CWR 2050 cc (million m^3)	Δ (%)	Δ cc (%)
Iran (Islamic Republic of)	8 823 642	46 738	47 849	46 959	49 479	−2	3	38 711	41 214	−19	−14	46 959	51 944	−2	9
Near East	10 568 152	44 242	44 623	53 323	61 705	19	38	50 292	59 078	13	32	53 381	65 994	20	48
Central Asia	13 677 878	55 664	56 451	56 439	62 246	0	10	52 389	58 631	−7	4	55 602	65 032	−2	15
South Asia	85 245 570	528 886	617 833	687 800	801 483	11	30	595 247	677 020	−4	10	656 718	762 395	6	23
East Asia	66 392 461	169 812	235 821	278 689	308 548	18	31	263 193	300 516	12	27	279 428	318 185	18	35
Mainland Southeast Asia	13 672 858	42 456	70 500	76 625	82 045	9	16	81 433	86 456	16	23	74 106	80 461	5	14
Maritime Southeast Asia	8 564 294	24 932	44 065	48 982	46 812	11	6	54 612	52 062	24	18	47 568	45 636	8	4
Northern Europe	837 947	504	504	615	823	22	63	580	805	15	60	890	1 273	77	153
Western Europe	4 300 929	3 765	3 808	5 202	6 920	37	82	4 855	6 561	28	72	6 308	9 095	66	139
Central Europe	3 575 931	1 100	1 155	1 409	1 884	22	63	1 386	2 015	20	74	1 578	2 408	37	108
Mediterranean Europe	10 085 452	24 086	24 914	35 223	40 881	41	64	28 091	34 059	13	37	38 331	49 223	54	98
Russian Federation	2 378 206	2 520	2 912	3 720	4 307	28	48	4 381	5 098	50	75	3 738	4 691	28	61
Eastern Europe	2 812 284	1 193	1 246	1 592	1 978	28	59	1 847	2 362	48	90	1 600	2 192	28	76
Australia and New Zealand	4 618 645	11 661	11 856	10 681	12 161	−10	3	10 879	12 197	−8	3	10 941	13 125	−8	11
WORLD	304 578 642	1 284 642	1 507 408	1 761 898	1 952 046	17	29	1 645 873	1 816 153	9	20	1 752 882	1 993 308	16	32

Note: cc = climate change; CWR = crop water requirements; ET = evapotranspiration.

Source: Adapted from **FAO**. 2022. *The state of the world's land and water resources for food and agriculture 2021: Systems at breaking point.* SOLAW 2021 background studies. In: *Land & Water.* Rome. www.fao.org/land-water/solaw2021/en

MAP 3.1 DROUGHT FREQUENCY ON RAINFED FARMING SYSTEMS, 1984–2018



Source: **FAO.** 2020. *The state of food and agriculture 2020. Overcoming water challenges in agriculture*. Rome. https://doi.org/10.4060/cb1447en

Modified to comply with to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Sudan and South Sudan has not yet been determined.

Map 3.1 shows the historical frequency of severe drought in relation to the distribution of rainfed cropland between 1984 and 2018. Drought frequency exceeding 30 percent is considered to amplify production risks. Map 3.2 can be interpreted to indicate the high level of drought risk on soils subject to over-grazing where reduced SOM and increased soil compaction combine with pressures on local groundwater resources to meet irrigation and livestock watering demands.

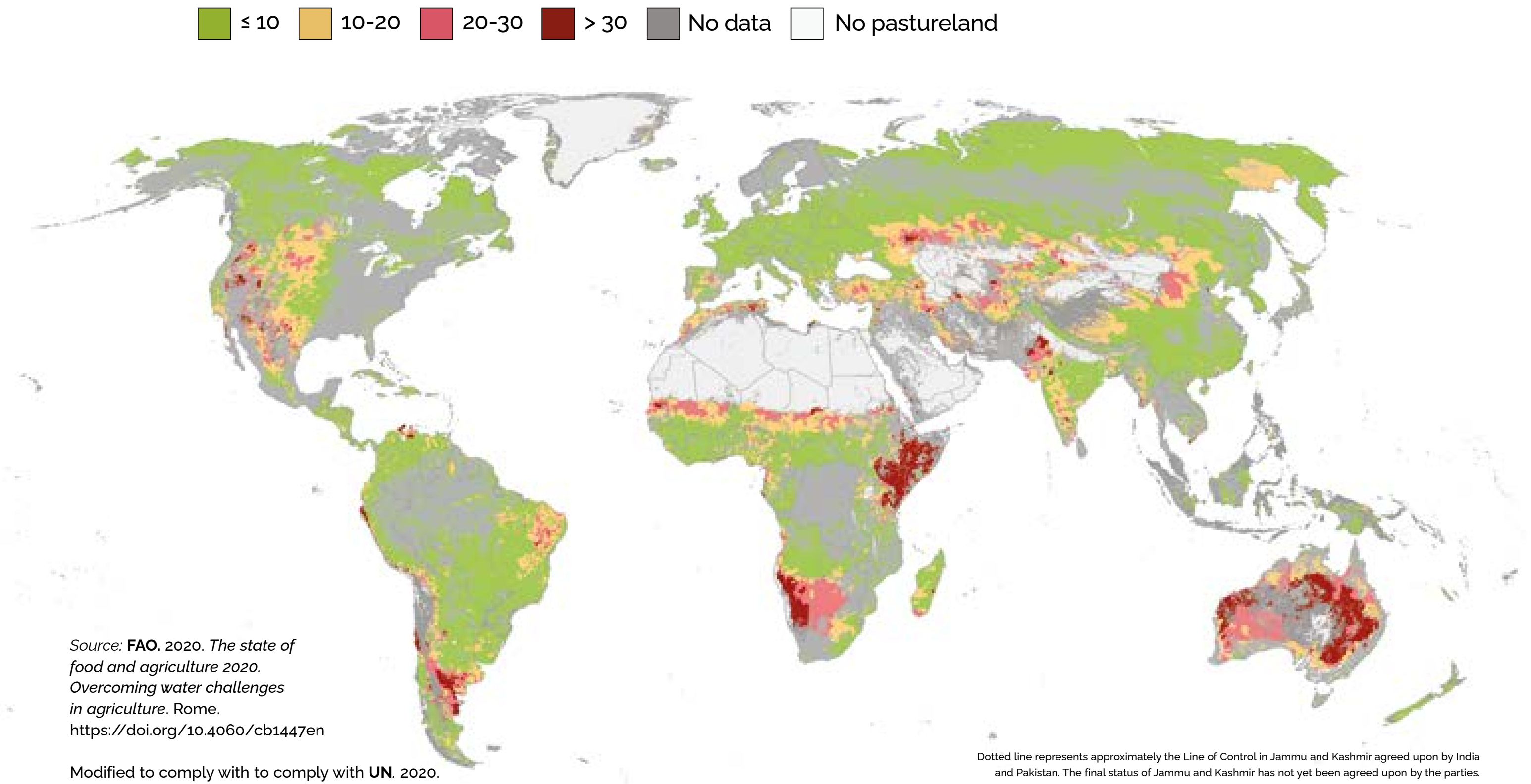
Pastoral systems

Pastoral systems also mostly depend on seasonal rainfall for forage, even if access to stored water in dams or aquifers mitigates the risk of dehydration (Map 3.2). The risk is high where there is low rainfall, soil desiccation, high temperature and limited or saline groundwater, as is the case in central Sudan and the Horn of Africa. Pastoral systems for dairy and meat products, including small ruminants, have most to lose when the drought frequency is greater than 30 percent, particularly where carrying capacity is frequently exceeded with the consequent breakdown in soil structure and loss of soil through wind and water erosion.

Irrigation systems

Concerns over irrigated areas are significant. The areas equipped for irrigation that are most productive are broad alluvial plains, deltas and coastal margins in subtropical climates with high evaporation rates but subject to monsoonal rainfall, inundation and susceptibility to salinization. In 2012, irrigated areas accounted for 42 percent of total production value using base-year commodity prices. This reflects higher land productivity (yield), greater cropping intensities and higher-value crops (FAO, 2018). Irrigated agriculture is concentrated on just 22 percent of cropland, and, together with hydrological variability, the risks from water stress and flood damage are relatively high (Map 3.3).

MAP 3.2 DROUGHT RISK ON PASTORAL FARMING SYSTEMS, 1984–2018

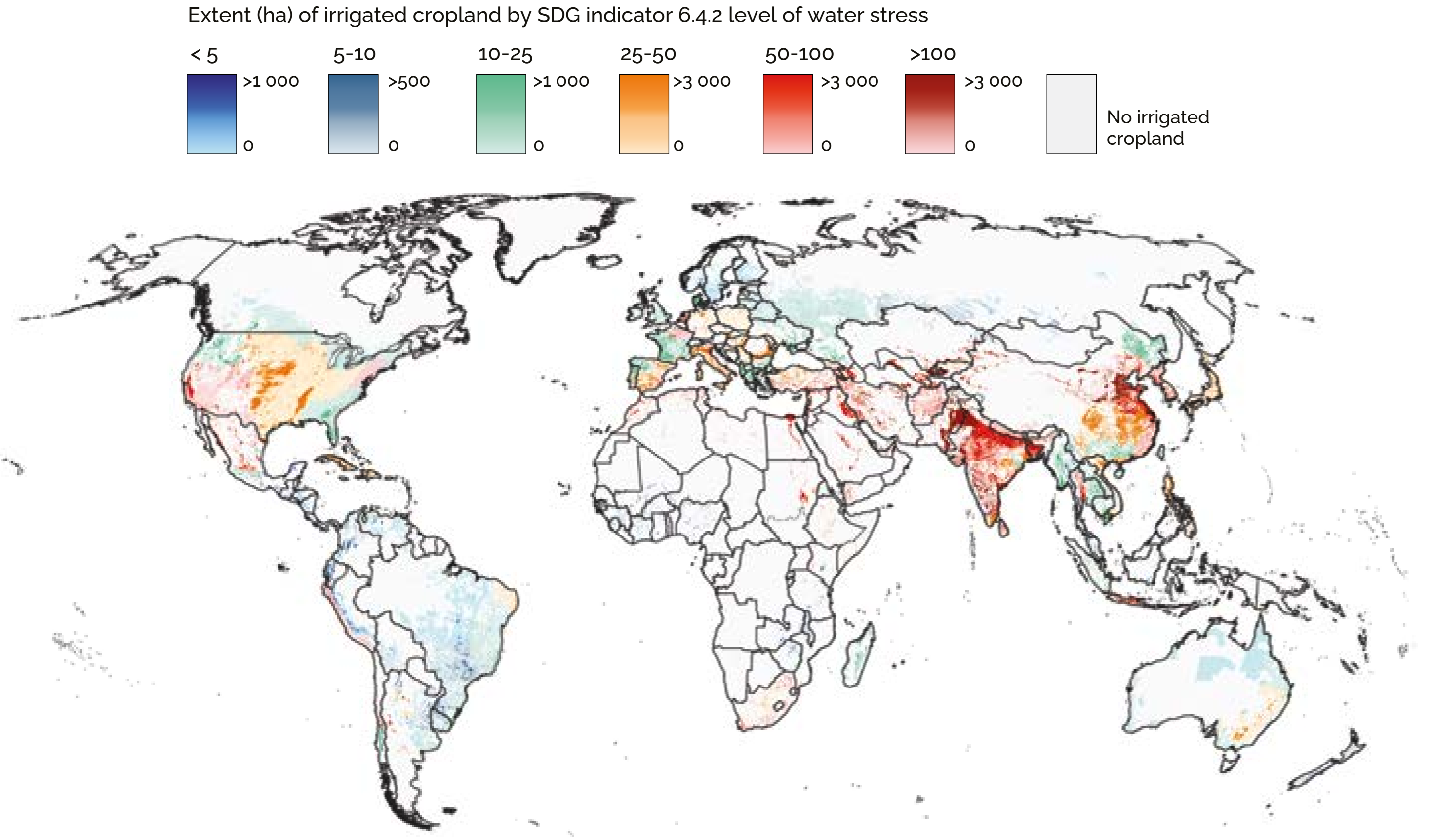


Source: **FAO.** 2020. *The state of food and agriculture 2020. Overcoming water challenges in agriculture*. Rome. https://doi.org/10.4060/cb1447en

Modified to comply with to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Sudan and South Sudan has not yet been determined.

MAP 3.3 LEVELS OF WATER STRESS ON IRRIGATED AREAS, 2015



Source: **FAO**. 2020. *The state of food and agriculture 2020. Overcoming water challenges in agriculture*. Rome. https://doi.org/10.4060/cb1447en. Modified to comply with to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

Final status of the Abyei area is not yet determined

The gradual loss of soil structure and fertility, and salt accumulation, multiply the production risks. The land's ability to recover from early frosts, heat flux and flooding to maintain cropping calendars is another crucial element of the resilience of irrigated farming systems and food security.

Areas needing urgent attention

The scale of risks to sustain production from land degradation and water scarcity requires urgent attention for improving agricultural practices and applying nature-based solutions (NbSs) to sustain productive systems, specifically on:

- Clusters of severely degraded land in coastal zones where depleted aquifers supply local and international food systems. For example, soil and water pressures are high where pollution from nutrient overenrichment produces dead zones, such as in the Mediterranean basin and coastal Southeast Asia.
- Broad alluvial plains dedicated to irrigated cereal production that lack adequate drainage and where soils have become saline and sodic, such as in the Indus basin.
- Semi-arid rangelands with limited aquifer storage supporting agropastoral systems on fragile soils experiencing high rates of pluvial and aeolian erosion and deposition, such as in the Sahel and East Africa uplands.
- Humid uplands experiencing high deforestation and soil erosion rates, such as in Central America and Caribbean, and Southern America regions.

Land and water management continually adapts to changing agroclimatic conditions and market demand to keep pace with an expanding global food system. The central concern remains. Maintaining sustainable levels of production while avoiding further damage to the natural resources and the provision of ecosystem services will continue to dominate a global debate on the future of food and agriculture. Agricultural and environmental practices will need to continuously improve to reverse trends and spread benefits where there continues to be unmet demand among vulnerable populations. Generating environmental benefits through agricultural practices that also sustain these vital agricultural systems is therefore critical. This aligns with SDG aspirations and associated targets, specifically SDG targets 15.3 and 6.4, which implicate land and water resources management in generating and spreading long-term benefits.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Land and water policy responses can focus on protecting and restoring locations where land and water resources are degrading and limiting agriculture's contribution to food production and global efforts to reduce poverty. Chapters 4 and 5 propose responses that align with global frameworks for assessing and monitoring risks.

3.3 Land degradation risk

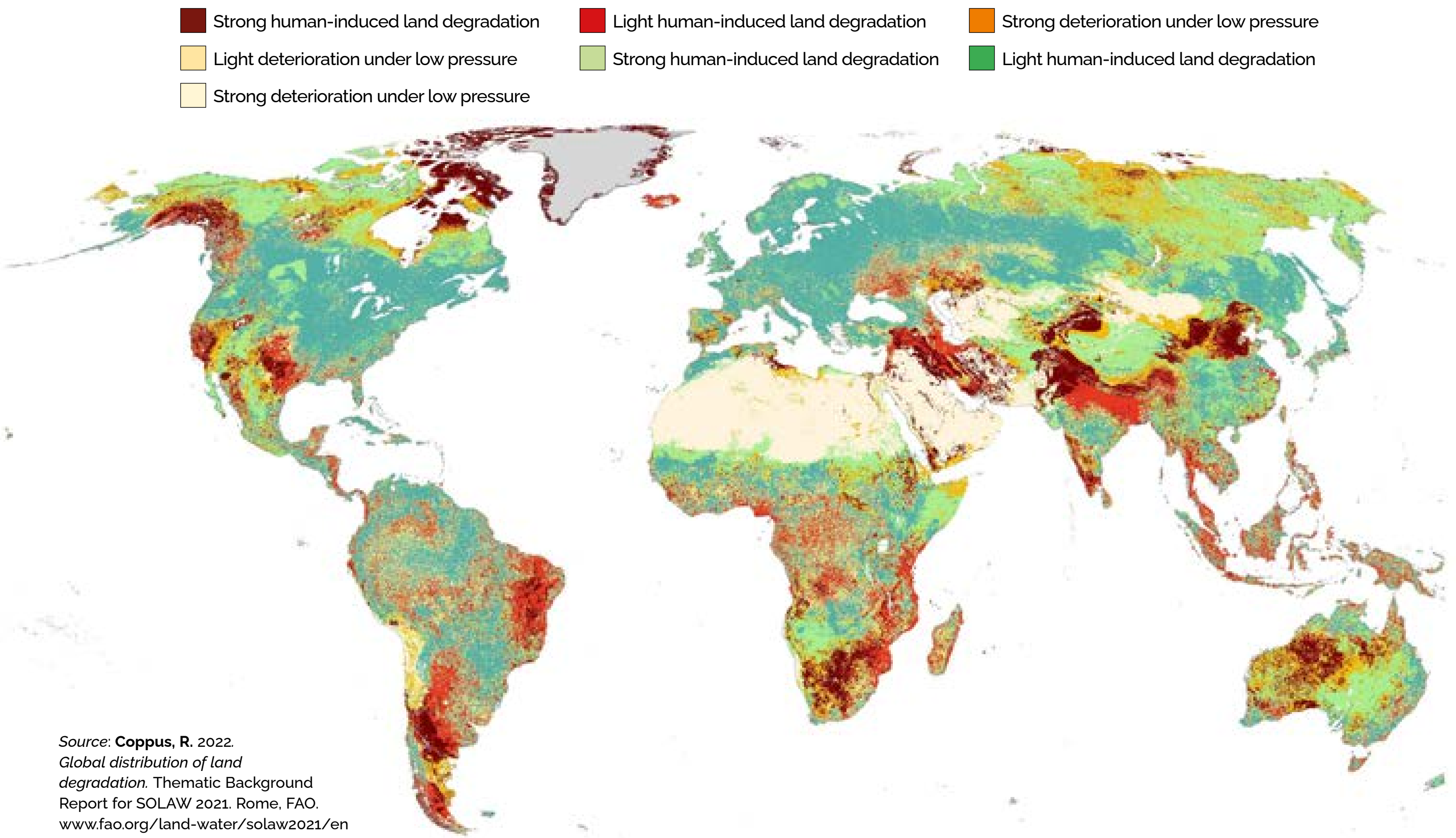
The FOFA scenarios (section 3.2.2) assume that the projected growth in rainfed and irrigated harvested areas will be on existing and available arable land. However, land degradation is expected to constrain anticipated growth in areas currently identified as at risk (Table 3.2). For this reason, most productive cropland and permanent pastures will require soil-conservation measures, and this section examines the risk. Chapter 4 (section

4.2.7) examines the change in land suitability under climate change in relation to land planning and management responses. If there is no action to reduce erosion, by 2050, cereal losses are expected to exceed 253 million tonnes (FAO and ITPS, 2015). This is equivalent to removing 1.5 million km² of land – equal to the total area of arable land in India – from crop production.

Estimates of land degradation (Coppus, 2022), applied to the GAEZ v4 cropland distribution, are expected to constrain anticipated (modelled) yield growth and harvested areas where land has been left uncultivated or even abandoned. Combining status and land degradation trends (Chapter 1) indicates areas at risk (Map 3.4 and Table 3.2). Regions at risk are large contiguous areas with low "status" and subject to light or strong deterioration. Regions with substantial degradation and interspersed high and low status are also at risk. Stable or improving areas are presently not at risk. In large parts of the United States of America, the main drivers are overgrazing and agricultural expansion, while invasive species and deforestation dominate Alaska, northern Canada, Northern Europe and Siberia. In the Asian steppe, significant risks come from fire and overgrazing, and in the south and southeast of the steppe, increasing population density and deforestation dominate. Australia faces fire risk, and New Zealand has high grazing densities. In Africa, fire and overgrazing are common, and grazing and deforestation dominate in the Central America and Caribbean, and Southern America regions.

The extent and impact of land degradation cannot be overemphasized. A combination of physical and chemical pressures from cultivation practices can reduce or eliminate soil functions and their ability to support sustainable production. Degraded soils have proved challenging to restore without comprehensive land management measures (Chapter 4).

MAP 3.4 **REGIONS AT RISK BASED ON STATUS AND TRENDS OF LAND DEGRADATION, 2021**



Source: **Coppus, R.** 2022. *Global distribution of land degradation.* Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en
Modified to comply with **UN**. *2020. Map of the World. https://www.un.org/geospatial/file/3420*

TABLE 3.2 PRODUCTIVE LAND AT RISK FROM LAND DEGRADATION, 2021

LAND COVER	TOTAL AREA (MILLION ha)	AREA AT RISK (MILLION ha)	AREA AT RISK (%)
Cropland	1 527	472	31
Rainfed	1 212	322	27
Irrigated	315	151	48
Grassland	1 910	660	35
Forestland	4 335	1 112	26

Source: **Coppus, R.** 2022. *Global distribution of land degradation.* Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en

3.3.1 Progressive soil erosion

The Status of the world's soil resources report (FAO and ITPS, 2015) ranks soil erosion as the most critical risk to agricultural production, because the process of erosion implies significant SOC, soil biodiversity and nutrient losses in addition to mechanical disturbances. However, the slow onset of soil resource depletion on non-erodible soils poses a more extensive set of risks to agricultural productivity and the stability of global food systems. The effort required for remediation is significant and possibly goes unrecognized. The anticipated impact of higher-intensity and longer-duration rainfall events combined with extended dry periods is expected to exacerbate this risk.

Numerous models are available to provide estimates of erosion at broader scales. These are essential for evaluating the extent of erosion and assessing its importance relative to other land degradation processes. However, field-based researchers often criticize modelling efforts for their simplified view of the complex nature of erosion and its controlling factors (Evans and Boardman, 2016). This is best illustrated by the erosion modelling efforts in Europe using a Europe-specific version of RUSLE, called the RUSLE2015 model (Panagos *et al.*, 2016), which draws upon the extensive, harmonized datasets amassed by the Joint Research Centre (JRC) of the European Commission (FAO, 2019).

In collaboration with several worldwide research institutes, JRC has established the Global Soil Erosion Modelling platform. A study assessed global soil erosion using a combination of remote sensing, GIS modelling and census data, and estimated the amount of soil eroded in 2012 to be 35.9 million tonnes/year (Borrelli *et al.*, 2017). The study also assessed the spatial and temporal effects of land-use change between 2001 and 2012 and the potential offset of applying conservation practices. It indicated a potential global increase in soil erosion driven by cropland expansion, with the most significant increases occurring in sub-Saharan Africa, Central America and Caribbean, Southern America and Southeast Asia. The least developed economies would experience the highest soil erosion rates (Map 3.4).

Overall, JRC found an area-specific annual soil erosion average of 2.8 tonnes/ha for 2001. This increased by 2.5 percent between 2001 and 2012, driven primarily by global land-use change. Some 6.1 percent of the global land-

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mass experiences annual erosion rates above 10 tonnes/ha, which is used to establish the tolerable soil loss value. Areas exceeding this level are lowest in Oceania (0.8 percent) and highest in Central America and Caribbean together with Southern America (both 8.3 percent). The global annual cropland rate is 12.7 tonnes/ha, which is 79 times higher than forest (0.16 tonnes/ha) and nearly seven times higher than other natural vegetation (1.84 tonnes/ha). These rates are expected to accelerate under a combination of more intensive land use, higher rainfall intensities and extended dry periods.

3.3.2 Potential soil organic carbon and biodiversity loss

Agricultural intensification threatens ecosystem functioning and land degradation. Unsustainable farming practices change soil environmental properties and disturb soil structure, leading to loss of SOM and soil organism habitats. Estimates indicate the annual global potential for SOC sequestration is 1.45–3.44 million tonnes of carbon (5.3–12.6 million tonnes CO_2-eq) (Lal *et al.*, 2018). In 2017, this represented 38–91 percent of global power industry fossil fuel emissions, 67–100 percent of global transport fossil fuel emissions (Muntean *et al.*, 2018) and 9–23 percent of the total global emissions (53 million tonnes CO_2-eq) from all sectors in that year (UNEP, 2018).

Monocultures and the use of fewer varieties reduce local variety traits, which can lead to soil biodiversity loss, though the magnitude is not quantified. The intensive use of inorganic fertilizers and pesticides will affect water quality and above- and below-ground biodiversity. Synthetic nitrogen fertilizers can affect microbial biomass, and arbuscular mycorrhizal fungal and faunal diversity. Tillage can reduce soil faunal and bacterial diversity.

Soil biodiversity loss reduces soil carbon sequestration, raising the risk of soil erosion, compaction and salinization. Adopting sustainable practices, such as promoting SOM accumulation and retention, can enhance soil biodiversity and improve soil health (de Graaff *et al.*, 2019).

A related concern under climate change is the increasing risk of SDSs, which involve a greater rate of aeolian erosion on susceptible soils, and higher rates and wider dispersion of aeolian deposits.

3.3.3 Soil nutrient loss

Soil nutrient mining is the most common form of soil degradation. Adverse impacts of soil nutrient loss on nutrient cycling and productivity result in less biomass and less soil cover, thereby exacerbating other soil degradation processes, such as SOM loss, soil erosion, acidification and the formation of hardpans.

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Low soil nutrient levels may result from poor farming practices by households with insufficient resources. In sub-Saharan Africa, increasing population densities and demand for land affect nutrient availability in soils. The traditional practice of leaving land fallow is no longer an option without sufficient external nutrient input (Vanlauwe *et al.*, 2015). Increasing micronutrient depletion rates inadvertently occur through increasing crop yields with nitrogen fertilizer applications. Long-term depletion of micronutrients presents a slow-onset risk.

Human migration has links to soil nutrient loss. Soil degradation, including nutrient loss and other forms of environmental change, has displaced millions of people (Warner, 2010).

Recent analyses suggest that, in some regions, increased annual additions of nitrogen in agricultural systems cannot occur without causing significant environmental harm. Phosphorus additions have exceeded safe boundaries in several major agricultural regions (Bijay-Singh and Craswell, 2021), while nutrient mining still occurs in those areas lacking fertilizer supply. Irrespective of the application method, nitrogen recovery efficiencies rarely exceed 50 percent (Delgado and Follett, 2010). Much of the unrecovered nitrogen accumulates in groundwater, wetlands and the atmosphere. This contributes to climate change and is an immediate risk that will require high levels of mitigation to reduce.

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3.3.4 Soil pollution

Growth in the use of alternative nutrient sources such as biosolids, sewage sludge and animal manure can present pollution risks. These organic fertilizers benefit soil health, but are also a source of contaminants, such as trace elements, heavy metals, pharmaceuticals, microplastics, organic contaminants and other toxic substances. Some are not easily removed during waste treatment or pass from livestock to their faeces and manure (Chen *et al.*, 2019).

Contaminants can also enter the food chain when crops and pastures absorb them from the soil and accumulate them in edible parts of plants. They can reduce crop yields and induce health problems in vulnerable communities unable to migrate to uncontaminated areas. In China, some 10 million tonnes of crops are lost annually because contamination reduces yields or renders crops and food products unmarketable (Wu *et al.*, 2010).

In turn, polluted soils affect aquatic ecosystems. Contaminants leach into groundwater and pollute surface water and marine environments. Rainfall, flooding, snowmelt and irrigation increase the soil water content and encourage runoff and flooding, which transport contaminants to nearby wetlands, rivers and lakes, causing eutrophication and eventually contaminants to reach coastal zones and the oceans. This reduces water quality, affects the effective functions of aquatic ecosystems, washes out soil particles that cause turbidity, and reduces the depth of watercourses and reservoirs (FAO and UNEP, 2021).

Managing SOC in urban soils offers an opportunity to improve soil ecosystem services within the urban fabric (Jansson, 2013). The spread of urban areas is now significant. Land-use patterns within urban environments include urban agriculture, forestry and


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green infrastructure. Urban soils are subject to strong anthropogenic influences, altering biogeochemical cycling, particularly carbon cycling and accumulation. Urban soils have substantial SOC storage potential and may accumulate SOC at high rates. Data from 116 cities worldwide showed the total carbon content of urban soils is 1.5–3 times higher and stored at a greater depth than rural soils (Vasenev and Kuzyakov, 2018).

3.3.5 Regional soil groups at risk

Black soils

Reports have highlighted the crucial role black soils play in food security and climate change mitigation, yet they are sensitive to anthropogenic intervention. They are prone to severe SOC loss, erosion, compaction, salinization and sodification, and can suffer from anthropogenic soil acidity (FAO and ITPS, 2015; see also Chapter 1). Further pressure on these soils is anticipated, particularly where changing land use and maladapted management is leading to a significant decline in SOC content in the weak (15 percent), medium (25 percent) and severely eroded (40 percent) black soils of the Russian Federation.

Studies show that 30 percent of SOC was lost in Ukrainian black soils (Balyuk and Medvedev, 2012). Chinese black soils experienced an average annual rate of decline in SOC in the top 900 mm soil profile of 0.91 percent and 0.48 percent under monocropping systems (Liu *et al.*, 2005). Excessive cultivation and summer fallowing in the Canadian prairie caused a 50 percent decline in SOC (Government of Canada, 2003). In Brazil, deforestation and subsequent cultivation depleted SOC by 60–85 percent (Rezapour and Alipour, 2017). In Argentina, SOC decreased by 36–53 percent after a long cropping period. Conservation practices are needed to reduce further loss and deterioration of soil quality (Liu *et al.*, 2012).

FAO established the International Network of Black Soils in 2017 as a platform to focus attention on black soil global importance in supporting food security and climate change mitigation. This network aims to bring together member countries to provide a scientific platform to discuss and contribute to improving management, conservation, mapping and monitoring (FAO, 2021b).

Permafrost soils

Permafrost soils, which cover 25 percent of the northern hemisphere and contain high levels of SOC, are in danger of thawing. This would exacerbate global warming, worsen soil erosion and threaten industrial infrastructure (see Chapter 1).

The constant increase in temperature and land-use change in permafrost regions could lead to carbon dioxide and methane being released into the atmosphere, with potentially devastating ecological and economic costs. Various scenarios show a possible release of 92 million tonnes of carbon (on average) by 2100 under the current climate warming trajectory (RCP 8.5); this will have impacts for centuries. Given the magnitude of carbon stocks and the high release potential, improved analyses that are more accurate using Earth systems models are crucial for assessing the physical and biological processes that control the dynamics of permafrost distribution and soil's thermal regimes (Schuur *et al.*, 2015). Conservation policies that transcend administrative borders will be essential.

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Peatlands (organic soils)

Although peatlands represent only 3 percent of the Earth's surface, they provide important ecosystem services, such as regulating the hydrological cycle, conserving biodiversity, providing forest products and recreation, and storing information about past environments. They store significant amounts of carbon (644 million tonnes of carbon to a 3 m depth). However, these are rapidly lost when the peatlands are drained for agriculture and commercial forestry (Hooijer *et al.*, 2010).

The FAO emissions database estimates there are 250 thousand km^2 of drained organic soils under cropland and grassland globally, with total GHG emissions of 0.9 million tonnes CO_2-eq/year in 2010. Significant contributions come from Asia (0.44 million tonnes CO_2-eq/year) and Europe (0.18 million tonnes CO_2-eq/year). Global estimates indicate more than 500 thousand km^2 of drained peatlands, including under forests, with carbon dioxide annual emissions increasing from 1.06 Pg of carbon dioxide in 1990 to 1.30 Pg of carbon dioxide in 2008 (FAO and ITPS, 2015).

Preserving, rewetting and managing peatlands sustainably (i.e. paludiculture) may offer a practical strategy for maintaining SOC and mitigating global warming (Leifeld and Menichetti, 2018).

3.4 Water scarcity risk to land productivity

3.4.1 Changing hydrological baseline

Immediate risks to agricultural production will persist where surface water is scarce, and groundwater is exploited intensively (see Chapter 1). Higher evaporative demand is expected to increase irrigation withdrawals and water stress at the local and basin levels. The FOFA projections (section 3.2.3) indicate that by 2050, crop water requirements will increase from the 2012 baseline by 17 percent under BAU assumptions and by almost 30 percent with climate forcing an additional 445 km^3 of evaporation in existing irrigated areas when temperature and precipitation changes are combined with the projected increase in harvested areas. This will double agricultural withdrawal volumes, assuming the current ratio of the global average for crop water requirement to withdrawals.

Countries with high groundwater dependency will experience greater stress from incremental evaporation (consumption) of 2–5 percent under BAU and of 5 percent in a worst-case (SSS) climate change scenario. This will significantly affect existing groundwater flow and storage, and diminish the chances of recharge, particularly in arid landscapes.

Longer-term water scarcity risk will become apparent as the interannual storage in snowpack and glaciers diminishes, affecting large, irrigated plains in all northern-hemisphere continents, but notably in the western United States of America (Lovelace *et al.*, 2020) and the Indus systems (Yu *et al.*, 2013).

The magnitude and frequency of flood events affecting agricultural production are becoming less predictable as climate change forces higher intensity, longer duration and increased frequency of rainfall. Open-channel irrigation systems could become prone to higher levels of flow perturbation and water control infrastructure failure.

Sea-level rise will increase the risk of saline intrusion into coastal aquifers, and attenuated crop yield growth can be expected as a result.

The FOFA projected growth in irrigation harvested areas is 92 million ha by 2050. As areas actually irrigated are typically about 15 percent less than the areas equipped for irrigation (FAO, 2021a), a significant proportion of that growth will occur within the extent of the areas equipped for irrigation (GMIA v5; FAO, 2021c).

The FOFA irrigation projections for the three scenarios indicate increases in harvested areas and proportionally more irrigation consumption per cubic metre of water withdrawn as yields improve and cropping intensities increase in line with overall productivity gains in agriculture (FAO, 2017). The regional- and country-level picture is variable, as increasing water scarcity will attenuate growth in some of the main centres of irrigation production (section 3.2.3).

3.4.2 Increasing agricultural withdrawals and water scarcity

Water scarcity trends (Chapter 1) are based on the requirements for SDG indicator 6.4.2, predicated on fixed environmental flow requirements and aggregated water withdrawals for all sectors. The limits of this approach notwithstanding (Vanham *et al.*, 2018), an analysis of projected crop water requirements with and without climate change was carried out to identify the level of future risk to irrigated agriculture (Table 3.1). In all SOLAW subregions except Northern Africa, Islamic Republic of Iran, Central Asia and Australia/New Zealand, crop water requirements show growth for all scenarios with and without climate change (cc). At the global level, the TSS + cc scenario results in a flattened rate of increase compared with BAU + cc, down from 29 percent under BAU + cc to 20 percent under TSS + cc. The SSS + cc scenario produces only a marginal increase in total crop water requirements, from 29 percent to 32 percent under BAU + cc. The influence of climate change under each of the scenarios is striking. Climate change almost doubles the crop water requirements for each scenario at the global level, largely because of increased evapotranspiration and diminished rainfall projected by the climate models on irrigated cropland. The increases may be higher or lower for individual subregions. The change compared with the 2012 baseline under BAU + cc ranges from 4 percent for Maritime Southeast Asia to 153 percent for Northern Europe under the SSS + cc scenario.

The decline in growth in total crop water requirements for Northern Africa, Islamic Republic of Iran, Central Asia and Australia/New Zealand is attributed to increased water scarcity and reduced growing seasons, as low rainfalls and high temperatures combine to reduce harvested areas.

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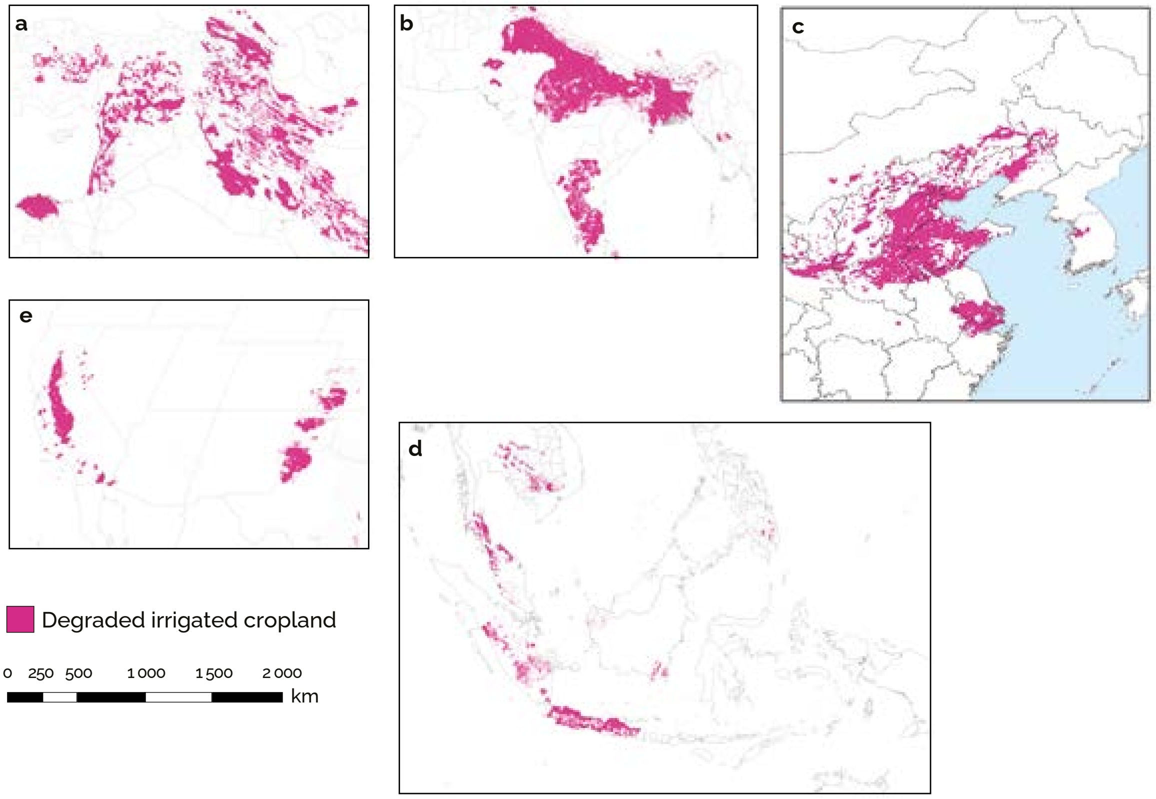
The GlobWat model also offers an analysis of risk based on agricultural water stress expressed as the ratio of irrigation consumption to water withdrawals (Hoogeveen *et al.*, 2015). The model considers water stress to be substantial when the incremental evaporation for irrigation exceeds 10 percent of the generated water resources in a river basin. A ratio exceeding 20 percent indicates critical stress. In 2012, the cluster of arid zone countries in Northern Africa, the Near East, the Arabian Peninsula, South Asia and Central Asia all lay well above the 10 percent limit. By 2050, incipient scarcity in the Mediterranean, Sudano-Sahel, Caucasus and East Asia will fall below the critical limit.

Given that 48 percent of some of the most productive irrigated cropland is at risk (Map 3.5), the combination of water scarcity induced by irrigation and land degradation is a reminder that efforts directed at soil and water conservation across these regions will need to intensify if the land and water systems are to remain in play.

3.4.3 Diminishing groundwater availability

The prospect of reducing abstraction from aquifers to sustainable levels is not promising, particularly given the scale of the projected increase in crop water requirements under the three FOFA scenarios. All signs point to intensifying groundwater use for irrigation as farmers switch away from reduced or regulated surface supplies (Dieter *et al.*, 2018). The subsequent risk for users

MAP 3.5 IRRIGATED CROPLAND SUBJECT TO HUMAN-INDUCED LAND DEGRADATION IN 2014: (a) AFRICA AND WESTERN ASIA, (b) SOUTH ASIA, (c) EAST ASIA, (d) SOUTHEAST ASIA AND (e) PARTS OF AMERICA



Note: Areas with more than 10 percent irrigated cropland cover are shown.
Source: **Coppus, R.** 2022. *Global distribution of land degradation.* Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en. Modified to comply with to comply with **UN**. 2020. *Map of the World.* https://www.un.org/geospatial/file/3420

of high-quality water for potable supply is magnified. In India, for example, approximately 90 million rural households depend directly on groundwater irrigation (Shah, 2009). Productive coastal margins present a formidable challenge as upstream inflows are curtailed, available land is more intensively cultivated, and urban pollution and saline intrusion threaten groundwater quality. The groundwater account is significantly overdrawn, leaving little recoverable freshwater margin in place. This produces a range of drawdown "externalities", such as ingress of low-quality groundwater and reduced leakage to adjacent aquifers.

Some large continental aquifers exploited for irrigation and stock watering cross national borders. There are more than 350 transboundary aquifers worldwide that have been delineated and described (UNESCO, 2021; TWAP, 2022). But much less is known about the impact of groundwater abstraction and pollution across borders, and few international water agreements refer to conjunctive management of shared surface water and groundwater (Chapter 5).

Current patterns of exploitation present long-term risks for sustained agricultural production where transboundary aquifers are decoupled from contemporary recharge, such as in the northwest Saharan, Nubian and Arabian aquifer systems. As the climate changes and affects recharge regimes, it will not always be possible to distinguish between renewable and non-renewable groundwater resources. Evidence from long-term aquifer monitoring in intensively irrigated areas indicates that long-term production risks can be expected to increase in terms of economically recoverable groundwater storage and associated groundwater quality (Shamsudduha *et al.*, 2011; Konikow, 2013; MacDonald *et al.*, 2016; see also the case study on understanding how groundwater responds to climate and anthropogenic abstraction).

Poor water quality limits options to increase groundwater use in many accessible aquifers. In China, even under natural conditions, only 63 percent of groundwater is potable. Arsenic and fluoride are the most common geogenic pollutants in Southeast Asia. Fertilizers and pesticides in agriculture are the primary sources of anthropogenic pollution globally (OECD and FAO, 2020). In Europe, nitrate pollution is the most frequent cause of poor groundwater quality, with 23 percent of groundwater bodies exceeding European Union standards (Kløve *et al.*, 2017). Pesticides and volatile organic compounds are commonly found across the United States of America (Toccalino *et al.*, 2014). Pollution due to mining (e.g. leakage of acidic leachate) and urbanization (e.g. wastewater, salinization in coastal cities or leakage from urban landfills) are additional global concerns.

Human activities and climate change are significantly increasing pressure on groundwater resources. Participatory watershed management and closer attention to the monitoring and assessment of groundwater resources will be vital to inform aquifer management and governance. There are some encouraging examples of stakeholder participation in agriculture leading to reduced irrigation demand and providing an environment for decisive joint management (Govardhan Das and Burke, 2013; Deines *et al.*, 2019).

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3.4.4 Emerging water quality risks

Freshwater pollution attributable to agriculture is an emerging global crisis with direct impacts on health, economic development and food security. Although other anthropogenic activities, such as human settlements (urbanization) and industries, are major contributors to water quality degradation, agriculture has become the main source of pollution in many countries. Agriculture intensification to provide more food to a growing population has also increased the use of inputs such as fertilizers, pesticides and antimicrobials. When not managed properly, agricultural practices can increase pollutant loads (nutrients, salts, sediments, agrochemicals and pathogens) into groundwater and surface water, making the water unfit for some other users.

Nutrients, particularly phosphorus and nitrogen, are exported from agricultural activities to the environment either through diffuse pollution or through emission into the atmosphere (i.e. reactive nitrogen). Phosphorus is a limiting element for surface water eutrophication, and nitrogen is a more significant threat to the environment, human health and urban infrastructure.

The capacity of receiving freshwater to dilute pollutants is decreasing rapidly, with some highly persistent pollutants active for extended periods (Chapter 1). Although a source of pollution, agriculture is threatened by poor water quality, particularly from aquifers used for irrigation. Tainted groundwater circulation is expected to persist, given that many organic and synthetic pollutants imprint themselves into the fabric of aquifers. A long-term impact on agricultural productivity and profitability can be anticipated for crops grown with contaminated groundwater, as biosafety provisions, brought into increasingly sophisticated food markets, catch up with food producers.

Contaminants of concern

Emerging pollutants, or contaminants of emerging concern, are "new" substances being used and discharged into the freshwater systems for which there are no regulations in place and little monitoring. Most are organic compounds and are present as pharmaceuticals, antibiotics, personal care products, hormones, food additives, pesticides, plasticizers, wood preservatives, laundry detergents, disinfectants, surfactants, flame retardants and other organic compounds. For example, every year, the Government of the United States of America receives notices for the discharge of more than a thousand new chemicals into the environment.

Wastewater treatment plants, where they exist, cannot entirely remove all chemical and biological contaminants. Countries like Iraq, Israel, Mexico or Pakistan primarily rely on wastewater for irrigation (FAO, 2010; Reznik, Dinar and Francesc Hernández-Sancho, 2019). Several contaminants are added to agricultural soils with wastewater, such as trace elements, polychlorinated dibenzo-p-dioxins and dibenzofurans, polychlorinated biphenyls, chlorinated paraffin and perfluorinated alkylated substances like perfluorooctane sulfonate or perfluorooctanoic acid, resulting in the pollution of agricultural soils. Crops treated with wastewater can absorb contaminants from the soil solution and accumulate them in above- and below-ground tissues. The contaminants thus enter the food chain.

Plastic waste is emerging as a significant global pollution problem on agriculture land and in rivers worldwide. Plastics are highly visible in waterways and oceans, unlike other pollutants. Estimates from sampled rivers between 2010 and 2014 indicated freshwater systems transported 1.15–2.41 million tonnes of plastic into the oceans. Asia accounted for 67 percent of this (Lebreton *et al.*, 2017). A resolution at the fifth session of the United Nations Environment Assembly was endorsed to end plastic pollution and forge an international legally binding agreement by 2024.

Looking at 192 coastal countries, Jambeck *et al.* (2015) estimated that 275 million tonnes of plastic wasted was produced in 2010, with between 4.8 and 12.7 million tonnes entering the oceans. A recent study indicated this volume entering the oceans might rise to 53 million tonnes annually by 2030 (Borrelle *et al.*, 2020). Attention is expected to shift from focusing on cleaning up plastic waste in inland and coastal waterways towards reducing the large quantities of plastic being produced and disposed of on land. Modelling indicates that reducing the global annual target to less than 8 million tonnes by 2030 would require a fundamental transformation in the plastics economy where end-of-life plastic products are valued rather than discarded as waste. This would involve a 25–40 percent reduction in plastic waste and an increase in plastic waste management from 6 to 60 percent in low-income economies.


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3.5 Conclusions

Land and water systems face significant and interconnected biophysical risks related to the increasing frequency and magnitude of agroclimatic events, including droughts and floods, and the slow onset of human-induced land and soil degradation.

The immediate risks to global food systems will remain associated with water scarcity. Irrespective of the long-term shift of climatic zones, the impacts of rainfall volatility and temperature events on rainfed agriculture will affect the main cereal production centres in the northern hemisphere. The pattern of irrigated production is expected to remain similar to the current GMIA (Chapter 1), except for lateral extension and new development where deeper groundwater can be exploited.

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A less-apparent risk is slow-onset land degradation. Soils traditionally used for continuous crop production, such as black soils, will experience declining soil health as they reach critical thresholds in soil structure and water chemistry and in their inherent productive capacity.

The current rate of land and water resource exploitation for agricultural production is compromising the levels of land productivity needed to meet long-term dietary requirements. The impact of land degradation and water scarcity on the productivity of agricultural land at a specific location is not predictable, but outcomes of climate projections become apparent at regional aggregated levels.

As climate zones shift, water scarcity and land quality risk already apparent today will escalate by the end of the twenty-first century. Extended growing seasons on northern temperate soils may alleviate concerns over limited harvested areas, but only if accompanied by adequate rainfall to maintain acceptable levels of soil moisture. The effects of extending the thermal growing season by more than 10 days for crops have been assessed in Europe. Chapter 4 details projections of climate futures for land suitability as part of the planning process.

Pressures on land and water systems risk compromising agricultural productivity in places where growth is most needed to meet global food security targets. Resource planners therefore respond to the challenge using remote-sensing, big data and innovative analytical methods that are revolutionizing approaches to resources planning.

A converging range of economic drivers and climate variability are affecting the long-term viability of global food systems. Climate change alone is expected to result in at least a 30 percent increase in total crop water requirements for irrigated production by 2050. When translated into withdrawals for irrigation, an additional ~600 km^3 of freshwater is needed on top of current withdrawals of 4 thousand km^3 with IRWRs of only 44 thousand km^3.

Global food systems are transforming and becoming more productive, but largely at the expense of long-term sustainability of land and water systems, which rely on available, yet limited and finite, land and water resources. Unsustainable agricultural intensification brings long-term environmental and economic challenges that affect the integrity and productive capacity of existing land and water systems and heighten the risk to production and the production growth needed to feed a global population.

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Case study: Understanding how groundwater responds to climate and anthropogenic abstraction

The Indus–Ganges–Brahmaputra–Meghna mega river basin is one of the world's largest transboundary aquifer systems and accounts for about 25 percent of global groundwater abstraction. Recharge from rainfall is delivered from June to September during the summer monsoon. This densely populated area is home to many thousands of smallholder farmers who rely on abstraction from shallow unconfined and deep confined aquifers across the basin for irrigated food production. This is thought to be one of the primary contributors to groundwater storage variability. However, the influence of the current climate is unknown, and climate change is expected to increase temporal and spatial rain variability throughout South Asia, thus affecting water resources and groundwater recharge.

The lack of evidence and understanding of the relative influence of climate and abstraction on the aquifer led to a study of the aquifer's response to climate (rainfall, and global climate cycles including the El Niño–Southern Oscillation, Indian Ocean Dipole, North Atlantic Oscillation and Pacific Decadal Oscillation) and human influence (mainly abstraction for irrigation and rural water supply). The analysis used observations from 6 753 wells over a period of 30 years (1985–2015) to highlight the variable patterns of phase lags between multidepth groundwater levels and rainfall depending on the different nature of climate and abstraction in various parts of the basin.

Some observations were intuitive, such as the rapid response in shallow groundwater and the relatively delayed response to the global climate patterns with increasing depth. Variations in influence were observed across the mega basin. Groundwater abstraction dominated the Indus and Meghna basins, while rainfall was more influential in the Brahmaputra and Meghna basins. In the Ganges basin, the influences of rainfall and abstraction were moderate. In the most exploited areas, such as the Indus basin, groundwater abstraction overwhelmed the hydrological processes. The influence of abstraction on groundwater levels in the deeper observation wells was stronger than the shallow observation wells. There was a rapid response in shallow groundwater and relatively delayed responses to climate patterns with increasing depth, leading to enhanced recharge of shallow unconfined groundwater aquifers.

Overall, the results suggested that groundwater abstraction was the dominant influence in most of the basin, particularly at the greater aquifer depths, highlighting the importance of understanding multidepth groundwater dynamics for future groundwater management and policy interventions. Recommendations included increasing monitoring of deep groundwater levels to enhance understanding of aquifer performance. In areas of overabstraction, effort priority should focus on regulating withdrawals from deep aquifers.

Source: **Malakar, P., Mukherjee, A., Bhanja, S.N., Ganguly, A.R., Ray, R.K., Zahid, A., Sarkar, S., Saha, D. & Chattopadhyay, S.** 2021. Three decades of depth-dependent groundwater response to climate variability and human regime in the transboundary Indus-Ganges-Brahmaputra-Meghna mega river basin aquifers. *Advances in Water Resources*, 149: 103856.


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Case study: Farmers and water utilities voluntarily cooperating to reduce nitrate concentrations in Germany

In Germany in the 1980s, water utilities set up a voluntary scheme with farmers to lower nitrates in drinking water from 90 mg/litre to 50 mg/litre, in line with government requirements. In some areas where agriculture was intensive and nitrate-laden soil water was slowly percolating into deeper groundwater, meeting this threshold would be a long-term challenge given the amount of fertilizer use.

The option to impose restrictions meant high administrative and control efforts to enforce them at a time when authorities did not have the capacity to do this. In water protection areas, standard ordinances would be required that determine restrictions on fertilizer practices. For example, to conduct nitrogen balances on plots and farms, limits would be imposed on the amount of fertilizers to be applied and lock-up periods set when manure application was prohibited. These measures would require farmers to shift to new, and unproven farming practices that would incur extra costs (e.g. for labour, machinery and manure storage facilities). Many farmers opposed this approach as the restrictions would limit their autonomy. Significant numbers of farmers were therefore unlikely to comply.

In contrast to prescriptive, rigid ordinances, voluntary cooperation allows farmers to take part in decision-making and to develop site-specific measures supported by agricultural advisers and funding. The cooperating parties agreed to work for common objectives endorsed in binding agreements, which had several common characteristics:

- voluntary establishment and membership;
- legal recognition;
- benefits for members only;
- free-of-charge advisory services for fertilizer practices;
- costs passed onto consumers via water utility charges offset against water abstraction charges; and
- payments to farmers for efforts that go beyond good agricultural practices.

Assessment studies indicate that cooperation successfully reduced nitrate concentrations in soil and untreated water. Agriculture and water administrations confirm that targeted advisory services were key to solving the nitrate problem. In 2021, most cooperation agreements still existed in Bavaria (>200), North Rhine-Westphalia (~113), Lower Saxony (~112) and Hesse (>70), and continue to have proactive support from regional governments.

Cooperation is effective when most farmers in a water protection area participate, and particularly in the areas most at risk. In view of the success, regional governments are now calling to establish cooperation agreements in other nitrate vulnerable areas.


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Case study: Land and water systems at risk in the Arab region due to climate change

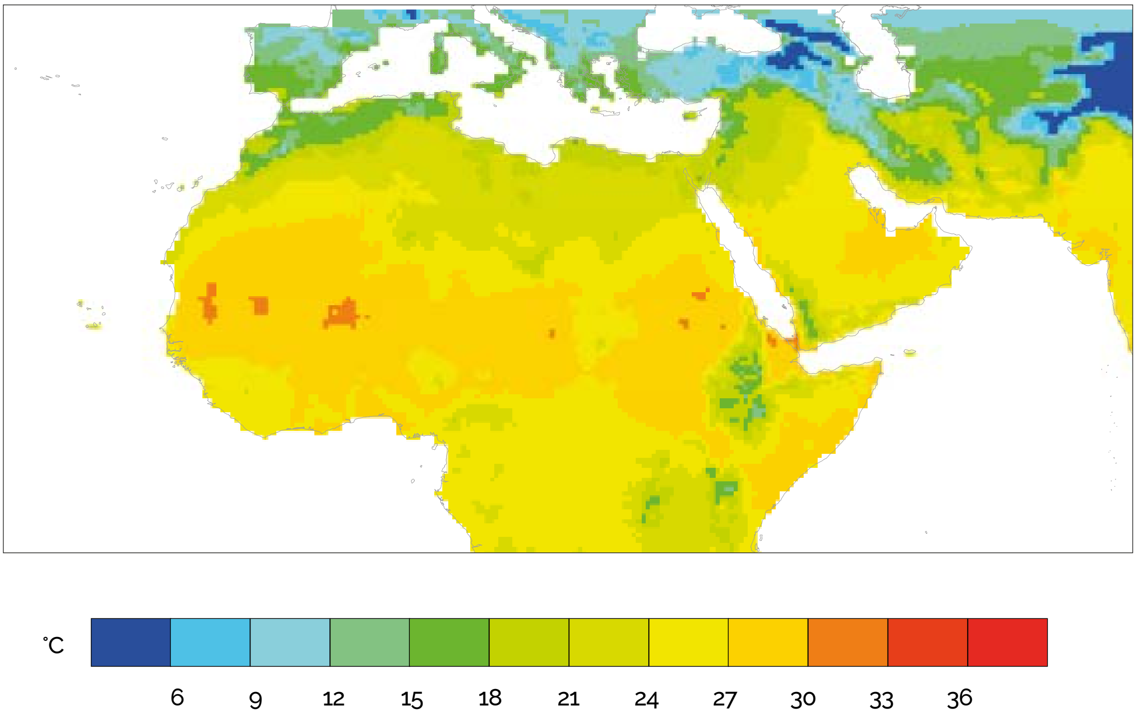
Owing to its unique and complex geopolitical and socioeconomic settings, the Arab region is facing land and water management challenges, evolving demographics and pressures on ecosystems. Climate change is expected to add to this complexity, affecting two-thirds of croplands and half of livestock areas within the region by 2050, with adverse impacts on freshwater quality and quantity, food security, rural livelihoods and biodiversity.

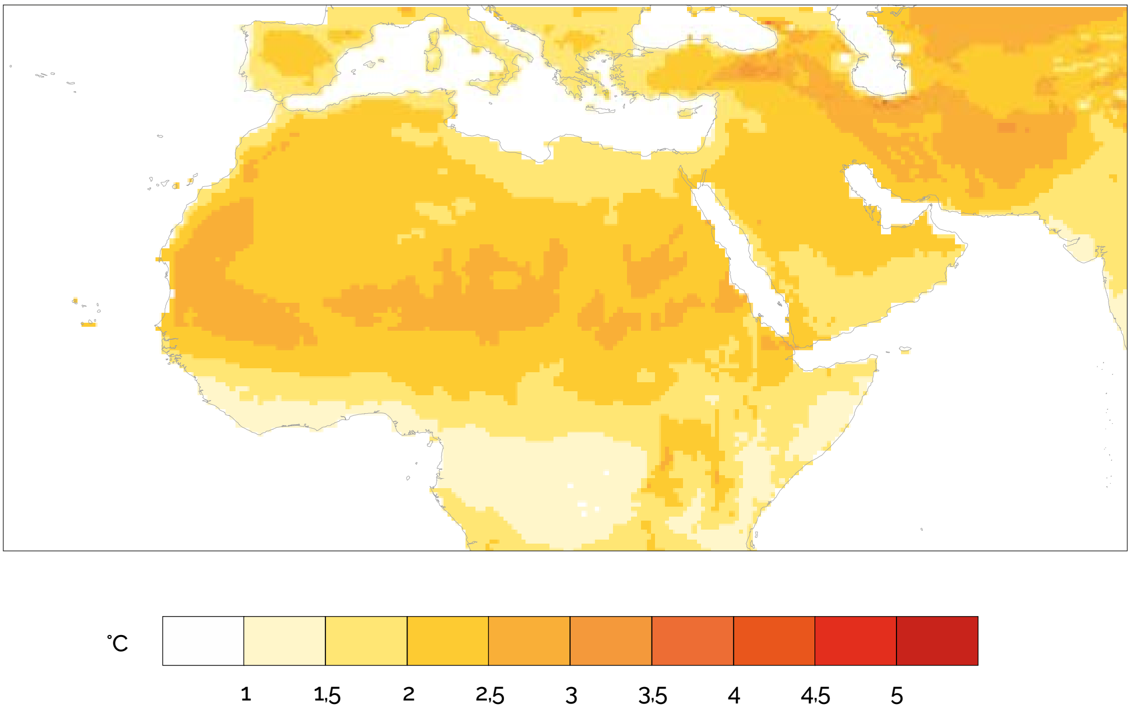
The Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region, which includes FAO and the United Nations Economic and Social Commission for Western Asia, aims to strengthen the science–policy interface by addressing climate change and sectoral vulnerabilities based on specific regional issues. Scientific methods are applied together with consultations to enhance access to knowledge, build capacity and strengthen institutions for climate change assessment in the Arab region. The initiative also provides a common platform for assessing, addressing and identifying regional climate change challenges, which, in turn, inform dialogue, priority setting, policy formulation and responses to climate change at the regional level.

The assessment methodology includes regional climate and hydrological modelling to inform sectoral vulnerability assessments through integrated mapping. Regional climate models better portray smaller-scale atmospheric processes than global climate models by focusing on specific geographical domains.

The Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region presents the RCP 8.5 scenario, regarded as a high-emissions BAU scenario. Regional climate modelling projects a general increase in average temperature of 1.7–2.6 °C by mid-century (2046–2065) compared to the reference period (1986–2005) (Map A). Higher temperature increases (> 3 °C) are projected in non-coastal areas, including the Sahara Desert.

MAP A TEMPERATURE FOR THE PERIOD 1986–2005 AND PROJECTED CHANGE IN TEMPERATURE FOR THE PERIOD 2046–2065

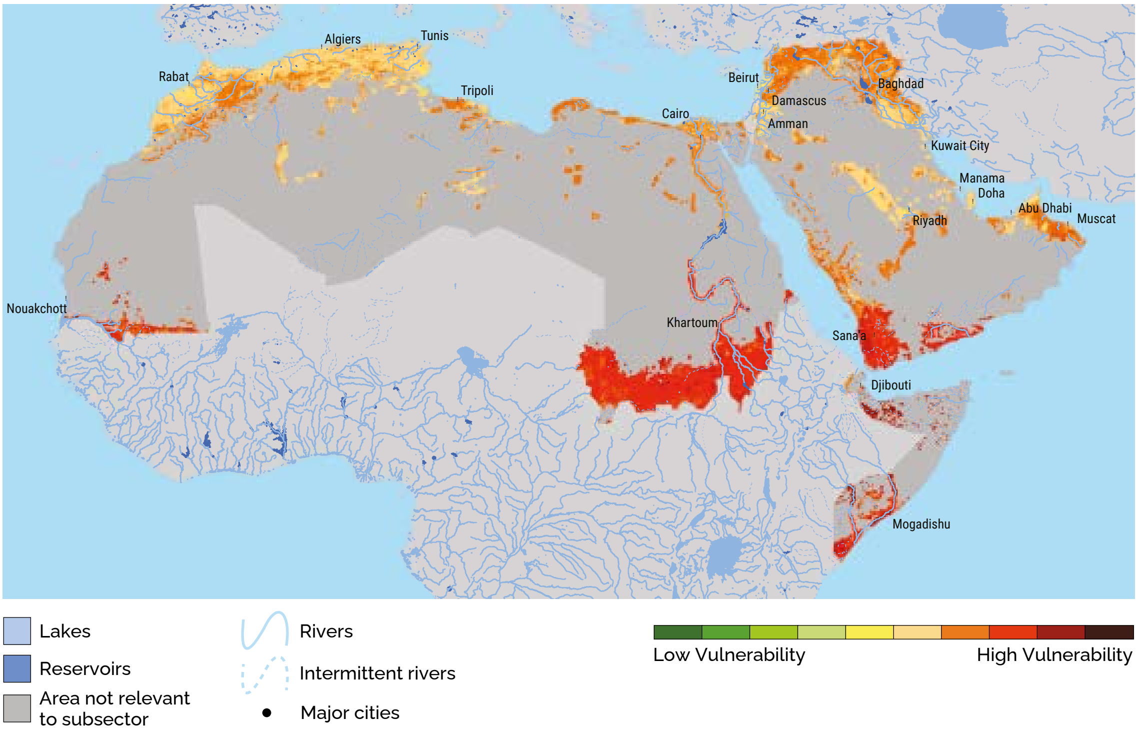




Source: **United Nations Economic and Social Commission for Western Asia.** 2017. *Arab climate change assessment report – Main report.* E/ESCWA/SDPD/2017/RICCAR/Report. Beirut.
https://www.unescwa.org/sites/default/files/pubs/pdf/riccar-main-report-2017-english_0.pdf
Modified to comply with to comply with **UN**. 2020. *Map of the World.* https://www.un.org/geospatial/file/3420

Map B indicates that 67 percent of croplands will be highly vulnerable to climate change by mid-century, with the remaining areas moderately vulnerable. Hotspots include the croplands of sub-Saharan Africa, the Horn of Africa and the southwestern Arabian Peninsula. These are largely rainfed and are thus vulnerable to increasing rainfall variability. The most productive farming systems are irrigated agriculture and dry savanna, and 85–90 percent of their combined areas fall within high vulnerability classes.

MAP B **PREDICTED EFFECTS OF CLIMATE CHANGE ON WATER AVAILABILITY FOR CROPS, 2046–2065**

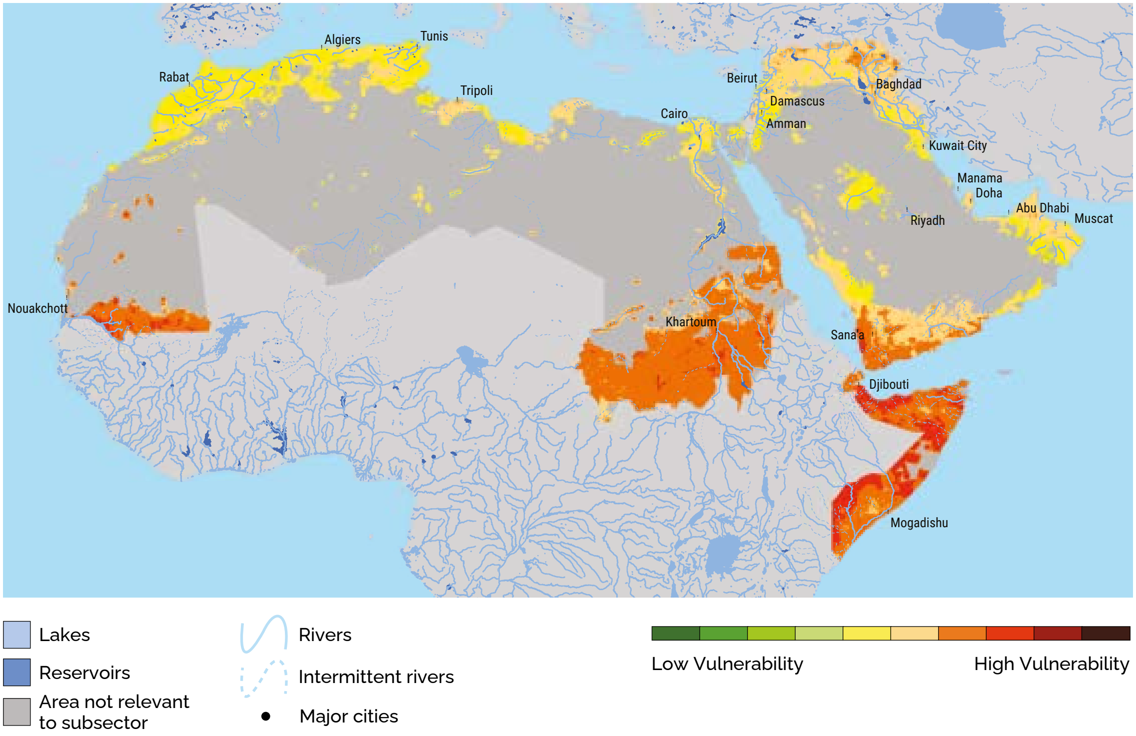


Source: **United Nations Economic and Social Commission for Western Asia.** 2017. *Arab climate change assessment report – Main report.* E/ESCWA/SDPD/2017/RICCAR/Report. Beirut.
https://www.unescwa.org/sites/default/files/pubs/pdf/riccar-main-report-2017-english_0.pdf
Modified to comply with to comply with **UN**. 2020. *Map of the World.* https://www.un.org/geospatial/file/3420

Water availability for livestock will experience high vulnerability (49 percent of livestock areas). The impacts are concentrated in the region's least developed countries, where incomes depend upon livestock production. Hotspots are dispersed in eastern sub-Saharan Africa, the southwestern Arabian Peninsula and southern Mauritania (Map C), where estimates suggest that 94 percent of available water is used for agriculture. High vulnerability will significantly affect rural livelihoods unless strong adaptation strategies are adopted. Options include switching from crop to mixed crop–livestock or livestock only systems. In dry and semi-dry lands, livestock systems based on grassland grazing will be more prone to climate shocks compared to mixed systems. Vulnerability can be reduced by adjusting animal movement cycles, modifying feed compositions and appropriate animal health interventions.

Sources: **United Nations Economic and Social Commission for Western Asia.** 2017. *Arab climate change assessment report – Main report.* E/ESCWA/SDPD/2017/RICCAR/Report. Beirut.
https://www.unescwa.org/sites/default/files/pubs/pdf/riccar-main-report-2017-english_0.pdf; **FAO, Deutsche Gesellschaft für Internationale Zusammenarbeit, the Arab Center for the Studies of Arid Zones and Dry Lands and the United Nations Economic and Social Commission for Western Asia.** 2018. *Climate change and adaptation solutions for the green sectors in the Arab region.* E/ESCWA/SDPD/2017/RICCAR/TechnicalReport.2. Beirut.
https://riccar.org/sites/default/files/2020-01/Technical%20Report2_Green%20Sectors_Final.pdf

MAP C PREDICTED EFFECTS OF CLIMATE CHANGE ON WATER AVAILABILITY FOR LIVESTOCK, 2046–2065



Source: **United Nations Economic and Social Commission for Western Asia.** 2017. *Arab climate change assessment report – Main report.* E/ESCWA/SDPD/2017/RICCAR/Report. Beirut.
https://www.unescwa.org/sites/default/files/pubs/pdf/riccar-main-report-2017-english_0.pdf
Modified to comply with to comply with **UN**. 2020. *Map of the World.* https://www.un.org/geospatial/file/3420

References

Balyuk, S.A. & Medvedev, V.V. 2012. *Strategy of balanced use, reproduction and management of soil resources of Ukraine*. Kiev, Agrarian Science.

Bijay-Singh & Craswell, E. 2021. Fertilizers and nitrate pollution of surface and ground water: An increasingly pervasive global problem. *SN Applied Sciences*, 3: 518.

Borrelle, S.B., Ringma, J., Law, K.L., Monnahan, C.C., Lebreton, L., McGivern, A., Murphy, E. *et al.* 2020. Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. *Science (New York, N.Y.)*, 369(6510): 1515–1518.

Borrelli, P., Robinson, D.A., Fleischer, L.R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K. *et al.* 2017. An assessment of the global impact of 21st century land use change on soil erosion. *Nature Communications*, 8: 2013.

Chen, Z., Zhang, W., Yang, L., Stedtfeld, R.D., Peng, A., Gu, C., Boyd, S.A. & Li, H. 2019. Antibiotic resistance genes and bacterial communities in cornfield and pasture soils receiving swine and dairy manures. *Environmental Pollution*, 248: 947–957.

Coppus, R. 2022. *Global distribution of land degradation*. Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en

Deines, J.M., Kendall, A.D., Crowley, M.A., Rapp, J., Cardille, J.A. & Hyndman, D.W. 2019. Mapping three decades of annual irrigation across the US High Plains Aquifer using Landsat and Google Earth Engine. *Remote Sensing of Environment*, 233: 111400.

de Graaff, M.A., Hornslein, N., Throop, H.L., Kardol, P. & van Diepen, L.T.A. 2019. Effects of agricultural intensification on soil biodiversity and implications for ecosystem functioning: A meta-analysis. *Advances in Agronomy*, 155: 1–44.

Delgado, J. & Follett, R. 2010. *Advances in nitrogen management for water quality*. United States Department of Agriculture Agricultural Research Service. www.ars.usda.gov/research/publications/publication/?seqNo115=258447

Dieter, C.A., Maupin, M.A., Caldwell, R.R., Harris, M.A., Ivahnenko, T.I., Lovelace, J.K., Barber, N.L. & Linsey, K.S. 2018. *Estimated use of water in the United States in 2015.* United States Geological Survey Circular 1441, Water Availability and Use Science Program.

Evans, R. & Boardman, J. 2016. A reply to Panagos *et al.*, 2016 (Environmental science & policy 59 (2016) 53–57. *Environmental Science & Policy*, 60: 63–68.

FAO. 2010. *The wealth of waste: The economics of wastewater use in agriculture.* Rome. www.fao.org/3/i1629e/i1629e.pdf

FAO. 2017. *The future of food and agriculture: Trends and challenges.* Rome. www.fao.org/3/a-i6583e.pdf

FAO. 2018. *The future of food and agriculture: Alternative pathways to 2050. Summary version.* Rome. www.fao.org/3/CA1553EN/ca1553en.pdf

FAO. 2019. *Soil erosion: The greatest challenge for sustainable soil management*, D. Pennock, C. Lefèvre, R. Vargas, L. Pennock & M. Sala, eds. Rome. www.fao.org/3/ca4395en/ca4395en.pdf

FAO. 2021a. AQUASTAT – FAO's Global Information System on Water and Agriculture. In: *FAO.* Rome. www.fao.org/aquastat/en

FAO. 2021b. International Network of Black Soils. In: *Global Soil Partnership.* Rome. www.fao.org/global-soil-partnership/inbs/en

FAO. 2021c. AQUASTAT – FAO's Global Information System on Water and Agriculture. In: *FAO.* Rome. www.fao.org/aquastat/en/geospatial-information/global-maps-irrigated-areas/latest-version

FAO & ITPS (Intergovernmental Technical Panel on Soils). 2015. *Status of the world's soil resources: Main report.* Rome. www.fao.org/3/i5199e/i5199e.pdf

FAO & UNEP (United Nations Environment Programme). 2021. *Global assessment of soil pollution: Report.* Rome. https://doi.org/10.4060/cb4894en

Gerten, D., Heck, V., Jägermeyr, J., Bodirsky, B.L., Fetzer, I., Jalava, M., Kummu, M. *et al.* 2020. Feeding ten billion people is possible within four terrestrial planetary boundaries. *Nature Sustainability*, 3(3): 200–208.

Gibbs, H.K. & Salmon, J.M. 2015. Mapping the world's degraded lands. *Applied Geography*, 57: 12–21.

Govardhan Das, S.V. & Burke, J. 2013. *Smallholders and sustainable wells. A retrospect: Participatory groundwater management in Andhra Pradesh (India).* Rome, FAO. www.fao.org/3/i3320e/i3320e.pdf

Government of Canada. 2003. Agriculture and Agri-food Canada. In: *Government of Canada.* https://publications.gc.ca/site/eng/245998/publication.html?wbdisable=true

Hoogeveen, J., Faurès, J.M., Peiser, L., Burke, J. & Van De Giesen, N. 2015. GlobWat – A global water balance model to assess water use in irrigated agriculture. *Hydrology and Earth System Sciences,* 19(9): 3829–3844.

Hooijer, A., Page, S., Canadell, J.G., Silvius, M., Kwadijk, J., Wösten, H. & Jauhiainen, J. 2010. Current and future CO_2 emissions from drained peatlands in Southeast Asia. *Biogeosciences,* 7(5): 1505–1514.

IPBES (Intergovernmental Science-Policy Platform on Biodiversity). 2018. *The IPBES assessment report on land degradation and restoration*, L. Montanarella, R. Scholes & A. Brainich, eds. Bonn.

IPCC (Intergovernmental Panel on Climate Change). 2014. *Climate change 2014: Synthesis report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Geneva. www.ipcc.ch/site/assets/uploads/2018/05/SYR_AR5_FINAL_full_wcover.pdf

IPCC. 2019. *Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*. Geneva. www.ipcc.ch/srccl/

IPCC. 2021. *Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, V. Masson-Delmotte, P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud *et al.*, eds. Cambridge, UK, Cambridge University Press. www.ipcc.ch/report/ar6/wg1/#TS

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R. & Law, K.L. 2015. Plastic waste inputs from land into the ocean. *Science*, 347(6223): 768–771.

Jansson, Å. 2013. Reaching for a sustainable, resilient urban future using the lens of ecosystem services. *Ecological Economics,* 86: 285–291.

Kløve, B., Kvitsand, H.M.L., Pitkänen, T., Gunnarsdottir, M.J., Gaut, S., Gardarsson, S.M., Rossi, P.M. & Miettinen, I. 2017. Overview of groundwater sources and water-supply systems, and associated microbial pollution, in Finland, Norway and Iceland. *Hydrogeology Journal,* 25(4): 1033–1044.

Konikow, L.F. 2013. *Groundwater depletion in the United States (1900–2008).* United States Geological Survey Scientific Investigations Report 2013–5079. http://pubs.usgs.gov/sir/2013/5079

Kummu, M., Heino, M., Taka, M., Varis, O. & Viviroli, D. 2021. Climate change risks to push one-third of global food production outside safe climatic space. *One Earth*, 4(5): 720–729.

Lal, R., Smith, P., Jungkunst, H., Mitsch, W., Lehmann, J., Nair, P.K., McBratney, A. *et al*. 2018. The carbon sequestration potential of terrestrial ecosystems. *Journal of Soil and Water Conservation,* 73(6): 145A–152A.

Latham, J., Cumani, R., Rosati, I. & Bloise, M. 2014. *Global Land Cover SHARE (GLC-SHARE) database.* Rome. www.fao.org/uploads/media/glc-share-doc.pdf

Lebreton, L.C.M., Van Der Zwet, J., Damsteeg, J.W., Slat, B., Andrady, A. & Reisser, J. 2017. River plastic emissions to the world’s oceans. *Nature Communications*, 8: 15611.

Leifeld, J. & Menichetti, L. 2018. The underappreciated potential of peatlands in global climate change mitigation strategies. *Nature Communications*, 9(1): 1071.

Liu, X., Liu, J., Xing, B., Herbert, S.J., Meng, K., Han, X. & Zhang, X. 2005. Effects of long-term continuous cropping, tillage, and fertilization on soil organic carbon and nitrogen of black soils in China. *Communications in Soil Science and Plant Analysis,* 36(9–10): 1229–1239.

Liu, X., Burras, C.L., Kravchenko, Y.S., Duran, A., Huffman, T., Morras, H., Studdert, G., Zhang, X., Cruse, R.M. & Yuan, X. 2012. Overview of Mollisols in the world: Distribution, land use and management. *Canadian Journal of Soil Science,* 92(3): 383–402.

Lovelace, J.K., Nielsen, M.G., Read, A.L., Murphy, C.J. & Maupin, M.A. 2020. *Estimated groundwater withdrawals from principal aquifers in the United States, 2015.* United States Geological Survey Circular 144, Version 1.2. https://doi.org/10.3133/cir1464

MacDonald, A.M., Bonsor, H.C., Ahmed, K.M., Burgess, W.G., Basharat, M., Calow, R.C., Dixit, A. *et al*. 2016. Groundwater quality and depletion in the Indo-Gangetic Basin mapped from in situ observations. *Nature Geoscience,* 9(10): 762–766.

Muntean, M., Guizzardi, D., Crippa, E., Solazzo, M., Olivier & Vignati, J.G.J. 2018. *Fossil CO_2 emissions of all world countries: 2018 report. JRC Science for Policy Report.* Luxembourg, Publications Office of the European Union. https://doi.org/10.2760/30158

OECD (Organisation for Economic Co-operation and Development) & FAO. 2020. *OECD-FAO agricultural outlook 2020-2029. Rome and Geneva.* https://doi.org/10.1787/1112c23b-en

O’Neill, B.C., Kriegler, E., Ebi, K.L., Kemp-Benedict, E., Riahi, K., Rothman, D.S., van Ruijven, B.J. *et al*. 2017. The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. *Global Environmental Change,* 42: 169–180.

Panagos, P., Imeson, A., Meusburger, K., Borrelli, P., Poesen, J. & Alewell, C. 2016. Soil conservation in Europe: Wish or reality? *Land Degradation & Development*, 27(6): 1547–1551.

Rezapour, S. & Alipour, O. 2017. Degradation of Mollisols quality after deforestation and cultivation on a transect with Mediterranean condition. *Environmental Earth Sciences,* 76(22): 755.

Reznik, A., Dinar, A. & Hernández-Sancho, F. 2019. Treated wastewater reuse: An efficient and sustainable solution for water resource scarcity. *Environmental and Resource Economics*, 74: 1647–1685.

Schuur, E.A.G., McGuire, A.D., Schädel, C., Grosse, G., Harden, J.W., Hayes, D.J., Hugelius, G. *et al.* 2015. Climate change and the permafrost carbon feedback. *Nature*, 520(7546): 171–179.

Shah, T. 2009. *Taming the anarchy: Groundwater governance in South Asia.* Washington, DC, Resources for the Future.

Shamsudduha, M., Taylor, R.G., Ahmed, K.M. & Zahid, A. 2011. The impact of intensive groundwater abstraction on recharge to a shallow regional aquifer system: Evidence from Bangladesh. *Hydrogeology Journal,* 19(4): 901–916.

Siebert, S., Henrich, V., Frenken, K. & Burke, J. 2013. *Update of the Digital Global Map of Irrigation Areas to version 5.* Rome, FAO.

Toccalino, P.L., Gilliom, R.J., Lindsey, B.D. & Rupert, M.G. 2014. Pesticides in groundwater of the United States: Decadal-scale changes, 1993–2011. *Groundwater*, 52(S1): 112–125.

TWAP (Transboundary Waters Assessment Programme). 2022. Transboundary Waters Assessment Programme. geftwap.org

UNDRR (United Nations Office for Disaster Risk Reduction). 2021. *GAR special report on drought 2021*. Geneva. www.undrr.org/publication/gar-special-report-drought-2021

UNEP (United Nations Environment Programme). 2018. *Emissions gap report 2018.* Nairobi. https://wedocs.unep.org/bitstream/handle/20.500.11822/26895/EGR2018_FullReport_EN.pdf?sequence=1&isAllowed=y

UNESCO (United Nations Educational, Scientific and Cultural Organization). 2021. ISARM - International Shared Aquifer Resources Management. In: *ISARM/UNESCO*. https://isarm.org

Vanham, D., Hoekstra, A.Y., Wada, Y., Bouraoui, F., de Roo, A., Mekonnen, M.M., van de Bund, W.J. *et al.* 2018. Physical water scarcity metrics for monitoring progress towards SDG target 6.4: An evaluation of indicator 6.4.2 "Level of water stress". *Science of the Total Environment,* 613–614(February): 218–232.

Vanlauwe, B., Six, J., Sanginga, N. & Adesina, A.A. 2015. Soil fertility decline at the base of rural poverty in sub-Saharan Africa. *Nature Plants*, 1: 15101.

Vasenev, V. & Kuzyakov, Y. 2018. Urban soils as hot spots of anthropogenic carbon accumulation: Review of stocks, mechanisms and driving factors. *Land Degradation and Development*, 29(6): 1607–1622.

Warner, K. 2010. Global environmental change and migration: Governance challenges. *Global Environmental Change,* 20(3): 402–413.

Wu, G., Kang, H., Zhang, X., Shao, H., Chu, L. & Ruan, C. 2010. A critical review on the bioremoval of hazardous heavy metals from contaminated soils: Issues, progress, eco-environmental concerns and opportunities. *Journal of Hazardous Materials,* 174(1–3): 1–8.

Yu, W., Yang, Y.-C., Savitsky, A., Alford, D., Brown, C., Wescoat, J., Debowicz, D. & Robinson, S. 2013. *The Indus Basin of Pakistan: The impacts of climate risks on water and agriculture.* World Bank Group. https://doi.org/10.1596/978-0-8213-9874-6

4

SUSTAINABLE RESOURCES PLANNING AND MANAGEMENT

Key messages

Land-use planning and land resources planning (LRP) are essential for managing limited resources for all agroclimatic zones and in crop, livestock, forest and mixed land-use systems. They are used to guide sustainable management of land and water resources and anticipate the challenges that come from population growth and increasing demand. Global assessments of land, soil, water, biodiversity, climate and ecosystems are now providing data and information. A wide range of resource planning tools and approaches are available to support decision-makers, planners and practitioners to take informed actions and promote the scaling out of sustainable and resilient options.

Lower rainfed crop yields and shifts in land suitability are anticipated in the future, in many regions, as the climate changes. Innovative tools are now available to support decision-makers in understanding the extent and location of existing yield gaps[7] and to anticipate shifts in areas suitable for different crops and to identify potential impacts on productivity; complementary options include breeding and selecting suitable crops, changing land use and switching to crops, including trees and livestock, more suited to the changing climate. Together, these offer the means of turning opportunities into realistic adaptations to climate change, local biophysical conditions and socioeconomic circumstances. All are vital elements for planning a sustainable future.

Reversing the trends in human-induced land degradation will be essential to meet global food security objectives. Preventing land degradation costs much less than restoration. Yet few countries have a specific competent environmental judicial body to enforce their national land protection legislation. Coordinated action and political will are needed to overcome long-entrenched degrading practices. The concept of land degradation neutrality (LDN) will become fundamental in planning interventions.

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[7] Yield gap refers to the difference between actual yields and yields expected under optimum growing conditions for particular soils and climate.

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Most countries need to move from crisis to risk-based management to lessen drought risks and impacts. Many countries still put drought in the same category of natural hazards as floods and earthquakes. This wastes valuable resources and does not help to build resilience for future events. A "three-pillar" approach that requires investment in monitoring and early warning systems, studies to assess vulnerability to drought and actions to reduce adverse impacts is now being deployed. A proactive drought risk management policy with strengthened institutional capacities would lead to more robust planning and investment decisions, with early intervention and mitigation and less costly damage due to drought.


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4.1 Introduction

This chapter responds to the risks, issues and emerging challenges identified in Chapter 3. It focuses on land-use planning that informs interventions and behaviour to face the challenge of climate change impacts on land suitability for agricultural production and the threat to land, soil and water resources from human-induced land degradation.

Innovations in land-use and land resources management and planning are described below. New tools are available that enable policymakers and planners to help practitioners tackle resource management challenges, make the best use of available resources, prepare for future climate change, and adapt agricultural resource use to sustain livelihoods and contribute to development goals. The latest climate models provide insights into climate change impacts on agricultural resource distribution, such as changes in productivity and geographic shifts in crop suitability. This allows the best future use of land resources to be identified for rainfed and irrigated production in terms of appropriate agronomic management, inputs and water supply systems according to land/soil potential and water resource availability. Scenario development offers options to help reverse human-induced land degradation in crop, livestock, aquaculture and mixed systems.

A special focus study at the end of the chapter is devoted to dryland systems. It describes the status and trends, risks and threats, and discusses the responses and management pathways for these unique and fragile landscapes.

4.2 Sustainable land resources planning

The increasing challenges of population growth and demands on limited resources by diverse actors, land degradation, biodiversity loss and climate change require the rational use of resources to sustain and enhance productivity and maintain resilient ecosystems.

Land-use planning and, more broadly, LRP are tools for achieving sustainable and efficient use of resources, considering biophysical and socioeconomic dimensions. Land resources planning encompasses land evaluation and land-use planning. It is the systematic assessment of land potential and alternatives for optimal land use, and improved economic and social conditions through participatory processes that are multisectoral, multistakeholder and scale dependent. It relies on an iterative process of implementing, refining, adapting and improving land-use systems and management practices based on results and experiences.

Land-suitability assessment provides decision-makers with viable land-use options based on the biophysical potential of resources and socioeconomic conditions. These options support land-use decision-making processes in fulfilling the needs of different sectors operating in a landscape while optimizing and sustaining resource use. Land resources planning plays an important role in integrating the various sociocultural and biophysical elements of landscapes and land-use dynamics, including responsible governance of tenure, to ensure stakeholders are not marginalized (FAO, 2020a). It provides tools for using land and water resources most efficiently, and promotes options to maintain sustainable, productive landscapes, ecosystems and food systems. This generates multiple benefits and investment opportunities for local and national economies and private/public investors.

4.2.1 Resource planning tools and approaches

Open information exchange underpins all aspects of natural resources planning, management and good governance. Global assessments of land, soil, water, biodiversity, climate and ecosystems are now providing essential data and information for planning and managing natural resources, informing global and national decision-makers and practitioners, and increasingly a wide range of stakeholders who participate in planning processes.

Resource planning tools and approaches are available to support decision-makers, planners and practitioners, working at different decision-making levels to design appropriate policies and plans, take informed actions and promote the scaling out of sustainable and resilient options. The tools and approaches can help to: (i) identify additional areas suitable for sustainable agricultural use and inform sustainable land-use and food system changes; (ii) create links among actors involved in land, soil and water resources to ensure effective use for agriculture and food production; (iii) locate and assess areas to enhance productivity to close yield gaps, and increase food and livelihood security; and (iv) pinpoint areas that are overexploited, hotspots for immediate restoration, and bright spots for future investment and management.


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The tools and knowledge required vary depending on the scale, purpose and nature of the planning process (Ziadat, Bunning and De Pauw, 2017). They also incorporate the socioeconomic circumstances of those who rely mainly on natural resources for their livelihoods, notably farmers, pastoralists and fishers, whose interests are increasingly managed through formalized participatory negotiation processes that have become a significant element of LRP (Tarrason, Andrian and Groppo, 2017; FAO, 2022a, 2022b).

Box 4.1 describes current LRP planning tools and approaches, and provides some important definitions of terms used in this and subsequent chapters of this report.

The LRP Toolbox (Ziadat, Bunning and De Pauw, 2017) contains summary descriptions and links to a comprehensive list of LRP tools and approaches developed by FAO and other institutions, including:

- Biophysical approaches/tools giving prominence to biophysical attributes (climate, soil, terrain and water) and methods that guide users towards suitable land-use options and alternatives to sustain resources quality and quantity and ecosystem functions and services, based mainly on these attributes and land-use and climate change impacts. Land suitability and similarity analysis are typical examples.

BOX 4.1
INNOVATIVE TOOLS AND APPROACHES FOR LAND-USE PLANNING

Agroecological zoning (AEZ) and land-suitability analysis, developed by FAO and IIASA, can help to identify areas for implementing land-use planning and management programmes based on specific crop/land-use/land management practices. It offers global-, regional- and national-level assessments of potential agricultural production options considering historical and future climate conditions, soil and terrain resources, land cover, land protection status and biodiversity, under three distinct levels of inputs and management for rainfed and irrigated water supply systems. It includes a spatial inventory of downscaled actual area, yield and production of the main agricultural commodities and the occurrence and significance of apparent yield gaps.

Sustainable land management (SLM) is defined as "the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions" (FAO, 2022c). It includes a range of complementary measures (policy, legislation, institutional reform and technologies) that are adapted to the biophysical and socioeconomic context for the protection, conservation and sustainable use of resources (soil, water and biodiversity), restoration or rehabilitation of degraded natural resources, and maintenance of the ecosystem functions and services that support the livelihood and well-being of people. Integrated LRP tools are needed to enhance the scaling out of SLM options.

Land-use planning is the systematic assessment of land potential and alternatives for optimal land use and improved economic, environmental and social conditions through participatory processes involving multisector, multistakeholder and scale-dependent processes (FAO, 1993). Land-use planning helps decision-makers to adopt appropriate options for the use of land and water resources based on their natural potential and hence avoid unsustainable exploitation and prevent further degradation. Proper planning should avoid detrimental land-use change and help land users to select and put SLM options into practice that support land/soil restoration in already degraded areas and sustain resources (soil, water and biodiversity) and ecosystem services.

Land resources planning is an overarching approach and set of tools for various land users to plan and manage land resources. Rather than a top-down process, participatory LRP involves the multiple sectors and stakeholders concerned in a given land area or territory (from the local community to the river basin, provincial, national or transboundary level). Land resources planning offers a set of tools – procedures, guidelines, methods and datasets, covering biophysical, economic, sociocultural and governance dimensions – that guide the design of implementation plans and decision-making for SLM and restoration and the delivery of ecosystem services. Land resources planning encompasses land evaluation and land-use planning, and addresses the biophysical, socioeconomic and negotiatory domains.

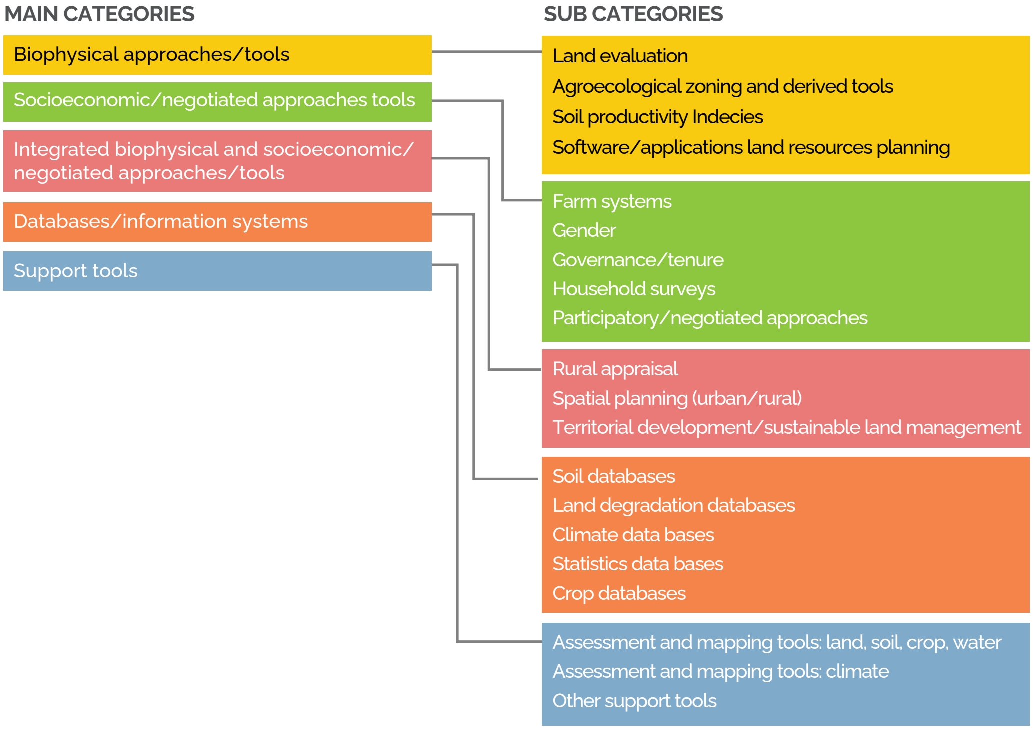
Integrated land-use planning can be used to support transformative change in land use and management so as to deliver a range of ecosystem services that support human well-being and livelihoods in line with SDGs. This can help to sustain or improve productivity, achieve land degradation targets, enhance climate change resilience and strengthen land-based mitigation, and address trade-offs in land use, taking into account national policies, priorities and regulations. Integrated land-use planning requires a participatory approach to ensure local communities and all stakeholders, including marginalized or vulnerable groups and the private sector, engage in consensual decision-making and conflict resolution. FAO offers technical support to Members to develop country-specific integrated land-use planning approaches that account for national land governance strategies and laws as well as diverse socioeconomic contexts, to enhance implementation, *inter alia*, through decentralized governance mechanisms, negotiated territorial development, tenure security, and access and user rights.

A land resources information management system (FAO, 2022d) is a tool designed to create a secure, reliable, efficient, accountable and equitable system of land resources management for agriculture. It comprises a comprehensive set of GIS-based tools (e.g. land suitability module and map generator) and a central spatial database, and provides an evaluation of land-use suitability based on modular multiple criteria analysis-based assessment, including a socioagricultural vulnerability analysis. It allows assessments of physical and socioeconomic conditions of the land and evaluation of benefits and constraints of different options by simulating various impact scenarios.

The Hand-In-Hand Initiative Data Platform (FAO, 2022e) is an evidence-based country-led FAO initiative to accelerate agricultural transformation and sustainable rural development to support SDGs. The platform guides action among partners and in keeping with national sustainable development priorities. Tools, such as geospatial modelling and analytics, are available to identify the best opportunities to raise incomes and reduce inequities and vulnerabilities among the rural poor and present an evidence-based view of economic opportunities to improve targeting and tailoring of policy interventions, innovation, finance and investment, and institutional reform.

The LRP Toolbox was developed by FAO in response to demand from a range of stakeholders (planners, policymakers, governments, institutions, communities, technical specialists, etc.) for a resource that supports participatory LRP. The toolbox provides information and an inventory of tools and approaches to support the planning requirements of different stakeholders working at different levels in different regions and sectors (Ziadat *et al.*, 2021). It is web based and freely available, and is regularly updated with summary descriptions and links to a comprehensive number of LRP tools and approaches developed by FAO and other institutions. In 2021, the toolbox comprised 157 tools grouped in five thematic domains in the land-use planning process: (i) biophysical approaches/tools, (ii) socioeconomic and negotiation approaches/tools, (iii) integrated biophysical, socioeconomic and negotiation approaches/tools, (iv) databases/information systems and (v) support tools. The tools are further characterized in terms of thematic area, type of tool, scale of applicability and user (see Figure 4.1).

FIGURE 4.1 SEARCH CRITERIA AND OPTIONS FOR THE LAND RESOURCES PLANNING TOOLBOX



MAIN CATEGORIES

- Biophysical approaches/tools
- Socioeconomic/negotiated approaches tools
- Integrated biophysical and socioeconomic/negotiated approaches/tools
- Databases/information systems
- Support tools

SUB CATEGORIES

Land evaluation
Agroecological zoning and derived tools
Soil productivity Indecies
Software/applications land resources planning

Farm systems
Gender
Governance/tenure
Household surveys
Participatory/negotiated approaches

Rural appraisal
Spatial planning (urban/rural)
Territorial development/sustainable land management

Soil databases
Land degradation databases
Climate data bases
Statistics data bases
Crop databases

Assessment and mapping tools: land, soil, crop, water
Assessment and mapping tools: climate
Other support tools

THEMATIC AREAS

Agriculture, statistics
Agriculture, productivity
Cadaster
Climate
Crops, distribution
Crops, productivity
Crops, suitability
Economy, statistics
Environment, the distichs
Farming systems
Food, statistics
forestry, statistics
General
Land degradation
Land evaluation
Land management/planning
Land/water rights
Land/cover
Population, distribution
Population, statistics
Remote sensing
Social participatory approaches
Social, statistics
Soils, distribution and properties
soils, management and conservation
Water, productivity
Water, statistics

TYPE OF TOOL

Data
Documentation/manuals
Educational materials
Framework/guidelines
Maps/GIS
Model
Questionnaire/survey
Software

SCALE OF APPLICABILITY

Global
Regional
National
Subnational/province/district
Watershed/basin/landscape
Locality/farm/site

Source: **FAO**. 2022. Land Resources Planning Toolbox. In: *Land & Water*. Rome. www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/en; adapted from **Ziadat, F., De Pauw, E., Nachtergaele, F. & Fetsi, T.** 2021. A land resources planning toolbox to promote sustainable land management. *Sustainable Agriculture Research*, 10(1): 73.

- Socioeconomic and negotiation approaches/tools covering aspects of the human environment (e.g. farming systems, tenure, gender, participatory planning and governance). These tools give prominence to social and economic settings required for land-use planning and include the participatory decision-making approaches and methods of those institutions and actors involved in land management and governance.

- Integrated biophysical, socioeconomic and negotiation approaches/tools are used to process information on biophysical characteristics and social and economic conditions, to consider access, user rights, competition and conflict over resources, and for managing trade-offs. They incorporate principles, approaches and methods of participatory land-use planning or LRP, with the overall objective of reaching mutually beneficial outcomes for all stakeholders, including socioeconomic and environmental benefits in line with the SDG framework.

The quality and availability of natural resources data at national, regional and global levels are increasing rapidly as new data sources come on stream. The climate crisis has substantially improved and increased climate resources data. Current terrain and land-cover data are detailed and reliable. However, the lack of spatial distribution and quality of soil resources data is constraining advances in land-use planning. The Global Soil Partnership (GSP) is improving data through its Global Soil Information System and building country capacities in soil data and mapping through the International Network of Soil Information Institutions. Similarly, there is room for improvement in acquiring surface water and groundwater data, particularly water quality data, an issue flagged in the SDG 6 synthesis report on water and sanitation (United Nations, 2018). Such deficiencies hinder sound planning and efforts to guide interventions and investments for sustainable land planning and management, such as locating and remedying hotspots. Improving monitoring and data collection must not be ignored; they should be harmonized and coordinated, drawing on public and private sector investments.

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4.2.2 Land suitability for crop production

Suitability analysis and land-suitability maps are important foundations for sound agricultural development planning. They provide information on potential land suitability and limitations. They also help planners and decision-makers to identify optimum land uses for current and potential agricultural lands while supporting the protection and sustainable use and restoration of land and water resources.

Recent developments in approaches to LRP for sustainable use and management of land and water resources exploit well-established databases on climate, soil, terrain, land cover, land use and crop requirements (Fischer *et al.*, 2021). They also exploit climate change modelling to assess anticipated changes in land suitability resulting from expected rising temperatures and changes in rainfall distribution. They aim to make the best use of limited land (and water) resources, to yield optimal benefits of rational land use while avoiding conflicts over how and who


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uses tracts of land (FAO, 1993). This process turns promising land-use types, defined in terms of products, agricultural inputs, management practices and water resources availability, into feasible production systems, such as in rainfed and irrigated agriculture, forestry and ruminant livestock production.

4.2.3 The Global Agro-Ecological Zones methodology

The GAEZ methodology, developed by FAO and IIASA (Fischer *et al.*, 2021), assesses the potential for growing crops in terms of the maximum potential and agronomically attainable crop yields for land resource units under different land-use types. The methodology uses agroclimatic, soil and terrain data and levels of agricultural inputs and management to establish areas suitable for sustainable agricultural use. These are generic agricultural production systems defined by crop parameters, such as harvest index, maximum rate of photosynthesis, maximum leaf area index, water supply systems in rainfed and irrigated systems, and levels of inputs and management ranging from low to high.

The first global AEZ assessment was in 2000. Since then, GAEZ assessments have been updated continuously and published through data portals, in 2000 (GAEZ v1), 2002 (GAEZ v2) and 2012 (GAEZ v3). The latest data portal for GAEZ v4 and the database are fully accessible to the public (FAO and IIASA, 2021). In this analysis, GAEZ v4 uses 2010 baseline data that include land cover, crop production, protected areas, renewable water resources, and climatic conditions for the period 1961–2010, and a selection of future climate simulations using the IPCC fifth assessment report climate model outputs for four RCPs. The analysis uses the latest version of the Harmonized World Soil Database (HWSD; FAO *et al.*, 2012).

The GAEZ method is a global AEZ method and is not designed for local-level use. However, a case study using the Land Potential Knowledge System (LandPKS) mobile application illustrates how GAEZ could be integrated with field data to downscale at local/farm level and benefit from the information in the GAEZ data portal (Box 4.2).

4.2.4 Land suitability for rainfed crops

In the analysis of this report, GAEZ data are used to illustrate a range of options available for land units now and in the future for ten widely grown crops (wheat, maize, rice, sorghum, citrus, tomato, alfalfa, chickpea, olives and coffee), to guide in the selection of promising land-use types based on climate data between 1981 and 2010.

The results for rainfed wheat provide an example of the mapping potential using the GAEZ methodology. Map 4.1 shows current potential production for rainfed wheat, assuming high input. The analysis uses data from the background report of Tuan *et al.* (2022). Access to georeferenced results and the GAEZ v4 data portal is also available at the SOLAW 2021 website (FAO, 2022f; FAO and IIASA, 2021).

Results for other crops can be processed using data available on the GAEZ v4 data portal. The procedure and results for selected crops are available in the current GAEZ v4 model documentation (Fischer *et al.*, 2021).

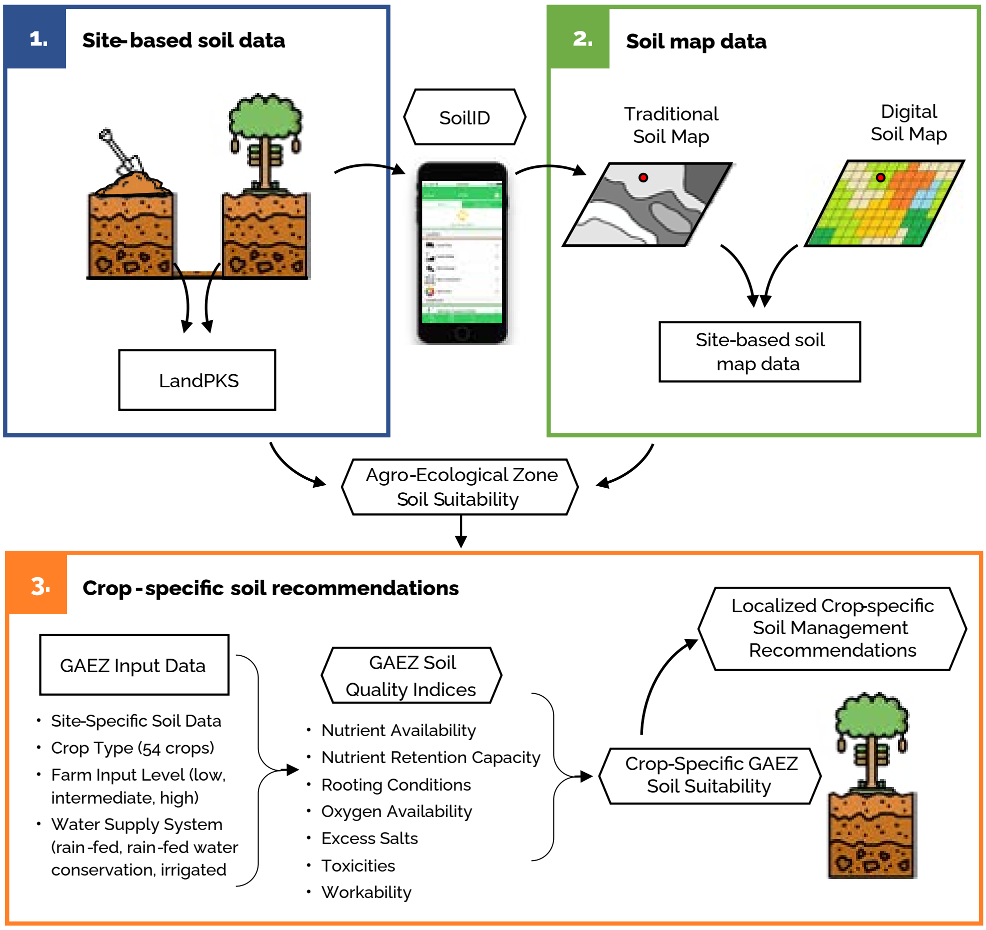
BOX 4.2

LOCALIZING/INCREASING ACCURACY OF GLOBAL AGRO-ECOLOGICAL ZONES PREDICTIONS WITH SITE-SPECIFIC SOIL DATA COLLECTED USING A MOBILE APPLICATION

A major obstacle to selecting the most appropriate crops and closing the yield gap is a lack of site-specific soil information. This adds a high level of uncertainty to valuable land-use and management planning tools, such as the FAO GAEZ soil suitability modelling framework.

The GAEZ framework uses soil data and detailed agronomic knowledge to predict crop-specific agronomic potential. It accomplishes this by calculating seven crop-specific soil quality indices used to generate crop-specific soil suitability ratings (Figure 4.2, item 3).

FIGURE 4.2 THE GLOBAL AGRO-ECOLOGICAL ZONES SOIL SUITABILITY DOWNSCALING FRAMEWORK



Source: Adapted from **Grameen Foundation, University of Colorado Boulder & United States Department of Agriculture, Agricultural Research Service.** 2020. *Map the the future (M2F): Integrating soil mapping into coca farm development plans in Ghana.* https://pubdocs.worldbank.org/en/613921612401424054/Grameen-Map2Future-Final-Report-low-res.pdf

Accurate soil information is critical for identifying limitations and management practices to improve crop yields. However, this can be difficult and costly to obtain. Recent advances in information technologies have made it possible to create mobile decision-support tools that can assist users in acquiring accurate site-specific soil data (Figure 4.2). The LandPKS application is one such example. It provides a complete mobile computing platform that allows non-soil scientists to describe and identify the soil at a location using limited, simple soil observations. The application offers a digital interface for collecting and recording soil profile data and a global soil identification tool (SoilID) that leverages user-recorded soil data, existing soil maps and cloud-based computing to determine the most probable soil type at a location (Figure 4.2, item 2).

Information on static soil properties can be used directly to inform farmer decisions on various management practices, such as irrigation frequency, the need for organic amendments and the likelihood of erosion. Soil identification with direct links to FAO and other soil survey information via LandPKS-SoilID can further tailor soil management decisions.

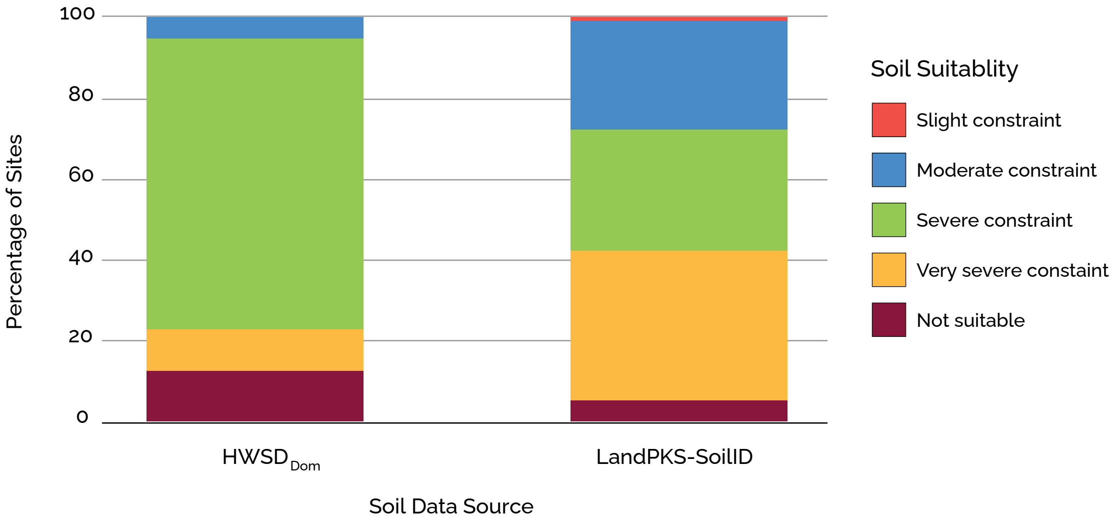
The AEZ modelling framework can translate site-specific soil information from LandPKS and other applications into crop-specific soil suitability ratings. Recent work by the Unites States Department of Agriculture's Agricultural Research Service and University of Colorado scientists working on LandPKS have taken the AEZ methodology and localized the soil suitability calculations by leveraging site-specific soil property data and the LandPKS-SoilID algorithm to identify the most likely soil and/or soil component at a sampling location from commonly used soil map products (Figure 4.2).

The AEZ downscaling framework (Figure 4.2) was evaluated at 6 065 LandPKS sampling sites in Ghana using the scenario of rainfed, low-input maize production systems (Figure 4.3). This analysis compares the soil suitability for maize based on the dominant mapped soil type from HWSD versus site-specific soil data measured using the LandPKS application, combined with the HWSD soil map data selected using the SoilID matching algorithm. This analysis shows that relying on the dominant soil mapped at a location will often lead to an under or overestimation of soil suitability due to the inability of soil maps to accurately characterize the variation of soil conditions across the sampling sites. These results demonstrate the importance of site-specific soil data for understanding a soil's agronomic limitations and the feasibility of soil management interventions for improving crop yields. When smallholder farmers have limited resources, these differences could mean success or failure or limited impact of the investments made.

Sources: **Herrick, J.E., Urama, K.C., Karl, J.W., Boos, J., Johnson, M.V.V., Shepherd, K.D., Hempel, J. *et al.*** 2013. The global Land-Potential Knowledge System (LandPKS): Supporting evidence-based, site-specific land use and management through cloud computing, mobile applications, and crowdsourcing. *Journal of Soil and Water Conservation*, 68(1); **Maynard, J.J., Salley, S.W., Beaudette, D.E. & Herrick, J.E.** 2020. Numerical soil classification supports soil identification by citizen scientists using limited, simple soil observations. *Soil Science Society of America Journal*, 84(5): 1675–1692.

FIGURE 4.3

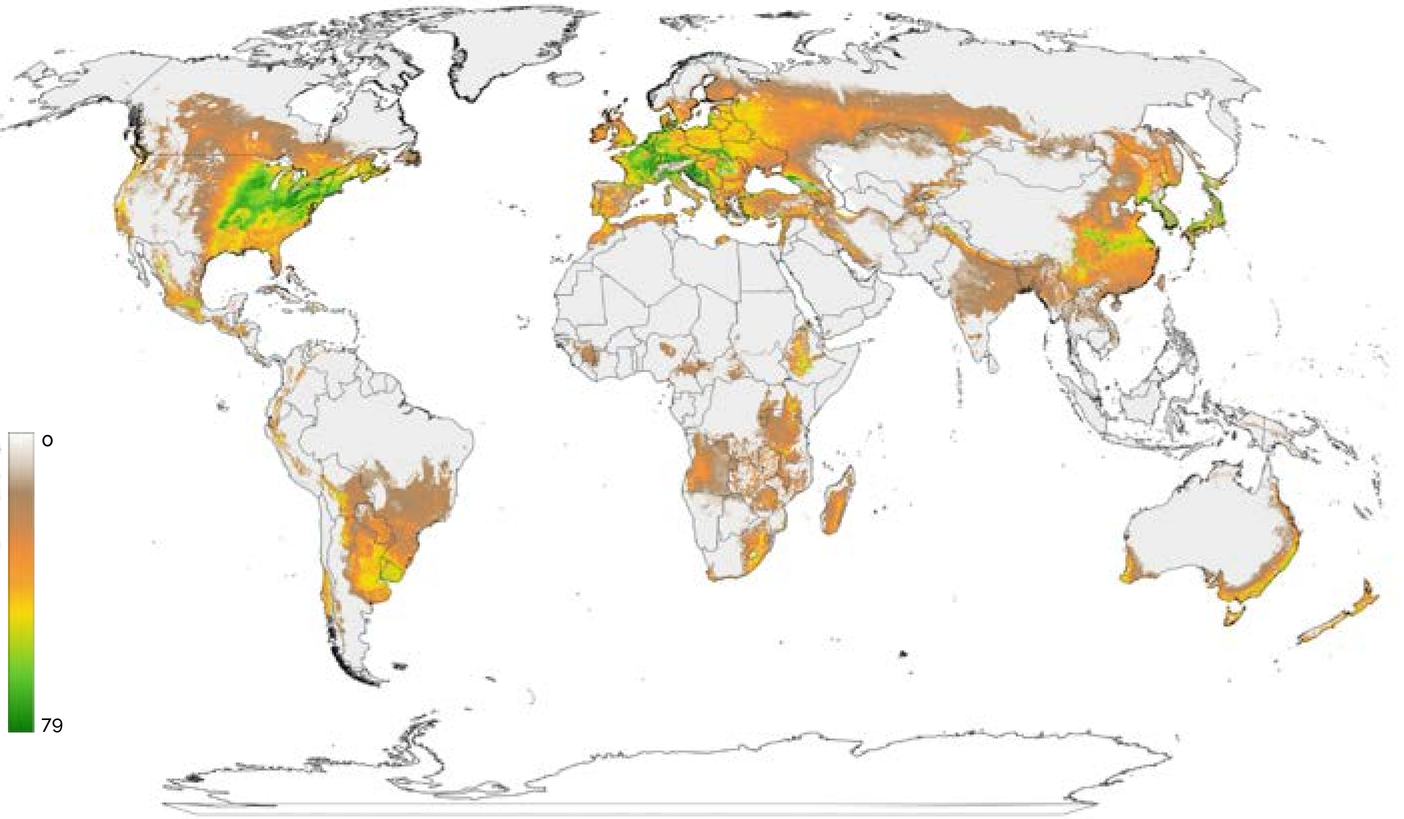
MAIZE SOIL SUITABILITY AT 6 065 LAND POTENTIAL KNOWLEDGE SYSTEM' SAMPLING SITES IN GHANA BASED ON LOW-INPUT RAINFED FARMING SYSTEMS



Note: HWSD$_{Dom}$ = dominant soil type mapped at a location.

Source: **Jonathan Maynard,** University of Colorado, Boulder

MAP 4.1 POTENTIAL PRODUCTION FOR RAINFED WHEAT AT HIGH INPUTS (TONNES/ha), BASED ON AVERAGE CLIMATE FROM 1981 TO 2010 AND GLOBAL SOIL AND TERRAIN INFORMATION



Source: **FAO & International Institute for Applied Systems Analysis**. 2021. Global Agro-Ecological Zoning version 4 (GAEZ v4). In: *FAO*. Rome. www.fao.org/gaez/entps://gaez-data-portal-hqfao.hub.arcgis.com Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

This analysis addresses land suitability for crop production. However, land-suitability maps for livestock, forestry mixed agroforestry and agropastoral systems are equally important. Marginal lands for cropland may be suitable for livestock and forestry enterprises (Box 4.3).

Policies for marginal environments should encourage the use of ecological processes instead of relying entirely on external inputs for crop production. Future technologies should account for and must be suited to the high degree of diversity in biophysical and socioeconomic conditions typical of marginal areas. Farm policies intended for marginal agriculture must therefore encourage property rights systems to secure the ownership rights over land and other resources. The impact of market reform policies on marginal areas has often been detrimental to the poor.

4.2.5 Mapping yields and production

The GAEZ methodology produces the most likely distribution (pixel level) of crops within cultivated land, their yields (mass per unit area) and production, by downscaling national and subnational land-use data from FAOSTAT, Agro-MAPS and national statistics, complemented with information on land cover and land suitability. Details of the procedure are available in the GAEZ v4 model documentation (Fischer *et al.*, 2021).

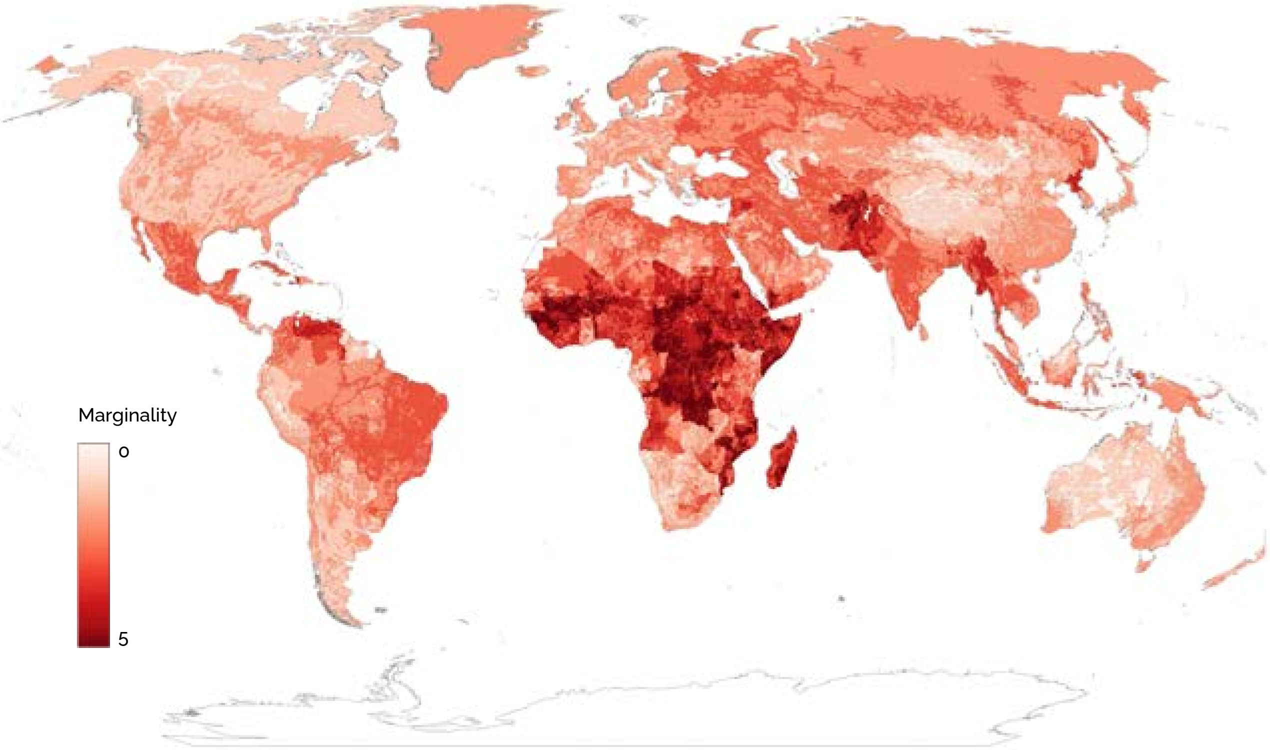
BOX 4.3
MARGINAL LANDS FOR CROP PRODUCTION

"Marginal land" refers to land that is no longer economical for crop production. However, it could still be important for grazing. Marginal land has little potential for profit, and often has poor soil or other undesirable characteristics. FAO and UNEP classified land supporting a yield of up to 40 percent of the crop potential as marginal. Such land is identified as areas where cost-effective production is not possible under given conditions, cultivation techniques, agriculture policies, and macroeconomic and legal settings.

Marginal areas are perceived to have low crop production potential, which has led to bias in policymaking to support the development of agriculture in marginal areas. However, marginality is not a static and permanent condition, and marginal lands are subject to change in land use, agricultural technologies and socioeconomic environment (Map 4.2). Investments in technologies and applying good management practices and tools could reverse this situation. Thus, unproductive and marginal lands could be transformed into productive agricultural lands. Marginal areas present opportunities for alternative models of development. Research and development and public policies towards these marginal lands need to be revised to target marginal producers, especially the extremely poor, to provide incentives to maintain and improve the natural resource base for production without further land degradation.

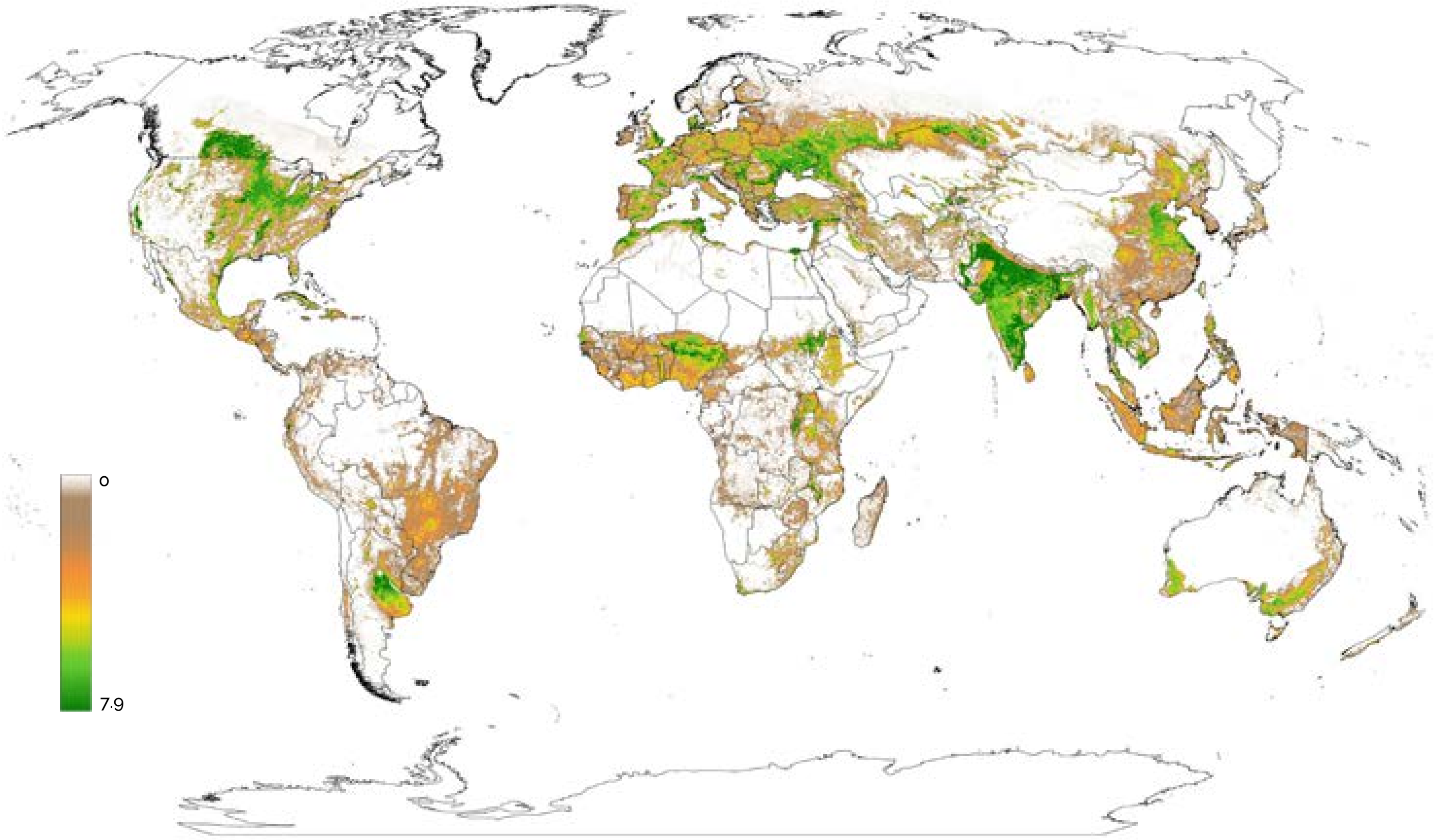
In 2010, about 1.75 billion people worldwide (38 percent of the rural populations) lived in remote less-favoured agricultural areas, up from 1.56 billion people in 2002, and the majority of them (1.6 billion out of 1.75 billion) were in developing countries.

MAP 4.2 **MARGINALITY HOTSPOTS – OVERLAPPING DIMENSIONS OF MARGINALITY**



Source: **V. Graw**, personal communication (2022), based on **Ahmadzai, H., Tutundjian, S. & Elouafi, I.** 2021. Policies for sustainable agriculture and livelihood in marginal lands: A review. *Sustainability (Switzerland)*, 13(16): 1–18.
Modified to comply with **UN**. 2020. *Map of the World.* https://www.un.org/geospatial/file/3420

MAP 4.3 DISTRIBUTION AND INTENSITY OF CROPLAND, 2010 (% OF 30 ARCSECOND GRID CELL)



Source: **FAO & International Institute for Applied Systems Analysis**. 2021. Global Agro-Ecological-Zoning version 4 (GAEZ v4). In: *FAO*. Rome. www.fao.org/gaez/en
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Final boundary between the Sudan and South Sudan has not yet been determined.

Map 4.3 shows the crop cover rate, between 0 and 100 percent, of cropland in a grid cell for 2010. This illustrates the heavy concentration of cropland in temperate and subtropical zones with the highest concentrations around the Great Lakes in Canada and the United States of America, Central and Eastern Europe, China, northern India and Pakistan. Map 4.4 illustrates georeferenced rainfed maize yields in 2010.

4.2.6 Mapping yield gaps

Current rainfed crop yields and production fall short of what is potentially achievable in many regions. For example, in sub-Saharan Africa, yields are only 24 percent of what is possible with higher levels of input and management. Understanding the extent and location of current and potential yield and production gaps is essential to exploit investment opportunities and enhance food production.

Comparing actual crop yields and potential attainable crop yields identifies areas where increases in food production are achievable by improving management practices.[8] More details on yield-gap analysis and calculations are available in GAEZ v4 model documentation (Fischer *et al.*, 2021).

Map 4.5 illustrates yield-gap ratios for maize in 2010. The most significant gaps occur in

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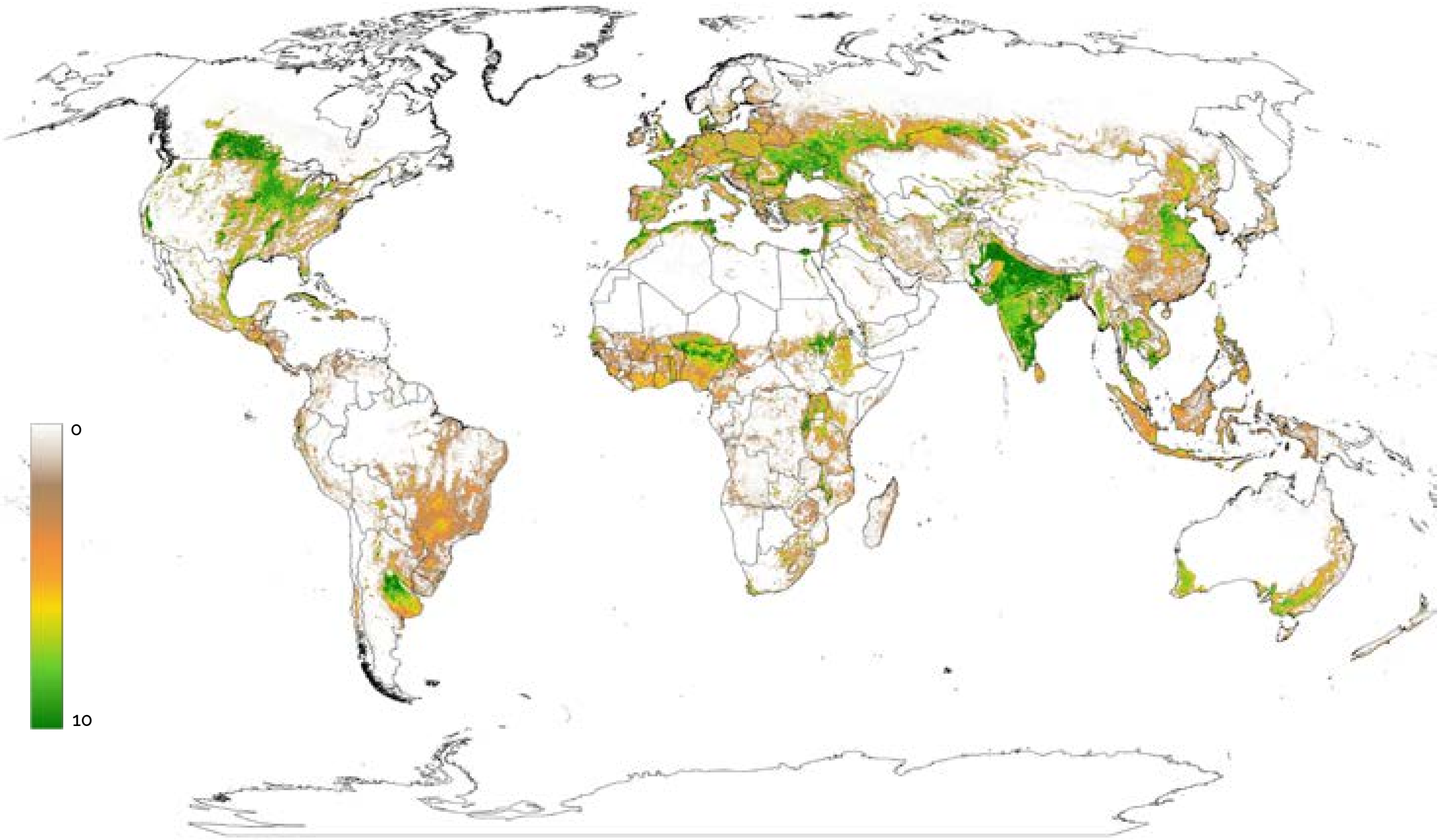
[8] Actual georeferenced crop distribution and yields, from downscaling 2009–2011 statistics, were compared with corresponding anticipated yields obtained using AEZ crop modelling (estimated in GAEZ v4).

MAP 4.4 DOWNSCALED YIELD OF RAINFED MAIZE, 2010 (TONNES/ha)



Source: **FAO & International Institute for Applied Systems Analysis**. 2021. Global Agro-Ecological Zoning version 4 (GAEZ v4). In: *FAO*. Rome. www.fao.org/gaez/en
Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

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India and most countries in Africa, signalling much lower yields than potentially achievable in these areas. Similar maps are available for other crops.

Map 4.6 illustrates the yield-gap occurrences based on 26 main crops.[9] The small gaps reflect high levels of management and inputs in Canada, the midwest of the United States of America, parts of Brazil, Western Europe, southern China and the southeast coast of Australia. Significant yield gaps in most of Africa, particularly in the Sahel, reflect current low levels of inputs and management. The substantial yield gaps in Central America, India and the Russian Federation are partly attributed to lower inputs and partly to suboptimum management.

Regions where the yields are high and the yield gaps are small (green) have the most significant land degradation risks due to unsustainable intensification. Sustainable management methods are needed to counter soil pollution, compaction and sealing, salinization, acidification, erosion, carbon and biodiversity loss and soil sealing (Chapter 5). Areas with low yields and significant yield

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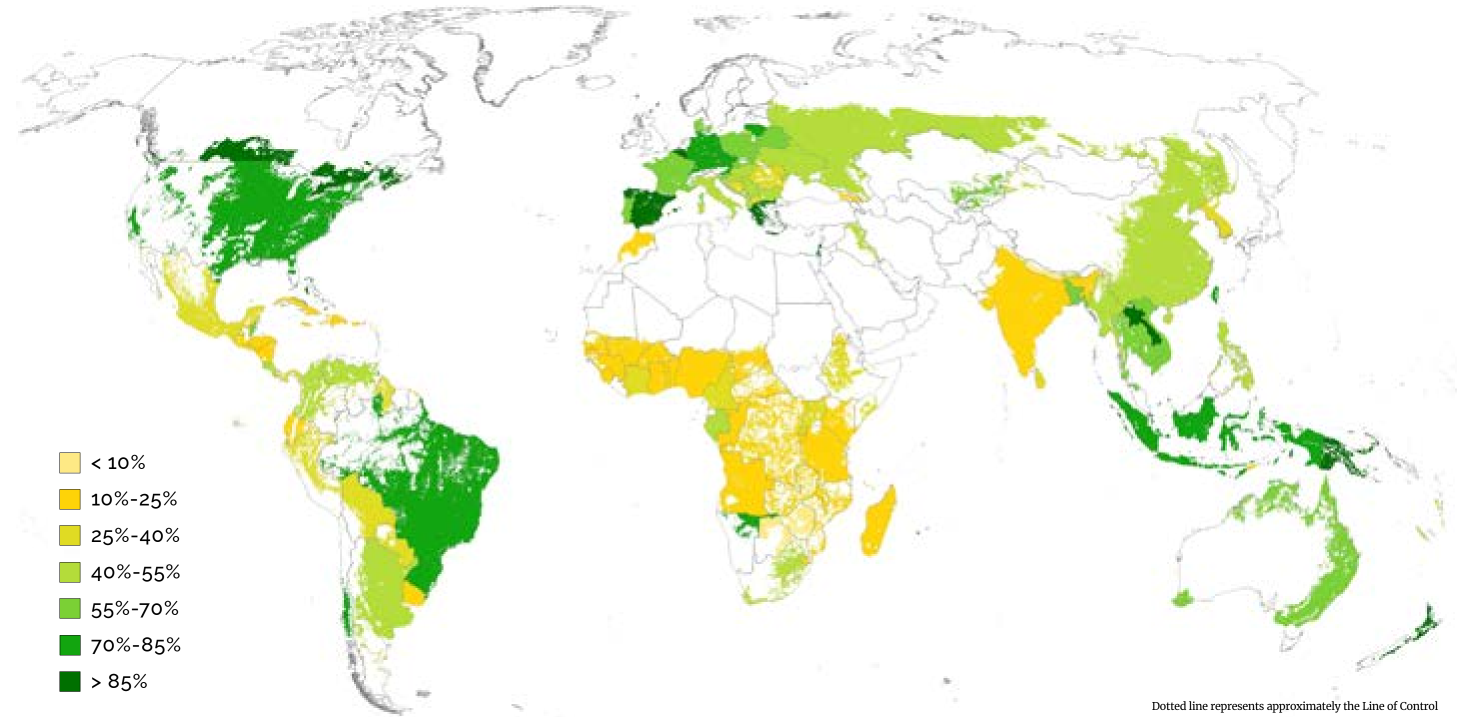
[9] Wheat, rice, maize, sorghum, millet, barley, other cereals (buckwheat, oats, rye, upland rice), tubers (sweet and white potato combined), cassava, yams and other roots, sugar beet, sugar cane, pulses (Phaseolus beans, chickpeas, cow peas, dry peas, pigeon peas, gram), soybean, rapeseed, sunflower, groundnut, oil palm fruit, olives, cotton, banana, tobacco, vegetables (cabbages, carrots, onions, tomatoes), stimulants (cocoa, coffee, tea), fodder crops and all other crops from FAOSTAT.

MAP 4.5 YIELD ACHIEVEMENT RATIO (100 × ACTUAL/POTENTIAL) FOR MAIZE UNDER RAINFED WATER SUPPLY CONDITIONS, 2010



Source: **FAO & International Institute for Applied Systems Analysis**. 2021. Global Agro-Ecological Zoning version 4 (GAEZ v4). In: *FAO*. Rome. www.fao.org/gaez/en. Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

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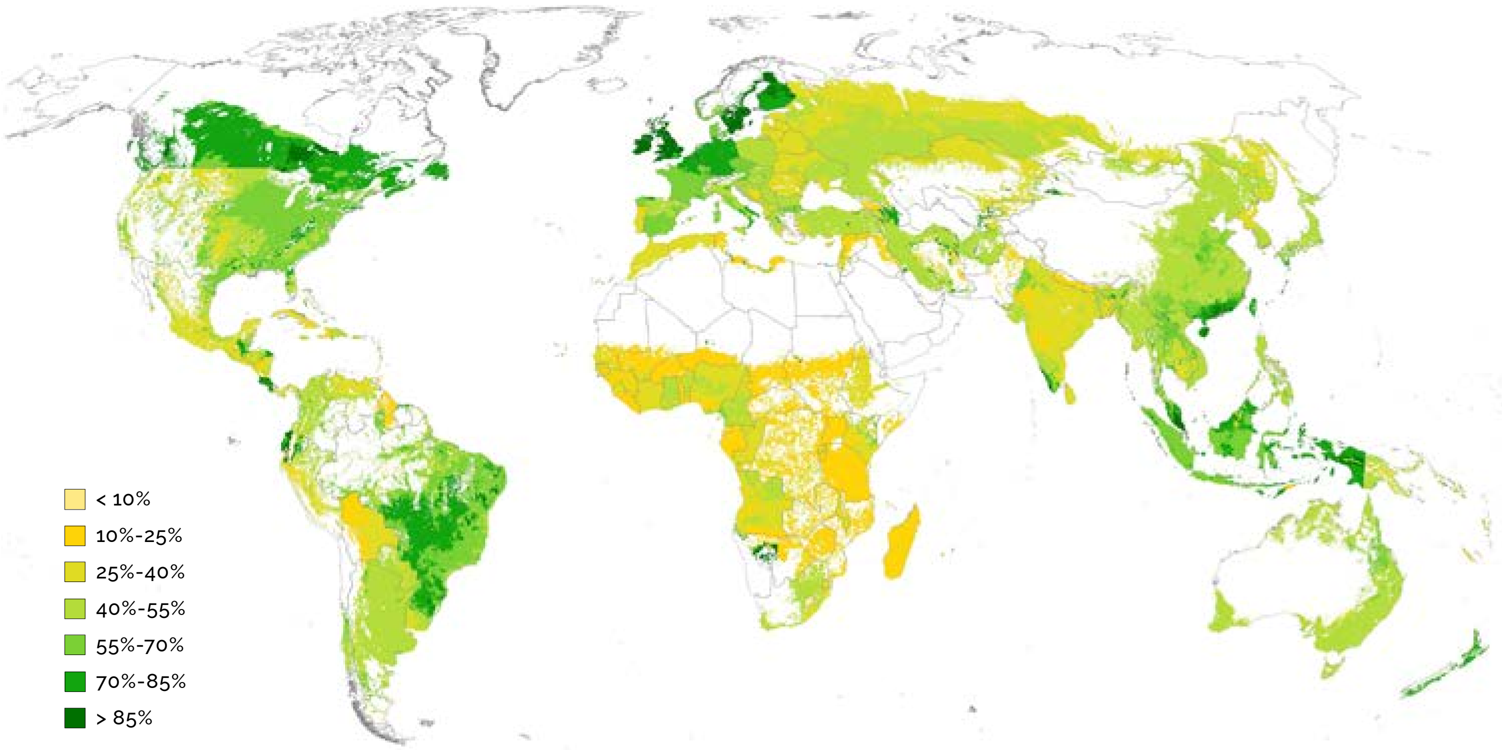
Final boundary between the Sudan and South Sudan has not yet been determined.

Final status of the Abyei area is not yet determined

MAP 4.6 YIELD ACHIEVEMENT RATIO (100 × ACTUAL/POTENTIAL) FOR 26 CROPS IN CURRENT RAINFED CROPLAND, 2009–2011



Source: **FAO & International Institute for Applied Systems Analysis**. 2021. Global Agro-Ecological Zoning version 4 (GAEZ v4). In: *FAO*. Rome. www.fao.org/gaez/en. Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

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gaps (yellow) reflect mainly soil nutrient deficiencies. They are at risk from different forms of land degradation resulting from nutrient mining, overgrazing and deforestation, including large-scale desertification, soil erosion and biodiversity loss. This points to the need to promote sustainable intensification in areas with small and large yield gaps.

The areas where significant yield gaps exist (yellow) are usually associated with subsistence and low-input farming. They are also areas where opportunities exist to increase production and productivity by selecting crops according to the current and near-future land suitability and by improving on-farm and territorial or watershed management practices. This analysis and mapping help identify yield-gap hotspots where future investment in sustainable land and water management is likely to succeed. Box 4.4 describes another approach based on real-time remote-sensing data.

Unlocking this yield potential is difficult. Several socioeconomic and ecological conditions determine whether farmers are willing to apply management practices and higher inputs that are affordable, desirable and feasible, and support the adoption of improved farming systems and management practices (SLM). Much depends on good governance at local and municipal levels (Chapter 5).

BOX 4.4
FORECAST CROP YIELDS INFORMING THE EUROPEAN UNION'S COMMON AGRICULTURAL POLICY AND DROUGHT MANAGEMENT

The European Commission's JRC in Ispra, Italy, houses the European Union's Food Security Unit, whose role is to forecast crop production during the current growing season to inform the European Commission's Common Agricultural Policy.

To do this, JRC developed the Monitoring Agricultural Resources (MARS) Crop Yield Forecasting System. This provided timely forecasts of crop production, including biofuel crops, for Europe and other strategic areas of the world, including Africa, China, India, Kazakhstan, the Russian Federation and South America since 1992. The system monitors crop vegetation growth (cereal, oil seed crops, protein crops, sugar beet, potatoes, pastures and rice), including the short-term effects of meteorological events on crop production. It also provides seasonal yield forecasts of key European crops, thereby contributing to evaluating global production estimates of crops such as wheat and maize to support Common Agricultural Policy management decisions.

Software tools are available to access the data for analysis to support decision-makers and are invaluable for informing users about the potential impacts of agricultural drought. The JRC MARS Explorer displays current weather conditions and progress in crop growth based on meteorological station data, crop growth simulations and remote-sensing observations originating from the MARS Crop Yield Forecasting System. An analysis of weather, crop conditions and quantitative crop yield forecasts for Europe is published monthly in the JRC MARS bulletins on crop monitoring in Europe.

Source: **European Commission**. 2022. Monitoring agricultural resources (MARS). In: *EU Science Hub*. https://ec.europa.eu/jrc/en/mars

4.2.7 Planning for land suitability under a changing climate

Climate change is likely to change land suitability and productivity in the future. Using the most advanced tools available, such as general circulation models, it is now possible to compare current land suitability and productivity at baseline climate (1981–2010) with anticipated changes in the 2080s (2070–2099). However, the resolution is coarse and the predicted rainfall distribution is less reliable than that of temperature. Several general circulation models exist with advantages and disadvantages, so an average ("ensemble") of results was used for five main models (Bindoff *et al.*, 2013). The most realistic pathway for SOLAW 2021 analysis is a middle-of-the-road RCP (RCP 4.5). This scenario leads to an expected temperature increase of 2.0 °C by 2100. A high-end scenario was also used with RCP 8.5, resulting in a temperature increase of 4.2 °C by 2100.

Several maps illustrate various options for the ten crops (wheat, maize, rice, sorghum, citrus, tomato, alfalfa, chickpea, olives and coffee). These show three important changes: changes in land suitability for some crops, which could mean higher or lower yields, shifts in suitable geographical areas expanding some and shrinking others, and opportunities for multiple cropping. Note that the model assumption is that soil conditions remain unchanged over time, and current fragile permafrost areas are assumed to remain permanently protected and are not included in agricultural projections.


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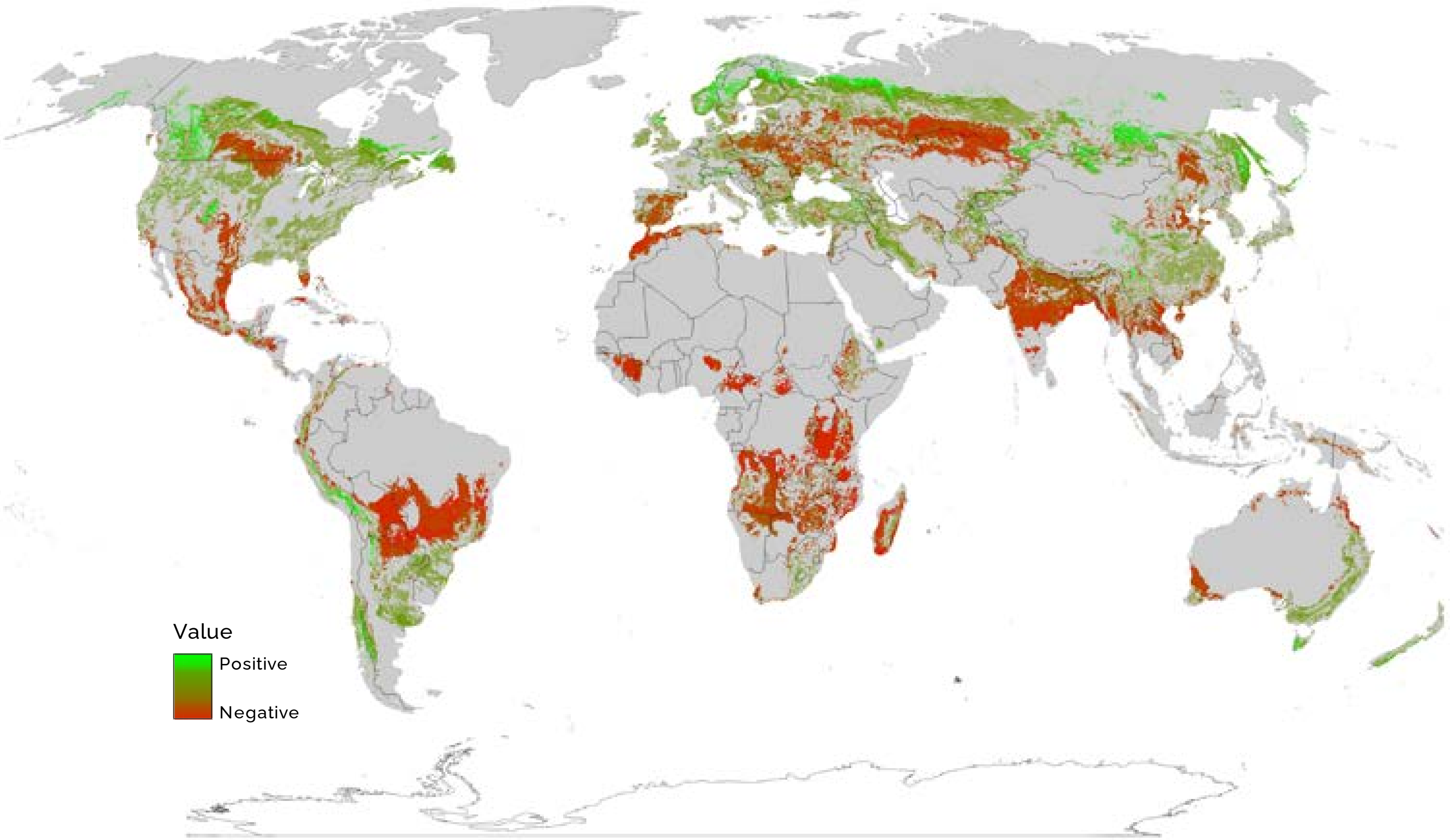
Shifts in land suitability. A common rainfed cereal crop (wheat) and a cash crop (coffee) illustrate the potential impacts of shifts in land suitability. Map 4.7 shows shifts in land suitability for wheat based on high inputs and RCP 4.5. Areas marked green show land-suitability increases, while those marked red show decreases. Thus, Argentina, Canada, Northern Eurasia, South Africa and the United States of America would see the areas of suitable land increasing (green) and northern Brazil, Central Africa and Eastern Europe would see areas decreasing (red). This does not mean that red areas would be unsuitable for wheat; instead, alternative crop types/improved species and varieties with adapted tolerance traits and crop management may be needed in the future.

Map 4.8 illustrates shifts in land suitability for rainfed coffee grown under RCP 4.5. Large areas presently suitable for growing coffee would decline. A significant decline is expected in Brazil and West Africa. Gains in land suitability for coffee are likely in East Africa and parts of China. Table 4.1 illus-

MAP 4.7

DIFFERENCE IN LAND SUITABILITY FOR RAINFED WHEAT WITH HIGH INPUTS ON ACTUAL CULTIVATED LAND BETWEEN BASELINE CLIMATE (1981–2010) AND THE PROJECTED CLIMATE FOR THE PERIOD 2070–2099, ENSEMBLE MEAN FOR REPRESENTATIVE CONCENTRATION PATHWAY 4.5 SCENARIO



Source: **Tuan, H., Nachtergaele, F., Chiozza, F. & Ziadat, F.** 2022. *Land suitability for crop production in the future*. Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en; based on GAEZ v4 data from **FAO & International Institute for Applied Systems Analysis**. 2021. Global Agro-Ecological Zoning version 4 (GAEZ v4). In: *FAO*. Rome. www.fao.org/gaez/en. Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

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trates how the total area of land-use suitability for coffee[10] may decline by the 2080s based on a conservative emission scenario of RCP 4.5. Of the areas currently most suited to growing coffee (880 thousand km^2), about 335 thousand km^2 (38 percent) would remain unchanged, but yields would decline on 545 thousand km^2 (62 percent), and 300 thousand km^2 (34 percent) would no longer be

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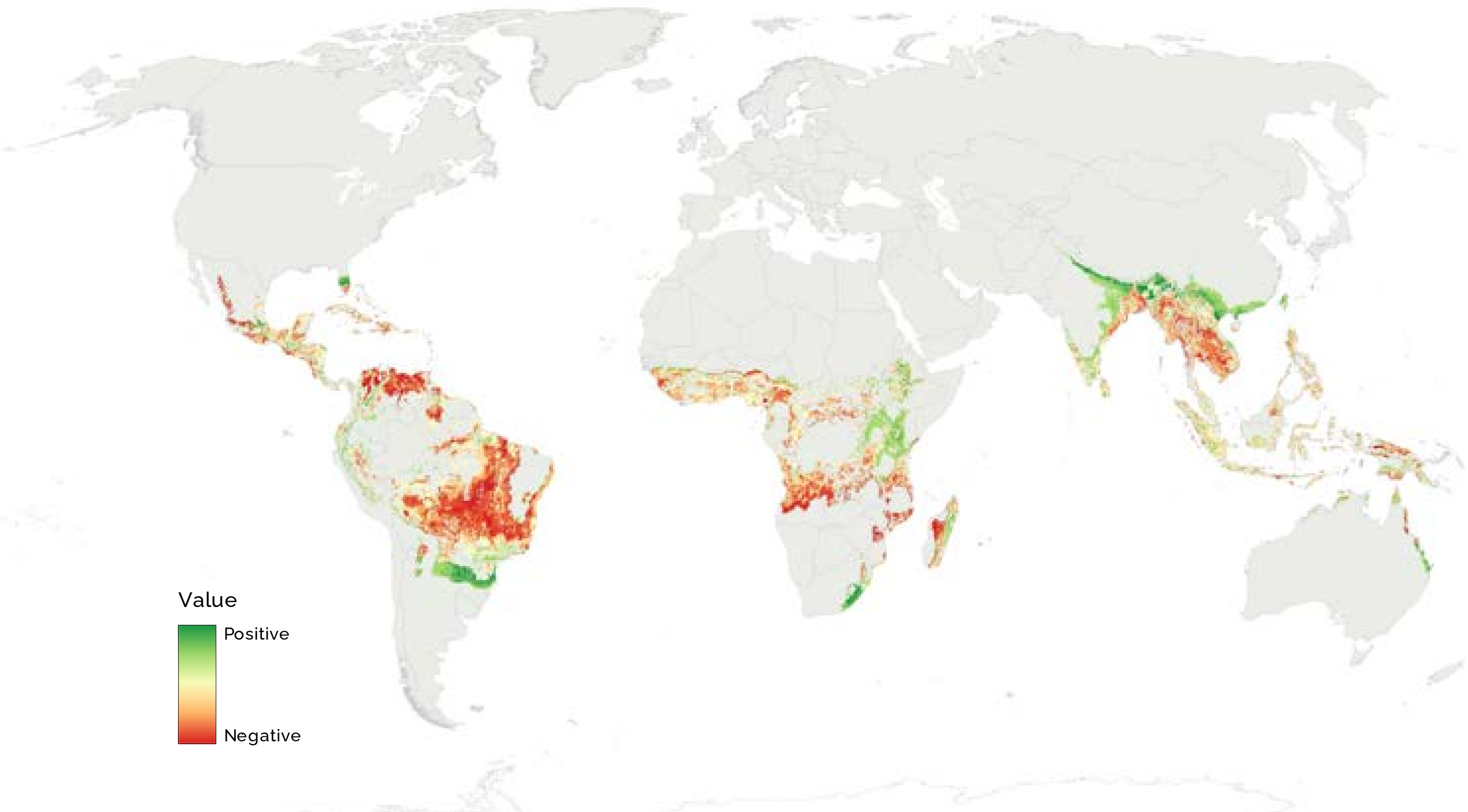
[10] The coffee scenario assesses land suitability for arabica and robusta varieties, and assumes an agronomic adaptation based on temperature. However, the overall message is that coffee growing will be seriously affected by climate change.

MAP 4.8

DIFFERENCE IN LAND SUITABILITY FOR RAINFED COFFEE BETWEEN BASELINE CLIMATE (1981–2010) AND THE CLIMATE IN THE PERIOD 2070–2099, ENSEMBLE MEAN FOR REPRESENTATIVE CONCENTRATION PATHWAY 4.5 SCENARIO



Source: **Tuan, H., Nachtergaele, F., Chiozza, F. & Ziadat, F.** 2022. *Land suitability for crop production in the future*. Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en; based on GAEZ v4 data from **FAO & International Institute for Applied Systems Analysis**. 2021. Global Agro-Ecological Zoning version 4 (GAEZ v4). In: *FAO*. Rome. www.fao.org/gaez/en. Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

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suitable. Table 4.1 also shows a range of suitability classes using the area suitability index (SI). These results emphasize the need to adjust coffee management practices or to shift locations of coffee production.

Other options include breeding and selecting crop resources, changing land use by switching to crops, including trees and livestock, more suited to the changing climate. This would involve changing land management practices and adapting food systems to turn these opportunities into realistic adaptations to climate change. However, there are many factors other than suitable land use to consider, such as local biophysical conditions and socioeconomic issues. Participatory land-use planning processes would provide the means of encouraging land users to consider changes backed up as needed by an appropriate enabling environment such as incentives, financing, enhancing capacity, policies, tenure security and marketing support.

Map 4.9 illustrates **shifts in land areas suitable for rainfed wheat** for a high-emission/high-temperature scenario (RCP 8.5), leading to a 4.2 °C temperature increase. Wheat production would increase in Argentina, Australia, Canada, Chile and Northern Eurasia, and decline in most of Central Africa and parts of Brazil, Central Asia and India. Other crop results are mixed,

TABLE 4.1 CHANGE IN THE EXTENT (km²) OF LAND SUITABILITY CLASSES FOR RAINFED COFFEE BETWEEN BASELINE CLIMATE (1981–2010) AND THE CLIMATE IN THE PERIOD 2070–2099 (2080S), FOR ENSEMBLE MEAN FOR REPRESENTATIVE CONCENTRATION PATHWAY 4.5 SCENARIO

SUITABILITY CLASS	AREA EXTENT (THOUSAND km²)	UNCHANGED SUITABILITY (THOUSAND km²)	ENHANCED SUITABILITY (THOUSAND km²)	DECREASED SUITABILITY (THOUSAND km²)	CHANGED TO NOT SUITABLE (THOUSAND km²)
	1980–2010	**2080**	**2080**	**2080**	**2080**
SI > 85	880	335	0	545	300
SI > 70	2 920	830	330	1 760	1 465
SI > 55	4 990	1 290	365	3 335	2 860
SI > 40	6 180	1 105	440	4 635	4 045
SI > 25	4 825	1 060	300	3 465	3 015
SI > 10	3 870	1 335	265	2 270	2 030
SI > 0	2 420	1 560	170	690	690
SI = 0	107 310	106 185	1 125	0	0
Total	**133 395**	**113 700**	**2 995**	**16 700**	**14 405**

Note: SI > 85 indicates very high suitability; SI > 70 indicates high suitability; SI > 55 indicates good suitability; SI > 40 indicates medium suitability; SI > 25 indicates moderate suitability; SI > 10 indicates marginal suitability; SI > 0 indicates very marginal suitability; SI = 0 indicates not suitable.

Source: **Tuan, H., Nachtergaele, F., Chiozza, F. & Ziadat, F.** 2022. *Land suitability for crop production in the future.* Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en; based on GAEZ v4 data from **FAO & International Institute for Applied Systems Analysis**. 2021. Global Agro-Ecological Zoning version 4 (GAEZ v4). In: *FAO*. Rome. www.fao.org/gaez/en

with some predicted to increase and others to reduce potential cropped areas.

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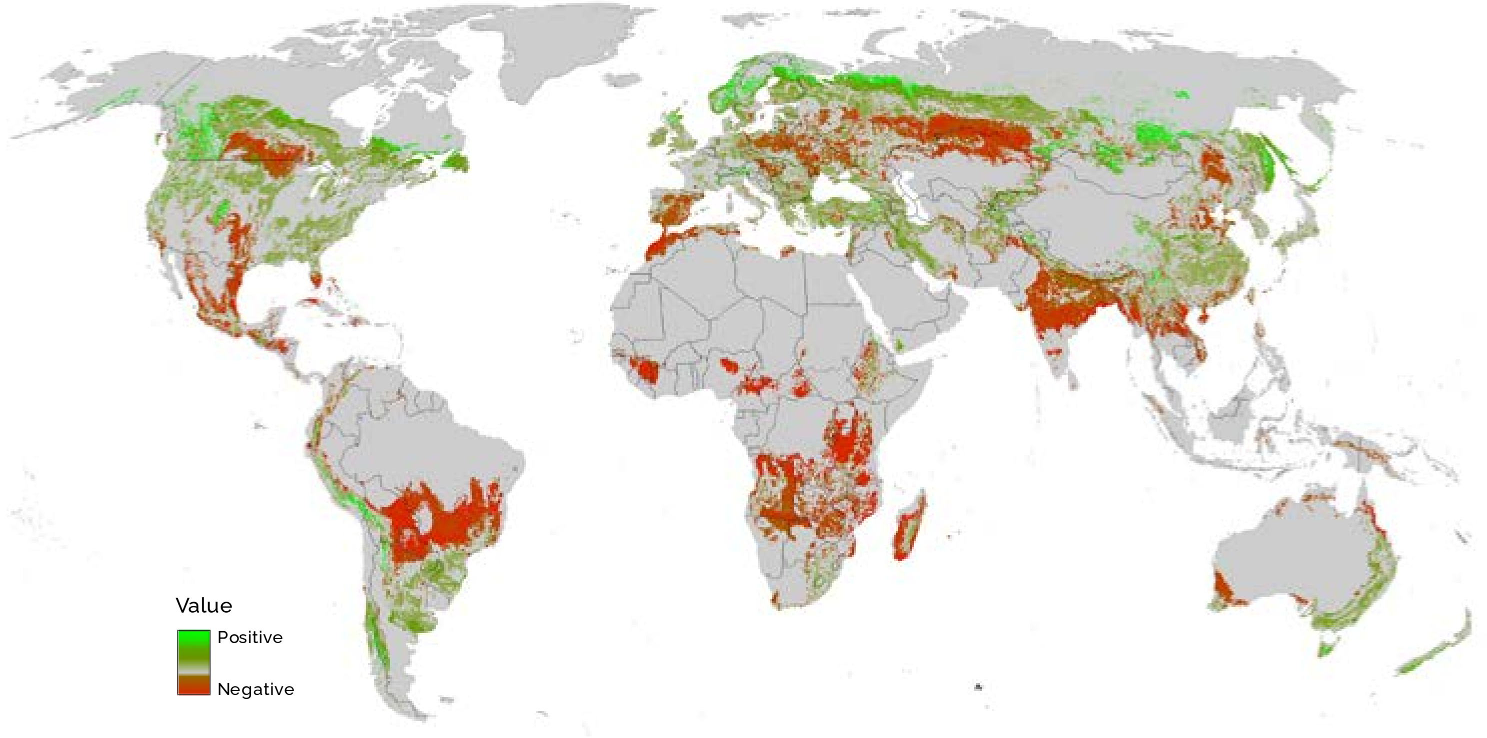
Shifts in opportunities for multiple cropping. Single crop yields do not reflect the full potential of the land for rainfed agriculture in areas where growing periods allow more than one crop to be grown annually or seasonally on the same tract of land. Several zones are defined by matching growth cycle and temperature requirements of individual crops with the time available for crop growth to assess multiple cropping potential. Parameters used were the number of days during which temperature and moisture conditions permit crop growth and the accumulated temperatures (degree day) required to meet heat unit requirements of individual crops or sequential crop combinations.

MAP 4.9

DIFFERENCE IN LAND SUITABILITY FOR RAINFED WHEAT BETWEEN BASELINE CLIMATE (1981–2010) AND THE CLIMATE IN THE PERIOD 2070–2099, ENSEMBLE MEAN FOR REPRESENTATIVE CONCENTRATION PATHWAY 8.5 SCENARIO



Source: **Tuan, H., Nachtergaele, F., Chiozza, F. & Ziadat, F.** 2022. *Land suitability for crop production in the future*. Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en; based on GAEZ v4 data from **FAO & International Institute for Applied Systems Analysis**. 2021. Global Agro-Ecological Zoning version 4 (GAEZ v4). In: *FAO*. Rome. www.fao.org/gaez/en. Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

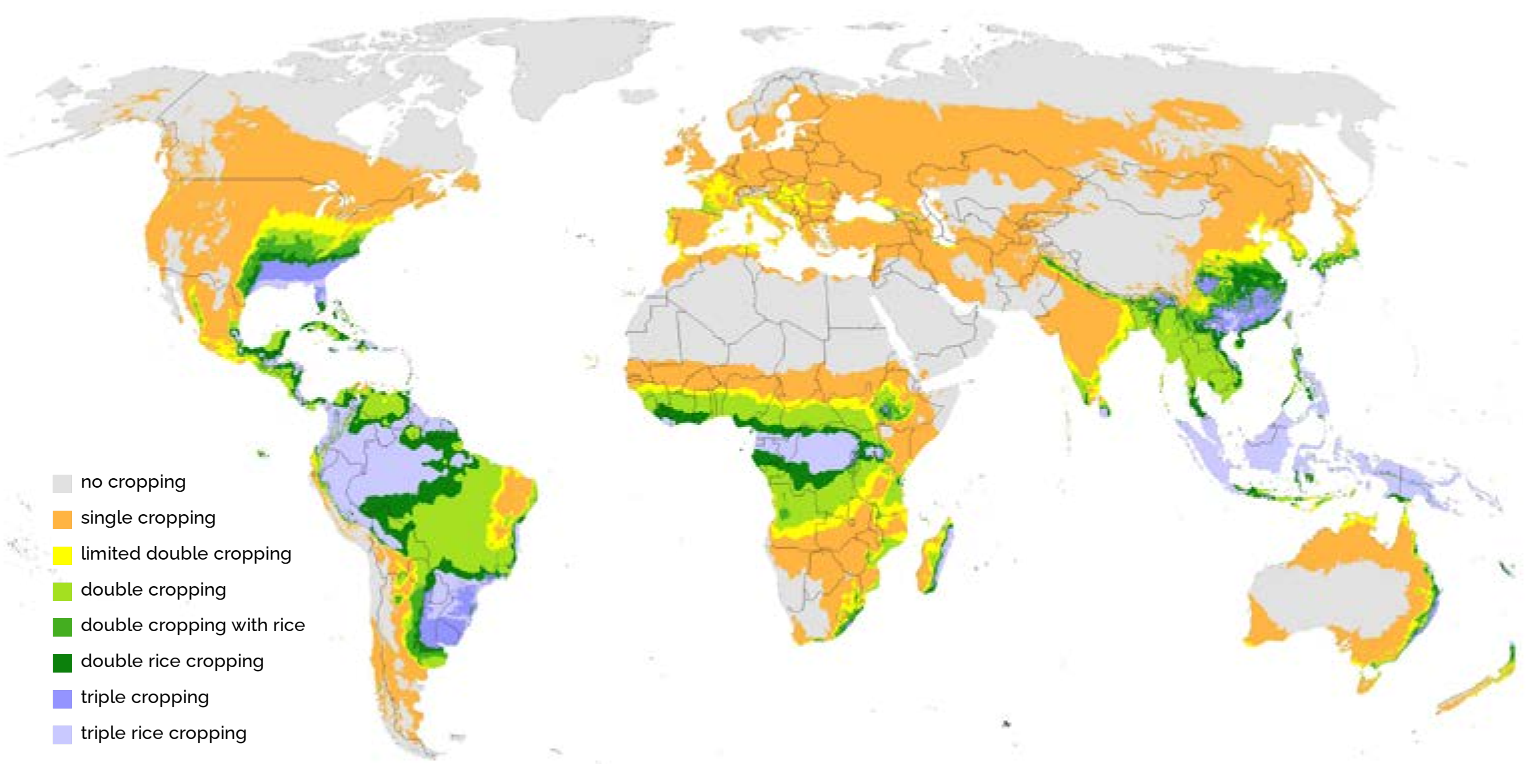
Map 4.10 illustrates the extent of multiple cropping zones for baseline climate (1981–2010). Map 4.11 illustrates multiple cropping zones for the 2080s (2070–2099), showing the effects of climate change. Supplementary irrigation could also extend the growing season and add value, but introducing irrigation brings another set of problems, such as access to equipment and water, cost and the required skills to practice efficient irrigation practices.

Table 4.2 lists the absolute and percentage changes in rainfed multiple cropping potential between baseline climate (1981–2010) and the 2080s (ENS-RCP 4.5 scenario). Selected significant changes are highlighted in red. Due to higher temperatures in the northern hemisphere and anticipated higher rainfall in some areas, the single-cropped area could increase by 9 751 thousand km^2 (20 percent) (from no cropping). Double cropping with rice could increase by 601 thousand km^2 (27 percent), and the potential for triple rice cropping would be 910 thousand km^2 (34.3 percent).

Apart from the adverse impact of climate change on current crop production systems, results indicate significant potential opportunities to increase crop production using alternative crops. Several land-use options are available to enhance farmers' resilience and adaptation to climate change. Realizing these "benefits" of climate change will largely depend on the ability of farmers to

MAP 4.10

MULTIPLE CROPPING ZONE CLASSES FOR RAINFED CONDITIONS, CLIMATE OF 1981–2010



Source: **FAO & International Institute for Applied Systems Analysis**. 2021. Global Agro-Ecological Zoning version 4 (GAEZ v4). In: *FAO*. Rome. www.fao.org/gaez/en. Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

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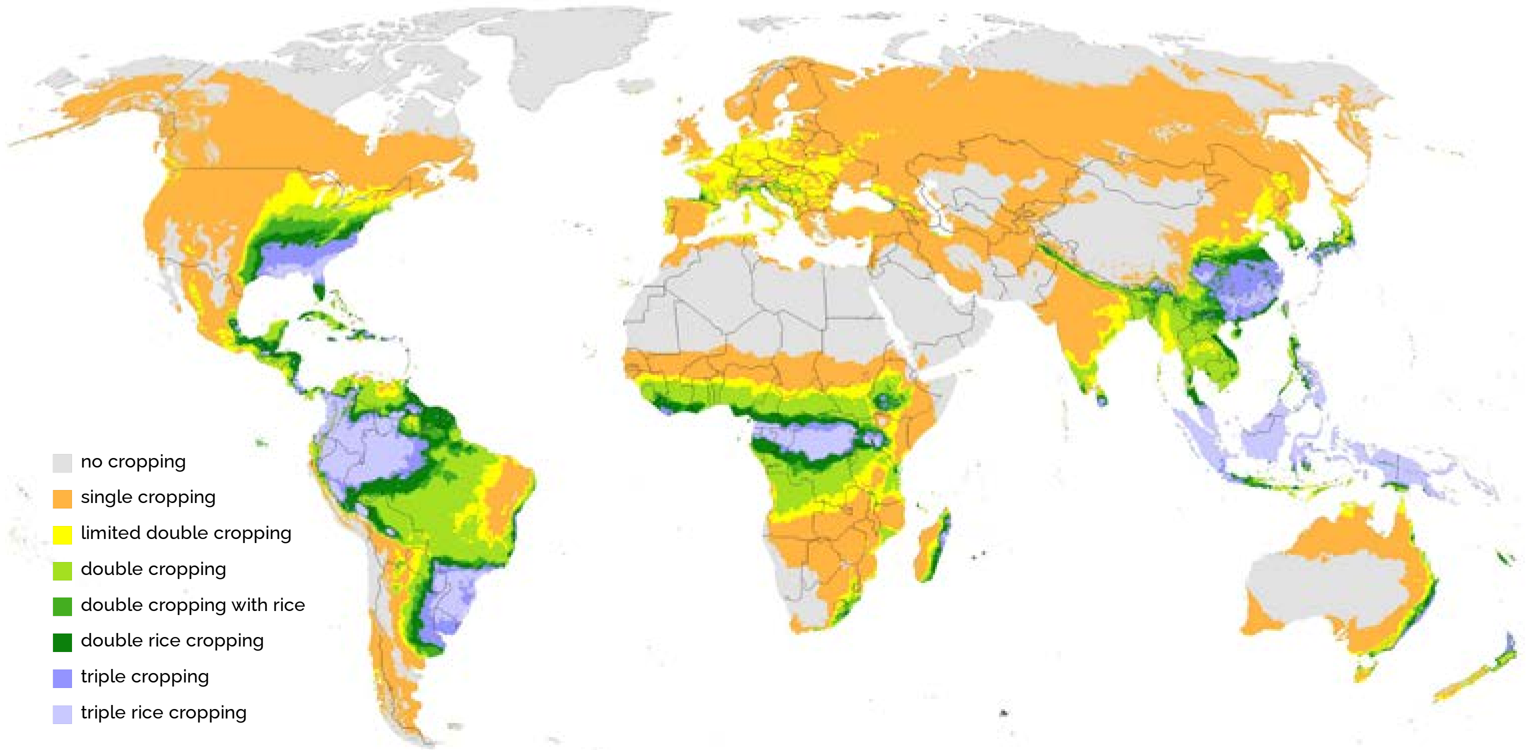
MAP 4.11

MULTIPLE CROPPING ZONE CLASSES FOR RAINFED CONDITIONS, AND THE CLIMATE IN THE PERIOD 2070–2099, ENSEMBLE MEAN FOR REPRESENTATIVE CONCENTRATION PATHWAY 4.5 SCENARIO



Source: **FAO & International Institute for Applied Systems Analysis**. 2021. Global Agro-Ecological Zoning version 4 (GAEZ v4). In: *FAO*. Rome. www.fao.org/gaez/en. Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

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TABLE 4.2 CHANGES OF RAINFED MULTIPLE CROPPING POTENTIALS BETWEEN BASELINE CLIMATE (1981–2010) AND THE 2080 CLIMATE (ENSEMBLE MEAN FOR REPRESENTATIVE CONCENTRATION PATHWAY 4.5)

		FUTURE CLIMATE (2080S ENS-RCP 4.5)								CHANGE			
	Rainfed multiple cropping zones (000 ha)	NO CROPPING	SINGLE CROPPING	LIMITED DOUBLE CROPPING	DOUBLE CROPPING	DOUBLE CROPPING WITH RICE	DOUBLE WETLAND RICE CROPPING	TRIPLE CROPPING	TRIPLE RICE CROPPING	TOTAL BASELINE CLIMATE (1981–2010)	TOTAL 2080S (ENS-RCP 4.5)	DIFFERENCE (000 ha)	DIFFERENCE (%)
BASELINE CLIMATE (1981–2010)	No cropping	38 628 100	9 751 000	38 800	500	0	0	0	0	48 418 400	39 817 000	−8 601 400	−18
	Single cropping	1 188 900	40 582 700	3 674 400	187 200	3 000	0	0	0	45 636 200	52 233 500	6 597 300	14
	Limited double cropping	0	1 659 500	3 325 500	1 352 700	424 900	10 700	300	0	6 773 600	8 897 800	2 124 200	31
	Double cropping	0	224 900	1 811 800	9 485 100	696 400	447 700	20 100	0	12 686 000	13 710 800	1 024 800	8
	Double cropping with wetland rice	0	15 400	46 800	538 200	534 100	601 700	486 500	0	2 222 700	1 857 500	−365 200	−16
	Double wetland rice cropping	0	0	500	2 057 600	140 500	3 328 500	849 500	36 400	6 413 000	6 781 900	368 900	6
	Triple cropping	0	0	0	21 200	58 600	367 600	1293 400	910 600	2 651 400	2 756 400	105 000	4
	Triple wetland rice cropping	0	0	0	68 300	0	2 025 700	106 600	7 325 900	9 526 500	8 272 900	−1 253 600	−13
	Total 2080s (RCP 4.5)	**3 981 7000**	**5 223 3500**	**889 7800**	**1 371 0800**	**185 7500**	**678 1900**	**275 6400**	**827 2900**				

Note: Green indicates no change.

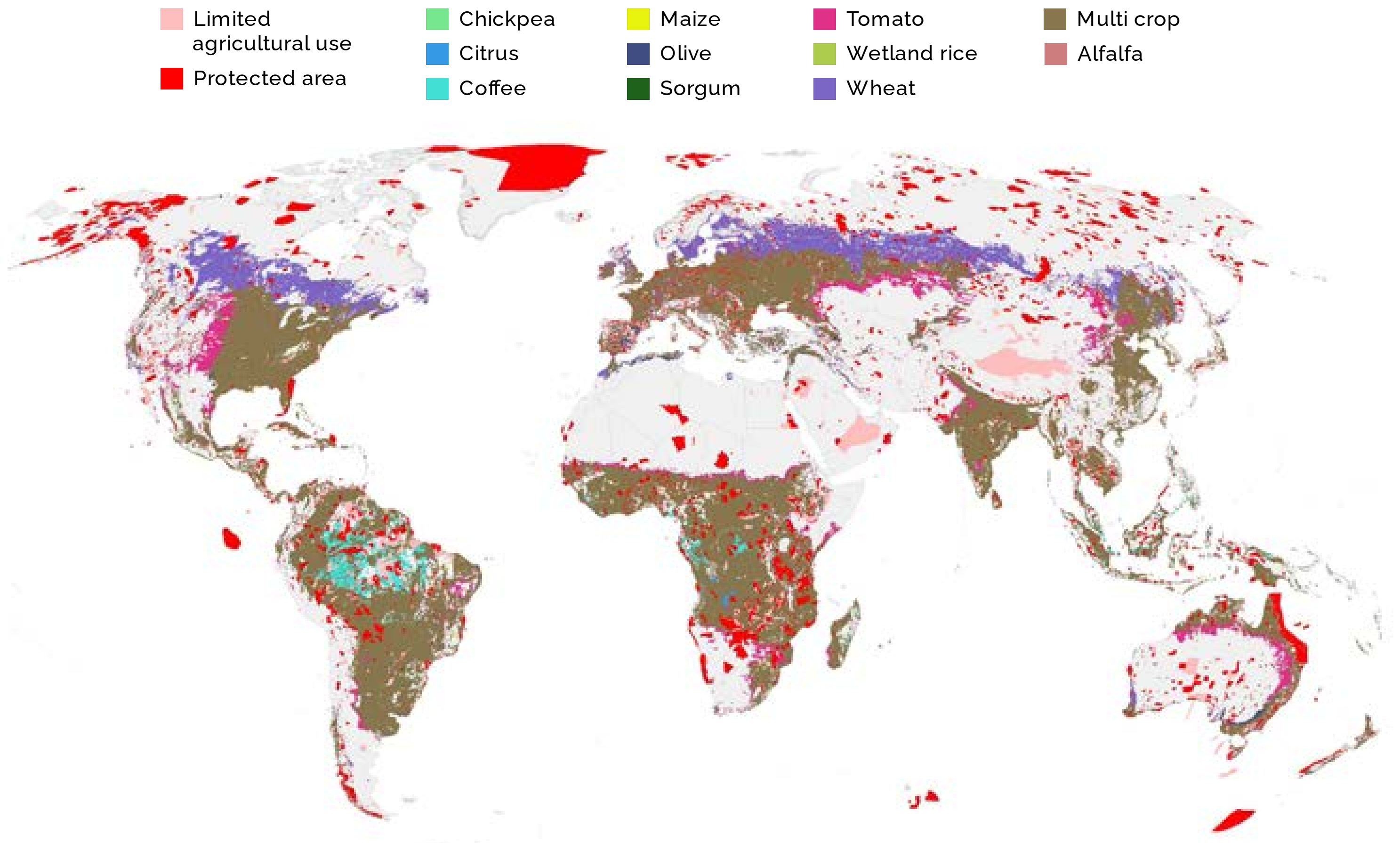
Source: **Tuan, H., Nachtergaele, F., Chiozza, F. & Ziadat, F.** 2022. *Land suitability for crop production in the future.* Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en; based on GAEZ v4 data from **FAO & International Institute for Applied Systems Analysis**. 2021. Global Agro-Ecological Zoning version 4 (GAEZ v4). In: *FAO*. Rome. www.fao.org/gaez/en

select suitable land uses and implement sustainable crop, land and water management practices.

Overall crop suitability under present and future climates. Ten crops (wheat, maize, rice, sorghum, citrus, tomato, alfalfa, chickpea, olives and coffee) were assessed for their suitability and subsequently mapped when their SI was greater than 40 (medium suitability). Map 4.12 shows the locations of those crops attributed with the highest suitability under baseline climate conditions (1981–2010). Map 4.13 presents the number of crops that can be grown (SI > 40) in the period 2070–2099 (ENS-RCP 4.5). Additional maps and results are available on the SOLAW 2021 website (FAO, 2022f).

Results show that more than one crop type is suitable for some locations, indicating a range of options available for future land use. However, these results are derived at a global level with limited crop selection and using globally available climate, soil and terrain datasets. This would support decision-making at global and possibly national levels, but it would be of limited value at a local level. To overcome this, FAO has developed high-resolution national AEZ (NAEZ) studies

MAP 4.12 MOST SUITABLE CROPS (SUITABILITY INDEX > 40) FOR 1981–2010 CLIMATE CONDITIONS BASED ON AN ANALYSIS OF TEN CROPS



Source: **Tuan, H., Nachtergaele, F., Chiozza, F. & Ziadat, F.** 2022. *Land suitability for crop production in the future.* Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en; based on GAEZ v4 data from **FAO & International Institute for Applied Systems Analysis**. 2021. Global Agro-Ecological Zoning version 4 (GAEZ v4). In: *FAO*. Rome. www.fao.org/gaez/en. Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

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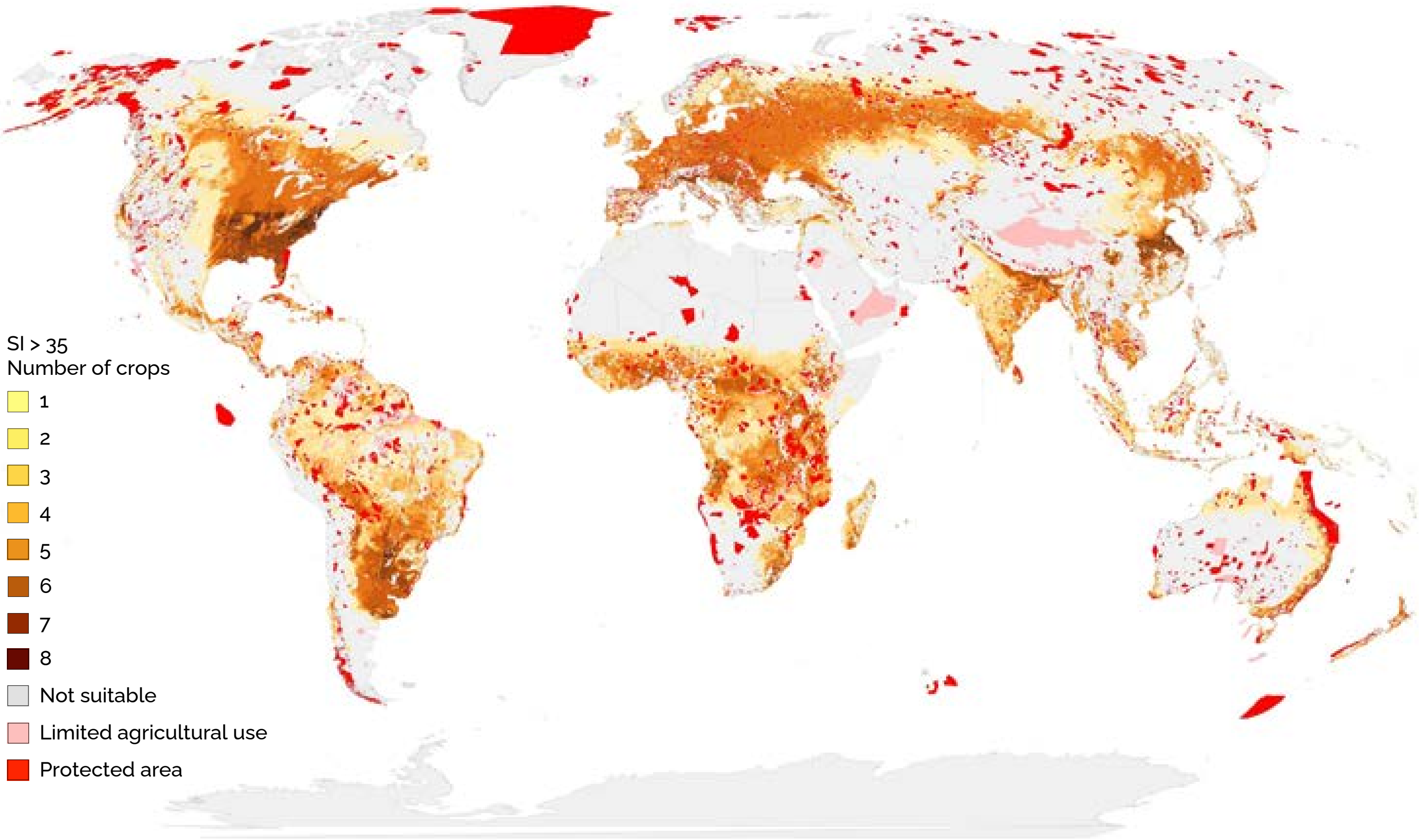
to support subnational decisions on crop type and management practices. Several NAEZ studies are available, including for Ghana (Box 4.5) and the case study using LandPKS (Box 4.2). A study in North Macedonia providing crop suitability maps at 100 m resolution is published as an *Agro-ecological atlas of the Republic of North Macedonia* (Aksoy *et al.*, 2020). The NAEZ studies are available for Afghanistan, Ghana, Lao People's Democratic Republic, Pakistan, Thailand and Turkey (FAO, 2022g).

4.2.8 Prospects for land-suitability analysis

The results from this land-suitability analysis provide general guidance for a range of options for land use and future crop selection (summarized in Box 4.6). However, climate modelling has limitations and inherent uncertainties for simulating the effects on land suitability and crops. The methodology does not account for changes in soil carbon, soil erosion (Borrelli *et al.*, 2020), land degradation, sea-level rise and anticipated changes in extreme weather events, nor

MAP 4.13

NUMBER OF DIFFERENT CROPS POSSIBLE TO BE GROWN (SUITABILITY INDEX > 40) FOR THE PERIOD 2070–2099 CLIMATE CONDITIONS (ENSEMBLE MEAN FOR REPRESENTATIVE CONCENTRATION PATHWAY 4.5) BASED ON ANALYSIS OF TEN CROPS



Source: **Tuan, H., Nachtergaele, F., Chiozza, F. & Ziadat, F.** 2022. *Land suitability for crop production in the future*. Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en; based on GAEZ v4 data from **FAO & International Institute for Applied Systems Analysis**. 2021. Global Agro-Ecological Zoning version 4 (GAEZ v4). In: *FAO*. Rome. www.fao.org/gaez/en. Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

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BOX 4.5

HIGH-END CLIMATE CHANGE IMPACT ON RAINFED CROPS IN GHANA

Climate change threatens rainfed production systems in sub-Saharan Africa. In Ghana, an NAEZ was developed to assess the impacts of high-end RCP 8.5 global warming on agricultural production until the end of this century.

Results highlight different potential impacts across the country, mainly due to significant increases in the number of days exceeding high-temperature thresholds. Rainfed production of several food and export crops could be significantly reduced compared to the historical 30 year average (1981–2010) (see Table 4.3). By the 2050s, plantain production (an important food crop) would be less than half of current levels, and fall by more than 90 percent by the 2080s. Suitable areas for cocoa production (an important cash crop) would be only one-third of current levels. Production of other crops, such as oil palm, sugar cane, robusta coffee and rubber, would also suffer. Maize, sorghum and millet production would cope much better in the warmer climate.

TABLE 4.3

CHANGES IN PRODUCTION FOR BASELINE CLIMATE AND CLIMATE SCENARIO ENSEMBLES FOR THE 2050S AND 2080S WITH (+) AND WITHOUT CARBON DIOXIDE FERTILIZATION ON VERY SUITABLE (VS), SUITABLE (S) AND MODERATELY SUITABLE (MS) LAND

RAINFED CROPS – HIGH INPUTS AND ADVANCED MANAGEMENT	VS+S+MS AREA	CHANGE IN PRODUCTION						
	PRODUCTION (THOUSAND TONNES)	BASE	ENS+ 2050S	ENS 2050S	CHANGE	ENS+ 2080S	ENS 2080S	CHANGE
Banana/plantain (perennial C3)	17 071	100	54	43	↓↓	21	8	↓↓
Beans (annual C3)	14 532	100	106	93	↓	111	89	↓
Cashew (perennial C3)	11 657	100	104	92	↓	82	65	↓
Cassava (perennial C3)	42 709	100	104	91	↓	100	80	↓
Cocoa (perennial C3)	6 685	100	72	62	↓	35	24	↓↓
Coconut (perennial C3)	12 655	100	98	84	↓	97	76	↓
Coffee (perennial C3)	7 967	100	82	70	↓	62	42	↓↓
Cotton (annual C3)	3 131	100	123	103	↔	129	95	↔
Groundnut (annual C3)	12 880	100	107	94	↓	108	85	↓
Maize (annual C4)	32 088	100	116	109	↑	123	111	↑
Mango (perennial C3)	24 143	100	92	81	↓	72	54	↓
Oil palm (perennial C3)	10 761	100	72	59	↓	73	51	↓
Pearl millet (annual C4)	7 059	100	164	141	↑	192	149	↑
Rubber (perennial C3)	2 912	100	67	53	↓	65	36	↓↓
Sorghum (annual C4)	20 238	100	134	126	↑	143	129	↑
Sugarcane (perennial C4)	26 936	100	79	72	↓	78	67	↓
Sweet potato (annual C3)	38 855	100	109	96	↔	109	88	↓
Yam (perennial C3)	34 129	100	101	89	↓	96	75	↓

Note: Arrows refer to results without carbon dioxide fertilization effects and indicate changes of less than 5 percent (↔), 5–25 percent (↓↑), 25–50 percent (↓↑) and losses of more than 50 percent (↓↓) compared to baseline conditions.

Source: **Fischer, G. & van Velthuizen, H.** 2018. *High-end climate change impacts on rain-fed crops in Ghana*. Rome, FAO. www.fao.org/3/cb5581en/cb5581en.pdf

BOX 4.6
SUMMARY OF ANTICIPATED SHIFTS IN LAND SUITABILITY

Indications are that climate change will bring shifts in land suitability. Some cropped areas will increase, while others will reduce or deteriorate, requiring changes in crop selection and management. Areas where suitable land for current crops decreases will require changes in crop variety (selection and breeding) or a switch to other crops better adapted to the changed conditions. Other options may include changes in water management, such as dryland farming options or irrigation with attention to maximizing water-use efficiency when water resources are available and/or a shift to more resilient mixed agroforestry or agropastoral systems.

Higher levels of carbon dioxide concentrations (RCP 8.5 compared to RCP 4.5) suggest a greater shift in the current land-use pattern, and more intensive land management and land-use changes may be needed in the future to maintain/enhance crop productivity.

Increasing temperatures would improve options for expanding cereal production to higher latitudes, benefiting especially Canada and Northern Eurasia. However, in other areas, such as the highly productive wheat areas in Central and Eastern Europe, it is likely to decline.

Moreover, increasing temperatures would reduce traditional cash crops, such as coffee in Brazil and West Africa and olives in the Maghreb. But better growing conditions for coffee may occur in other areas such as East Africa.

Alternative crops (adaptation) and adjustments in management practices, including technology transfer programmes, will be needed in some regions where farmers must change their traditional cropping patterns.

There are large areas where crop production would benefit from adopting higher inputs and improved crop management.

Climate change may bring opportunities for increasing multiple rainfed cropping, particularly in the tropics and parts of the subtropics.

Increasing investment in germplasm and seed exchange among ecoregions and crop breeding for tolerant traits will be crucial in developing crops and varieties that can withstand future changes in temperature, soil moisture supply, salinity, wind speed and evaporation.

For those areas where the climate becomes marginal for current staple and niche crops, there are alternative annual and perennial tree crops, livestock, and soil and water management options available. Experiences from similar ecoregions and other socioeconomic contexts should be analysed to guide how the land is best used in the future.

Socioeconomic and ecological conditions will essentially determine the feasibility and justify investing in the most appropriate adaptations. Such analysis and scenario development are essential elements of land-use planning, as are participatory approaches that involve all stakeholders, notably farmers, pastoralists, and fishers and foresters and their rural communities, and other users of the land and water resources (in aquaculture, beekeeping, greenhouse use, carbon manufacture and sand mining).

Whatever the choices, future cropping should avoid protected areas and fragile lands, such as land under permafrost, peatland, steep lands and rainforests. Measures should be taken to ensure appropriate soil and water conservation and restoration in accordance with country LDN targets and SLM strategies.


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does it include future water availability for irrigation. Although this analysis has focused on specific crop options, alternative land-use and diversification options could be explored in any specific national or territorial context.

Nevertheless, the analysis provides a good indication of future hotspots and bright spots at the global and regional scales for growing specific crops, and guides expected shifts in land suitability. The likely severe socio-economic stress resulting from the need to adapt land use and the changes in cropping systems, including knowledge, access to inputs and marketing perspectives, cannot be underestimated, and so any anticipated shift would depend as much on the enabling environment for technology transfer and prevailing socioeconomic circumstances as on the environmental conditions.

This analysis of transitioning to sustainable and diversified land-use systems to address degradation and climate trends aligns with the findings of recent flagship reports such as *The state of food and agriculture* (FAO, 2020b) and *The state of food insecurity and nutrition in the world* (FAO *et al.*, 2021). In particular, this aligns with the vision of the United Nations Food Systems Summit, calling for joint action for transforming and rebuilding food systems worldwide to make progress towards all 17 SDGs.

4.3 Reversing human-induced degradation

Chapter 3 described the significant risks to agricultural production and food security from human-induced land degradation. It highlighted that these are rarely considered until cropland soils and pastures are lost or productivity severely compromised due to human-induced erosion, salinization and pollution or other degradation processes. Human-induced land degradation constrains anticipated growth, particularly on cultivated and productive land where soil and water conservation measures are lacking or inadequate. Climate change is expected to further affect growing conditions for crops and associated livestock and forest systems, and natural ecosystems, particularly in subtropical developing countries. However, preventing and reversing degradation will help to build resilience, in line with the LDN hierarchy, through protection (Avoid), conservation (Reduce) and restoration (Reverse) measures (section 4.3.4).

Avoiding and reducing degradation, restoring degraded lands and avoiding associated biodiversity loss are crucial to meeting global aspirations for achieving SDGs, including SDG 1 (no poverty), SDG 2 (zero hunger), SDG 6 (clean water and sanitation), SDG 13 (climate action) and SDG 15 (life on land). This is particularly central to achieving SDG 15: "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss" (United Nations, 2015).

4.3.1 Initiatives to address degradation

International attention has focused on sustainable land resources management over the past three decades. This began with the 1992 United Nations Conference on Environment and Development and the Rio multilateral environmental conventions, and the 2012 United Nations Conference on Sustainable Development outcome document *The future we want* (United Nations, 2012). This focused on achieving a world that is land degradation neutral. The 2030 Agenda followed in 2015, with the SDG framework including a dedicated SDG on land.

An important global initiative calling for the restoration of degraded lands worldwide is detailed in the second edition of the UNCCD global land outlook (UNCCD, 2022a). This focuses on conservation, rehabilitation and sustainable management of land and water resources in dry lands prone to desertification. It acknowledges the importance of land-use planning and secure tenure for successful implementation.


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Other global initiatives, endorsed by governments to address degradation, and support the conventions on biological diversity (CBD) and climate change (UNFCCC), include:

- Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD+), a UNFCCC mechanism initiated in 2005;
- Aichi Biodiversity Target 15 of the Strategic Plan for Biodiversity 2011–2020, adopted under CBD in 2010;[11]
- the Bonn Challenge on forests, climate change and biodiversity, launched by the Government of Germany and IUCN in 2011 that focuses on forest landscape restoration;
- the New York Declaration on Forests in 2014, aiming to halve the loss of natural forests by 2020, and striving to end it by 2030, and restore degraded forests and reduce carbon losses; and
- World Soil Day, held annually on 5 December, raising awareness of the need for effective partnership in implementing plans towards sustainable soil management and applying voluntary guidelines for sustainable soil management.

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[11] "By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification."


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These initiatives are designed to generate additional benefits through effective participation of the rural poor, women, Indigenous and local communities, civil society organizations, and stakeholders from multiple sectors and the private sector.

The United Nations Decade on Ecosystem Restoration, 2021–2030, is a broad-based global movement, led by UNEP and FAO, to ramp up restoration efforts as a basis for enhancing livelihoods, counteracting climate change and stopping the collapse of biodiversity.

Several global initiatives focus specifically on dryland sustainable management (see the in-focus study on dryland systems at the end of this chapter) and include:

- the CBD Programme of Work on the Biological Diversity of Dry and Sub-humid Lands, initiated in 2000;
- the African Union's Great Green Wall for the Sahara and Sahel Initiative, launched in 2007;
- the FAO Dryland Restoration Initiative Platform, initiated in 2015 (FAO, 2016a);
- the IUCN Global Drylands Initiative (drynet, 2022); and
- the Consultative Group on International Agricultural Research Program on Dryland Systems, 2007–2017.

Global and national statistics are being compiled by GSP on the status of salt-affected soils to develop the first global soil salinity map directly involving countries in developing their national maps. The global map will provide the foundation for regular monitoring. In 2019, GSP and the International Center for Biosaline Agriculture established the International Network of Salt-Affected Soils to address soil salinity issues at global, regional and national levels and control the increase of salt-affected soils in agricultural areas.

4.3.2 Sustainable land management

Sustainable land management refers to the land-use and management actions and complementary measures (policy, legislation, institutional reform and technologies) adapted to the biophysical and socioeconomic contexts to maintain and restore ecosystem functions and services that land resources provide for people's livelihoods and well-being.

Sustainable land management encompasses land-use systems and the management practices of soils, water and biological diversity by land users for sustained production of goods to meet changing human needs while ensuring the long-term productive potential of these resources and their environmental functions. Understanding and managing the interrelations among soil, water, biological resources and the atmosphere are crucial for sustaining the capacity to mitigate and adapt to climate change.

The focus on SLM for sustainable agriculture and food systems gives due attention to the need for:

- efficient, resilient, inclusive and climate-smart management practices and agri-food systems;
- balancing the interconnected economic, social and environmental dimensions of sustainable development; and
- minimizing risk and uncertainty in the face of climate change and variability, and other shocks.

Interventions to promote SLM should enable land and water users to enhance and sustain productivity to meet the increasing demands of rural and urban populations and optimize the economic and social benefits from the land. This involves: (i) protecting or conserving the resource base and ecological functions, (ii) using the resources in a sustainable manner (reducing or minimizing degradation risks) and (iii) restoring or rehabilitating degraded resources and thereby (iv) maintaining or enhancing ecosystem services (Box 4.7). The FAO strategic framework sums up this response in the agrifood sectors as "*better production, better nutrition, a better environment, and a better life*" (FAO, 2021).

BOX 4.7
SUSTAINABLE LAND MANAGEMENT OBJECTIVES

Sustainable land management is key for implementing SDG 15: to "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and biodiversity loss". Target 15.3 aims, by 2030, to combat desertification, and restore degraded land and soil, including land affected by desertification, drought and floods, and strives to achieve a world that is land degradation neutral, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

In considering the linkages among SLM practices to address degraded land, desertification and drought, climate change adaptation and mitigation, and resulting synergies and trade-offs, SPI specifies: "SLM represents a holistic approach to achieving long-term productive ecosystems by integrating biophysical, sociocultural and economic needs and values. SLM is one of the main mechanisms to achieve Land Degradation Neutrality (LDN)." In its key terms, SPI cites the framework for evaluating SLM (FAO, 1993).

Sustainable land management combines technologies, policies and activities, and aims to integrate socioeconomic principles with environmental concerns, to simultaneously: maintain or enhance production/services; reduce the level of production risk; protect the potential of natural resources, and prevent soil and water quality degradation; be economically viable; and be socially acceptable.

Ecosystem services include: the supply of nutritious food, fibre, raw materials, energy and drinking water; water supply regulation; soil formation and nutrient cycling; carbon cycle regulation (sequestration and emissions); reduction of natural hazards; pest and disease control; and conservation of biodiversity, cultural heritage, and spiritual and recreational benefits.

Sustainable land management thus contributes directly to SDG 15 (life on land), SDG 2 (zero hunger), SDG 6 (clean water and sanitation), SDG 7 (affordable and clean energy), SDG 12 (responsible consumption and production), SDG 13 (climate action) and SDG 3 (good health and well-being), which is intrinsically linked to the other SDGs.


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4.3.3 Nature-based solutions

Nature-based solutions address societal challenges through working with nature and biodiversity. First used by the World Bank in 2008, NbSs have been highlighted in recent global assessment reports (IPBES, 2018; IPCC, 2019), and were high on the agenda at the World Economic Forum and the Climate Adaptation Summit in January 2021.

Nature-based solutions are defined as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham *et al.*, 2016). They are restorative and regenerative by design and aim to increase productivity and reduce waste, aligning with the principles of the circular economy.

Using NbSs is a potentially valuable strategy for transforming the agricultural sector into a beneficiary and a custodian of ecosystems (FAO, 2018b). Nature-based solutions represent effective, long-term and cost-effective interventions to address water management, ecosystem services and soil restoration. The *United Nations world water development report 2018* (WWAP/UN-Water, 2018) focused on documenting the experiences and potential for NbSs for water.

Nature-based solutions offer multiple benefits (FAO *et al.*, 2020). Analysis by FAO and The Nature Conservancy (Iseman and Miralles-Wilhelm, 2021) in agricultural landscapes includes:

- enhancing farmer resilience to increase food production and improve rural livelihoods, through restoring soil health and soil moisture, downstream water supply and quality, and nutritious food;
- mitigating and adapting to climate change through soil, wetlands and forest carbon sequestration;
- improving ecosystems and increasing biodiversity and associated benefits; and
- achieving net-zero environmental impacts in agricultural production and supply chains.

Policymakers need to address the potential synergies and trade-offs associated with NbSs. Concerns about the focus on large-scale internationally supported tree planting and forest systems as a primary climate mitigation solution distract from the need to protect and sustainably manage a range of terrestrial and aquatic ecosystems. Attention is needed to protect resource rights and implement NbSs in ways that respect cultural and ecological rights (Seddon *et al.*, 2021).

4.3.4 Land degradation neutrality

The concept of LDN, introduced at the 2012 United Nations Conference on Sustainable Development, is designed to support SDG target 15.3 and avoid loss of natural capital by restoring and rehabilitating degraded lands.

Parties to UNCCD agreed to "formulate voluntary targets to achieve LDN following their specific national circumstances and development priorities" and to "integrate such targets in their National Action Programme". The UNCCD SPI provides scientifically based guidance for understanding, planning, implementing and monitoring LDN (Cowie and Orr, 2017). Land degradation neutrality is defined by UNCCD as "a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems."

Figure 4.4 captures the LDN vision and how best to achieve this by assessing land degradation, identifying appropriate management actions and reporting progress. The objective is to maintain and enhance the land resource base, including the stocks of natural capital associated with land resources and the ecosystem services that flow from them, to ensure healthy linkages between human prosperity and land-based natural capital. The balance scale illustrates the mechanism for achieving neutrality: counterbalancing future land degradation (losses) with planned positive actions elsewhere (gains) within the same land type.

The fulcrum in Figure 4.4 illustrates the hierarchy of responses to Avoid > Reduce > Reverse land degradation when planning LDN interventions at landscape level. This recognizes that prevention is better than cure, as avoiding land degradation is usually more cost-effective than efforts to restore moderately to severely degraded lands.

Neutrality is assessed by monitoring LDN indicators relative to a fixed baseline at the national level. These indicators include land productivity, carbon stocks and land cover, reflecting land-based natural capital. The arrow in Figure 4.4 indicates that neutrality needs maintenance over time through land-use planning that predicts losses and gains. This requires adaptive learning and tracking impacts and achievements to enable plans to be continually adjusted and updated.

The LDN conceptual framework is applicable across all land types, land uses and ecosystem services. It is implemented at the landscape scale, considering all land units of each land type and their interactions and ecological trajectories. This allows for optimizing LDN interventions among those land units to maintain or exceed no net loss at the land-type level (Cowie and Orr, 2017). By 2022, 128 countries had committed to setting LDN targets, more than 100 had set them, and many had secured high-level government commitment to achieving LDN (UNCCD, 2022b).

A minimum set of three global indicators and associated metrics are proxies for changes in land-based natural capital: land cover (physical land-cover class), land productivity (net primary productivity) and carbon stocks (SOC) (Cowie *et al.*, 2018). These are complementary and universally applicable to allow global tracking of progress.

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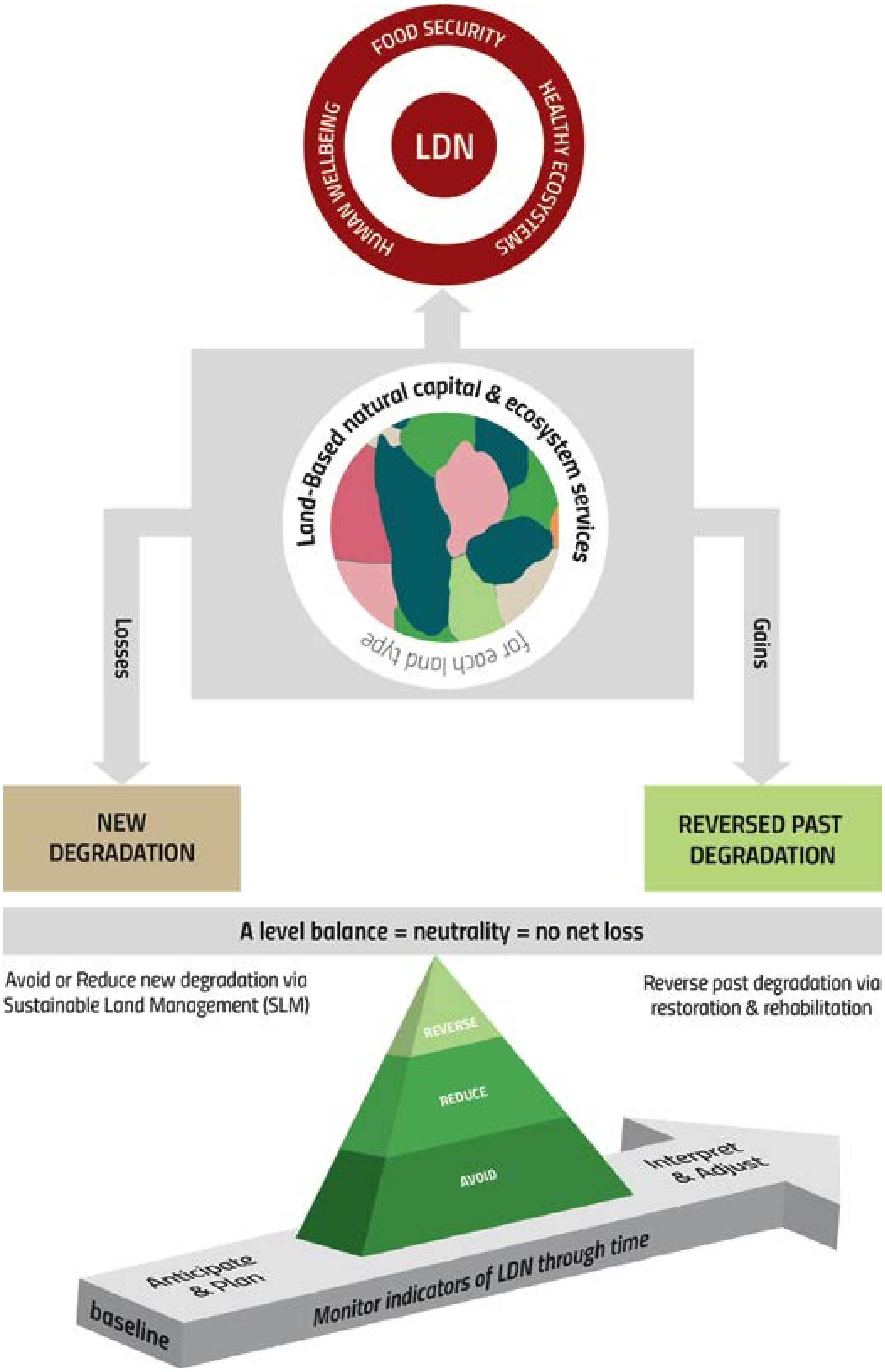
FIGURE 4.4 LAND DEGRADATION NEUTRALITY CONCEPTUAL FRAMEWORK



Source: Orr, B.J., Cowie, A.L., Castillo Sanchez, V.M., Chasek, P., Crossman, N.D., Erlewein, A., Louwagie, G. *et al.* 2017. *Scientific conceptual framework for land degradation neutrality. A report of the Science-Policy Interface.* Bonn, United Nations Convention to Combat Desertification. https://www.unccd.int/sites/default/files/2018-09/LDN_CF_report_web-english.pdf

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The precautionary principle of "one-out, all-out" is applied. If one of the three key indicators shows a negative change, LDN is not achieved, even if the others are substantially positive.

These biophysical indicators should be supplemented by national (or subnational) indicators, according to the context, to capture land-based ecosystem services including indicators of the social and economic impact of LDN on human well-being, such as safeguarding land tenure rights, and impacts on local communities (Cowie and Orr, 2017). Indicators could measure progress in establishing LDN enabling policies and monitoring systems, and LDN field interventions such as the areas of SLM and restoration and rehabilitation activities.

The LDN concept is ground-breaking in establishing an agreed mechanism and mobilizing country commitments to establish a baseline and set targets for implementation to protect the land from degradation, reduce degradation processes and rehabilitate degraded lands under SDG target 15.3.

4.3.5 Reversing the degradation trend

The IPBES assessment report on land degradation and restoration provides evidence that land degradation is avoidable, and in many instances, reversible (IPBES, 2018). This SOLAW 2021 report, the IPCC special report on climate and land (IPCC, 2019) and previous IPCC reports establish the symbiotic relationship between land degradation and climate change. Solving one problem contributes to solving the other. The reports by IPBES and IPCC lay out the policy imperative and show institutional reform and adapted policies can change incentives that would go a long way towards making land part of the solution rather than part of the problem.

Although some signs of degradation are easily recognizable (in the field through evidence of erosion and silting, and through productivity decline, often compensated through increased nutrient inputs). Unlike climate change, there are many reasons why land degradation has failed to attract adequate global attention. Land degradation is a slow-onset process, and people perceive degradation differently depending on their relationship with the land. Some see it as an unavoidable side effect of development, and others see little urgency when benefiting economically from exploiting the land. Usually, they are not those suffering the consequences of degradation. A simple cause–effect relationship does not exist, and this makes the issue easy to dismiss. There is also a disconnect between degradation and remedial action. Policymakers and consumers are often unaware or do not feel responsible for land degradation (Willemen *et al.*, 2020).

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The analysis in this chapter uses land-suitability assessment and LDN to help understand the complex factors that drive degradation, from a highly visible phenomenon that is difficult to measure directly, to one that can be assessed, classified and mapped to identify areas for remedial action.

Sustainable Development Goals set the basis for creating well-defined and measurable metrics to guide policy. However, a challenge remains on integrating the assessment, monitoring and decision-making processes for the different SDGs, as the responsibility is fragmented among various institutions in each country.

More information and data, and specific national and subnational analyses, are required to guide national policy development and investments to implement effective, cost-efficient and equitable outcomes.

Conservation, sustainable use and restoration are best achieved by engaging a broad coalition of stakeholders with shared interests that facilitate collective action at appropriate territorial scales. A transparent legal environment, a coherent agenda, sufficient finance and effective incentives are essential to promote action at scale and to ensure equitable sharing of costs and benefits. Scaling up restoration from current pilot activities means transitioning from a time-bound project focus to a long-term sustained landscape and ecosystem focus. This requires good governance and competent institutions for planning at landscape and regional scales. Scaling up restoration also requires capacity building supported by appropriate technology, knowledge-sharing, continual refinement and improvement, building on progress and experiences, and infrastructure and sustainable financing. Restoration should be a sustainable economic activity, and building confidence for the long-term requires accountability and transparency about who is paying what costs and who is receiving the various socioeconomic and environmental benefits.

4.3.6 Identifying restoration areas, mobilizing investments and strategic vision

One approach to restoration is to identify target areas where SLM options have a high potential for success and guide the implementation and scaling out programme supported by appropriate policies and financial mechanisms (Vlek, Khamzina and Tamene, 2017).

The Global Environment Facility (GEF) is supporting UNCCD implementation through mobilizing investments at country and regional levels to improve data acquisition and understanding, to develop tools and strengthen institutional capacities for planning and policy development, including extension services for promoting SLM actions on the ground.

Lessons learned on scaling up policies, investments and actions from the TerrAfrica Strategic Investment Programme (SIP) on SLM in sub-Saharan Africa are available from the portfolio of 36 projects in 26 countries (Box 4.8).

BOX 4.8
LESSONS LEARNED FROM THE TERRAFRICA STRATEGIC INVESTMENT PROGRAMME

The TerrAfrica SIP was the first opportunity to give a high profile and visibility to the importance of promoting SLM in Africa. Some USD 150 million of GEF grants mobilized an estimated USD 800 million of cofinancing for 36 projects in 26 countries between 2010 and 2015, including four transboundary river basin/watershed projects and four regional thematic projects.

Lessons learned from SIP demonstrate that landscapes may be the most appropriate geographic areas or territorial units for SLM interventions and investment projects. However, local circumstances should determine the most appropriate scale, approach and required support mechanisms. The SIP portfolio highlights include:

- The importance of mainstreaming SLM for food security, poverty reduction and climate change.
- Prospects for SLM are increased when measures are mainstreamed in national policies and laws, by-laws and regulations enforceable at local level.
- SLM scaling up needs to be flexible and able to react to change from local to global levels.
- Blanket approaches and top-down processes should be avoided.
- People and their actions cause land degradation and need to be at the centre of SLM programmes. Women represent a large share of direct and indirect beneficiaries and need to be formally recognized.
- Most SLM technologies in crop and grazing lands contribute to climate-smart agriculture.
- More success is achieved by combining technologies on large areas.

Source: **FAO**. 2016. *Informing future interventions for scaling-up sustainable land management*. Rome. www.fao.org/3/i5621e/i5621e.pdf

Forest and landscape restoration received renewed attention through the global Bonn Challenge, launched by the Government of Germany and IUCN in 2011, to bring 150 million ha of degraded and deforested landscapes into restoration by 2020 and 350 million ha by 2030. Such restoration seeks sustainability in all land uses in a given landscape and prioritizes biodiversity conservation and human livelihoods. The 150 million ha milestone for pledges was surpassed in 2017, through regional initiatives in Central America and the Caribbean, Europe, the Caucasus and Central Asia, and Asia and the Pacific.

The Great Green Wall for the Sahel and Sahara Initiative began in 2007 to restore 100 million ha of degraded arid and semi-arid land, sequester 250 million tonnes of carbon and create 10 million green jobs by 2030 across the Horn of Africa, North Africa and the Sahel, through a mosaic of green and productive landscape spanning over 8 thousand km^2 from Senegal to Djibouti. It supports communities to expand fertile land, economic opportunities for the world's youngest population, food security for millions and climate resilience. Implementation has begun in more than 20 countries across Africa, with support from many partners with pledges of more than USD 8 billion. Reports indicate that 20 million ha has been restored.

Achieving the 2030 goal will require a faster pace to restore 8.2 million ha annually at an annual cost of USD 3.6 billion (Box 4.9).

Restoration needs and opportunities for the Great Green Wall for the Sahel and Sahara Initiative were mapped and quantified by the global drylands assessment conducted by FAO and partners (FAO, 2016b). FAO has supported field projects through the FAO Action Against Desertification programme. Based on experiences, 50 thousand ha of barren lands has been restored in more than 400 communities, improving livelihoods for close to 1 million people. A comprehensive restoration approach provides a guide for scaling up (FAO, 2016b).

Numerous studies have attempted to estimate sustainable use and restoration costs and benefits to ensure viable interventions, but they have tended to focus on specific regions or ecosystems. One study suggests the restoration cost was only 34 percent of the cost of inaction (Nkonya *et al.*, 2016). A field study in Madhya Pradesh, India,

BOX 4.9

RESTORATION INTERVENTIONS IN THE GREAT GREEN WALL FOR THE SAHARA AND SAHEL INITIATIVE

Restoration connects plant science to communities, supplementing tree planting with the cultivation of fodder for livestock, and deploying mechanization, where appropriate, for water harvesting. It emphasizes the link between ecology and economics, through developing value chains for non-timber forest products to generate income for vulnerable rural communities, particularly women, to improve their livelihoods and resilience. A toolkit supports capacity development for national experts in modern geospatial technologies for innovative monitoring and evaluation of operations.

Actions include:

- Promoting natural regeneration, in which farmers protect and manage the natural regeneration of native species in forests, croplands and grasslands (most effective in dry subhumid and semi-arid zones).
- Investing in large-scale land preparation and enrichment planting where degradation is so severe that natural vegetation will not regenerate on its own; communities select the native woody and grass species to be used (mostly arid and semi-arid zones).
- Fighting sand encroachment by establishing and protecting native woody and grassy vegetation adapted to sandy and arid environments (mostly in the hyper-arid zone).
- Mobilizing high-quality seeds and planting materials of well-adapted native species to build ecological and social resilience.
- Developing comprehensive value chains that benefit local communities and countries and enable green economies and enterprises to flourish.
- Building inexpensive, participatory information systems to support baseline assessments, identify interventions, track progress, inform stakeholders and investors, and aid learning and adaptive management.

Sources: **Liniger, H.P., Mekdaschi Studer, R., Hauert, C. & Gurtne, M.** 2011. *Sustainable land management in practice: Guidelines and best practice for sub-Saharan Africa.* TerrAfrica, World Overview of Conservation Approaches and Technologies and FAO. www.fao.org/3/i1861e/i1861e.pdf; **FAO**. 2016. *Building Africa's great green wall: Restoring degraded drylands for stronger and more resilient communities.* Rome. www.fao.org/3/i6476e/i6476e.pdf suggests that interventions to build local community capacity to implement watershed development with climate adaptive measures systematically and to maintain the structures is economically viable and protects the ecosystem regenerated for periods of normal rainfall and extreme events (Das *et al.*, 2020).

Analysing the economic potential for coastal zone restoration suggests this is expensive and, in many situations, not cost-effective in strictly financial terms. However, coastal mangrove restoration is among the more cost-effective options (Bayraktarov *et al.*, 2015; Jakovac *et al.*, 2020). Restoring salt-affected soils is economically feasible under some conditions (Qadir *et al.*, 2014). Public investments will be required where there is a public good, particularly for projects initiated by the private sector and where there are public and private benefits.

4.3.7 Tools for implementation

Many resources exist to support countries to develop locally adapted SLM and land restoration programmes at different scales. Experiences are documented on multicountry and transboundary responses, through the TerrAfrica and the Great Green Wall for the Sahara and Sahel Initiative, supported under the GEF land degradation portfolio, the GEF International Waters programme, and associated transboundary river basin and source to sea projects.

The Global Land Outlook is a UNCCD Secretariat strategic communications platform with associated publications to demonstrate the central importance of land quality to human well-being. It focuses on land degradation and land-use change, the driving factors and human impacts, and scenarios for future challenges and opportunities. It aims to communicate a new and transformative vision for land management policy, planning and practice at global and national scales.

The World Overview of Conservation Approaches and Technologies (WOCAT) is a well-regarded global network among scientists, technical experts and practitioners that promotes sharing and use of knowledge to support SLM adaptation, innovation and decision-making. The global SLM database is updated regularly to support SLM best practices on conservation and restoration. The 1 500 technologies and approaches in the multilingual database are supported by a quality control process and tagged to the LDN hierarchy (Liniger and Studer, 2019; WOCAT, 2022). Eight consortium partners (Deutsche Gesellschaft für Internationale Zusammenarbeit, FAO, International Center for Agricultural Research in the Dry Areas, International Centre for Integrated Mountain Development, International Centre for Tropical Agriculture, Swiss Agency for Development and Cooperation, the University of Bern's Centre for Development and Environment and World Soil Information), WOCAT regional and WOCAT national institutions and individual members support tool development and piloting, and contribute to the WOCAT knowledge products.

The global GEF/FAO project Decision Support for Mainstreaming and Scaling out Sustainable Land Management provides a knowledge management and decision-support system and tools from local to national levels. Under this project, the lessons learned in mainstreaming and scaling up are available in the WOCAT knowledge system to inform wider SLM and LDN implementation.

The FAO Sustainable Forest Management Toolbox provides resources for planning forest and landscape restoration, including decisions on the appropriate types of interventions, institutional arrangements, financial considerations and more. The toolbox also provides case studies of successful restoration and rehabilitation efforts (FAO, 2022h).

The Restoration Opportunities Assessment Methodology, produced by IUCN and the World Resources Institute, provides a flexible framework for countries to rapidly identify and analyse priority areas for forest landscape restoration at national and subnational levels (IUCN, 2022).

The farmer field school (FFS) approach has been successful in building capacity to enable land users to adapt to land management practices and SLM. The approach combines local and traditional knowledge with modern science and shares experiences farmer to farmer through improved farmer–extension–research interaction (Box 4.10).

These are just a few available tools to help plan and implement SLM and restoration initiatives for large and small schemes. The list will continue to grow as stakeholders learn and share experiences.

4.4 Planning for drought

4.4.1 From crisis to risk management

Responding to the impacts of drought and providing relief and recovery are more complex than other natural hazards (Wilhite, 2011). Droughts are consistently underreported (Gall, Borden and Cutter, 2009), and indirect losses can dwarf direct losses. Droughts do not usually affect infrastructure but they can adversely affect large geographical areas and millions of people. They bring lost revenue and slow growth, and exacerbate long-term food insecurity, poverty and inequality. In developing countries, the cost of droughts is borne disproportionately by the most vulnerable people, which can mean famine and death. The *GAR special report on drought 2021* (UNDRR, 2021) estimated direct annual costs of droughts in the United States of America of USD 6.4 billion, in the European Union the figure is EUR 9 billion, and the agricultural productivity in Australia fell by 18 percent in the period 2002–2010 due to the Australian Millennium Drought. In India, drought is estimated to cost as much as 2–5 percent of the country's GDP.

Most countries still deal with droughts as crises in much the same way they approach other natural hazards such as floods and earthquakes, and often with little done in the aftermath to prepare for the next one. However, emergency action treats only the symptoms of drought, hunger, famine and water shortages, not the root causes of drought impacts. The High-Level Meeting on National Drought Policy in 2013 (WMO, 2013) initiated a dialogue on the need for governments to shift from crisis management to drought risk management. This approach seeks mitigation and adaptation measures that lessen the risks of drought impacts through planning and by improving a nation's resilience and coping capacity (WMO and GWP, 2014). Rather than recovery alone, which re-establishes the status quo, this requires a complete "disaster management" cycle (recovery plus protection) as shown in Figure 4.6.

The High-Level Meeting on National Drought Policy also established the elements of a national drought management policy to include:

BOX 4.10

FARMERS FIELD SCHOOLS DEVELOP SUSTAINABLE LAND MANAGEMENT CAPACITY

In the Kagera basin in East Africa, the FFS approach has been a successful strategy to increase farmer capacities to manage SLM and water management as part of small-scale watershed management.

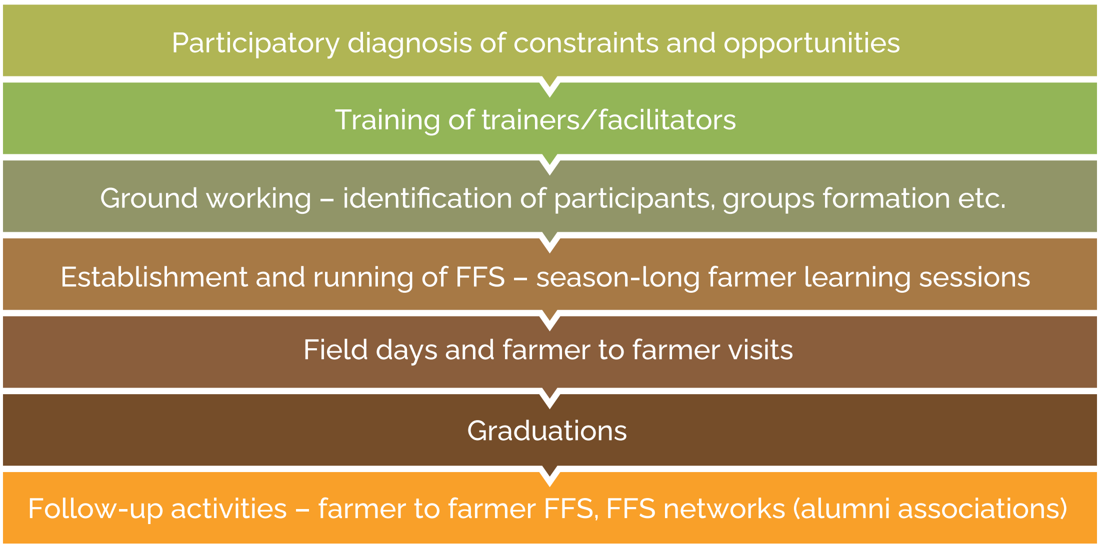
A capacity needs assessment established the baseline for training and the knowledge gaps. During this phase, the causes of land degradation and other production constraints were identified and documented, and solutions were identified and prioritized with local actors (using WOCAT and LADA1 tools). This defined the FFS learning curriculum and the opportunities and good practices.

A development phase followed to establish FFS sites in microcatchments, select potential facilitators, train trainers, and develop the curriculum and action plans, including participatory monitoring and evaluation.

The implementation phase built farmer capacity through the growing season and provided year-long learning groups and backstopping by facilitators and extension officers/service providers, including exchanging experiences among districts/provinces and countries. Monitoring and evaluation entailed follow-up activities, monitoring and fostering adoption, documentation of FFS activities at all levels and reporting. The monitoring and evaluation phase was continuous during all project phases.

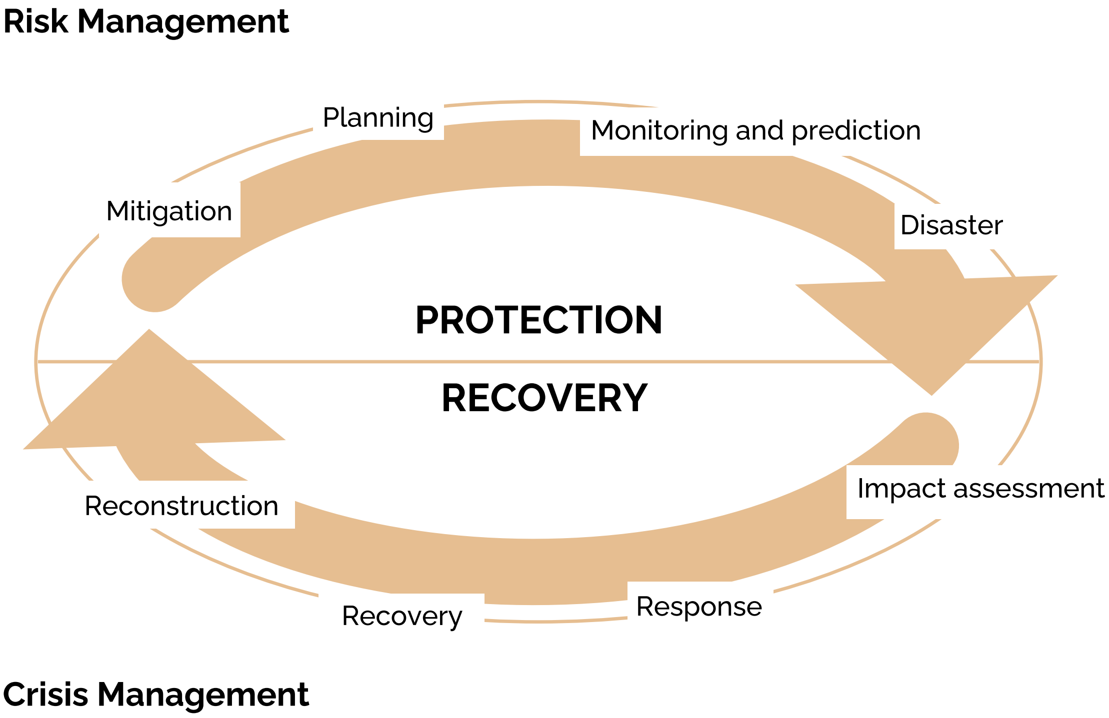
In the final action stage, the FFS development process followed a sequence of activities for mainstreaming and scaling up, including policy support on territorial planning and tenure security and resource mobilization through FAO, the International Fund for Agricultural Development and the World Bank Lake Victoria development programme (Figure 4.5).

FIGURE 4.5 FARMER FIELD SCHOOL GENERIC SEQUENCE OF ACTIVITIES



Source: **FAO**. 2017. *Sustainable land management (SLM) in practice in the Kagera basin. Lessons learned for scaling up at landscape level. Results of the Kagera Transboundary Agro-ecosystem Management Project (Kagera TAMP).* Rome. www.fao.org/3/i6085e/i6085e.pdf

FIGURE 4.6 CYCLE OF DISASTER MANAGEMENT



Source: **World Meteorological Organization & Global Water Partnership**. 2014. *National drought management policy guidelines: A template for action*. Integrated Drought Management Programme Tools and Guidelines Series 1. Geneva and Stockholm. www.droughtmanagement.info/literature/IDMP_NDMPG_en.pdf

- establishing a clear set of principles or operating guidelines to govern the management of droughts and their impacts;
- promoting standard approaches to vulnerability and impact assessment;
- implementing effective drought monitoring and early warning systems (MEWS);
- enhancing preparedness and mitigation actions;
- implementing mitigation, emergency response and recovery measures that reinforce national drought management policy goals; and
- developing a drought plan – the instrument through which the above policy principles are executed.

The World Meteorological Organization and the Global Water Partnership initiated the Integrated Drought Management Programme in 2014. This proposes a generic ten-step process to support governments in developing national drought management policies and plans. Its three pillars – monitoring and early warning; vulnerability and impact assessment; and preparedness, mitigation and response – provide a foundation for planning and management (WMO and GWP, 2014) (Figure 4.7).

Monitoring and early warning systems (pillar 1) provide a repository for climate data and drought indicators and the capacity to analyse data, assess information, and communicate it promptly and effectively to those exposed to drought and who need to take action and reduce risk. Most countries have systems to monitor hazards like earth-

FIGURE 4.7 (TOP) TEN STEPS AND (BOTTOM) THREE PILLARS OF DROUGHT POLICY AND PREPAREDNESS

Source: **United Nations Office for Disaster Risk Reduction**. 2021. *GAR special report on drought 2021*. Geneva. www.undrr.org/publication/gar-special-report-drought-2021; adapted from **World Meteorological Organization & Global Water Partnership**. 2014. *National drought management policy guidelines: A template for action*. Integrated Drought Management Programme Tools and Guidelines Series 1. Geneva and Stockholm. www.droughtmanagement.info/literature/IDMP_NDMPG_en.pdf and **Pischke, F. & Stefanski, R.** 2018. Integrated drought management initiatives. In: *Drought and water crises: Integrating science, management and policy*, pp. 39–55. CRC Press.

quakes, flooding, storms and forest fires, but few can detect the early signs of drought and how the event will unfold, to trigger actions and improve proactive responses.

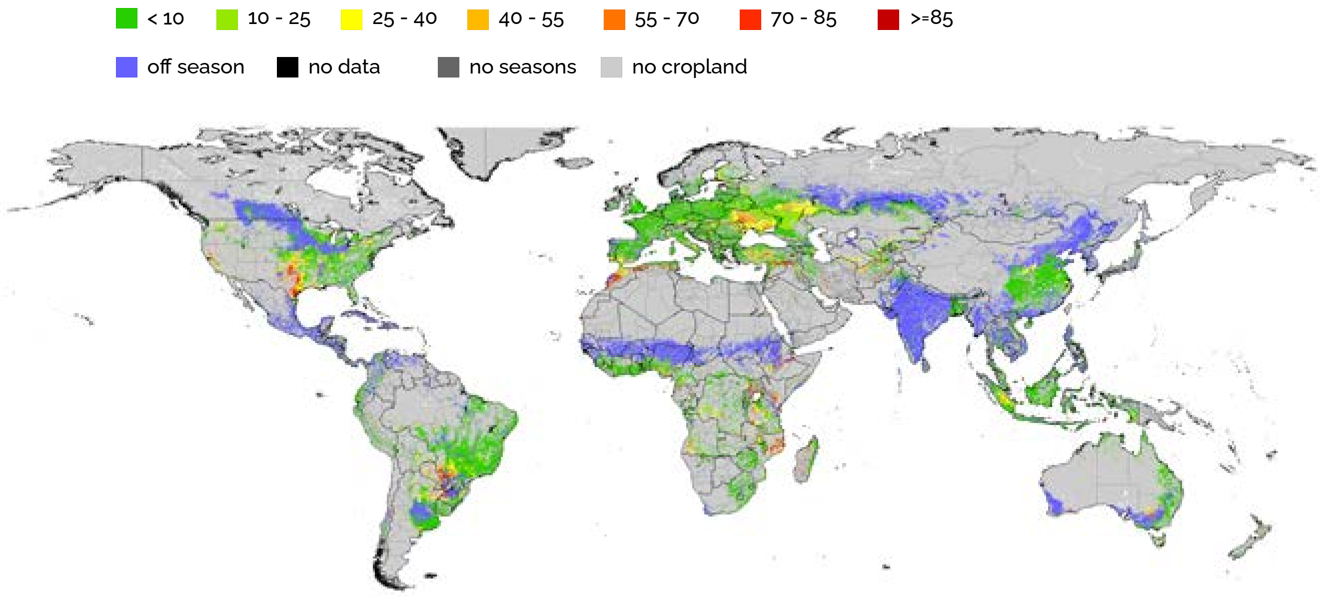
Most countries lack capacity to monitor and rapidly communicate real-time conditions, which are essential for dealing with the impacts on agriculture and food systems. They lack data and the capacity to collect and process information and communicate this for effective and timely intervention. Media and internet communications can play an important part in bridging this information gap, but they can do this only when provided with reliable and timely information.

Box 4.11 outlines some global and regional MEWS and initiatives (in the Caribbean, Horn of Africa, Sahel and United States of America). However, much more is needed at national and local levels to cope with local circumstances.

BOX 4.11
MONITORING AND EARLY WARNING SYSTEMS

The FAO Global Information and Early Warning System on Food and Agriculture monitors the condition of major food crops across the globe to assess production prospects. It uses remote-sensing data to provide valuable insights on water availability and vegetation health during the cropping seasons to support the analysis and supplement ground-based information. In addition to rainfall estimates and NDVI, the Global Information and Early Warning System and FAO have developed an agricultural stress index, a quick-look indicator for early identification of agricultural areas probably affected by dry spells or drought in extreme cases (see Map 4.14). This map represents one date, but multi-temporal changes are better to understand agricultural stress areas.

MAP 4.14 **AGRICULTURAL STRESS INDEX FOR 1 MAY 2021 (%)**



Source: **FAO**. 2022. GIEWS - Global Information and Early Warning System on Food and Agriculture. In: *FAO*. Rome. www.fao.org/giews/en. Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

CARIBBEAN

The Caribbean MEWS involves several institutes across the region that collaborate to monitor and attempt to assess drought severity using indicators and by making short-term rainfall predictions. As the Caribbean comprises many small islands surrounded by large ocean areas, the region lends itself to meteorological monitoring and early warning. The Caribbean Drought and Precipitation Monitoring Network launched in haste in 2009, during a severe drought, and which has proved effective, continues to make regional rainfall predictions three months and six months ahead using a consensus among 20 organizations from across the region. Such regional forecasts are helpful, but island forecasts would be ideal as the individual small islands differ in their drought risks.

Source: **FAO**. 2016. *Drought characteristics and management in the Caribbean*. FAO Water Reports 42. Rome. www.fao.org/3/i5695e/i5695e.pdf

HORN OF AFRICA

In the Horn of Africa, the Intergovernmental Authority on Development's Climate Prediction and Applications Centre was tasked in 2003 with monitoring, predicting and providing early warning of climate-related disasters, including droughts. The centre is responsible for regional climate outlook forums to provide consensus early warning seasonal climate information to support the regional disaster resilience and sustainability strategy frameworks. Generally, however, existing meteorological stations are far from adequate, their numbers are declining and none exist in Somalia and South Sudan. Satellite observations complement ground-based systems, but human and institutional capacity to support this initiative is insufficient.

Source: **FAO**. 2018. *Drought characteristics and management in North Africa and the Near East*. FAO Water Reports 45. Rome. www.fao.org/3/CA0034EN/ca0034en.pdf

SAHEL

Sahel countries have established a network of national and regional institutions to avert ecological disasters such as the tragic deaths in the drought of 1968–1973. Central to this is the Permanent Interstate Committee for Drought Control in the Sahel, which collects and analyses natural resource data and operates a MEWS to provide alerts of potential drought and locust outbreaks and conducts socioeconomic research.

Source: **FAO**. 2018. *Drought characteristics and management in North Africa and the Near East*. FAO Water Reports 45. Rome. www.fao.org/3/CA0034EN/ca0034en.pdf

UNITED STATES OF AMERICA

In the United States of America, a multiagency and cross-ministerial coordination mechanism facilitates data sharing in real-time informatics related to drought for all sectors under the national drought policy and supported by the national integrated drought information system. This coordinates drought monitoring, forecasting, planning and information at national, tribal, state and local levels. Updated weekly, it shows the location and intensity of drought across the country giving expert assessments of conditions related to dryness and drought including observations of how much water is available in streams, lakes and soils compared to usual for the same time of year.

Source: **National Integrated Drought Information System**. 2022. Advancing drought science and preparedness across the nation. www.drought.gov

Vulnerability and impact assessments (pillar 2) are essential in guiding MEWS and investment in mitigation and adaptation. They address key questions such as:

- Who is affected by drought?
- What is at risk and why?
- What are the priorities/ranking for dealing with them?

Most developing countries in the FAO drought survey (FAO, 2018b) listed agriculture and smallholder subsistence farming families as most at risk because they depend on the uncertainties of meagre seasonal rainfall and rainfed farming for their livelihood.

The dryland corridor in Central America, the Andean region and Southern Africa are prone to severe drought, even though the subregions as a whole are well endowed with water resources. Box 4.12 illustrates the case of the Horn of Africa, where food security depends on smallholder farming and pastoralism, and severe droughts and floods have life-threatening consequences.

Preparedness, mitigation and response (pillar 3) comprise measures taken to reduce adverse drought impacts and respond to drought emergencies informed by MEWS and vulnerability and impact assessments. In turn, mitigation and response determine the critical indicators for MEWS and affect impacts and vulnerability.

Thus, coping with drought relies on all three pillars, across which collaboration and continuous information feedback are essential. Deficiencies in any pillar, as with weakness in one leg of a three-legged stool, will inhibit the effectiveness of drought planning and management.

BOX 4.12
RESPONDING TO CRISES IN THE HORN OF AFRICA

About 80 percent of people in the Horn of Africa rely on agriculture and pastoralism as their primary source of food and income. In 2011, this subregion faced one of the driest years in 60 years, causing a food crisis that escalated into famine in places, such as southern Somalia. Some 12.4 million people were in need of urgent assistance. This number nearly doubled in subsequent months. FAO assisted local populations and governments to respond to the crisis and ensured communities were better equipped to cope with future droughts.

Heavy rainfall caused severe flooding in Sudan in July 2020, leading to displacement, destruction of homes, loss of more than 1 thousand ha of agricultural land in the harvest season, and human and livestock deaths. Hundreds of thousands of people were affected in 17 of the country's 18 states. The Nile River reached its highest level in a century.

In Sudan, in response to the COVID-19 pandemic, FAO updated its humanitarian response plan for 2020, working with partners to improve the availability and access to quality and nutritious food to enhance the resilience of vulnerable people. It continued to provide agricultural and livestock inputs and animal health support to enable smallholder farmers and pastoralists to maintain their production and livelihood activities.

FAO provides long-term support to Somalia through the Water and Land Information Management project to strengthen community resilience using FAO early warning information to improve flood and drought risk reduction, preparedness and mitigation.

Source: **FAO**. 2022. FAO in emergencies. In: *FAO*. Rome. www.fao.org/emergencies/fao-in-action/stories/en

4.4.2 Formulating a national drought policy

Formulating, developing and implementing a national drought policy requires harmonizing policies and legal and institutional frameworks and strengthening multisectoral coordination. Governments need updated water laws and guidelines on possible courses of action, established contingency plans and operational modalities. A proactive drought risk management policy with strengthened institutional capacities would lead to more robust planning and investment decisions, with early intervention and mitigation and less costly damage due to drought.

Although most countries recognize the need to prepare a national drought policy and national and subnational preparedness plans, many continue to deal with drought as an emergency response to a meteorological event rather than focusing on subsequent impacts.

Few have embarked on the first steps identified in the ten-step process, and even fewer have reached a point of putting policy and plans into practice. One of the main constraints is complacency and the apathy that so often sets in during periods of "normal" rainfall. Urgency and action for drought planning are strongest during drought, but when the rains begin again, interest wanes as other, more immediate issues push drought down the political agenda. There is often little appetite and funding for gathering and analysing data, which may take many years and untangling of the effects of drought from other socioeconomic events. Persistence among organizations involved will be essential for effective drought preparedness.

Risk management requires all those involved, from government departments to communities, to work together, solve problems, and make and implement plans to reduce drought risks. This process should be an integral part of national water policies, IWRM and the drive to improve water resources management and increase water security under SDG 6.

The 2030 Agenda, which calls for an integrated approach to water resources management, offers opportunities to integrate effective drought preparedness and management.

4.4.3 Drought management and its development

There is often a tacit assumption that mitigation and adaptation are synonymous with long-term economic development and investment in water infrastructure and water security. This is true to some extent. But if economic development were the answer, the United States of America and countries across Europe would be relatively free of drought impacts. Recent experiences in both regions demonstrate this is not the case, as they continue to experience the effects of severe droughts. An encouraging example is an initiative taken in 2013 by ten Central and Eastern European countries to establish an integrated drought management plan to combat severe threats to the region's agriculture (Box 4.13).

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BOX 4.13
AN INTEGRATED DROUGHT MANAGEMENT PLAN IN CENTRAL AND EASTERN EUROPE

All Central and Eastern European countries have well-developed meteorological and hydrological monitoring systems, but many do not yet have systems to make good use of the information to support decision-making in areas like agriculture and energy production. Drought also does not recognize administrative borders, which adds to the complexity of managing shared water resources and drought in the region. Most Central and Eastern European countries share water in river basins, such as the Danube, Sava and Tisza. Several platforms are now in place to encourage information sharing: Sava GIS, a river commission platform for data sharing, the Drought Management Centre for Southeastern Europe and Drought Watch (Danube Interreg Programme, 2022).

In 2013, ten Central and Eastern European countries made the first steps towards an integrated approach to drought management and launched an integrated drought management programme to combat the growing threat. The first phase (2015–2017) brought together policymakers and stakeholders, including farmers, from over 40 organizations across the Central and Eastern European countries, to identify strong and weak areas and examine how they could make plans to improve drought management. The main achievements of the first phase were (WMO and GWP, 2014):

- a concise overview of the current approaches to drought management in Central and Eastern European countries;
- a guideline published for preparing a drought management plan that complements the European Union Water Framework Directive;
- improved communication links among experts and policymakers at the country level;
- increased capacity to implement national drought management plans;
- a collection of existing drought monitoring indices, methods and approaches from the Central and Eastern Europe region, and the establishment of a link and integration of data into the European database and monitoring service (European Drought Observatory);
- demonstrated innovative approaches to drought management; and
- exchanges of information and results with organizations in the region that deal with similar issues.

Phase II (2017–2019) focused on building capacity to change ad hoc drought responses into proactive drought management

Developing drought management plans and putting them into practice is still in its infancy. Clearly, this is a marathon rather than a sprint. It is also a process and not a project; it has milestones, but there is no "completion" date. It will be a process of collaboration and continually improving facilities and services to reduce risks and tackle emergency droughts as they occur. It is about moving from recovery to protection, from crisis management to risk management.

Source: **Bokal, S. & Müller, R.** 2018. Integrated drought management in central and eastern Europe. *WMO Bulletin*, 67(1).

In Southern Africa, concerns about climate change drive the drought risk agenda, as long-term development plans are put into place to help protect the many millions of smallholders who rely on rainfed farming for their livelihoods. The Caribbean Disaster Emergency Management Agency seeks to integrate disaster management with development planning, with clear linkages with planning for climate change. Although primarily concerned with responding to cyclones and flood risks, droughts are now a recognized hazard requiring more strategic management in the Caribbean (FAO, 2016c).

4.5 Conclusions

This chapter has anticipated that climate change will bring shifts in land suitability for all types of cultivation, notably the key staple crops, and that with the combination of changing economic and ecological conditions, better-informed land-use planning will become the first line of adaptive management response.

Although climate change has many adverse impacts, the analysis also shows opportunities to maintain or increase crop production and diversify farming systems. Alternative crops and land-use options are available to enhance the resilience and adaptation of farmers. Realizing these benefits will largely depend on the capacity of supporting services to guide an informed adaptation process and farmers' ability to select suitable options and implement sustainable crop, land and water management practices. This includes the conducive enabling environment to support the shift or transformation.

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To address the range of adaptive management and attain national emission targets for agricultural land, it is important to take stock of land and water assets and develop realistic forms of spatial planning for agricultural land use, for which economic trade-offs can be evaluated and policies in public subsidies developed.

On-farm operational decisions for agriculture are manifold if the overall risk to food production is to be avoided or mitigated by transforming agricultural and land management practices. Decisions become more complex when calculating how to reduce negative impacts on livelihoods, human health and the delivery of ecosystem services. Land-use planning and, more broadly, land resources planning are therefore needed at different levels of decision-making to address challenges set by changing human demands. When matched with conformable SLM options and financing mechanisms, land resources planning can provide the essential impetus to reverse trends in land degradation.

The tools for sustainable land-use planning and management are available to assess the potential impacts of climate change on crop production and tackle the growing pressures on freshwater ecosystems and degrading land, soil and water quality. Monitoring the accumulated impact of climate change in relation to agroecological suitability will


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prove essential for planning resource use along the entire food value and supply chains. Planning tools can define critical thresholds in natural resource systems, leading to the reversal of land degradation when wrapped up as packages or programmes of technical, institutional, governance and financial support. In this respect, LDN can help governments set targets and plan interventions based on the principle of Avoid > Reduce > Reverse land degradation.

Models are now essential tools for land-use planning and LRP, and are increasingly used together with participatory approaches to develop better adapted food and agricultural systems. Combining LRP tools, including GAEZ methods, with the latest climate models provides invaluable insights into how these changes will redistribute land available for agricultural production and affect water availability. This includes shifts in areas suitable for different crop and livestock species and farming systems, and identifying potential impacts on productivity and yield gaps. In particular, shifting to a risk management approach can significantly lessen drought risks and impacts.

Integrated multisectoral approaches need not be complex, they can be intuitive. However, solutions require close collaboration across sectoral boundaries where interests align. Planning and implementing measures that sustain productivity, reduce pollution, sequester carbon and mitigate emissions can be straightforward, and tested technologies in SLM can be married with inclusive planning approaches at scale when good land and water governance is in place.

Resource planners can now respond to the challenge using remote sensing, big data and innovative analytical methods that are revolutionizing approaches to resources planning. A wide range of resource planning tools and approaches support decision-makers, planners and practitioners, working at global, national and local levels to plan, take actions and scale out SLM options. However, integrated solutions need to be planned at all levels if they are to be taken to scale.


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Case study: Participatory land resources planning to promote sustainable land management in Morocco

Land degradation poses many challenges on the livelihoods of rural communities in Morocco. An assessment of land degradation at subnational and landscape/local levels at pilot sites in the Souss-Massa region has initiated a participatory territorial planning process and action plans to promote and scale out SLM across the region/country.

Morocco is characterized by scarcity of land and water resources. The agricultural sector is therefore vulnerable to climate change and impacts on the livelihoods of rural communities and the national economy. Morocco was selected as one of 14 countries to participate in a project to provide decision support for mainstreaming and scaling up SLM (FAO, 2018a). The aim was to enhance knowledge and understanding of land degradation, strengthen institutional capacities and generate decision-support tools to mainstream and scale out SLM nationally.

Pilot sites were selected at Ameskroud, Aziar and Tamri in the Souss-Massa region according to the severity of land degradation (low, medium and high). The LADA tools (FAO, 2013a) were used for the assessment at both levels and enabled the identification and analysis of different forms and severity of land degradation. The LADA–WOCAT methodology (WOCAT, 2022) at subnational level included the development of regional maps for land-cover types, land-use systems, main types of degradation, severity of degradation and identification of good agricultural practices.

At the landscape/local level, the methodology included the identification and mapping of land-use systems, socioeconomic and biophysical assessments and mapping of good practices in each of the three pilot sites. Qualitative and quantitative data from the landscape-level assessment were reviewed with several stakeholders (institutional parties, local authorities and local development associations) during a regional consultation workshop to identify, negotiate and select territorial responses, considering existing plans and implementation mechanisms.

Following the consultations, a participatory SLM territorial planning pact was developed and the actions agreed between the stakeholders. These comprised: (i) local demonstration areas to test good practices in each of the three rural communes, (ii) a list of good practices to be implemented to commit financial and technical input of stakeholders, (iii) territorial watershed or community approaches developed by FAO and WOCAT and synthesis of the main results, products and lessons learned to support integration and scaling up of SLM and (iv) simple, measurable indicators for monitoring the impacts from implementing good practices, and their degree of adoption.

Capacity was built throughout the project to allow partners to use these tools and approaches to facilitate scaling up and cultivate ownership of the process and ensure sustainable management of natural resources.

Following the pilot studies, a three-year action plan was developed according to the LADA–WOCAT approach involving stakeholder participation from the beginning to scale out SLM in the Prefecture of Agadir-Ida-Ou Tanane. The plan was aligned with the development plans for the prefecture and the regional development strategy for the Souss-Mass region and comprised: (i) mitigating the effects of water erosion, (ii) improving vegetation cover and management, (iii) building capacity and creating awareness among stakeholders and (iv) promoting SLM. Sustainable land management good practices (eight practices) were promoted in nine villages, with an overall cost of MAD 180 565 000 (MAD 1 = USD 0.11).

Source: **Rouchdi, M., Sabir, M., Qarro, M. & Chattou, Z.** 2018. *Degradation assessments and good sustainable land management practices within and through their systems of use, "Souss-Massa region / permanent ecological monitoring and surveillance observatories"*. Project Report. Rabat.


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Case study: Information-based climate-proof land management in the Lao People's Democratic Republic

Agricultural planning in the face of climate change presents a unique challenge because it involves assessing trade-offs between different land-use strategies now and in the future, based on uncertain and incomplete information about the nature of the future climate and the state of land resources.

Developing materials to inform planning processes under these conditions is complicated, requiring a mix of historical data, integrated modelling and scenario building. Developing countries often lack the human and technical capacity to develop the national-level data, and undertake modelling exercises required to inform sophisticated scenario development exercises and government responses to climate change impacts on agriculture. Scenario-based analysis is important in contexts involving uncertainty and complexity to allow for consideration of a wide range of potential future changes in drivers such as climate change, human population, demand for food and possible trade-offs between different responses (van Soesbergen *et al.*, 2016; van den Ende *et al.*, 2021). It helps to assess potential alternative futures (Habegger, 2010; Bourgeois *et al.*, 2012) without giving a false impression of confidence to information users (Nissan *et al.*, 2019).

Tools drawing on widely accepted technical standards and global data and information, such as GAEZ, have been developed to address the gaps. However, institutional issues can limit the integration and adoption of such globally oriented tools and data outputs into national decision-making processes. Many countries will not use global modelling data and outputs in national planning and policy documents, even if the local capacity to produce similar analysis is available. As a result, despite efforts by a range of technical advisory agencies to improve agricultural land-use planning processes and tools, the capacity gaps remain while the risks posed by climate change to agriculture continue to grow and are poorly understood.

The project Strengthening Agro-climatic Monitoring and Information Systems (SAMIS) to improve adaptation to climate change and food security in the Lao People's Democratic Republic is increasing decision-making and planning capacity for the agricultural sector at national and decentralized levels in the country. Its objective is to enhance capacities to gather, process, analyse and share climatic and geospatial information so these can be applied to planning and decision-making (FAO and GEF, 2022). Under SAMIS, the Government of the Lao People's Democratic Republic has developed land-suitability and land-use models coupled with climate change projections to produce scenarios informing decision-making processes.

The process developed through SAMIS is centred around the efforts of local agencies to develop needed national-level datasets to inform modelling and scenario-building exercises. An annual agricultural map was prepared using machine learning. The soil map was updated using FAO World Reference Base classification. Participatory data-collection exercises were conducted at district and province levels to collect information on land utilization type, crop calendar database and livelihoods. National climate observation was used to dynamically downscale daily climatic data for the last 30 years and produce statistically downscaled future scenarios. These data inputs are now being used to drive the development of suitability maps for six crops under current and future climate conditions using a tailored software, called pyAEZ, developed by FAO and the Asian Institute of Technology based on the FAO AEZ approach. This effort represents the first nationally led exercise to produce AEZ analysis using national data by national experts.

The SAMIS project has demonstrated that fast progress in developing land management planning exercises to address climate change impacts is possible, even in countries with limited technical capacity. The pyAEZ software has been instrumental in achieving this quick success, and has enabled the algorithms underpinning the FAO AEZ approach to be openly accessible and run by local operators with minimal additional technical input or guidance. The SAMIS project has also empowered technical staff to lead scenario development and modelling exercises by assigning clear roles to staff, recognizing success and establishing a process of rewarding for technical staff capacities.

From an institutional perspective, the Government of the Lao People's Democratic Republic has worked to address barriers to data sharing among agencies. The scenarios developed by SAMIS required inputs from several sources. The scenario-building exercises developed involved multiple data producers and coordination, and in some cases, negotiation, among entities at different scales and levels. The usefulness of most of the data shared was dependent upon the availability of related datasets held by other agencies. Open and transparent scenario-building exercises that recognize the power implicit in data management and different data users' needs helped address sensitive data-sharing issues.

The datasets and information products developed by SAMIS include policy processes. They regularly inform planning and policy processes at national and subnational levels. Anticipatory governance for climate adaptation has been tested (Vervoort and Gupta, 2018). A machine-learning crop monitoring procedure pioneered by SAMIS is used to validate progress against the National Socio-Economic Development Plan. The SAMIS tools are also being used to inform crop yield estimation exercises at village levels to inform prioritization of different investments.


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Case study: Restoring degraded land in Rohingya refugee camp in Cox's Bazar, Bangladesh

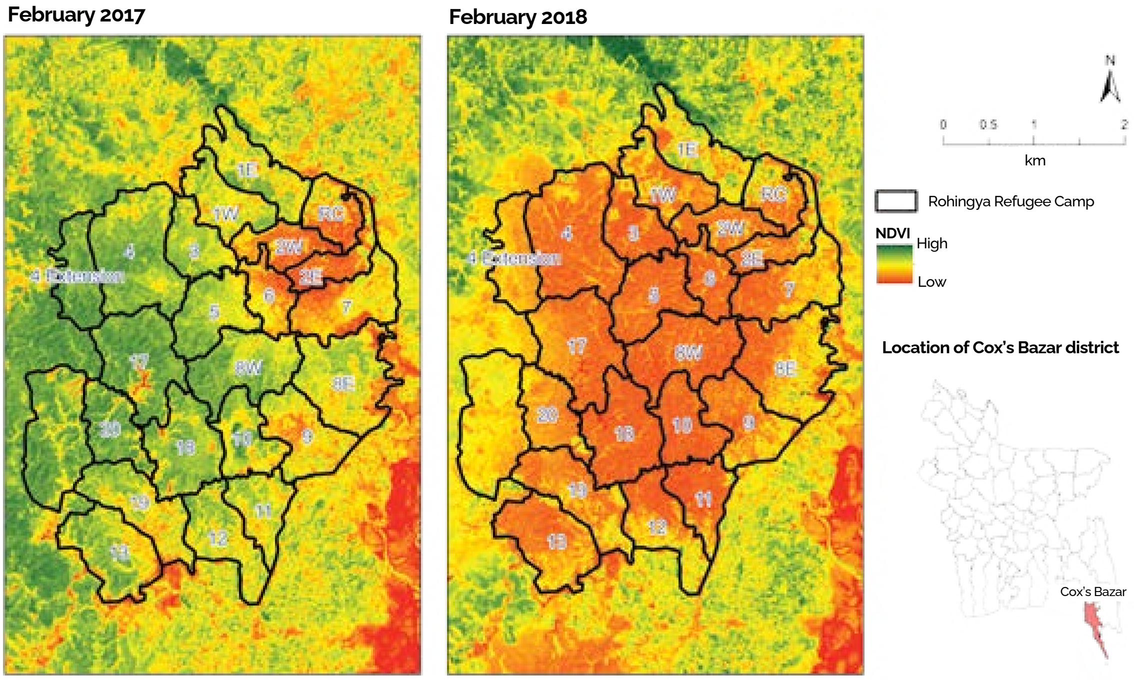
New geospatial technologies are providing timely and detailed information on natural resources and SLM in a complex refugee camp setting as part of a humanitarian response. One outcome over the past three years is the participation of the refugee community in restoring over 350 ha of degraded land inside the refugee camp in Cox's Bazar, Bangladesh. This is reducing the risks from natural disasters, and improving ecosystem services and general living conditions inside and around the camps.

Since 2017, there has been a huge increase in the number of Rohingya people displaced, and 742 000 refugees have fled to Bangladesh, which has led to the development of the world's largest refugee camp in Cox's Bazar. This has put intolerable pressure on the regional landscape and is posing challenges to sustaining human health, food security, nutrition, water supply and sanitation, providing shelter, education, environmental services and energy, not just for the refugees but also for the host communities.

Trees have provided fuelwood, and grass covering and soils have been excavated to level the land for building shelters (UNDP and UN WOMEN, 2018). Land degradation was severe, forests and topsoils were lost, which intensified surface water runoff, increasing the risk of landslides and flash floods, putting thousands of people at risk, and provoking conflict between host communities and the Rohingya refugees.

The initial humanitarian response to land degradation had mixed results, mainly due to lack of informed decision-making and collaboration. To overcome this, FAO introduced geospatial technologies and remote sensing to provide information to enable planners to assess land use and inform resources planning. An example was remote sensing used to illustrate and measure the changes in land use and vegetative cover on 7 220 ha of degraded forestland in and around the camp area (see map, which illustrates the changes between February 2017 and February 2018). Experts predicted that the entire forest area of Cox's Bazar was likely to disappear by 2019 if the rate of deforestation continued unabated.

CHANGE OF VEGETATION BETWEEN FEBRUARY 2017 AND FEBRUARY 2018, AS DEPICTED BY DECREASED NDVI (A LOWER NDVI MEANS LESS VEGETATION COVER)



Source: **Mahamud, R., Tanjim, A., Ritu, S., Mondal, F.K. & Arafat, F.** 2021

Since 2018, an integrated approach has evolved that is helping to reverse the degradation, reduce the risk of natural hazards, and improve the living conditions among refugees and local communities. FAO, in close coordination with the Energy and Environment Technical Working group and United Nations organizations (International Organization for Migration, United Nations High Commissioner for Refugees and World Food Programme), international and national partners, such as the Bangladesh Ministry of Environment, Forest and Climate Change, local communities and Rohingya refugees have brought the degraded lands together under a land restoration programme.

This programme has: (i) engaged a range of partners for coordinated planning, implementing and monitoring land restoration activities, (ii) used evidence-based information to assess gaps and needs, in particular subsistence issues such as energy supply access and demand, (iii) prepared technical guidance for land restoration activities including increasing the supply of fuelwood and (iv) used advanced geospatial technologies and remote sensing to conduct analysis for planning, coordination and monitoring of land restoration activities.

The information derived from using the geospatial technologies and understanding the drivers of land degradation from the beginning of the crisis was key to integrating evidence-based ecosystem restoration into the humanitarian response plan. The successful implementation and sustainability of restoration activities in a displacement and emergency setting are highly challenging. After three years of raising trees in nurseries, stabilizing land and planting trees inside and outside the camps, the benefits can be seen, on satellite images and on the ground. The WOCAT network also proved to be an invaluable resource in providing overall guidance for landscape restoration (WOCAT, 2022).

Though every refugee crisis has its own challenges, the approach taken in Cox's Bazar has potential for wider application. It must be flexible enough to adapt to rapid changes, collaborative to engage various stakeholders, coordinated to maximize synergies, and based on robust and documented evidence for adequate resource allocation.

WATERING BY A ROHINGYA REFUGEE AT A REFORESTATION SITE IN THE CAMP

© FAO/Saikat Majumder

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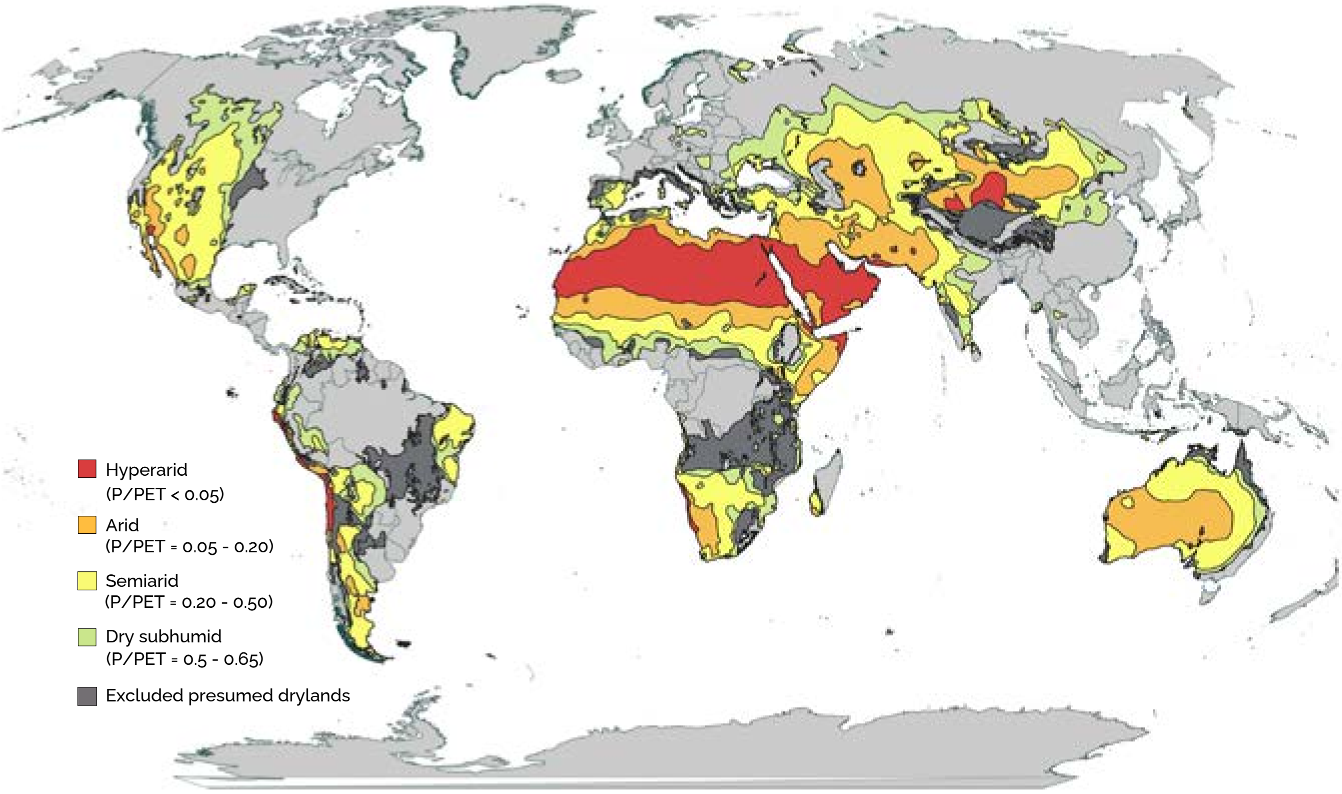
In focus: Dryland systems

This focus study highlights the issues facing dryland systems. It looks at their status and trends and their role in supporting food and nutrition security for billions of people, with attention to the drivers and pressures, risks and responses. Despite their importance, dry lands are at particular risk. They face complex challenges of population pressures, unsustainable farming methods, overgrazing and climate change, leading to land and soil degradation and water scarcity. The required responses and actions presented here aim to stop and reverse land degradation, and also to sustain and increase agricultural production, close yield gaps, capture atmospheric carbon in soils, and increase the overall resilience of communities and ecosystems throughout the dry lands. Many of these issues are not unique to dry lands, so references here complement those raised in the chapters of this report.

Status of dry lands

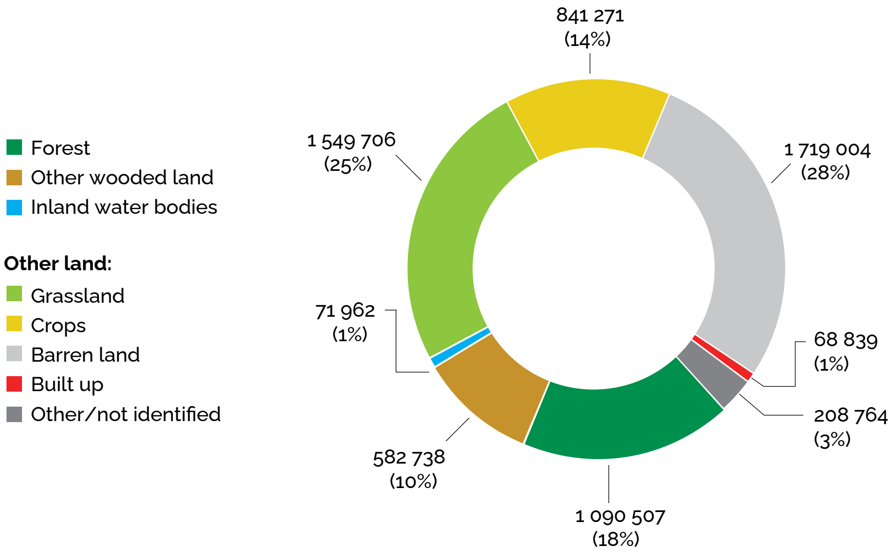
The United Nations defines dry lands as lands where the ratio of annual precipitation to mean annual potential evapotranspiration is less than 0.65 (United Nations, 1992). Dry lands occur on most continents (Map A). They cover more than 47 percent of the global land surface (6.1 billion ha), with the largest areas in Australia, China, Kazakhstan, the Russian Federation and the United States of America. Six countries have at least 99 percent of their area classified as dry and subhumid lands: Botswana, Burkina Faso, Iraq, Kazakhstan, the Republic of Moldova and Turkmenistan (Mortimore, 2009). A common misperception is that dry lands are “economic wastelands” with low productivity and are unworthy of investment. They account for about 44 percent of cultivated land and more than half of the world’s livestock (UNCCD, 2017). A global assessment (FAO, 2019) revealed that dry lands have diverse land cover and land use (Figure A). They include 27 percent of the world’s forests (1.1 billion ha), 25 percent of the grasslands and croplands and 28 percent of the barren lands (FAO, 2019). Some 16 percent of dry lands are the “hyper-arid zone”, comprising mainly desert sandy and rocky landscapes and hence not suitable for agricultural or forest production.

MAP A THE WORLD'S DRY LANDS



Source: **United Nations Environment Programme World Conservation Monitoring Centre**. 2007. *A spatial analysis approach to the global delineation of dryland areas of relevance to the CBD Programme of Work on Dry and Subhumid Lands*. Cambridge. https://www.unep-wcmc.org/system/dataset_file_fields/files/000/000/323/original/dryland_report_final_HR.pdf?1439378321. Dataset based on spatial analysis between WWF terrestrial ecoregions (WWF-US, 2004) and aridity zones (CRU/UEA; UNEPGRID, 1991). Dataset checked and refined to remove many gaps, overlaps and slivers (July 2014); based on **Miles, L., Newton, A.C., DeFries, R.S. Ravilious, C., May, I., Blyth, S., Kapos, V. & Gordon, J.E.** 2006. A global overview of the conservation status of tropical dry forests. *Journal of Biogeography*, 33: 491–505; and **Sörensen, L.** 2007. *A spatial analysis approach to the global delineation of dryland areas of relevance to the CBD Programme of Work on Dry and Subhumid Lands*. United Nations Environment Programme. www.unep-wcmc.org/system/dataset_file_fields/files/000/000/323/original/dryland_report_final_HR.pdf?1439378321. Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

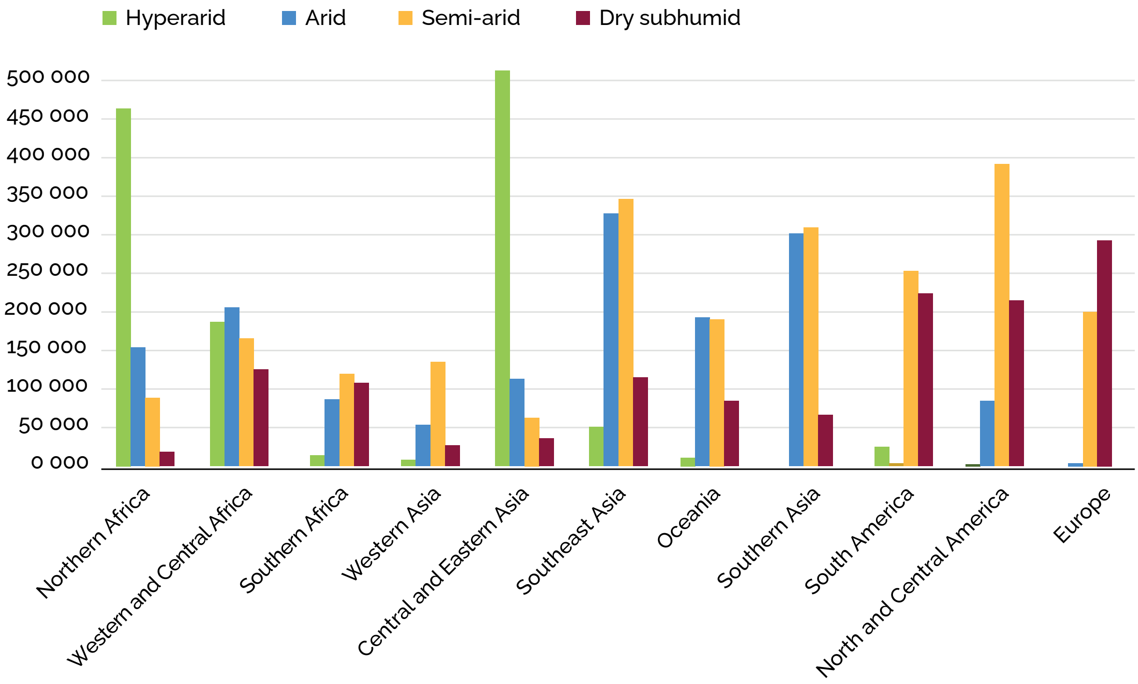
FIGURE A DISTRIBUTION OF LAND USES IN DRY LANDS (THOUSAND ha)



Source: **FAO**. 2019. *Trees, forests and land use in drylands: The first global assessment*. FAO Forestry Paper 184. Rome. www.fao.org/3/ca7148en/ca7148en.pdf

Dry lands are characterized by aridity (Figure B), yet they support rich biodiversity and are home to diverse human cultures, including some of the world's largest cities (UNCCD, 2017). Some 2.1 billion people live in dry lands, most of whom depend on forests, grasslands and agricultural areas for their livelihoods and food security, including income, food, shelter and fuelwood for cooking and heating. Rural communities in dry lands are often more impoverished than elsewhere, and the land is more vulnerable to human-induced degradation.

FIGURE B **DISTRIBUTION OF DRY LANDS AMONG ARIDITY ZONES (THOUSAND ha)**



Source: **FAO**. 2019. *Trees, forests and land use in drylands: The first global assessment*. FAO Forestry Paper 184. Rome. www.fao.org/3/ca7148en/ca7148en.pdf

Dry lands are often considered marginal lands (Box 4.3), yet this is in terms of mainstream crop production only. They are home to important rangeland and grazing systems and mixed crop–livestock systems that rely on short-season drought-resilient crops and receding floodwaters alongside wetlands and river plains. These have evolved to cope with aridity and drought and provide invaluable and resilient livelihood systems.

Despite their name, dry lands include globally important watersheds that supply clean water to millions of people, regulate water flows and mitigate the risks of floods and droughts. Some 15 percent of the world's major river basins fall within dry lands (Davies, 2017; Cowie *et al.*, 2018).

The highly variable and unpredictable weather events prevailing in dry lands, including droughts and floods, have shaped the strong resilience of dryland systems and driven species adaptation. Dryland capacity to capture and store water, minimize evaporation and increase transpiration determines how well they function. Examples include how termites in savannahs help maintain soil porosity and recycle organic matter in the driest and nutrient-poor soils (Davies, 2017). Bacteria in the guts of large-hoofed herbivores support soil fertility by digesting vegetation and providing manure that accelerates nutrient cycling on grass growth in the African Serengeti reserve and the Asian Steppes.

Flora and fauna in dry lands have developed a notable capacity for adapting to periods of water stress. Many of the grasses, shrubs and trees have acquired deep roots that enhance access to water. Their leaf form reduces evapotranspiration, and others can store water in their roots and leaves or rely on dormancy during the dry season. Animals minimize their water loss either through physiological adaptation or migration to regions that are more humid. Some plants rely on fires (a common hazard in dry lands) for their reproduction and growth (Davies, 2017).

Risks and emerging issues

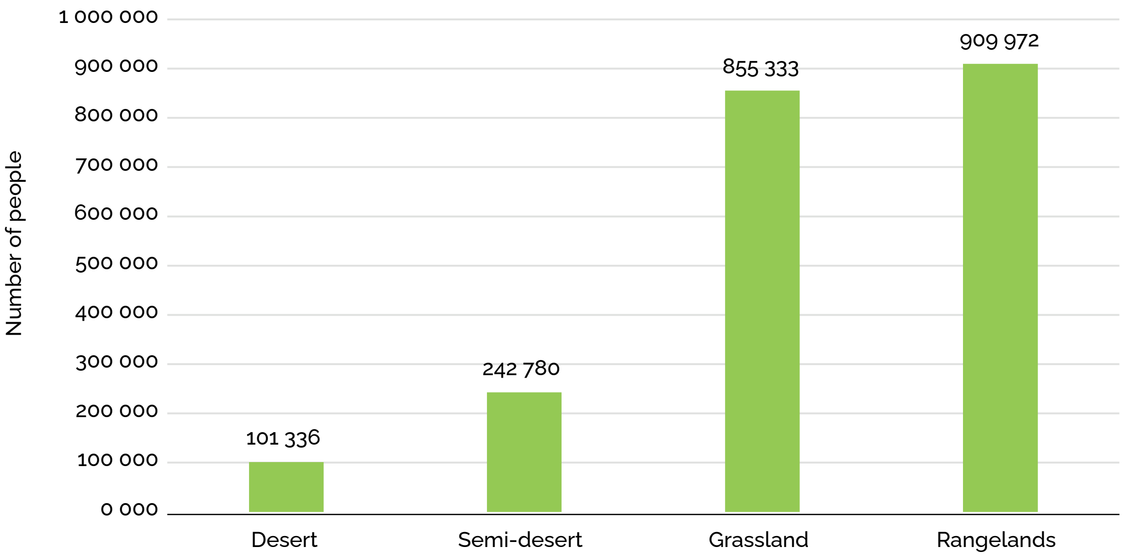
Dry lands face numerous challenges linked to population pressures, climate change, land degradation and desertification, overharvesting, overgrazing and mismanagement of land, soil and water resources.

Approximately one-third of global conservation biologically diverse and seriously threatened hotspots lie in dry lands (Davies, 2017). The biodiversity in dry lands is well adapted to the harsh conditions typified by inconsistent rainfall patterns. In many cases, high temperatures and dry lands have fragile environments that warrant priority attention to avoid irreversible loss of biological diversity.

Population growth

About one-third of the global population inhabits dry lands (UNCCD, 2022b), with 90 percent living in developing countries (Figure C). The population growth rate is about 18.5 percent, which is faster than in any other ecological zone. Population density decreases as aridity increases, ranging from 10 people/km^2 in deserts to 71 people/km^2 in dry subhumid rangeland areas (Lambin *et al.*, 2001; Mortimore, 2009), including in rural and urban areas. Indeed, some of the world's largest cities, such as Cairo, Los Angeles, Mexico City and New Delhi, are located in dry lands, and cities now occupy about 10 percent of dry lands. As urban growth continues, the land and water available for crop production will decrease with the likelihood of increasing environmental and socioeconomic stresses (UNCCD, 2022b).

FIGURE C TOTAL DRYLAND POPULATION PER ECOSYSTEM TYPE



Source: **United Nations Decade for Deserts and the Fight Against Desertification**. 2020. Why now? In: *United Nations 2010-2020 Decade for Deserts and the Fight Against Desertification*. www.un.org/en/events/desertification_decade/whynow.shtml

Population growth is driving land degradation and desertification, and is increasing demands on dryland ecosystems to produce food, fuel and fibre. This adds to the general decrease in area of agricultural land available and compounds the problems of reduced land productivity from declining soil fertility and water availability.

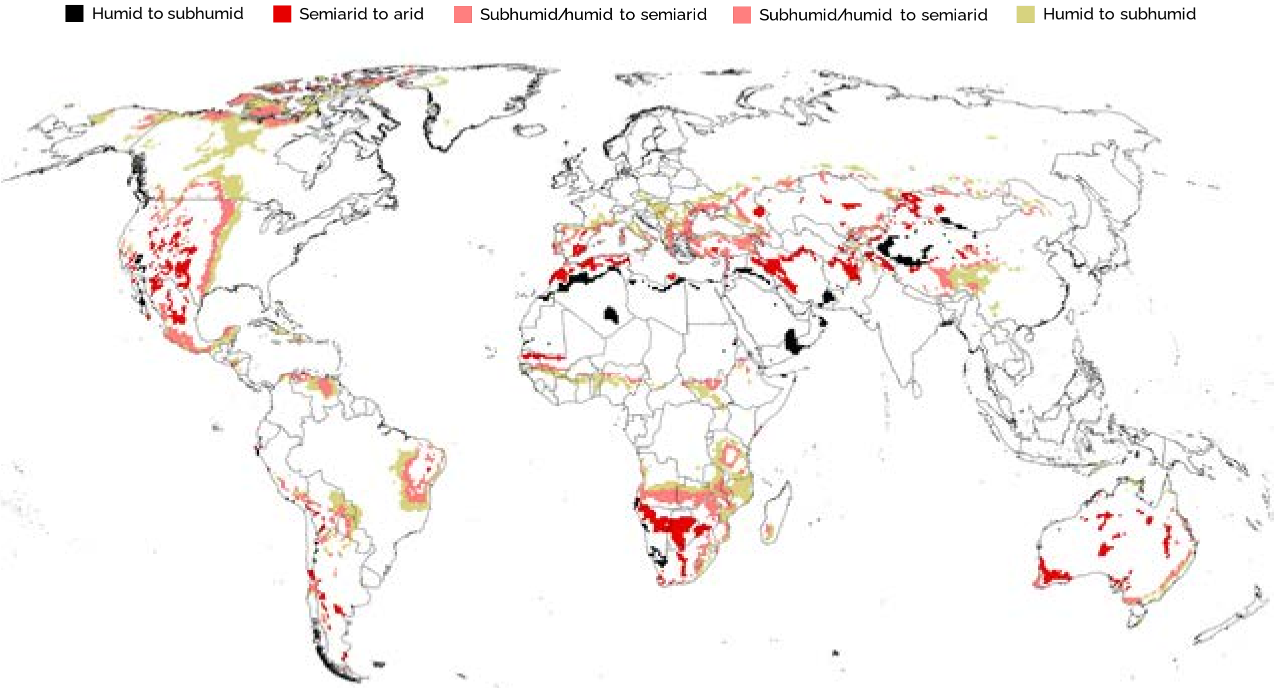
Climate change

Societies have adapted and prospered in dry lands for centuries by implementing a multitude of SLM methods. Many can no longer cope with the speed of change, especially changes in the climate (Mortimore, 2009). Changing land use and practices have led to land degradation and desertification, water shortages and significant losses in environmental and ecosystem services, as in the extreme case of the Aral Sea illustrated in Box A.

Dry lands are vulnerable to climatic variability and change, mainly due to rainfall scarcity, where small changes can have significant impacts. The drying trend in the 1950s is attributed to a 10 percent increase in global dryland areas, mainly in East Asia, the Sahel in West Africa, Southern Africa and eastern Australia. Recent research indicates that the widespread drying trend over the global land surface from 1950 to 2015 can be partially attributed to global warming. It is estimated that dry areas increased by about 10.4 percent of global land area between 1950 and 2008. But large areas with a weak wetting trend still exist, especially at high latitudes in the northern hemisphere. The increasing magnitude and spatial extent of aridity affect dryland ecosystems' functional performance (Huang *et al.*, 2017).

Model climate projections illustrate that drying is much more widespread than wetting in the tropics, subtropics and mid-latitudes, because of increases in evapotranspiration (Map B). Observations and model simulations have also indicated that rainfall and temperature changes play an important role as the climate shifts (Huang *et al.*, 2017). The frequency and probability of climatic variables, such as precipitation and temperature extremes, and their long-term historical trends must be monitored and evaluated at local scales to help identify suitable types of agricultural practice and crop cultivars. These measures are essential to mitigate the impacts of climate change and for sustainable development.

MAP B **ARIDITY PROJECTIONS – DRIER TYPES**



Source: **European Commission Joint Research Centre**. 2018. Aridity projections – drier types. In: *World atlas of desertification*. https://wad.jrc.ec.europa.eu/aridityprojections. Modified to comply with **UN**. 2020. *Map of the World*. https://www.un.org/geospatial/file/3420

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

BOX A
THE ARAL SEA: IMPACTS OF LAND DEGRADATION ON ECOSYSTEMS AND HUMAN HEALTH

One of the best examples of environmental degradation with multiple impacts on ecosystems and human health is the Aral Sea. This is the site of one of the most significant ecological disasters in the world, covering the five states of Central Asia and affecting almost 50 million people. In the 1900s, the Aral Sea was the world's fourth-largest inland lake and an important ecosystem providing natural resources to many communities with good access to fishing, water and land.

The water level and salinity of the Aral Sea remained stable by inflows of freshwater from two rivers: the Syr Darya in the east and the Amu Darya in the south. After 1918, policymakers from the former Soviet Union decided to divert the rivers to irrigate cotton for export. Millions of people from the region were employed, and the production area was raised from 2.5 million ha to 6.25 million ha within two decades.

In the early 1960s, the Aral Sea began shrinking, and an environmental crisis ensued. It had lost half of its surface area by 2005. Impacts on the ecosystem within the region included a collapsed fishing industry, with 60 thousand fishing-related jobs lost, and dust storms from the dried sea bed carrying chemicals and pesticides originating from the intensive monoculture agriculture occurring along the two rivers leading to toxic air and water pollution (Akramkhanov *et al.*, 2021).

Moreover, many health impacts emerged: cancers, respiratory diseases, anaemia, miscarriages, maternal and infant mortality, maternal milk toxicity, kidney and liver diseases, and infectious diseases. The average life expectancy declined from 64 years to 51 years, and almost half of the population reported emotional stress. Furthermore, people were forced to migrate due to damaged livelihoods, health and well-being and increasing unfavourable living conditions. Some remedial measures are under way with good results, but a large area of the Aral Sea is still disappearing.

The main revival in the North Aral Sea ecosystem, realized between 2011 and 2020, followed completion of the Kokaral Dam project with the assistance of the World Bank. This made significant improvements to the Syr Darya River and increased water flow into the Aral Sea.

The second phase of the Kokaral Dam project is anticipated to bring further improvements in employment and poverty levels, health of locals, environmental quality and overall living standards.

Source: **Aladin, N., Chida, T., Cretaux, J.F., Ermakhanov, Z., Jollibekov, B., Karimov, B. & Toman, M.** 2017. Current status of Lake Aral – challenges and future opportunities. Lake ecosystem health and its resilience: Diversity and risks of extinction. *Proceedings of the 16th World Lake Conference*, pp. 448–457. www.zin.ru/labs/brackish/presentations/Current_status_of_Lake_Aral_%E2%80%93_challenges_and_future_opportunities.pdf

Overharvesting and natural resources mismanagement

Mismanagement of natural resources includes transforming rangelands and other silvopastoral systems into cultivated croplands, inappropriate cultivation and grazing practices, unsustainable allocation of water resources and wasteful water use, introduction of non-native plants, overharvesting of fuelwood and wild species, and excessive use of chemical fertilizers for artificial enrichment of grassland fertility (UN DPA and UNEP, 2015). Such land-use changes and inappropriate practices have led to widespread human-induced degradation of dryland ecosystems, especially forests, that affects biodiversity, soil fertility and water availability, and consequently, the livelihoods of local communities (Mortimore, 2009).

Natural regeneration of soils and vegetation cover in arid areas takes five to ten times longer than in areas with more regular rainfall. Desertification hotspots, identified by a significant decline in vegetation productivity from the 1980s to the 2000s, included 9.2 percent of dry lands and affected 500 million people in 2015 (Mirzabaev *et al.*, 2019). Dry lands cover one-third of the Mediterranean region, where poor land management, deforestation, overgrazing, natural hazards and resulting desertification threaten 30 percent of the semi-arid lands (Zdruli, 2014; Ziadat *et al.*, 2022).

Traditional biomass used for cooking and heating by some 2.8 billion people in non-OECD countries (38 percent of the global population), accounts for more than half of all bioenergy used worldwide and contributes to land degradation, losses in biodiversity and reduced ecosystem services (REN21, 2018) and 1.9–2.3 percent of global GHG emissions. In hotspots in East Africa and South Asia, land degradation and deforestation are mainly driven through reliance on open fires, inefficient stoves and overharvesting fuelwood (Bailis *et al.*, 2015). Excessive removal and use of agricultural wastes and residues in South and Southeast Asia are due to woody biomass scarcity. Overharvesting wood for charcoal is fuelling severe deforestation in sub-Saharan Africa (five times the world average).

Responding to the risks

Like in other agroclimatic zones, simple and fragmented responses, such as planting trees, are insufficient to resolve dryland challenges. A wide range of options is needed to avoid, reduce and reverse degradation across dryland areas. Many of the actions required for SLM also contribute to climate change adaptation and mitigation, with further sustainable development cobenefits in poverty alleviation and food security (Mirzabaev *et al.*, 2019). Holistic SLM approaches, planned at the landscape level and tailored to specific socioeconomic and environmental conditions, are needed to stop and reverse land degradation, close the yield gaps in agricultural production, capture atmospheric carbon in soils, and increase the overall resilience of communities and ecosystems throughout the dry lands (UNCCD, 2017). These approaches include soil- and water-conservation measures and sustainable crop production, livestock-raising practices, and land-use and food system diversification through adapted species and varieties, agroforestry and agropastoral systems, and associated marketing and value chain support.

At an international level, global frameworks recognize and understand the urgent need for action. However, responses are essential at the national and subnational levels to develop policies and institutional structures founded on integrated, intersectoral land-use planning and SLM. At the local community, landscape and municipal levels, responses are to implement technical options such as integrated crop–soil–water management and grazing and fire management that consider socioeconomic circumstances.

Analysing the interlinkages between land degradation, resource base management and food security in the Near East and North Africa region offers mitigation and remediation options. These include knowledge management and sharing, establishment of a regional platform to facilitate dialogue, public and private investment opportunities, provision of tools to scale out sustainable land and water management options, and creation of a conducive enabling environment supported by policies and strategies. This provides policy and decision-makers with priority actions and options to enhance productivity, and combat land degradation to improve food security in the Near East and North Africa region (Ziadat *et al.*, 2022).

The CBD programme of work on dry lands and subhumid lands, initiated in 2000, focuses on the biodiversity of dryland, Mediterranean, arid, semi-arid, grassland and savannah ecosystems. It applies an ecosystem approach with attention to water resources management and climate change. There is interaction with UNCCD for synergy and to avoid duplication of efforts. Activities are carried out through capacity building, particularly at national and local levels, establishing an international network of designated demonstration sites and case studies on successful management and partnerships among relevant stakeholders.

The FAO Dryland Restoration Initiative Platform aims to enhance measurement of restoration efforts and country reporting, project analysis, sharing of best practices and successful approaches, and improvement of efforts of practitioners and decision-makers to address challenges and scaling out. This builds from the Rome Promise on Monitoring and Assessing Drylands for Sustainable Management and Restoration, agreed by FAO and partners in 2015, as a basis for informing sustainable management and restoration (Box B).

BOX B

ROME PROMISE ON MONITORING AND ASSESSMENT OF DRYLANDS FOR SUSTAINABLE MANAGEMENT AND RESTORATION

In 2014, the FAO Committee on Forestry called for action and investment in dryland assessment, monitoring, sustainable management and restoration. It requested FAO to undertake a global assessment of the extent and status of dryland forests, rangelands and agro-silvopastoral systems to prioritize and target the investments needed for dryland restoration and management.

A workshop in 2015 called for developing more comprehensive and cost-effective methods, including using existing methods and tools as building blocks and developing new methods integrating remote sensing and local participation. Through the Rome Promise, participants agreed to: (i) form an open-ended collaborative network or community of practice to advance monitoring and assessment of dry lands, including an understanding of their users; (ii) communicate the value and importance of dryland monitoring to relevant stakeholders, including policymakers and resource partners; and (iii) develop a dynamic road map for collaborative action.

The first FAO global assessment of dry lands was among the initial steps in implementing the Rome Promise, building a robust baseline for future monitoring, which will support countries in their efforts to develop needed strategies and identify appropriate investments for sustainable management of dry lands. Results demonstrate that dry lands are productive landscapes with considerable economic potential and environmental value.

This is a step towards regular monitoring of changes in dry landscapes, which is vital to evaluate the impact of climate change, human activities and the results of adaptation and mitigation measures and progress towards meeting regional LDN targets. The process should include assessing the effects of different governance frameworks, policies and legislation related to land use for more effective support in improving the livelihoods and climate change resilience of dryland populations.

Source: **FAO**. 2015. *Dryland monitoring week 2015: The Rome Promise on Monitoring and Assessment of Drylands for Sustainable Management and Restoration*. Rome. www.fao.org/3/a-i5600e.pdf

The IUCN Global Drylands Initiative[12] supports adapted ecological assessments for targeted monitoring of dryland conditions and trends, strengthening sustainable land and ecosystem management governance. It established an agreement with UNCCD in 2015 to support progress towards policies and programmes that deliver LDN by applying NbSs at national and subnational levels.

The Consultative Group on International Agricultural Research Program on Dryland Systems was a global agricultural research partnership from 2007 to 2017 to reduce the vulnerability of poor, marginalized, dryland communities, to sustainably intensify agriculture for improved food security and income, and to develop more equitable and sustainable management of land and natural resources. It targeted 1.6 million smallholders in dry lands in the Sahel and dryland savannahs of West Africa, North Africa, East and Southern Africa, West Asia, South Asia and Central Asia. Research efforts in dry lands continue through restructured global agrifood systems research programmes, notably Water, Land and Ecosystems, Climate Change Agriculture and Food Security and specific-crop-based programmes (CGIAR, 2022).

Implementing land degradation neutrality

Public policy response

Initially, the LDN concept targeted dry lands as the most vulnerable to land degradation. However, during the twelfth session of the UNCCD Conference of the Parties in 2015, LDN was adopted as a global concept. In 2015, it became SDG target 15.3, which states that the global community shall "By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world" (United Nations, 2015).

Pursuing LDN will be essential to achieving the SDGs related to food security, environmental protection and sustainable natural resources (Gilbey, 2018). Dry lands can greatly benefit from this global drive to achieve the LDN target of "no net loss" through a dual-pronged approach to avoid or reduce land degradation, combined with measures to reverse already existing desertification and land degradation via restoration, such that losses are balanced by gains (Safriel, 2017).

Successful SLM and achieving LDN targets in each country must be founded on integrated and intersectoral land-use planning. Integrated land-use planning can reconcile LDN and other targets through a policy process that leads to desirable land use (UNCCD, 2019).

Inclusive and responsible land governance is required to ensure the development of effective policy, legal and organizational frameworks that secure land tenure and foster sustainability, and improve livelihoods and well-being. This should include governance over water resources, agricultural land, rangeland, forestland and other uses of fragile dryland resources such as mining, urban expansion and tourism. Ensuring that dry lands are under secure tenure, with recognized and safeguarded rights to use and manage land, provides land managers with the freedom and legitimacy to implement SLM strategies (Davies, 2017). Policies that promote land tenure security for all legitimate land tenure rights should be designed to support increasing agricultural productivity and incomes, including sedentary and nomadic livestock production, as well as minimize random appropriation of land, for example, for large-scale commercial farms, especially in communally managed lands.

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[12] A comprehensive list of regional and national programmes on dryland related issues is available (drynet, 2022) .

There is a need to improve understanding of formal and informal legitimate land tenure rights and develop innovative solutions that bring together statutory law and customary rights or practices. In many countries, land tenure and planning processes are administered locally to enable greater participation in local-level decision-making and to enable more respect for local rights and responsibilities. Strong local institutions are a vital interface between statutory and customary legal systems, and are key to combining improved local governance and access to markets and other services (UNCCD, 2019).

Policies to improve access to markets help farmers and livestock producers to increase profits and encourage the adoption of SLM practices. Policies that promote payments for ecosystem services (PES) or other incentive measures for investing in SLM provide incentives to restore degraded land or increase ecosystem services (Garrett and Neves, 2016). However, individual landowners usually underinvest in SLM as they are unable to reap the full benefits. Incentives for ecosystem services provide a mechanism to transfer some of these benefits to landowners and stimulate further investment in SLM (UNCCD, 2019). Effective incentives for ecosystem services/PES schemes (FAO, 2022i) depend on land tenure security and appropriate policy design that considers specific local conditions, with equity and justice in distributing the benefits. Decentralized approaches that provide local communities with a larger role in the decision-making process can also improve the impact of PES (Mirzabaev *et al.*, 2019).

Promoting renewable energy resources can help reduce deforestation by populations in developing countries dependent on traditional biomass, especially fuelwood and charcoal, for their energy needs.

Policies that empower women and secure their land rights also enhance SLM. They target changes in customary norms and practices that undervalue women and efforts to safeguard women's equitable access to knowledge, support services, markets and resources. Policies that promote education and capacity building and expand access to information and agricultural services with attention to gender tend to accelerate the adoption of SLM practices

The private sector's role

The increase of large- and medium-scale commercial farms (see Chapter 2) with stronger bonds to an integrated value chain has amplified the role of the private sector and corporate organizations in land management and agricultural production (UNCCD, 2019; Debonne *et al.*, 2021). Corporate investments are channelled towards large-scale land acquisition. There are concerns about the potentially negative impacts on the environment, national economies, social welfare and human right to land tenure (Baker-Smith and Attila, 2016). Smaller-scale land transfers also lead to unplanned and unregulated changes in land use (Davies, 2017). Such investment and land governance arrangements can threaten global and regional LDN targets when using highly intensive and unsustainable modes of production. Private sector involvement must consider LDN initiatives to ensure progress and success at scale in implementing SLM and land restoration. Greater attention is needed to ensure the right investors are attracted to suitable investments and respect the principles for agricultural investments (CFS, 2014), building on VGGT through a consensual approach, respecting rights, livelihoods and the environment (see Chapter 5).

Although there are concerns over private sector actions, investment is also flowing from the business sector to support land restoration and funding from national governments, international organizations and local communities. More corporations are moving towards SLM practices, using agricultural training, ecocertification and other instruments (FAO, 2015). Although welcome, investments are far short of what is needed. Governments must increase efforts to mobilize private investment that supports existing land users to improve their land management and develop public land-use plans effective at a landscape level. This can support integrated crop farming, grazing, forest management, wildlife management and wetlands protection (Davies, 2017).

Making dry lands more attractive for private sector investment can be achieved through effective policies, regulation, incentives and technical measures. Developing innovative and productive partnerships between the private sector and local communities can also help create an environment that fosters private sector investment (FAO, 2015). Non-governmental organizations (NGOs) also have an important role in accessing innovative financing sources seeking attractive and diverse returns. An example addresses the gap in national and international forest restoration financing and translating investments into practical action that safeguards the ecosystem and people's livelihoods (Gutierrez and Keijzer, 2015).

Examples of private sector participation in LDN initiatives include the Great Green Wall for the Sahara and Sahel Initiative, involving working with national governments, civil society and development organizations under pan-African coordination to halt land degradation. The UNCCD Global Mechanism is supporting the development of sustainable value chains. It works with the private sector in the Sahel and guarantees dryland products, leading to thousands of new land-based jobs for rural women in the region.

Smallholder farmers are also active members of the private sector, and their small-scale investments are central to achieving sustainable farming practices. Farmers are the largest investors in developing country agriculture and their capacity to invest needs to be strengthened (CFS, 2014). Dryland farmers and pastoralists invest in many ways on a small scale, but this is multiplied thousands of times across a landscape. These investments can be difficult to evaluate, but they represent a diverse financial, labour and social capital portfolio that generates a wide array of revenues in food, insurance and ecosystem services (Davies, 2017). A particular effort is needed to mobilize local entrepreneurs and develop small- and medium-sized enterprises on farms and along the supply chains to strengthen and diversify rural livelihoods (Davies, 2017).

Local-level sustainable land management actions

Proven nature-based approaches at the landscape and farm levels exist that encourage sustainable agriculture, enhance ecosystem services, decrease land degradation and increase resilience among vulnerable communities, some of which are outlined below.

Integrated crop–soil–water management

Integrated cropland management is a long-established and continuing practice in dry lands (Mirzabaev *et al.*, 2019). Actions include diversifying crop species and drought-resilient and ecologically appropriate plants, reducing or avoiding tillage, maintaining healthy vegetation and mulch cover, applying organic compost and fertilizers, and adopting water-conserving irrigation practices.

Changing agronomic practices, such as adopting intercropping and relay cropping, using drought-tolerant species and varieties, and minimizing tillage, help to reduce soil loss, maintain soil cover and improve soil health. Different forms of agroforestry and shelterbelts help to reduce erosion, improve soil conditions and maintain SOC (FAO, 2013b).

Rainwater harvesting is receiving increasing attention for bridging short dry spells, and thus decreasing risk in rainfed agriculture (Wani, Rockström and Oweis, 2008). However, such techniques generally do not protect crops from the long dry spells that lead to crop failure. A global assessment suggested that rainwater harvesting increased crop production by an average of 78 percent. Although care is needed to avoid erosion and impacts downstream, capturing runoff may reduce the amount of water available to those farmers who traditionally rely on the flow downstream.

Sustainable rangeland management

Rangelands account for 69 percent of dry lands or some 4.2 billion ha. In sub-Saharan Africa, rangelands are estimated to feed over 55 percent of Africa's livestock and provide a major source of income to 268 million pastoralists and agropastoralists. However, rangelands face complex challenges of degradation, mobility, conflict, access to markets and so forth.

The report *Sustainable rangeland management in sub-Saharan Africa: Guidelines to good practice* (Liniger and Studer, 2019) was prepared for the TerrAfrica partnership and documents 30 case studies. They cover a diverse range of practices and systems from small-scale settled pasture to bounded rangelands with wildlife management and pastoral rangelands (Box C). The research and experiences throughout the region highlight the importance of integrated land and water management.

BOX C
SUSTAINABLE LAND MANAGEMENT PRACTICES IN RANGELANDS IN SUB-SAHARAN AFRICA

The following practices were identified:

Enabled mobility, including improved access, involves practices that assist grazing over large/diverse areas to seek forage and water using traditional knowledge and innovations and new technologies (e.g. satellite image analysis and early warning systems at large scales).

Controlled grazing, including seasonal grazing, involves enclosures, physical or social fencing, rotations, grazing reserves (fodder banks), regulating grazing and mobility.

Range improvement involves management of fire, grazing quality, soil fertility and moisture.

Supplementary feeding for increased milk and meat production and as a life-saving strategy during an emergency such as drought may involve fodder collection within or outside the rangeland areas including production or buying of processed or compound feed.

Infrastructure improvement includes water points and macrocatchments, floodwater spreading, soil- and water-conservation trenches, protecting drinking water quality, livestock corridors, access roads and transport routes of animals and feed.

Source: **Liniger, H.P. & Studer, M.** 2019. *Sustainable rangeland management in sub-Saharan Africa: Guidelines to good practice.* TerrAfrica, World Bank, World Overview of Conservation Approaches and Technologies, World Bank Group and Centre for Development and Environment and University of Bern. www.wocat.net/library/media/174

Sustainable grazing approaches and revegetation increase rangeland productivity. However, they require pastoralists to carefully manage rangelands to avoid overgrazing and fire by changing frequency and intensity of use. Controlled fire is an essential component of rangeland management. It encourages fresh growth of pastures and removes waning and inedible forage, exotic weeds and woody species that harbour parasites (Davies, 2017). Grazing and fire regimes determine the relative abundance of trees versus grasses and the health of species richness and basal cover within grasslands, savannah and woodland areas. This affects levels of soil erosion, soil nutrients, secondary production and additional ecosystem services. Although fire has a lower impact on SOC and soil nutrients than grazing, elevated fire frequency does increase SOC and nitrogen loss (Mirzabaev *et al.*, 2019). A context-specific evaluation of grazing and fire influences on particular species ensures the persistence of target species over time.

Proactive management to prevent land degradation by changing grazing systems or clearing bush encroachment can be more cost-effective than restoring already degraded land. Drought forecasting and contingency planning can also help to reduce land degradation. Intensive bush encroachment is a form of desertification, but some levels of encroachment may lead to a net increase in ecosystem services, preserve fodder production, and increase wood production and associated products (Mirzabaev *et al.*, 2019).

Reviving traditional Indigenous practices

Indigenous and local knowledge can enhance the success of SLM and address desertification and land degradation. Building Indigenous knowledge among dryland communities and combining it with modern scientific knowledge and methods can bring significant benefits.

FAO global guidelines for restoring degraded forests and landscapes in dry lands are starting points. Such guidance can help to adapt and develop, rather than replace, local communities' tested management strategies and enhance knowledge on how to adapt to changing and unpredictable climates (Mortimore, 2009).

Other practices in dry lands

Dune stabilization techniques and building palisades to prevent the movement of sand and reduce sand deposits on infrastructure can reduce SDSs. Calcium bentonite or silica gel can stabilize mobile sand, and permanent plant cover using pasture species can improve grazing at the same time. When dunes are stabilized, suitable woody perennials can be planted to stabilize the soils (Mirzabaev *et al.*, 2019).

Halophytes or salt-tolerant crops offer an alternative with high economic potential on land where salinity is a problem. The use of saline land and water in biosaline agricultural production may provide an attractive alternative. The biomass can be useful for forage, food, feed, essential oils, timber, fuelwood and biofuel, and can enhance terrestrial carbon stocks (ICBA, 2021).

Catalysing sustainable land management adoption

As part of a land and water planning process, socioeconomic and policy responses can be a catalyst for adopting SLM practices that interact to achieve LDN. Collective community action for natural resources management at territorial level supported by reliable networks and mutual trust and cooperation in and among communities can also favour SLM practices. Encouraging farmers and pastoralists to adopt SLM practices can be more successful than introducing external technologies. Peer-to-peer mutual learning and sharing expertise and experience can positively contribute to better technology adoption (Mirzabaev *et al.*, 2019).

Global evidence based on the past 30 years suggests that USD 1 invested in restoring degraded lands yields USD 3–6 in social returns, including ecosystem services. Despite these returns, the take-up of SLM practices remains relatively low, as many social benefits are intangible. Economic and institutional barriers also exist that seriously limit SLM strategies.

Agricultural communities in dry lands also depend on diversification into non-farm employment, including through migration and improved marketing and alternative incomes. Such activities can improve livelihoods and provide the finance for investment in SLM (Mirzabaev *et al.*, 2019). Wildlife management and tourism are opportunities for the conservation and sustainable use of biodiversity and income generation. Investment in infrastructure may be needed to improve access to water resources (surface and groundwater) and markets (Liniger and Studer, 2019).

Looking forward

Enhancing land and water productivity, reversing land degradation, and coping with water scarcity and drought are all crucial for achieving food security, sustainable agriculture and SDGs in dry lands. Technical options for SLM provide promising solutions for various land users to reduce and reverse degradation and enhance productivity and livelihoods through improved water, land and soil resources, and ecosystem management. Options are also available to advance land restoration in high-potential areas.

However, participatory resources planning at community level supported by technical services is also needed to identify potential practices to suit the prevailing socioeconomic and biophysical conditions and adapt to climate change, coupled with a favourable enabling environment through policy support and financial/investment mechanisms, including private sector partnerships, to enhance uptake and continuous adaptation of improved practices and strengthen preparedness to current and future challenges.

Finally, land tenure security, including rights of access to water, through improved governance and land administration is also a critical part of the enabling environment, as a lack of clear land rights hinders all public and private investments in sustainable water, land and soil management, as elaborated in Chapters 2 and 5.

References

Akramkhanov, A., Strohmeier, S., Yigezu, Y.A., Haddad, M., Smeets, T., Sterk, G., Zucca, C. ***et al.*** 2021. *The value of landscape restoration in Uzbekistan to reduce sand and dust storms from the Aral seabed*. Washington, DC, World Bank. https://openknowledge.worldbank.org/handle/10986/36461?locale-attribute=fr

Aksoy, E., Arsov, S., Mincev, I. & Fang, C. 2020. *Agro-ecological atlas of the Republic of North Macedonia*. Rome, FAO. www.fao.org/publications/card/en/c/CA7519EN

Bailis, R., Drigo, R., Ghilardi, A. & Masera, O. 2015. The carbon footprint of traditional woodfuels. *Nature Climate Change*, 5: 266–272.

Baker-Smith, K. & Attila, S.B.M. 2016. *What is land grabbing? A critical review of existing definitions*. Romania, Eco Ruralis. www.farmlandgrab.org/uploads/attachment/EcoRuralis_WhatIsLand-Grabbing_2016.pdf

Bayraktarov, E., Saunders, M.I., Abdullah, S., Mills, M., Beher, J., Possingham, H.P., Mumby, P.J. & Lovelock, C.E. 2015. The cost and feasibility of marine coastal restoration. *Ecological Applications*, 26(4): 1055–1074.

Bindoff, N.L., Stott, P.A., AchutaRao, K.M., Allen, M.R., Gillett, N., Gutzler, D., Hansingo, K. ***et al.*** 2013. Detection and attribution of climate change: From global to regional – Supplementary material. In: T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels *et al*., eds. *Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Geneva, Intergovernmental Panel on Climate Change. www.ipcc.ch/site/assets/uploads/2018/07/WGI_AR5__Chap.10__SM.pdf

Borrelli, P., Robinson, D.A., Panagos, P., Lugato, E., Yang, J.E., Alewell, C., Wuepper, D., Montanarella, L. & Ballabio, C. 2020. Land use and climate change impacts on global soil erosion by water (2015-2070). *Proceedings of the National Academy of Sciences of the United States of America*, 117(36): 21994–22001.

Bourgeois, R., Ekboir, J., Sette, C. & Egal, C. 2012. The state of foresight in food and agriculture and the roads toward improvement. Conference presentation at Second Global Conference on Agricultural Research for Development, 2012. https://agritrop.cirad.fr/570486/1/document_570486.pdf

CFS (Committee on World Food Security). 2014. *Principles for responsible investment in agriculture and food systems*. Rome, FAO. www.fao.org/3/au866e/au866e.pdf

CGIAR. 2022. Research portfolio 2017–2021. In: *CGIAR*. www.cgiar.org/research/research-portfolio

Cohen-Shacham, E., Walters, G., Janzen, C. & Maginnis, S., eds. 2016. *Nature-based solutions to address global societal challenges*. Gland, International Union for Conservation of Nature. https://portals.iucn.org/library/sites/library/files/documents/2016-036.pdf

Cowie, A. & Orr, B. 2017. *The scientific conceptual framework for land degradation neutrality*. Bonn, United Nations Convention to Combat Desertification. www.unccd.int/sites/default/files/relevant-links/2017-09/CST13_Item2a_Cowie_Orr_LDN conceptual framework_0.pdf

Cowie, A.L., Orr, B.J., Castillo Sanchez, V.M., Chasek, P., Crossman, N.D., Erlewein, A., Louwagie, G. *et al.* 2018. Land in balance: The scientific conceptual framework for land degradation neutrality. *Environmental Science & Policy*, 79: 25–35.

Danube Interreg Programme. 2022. Drought Watch. https://droughtwatch.eu/

Das, S., Duraisamy, V., Yaduvansh, Ia., Shinde, A., Ankita, Y., Solanky, V., D'Souza, M., Jatav, Y. & Garg, R. 2020. *Economic valuation of reducing land degradation through watershed development in east Madhya Pradesh under risks of climate extremes*. Pune, Watershed Organisation Trust. www.eld-initiative.org/fileadmin/pdf/WOTR_2020_ELD_Madhya_Pradesh_Report_final.pdf

Davies, J. 2017. *The land in drylands: Thriving in uncertainty through diversity*. Global Land Outlook Working Paper. Bonn, United Nations Convention to Combat Desertification. https://knowledge.unccd.int/publication/land-drylands-thriving-uncertainty-through-diversity

Debonne, N., van Vliet, J., Metternicht, G. & Verburg, P. 2021. Agency shifts in agricultural land governance and their implications for land degradation neutrality. *Global Environmental Change*, 66: 102221.

drynet. 2022. Useful links. In: *drynet: A global initiative, giving future to drylands*. https://dry-net.org/about-us/useful-links

FAO. 1993. *Guidelines for land-use planning*. FAO Development Series 1. Rome. www.fao.org/3/t0715e/t0715e00.htm

FAO. 2013a. *Land degradation assessment in drylands: Methodology and results*. Rome. www.fao.org/3/a-i3241e.pdf

FAO. 2013b. *Climate-smart agriculture source book*. Rome. www.fao.org/3/i3325e/i3325e.pdf

FAO. 2015. *Natural capital impacts in agriculture: Supporting better business decision-making*. Rome. www.fao.org/fileadmin/templates/nr/sustainability_pathways/docs/2015-11-19_Natural_Capital_Impacts_in_Agriculture-Supporting_Better_Business_Descision-Making_v8.pdf

FAO. 2016a. *Dryland Restoration Initiative Platform*. Rome. www.fao.org/3/i6509e/i6509e.pdf

FAO. 2016b. *Building Africa's great green wall: Restoring degraded drylands for stronger and more resilient communities*. Rome. www.fao.org/3/i6476e/i6476e.pdf

FAO. 2016c. *Drought characteristics and management in the Caribbean*. FAO Water Reports 42. Rome. www.fao.org/3/i5695e/i5695e.pdf

FAO. 2018a. *Decision support for mainstreaming and scaling up of sustainable land management (DS-SLM)*. Rome. www.wocat.net/documents/462/DS-SLM_fact_sheet_pr00ihQ.pdf

FAO. 2018b. *Drought characteristics and management in North Africa and the Near East*. FAO Water Reports 45. Rome. www.fao.org/3/CA0034EN/ca0034en.pdf

FAO. 2019. *Trees, forests and land use in drylands: The first global assessment.* FAO Forestry Paper 184. Rome. www.fao.org/3/ca7148en/ca7148en.pdf

FAO. 2020a. *Strengthening civic spaces in spatial planning processes*. Governance of Tenure Technical Guide 12. Rome. https://doi.org/10.4060/cb0422en

FAO. 2020b. *The state of food and agriculture 2020. Overcoming water challenges in agriculture.* Rome. https://doi.org/10.4060/cb1447en

FAO. 2021. FAO strategic framework. In: *Office of Strategy, Programme and Budget (OSP)*. Rome. www.fao.org/about/strategy-programme-budget/strategic-framework/en

FAO. 2022a. Toolkit for the application of Green Negotiated Territorial Development (GreeNTD). In: *Land & Water*. Rome. www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/category/details/en/c/1047635

FAO. 2022b. Participatory and Negotiated Territorial Development (PNTD). In: *Land & Water*. Rome. www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/category/details/en/c/1043145

FAO. 2022c. *Sustainable land management*. Rome. www.fao.org/3/i4593e/i4593e.pdf

FAO. 2022d. Land Resources Information Management Systems (LRIMS). In: *Geospatial information for sustainable food systems*. Rome. www.fao.org/geospatial/resources/tools/lrims/en

FAO. 2022e. The Hand-In-Hand Initiative Data Platform. In: *FAO*. Rome. https://data.apps.fao.org

FAO. 2022f. The state of the world's land and water resources for food and agriculture 2021: Systems at breaking point. In: *Land & Water*. Rome. www.fao.org/land-water/solaw2021/en

FAO. 2022g. Projects. In: *Geospatial information for sustainable food systems*. Rome. https://www.fao.org/geospatial/projects/en

FAO. 2022h. Sustainable Forest Management (SFM) toolbox. In: *FAO*. Rome. www.fao.org/sustainable-forest-management/toolbox/en

FAO. 2022i. Incentives for ecosystem services. In: *Land & Water*. Rome. www.fao.org/land-water/overview/integrated-landscape-management/incentives-for-ecosystem-services/en

FAO & GEF (Global Environment Facility). 2022. Strengthening Agro-climatic Monitoring and Information System (SAMIS). In: *FAO*. Rome. www.fao.org/in-action/samis/en

FAO & IIASA (International Institute for Applied Systems Analysis). 2021. Global Agro-Ecological Zoning version 4 (GAEZ v4). In: *FAO*. Rome. www.fao.org/gaez/en

FAO, IIASA, International Soil Reference and Information Centre, Institute of Soil Science – Chinese Academy of Sciences & JRC. 2012. *Harmonized world soil database (version 1.2)*. https://esdac.jrc.ec.europa.eu/ESDB_Archive/Soil_Data/Docs_GlobalData/Harmonized_World_Soi_Database_v1.2.pdf

FAO, International Fund for Agricultural Development, United Nations Children's Fund & World Health Organization. 2021. *The state of food security and nutrition in the world 2021. Transforming food systems for food security, improved nutrition and affordable healthy diets for all.* Rome, FAO. https://doi.org/10.4060/cb4474en

FAO, Intergovernmental Technical Panel on Soils, Global Soil Biodiversity Initiative, Convention on Biological Diversity & European Commission. 2020. *State of knowledge of soil biodiversity: Status, challenges and potentialities.* Rome, FAO. https://doi.org/10.4060/cb1928en

Fischer, G., Nachtergaele, F.O., van Velthuizen, H.T., Chiozza, F., Franceschini, G., Henry, M., Muchoney, D. & Tramberend, S. 2021. *Global Agro-Ecological Zones v4 – Model documentation.* Rome, FAO. https://doi.org/10.4060/cb4744en

Gall, M., Borden, K.A. & Cutter, S.L. 2009. When do losses count? Six fallacies of natural hazards loss data. *Bulletin of the American Meteorological Society*, 90(6): 799–810.

Garrett, L. & Neves, B. 2016. *Incentives for ecosystem services: Spectrum*. Rome, FAO. https://www.slideshare.net/FAOoftheUN/incentives-for-ecosystem-services-spectrum

Gilbey, B. 2018. *A review of the land degradation neutrality process*. Gland, International Union for Conservation of Nature. http://comunidadpnacc.com/wp-content/uploads/2020/01/ldn_process_review_formatted-1.pdf

Gutierrez, V. & Keijzer, M.-N. 2015. Funding forest landscape restoration using a business-centred approach: An NGO's perspective. *Unasylva 245*, 66: 99–106.

Habegger, B. 2010. Strategic foresight in public policy: Reviewing the experiences of the UK, Singapore, and the Netherlands. *Futures*, 42(1): 49–58.

Huang, J., Li, Y., Fu, C., Chen, F., Fu, Q., Dai, A., Shinoda, M. *et al*. 2017. Dryland climate change: Recent progress and challenges. *Reviews of Geophysics*, 55(3): 719–778.

ICBA (International Center for Biosaline Agriculture). 2021. *ICBA*. Dubai. www.biosaline.org

IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services). 2018. *The IPBES assessment report on land degradation and restoration*, L. Montanarella, R. Scholes & A. Brainich, eds. Bonn. https://ipbes.net/assessment-reports/ld

IPCC (Intergovernmental Panel on Climate Change). 2019. *Climate change and land*: *An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.* Geneva. www.ipcc.ch/srccl/

Iseman, T. & Miralles-Wilhelm, F. 2021. *Nature-based solutions in agriculture: The case and pathway for adoption*. Virginia, FAO and The Nature Conservancy. https://doi.org/10.4060/cb3141en

IUCN (International Union for Conservation of Nature). 2022. Restoration Opportunities Assessment Methodology (ROAM). In: *IUCN.* Gland. www.iucn.org/theme/forests/our-work/forest-landscape-restoration/restoration-opportunities-assessment-methodology-roam

Jakovac, C.C., Latawiec, A.E., Lacerda, E., Leite Lucas, I., Korys, K.A., Iribarrem, A., Malaguti, G.A. *et al.* 2020. Costs and carbon benefits of mangrove conservation and restoration: A global analysis. *Ecological Economics*, 176: 106758.

Lambin, E.F., Turner, B.L., Geist, H.J., Agbola, S.B., Angelsen, A., Bruce, J.W., Coomes, O.T. *et al.* 2001. The causes of land-use and land-cover change: Moving beyond the myths. *Global Environmental Change*, 11(4): 261–269.

Liniger, H.P. & Studer, M. 2019. *Sustainable rangeland management in sub-Saharan Africa: Guidelines to good practice*. TerrAfrica, World Bank, World Overview of Conservation Approaches and Technologies, World Bank Group and Centre for Development and Environment and University of Bern. www.wocat.net/library/media/174

Mirzabaev, A., Wu, J., Evans, J., García-Oliva, F., Hussein, I., Iqbal, M., Kimutai, J. *et al.* 2019. Desertification. In: P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D.C. Roberts, P. Zhai *et al.* eds. *Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*. Geneva, IPCC. www.ipcc.ch/site/assets/uploads/sites/4/2019/11/06_Chapter-3.pdf

Mortimore, M. 2009. *Dryland opportunities: A new paradigm for people, ecosystems and development.* Gland, IUCN. www.cbd.int/doc/case-studies/inc/cs-inc-iucn-dryland-en.pdf

Nissan, H., Goddard, L., de Perez, E.C., Furlow, J., Baethgen, W., Thomson, M.C. & Mason, S.J. 2019. On the use and misuse of climate change projections in international development. *Wiley Interdisciplinary Reviews: Climate Change*, 10(3): e579.

Nkonya, E., Anderson, W., Kato, E., Koo, J., Mirzabaev, A., von Braun, J. & Meyer, S. 2016. Global cost of land degradation. In: E. Nkonya, A. Mirzabaev & J. von Braun, eds. *Economics of land degradation and improvement: A global assessment for sustainable development*, pp. 117–165. Cham, Springer International Publishing.

Qadir, M., Quillérou, E., Nangia, V., Murtaza, G., Singh, M., Thomas, R.J., Drechsel, P. & Noble, A.D. 2014. Economics of salt-induced land degradation and restoration. *Natural Resources Forum*, 38(4): 282–295.

REN21 (Renewable Energy Policy Network for the 21st Century). 2018. *Renewables 2018: Global status report.* www.ren21.net/wp-content/uploads/2019/05/GSR2018_Full-Report_English.pdf

Safriel, U. 2017. Land degradation neutrality (LDN) in drylands and beyond – where has it come from and where does it go. *Silva Fennica*, 51(1B): 1650.

Seddon, N., Smith, A., Smith, P., Key, I., Chausson, A., Girardin, C., House, J., Srivastava, S. & Turner, B. 2021. Getting the message right on nature-based solutions to climate change. *Global Change Biology*, 27(8): 1518–1546.

Tarrason, D., Andrian, G. & Groppo, P. 2017. *Toolkit for the application of green negotiated territorial development (GreeNTD)*. Land and Water Division Working Paper 16b. Rome, FAO. www.fao.org/3/a-i6591e.pdf

Tuan, H., Nachtergaele, F., Chiozza, F. & Ziadat, F. 2022. *Land suitability for crop production in the future*. Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en

UNCCD (United Nations Convention to Combat Desertification). 2017. *Global land outlook: First edition*. Bonn. https://knowledge.unccd.int/sites/default/files/2018-06/GLO English_Full_Report_rev1.pdf

UNCCD. 2019. *Land under pressure – Health under stress*. Global Land Outlook Working Paper. https://catalogue.unccd.int/1463_Land_under_pressure_Health_under_stress.pdf

UNCCD. 2022a. *Global land outlook: Second edition.* Bonn. https://www.unccd.int/resources/global-land-outlook/global-land-outlook-2nd-edition

UNCCD. 2022b. The LDN target setting programme. In: *UNCCD.* www.unccd.int/actions/ldn-target-setting-programme

UNDP (United Nations Development Programme) & UN WOMEN. 2018. *Report on environmental impact of Rohingya influx.* Bangladesh. www.bd.undp.org/content/bangladesh/en/home/library/environment_energy/a-new-land-use-model--forest-fruit-fish1.html?utm_source=EN&utm_medium=GSR&utm_content=US_UNDP_PaidSearch_Brand_English&utm_campaign=CENTRAL&c_src=CENTRAL&c_src2=GSR&gclid=CjwKCAiAyPy-QBhB6EiwAFUuakszdxjx2-Qi51AMINuyb85A9pRngfDU6K6D53YW5Y8iG7pjTCjbEBhoCq-fYQAvD_BwE

UN DPA (United Nations Department of Political Affairs) & UNEP (United Nations Environment Programme). 2015. *Natural resources and conflict: A guide for mediation practitioners*. Nairobi. https://wedocs.unep.org/bitstream/handle/20.500.11822/9294/-Natural_resources_and_conflic.pdf?sequence=2&amp%3BisAllowed=

UNDRR (United Nations Office for Disaster Risk Reduction). 2021. *GAR special report on drought 2021*. Geneva. www.undrr.org/publication/gar-special-report-drought-2021

United Nations. 1992. *United Nations Conference on Environment & Development Agenda 21*. https://sustainabledevelopment.un.org

United Nations. 2012. *The future we want: Outcome document of the United Nations Conference on Sustainable Development*. Rio de Janeiro. https://sustainabledevelopment.un.org/content/documents/733FutureWeWant.pdf

United Nations. 2015. *Transforming our world: The 2030 agenda for sustainable development*. New York. A/RES/70/1. www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E

United Nations. 2018. *Sustainable Development Goal 6: Synthesis report 2018 on water and sanitation*. New York. www.unwater.org/publications/sdg-6-synthesis-report-2018-on-water-and-sanitation

van den Ende, M., Wardekker, A., Mees, H. & Hegger, D. 2021. Towards a climate-resilient future together: A toolbox with participatory foresight methods, tools and examples from climate and food governance. Utrecht University. www.researchgate.net/publication/345733771_Towards_a_climate-resilient_future_together_A_toolbox_with_participatory_foresight_methods_tools_and_examples_from_climate_and_food_governance

van Soesbergen, A., Arnell, A.P., Sassen, M., Stuch, B., Schaldach, R., Göpel, J., Vervoort, J., Mason-D'Croz, D., Islam, S. & Palazzo, A. 2016. Exploring future agricultural development and biodiversity in Uganda, Rwanda and Burundi: A spatially explicit scenario-based assessment. *Regional Environmental Change*, 17(5): 1409–1420.

Vervoort, J. & Gupta, A. 2018. Anticipating climate futures in a 1.5 °C era: The link between foresight and governance. *Current Opinion in Environmental Sustainability*, 31: 104–111.

Vlek, P.L.G., Khamzina, A. & Tamene, L., eds. 2017. *Land degradation and the Sustainable Development Goals: Threats and potential remedies*. Publication No. 440. Nairobi, International Center for Tropical Agriculture. https://cgspace.cgiar.org/handle/10568/81313

Wani, S., Rockström, J. & Oweis, T., eds. 2008. *Rainfed agriculture: Unlocking the potential.* Comprehensive Assessment of Water Management in Agriculture Series No. 7. CAB International. www.iwmi.cgiar.org/Publications/CABI_Publications/CA_CABI_Series/Rainfed_Agriculture/Protected/Rainfed_Agriculture_Unlocking_the_Potential.pdf

Wilhite, D. 2011. *Quantification of agricultural drought for effective drought mitigation and preparedness: Key issues and challenges*. Drought Mitigation Centre Faculty Publications Paper 82. https://digitalcommons.unl.edu/droughtfacpub/82/?utm_source=digitalcommons.unl.edu%2Fdroughtfacpub%2F82&utm_medium=PDF&utm_campaign=PDFCoverPages

Willemen, L., Barger, N.N., ten Brink, B., Cantele, M., Erasmus, B.F.N., Fisher, J.L., Gardner, T. *et al.* 2020. How to halt the global decline of lands. *Nature Sustainability*, 3(3): 164–166.

WMO (World Meteorological Organization). 2013. High-level Meeting on National Drought Policy (HMNDP). In: *WMO.* Geneva. https://community.wmo.int/meetings/high-level-meeting-national-drought-policy-hmndp

WMO & GWP (Global Water Partnership). 2014. *National drought management policy guidelines: A template for action*. Integrated Drought Management Programme Tools and Guidelines Series 1. Geneva and Stockholm. www.droughtmanagement.info/literature/IDMP_NDMPG_en.pdf

WOCAT (World Overview of Conservation Approaches and Technologies). 2022. WOCAT: Welcome to WOCAT. In: *WOCAT.* www.wocat.net/en

WWAP (United Nations World Water Assessment Programme)/UN-Water. 2018. *The United Nations world water development report 2018: Nature-based solutions for water*. Paris, United

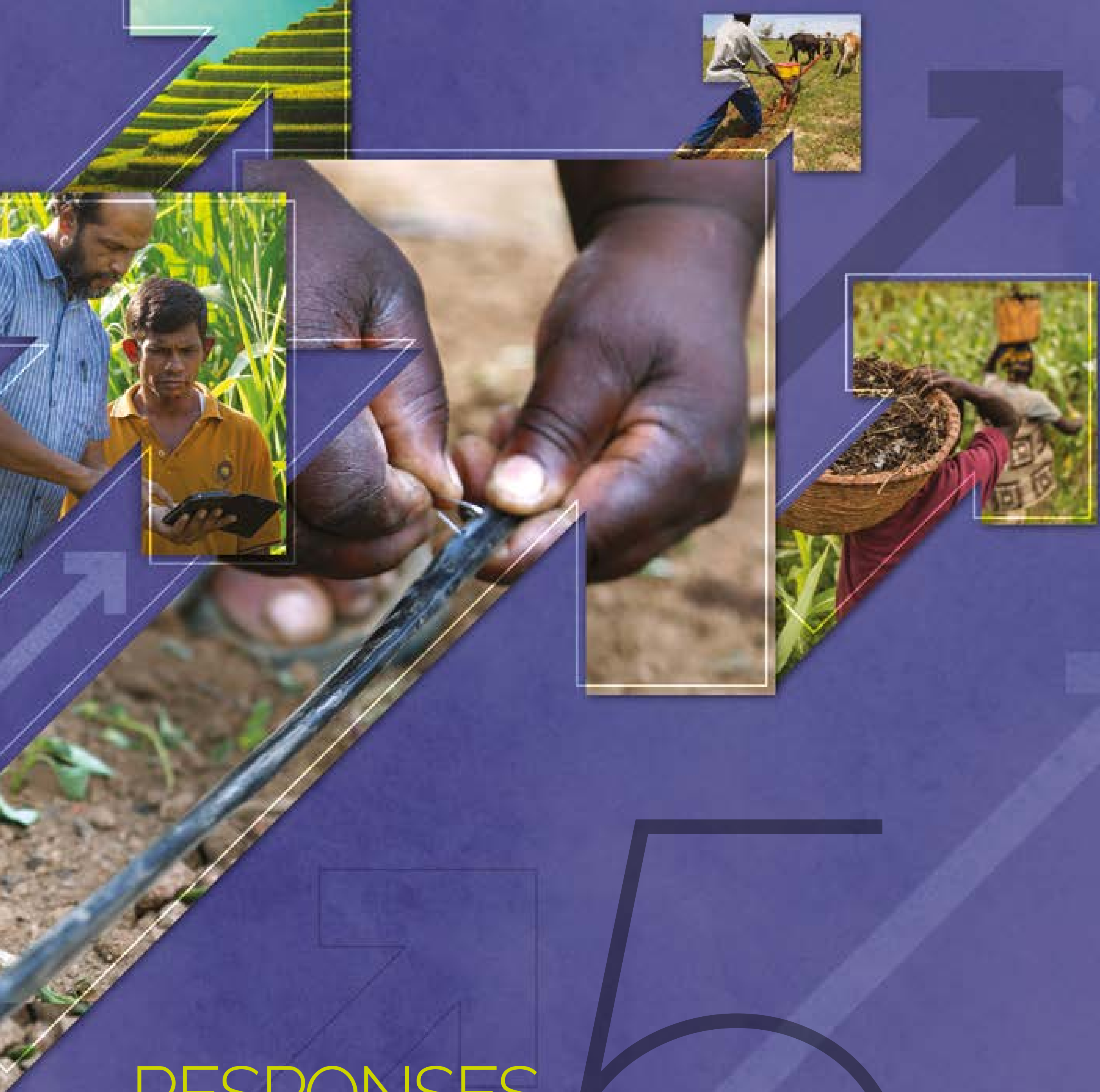
Nations Educational, Scientific and Cultural Organization. https://www.unwater.org/publications/world-water-development-report-2018/

Zdruli, P. 2014. Land resources of the Mediterranean: Status, pressures, trends and impacts on future regional development. *Land Degradation & Development*, 25(4): 373–384.

Ziadat, F., Bunning, S. & De Pauw, E. 2017. *Land resource planning for sustainable land management: Current and emerging needs in land resource planning for food security, sustainable livelihoods, integrated landscape management and restoration*. Land and Water Division Working Paper 14. Rome, FAO. www.fao.org/3/a-i5937e.pdf

Ziadat, F., De Pauw, E., Nachtergaele, F. & Fetsi, T. 2021. A land resources planning toolbox to promote sustainable land management. *Sustainable Agriculture Research*, 10(1): 73.

Ziadat, F.M., Zdruli, P., Christiansen, S., Caon, L., Abdel Monem, M. & Fetsi, T. 2022. An overview of land degradation and sustainable land management in the Near East and North Africa. *Sustainable Agriculture Research*, 11(1): 11–24.



5

RESPONSES AND ACTION AREAS

Key messages

Four key action areas emerge from this report to facilitate a programmatic approach to land, soil and water resources planning and management to turn natural processes and human action towards a desired state or new equilibrium. They do not lead to prescriptive single-purpose "solutions", as the operational issues facing today's agriculture are multifaceted. But as agriculture plays a large role in the processes that cause natural resource scarcity and degradation, it must also be part of any solution.

Land and water governance needs to be more inclusive and adaptive. Inclusive governance is essential for allocating, planning and managing natural resources to continue to meet increasing demands. Technical solutions to mitigate land degradation and water scarcity are unlikely to succeed without adaptive governance with all concerned institutions and actors.

Integrated solutions need planning with stakeholders and need to be mainstreamed to take them to scale. Planning is essential for best and optimum solutions with multiple actors that maintain resource use below critical thresholds in natural resource systems and lead to restoration of resources and ecosystem services when supported by appropriate technical, institutional, governance and financial packages or programmes.

Technical and managerial innovation needs to be targeted to address priorities, reduce risks and enhance resilience of people and ecosystems. Caring for neglected soils, addressing drought and coping with water scarcity will need special measures for incentivizing local adaptation and wide adoption of new technologies and management approaches.

Agricultural support and investment should be redirected towards social and environmental gains derived from the range of land and water management solutions available, leaving no one behind. There is now scope for progressive multiphased financing of agrienvironmental interventions linked with redirected subsidies to keep land and water systems in play and to contribute towards multiple SDGs, notably those on food security and poverty alleviation.

5.1 Introduction

The responses in this chapter build on and complement the land planning and integrated management options presented in Chapter 4 and add to the analysis in Chapters 1–3. Responses in policy, institutions and technical domains can be applied to create positive and transformative changes that keep land, soil and water systems in play and mitigate the further build-up of pressures.

The basis for resource management decisions is established in broad terms by taking stock of the trends in land and water resource use (Chapter 1). However, in practice, such decisions will occur in socioeconomic settings and under governance regimes that may facilitate or limit societal capacity to implement them (Chapter 2). Socioeconomic trade-offs become increasingly complex to evaluate as resource use intensifies, and the broader goals of eliminating hunger and sustaining the natural environment need to be reconciled. They extend across social and economic sectors, water-cycle components, stages of the food value chain and supply chains above and below the land. They bring about higher-level interdependencies and establish the basis for cobenefits in dealing with the multiple aspects of natural resources management and food and agricultural systems.

Since the COVID-19 pandemic that began in 2020, the development priority has focused on tackling health issues, the economic downturn and impacts on food security (FAO *et al.*, 2021). Yet, other serious challenges are emerging, driven by poverty and climate change, including natural disasters and migration trends. Severe floods and droughts have caused loss of life, damage to infrastructure, significant agricultural losses and food security impacts. The pandemic and associated policy responses have also exposed and exploited governance weaknesses and inequalities in the global food system, including among and within countries and population groups.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This SOLAW 2021 report comes at a time when driving forces are accelerating change. Urgent, coordinated action across many sectors is required to meet the food demand of a global population that continues to grow, although at a decelerated rate, within the carrying capacity of natural resources and without compromising the ecosystem services on which all life depends. Recent assessments and global reviews related to SDGs confirm this urgency.

This chapter therefore offers a structured selection of key response options that policymakers can put together to find the best combination according to their circumstances, needs and capabilities. These are grouped under four action areas:

I. Adopting inclusive land and water governance (section 5.3).

II. Implementing integrated solutions at scale (section 5.4).

III. Embracing innovative technologies and management (section 5.5).

IV. Investing in long-term sustainability (section 5.6).

But first, it is important to take stock of the various platforms for responding to land and water degradation and water scarcity, which is briefly reviewed in the next section.

5.2 Response platform: from global to individual efforts

At the global level, concerns over the state of land and water resources were embedded in the United Nations Rio Conventions arising from the 1992 United Nations Conference on Environment and Development (the Rio Earth Summit) and their financing instruments (including the Green Climate Fund and GEF). Many regional and local initiatives for land and water resources management are now guided by the 2030 Agenda. In addition, regional economic initiatives will remain important. For instance, the European Green Deal is expected to mainstream sustainable development and land and water resources management in Europe and beyond, through policy initiatives and focused investments and incentives by the European Commission towards a "climate-neutral continent" by 2050 (EC, 2019).

Land and water resources are implicated in the 2030 Agenda, for example in: SDG 2, ending hunger and achieving sustainable food and agriculture systems (via increasing the proportion of agricultural area under productive and sustainable agriculture); SDG 6, securing water and sanitation for all; SDG 13, combating climate change and its impacts; and SDG 15, sustainably managing terrestrial ecosystems. Target-level linkages extend to most other SDGs: SDG 1, ending poverty; SDG 5, achieving gender equality; SDG 7, ensuring access to sustainable energy; SDG 12, ensuring responsible consumption; SDG 14, land–freshwater–oceans interlinkages and the impact on food security; and SDG 17, revitalizing the role of partnerships. The analyses and state indicators of SOLAW 2021 align well with the various SDG targets and their indicators.

The decisions and priorities of the three multilateral Rio Conventions – addressing biodiversity (CBD), desertification, land degradation and drought (UNCCD) and climate change (UNFCCC) – the Ramsar Convention on Wetlands of International Importance Especially as Waterfowl Habitat (Ramsar Convention, see below), and the water and watercourse conventions (see below) provide scope for solutions that concern land and water for food and agriculture (Box 5.1). The UNCCD LDN target-setting programme explicitly includes water and food security while aiming to avoid, reduce and reverse land degradation. The CBD (Box 5.1) promotes the restoration and maintenance of biologically diverse ecosystems through thematic programmes (inland waters, marine and coastal, agriculture, forests and dry lands) and an integrated ecosystem approach. The decisions and commitments under CBD, SDG 15 targets and UNCCD contribute to improving land and water management as a basis for conservation and sustainable use of above- and below-ground biodiversity, to protection and restoration of soil and water resources and ecosystem services, and to improved availability and access to clean drinking water.

The 2015 Paris Agreement under the UNFCCC (Box 5.1) was a milestone in making agriculture part of the solution rather than a primary cause of climate change. Under the agreement, countries agreed to work together to ensure agricultural development increases food security in the face of climate change and also reduces GHG emissions. The landmark Koronivia Joint Work on Agriculture (KJWA) mainstreams agriculture's role in tackling climate change through requesting two subsidiary bodies under UNFCCC to address issues related to agriculture (section 5.4.2). It provides a platform for land and water policy coherence in climate adaptation and mitigation across agricultural sectors.

The Ramsar Convention (Box 5.1) was signed in 1971 and entered into force in 1975. Almost 90 percent of United Nations Member States have become contracting partners since then. This treaty provides a framework for national action and international cooperation for conserving and wise use of wetlands and their resources.

The international community agreed to establish two United Nations global water conventions for transboundary watercourses:

- The Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention) was adopted in 1992 in Helsinki and entered into force in 1996 by and for the Member States of the United Nations Economic Commission for Europe. The Water Convention was opened to global accession in 2016 (Box 5.1).
- The Convention on the Law of the Non-Navigational Uses of International Watercourses (Watercourses Convention) was adopted by the United Nations in 1997 in New York, and entered into force in 2014 (Box 5.1).

The CFS is a multistakeholder, inclusive international and intergovernmental platform that develops and endorses policy recommendations and guidance for the United Nations system on a wide range of food security and nutrition topics to ensure food security and nutrition for all (CFS, 2015). It is supported by: scientific and evidence-based reports produced by a high-level panel of experts; technical support from the Rome-based United Nations agencies (FAO, International Fund for Agricultural Development and World Food Programme); the CFS Bureau, composed of governments; and the CFS Advisory Group, comprising relevant United Nations organizations, international organizations, civil society organizations and NGOs.


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At its forty-second session in 2015, CFS stressed the key role of water in achieving the 2030 Agenda, and encouraged stakeholders to join forces to address the challenges related to water's contribution to food security and nutrition through ecosystem and people-centred approaches. It recalled that water is essential for realizing the right to adequate food in the context of national food security, and the right to safe drinking water and sanitation. It offered eight specific policy recommendations on water for food security and nutrition (CFS, 2015).

The state of food security and nutrition in the world 2021 (FAO *et al.*, 2021) and the multi-actor consultative dialogues and prioritized work under five interlinked Action Tracks through the 2021 United Nations Food Systems Summit process were guided by CFS, and focused on transforming food systems for food security, improved nutrition and affordable healthy diets for all.

Endorsed by its member governments, OECD has launched a water governance initiative that provides policy guidance and recommendations on rules, processes and institutions involved in sound water governance, with specific focus on stakeholder involvement. The OECD also provides support for sustainable use and management of natural resources, including land and water (OECD, 2022).

The private sector's engagement with land and water will remain fundamental at all stages of the food value chain. The choice of technology and site selection for operations, environmental stewardship and social responsibility practices are under a spotlight, and offer more initiatives and examples of best practices, including certification and corporate disclosure schemes. There is a need to foster greater public and private sector collaborative engagement to finance governance, and systemic and technological innovations for sustainable and resilient land and water management. These could involve diverse private financiers and development financing institutions, bilateral donors, international organizations, research by academia and implementation by civil society organizations.

The investment cost needed at the farm level towards sustainability is typically large in relation to the incremental price that consumers are willing to pay. This makes it necessary for governments to introduce regulations that directly operate at the farm and territorial scales, such as limiting fertilizer and pesticide use and retaining natural habitats, and at intermediary level to reduce externalities of food waste, transport and energy use. Behaviour change at the consumer level may not be sending a strong enough signal to producers, due to the large amount of value added in supply chains.

The broad and circumstance-specific actions presented in this chapter are neither prescriptions nor templates for action, but are intended to inform and guide stakeholders, from leaders to individuals, and from producers to consumers, in their decision-making to produce actionable ways forward for their circumstances and blend of issues. These actions combined provide a sound framework to mitigate the risks identified in Chapter 3, and enhance sustainable development, economic growth and food security, with attention to smallholders, women farmers and vulnerable groups. Policymakers are urged to incorporate these options into strategic actions that protect and enhance efficiency, productivity and resource availability, and ensure food security and nutrition for all. Some options are already proving successful in practice and can be replicated and scaled up at all levels –

BOX 5.1
INTERNATIONAL FRAMEWORKS: CONVERGENCE AROUND INTEGRATED, SUSTAINABLE AND EQUITABLE LAND AND WATER GOVERNANCE

In addition to the 2030 Agenda, many international legal agreements and high-level international political commitments form a strong mandate for promoting multisectoral and integrated approaches to land and water governance. These frameworks shift the international development agenda focus to inclusion, equity and ecosystem integrity, and resilience as essential foundations for sustainable development.

Convention on Biological Diversity: This is in a critical phase of post-2020 planning to reinvigorate action to achieve the Aichi Targets most closely related to land and water governance. Under sustainable agriculture, the Global Biodiversity Outlook 5 calls for integrated land and water policies to support reduced pollution, increased irrigation efficiency and redirection of perverse subsidies and incentives. In the first draft of the Post-2020 Global Biodiversity Framework, 4 of the 21 action-oriented targets are directly relevant to the land and water agenda (UNEP, 2021) for "Reducing threats to biodiversity" (targets 1–3) and for providing "Tools and solutions for implementation and mainstreaming" (target 21):

"Target 1. Ensure that all land and sea areas globally are under integrated biodiversity-inclusive spatial planning addressing land- and sea-use change, retaining existing intact and wilderness areas."

BOX 5.1 (CONTINUED)

“Target 2. Ensure that at least 20 per cent of degraded freshwater, marine and terrestrial ecosystems are under restoration, ensuring connectivity among them and focusing on priority ecosystems.”

“Target 3. Ensure that at least 30 per cent globally of land areas and of sea areas, especially areas of particular importance for biodiversity and its contributions to people, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.”

“Target 21. Ensure equitable and effective participation in decision-making related to biodiversity by indigenous peoples and local communities, respect their rights over lands, territories and resources, as well as by women and girls, and youth.”

Paris Agreement: This emphasizes the “intrinsic relationship that climate change actions, responses and impacts have with equitable access to sustainable development and eradication of poverty” and the “fundamental priority of safeguarding food security”. Integrated, holistic and balanced approaches that aim to enable opportunities for coordination across instruments and relevant institutional arrangements are also emphasized (Article 6), and in taking these measures, countries shall cooperate in enhancing access to information, public awareness and public participation (Article 12). This is reflected in the IPCC special report on climate change and land (IPCC, 2019), which demonstrates that land is part of the climate solution and how managing land resources sustainably can help address climate change with attention to desertification, land degradation, SLM, food security and GHG fluxes in terrestrial ecosystems.

Ramsar Convention: This is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

Sendai Framework for Disaster Risk Reduction 2015–2030: This emphasizes reduced exposure and vulnerability to disaster risks through more people-centred, inclusive and coordinated intersectoral approaches that address the underlying drivers of those risks. The framework calls explicitly for implementing integrated and inclusive legal, political and institutional measures that mainstream disaster risk reduction into land and water policies, implement and enforce land-use and resource regulatory mechanisms to ensure ecosystem health, and support intersectoral coordination appropriate to national systems of governance while empowering effective engagement of women, youth, the elderly, migrants, people with disabilities and indigenous people.

United Nations Convention to Combat Desertification: As the legally binding international agreement linking environment and development to SLM, this convention complements biodiversity, climate and land dynamics, and is aligned in its objectives to tackle desertification, land degradation and the effects of droughts in the SDG suite, with particular emphasis on SDG 15. Land degradation neutrality has gained momentum in recent years. By 2022, 128 countries had committed to setting targets and more than 100 countries had agreed targets to avoid and reduce degradation and restore degraded lands. It promises to be a high-priority agenda item for governments to support UNCCD objectives, the 2030 Agenda, the United Nations Watercourses Convention and the United Nations Economic Commission for Europe Water Convention.

United Nations Watercourses Convention and United Nations Economic Commission for Europe Water Convention: These two conventions address transboundary watercourses, covering 85 percent of all river basins and some 40 percent of the global population (UNECE, 2021).

community, subnational, national, regional and global – for wide-scale and long-term implementation and continuous adaptation towards sustainable land and water management and sustainable agrifood systems.

5.3 Action area I: Adopting inclusive and adaptive land and water governance

The variety of governance approaches to land and water identified in Chapter 2 point to an overall rigidity in tenure systems. This can lead to missed opportunities to be more inclusive and more adaptive towards environmental change. The governance and management of land, soil and water resources require transformative changes that enable actions towards sustainable agriculture and food systems, from production to consumption. Changes in policy, institutional and technical domains that disrupt BAU responses may be required.

Inclusive governance approaches for policy action in land and water include:

- multistakeholder collaboration to draw on various knowledge systems, values and experiences (Pahl-Wostl, Mostert and Tàbara, 2008);
- polycentric governance systems with shared governance responsibilities across decision-making at various levels of governance (Ostrom, 2010; Pahl-Wostl *et al.*, 2013);
- experimentation and flexibility in testing policy interventions; and
- social and adaptive learning that builds on multistakeholder collaboration (Reed and Massie, 2013).

Increasing uncertainties and complexities surrounding land and water governance require an adaptive approach to policies and management systems (Pahl-Wostl, 2015). Efforts to enhance adaptive capacity have attempted to distil and operationalize "adaptive governance" approaches that build on adaptive management and comanagement, in which governments share powers with resource users (Folke *et al.*, 2005; Ostrom, 2005; Chaffin, Gosnell and Cosens, 2014). Many of the core components of adaptive governance across countries and local contexts closely align with other governance approaches explored in this chapter (Pahl-Wostl *et al.*, 2007; Plummer *et al.*, 2012; Chaffin, Gosnell and Cosens, 2014). For adaptive governance to work in practice, the increased need for flexibility should be balanced with considerations of legitimacy and stability that prevent arbitrariness (Cosens *et al.*, 2017).

Investments can help to strengthen governance arrangements and policy change. These include planning and management actions at farm and landscape levels and associated technological innovation. However, behavioural change is also required. People-centred

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governance approaches are needed to include all stakeholders, and collaborative decision-making and learning require deliberate linkages across institutions, scales and sectors to capitalize on stakeholder interests.

There is increasing recognition in international frameworks and national governance mechanisms of the crucial role of land and water management in climate change (Box 5.2). The IPCC special report on climate change and land (IPCC, 2019) highlights that land must remain productive to maintain food security as the population increases and the impacts of climate change on soils and crops are felt. The roles of soil and land management in carbon sequestration and emission mitigation are particularly important. They require recognition in policies and governance instruments backed up by land-use and resource evaluation and vulnerability risk assessments.

Inclusive governance is key to building capability and competent and informed institutions and organizations at all levels of decision-making. This enables mainstreaming and mobilizing effective and wide adoption of sustainable and transformative land-use and food systems and practices adapted to specific socioeconomic and ecological settings.

The need to recognize and protect land and water tenure rights (particularly among rural communities, indigenous people, women and other vulnerable groups) underpins food security and nutrition, sustainable livelihoods and climate resilience. Harmonizing land and water governance systems is essential and should build on experiences in addressing specific land and water governance challenges. Addressing the needs of vulnerable and marginalized populations requires an understanding of power structures and incentives within society that govern natural resources access, incorporating their specific needs into policy, planning and investments.

Previous chapters have highlighted the challenges facing land and water resources as increasing demands for food and agriculture, energy, industries and municipalities compete with conserving and enhancing ecosystems and their services. Food systems drive climate change and contribute to land

BOX 5.2
FACILITATING POLICY COHERENCE AND INTEGRATED LAND AND WATER GOVERNANCE THROUGH CLIMATE RESPONSES

The ability of socioecological systems to respond, recover and adapt to climate impacts is closely linked to how well climate mitigation can be achieved. Integrated approaches to adaptation and mitigation can reduce risks and identify synergies that mitigate threats to food security (Di Gregorio *et al.*, 2016).

The REDD+ initiative, originally conceived as a mitigation solution, has evolved to include conservation and sustainable forest management and enhanced forest carbon stocks through interventions to address a suite of forest governance issues, including tenure, gender equality and stakeholder participation. For example, the Lower Zambezi REDD+ project focuses on establishing community-based forest mitigation through conservation farming and tree nursery development to create sustainable alternatives to deforestation, thus increasing communities' resilience while preventing emissions (Munroe and Mant, 2014).

The KJWA provides a platform for strengthening land and water governance by integrating climate adaptation and mitigation policies across agricultural sectors (see section 5.4.2).

and soil degradation, water scarcity and biodiversity loss. The COVID-19 pandemic has exacerbated these challenges, which disproportionately affect vulnerable and marginalized populations.

Building on the land and water governance issues raised in Chapter 2, five governance responses promise effective transformation:

- developing coordinated and coherent policies and approaches;
- strengthening and harmonizing land and water tenure systems;
- effectively engaging actors in negotiation;
- improving employment, livelihoods and gender equity; and
- undertaking governance analysis.

5.3.1 Developing coordinated and coherent policies and approaches

Most countries have adopted policy and legal frameworks governing land and water resources. However, in many cases, such frameworks are fragmented and lack effective implementation in practice. This is because traditional siloed land and water management and sectoral agricultural (crops, livestock and forestry) approaches persist, and effective links among levels of decision-making are weak. A focus on technical solutions has frequently resulted in fragmented jurisdiction over ecologically interconnected resources.


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Power imbalances inhibit coordination among ministries and technical sectors, limit competition over budgetary resources and foster mistrust among agencies. To counter this, competent institutions need to promote participatory planning and administration processes in land and water sectors, through which "red line" targets and thresholds can be established as a basis for monitoring progress, assessing risks and developing investment plans. Desirable outcomes will depend on locally appropriate policies and governance systems and competent institutions for their implementation. International instruments (Box 5.1), national policies and legislative frameworks recognize the interconnectedness of development issues and promote integrated and intersectoral approaches.

Improved intersectoral coordination (land, water, agriculture, environment, finance and planning) can help identify and address overlaps and trade-offs, improve performance across multiple levels of government, reduce costs and identify areas where lines of authority can be better delineated should a conflict arise, and clarify to stakeholders who is accountable for decisions and actions (Kristensen, 2004; Tripathi *et al.*, 2019; UNEP, 2019). Improved coordination is necessary to equitably distribute cobenefits from policies and decisions, especially for vulnerable populations.

Finding appropriate pathways to make integrated approaches work is critical to stemming overexploitation, degradation of land and soil resources, and water scarcity, which could undermine resilient ecosystems and sustainable development. This requires innovative governance responses and enhanced institutional and societal capacities to build on synergies, address trade-offs and manage processes that may involve (re)allocating limited resources, addressing inequalities and changing the way of empowering actors at different levels of decision-making.

5.3.2 Strengthening and harmonizing land and water tenure systems

Land and water tenure systems determine how individuals, communities and others acquire rights and associated duties to use, manage and benefit from land and water resources. Although data on tenure security are incomplete (to be improved under SDG indicator 1.4.2), insecurity of tenure rights continues to threaten the livelihoods and well-being of a significant share of the population dependent on land and water resources for their livelihoods. This weakens incentives for farmers and other rural land users to invest in improving their land and water resources (RRI, 2017). Insecurity also reduces access to credit, further undermining the capacity to sustain and improve agricultural productivity.

Over the past decade, a key milestone has been achieved to support countries in improving tenure security for all, in particular the most vulnerable, with negotiation and adoption by government, civil society, private sector and academia representatives, under CFS, of the VGGT (CFS and FAO, 2012). As a common international standard of responsible governance of tenure, the guidelines are being implemented in over 100 countries (Global Donor Platform for Rural Development, 2022), supporting tackling specific tenure issues or supporting broad land governance programmes providing multiple benefits.

Recent progress has secured communities' land and forest tenure rights, attributable in part to developing and implementing principles and tools to guide policy and legal reform. Of note in this regard are the VGGT and concerted advocacy efforts on behalf of rural communities (CFS and FAO, 2012). However, a significant gap remains between commitments and practice.

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Most countries fail to recognize the interrelations among land and water tenure rights, legally and in practice (RRI and ELI, 2020; FAO, 2020a). Yet, recent work demonstrates that it is possible to articulate, conceptually and based on legislative practice, a core set of water-related rights that comprise the diverse water tenure regimes found worldwide. Taking a "bundle of rights" approach enables countries to identify areas for harmonization across water, land, forest, fisheries and other key resource sector legislation for improved and integrated land and water governance (FAO, 2020b; RRI and ELI, 2020). FAO is now facilitating international debate to develop further the concept of water tenure and guidance for countries and to address water tenure reforms to support food security, sustainable livelihoods, climate resilience and development goals (FAO, 2020c).

FAO work on water governance and tenure includes raising awareness and developing tools and capacity for integrating tenure assessment to strengthen water governance. This forms the basis for sustainable and equitable water management, recognizing the legitimate tenure rights of pastoralists and pastoralism and formalizing women's land and water rights for gender-equitable outcomes (Box 5.3).

BOX 5.3
STRENGTHENING WATER GOVERNANCE AND WATER TENURE RIGHTS

Water governance through tenure assessment and governance analysis

Under the Knowing Water Better project, FAO is working in Rwanda, Senegal and Sri Lanka to strengthen water governance processes through water accounting, governance and tenure assessment. The project is piloting a national water tenure assessment methodology that can map water tenure regimes (including those of individuals, the private sector and communities) and identify gaps and overlaps in sectoral legislation, where customary practices present threats to water tenure security.

Additional work under the water efficiency, productivity and sustainability project (which focuses on implementing the 2030 Agenda for water efficiency and productivity in eight Near East and North Africa countries) provides data and information for sustainable water management that balances environmental, economic and social sustainability to improve rural livelihoods, especially smallholder farming. This project is also piloting a combined water accounting and auditing/governance analysis to help policymakers achieve sustainable and equitable water management and use.

Sources: **FAO**. 2021. Methodology. In*: Knowing water better: Towards fairer and more sustainable access to natural resources - KnoWat*. Cited 3 March 2022. www.fao.org/in-action/knowat/wt-assessment/methodology/en; **FAO**. 2021. Water efficiency, productivity and sustainability in the NENA regions (WEPS-NENA). In: *FAO*. www.fao.org/in-action/water-efficiency-nena/en

Recognizing customary land and water tenure in pastoralism

Customary laws and practices often determine how rural communities access, use and govern their land and water resources. Where customary rights are not legally recognized, they may be ignored or manipulated when competing claims for resources arise, thus increasing the vulnerability of communities. Insecure tenure also reduces communities' ability to invest in maintaining and sustaining local agriculture and forest-based food systems. This undermines their key role in storing and managing forest carbon (Byagmugisha, 2013; Oxfam and ILC, 2016).

Globally, 500 million people rely on pastoralism for livelihoods. Water tenure rights are critical, as communities are often organized around access to various grazing lands and their limited water supplies. Yet, in many countries, particularly where pastoral communities cross national boundaries, overlapping or competing customary and formal governance systems do not recognize resource rights (De Haan *et al.*, 2016; Davies *et al.*, 2018).

Governments and regional organizations are beginning to recognize the legitimate tenure rights of pastoralists and pastoralism as an important and appropriate use of land and water resources. Burkina Faso, Mail and Mauritania have passed legislation protecting grazing land and granting herders rights to land and water resources, recognizing existing access and sharing arrangements and livestock corridors as a critical tool to protect customary pastoral water tenure rights.

Sources: **République du Mali.** 2001. *Loi n° 01-004 du 27 fevrier 2001, portant charte pastorale du Mali.* Mali; **Behnke, R. & Freudenberger, D.** 2013. Pastoral land rights and resource governance. In: *LandLinks.* Cited 2 March 2022. https://land-links.org/issue-brief/pastoral-land-rights-and-resource-governance; **Davies, J., Herrera, P., Ruiz-Mirazo, J., Mohamed-Katerere, J., Hannam, I. & Nuesiri, E.** 2016. *Improving governance of pastoral lands: Implementing the voluntary guidelines on the responsible governance of tenure of land, fisheries and forests in the context of national food security.* Governance of Tenure Technical Guide 6. Rome, FAO. www.fao.org/3/i5771e/I5771E.pdf

Women's land and water tenure rights drive social development and growth

Women's land and water resource rights are important drivers of social development and economic growth. Yet, in many instances, legislative and customary systems fail to promote women's secure land and water tenure (Keene, Troell and Ginsburg, 2020). Even where women are landholders, they frequently face challenges in accessing productive resources, hold land of lower quality and have lower levels of agricultural productivity than men. Women's water tenure also depends on their legally recognized land rights, further emphasizing the importance of strengthening their land and forest tenure (Keene, Troell and Ginsburg, 2020).

BOX 5.3 (CONTINUED

Where women do have secure tenure rights, they tend to invest in improving land, participate in land rental markets, and contribute to family food security, children's health and sustainable agricultural productivity (USAID, 2016). In Rwanda, women with formalized land rights were 19 percent more likely to invest in soil conservation, compared to only 10 percent of men. Globally, children whose mothers own land are 33 percent less likely to be undernourished (Viña, 2020). Secure land rights also improve women's participation and leadership in community governance institutions.

Formalizing women's land and water rights is crucial in analysing gender inequities in legal frameworks (including marriage and inheritance laws), and also in the political economy of land and water resource governance at the local level to facilitate women's equal participation and achieve truly gender-equitable outcomes (Doss and Meinzen-Dick, 2020).

Source: **FAO.** 2020. *The state of food and agriculture 2020. Overcoming water challenges in agriculture.*
Rome. https://doi.org/10.4060/cb1447en

5.3.3 Effectively engaging actors in negotiation

National governance should help to secure tenure rights, and recognize and protect local land rights that people consider socially legitimate, including customary rights where relevant. It should also tackle competition over limited land resources, in law and in practice. This can help to avoid the risk of inequalities due to social differentiation (e.g. depriving local communities from access to natural resources on which they depend) or expropriation of marginalized groups with limited rights (e.g. women, youth and migrants) through investments in land. Enabling legal frameworks and financing for implementation is crucial to effective civic engagement and rights-based approaches.

Participatory negotiated territorial development approaches can promote multistakeholder dialogues on territorial development opportunities to address competition over land and water resources. Such approaches have been developed through practice and successfully applied in many recovery situations, after conflict and in complex emergencies (e.g. in Angola, Democratic Republic of the Congo and Mozambique). The Green Negotiated Territorial Development approach adapted such a methodology to safeguard ecological integrity (Box 5.4).

Engaging diverse stakeholders in policy decisions about land and water governance brings multiple sources of knowledge, values and information to the table, contributing to building trust, social cohesion and the rule of law. Participatory policymaking and decision-making also help defuse conflict and reframe issues holistically by identifying trade-offs and synergies across constituencies.

At the national level, some countries include legal requirements for civic engagement in land and water decision-making in their framework environmental laws, water and land sectoral laws, and planning laws, as part of impact assessment requirements. Impact assessment laws can ensure proposed projects and activities are subject to public consultation if implemented and enforced appropriately (UNEP, 2019). Civic engagement in permitting processes is also a critical means for individuals and communities to have notice of potential infringements on their land and water rights. Some countries require environmental and social impact

BOX 5.4

GREEN NEGOTIATED TERRITORIAL DEVELOPMENT AND ITS CONTRIBUTION TO IMPROVING LIVELIHOODS RESILIENCE

The Green Negotiated Territorial Development approach facilitates interaction among stakeholders involving land disputes to find solutions to competition and other problems of accessing land and limited natural resources. It is adaptable to different scales of intervention and various stakeholders, namely policymakers, tenants, communities, entrepreneurs and NGOs, and those who provide expertise and economic resources. The process consists of five phases and concludes by the signing of a Socio-Ecological Territorial Agreement:

- Preparatory work: Identifying the territorial perimeter, and the stakeholders and their motivations to intervene.
- Phase I. Views: Understanding the territory as a socioecological system; preparing a first analytical framework of concerned stakeholders, differentiating their positions, interests and strategies, and creating an information system (socioeconomic, productive and ecosystemic) to better understand the impacts, risks and conflicts.
- Phase II. Horizons: Outlining coherent and feasible proposals for territorial development; setting scenarios to facilitate consensus; and identifying the issues that adversely affect the territory.
- Phase III. Negotiation: Seeking consensus for territorial development; creating round-table negotiations involving all stakeholders; and analytical work for coherent, feasible, efficient and sustainable interventions.
- Phase IV. Stakeholders sign the Socio-Ecological Territorial Agreement: The fundamental basis for implementing short-, medium- and long-term business plans, formalizing rights and duties, and creating an implementation stakeholder platform.
- Phase V. Monitoring and evaluating the activities.

*Source***: FAO.** 2017. *Toolkit for the application of green negotiated territorial development (GreeNTD).*
Land and Water Working Paper 16b. Rome. www.fao.org/3/i6591e/i6591e.pdf

assessments in determining the validity of permit applications. Meaningful engagement is often challenging, requiring substantial efforts to build relationships, facilitate collaboration, build the capacity of marginalized stakeholders to participate and link these processes to policy outcomes.

5.3.4 Improving employment, livelihoods and gender equity

Sustainable land and water management offers promising pathways to improve livelihoods, create new employment opportunities, close gender gaps and enhance the resilience of people and ecosystems. Increased production stimulates demand for labour during the primary cropping seasons and the dry season (livestock, processing and marketing), increasing the number of workers required and extending periods of employment. Introducing circular food systems can also increase employment opportunities through green jobs (FAO, 2014a), the range of labour-intensive activities (UNEP, 2015) and payment or other incentives for the provision or restoration of ecosystem services. High-value production and inclusive value chain development models can create additional value and jobs (Pfitzer and Krishnaswamy, 2007). Reusing resources from waste in agriculture also offers various opportunities to reduce pollution,

BOX 5.5
ROLE OF WOMEN IN WATER RESOURCES MANAGEMENT IN AGRICULTURE

In Northern Africa, a study in Algeria and Tunisia on the role of women in water resources management and water in agriculture concluded that:

- Women play a crucial role and participate actively in irrigated agriculture management.
- The level of education of women producers is low and their poor financial situation is due to their social position, which limits their participation in remunerated work and decision-making.
- There is a gap between women's workload in agriculture and their access to land, credit and organizations. Women are not usually members of water user/farmer associations.
- Development programmes do not benefit everyone equally, especially within the family.
- Participation of women in agriculture is different among countries. They participate in decisions about crops and livestock, but less so in decisions about investment and equipment.
- There is a lack of data at the national level on agriculture and gender, and more specifically, agricultural water and gender.

A further study to develop and propose several gender-differentiated water indicators for integration in AQUASTAT, as a basis to address men's and women's differential situations included:

- access to drinking water;
- economic contribution to irrigated agriculture;
- access to economic resources in irrigated area;
- competency in water resources management/irrigation;
- technical management capacity;
- participation in water governance; and
- perceptions and practice of roles in water management.

Sources: **FAO.** 2014. *Le rôle des femmes dans la gestion des ressources en eau en général et de l'eau agricole en particulier.* Rome. www.fao.org/3/a-bc820f.pdf; **FAO.** 2016. *Le rôle des femmes dans la gestion des ressources en eau agricole – Phase 2.* Rome. www.fao.org/3/i5680f/i5680f.pdf

improve sanitation, create additional value and increase employment (Otoo and Drechsel, 2005).

Sustainable land and water management can help to close the gender gap, given that women comprise 43 percent of the agricultural labour force globally, and over 50 percent in many African and Asian countries (FAO, 2019a). Enhanced and stable income can improve the education and technical capacity of women. New technological solutions within a circular food system can open up new income-generating employment opportunities for women. Empowering women through education, income, organization and recognition, updating legislation and ensuring representation enables them to seek and acquire formal rights to land and water and to participate in future planning and decision-making (FAO, 2016a).

To improve women producers' access to water and economic resources, their participation in water management decisions and establishing working conditions requires systematic disaggregation of gender data at the national level. This requires appropriate coordination among agriculture and water sectors and national statistical services (FAO, 2016a). Box 5.5 provides key indicators for improving knowledge and thereby addressing gender bias.

In this context, municipalities can also play a critical role in planning and implementing the shift towards sustainable food systems. An example is the Milan Urban Food Policy Pact, signed by over 200 cities, to develop sustainable food systems that are inclusive, resilient, safe and diverse, which provide healthy and affordable food to all people in a human-rights-based framework, and which minimize waste and conserve biodiversity while adapting to and mitigating the impacts of climate change. Another example is the Quito Agri-Food Strategy, which is a multi-stakeholder engagement that addresses the limited availability of fresh and nutritious foods in vulnerable neighbourhoods. This concerns the development of urban gardens, 84 percent of which are led by women, for home consumption and supply to local food markets, thus creating lower costs due to shorter supply chains and enhancing resilience during the COVID-19 pandemic.

5.3.5 Undertaking governance analysis

Simultaneously achieving diverse but interrelated goals requires that sectors understand the root causes of problems and related socio-economic and political dynamics. Pragmatic governance analysis facilitates understanding of existing institutions, how they have evolved and how the relative power and capacities of different actors influence the work of those institutions in practice (FAO, forthcoming).

Water governance has lagged behind land governance. However, OECD developed 12 principles for efficient, effective and inclusive water governance (OECD, 2015), and a water governance indicator framework (OECD, 2018) to assess and guide better water policies and reform. Recent research (FAO, forthcoming) has led to identifying the core elements of water tenure, based on how water tenure systems function in practice and how they are legally recognized at the national level. This analysis highlights the legal interdependencies across water, land and forest resource tenure systems that shape equitable and sustainable use, management and development of terrestrial and freshwater resources. Water and other sectoral policies and legislation need to better reflect the practical needs and realities of governments and the users of water and land resources. The need is to secure access and user rights, as a basis for sustainable livelihoods, equitable development and climate resilience, particularly for indigenous people, rural communities and other vulnerable populations.

FAO is supporting water governance analysis in several regions under its Water Scarcity Initiative including Southern America, the Near East and North Africa, and Asia and the Pacific (Box 5.6) as a basis for improved water resource management, access and use by multiple stakeholders.

5.4 Action area II: Implementing integrated solutions at scale

Evidence shows that restoring degraded resources, sustainable intensification and resilience can be achieved through planning and implementing integrated and multi-stakeholder initiatives at scale. This requires

BOX 5.6
SUPPORTING WATER GOVERNANCE ANALYSIS

Politically smart, locally led development in Western Odisha, India

The Western Odisha Livelihoods Project was a ten-year initiative (supported by the Department for International Development, United Kingdom of Great Britain and Northern Ireland) in India to reduce poverty by improving community water infrastructure for irrigation and flood control, and by improving agricultural practices. Tangible achievements included improved agricultural productivity in over 70 percent of the watersheds, and reduced poverty levels in up to 75 percent. Key factors related to success include:

- Locally negotiated and delivered processes. Local leadership was prioritized as local experts provided motivation, credibility, knowledge and networks.
- Effective partnerships, based on investment in strategic relationship building that created mutual accountability.
- Iterative problem solving. Project development and design was undertaken with the state government and with project beneficiaries, allowing a strategy of piloting approaches that provided for ongoing learning and adjustment.
- Long-term commitment. The programme enabled up-front investment in relationship building and allowed for an adaptive approach to testing realistic solutions within the political environment.
- An integrated, anticorruption approach emphasized community-level accountability and transparency to beneficiaries in villages.

Sources: **Independent Commission for Aid Impact**. 2013. *DFID's livelihoods work in Western Odisha.* Report 18. https://icai.independent.gov.uk/wp-content/uploads/ICAI-Report-DFIDs-Livelihoods-Work-in-Western-Odisha.pdf; **Booth, D. & Unsworth, S.** 2014. *Politically smart, locally led development.* Discussion Paper. London, Overseas Development Institute. https://cdn.odi.org/media/documents/9204.pdf

Countries facing water shortage in Central and Southern America

Case studies on water governance in selected agricultural territories and river basins in Andean countries (Plurinational State of Bolivia, Chile and Peru) and in the dry corridor of Meso-America (El Salvador, Guatemala and Panama), and consultations with government and non-state actors, identified and analysed challenges and gaps. This allowed the development of recommendations for addressing water scarcity, food insecurity and resilience to climate change, and led to development of policy briefs. The findings varied within and among river basins, but four main recommendation areas were identified, in line with OECD water governance principles, for effective governance towards sustainable policy goals, efficient governance for maximizing benefits of sustainable water management, and trust and engagement of stakeholders for legitimacy and equity:

- reform and strengthen the water-related institutional framework (sectoral and territorial);
- improve the efficient and equitable use of water in agricultural territories for productivity and climate resilience;
- promote watershed management to improve water availability for production, consumption and climate resilience; and
- integrated management of groundwater and surface water.

Sources: **Organisation for Economic Co-operation and Development**. 2015. *OECD principles on water governance.* Paris. www.oecd.org/cfe/regionaldevelopment/OECD-Principles-on-Water-Governance.pdf; **FAO**. 2021. *Abordando la gobernanza del agua en territorios agrícolas de países andinas con escasez hídrica.* Policy Brief. Rome. www.fao.org/3/cb5938es/cb5938es.pdf; **FAO**. 2021. FAO publica estudios de gestión del agua en países de Centro y Sudamérica. In: *FAO Regional Office for Latin America and the Caribbean.* www.fao.org/americas/noticias/ver/en/c/1382637 long-term strategies, investments and innovative financing, as well as partnerships to sustain initiatives and improve livelihoods.

The wide range of agricultural and environmental policies can change and shift over time, and can influence agricultural production beyond the farm gate. Public subsidy and agricultural tariffs to promote domestic production and food security remain the policy instruments of choice for many developing countries. However, many other policy options that have a direct bearing on land and water management are now mainstream. This section describes some important options and their influences. It includes current approaches to reconciling agricultural production and ecosystem services, supporting agricultural productivity growth, reducing FLW, changing food consumption patterns and promoting sustainable diets, and the advent of circular food system approaches that address resource-use efficiency. These reflect the potential benefits of adopting advanced forms of sustainable agriculture that generate employment and secure livelihoods and contribute to food security and nutrition across diverse landscapes and social settings.

5.4.1 Applying integrated approaches

Various approaches to intersectoral coordination and integrated natural resources planning and management have emerged that recognize the complex and intersectoral nature of land and water ecosystems. They share many elements, including emphasizing adaptive and collaborative learning, stakeholder participation, focusing on community-based management nested in accountable multilevel governance, and increased policy, legal and institutional coherence, and coordination across sectors. In practice, such approaches often cut across existing institutional and jurisdictional boundaries, frequently resulting in an institutional ownership vacuum or overlapping authority (Ros-Tonen, Reed and Sunderland, 2018).

Integrated landscape management

Experiences on the ground show that integrated landscape management, including local territorial or catchment planning and appropriate governance approaches, can effectively promote sustainable land resources and landscape management (Box 5.7).

Effective integrated landscape management requires strategic legal and policy tools, particularly land-use planning, and appropriate incentive structures (Clinton *et al.*, 2018). Integrated land-use planning involves several legal frameworks, including land-use planning laws, zoning laws and planning provisions within relevant sectoral legislation to mainstream sustainable use across these diverse frameworks at national and landscape levels (Lausche, 2019). National support is needed for developing capacities of national and decentralized institutions (including provincial and local planning bodies and municipalities) in integrated spatial and participatory planning tools. This includes the use of remote sensing and diagnostic tools on the ground, and stakeholder analysis to integrate environmental and socioeconomic development goals and address rural–urban interactions.

Implementation of plans also requires robust systems for permitting environmental impact assessments and aligning incentives through subsidies and PES. Strategic environmental assessment can facilitate intersectoral and cumulative impacts on a landscape and provide opportunities for public participation

BOX 5.7

WATERSHED MANAGEMENT FOR RESILIENCE AND SUSTAINABLE LAND MANAGEMENT SCALING OUT

In 2017, FAO conducted a comparative study of watershed management projects in 12 countries in Latin America, Africa and Asia to bring together and disseminate the lessons learned and to provide recommendations for use by practitioners in watershed-related initiatives at national, subnational and local levels. The study concluded watershed management promotes the transition to more sustainable production systems and practices in the crop, livestock, forestry and fisheries sectors, while enhancing access to nutritious food for all and maintaining ecosystem services, functions and biodiversity to support current and future human needs. It was confirmed as an effective approach for responding to global challenges of water supply, land restoration, climate change adaptation, disaster risk management and fighting hunger. However, the study highlighted that to meet these challenges, watershed management initiatives must be implemented over longer time frames, and require sustained and coordinated investment from the public and private sectors. In particular, the review identified five areas for building robust cooperative approaches in watershed management (FAO, 2017a):

- **Institutional strengthening for improved watershed governance.** Based on sound analysis of underlying policy and institutional challenges and the causes of resource competition, interventions should support strategic planning and institutional coordination processes and create incentives for multistakeholder dialogue and action platforms.

- **Watershed monitoring.** Priority must be given to systematic and regular collection and analysis of data on conditions in the watersheds. Technical guidance and tools are needed to support the selection of appropriate indicators and develop stakeholders' capacities to monitor processes in watersheds. Capitalizing on increased data availability and more systematic use of increasingly available geospatial data and tools may complement on-the-ground assessments and contribute to improved quality of environmental information while reducing time and costs.

- **Increased data availability.** A more systematic use of satellite and mobile data tools in watershed management may complement on-the-ground assessments and contribute to the improved quality of environmental information.

- **Knowledge-sharing and learning.** A platform for systematic sharing of watershed management experiences, approaches and tools among development partners and research organizations could avoid duplication of effort, help future programmes take advantage of the latest knowledge and contribute to harmonization of approaches.

- **Strategic partnerships for joint action on the ground.** Technical assistance projects by FAO can be associated with larger investment programmes by the International Fund for Agricultural Development, the World Bank and regional development banks for guidance on responsible investments and greater impacts, as well as other international organizations working on broader landscape management and restoration initiatives.

As an example, in the Transboundary Agro-ecosystem Management Project in the Kagera River basin, supported by FAO, GEF and participating governments, catchment planning and management approaches were integrated into local governance strategies to promote participatory and sustainable land, water and biodiversity management. In Burundi and the United Republic of Tanzania, watershed management groups were established to prioritize and oversee implementation, resulting in improvements in food security and resolving resource conflicts. In Uganda and the United Republic of Tanzania, participatory land-use planning enabled communities and the government to endorse the results of catchment planning and integrated agroecosystem management for achieving agricultural productivity, natural resources, climate, biodiversity, food security and livelihood benefits. Benefits included building community capacity using FFSs to improve practices at farm and catchment scales, and collaboration and exchange among local, provincial and national government bodies and among the four riparian countries enabled identification of policy support for managing transboundary land and water resources and livestock (FAO, 2017b, 2017c).

in strategic decision-making (OECD, 2017; Whitehead, Kujala and Wintle, 2017). Competent institutions and adequate financing mechanisms are needed to support a dynamic and participatory land planning process with regular assessments of implementation and results by the range of stakeholders, to adjust and update plans, and revise human and financial allocations to meet goals and address emerging issues. The effective engagement of all land users and other non-state actors is also essential to ensure their specific challenges and uncertainties are addressed, including those of vulnerable groups and indigenous people (Ziadat, Bunning and De Pauw, 2017).

Payment for ecosystem services and other regulatory incentives can also distribute benefits fairly across a landscape to compensate for trade-offs. Each tool needs to be well calibrated to the social, economic, cultural and ecological status and goals. They are often most successful when local authorities and stakeholders take a leadership role in every design and implementation stage. Reviews of experiences worldwide in scaling up SLM and restoration through large-scale initiatives demonstrate the need for substantial, long-term and targeted incentives to engage the various stakeholders from the design stage and through planning, implementation and monitoring, as well as clear land tenure and use rights to ensure the benefits are equitably accrued. Reviews of successful forest landscape restoration highlight engaging private landowners and well-enforced legal protection of forests (Mansourian, Dudley and Vallauri, 2017). Valuation of resources and ecosystem services can also be critical to identify optimal use scenarios (FAO, 2017d).


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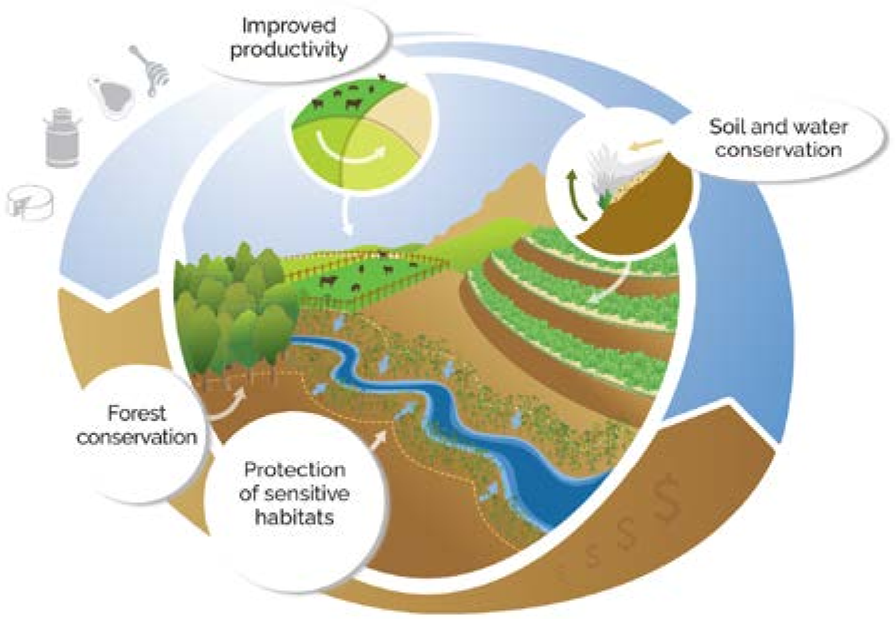
The high economic value of ecosystems rarely translates into monetary benefits for users, perversely incentivizing activities that result in resource degradation or destruction. Payment for ecosystem services aligns incentives and generates revenue for conservation through payments from ecosystem service beneficiaries (e.g. users of clean water or bulk water service providers) to the service providers (e.g. upstream communities responsible for watershed stewardship). Thus, PES can provide a framework for integrated land and water management approaches (Box 5.8; Figure 5.1 and Figure 5.2). Other incentives range from policy measures (e.g. rights, regulations, subsidies or taxes) to green bonds or concessions and marketing labels or certificates.

BOX 5.8
PAYMENT FOR ECOSYSTEM SERVICES: INVESTING IN NATURE, INVESTING IN PEOPLE

In 2010, Viet Nam adopted a PES system for forest ecosystem services that provides funding for landscape management, generating revenue comprising about 22 percent of the overall investment in the forestry sector (Pham *et al.*, 2018). Under the Viet Nam Law on Forestry (Forest Environmental Services), hydroelectric facilities, water utilities, industrial water users and aquaculture operators pay those with legitimate forest tenure rights for ecosystem services, including erosion protection and water quality maintenance. The government sets the payment amounts, channels them through forest protection and development funds, and reaches over 500 000 households. In some cases, this represents 80 percent of the annual household cash income and contributes to a 75 percent reduction in the degraded forest area (Pham *et al.*, 2018; Duong and Groot, 2020; McElwee, Huber and Nguyễn, 2020).

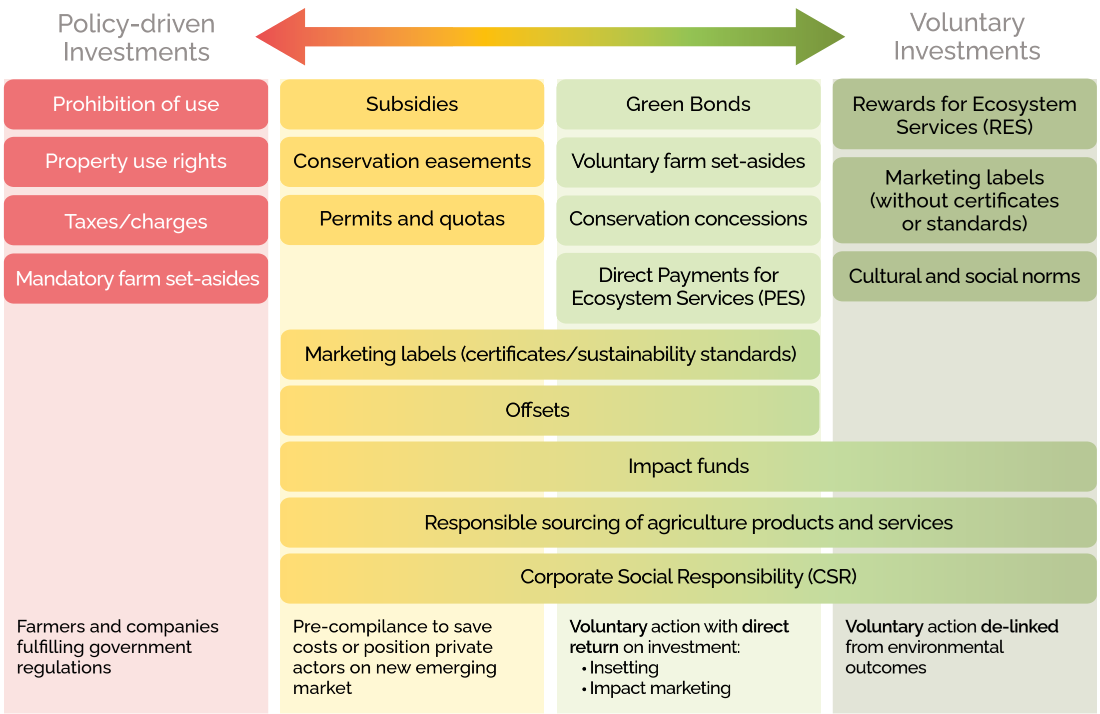
BOX 5.8 (CONTINUED)

FIGURE 5.1 ECOSYSTEM SERVICES FROM LAND, SOIL AND WATER



Source: **FAO**. 2021. Incentives for ecosystem services. In: *Land & Water*. Rome. www.fao.org/land-water/overview/integrated-landscape-management/incentives-for-ecosystem-services/en

FIGURE 5.2 SOURCES OF INCENTIVES



Policy-driven Investments ⟷ Voluntary Investments

Policy-driven Investments			Voluntary Investments
Prohibition of use	Subsidies	Green Bonds	Rewards for Ecosystem Services (RES)
Property use rights	Conservation easements	Voluntary farm set-asides	Marketing labels (without certificates or standards)
Taxes/charges	Permits and quotas	Conservation concessions	Cultural and social norms
Mandatory farm set-asides		Direct Payments for Ecosystem Services (PES)	
	Marketing labels (certificates/sustainability standards)		
	Offsets		
	Impact funds		
	Responsible sourcing of agriculture products and services		
	Corporate Social Responsibility (CSR)		
Farmers and companies fulfilling government regulations	Pre-compilance to save costs or position private actors on new emerging market	**Voluntary** action with **direct return** on investment: • Insetting • Impact marketing	**Voluntary** action **de-linked** from environmental outcomes

Source: **FAO**. 2021. Incentives for ecosystem services. In: *Land & Water*. Rome. www.fao.org/land-water/overview/integrated-landscape-management/incentives-for-ecosystem-services/en

An adapted resilient watershed management approach is being applied in several FAO projects, including in Peru and the Philippines, which includes climate change and disaster risk management in the overall integrated watershed management approach. Projects also incorporate a landscape approach, where planning, design and implementation are carried out based on specific areas affected by a particular hazard, including microwatersheds, multiple watersheds or risk reduction opportunity areas. The overall aim is to strengthen the resilience of communities and ensure sustainable ecosystem services, while reducing existing disaster and climate risks and preventing new ones.

Interlinkages: from integrated water resources management to nexus approaches

Integrated water resources management is now widely endorsed as the dominant global approach to water management, supported by SDG target 6.5: "By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate". Integrated water resources management uses water as an entry point to stress the need for coordinated development and management of water, land and related resources, to resolve trade-offs across multiple water users, acknowledging the interconnected nature of hydrological resources, and balancing social, economic and environmental goals.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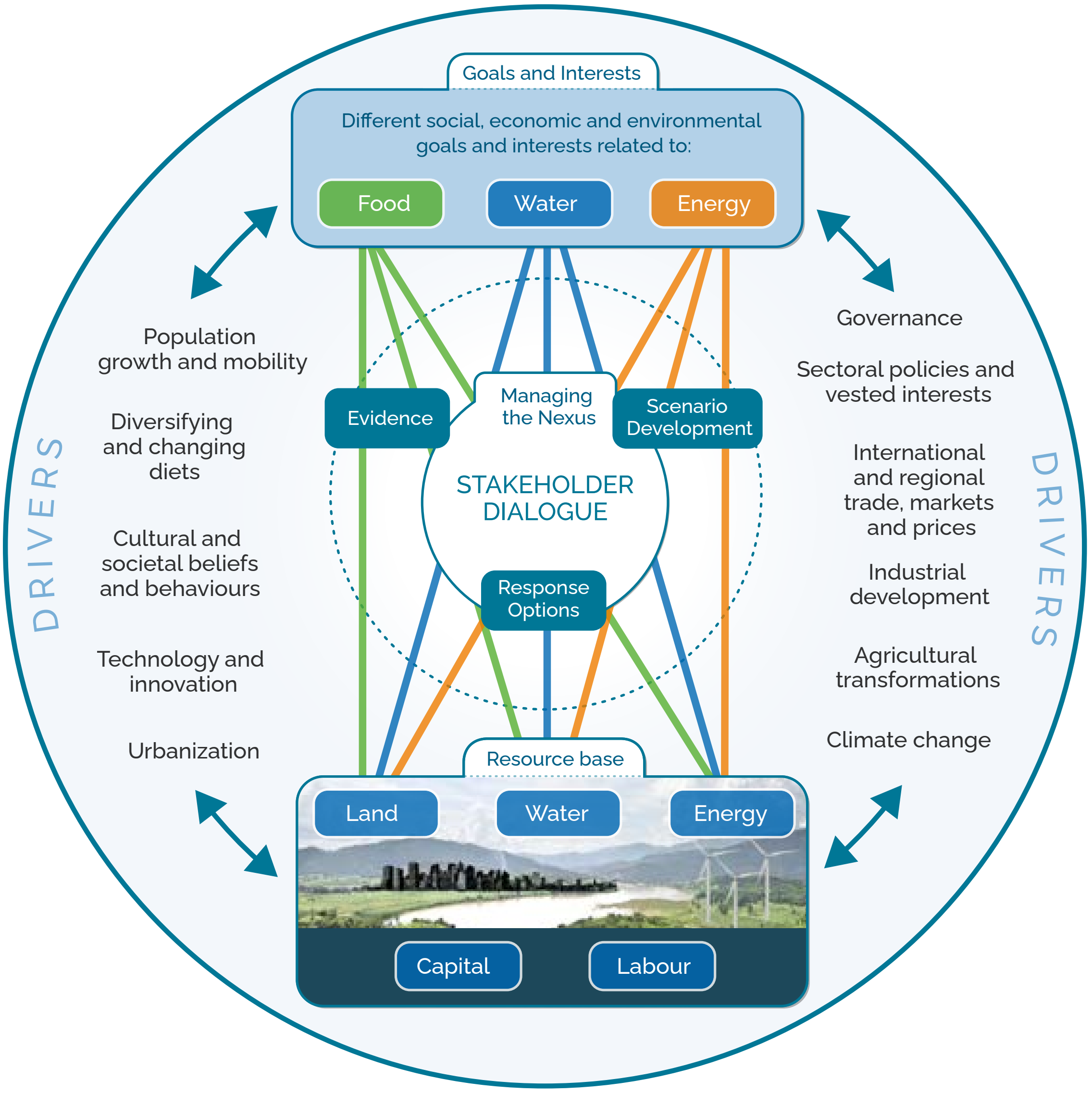
Nexus approaches attempt to tackle the challenges facing IWRM by bringing sectors together as an interrelated system; the most well-developed such approach is the water–food–energy nexus. FAO adopted this to develop sustainable food and agriculture based on integrated land, water and ecosystems (FAO, 2014b). Nexus approaches inevitably introduce higher levels of complexity but also present opportunities for more comprehensive policy solutions. Despite the challenges, implementing this approach at various scales of governance reveals lessons concerning different intersectoral assessment and analytical tools that require tailoring to produce policy-relevant outcomes (Allouche, Middleton and Gyawali, 2015; Albrecht, Crootof and Scott, 2018) (Figure 5.3).

The Economic Commission for Latin America and the Caribbean has published a methodological guide on the design of actions with a focus on the nexus between water, energy and food for Latin American and Caribbean countries (Naranjo and Willaarts, 2020). It has also developed training videos to support countries to evaluate and adopt the nexus approach in policies, plans, programmes and projects in the water, energy, agriculture and environment sectors.

Case studies applying the nexus approach in the Central and Southern America subregions (irrigation policy in the Plurinational State of Bolivia and Chile, multipurpose dams in the Plurinational State of Bolivia and Ecuador, and IWRM in the Plurinational State of Bolivia) demonstrate the benefits and synergies of integrated policies in achieving food, water and energy security and more efficient use of resources contributing to SDGs 2, 6, 7 and 13. They require policy leadership and alignment, participation and consensus-building across actors and sectors, coherent planning and finance (Economic Commission for Latin America and the Caribbean, 2021). Box 5.9 illustrates the nexus experience in irrigated agriculture in Asia.

FIGURE 5.3 THE NEXUS APPROACH



Source: **FAO**. 2014. *The water-energy-food nexus: A new approach in support of food security and sustainable agriculture.* Rome. www.fao.org/3/bl496e/bl496e.pdf

5.4.2 Initiatives to address climate change impacts

Climate-smart agriculture now helps guide actions needed to transform and reorient agricultural systems to effectively support development and ensure food security in a changing climate. It has three main pillars: sustainably increasing agricultural productivity and incomes, adapting and building resilience to climate change, and reducing and removing GHGs where possible. FAO mobilizes resources for climate-smart agriculture implementation and knowledge-sharing to contribute to FAO strategic objectives to make agriculture, forestry and fisheries more productive and sustainable. Knowledge has been synthesized and updated from applica-

BOX 5.9
THE NEXUS APPROACH

Breaking the deadlock for irrigated agriculture in India

Gujarat is one of the driest states in India. In the 1980s, electricity subsidies encouraged private investment in tube wells to facilitate groundwater irrigation and boost rural food and livelihood security. Unfortunately, this led to heavily depleted aquifers.

In 2003, the state government initiated Jyotigram Yojana, which is a policy for "intelligent power rationing" that separates electricity lines for agricultural and non-agricultural users. This limited power to farms while allowing continuous supply for domestic and industrial users. Farmers accepted the rationed supply because the reduced supply enabled uninterrupted service, reduced the aggregate subsidy burden and capped groundwater withdrawals without hurting farmer welfare. The campaign affected more than 40 million people over 3.5–4.0 million ha of irrigated agriculture, reorganized, modernized and increased power generation capacity, and raised agricultural GDP by nearly 10 percent while restoring groundwater levels.

The state government later introduced solar-powered irrigation pumps to explore whether farmers would use their land to increase solar power for irrigation and earn income by selling surplus solar energy. Over 45 months, members of the cooperative sold over 250 thousand kWh of electricity worth USD 22 000. In 2018, this approach reached up to 33 districts. Rather than focusing on sector-based processes, the political will to seek optimized solutions was critical in breaking the deadlock among the sectoral stakeholders (Bird *et al.*, 2014; Shah, 2022).

The nexus approach in the Red River basin in Viet Nam

Reservoirs in the upstream reaches of the Red River in northern Viet Nam regulate flows and generate much of the electricity needed for the modernization and industrialization strategies of Viet Nam. The same system supplies water for domestic use for irrigating 750 000 ha of rice in the Red River delta, which is critical to social stability and food security. Most irrigation systems use electric pumps with energy supplied from upstream hydropower schemes.

As water becomes scarce and competition between the energy and agricultural sectors increases, there is still a lack of reliable and policy-relevant data and information to guide water allocation choices. Effective intersectoral consultation is needed to address this problem and to ensure decisions on water release and allocation are taken as part of an integrated, long-term and multisectoral strategy.

tions across the regions in a climate-smart agriculture sourcebook (FAO, 2017e). Successful case studies have been analysed and documented to show how the management of farms, crops, livestock and aquaculture can reduce climate risks/impacts, and balance short- and long-term food security needs with priorities to enable farmers to adapt to and mitigate GHGs (FAO, 2018a).

Measures to adapt to and mitigate the impacts of climate change in agriculture are part of a continuum ranging from addressing the drivers of vulnerability to those explicitly targeting the impacts of climate change. The landmark KJWA (Box 5.10) places soil and water management practices within a systems approach for tackling mitigation and adaptation in agriculture. Specific issues addressed under KJWA include

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methods and approaches for assessing adaptation, adaptation cobenefits, mitigation, improved soil carbon, health and fertility in grasslands and croplands and improved livestock management, including agropastoral production and water management. Through their work, two UNFCCC subsidiary bodies – the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation – emphasize agriculture and food system vulnerabilities to climate change, drive transformation, and identify the synergies and trade-offs among adaptation, mitigation and agricultural productivity, explicitly referencing soil and water management.

Adaptation requires a focus on irrigated and rainfed systems. Changes in water availability and seasonal distribution driven by climate change amplify the pressures and competition for water among all water-using sectors. Soil- and water-conservation measures, rainwater harvesting and increasing water storage reduce the risks of floods and droughts. Sustainable improvements in land and water productivity for irrigated crops under conditions of scarcity align well with adaptation. So does conservation agriculture for rainfed farming. Improving water-conservation measures and soil health enables farmers to diversify their systems, amend cropping patterns and introduce aquaculture. More attention to climate forecasting and early warning systems will also support adaptation. Figure 5.4 offers a logical framework for planning and implementing changes in land and water management for adapting to climate change in Eastern Africa.

Soil-centred initiatives

Sustainable soil management helps to minimize GHG emissions, including reducing nitrous oxide emissions (primarily from fertilizer misuse), reducing methane emissions (e.g. from paddy rice systems, and draining peatlands and wetlands) and reducing carbon dioxide emissions (e.g. from burning and tillage).

Conservation agriculture is a movement that has been expanding worldwide and is now practised on about 180 million ha of cropland, corresponding to about 12.5 percent of the total global cropland. It has increased by some 69 percent globally since 2008. Its adoption has been reported by 78 countries, with largest extents in Southern and Northern America, followed by Australia and New Zealand, Asia, Russian Federation, Ukraine, Europe and Africa. The combined application of no or minimum mechanical soil disturbance, crop rotations that improve SOM and the use of cover crops or mulch contribute to reduced carbon dioxide emissions and enhance soil carbon sequestration (Kassam, Friedrich and Derpsch, 2018).

The Global Peatlands Initiative is an effort to improve the conservation, restoration and sustainable management of peatlands in over 180 countries worldwide (Chapter 1). In 2012, FAO, the Migration of Climate Change in Agriculture programme and Wetlands International launched the organic soils and peatlands climate change mitigation initiative, in which ten institutions were involved.

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BOX 5.10
KORONIVIA JOINT WORK ON AGRICULTURE

The Conference of the Parties to UNFCCC, at its twelfth plenary meeting (17 November 2017):

"*Recalling* decision 2/CP.17, particularly paragraphs 75–77,

Having considered the reports to the Subsidiary Body for Scientific and Technological Advice on the five in-session workshops on issues related to agriculture,

1. *Requests* the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation to jointly address issues related to agriculture, including through workshops and expert meetings, working with constituted bodies under the Convention and taking into consideration the vulnerabilities of agriculture to climate change and approaches to addressing food security;

2. *Invites* Parties and observers to submit, by 31 March 2018, their views on elements to be included in the work referred to in paragraph 1 above for consideration at the forty-eighth sessions of the subsidiary bodies (April–May 2018), starting with but not limited to the following:

    (a) Modalities for implementation of the outcomes of the five in-session workshops on issues related to agriculture and other future topics that may arise from this work;

    (b) Methods and approaches for assessing adaptation, adaptation co-benefits and resilience;

    (c) Improved soil carbon, soil health and soil fertility under grassland and cropland as well as integrated systems, including water management;

    (d) Improved nutrient use and manure management towards sustainable and resilient agricultural systems;

    (e) Improved livestock management systems;

    (f) Socioeconomic and food security dimensions of climate change in the agricultural sector;

3. *Requests* that any actions of the secretariat resulting from the provisions in paragraph 1 above be undertaken subject to the availability of financial resources;

4. *Also requests* the subsidiary bodies to report to the Conference of the Parties on the progress and outcomes of the work referred to in paragraph 1 above at its twenty-sixth session (November 2020)."

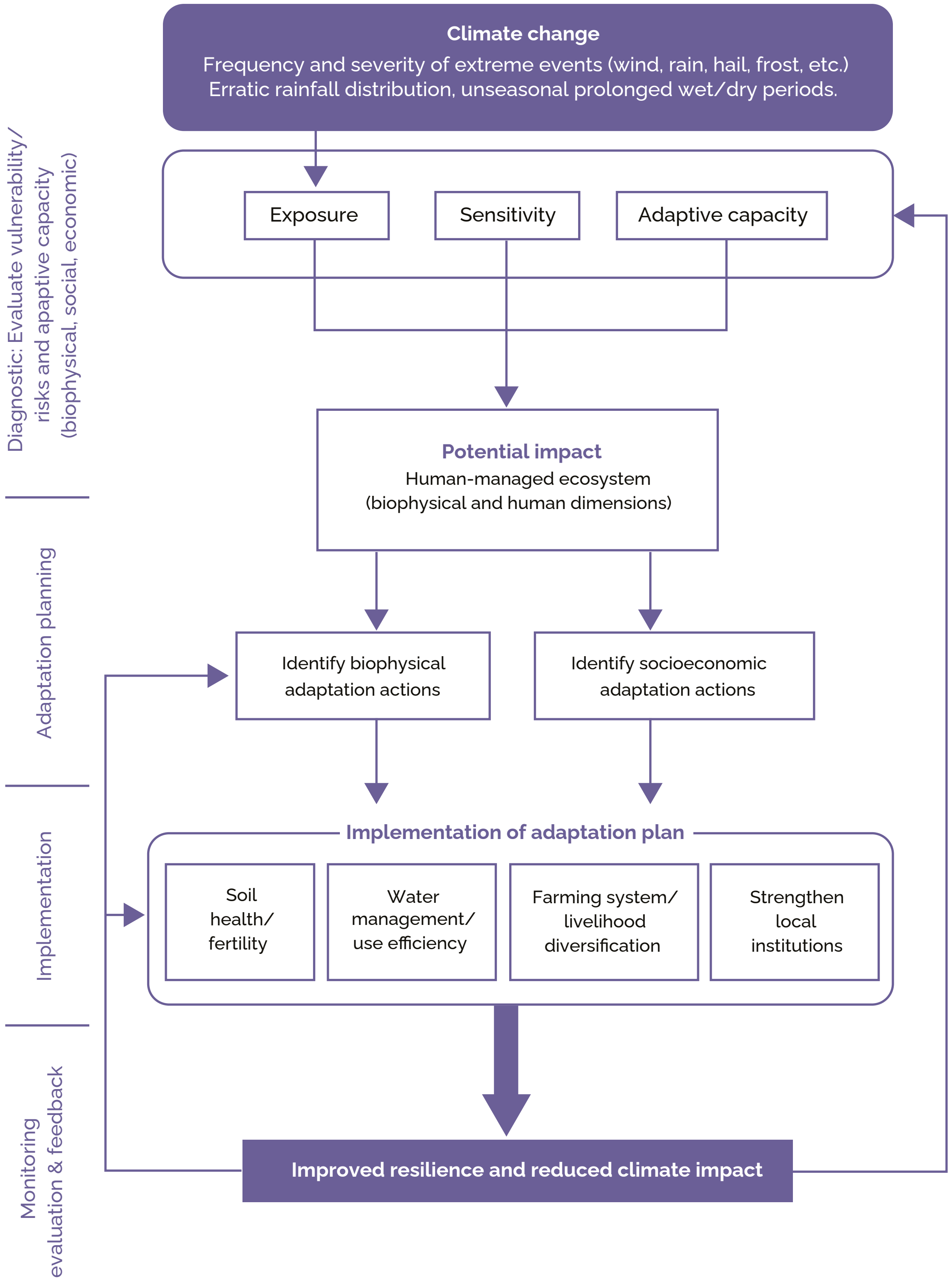
In June 2019, the two subsidiary bodies also requested the secretariat to organize an intersessional workshop to take into account two further topics:

- sustainable land and water management, including integrated watershed management strategies, to ensure food security; and

- strategies and modalities to scale up implementation of best practices, innovations and technologies that increase resilience and sustainable production in agricultural systems according to national circumstances.

Source: **United Nations Framework Convention on Climate Change.** 2018. Decision 4/CP.23. In: *Report of the Conference of the Parties on its twenty-third session, held in Bonn from 6 to 18 November 2017.* FCCC/CP/2017/11/Add.1.
https://undocs.org/en/FCCC/CP/2017/11/Add.1

FIGURE 5.4 LOGICAL FRAMEWORK FOR ADAPTING TO CLIMATE CHANGE THROUGH LAND AND WATER MANAGEMENT IN EASTERN AFRICA



Source: **FAO**. 2014. *Adapting to climate change through land and water management in Eastern Africa: Results of pilot projects in Ethiopia, Kenya, and Tanzania.* Rome. www.fao.org/publications/card/en/c/96164f0a-c3dc-422d-afc3-1b3f605aefd3

FAO is also supporting countries in peatland mapping and monitoring (FAO, 2020d).

Recarbonization of Global Soils is a GSP initiative for recarbonizing agricultural soils worldwide through SOC sequestration. The GSP has the tools to assess and map SOC stocks and their potential, and measure, report and verify SOC sequestrations and the impact on GHG emissions (FAO, 2022a). From 2021, it has supported countries to establish agreements with farmer organizations and provide technical support for adopting a set of soil management practices and incentives through green benefits and carbon credits.

Nature-based solutions

The NbS approach can help mitigate drought and floods, notably through watershed and river basin management, increasing and maximizing water storage capacities upstream that slow the release of water, providing flood protection, and increasing preparedness in low-lying lands and urban areas (FAO, 2018b) (Box 5.11). Such integrated approaches need to be supported with land-use planning and regulations, early warning systems, and emergency response and recovery plans (WMO and GWP, 2017). Even though soils constitute one of the main reservoirs of biodiversity at the global level and host more than 25 percent of the world's biological diversity, soil biodiversity and overall sustainable soil management are neglected. The economic implications of biodiversity loss have been profound (Dasgupta, 2021).

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Agroecological approaches

Innovative approaches that target transitioning to sustainable food systems that serve food security and nutrition have emerged and found application in specific land and water settings in all regions, but to different extents according to enabling policies, technical skills and market forces. These include agroecology, conservation agriculture, organic agriculture, agroforestry, integrated crop–livestock systems and innovations for sustainable rangeland management in dry lands (Chapter 4).

Agroecological approaches combine modern agronomic methods with traditional knowledge and local food production practices, and focus on conserving water resources and soil biodiversity. They can close the nitrogen cycle, improve overall productivity and provide environmental cobenefits, including reduced waste and pollution at the landscape level and increased economic efficiency on farms (FAO, 2017f). Agroecology can play an important role in building resilience and adapting to climate change by building ecological buffers, SOM and soil moisture retention.

Conservation agriculture is an alternative to conventional tillage; it seeks to conserve natural resources while increasing crop yields. It promotes minimum soil disturbance through direct seeding or planting and reduced farm machinery traffic, maintaining soil cover and using diverse plant species to enhance biomass, SOM and soil structure. In particular, it enhances biodiversity and natural biological processes above and below ground, contributing to increased water and nutrient use efficiency and improved and sustained crop production.

BOX 5.11
NATURE-BASED SOLUTIONS HELP MITIGATE DROUGHTS AND FLOODS

An example of drought adaptation is the sand dams in seasonal river beds in Southern Africa that store increasing amounts of water as the sediments build up and the dam height is raised. Solar and treadle pumps lift water to irrigate a second cash crop and water livestock. This cost-effective technology deserves to be scaled out to build resilience to drought and climate variability.

A second example is catchment management in Rajasthan, India, which combines small-scale water harvesting structures with regenerating forest cover, soils and farmland, to help improve groundwater recharge. This has had significant impacts on water availability for a thousand villages across the state. Flow has returned and fisheries have resumed in five rivers that used to run dry after the annual monsoon season, groundwater levels have risen by some 6 m, productive farmland has increased from 20 percent to 80 percent of the catchment, and forest cover in the upper catchments has increased by 33 percent.

Examples of NbSs to reduce flooding include the construction of artificial reefs such as oyster beds to prevent sea surges, using inland low-lying delta areas for flood prevention while cultivating salt-tolerant rice varieties, and retaining flood water in coastal reservoirs for storage and cultivating halophytes (salt-tolerant plants) and salt-tolerant crops. *Natural and nature-based flood management: A green guide* (or Flood Green Guide) is a holistic NbS framework to support communities (WWF, 2017). The Global Water Partnership and the World Meteorological Organization have set out a range of approaches to decrease flood risk in watershed, river and coastal area management, and in urban areas. These approaches are combined with land-use planning, regulations, early warning systems, evacuation plans, emergency responses and recovery plans (WMO and GWP, 2017).

Labour requirements for land preparation and planting are minimal, and the reduced application of synthetic fertilizers, pesticides and fossil fuels makes conservation agriculture a practice with a low carbon footprint. Simultaneous use of these techniques has synergetic effects that allow sustainable improvements in productivity and the environment. Conservation agriculture is suited to small- and large-scale farming, and is appropriate where labour is in short supply and agricultural input costs are high (FAO and ITPS, 2015). However, it requires research–extension–farmer collaboration, adaptation and fine-tuning to each context to develop appropriate rotations, mixes of cover crops, and practices and tools for management to maximize protective cover and minimize use of herbicides. It also takes time, maybe several years, to restore soil biological functions after transitioning from conventional tillage.

Agroforestry systems

Agroforestry is a land-use system that integrates woody perennial crops and livestock to balance agricultural production with sustainable harvesting of forest resources. Agroforestry includes forest farming, alley cropping, and the use of riparian forest buffers and windbreaks. Many of the practices are part of traditional land-use systems, which can benefit from introducing new technologies to enhance synergetic effects (pest and disease control or nutrient uptake) and productivity. Agroforestry systems can significantly improve soil fertility, especially when practised with conservation agriculture. Yields of grain crops are usually higher under specific trees such as leguminous species than in open fields. This is attributed to higher SOM and the fertilizing effect of decomposing foliage and dung droppings of animals grazing in the shade of trees in agroforestry settings (Box 5.12).

Integrated crop–livestock systems

Integrated crop–livestock systems benefit from the synergies of crop rotations and animal wastes to restore soil nutrients and produce fodder crops and residues to enhance animal productivity. They include agropastoral systems that control grazing to improve biomass production and livestock quality and productivity, and short-season cropping. Examples include sedentary farmers, who raise livestock herds, the size of which varies according to farmland area and access to grazing land or fodder within the vicinity of the farm, and transhumant pastoralists who move from lowlands to highlands or may plant a crop on their seasonal migration to wet-season pastures (up to 100 km away) and harvest upon their return. There are different degrees of transhumance, size and composition of livestock herds, and types of cropping systems associated with such mixed systems (Box 5.13).


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Mitigation and adaptation are also central concerns for sustainable and resilient livestock systems. The livestock sector is a major user of land and water resources. Efforts need to be made where possible to reduce soil degradation, consumptive use of water and pollution from intensive systems, in response to water scarcity and climate change. Solutions include soil and water conservation, improved water storage and delivery to reduce losses, improved water productivity in feed crops, use of manure for cropland, and use of wastewater for grazing land, buffer strips and wetland management to reduce runoff and nutrient entry into waterways.

BOX 5.12
AGROFORESTRY CAN ENHANCE SOIL FERTILITY

Combining agroforestry with conservation farming is emerging as an affordable and accessible science-based solution to reduce soil depletion and increase smallholder food production. Millions of farmers in Burkina Faso, Malawi, Niger and Zambia are restoring depleted soils and increasing crop yields and incomes using this approach. The most promising results come from integrating “fertilizer trees”, such as *Sesbania*, *Gliricidia*, *Tephrosia* and the indigenous *African Acacia* (*Faidherbia albida*), into cropping systems. These improve soil fertility by facilitating nitrogen uptake from the air and transferring it to the soil through their roots and leaf litter.

In Zambia, 160 000 farmers grow food crops within the agroforests of *Faidherbia* covering 300 000 ha. The Conservation Farming Unit observed that unfertilized maize yields in the vicinity of *Faidherbia* trees averaged 4.1 tonnes/ha, compared with 1.3 tonnes/ha beyond the tree canopy. Similar promising results have emerged from Malawi, where maize yields increased by up to 280 percent under the canopy of *Faidherbia* trees compared with the zones outside. In Niger, there are now more than 4.8 million ha of *Faidherbia*-dominated agroforests, enhancing millet and sorghum production.

Source: **Garrity, D.P., Akinnifesi, F.K., Ajayi, O.C., Weldesemayat, S.G., Mowo, J.G., Kalinganire, A., Larwanou, M. & Bayala, J.** 2010. Evergreen agriculture: A robust approach to sustainable food security in Africa. *Food Security*, 2(3): 197–214.

A wide range of land and water management practices exist for sustainable pastoral and agropastoral systems in rangelands, which have evolved over generations to support the livelihoods of sedentary and nomadic communities (see the focus on dryland systems at the end of Chapter 4).

Since 2012, the FAO-led Livestock Environmental Assessment and Performance multi-stakeholder global initiative has aimed to accelerate sustainable development of the livestock supply chain. Support includes integrating livestock into NDCs under the Paris Agreement (reported in 92 countries), quantitative assessment and improved management practices to reduce emissions from livestock systems by about 30 percent. Guidelines include measuring and modelling soil carbon stocks and stock changes in livestock production systems (FAO, 2019b), assessing water use in livestock production systems and supply chains (Davies *et al.*, 2018) and environmental performance of feed additives in livestock supply chains (FAO, 2020e).

BOX 5.13
REDUCING RISKS, ADDRESSING VULNERABILITY AND ENHANCING PASTORALIST RESILIENCE IN AFRICA

Pastoralism is the main livelihood for about 268 million people across Africa's dry lands, from the Sahelian West to the rangelands of Eastern Africa and the Horn of Africa, and the nomadic populations of Southern Africa. It represents one of the most viable, and sometimes the only suitable, livelihood options in dry lands. It makes enormous contributions to social, environmental and economic well-being in dryland areas and beyond. The mobility of pastoralists exploiting animal feed resources along different ecological zones represents a flexible response to a dry and increasingly variable environment. Pastoralism ensures livestock access sufficient high-quality grazing, and creates economic value by converting scarce natural resources into meat, milk, income and livelihoods.

Yet, pastoral livelihoods have been severely undermined by decades of neglect (with as low as 1 percent of government budget allocation), violence and displacement, insecure land rights and access, deteriorating natural resources, climate variability and change, and growing risk of animal and zoonotic diseases. The pastoral system is increasingly threatened despite demonstrated remarkable resilience and being well adapted to manage the risks and uncertainties faced in Africa's dry lands. Pastoralist populations are increasingly vulnerable to malnutrition and food insecurity as their capacity to adapt to and recover from crises declines in the face of recurrent and often overlapping shocks.

FAO advocates for enhanced efforts and more robust partnerships among all actors to strengthen the resilience of pastoral livelihoods through a deliberate mix of short-, medium- and long-term actions across the humanitarian–development–peace nexus. Exchange of experiences and analysis by experts and partners in Western and Eastern Africa and consultation under FAO resilience hubs in Kenya and Senegal in 2018 led to several recommendations, including engaging pastoralists in policymaking and decision-making, engaging local, national and regional partners to address the cross-border dimension of pastoralism, and developing livelihood-based information and monitoring systems.

Moreover, the development of an enabling policy environment for sustainable pastoral and agropastoral systems in marginal and fragile ecosystems should also consider incentives for the private sector to flourish and continued investments in innovation and technologies.

Source: **FAO**. 2018. *Pastoralism in Africa's drylands: Reducing risks, addressing vulnerability and enhancing resilience.* Rome. www.fao.org/3/CA1312EN/ca1312en.pdf


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5.5 Action area III: Embracing innovative technologies and management

A wide range of innovative technological and management responses are now available within the immediate farming domain for rainfed (dry lands) and irrigated farming. They include practices for achieving sustainable soil management, restoring soil health, improving soil water management, accessing non-conventional water resources, adopting NbSs, managing environmental risks, coping with climate change, reducing carbon emissions, and using information and communications technology (ICT) and big data. They also include prospects for scaling up and implementing technical solutions.

Agricultural agencies need to update the capacity and tools for managing GISs, developing and using maps and plans, and monitoring trends and impacts. These tools are now required to manage agricultural production and mitigate GHG emissions from land.

For irrigated agriculture, more capital-intensive options are available for augmenting water resources and modernizing irrigation systems. Improving crop water productivity and water-use efficiency and investing in non-conventional water resources are among the technical options for improving irrigation production systems.

The management of dry lands is an important aspect of sustainable agriculture land and water management and restoring degraded lands, given their extent, populations affected in terms of poverty and climate change and variability, and opportunities for investment. The focus on dryland systems at the end of Chapter 4 analyses drivers and pressures and appropriate responses for sustainable land and water management including dryland cropping, and livestock and rangeland management.

5.5.1 Sustainable soil management and soil health

Led by FAO through GSP, there is an iterative process of country to global assessments, international symposia and outcome documents outlining status, threats and responses. This has led to data collection, raised awareness, action plans, solutions and guidance for addressing loss of SOM and SOC (issued in 2017), soil erosion (2019), nutrient imbalance and use of fertilizers (2019), loss of soil biodiversity (2020), soil pollution (2021) and salt-affected soils (2021).

A wide range of proven soil- and water-conservation technologies are available to reduce runoff, tackle soil erosion, restore SOM and SOC, and improve soil fertility. These include regenerative agriculture practices to build soil health and reverse adverse effects of tillage, such as conservation agriculture, intercropping, agroforestry and sustainable rangeland management. Successful intervention approaches include FFS approaches for capacity-building and information exchange, and watershed or other territorial planning and management.

The *Voluntary guidelines for sustainable soil management* (FAO and ITPS, 2017) guide strategic and context-specific decision-making at all levels to promote practices that address soil threats and the means to restore and maintain soil health (Box 5.14). The GSP secretariat and the Intergovernmental Technical Panel on Soils have established a protocol to assess the voluntary guidelines' interventions and to ensure improvements in production systems, ecosystem restoration and carbon sequestration are sustainable (FAO and ITPS, 2020) and to address the interlinked problems of land degradation, climate change and biodiversity loss.

The WOCAT database, endorsed by UNCCD for country sharing of best practices, provides many SLM practices and experiences. There is a need to encourage further sharing of technologies, innovation and results from different ecological and socioeconomic contexts, and across actors and institutions, for example, to reduce soil and water contamination, ameliorate soil salinization, restore soil biodiversity, and improve water use and reuse in rainfed and irrigated systems.

Soil and crop management practices should provide a favourable environment for soil organisms and their biological activity, such as reducing soil disturbance, maintaining soil cover and rotating crops. Inoculating selected *Bradyrhizobium* bacterial strains in soybean production is a successful and cost-effective biotechnology used in Argentina, Brazil and Uruguay to replace mineral nitrogen fertilizers and to avoid leaching and volatilization of nitrogen compounds (Franco, 2009). Wider uptake of such practices requires filling knowledge gaps, good research–extension–farmer links and supportive policy (Box 5.14).

The Global Soil Doctors programme launched in 2020 is a farmer-to-farmer training initiative to enhance farmer capacities and knowledge in sustainable soil management at the farm level. The programme has been successful in some countries in Asia and particularly useful in locations where soil extension services are weak or absent. It aims to empower farmers within a community by training a lead farmer (soil doctor) in diffusing methods and tools to detect and provide practical solutions to soil degradation. It provides educational materials and a soil testing kit for assessing soil conditions and a set of good practices under the sustainable soil management voluntary guidelines.

Despite significant growth in the use of chemical fertilizers in some countries, such as in sub-Saharan Africa, soil testing and fertilizer use are low due to high costs, weak supply chains and lack of extension to support their wise use on farms. Fertilizers require tailoring to site-specific ecological and socioeconomic conditions. The International Code of Conduct for the Sustainable Use and Management of Fertilizers (Fertilizer Code) offers guidance to tackle misuse, underuse and overuse of fertilizers, bearing in mind nutrient imbalances and soil and water pollution (FAO, 2019c).

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BOX 5.14
SOIL BIOLOGICAL DIVERSITY AT THE HEART OF SUSTAINABLE SOIL MANAGEMENT

The Post-2020 Global Biodiversity Framework for soil biodiversity and ecosystem services is critical to the success of the recently declared United Nations Decade on Ecosystem Restoration (2021–2030). Maintaining soil biodiversity is an effective NbS to address degradation, food insecurity, climate change and poverty-related problems facing humanity from the field scale to the global scale.

This requires increased attention to the conservation and sustainable use of biodiversity as part of sustainable soil management practices to restore SOM and the substrate for soil organisms, and to increase favourable conditions for soil biological activity. This includes the vital role of soil organisms in plant growth and nutrition (on which crop and livestock productivity depend), and mitigating processes of land degradation.

Soil biodiversity is the large reservoir of organisms in the soil responsible for a multitude of soil functions from microbial bacteria, fungi and microfauna (nematodes and protozoa) that are invisible to the naked eye, to mesofauna (mites and springtails) to macrofauna (centipedes, millipedes, ants, ground beetles, spiders and earthworms) and megafauna (moles and other vertebrates) that live on and in the soil. More than 40 percent of living organisms in terrestrial ecosystems are directly associated with soils during their life cycle.

These soil organisms are largely invisible yet make a vital contribution to agricultural production. They make macro and micro nutrients available for growth and nutrition, and minimize cost and dependence on synthetic fertilizers in agriculture by:

- providing the nutrients in soils that plants need to fix carbon from the atmosphere and create biomass;
- playing a vital role in the physical breakdown of plant residues and allowing soil microorganisms to liberate nutrients and energy bound up in the organic plant material;
- participating in filtering, degrading and immobilizing contaminants in water and soil; and
- including "ecosystem engineers" that modify soil porosity, water and gas transport, and bind together soil particles into stable aggregates that hold the soil in place, reducing soil erosion, and retaining soil moisture and nutrients.

Source: **FAO, Intergovernmental Technical Panel on Soils, Global Soil Biodiversity Initiative, Convention on Biological Diversity & European Commission.** 2020. *State of knowledge of soil biodiversity: Status, challenges and potentialities.* Rome, FAO. https://doi.org/10.4060/cb1928en

Integrated soil fertility management is a strategy for combining organic and inorganic mineral nutrients. It relies on nutrient application from organic inputs such as compost, manure and inorganic fertilizers, together with growing nutrient-fixing crops in rotations, growing cover crops and minimum tillage. Mixing organic and inorganic (mineral) fertilizers can optimize nutrient availability according to soil deficits, crop type and growth stage, and has many positive interactions. However, for lasting effects on soil health, it is essential to avoid soil pollution and soil tillage. The integrated soil fertility management framework has proved its suitability for an extensive range of soil fertility conditions, agroecological zones and cropping systems (Roobroek *et al.*, 2015).

Combining organic and mineral fertilizers and implementing sustainable soil management practices can also support nutrition-sensitive agriculture (FAO, 2014c). Research

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data confirm the micronutrient superiority of some lesser-known cultivars and wild varieties over other, more extensively utilized cultivars. For example, sweet potato cultivars differ in their carotenoid content by two orders of magnitude or more, the protein content of rice varieties can range from 5 percent to 13 percent, and the provitamin A carotenoid content of bananas can vary from 1 µg/100 g to 8 500 µg/100 g among cultivars. This shows the importance of selecting crop varieties for food composition and not just for yield (Burlingame, Charrondiere and Mouille, 2009).

5.5.2 Addressing drought in rainfed systems

Improving rainfed agricultural production requires optimizing soil moisture and making the best use of rainwater by maximizing infiltration and minimizing runoff and evaporation. Soils provide the buffer between rainfall events and crop water demands, and help protect crops against drought, flood and climate variability. Sustainable soil management practices, including integrated soil fertility management, complement and enhance buffering for nutrients and pH through building up SOM and improving cation exchange capacity. They offer the potential to increase production and provide reliable yields.

Soil water is usually the only source available for producing biomass, and this depends mainly on the soil's capacity to store water during the dry seasons. Water availability correlates directly with SOC, soil structure and nutrient availability (FAO, 2020f). Deep, non-stony, non-saline, fine-textured and organic carbon-rich soils have the highest available water-holding capacity and so are more resilient to droughts.

A package of incentives for sustaining ecosystem services can overcome barriers to more sustainable agricultural systems, combining public policies to improve farm productivity with those that reward conservation practices and partnering with green business strategies. Case studies illustrate the value of incentives for groundwater recharge and watershed management for water supply and quality (FAO, 2022b).

Enhancing water productivity in rainfed systems

Recent productivity measures have focused on nutritional water productivity, "better nutrition per drop" (Renault and Wallender, 2000), linking water, agriculture and nutrition (Lundqvist and Unver, 2018). FAO is exploring the concept of nutritional water productivity and expanding the methodology to include crop production, nutrient content and economic value (Lundqvist *et al.*, 2021). Another approach from an ecological perspective suggests using "less drop per crop" as a measure of wise water use.

The scope for improving water productivity varies with production systems and regions. Water productivity is higher in Australia, Europe, Northern America and the Yellow River basin in China. Areas with the highest potential for water productivity gains are sub-Saharan Africa and South, Southeast and Central Asia.

BOX 5.15

RAINWATER HARVESTING SERVES PROTECTED CROPPING IN LEBANON

Lebanese growers using protected cropping under glass were concerned about the reliability of groundwater and its overexploitation, and have turned to rainwater harvesting from microcatchments as an alternative water source. National guidelines for greenhouse rainwater harvesting systems offer information to growers on all aspects of design and installation. They provide a brief overview of greenhouse types used in Lebanon, irrigation scheduling, crop water requirements and main crops grown in protected environments. They focus on microcatchment rainwater harvesting systems (direct/indirect pumping and gravity fed) and describe the main system components that follow the water flow, starting with the catchment area, collection and conveyance system, rainwater quality, and pretreatment, storage and pumping and distribution systems.

FAO has developed a multicriteria assessment method for selecting water harvesting methods. Each criterion pools several dedicated indicators to appraise the suitability of techniques and support decision-making.

Source: **United Nations Development Programme & Lebanese Ministry of Energy and Water**. 2016.
National guideline for rainwater harvesting systems. Beirut.

The water productivity index (WPI) was introduced as a tool to support policymakers in making more informed decisions on water resources management and allocating scarce water resources. However, changes in WPI can be attributed to factors other than water, such as national macroeconomy structure, applied technologies and management practices, and climatic conditions that short-term policy measures cannot modify. Furthermore, WPI does not reflect the uneven spatial distribution of resources or geographic conditions and may mask local differences. However, WPI is useful for assessing incremental benefits at different scales, from individual crops, farms and irrigation systems to basins and regions.

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Harvesting rainwater

Water harvesting offers opportunities for improving agricultural productivity in dry regions. It can boost yields two to threefold over rainfed production, especially when combined with minimum-tillage methods that enhance water conservation (Oweis, 2016). Water harvesting can also augment available irrigation water supplies (Box 5.15) and improve household access to water.

The WOCAT water harvesting guidelines for good practice (WOCAT, 2013) provide comprehensive and practical advice covering a wide range of flood, macro and micro catchments, and rooftop/courtyard water harvesting techniques. Although rainwater harvesting is a common practice, even for household use, it is illegal for households to capture rainfall in the arid states of Colorado and Utah in the United States of America. Likewise, in Chile, the Water Code enables farmers to abstract surface water and groundwater, but does not allow them to harvest surface water runoff from the land. Uneven water access, due to the allocation of rights of water access to initiatives with the greatest market value, is


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a critical issue as large-scale farmers with inherited or traded rights are able to extract disproportionate amounts of water (a large share for export crops), which can compromise smallholder and rural community access (OECD, 2017; Lobos, 2021).

The conjunctive management of groundwater and surface water needs to be enhanced in countries through integrated watershed/basin management with all stakeholders. It also needs to take into account the current water rights and climate change context, to safeguard the interests of smallholders and other water users reliant on ecosystems services for their livelihoods.

5.5.3 Coping with water scarcity in irrigated systems

Agriculture dominates freshwater withdrawals, mainly through irrigated agriculture, which accounts for almost 70 percent of all freshwater withdrawals to produce 40 percent of the world's food, fibre and fuel needs. Irrigation (see Chapter 1) can remove the uncertainties of inadequate and unreliable rainfall and significantly increase crop production and water productivity when adequate water resources are available. However, irrigation has a reputation for inefficiency; in many instances, this is undeserved. The global average agricultural water-use efficiency is estimated to be 55 percent, with national figures ranging from 40 percent to 60 percent, measured as a ratio of crop water evapotranspiration to water withdrawal for irrigation (Hoogeveen *et al.*, 2015). The implication is that much of the water diverted for irrigation never reaches the crops and is lost through seepage in canal systems and poor on-farm water management, creating further problems such as waterlogging, salinity and pollution.

As water demand for agriculture increases, the 2018 United Nations SDG 6 synthesis report on water and sanitation suggested that agriculture (mainly irrigation), as the largest user of water, offers the most significant potential for saving water: "Saving just a fraction can significantly alleviate water stress in other sectors, particularly in arid countries where agriculture consumes a considerable amount of the available water resources" (United Nations, 2018). However, although it appears that significant water savings are possible, recent research shows that in many instances, "real" water savings are much less than expected (see the following section on water-use efficiency).

Meeting the increasing demand for food from limited land will lead to increases in irrigation on current rainfed croplands, where sufficient water resources are available (see FOFA scenarios in Chapter 3). There is renewed investment interest in irrigation, but developing new irrigation schemes will present significant challenges, and so will modernizing existing systems that have long been criticized for their poor overall performance, not just in terms of water-use efficiency. The lack of institutional and economic capacity may constrain development. In addition, the location and productive potential of economically water-scarce croplands are unknown (Rosa *et al.*, 2020).

Improving water-use efficiency

Terminology around water-use efficiency is confusing; different definitions exist across disciplines and scales. For example, the classic definition (ratio of water consumed by a crop to the amount of water withdrawn from a river or groundwater) is useful for planning and designing irrigation schemes. However, when it is used to evaluate performance, it assumes that any excess water applied is lost and ignores that those "losses" may be used elsewhere by others downstream. The multiplicity of definitions across disciplines and the lack of agreed terminology can lead to serious misunderstandings at technical and policy levels (Balasubramanya and Stifel, 2020).

Reducing water losses is never easy; confusion over efficiency measurements adds to the problem. This has led to traditional approaches to improving water use in irrigation, such as lining canals and switching to trickle irrigation, being challenged. Studies show that what appear to be more "efficient" technologies can increase water use rather than reduce it. FAO has published a review demonstrating that farmers investing in water-saving technologies did not return surplus water for others to use, as might be assumed (FAO, 2017g). Instead, farmers used the extra water to expand irrigated areas or switch to crops that were more water intensive, thereby increasing water productivity to improve farm incomes, but not resulting in water resource conservation or redistribution.

Similarly, on irrigation schemes described as "inefficient", seepage from irrigation distribution channels or excessive application returns to the river through soil drainage or recharge to shallow groundwater, and provides a source of water for irrigators and other users downstream. Thus, improving "efficiency" on upstream farms can reduce water available to others downstream. As such, irrigation's reputation for using too much water is not always justified (Kay, 2020). Box 5.16 illustrates the complexity of investing in technologies to save water and the unexpected consequences.

BOX 5.16
MONTANA VERSUS WYOMING: SPRINKLERS, IRRIGATION EFFICIENCY AND RECAPTURING RETURN FLOWS

In 2012, a legal case in the United States of America demonstrated the serious and unexpected impacts of increasing irrigation efficiencies to reduce water losses (called "return flows"). The Yellowstone River basin is nearly equally divided between the states of Montana and Wyoming. In 1950, the two states agreed to apportion the available water for irrigation and other purposes. However, in 2007, following a severe drought between 2000 and 2006, Wyoming invested in sprinkler and trickle irrigation to increase irrigation efficiency to use its limited water allocation better. But Montana had long benefited from the inefficiencies in Wyoming. The impact of increasing efficiency in Wyoming was to reduce the return flows to the detriment of Montana. Montana alleged sprinklers increased water consumption from 65 percent to 90 percent, reducing return flows from 35 percent to only 10 percent. Montana argued that Wyoming should have imposed administrative requirements to offset these adverse effects on Montana.

This was a complex legal case, and dealt with the laws of the doctrine of recapture. Can farmers recapture their water losses by increasing their irrigation efficiency when others downstream have long benefited from those losses? The court held that such improvements were permitted under the Yellowstone River agreement. However, this may not be the case for irrigation schemes in other parts of the world, where legislation is unclear or non-existent.

Source: **MacDonnell, L.** 2012. Montana v. Wyoming: Sprinklers, irrigation water use efficiency and the doctrine of recapture. *Golden Gate University Environmental Law Journal*, 5(2).

The FAO Water Scarcity Programme developed the Real Water Savings (REWAS) tool to assess "real" water savings in irrigation, rather than what is described as "dry" water savings (Seckler, 1996). The guiding principle is to "follow the water" (Kaune *et al.*, 2020). Box 5.17 illustrates this tool, based on the principles of water accounting.

To add to the confusion over efficiency definitions, SDG target 6.4 requires the increase in water-use efficiency, which can be described as the ratio of the gross value added per unit of water, measured in United States dollars per cubic metre. This assesses the economic and social use of water resources in terms of the value added when using water in different sectors of the economy (United Nations, 2018). Using this metric in a highly industrialized country in a temperate climate would score high efficiency values, whereas a developing country in a semi-arid climate, dependent on irrigation for staple food crops, would score low values. Thus, results published for SDG target 6.4 require careful interpretation in context to be helpful in decision-making. Steps are underway in many countries to clarify what efficiency means in a local context.

The confusion over the meaning of efficiency highlights the complex relationships among water, agriculture and poverty, and the essential need for a common language among multiple disciplines to inform decision-makers on water resources planning and management. Policymakers must be clear in the terminology they use, and understand the misconceptions in common use.

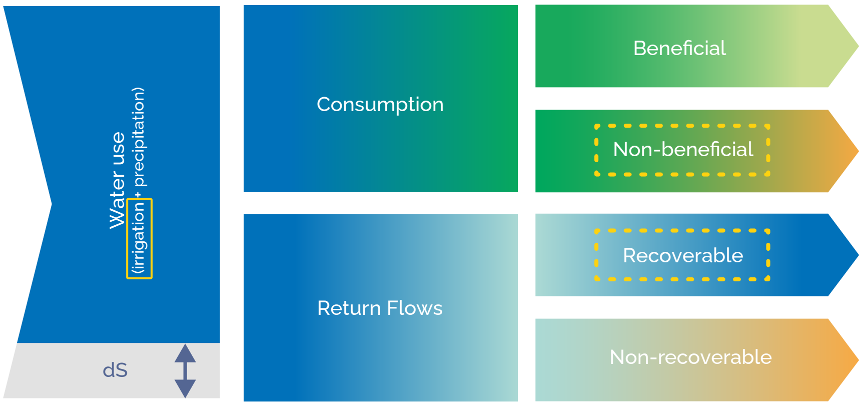
BOX 5.17
"FOLLOWING THE WATER" TO ASSESS "REAL" WATER SAVINGS

A river basin study in Nepal reported irrigation water savings of 75 percent. However, the study failed to adhere to the "follow the water" principle as it assumed that all return flows were losses. Fully accounting for all the water flows found that 80 percent of the "losses" were return flows, which were recovered and used by irrigators downstream.

The original study focused only on the amount of water diverted for irrigation and the amount used by crops. The REWAS analysis focused on the return flows and non-beneficial consumption (dotted yellow boxes in Figure 5.5) as these were recoverable and could be available for others to use.

The results showed "real" water saving in the river basin was only 6 percent.

FIGURE 5.5 **SOURCES OF INCENTIVES**



Note: dS refers to water storage in the soil.

Sources: **Droogers, P., Kaune, A., Opstal, J. Van, Perry, C. & Steduto, P.** 2020. *Training manual: Crop water productivity options to achieve real water savings.* FutureWater Report 199. Wageningen, FutureWater. www.futurewater.nl/wp-content/uploads/2020/05/FAO_Training_v11.pdf;
Kaune, A., Droogers, P., Van Opstal, J., Steduto, P. & Perry, C. 2020. *REWAS: REal WAter Savings tool: Technical Document.* FutureWater Report 200. Rome. www.futurewater.nl/wp-content/uploads/2020/06/FAO_REWAS_v08.pdf

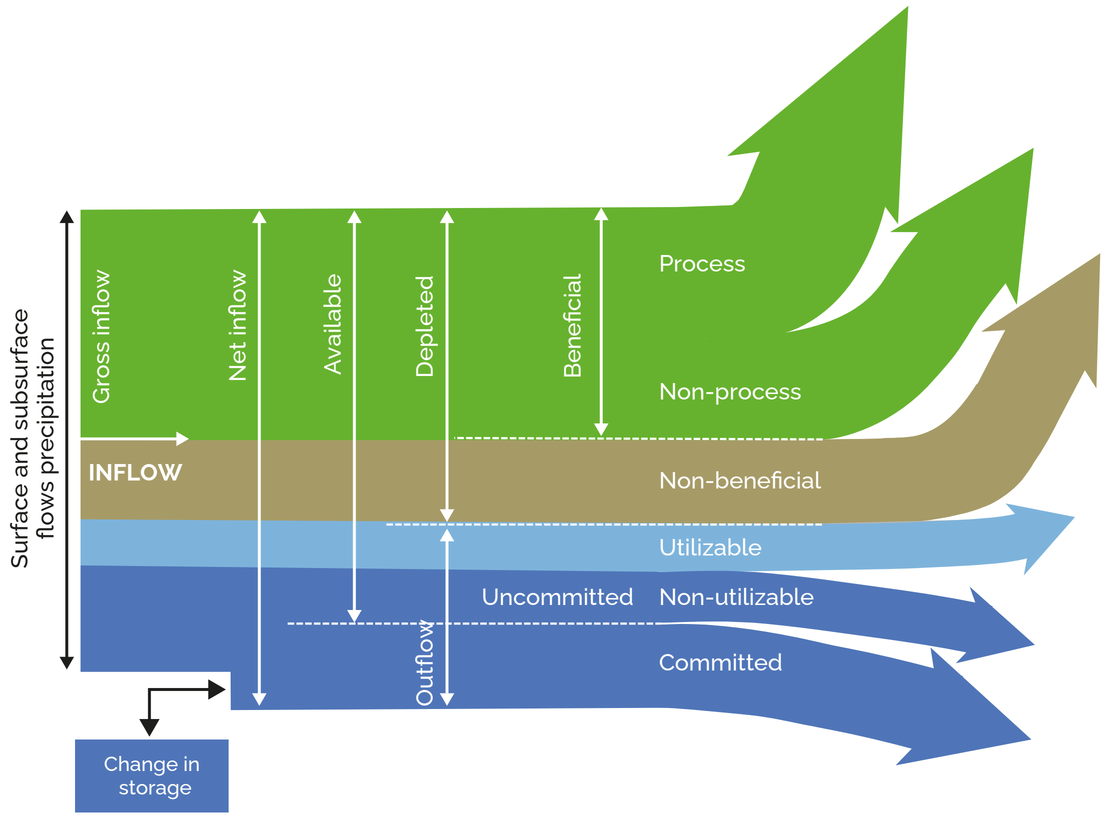
Water accounting and auditing

A growing number of international organizations are promoting water accounting and auditing as an invaluable tool for water resources planning and management, mainly when water is scarce and risks and uncertainties over water availability increase. The aim is to use water-related information better when matching and adapting coping strategies to different biophysical and societal contexts (Box 5.18).

BOX 5.18
WATER ACCOUNTING AND AUDITING

When there is competition for scarce water resources, any analysis must go beyond a simple water balance and account for proper comparison and assessment of resources and all water uses. Water accounting and auditing provides the framework. Water accounting brings together the hydrological cycle water balance with assessments of spatial and seasonal variations in the climate and medium- and long-term changes in demand across all water users (Figure 5.6). It also informs water resources planning and infrastructure investment. Water auditing provides a connection between water accounting and effective water governance by providing sound evidence for decision-making. It offers qualitative judgments to the water account and puts the recommendations of water accounting into the broader societal context of water management (Karimi, Bastiaanssen and Molden, 2013; FAO, 2016b, 2018c).

FIGURE 5.6 WATER ACCOUNTING BRINGS TOGETHER ALL WATER FLOWS AND USES



Source: **Kaune, A., Droogers, P., Van Opstal, J., Steduto, P. & Perry, C.** 2020. *REWAS: REal WAter Savings tool: Technical Document.* FutureWater Report 200. Rome. www.futurewater.nl/wp-content/uploads/2020/06/FAO_REWAS_v08.pdf

BOX 5.18 (CONTINUED)

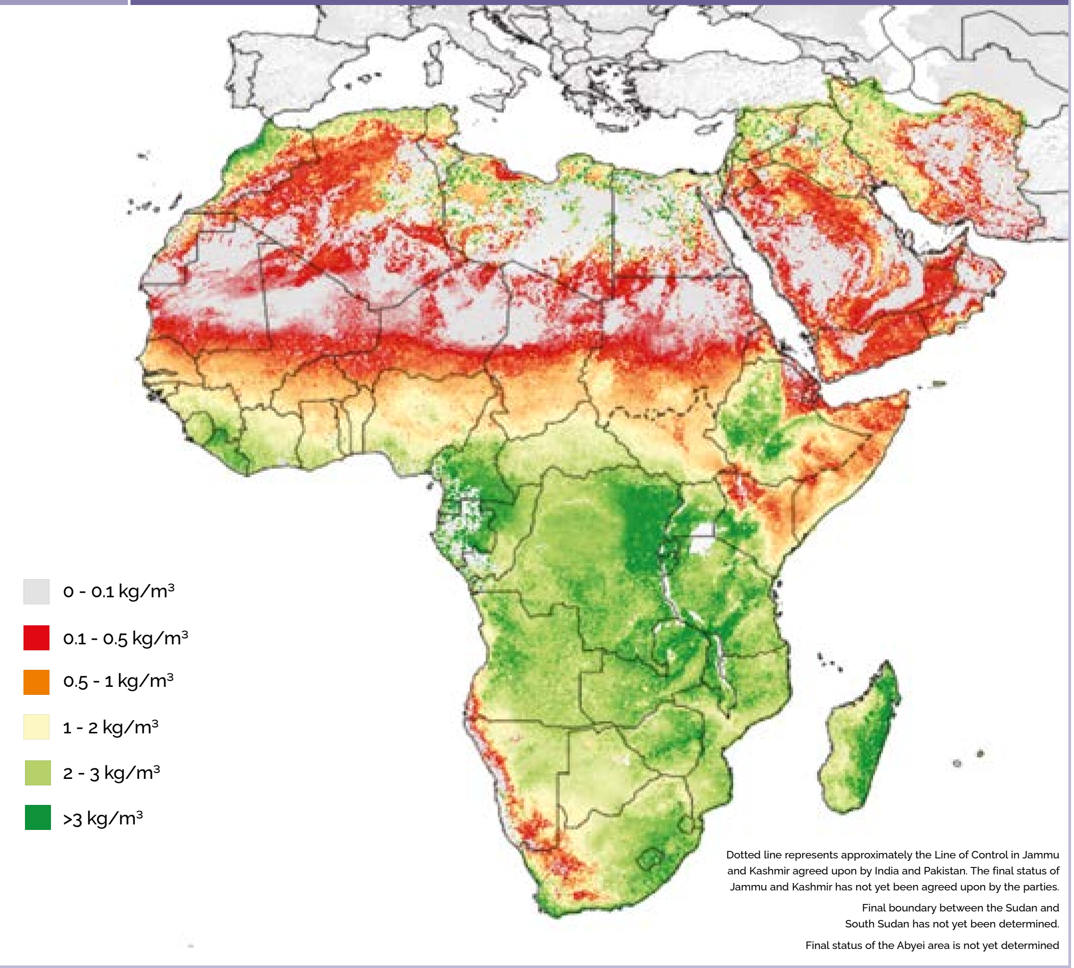
Combining water accounting with data from WaPOR

Water accounting is a powerful tool for accurately assessing crop water consumption on irrigation schemes. Many countries still do not have the capability to measure the amount of water they use for irrigation. Some rely on measuring the volume of water diverted, but this is usually significantly greater than the amount consumed by the crops. Measuring crop water use rather than depending on irrigation diversion data is vital to producing an accurate water budget for a scheme or basin, mainly when irrigation takes a large percentage of the blue water resource. Water accounting and remote sensing offer a solution.

An example is the Litani River basin in Lebanon. Water accounting used the FAO WaPOR data portal, which uses remote-sensing technologies to monitor and report agricultural productivity over Africa and the Near East to overcome limited data availability. The system measures irrigated crop areas and water consumed by crops, thus providing a more accurate picture of water use; rather than relying on patchy water withdrawal data (FAO and IHE Delft Institute for Water Education, 2019).

The WaPOR data portal also provides gross biomass water productivity data across Africa and the Near East (Figure 5.7).

FIGURE 5.7 **GROSS BIOMASS WATER PRODUCTIVITY, 2020**



Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Final boundary between the Sudan and South Sudan has not yet been determined.

Final status of the Abyei area is not yet determined

Source: **FAO**. 2020. WaPOR: The FAO portal to monitor WAter Productivity through Open access of Remotely sensed derived data. In: *FAO*. Rome. https://wapor.apps.fao.org/home/WAPOR_2/1

Modernizing medium- and large-scale irrigation schemes

Medium- and large-scale irrigation schemes are generally owned and operated by government agencies that supply water and services to individuals and groups of smallholder farmers. Although over the past 50 years, large-scale canal irrigation has made a significant contribution to increasing food production, reducing hunger and poverty, increasing employment and securing rural livelihoods for many millions of smallholder farmers, critics have suggested that the planning and design have remained technically stagnant (Plusquellec, 2014). Canal irrigation continues to suffer from problems of poor flow regulation to farmers, and there have long been significant discrepancies between design assumptions and actual performance – hydraulically, economically and socially. Water scarcity exacerbates this situation, which is now the main driver to improve performance by modernizing existing schemes and designing new schemes to overcome past problems.

Modernization is a complex process and is not just about saving water. It requires significant changes in the way schemes are planned, designed and managed. In the 1990s, FAO coined modernization as "a process of technical and managerial upgrading (as opposed to mere rehabilitation) of irrigation schemes with the objective to improve resource utilization (water, labour, economic, and environmental) and water delivery to farms". Implicit in modernization is a shift from traditional supply-driven irrigation to demand-driven irrigation and introducing the concept of providing irrigation services to farmers (FAO, 2007a).

Modernizing irrigation is a means of rectifying past mistakes by taking a more holistic and coordinated approach to improving irrigation performance by upgrading and improving all aspects of an irrigation scheme to respond to modern farming requirements. It is driven partly by farmers who want more flexible and reliable water delivery and partly by governments concerned about making the best use of available water resources and the rising costs of scheme construction, operation and maintenance.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Modernization usually requires upgrading technologies – the "hardware" – which goes beyond rehabilitation, and which replaces only what is already there. This is the more visible part of a system. Options for improvement include installing networks and control structures, automation, lining canals, constructing reservoirs and installing modern information systems to improve management and control. As more than 90 percent of irrigation globally uses surface irrigation methods, most technology upgrades must focus on simplifying canal management and surface irrigation performance. Modernization also requires hardware improvements on farms, such as control systems that simplify canal management and provide farmers with flexible and reliable water supplies. Reliability creates confidence in managers and farmers, enabling them to switch off water supplies when irrigation ends. Where appropriate, farmers can also consider switching from gravity-fed to pressurized sprinkler and trickle irrigation to improve control over water application. Installing drainage can help to remove excess water and control salinity.

Modernization does not refer only to high-technology solutions such as canal automation and pressurized sprinkler and trickle irrigation systems. Such technologies have a role to play, but significant improvements are also possible using simple gravity-fed technologies, such as night storage to balance supply and demand at farm level and fixed broad weirs to simplify water level and discharge control (Horst, 1998).

Equally important is upgrading the management and institutional structures that govern irrigation, the "software", which is much less visible than the hardware. This includes increasing the capacity and capability of organizations to provide services to farmers appropriate to modern irrigation farming (Kay and Renault, 2004; Kay, 2020). Improvements include changing the traditional "top-down" approaches to scheme management to ones that accept farmer participation in management decision-making at all levels. This may involve transferring scheme management and maintenance at the tertiary level to farmer organizations and providing a reliable water delivery service for which farmers are willing to pay. Above all, these changes need strong political support at the highest level and an enabling environment that provides farmers with incentives, manageable risks and uninterrupted access to markets (FAO, 2007b).

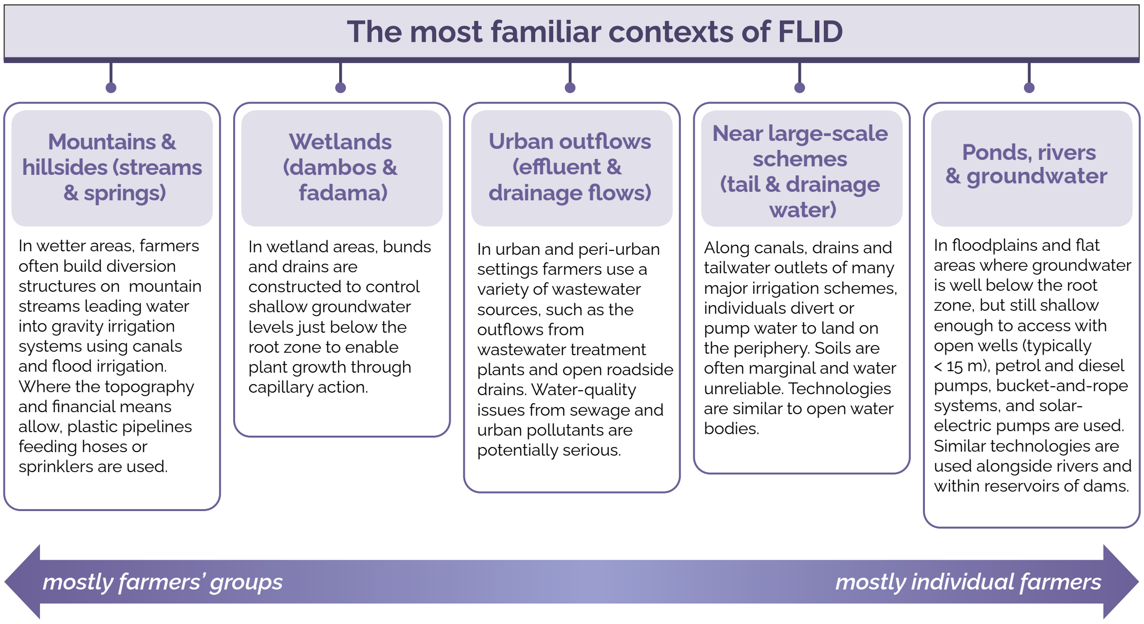
FAO developed the Mapping Systems and Services for Canal Operating Techniques methodology in 2007, designed to assist technical experts, irrigation professionals and scheme managers in modernizing schemes (FAO, 2007a). The entry point is canal operation, but the focus is on identifying targets, including finance and water use, and meeting environmental requirements. Although based mainly on FAO experiences in Asia, the Mapping Systems and Services for Canal Operating Techniques is a generic methodology that applies to medium and large irrigation schemes elsewhere. The methodology seeks to stimulate a critical sense among scheme managers to diagnose and evaluate obstacles, constraints and opportunities, and develop a consistent modernization strategy. A step-by-step approach is offered to convert a complex set of circumstances into simple elements that can be explored and improved. FAO is developing a similar methodology for pressurized systems, Mapping System and Services for Pressurized Irrigation, to enable scheme managers to optimize sprinkler and trickle systems designed to respond to irrigation on demand.

Enhancing smallholder irrigation

Irrigation is an integral part of smallholder farming for many millions of smallholders across the Near East and North Africa, sub-Saharan Africa and Asia. Smallholder irrigation is usually farmer led, and refers to individuals or small groups of farmers who own and operate their systems independent of government control (Figure 5.8). Individual farms are small, 2–5 ha in size, and farmers exploit water resources in many ways, including using surface water and shallow groundwater, water harvesting, natural springs and wetlands, spate flows in rivers and recession flows in flooded areas (Izzi, Denison and Veldwisch, 2021).

Smallholder irrigation systems exist in almost all agroecological zones. However, they are particularly important in arid and semi-arid areas where subsistence farming prevails on marginal lands and where unpredictable and inadequate rainfall limits crop production. Productivity is typically well below that of medium- and large-scale irrigation schemes due to the lack of modern water control technologies, agronomic practices, farm inputs, access to markets and economies

FIGURE 5.8 **FARMER-LED IRRIGATION DEVELOPMENT**



The most familiar contexts of FLID

Mountains & hillsides (streams & springs)

In wetter areas, farmers often build diversion structures on mountain streams leading water into gravity irrigation systems using canals and flood irrigation. Where the topography and financial means allow, plastic pipelines feeding hoses or sprinklers are used.

Wetlands (dambos & fadama)

In wetland areas, bunds and drains are constructed to control shallow groundwater levels just below the root zone to enable plant growth through capillary action.

Urban outflows (effluent & drainage flows)

In urban and peri-urban settings farmers use a variety of wastewater sources, such as the outflows from wastewater treatment plants and open roadside drains. Water-quality issues from sewage and urban pollutants are potentially serious.

Near large-scale schemes (tail & drainage water)

Along canals, drains and tailwater outlets of many major irrigation schemes, individuals divert or pump water to land on the periphery. Soils are often marginal and water unreliable. Technologies are similar to open water bodies.

Ponds, rivers & groundwater

In floodplains and flat areas where groundwater is well below the root zone, but still shallow enough to access with open wells (typically < 15 m), petrol and diesel pumps, bucket-and-rope systems, and solar-electric pumps are used. Similar technologies are used alongside rivers and within reservoirs of dams.

Note: *FLID = farmer-led irrigation development.*

Source: **Izzi, G., Denison, J. & Veldwisch, G.** 2021. *The farmer-led irrigation development guide: A what, why and how-to for intervention design.* Washington, DC, International Bank for Reconstruction and Development/The World Bank. https://pubdocs.worldbank.org/en/751751616427201865/FLID-Guide-March-2021-Final.pdf

of scale. However, the systems benefit from deep-rooted indigenous knowledge, good soil and water management practices, and reliable local social networks that support subsistence farming. Simple measures that do not change local management practices can improve schemes, such as lining canals for local spring-fed schemes. Localized approaches to the transfer of knowledge and technology that benefit from indigenous experience are more likely to secure investment and long-term support of engaged communities.

Special care is needed to ensure introducing change is gender sensitive, to avoid disadvantaging women farmers and to avoid compromising existing sustainable practices or adversely affecting land and water tenure arrangements. For example, planting tree crops could affect land tenure security in specific tenure regimes, and improving irrigation technology could favour male farmers as de facto landowners and displace women farmers from seasonal farming in wetlands.

In general, farmers are more interested in saving money than water, but adopting the best water management and agronomic practices can benefit both. Best practices include: ranking irrigation highly within farm management activities; understanding the interactions among soils, crops and water; scheduling irrigation; using objective monitoring tools where possible; and remaining open to new ideas such as solar pumps for renewable energy. Benchmarking also helps farmers improve performance, and, together with WUAs, can provide opportunities for farmers to work together to share ideas, compare performance and transfer knowledge. Understanding and applying best practices can help to ensure farmers become agricultural water stewards.

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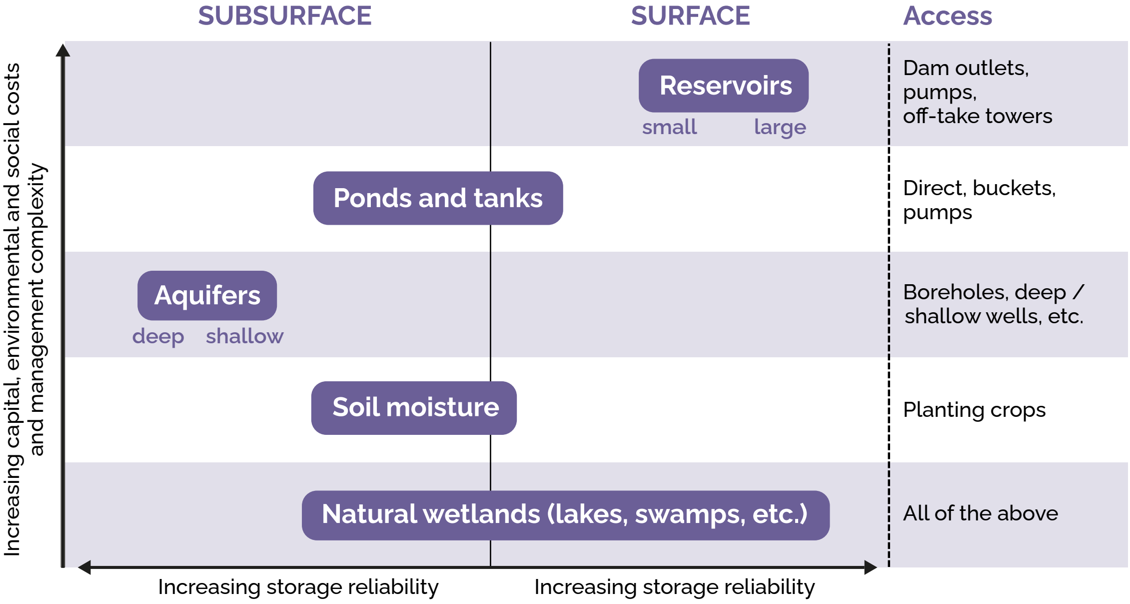
Optimizing water storage

Water storage provides a buffer for managing climate uncertainty and variability, and is essential in building resilience to climate change. It can help water managers cope with changing societal priorities and water demand patterns. It can balance supply and demand to mitigate shocks such as drought and floods. Storing water during the wet season enables farmers to grow crops and provide water for livestock during the dry season. For irrigation schemes, overnight storage allows farmers to continuously take water from a canal system and irrigate crops according to their water needs rather than a fixed water schedule determined by scheme managers. Conjunctive use in irrigation using natural groundwater storage and built surface water storage is another example of balancing water supply with variable daily and seasonal irrigation demand.

Storage has many forms, in natural and built infrastructure. Nature has always supplied the bulk of water storage (GWP and IWMI, 2021). People have long relied on natural storage in ponds, lakes, wetlands and rivers (Figure 5.9). Groundwater is a significant store of water exploited for irrigated agriculture, as is soil water storage, which farmers are encouraged to increase using conservation agriculture practices for rainfed crops.

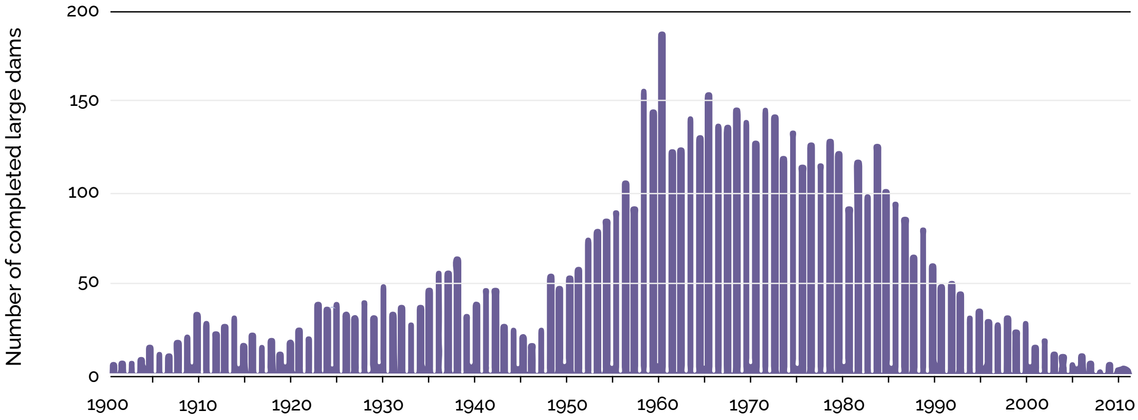
Although the number of large built-storage dams increased significantly over the twentieth century (Figure 5.10), the Global Reservoir and Dam Database recorded a significant decrease in the number of large dams completed since the 1990s (Lehner *et al.*, 2011). Lower investment requirements make smaller storage facilities more justifiable, especially for irrigation. Myriad small storage reservoirs are serving small irrigation schemes, but data are sparse or non-existent. Ultimately, the scale of surface water resources development depends on the scale of water allocation for irrigation. Such decisions are usually taken at the basin level or within a national IWRM plan.

FIGURE 5.9 THE WATER STORAGE CONTINUUM



Source: **McCartney, M. & Smakhtin, V.** 2010. *Water storage in an era of climate change: Addressing the challenge of increasing rainfall variability.* Blue Paper. International Water Management Institute. www.iwmi.cgiar.org/Publications/Blue_Papers/PDF/Blue_Paper_2010-final.pdf

FIGURE 5.10 NUMBER OF LARGE BUILT-STORAGE DAMS, 1900–2010



Source: **FAO**. 2022. Geo-referenced database on dams. In: *AQUASTAT - FAO's Global Information System on Water and Agriculture.* https://www.fao.org/aquastat/en/databases/dams

Just how effective storage can be depends on catchment characteristics such as vegetation, soils, rainfall runoff response, and land cover and use. Changes in catchment parameters will affect the amount and quality of storage. Investment in watershed management may benefit afforestation, reforestation, soil conservation, soil moisture retention and groundwater recharge. However, it may reduce the capacity to harvest runoff in reservoirs, affect the hydrological flow regime in streams and rivers, and reduce surface storage reliability. But soil-conservation measures may reduce suspended sediment and increase dry-season river flows that benefit storage and irrigation farming (McCartney *et al.*, 2019).

Despite the decline in large built-storage facilities in recent years, the global need for more water storage is growing as water demand increases across all sectors. However, even the available built storage decreases due to sedimentation resulting from soil erosion and the effects of environmental degradation and climate change on natural storage. A review of water storage (GWP and IWMI, 2021) suggests there is already a gap between available storage and the amount needed, and it is widening. There are variations, and countries have different priorities, but the storage gap threatens sustainable development for many. The economic cost of an increasing storage gap is significant. Benefits from agricultural water storage come from extending the area under irrigation and increasing the reliability of supply to farmers, consequently reducing rural poverty and hunger, and promoting growth. More storage and storage types are urgently needed, and existing storage needs managing better.

The availability of buffering capacity in natural and built storage systems can significantly reduce drought impacts. Most developing countries suffer from "difficult" hydrology,[13]

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[13] Europe, in contrast, has mostly "easy hydrology", which lacks the extremes seen in developing countries. This is much simpler to deal with technologically and institutionally, and the countries involved are usually wealthy enough to invest in well-designed and robust water infrastructure and strong institutions.

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which produces extreme drought and flood events that are difficult and costly to control, and funding is limited to mitigating the impacts. The strong correlation between drought events and low GDP aptly demonstrates the need for more storage in Ethiopia and the United Republic of Tanzania (Figure 5.11), to decouple climate and water security.

Investment in storage tends not to be highlighted in infrastructure studies. Instead, storage is sector driven and is an integral part of water supply, irrigation and flood control. However, this can inhibit investment in multipurpose storage that could be effective in meeting several sector objectives.

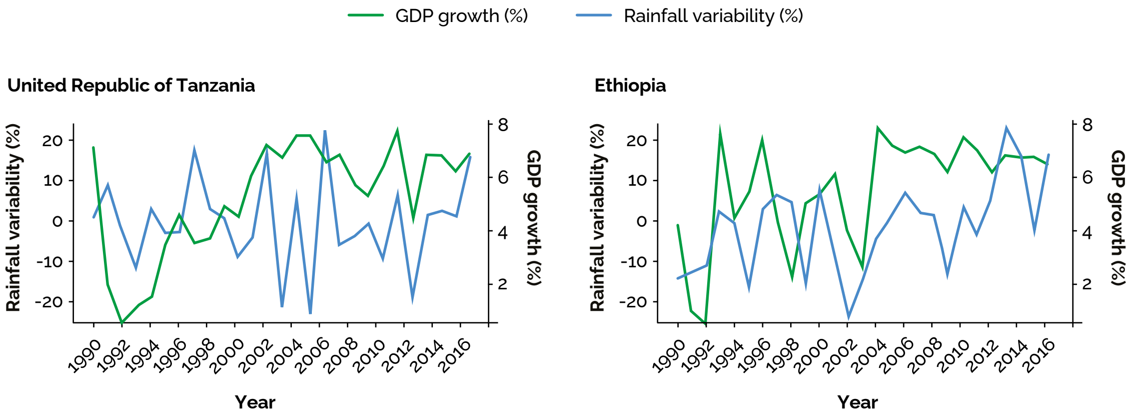
The review of water storage recommends a new agenda that changes current silo thinking about water storage to one that addresses all the many different kinds of storage, natural and built, in an integrated system that provides multiple benefits (GWP and IWMI, 2021). This includes assessing the socioeconomic costs and benefits of integrated storage systems, developing innovative approaches to water storage, and optimizing integrated storage planning and operations.

Protecting groundwater

There has been consistent growth in groundwater use for irrigation, livestock watering and agricultural processing, despite the widespread problems of aquifer depletion and pollution associated with agricultural land management for crop production and livestock grazing. It has increased in absolute terms and as a percentage of total irrigation (section 1.7.4). Limiting groundwater exploitation to maintain a wide range of water supply and environmental services is well recognized as being essential (Foster and Loucks, 2006). However, efforts to manage demand across the large continental aquifers in the United States of America are still being evaluated (Haacker, Kendall and Hyndman, 2016; Lubell, Blomquist and Beutler, 2020). Adopting irrigation technologies, designed to make better use of available water resources, has not proven effective in reducing overall demand (Batchelor *et al.*, 2014).

Groundwater use in irrigation has been increasing in absolute terms and as a percentage of total irrigation, despite the problems of depletion and pollution. Thus, limiting groundwater exploitation to sustainable levels is desirable and essential.

FIGURE 5.11 RELATIONSHIP BETWEEN RAINFALL VARIABILITY AND GROSS DOMESTIC PRODUCT, 1990–2016



Source: **Global Water Partnership & International Water Management Institute.** 2021. *Storing water: A new integrated approach for resilient development*, W. Yu, W. Rex, M. McCartney, S. Uhlenbrook, R. Von Gnechten & J.D. Priscoli, eds. Stockholm, Global Water Partnership. www.gwp.org/globalassets/global/toolbox/publications/perspective-papers/perspectives-paper-on-water-storage.pdf

Groundwater pumping technologies continue to improve, along with borehole technologies adopted from petroleum and mining industries, giving more range to recover groundwater from energy-efficient variable drive pumps to solar-powered pumps (FAO and IWMI, 2018). The demand pull from irrigated agriculture and livestock watering is thus expected to increase but with more accurate targeting of shallow and deep aquifers. Attempts to moderate groundwater withdrawals through energy pricing is one approach that has met with a degree of success in various states in India (Shah, 2009).

Land management can play a crucial role in maintaining patterns of aquifer recharge. Large-scale managed aquifer recharge must be part of a landscape approach to improving land and water quality (Dillon *et al.*, 2020). Maintaining healthy soils, free of contamination, should be an essential starting point, bearing in mind that conserving natural biodiversity in protected areas will be as important as adopting conservation agriculture techniques on cultivated land.

5.5.4 Managing environmental risks

The agricultural sector is responsible for managing environmental risks by reducing pollution and the harmful effects of fertilizers, pesticides, herbicides and livestock waste, by minimizing antibiotic use and avoiding secondary health issues such as microbial resistance, and by reducing GHG emissions.

There are also risks to health from chemical pollution and water-related diseases, such as diarrhoea, and water-borne diseases, such as bilharzia and malaria, often called the diseases of irrigation because of their prevalence in stagnant water in poorly maintained schemes. The livestock sector is associated with land and water pollution due to inadequate management of livestock waste, especially from intensive feedlots.

Attenuating contamination by nutrients and fertilizers

Various nutrients and organic amendments to enhance soil fertility, stability and function all require proper management to avoid or mitigate soil contamination and associated processes. These include surface water and groundwater pollution, nitrous oxide and methane emissions, eutrophication and acidification.

Responsible use and management of fertilizers is vital for sustainable intensive agriculture. The FAO Fertilizer Code guides their use (FAO, 2019c) (Box 5.19). Chemical use must be considered at the landscape, regional and global levels. This requires a holistic approach to using nutrients and their cycles in soils, plants, animals, humans, water and the environment.

Nitrogen and phosphorus compounds are essential for crop growth. However, nitrogen fertilizers are highly water soluble and rapidly cycled in the soil. Unused nitrogen can find its way into drainage systems, watercourses and groundwater. Reducing nitrogen losses requires better fertilizer application practices, improved water management, and maintenance of healthy plants with good nitrogen uptake and healthy soil that holds and transforms the nitrogen.

Slow-release nitrogen compounds can help reduce the risk of leaching, and biological additives can enhance nitrogen-use efficiency by inducing more robust root growth and more active uptake. But farmers need training to encourage their use, regulation and incentives.

BOX 5.19
THE FERTILIZER CODE

The Fertilizer Code was developed in response to the request of the Committee on Agriculture to increase food safety and the safe use of fertilizers. It is also a response to the declaration of the third United Nations Environment Assembly on soil pollution, which aims to ensure broader support for implementing the *Voluntary guidelines for sustainable soil management* (FAO and ITPS, 2017).

The Fertilizer Code provides a locally adaptable framework to avoid misuse, overuse and underuse of fertilizers and a set of voluntary practices for stakeholders involved with fertilizers. Adhering to the principles of the Fertilizer Code contributes to sustainable agriculture and food security from a nutrient management perspective. It aims to assist countries in addressing the multiple and complex issues related to responsible use and management of fertilizers at farm, ecosystem and national levels. The Fertilizer Code helps stakeholders establish systems for monitoring production, distribution (including sale), quality, management and use of fertilizers to achieve sustainable agriculture and SDGs by promoting integrated, efficient and effective use of quality fertilizers.

Source: **FAO**. 2019. *The international code of conduct for the sustainable use and management of fertilizers.* Rome. www.fao.org/3/ca5253en/ca5253en.pdf

Minimum-tillage or no-tillage agriculture and other practices that restore SOM help maintain healthy soils and reduce nitrate and phosphate pollution in linked water bodies. Unlike nitrogen, phosphorous is generally bound to soil particles and is released slowly to plants. It is therefore less likely to find its way into groundwater or drainage systems. However, runoff from farms represents a significant risk of phosphorus entering rivers, lakes and coastal systems.

Reducing pesticides and other contaminants

A range of integrated pest management methods are available to help reduce chemical pesticide use, and associated soil and water pollution and health risks. FAO supports countries to apply the International Code of Conduct on Pesticide Management for distributing pesticides and their use, and for ensuring the safe storage of pesticides and safe disposal of obsolete pesticides.

Large-scale farms in developed industrial countries have adopted integrated pest management methods to reduce production costs and respond to environmental awareness. In developing countries, uptake of integrated pest management is much slower, although FFSs effectively improve farmer knowledge (Settle and Garba, 2011). The slow progress in establishing regulatory and legislative frameworks for approval and safe use of pesticides is a cause for concern. This is especially true for cheap generic brands of harmful pesticides, which some countries still produce and use, although they are banned in international markets.

Some agricultural practices release other contaminants, such as trace elements, microplastics, antibiotics, antimicrobial resistant bacteria and pathogens, into soils. Examples include irrigating with untreated wastewater, applying fresh manure from animals treated with high-dose antibiotics (Zhang *et al.*, 2016) or fed with food rich in trace elements, using sewage sludge as organic fertilizer and abandoning agricultural plastics in the field (Nizzetto, Futter and Langaas, 2016).

Simple alternatives are available to avoid soil pollution at the field level and to avoid contaminants entering the food chain.

On-farm waste-management plans include complete removal of packaging waste and other plastics from the soil, proper management of animal faeces and urine, and establishing controlled and impermeable collection areas to prevent leakage. Beyond the farm gate, vegetative and physical barriers and drainage improvements in agricultural areas close to potential sources of contaminants, such as heavy-traffic roads, mines and industries, offer low-cost solutions to prevent pollutants from reaching agricultural soils (Kibblewhite, 2018).

Wastewater use, particularly from densely populated and industrial areas, requires at least secondary treatment. Selecting cultivars with lower contaminant uptake capacity or cultivating industrial and bioenergy crops on farms are other options. Treating soils with inorganic soil amendments, such as lime and iron oxides, and improving SOC content can help to immobilize contaminants. Soil biodiversity has an important role in the bioremediation of contaminated soils as certain bacteria and fungi can degrade and immobilize specific environmental contaminants such as aromatic hydrocarbons (FAO *et al.*, 2020).

Managing soil and groundwater salinity

Over 1 100 million ha of soils are affected by salinity and sodicity, of which 60 percent are saline, 26 percent are sodic and the remaining 14 percent are saline–sodic. The regions most affected are arid or semi-arid zones in Australia, Central Asia, Near East and Northern Africa. Estimates of irrigated salt-affected soils vary widely between 20 percent and 50 percent of the irrigated area (FAO, 2022a). Thus, GSP prioritized soil salinity mapping to identify the scale of the problem in each region and the required investment in remedial measures (Chapter 4).

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Risks of soil salinization have long been a problem in irrigation, particularly in arid and semi-arid areas, where salts build up in the surface soil through evaporation and wastewater is reused for irrigation (Sjoerd *et al.*, 2017). The traditional solution for removing salts in soils with shallow groundwater is to leach excess water through the soil profile into underground tile drains and open ditches. Plastic soil mulching is also used for improving water and salt balances, but this may have environmental impacts. Managing soil salinity involves reducing evaporation from the soil surface through controlling water applications to meet crop demand and providing a leaching fraction to maintain an acceptable salt balance in the soil.

One option is to accept saline drainage water and adopt biosaline agriculture by selecting salt-tolerant crops and appropriate cropping patterns and management practices. If planned at the watershed or landscape level, this adaptive approach can reduce environmental degradation and contribute to ecosystem restoration in dry lands. A handbook for saline soil management (FAO, 2018d) provides innovative methods and technologies for ameliorating salt-affected soils, including a proximal technique of electro-melioration, precision agriculture, diversification of salt-resistant crops and the use of halophytes.


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In Central Asia, 40–60 percent of irrigated land is salt affected or waterlogged. Countries in Central Asia and Turkey have been supported to develop integrated natural resources management in drought-prone and salt-affected agricultural production landscapes. Activities include soil mapping, applying innovative approaches and biotechnologies to restore soil fertility, and incentives for adoption. This is supported by the Central Asian Countries Initiative for Land Management, FAO, GEF, the International Center for Biosaline Agriculture and country partners (FAO, 2018e). How countries use their salt-affected soils will be important for their future food security, but will require strong political support and funding.

5.5.5 Going beyond the farm

Research is vital

New crop varieties will need to adapt to a wide range of rapidly changing climate and socioeconomic conditions. They must cope with increasing frequency of damaging high-temperature events, new pest and disease pressures, increasing weed competition, more frequent and prolonged extreme weather events, increasing water scarcity and quality deterioration, and decreasing use of agrochemicals. Productivity must also increase faster than historical trends and include improved nutritional values. Breeding cycles must speed up, particularly in developing countries where programmes can take up to ten years or more to develop new generations of seeds, plus many more years to disseminate them (Atlin, Cairns and Das, 2017).

Improving crop nutritional value is important given that over 2 billion people worldwide are food insecure and 688 million are undernourished (Ziadat, Bunning and De Pauw, 2017; FAO, 2020b). Future breeding programmes must also focus beyond traditional staple crops, such as maize, wheat, rice and soybeans, to include neglected crops vital for nutrition and resilience, such as cassava, millet, peas and sorghum. There are myriad traditional varieties of crops and livestock breeds, and also crop wild relatives that may show beneficial nutritional and climate resilience traits that require identification, safeguarding, improvement and prioritization. Policies that are biodiversity friendly and participatory breeding efforts are needed that recognize the enormous contribution of indigenous people and smallholder farmers as custodians of the world's food crops and domesticated animals and farmers' rights.

Future efforts can take advantage of biotechnologies that can reduce the plant breeding cycle from ten to two years, such as marker-assisted and genomics-assisted breeding that uses molecular biology tools and information technology to identify promising crop traits (Varshney *et al.*, 2012).


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Genetically modified crops continue to be the subject of a long-running debate. One unfortunate consequence of this is that other successful biotechnologies have been overshadowed (FAO, 2017f). New Rice for Africa varieties, which are now widely distributed in sub-Saharan Africa, have been developed using biotechnologies that combine high-yielding Asian rice with the robustness of African rice. Adopting "biotech crops" is the most pronounced crop technology trend (James, 2014). Genetically modified crops are likely to become much more widely used when tested in new forms to counterbalance the various associated risks. But new techno-bio-socio-cultural solutions will be required, and which also need to be accepted by people (IIASA, 2019). Gene-editing technologies can avoid the drawbacks of traditional genetic engineering technologies. They could transform conventional agriculture, create new laboratory farming practices and help find new ways to leverage complementary agroecological approaches (Zhang *et al.*, 2018).

Biofortification is a promising, cost-effective and sustainable technology that can improve nutritional quality through agronomic practices, conventional plant breeding or modern biotechnology (Garg *et al.*, 2018). It offers a way to reach the rural poor who rarely have access to commercially fortified foods. More than 20 million smallholders in developing countries grow and consume biofortified crops (Venkatesh and Hurrell, 2018) such as vitamin A in sweet potatoes, zinc in rice and iron in beans.

A comprehensive inventory is available of near-ready and future technologies that can increase food production while reducing pressure on land and water resources (Herrero *et al.*, 2020). Among these, biorefineries already exist to manufacture meat and vegetable substitutes, but overcoming public perceptions of quality and health risks will be challenging (IIASA, 2019).

Urban farming is emerging as a means of enhancing food security within cities (Box 5.20). Vertical farms grow produce inside or on top of buildings, and hydroponic agriculture grows plants without soil with plant roots in a water solution of mineral nutri-

BOX 5.20
URBAN FARMING: A SOLUTION TO ENHANCE FOOD SECURITY IN CITIES

Urban farming is a form of natural capital for growing food and other crops within cities. It offers the potential to ameliorate urban environmental problems by increasing vegetation cover and contributing to a decrease in the urban heat island intensity, improving the liveability of cities and providing enhanced food security. A global assessment of urban farming ecosystem services indicates a potential annual food production of 100–180 million tonnes, energy savings of 14–15 billion kWh, nitrogen sequestration of between 100 000 and 170 000 tonnes, and avoided stormwater runoff of between 45 and 57 billion m^3 annually. The value of the ecosystem services provided by urban farming could be worth as much as USD 80–160 billion annually.

High- and low-technology solutions exist for urban farming. One company introduced a low-cost aquaponics system combining fish farming with vegetable cultivation in closed-loop water circulation to smallholder farmers in tropical areas, where it increases food and nutrition security in the dry season and contributes to generating additional income. Another company in Dubai, United Arab Emirates, uses hydroponics technology to grow vegetables for top restaurants and caterers.

Source: **Clinton, N., Stuhlmacher, M., Miles, A., Uludere Aragon, N., Wagner, M., Georgescu, M., Herwig, C. & Gong, P.** 2018. A global geospatial ecosystem services estimate of urban agriculture. *Earth's Future,* 6(1): 40–60.


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ents. Aquaponic farms leverage the symbiosis between hydroponic agriculture and aquaculture: plants absorb fish excretions as nutrients and clean water returns to the fish basins. Such systems operate in controlled environments, enabling faster crop cycles and more crop rotations each year. They use 70–90 percent less fertilizer and water by capturing and condensing evapotranspiration and recirculating them within the system (Crawford, 2018). However, not all crops can be grown in a controlled environment. They are currently limited mainly to vegetables and herbs, and there are challenges in scaling up these solutions (Foley, 2018).

Several constraints still impede the uptake of near-future technologies. For example, inadequate market infrastructure has limited fertilizer adoption by African smallholders (FAO, 2011a). Uptake requires investment in research and establishing regulatory frameworks to ensure that innovations meet acceptable human health, social and environmental standards, that commercial interests do not monopolize technologies, and that there is increasing awareness of the potential benefits as well as risks (Searchinger *et al.*, 2019). Also, tenure security and farmers' rights must be recognized and applied, to reduce inequity in access to natural resources. It is essential to acknowledge the vital role of smallholder farmers and indigenous people in conserving, using, exchanging and improving genetic resources for food and agriculture, the importance of safeguarding indigenous knowledge, and the importance of their participation in decision-making and benefit sharing.

Using information and communications technology and big data

Opportunities are emerging from advances in ICT. The application of ICT to agriculture can also help improve productivity, manage associated environmental risks, and ensure sustainable land and water management.

Recent advances in ICT, big data science, Earth observation systems, open access, artificial intelligence, machine learning and cloud computing platforms, along with smartphone-enabled citizen science, have increasingly made big data analytics much smarter and more useful for agricultural planning and management. They have also created baseline information for better-informed decision-making and opened up opportunities to fill knowledge gaps at multiple levels (e.g. data, yield, ecology, economy and resilience) and scales (e.g. space, time and package) to target demand-driven interventions for sustainable land and water management.

Box 5.21 illustrates the potential for big data to benefit smallholder rice growers, enabling them to increase their cropping intensity. This is an example of a multicriteria assessment of farming systems and resources that allows upscaling from farm to national and regional levels (Löw *et al.*, 2017; Biradar *et al.*, 2020).

Critical questions require soil data and information at the global scale to understand Earth processes and to provide the context for national to local decision-making. To achieve this, GSP and the International Network of Soil Information Institutions are developing GLOSIS – a federation of soil information systems that shares soil datasets via web services. This aims to empower countries to build their national soil information systems as reference centres. Its architecture allows holders of soil data to engage at different levels, according to technical skills and

BOX 5.21

INTENSIFYING PRODUCTION USING RICE FALLOWS TO GROW PULSES AND VEGETABLES

As the area of arable land is not expected to increase significantly, agricultural fallow areas offer opportunities for growing additional food and nutrition provided their production potential can be unlocked (Biradar *et al.*, 2019).

An example is the potential use of rice fallows. A digital platform was developed to provide near-real-time information that identifies "hotspots" of suitable areas for specific crops, lengths of crop fallows, soil moisture and water harvesting potential for supplementary irrigation. Among other opportunities, this system was used to identify rice fallows suitable for growing food legumes in the Eastern Gangetic Plains.

Fine spatial resolution data from the Copernicus Sentinel series of satellites have enabled rice fallow areas on smallholdings of less than 2 ha to be mapped and assessed as suitable for growing pulses using conservation agriculture to increase farm income and supporting marginalized farmers. With a temporal resolution of 10 m and a frequency of 3–5 days between mapping, this system enabled small parcels of land to be monitored for sustainable agricultural practices, specifically pulse intensification in rice fallow areas.

Sources: **Biradar, C., Sarker, A., Krishna, G., Kumar, S. & Wery, J.** 2020. Assessing farming systems and resources for sustainable pulses intensification. Conference presentation at Pulses the Climate Smart Crops: Challenges and Opportunities (ICPulse2020); **International Center for Agricultural Research in the Dry Areas.** 2022. Agricultural intensification and crop diversification.
http://geoagro.icarda.org/intensification

ambitions, to set up and maintain national soil information systems. A series of thematic soil assessments feed into GLOSIS to improve understanding for informed responses.

Agencies involved in land and water planning and management need to update the capacity and tools for managing GISs, develop and use maps and plans, and monitor trends and impacts. This is often a critical capacity and investment gap that takes time to fill and can limit progress on planning.

Reducing food loss and waste

Food loss and waste is a function of marketing and distribution that ultimately influences land use. Reducing FLW is one measure to improve food security, lower production costs, reduce pressures on natural resources and improve environmental sustainability. The SDG target 12.3 calls for halving per capita global food waste at the retail and consumer levels and reducing food losses along production and supply chains by 2030 (United Nations, 2015).

The *State of food and agriculture 2019* report (FAO, 2019d) distinguishes between food "loss", which occurs post-harvest, but not including the retail level, and food "waste", which refers to the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food service providers and consumers. This aligns with the distinction implicit in SDG target 12.3.

Food loss and waste represents an inefficient use of valuable agricultural resources, and causes avoidable environmental degradation (HLPE, 2014). Globally, FLW accounts for 24 percent of total freshwater used in food crop production, 23 percent of cropland area and 23 percent of fertilizer use (Kummu *et al.*, 2012). Halving FLW would provide enough food for approximately 1 billion people. Alternatively, resources used to grow FLW could be redirected to higher-value use or support more environmentally sustainable agricultural production and consumption.


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Measures for reducing FLW for different production stages vary along the food supply chain (Searchinger *et al.*, 2019). They need adapting to local conditions and targeting towards critical loss points to cope with the various barriers. They vary by region, food supply chain stage and supply chain actors, and include poor institutional regulations, limited financial sources, resources constraints, information gaps and consumer behaviour (Shafiee-Jood and Cai, 2016). Box 5.22 illustrates measures to substantially reduce food losses in two example countries.

Reducing FLW will require broadly shared commitments to quantitative goals, careful measurement and persistent action. In terms of policies and infrastructure investments, public interventions may create an enabling environment that allows private actors to invest in reducing FLW (FAO, 2019d) (see also the section on harnessing circular economies for natural resources).

Promoting sustainable diets and consumer options

Rapidly rising incomes and urbanization are driving a global change in lifestyle and food consumption patterns, in which traditional diets are being replaced by diets higher in animal-based foods, refined sugar and fat (FAO *et al.*, 2018).

Dietary shifts have traditionally sought to promote health and well-being but are now linked to reducing the environmental impacts of food production (Springmann *et al.*, 2018; IPCC, 2019). Dietary patterns with low environmental impacts can also be consistent with good health (Gonzalez Fischer and Garnett, 2016). However, researchers have not yet calculated the adjusted land and water resource requirements to service the change in crop production to substitute for animal protein.

With rising urbanization, interest in peri-urban and urban farming to meet the increasing demand for local, fresh and relatively unprocessed food is growing. Organizing short supply chains between local

BOX 5.22
REDUCING FOOD LOSS AND WASTE IN SENEGAL AND THE UNITED KINGDOM

In Senegal in the early 1990s, hand threshing led to losses of 35 percent of harvested rice. Researchers worked with farmers to modify a mechanized threshing tool for local conditions that harvested 6 tonnes of rice per day and captured 99 percent of grains. Despite a cost of USD 5 000, the benefits were sufficiently high that the technology is used to harvest about half of rice production in Senegal (Diagnea, Demonta and Diagneb, 2009).

The United Kingdom achieved a 21 percent reduction in household food waste between 2007 and 2012, mainly through various labelling and public relations efforts. Supermarket chains printed tips for improving food storage and lengthening shelf life for fruits and vegetables directly onto the plastic produce bags in which customers place their purchases. Some chains shifted away from “buy one get one free” promotions for perishable goods towards using price promotions. The government revised guidance on food date labels, suggesting retailers remove “sell by” dates as many consumers mistakenly interpreted this as meaning food was unfit to eat after that date. Instead, they displayed “use by” dates, which more clearly communicate when food is no longer fit for consumption. Also, many food manufacturers, food retailers and local government authorities participated in the Love Food Hate Waste campaign, which raised public awareness and provided practical waste reduction tips through in-store displays, pamphlets and the media (Searchinger *et al.*, 2019).

farms and retailers or consumers in nearby cities reduces food transport.

New digital marketplace platforms connect farmers to food purchasers to provide food traceability, greater price transparency and faster, round-the-clock access to information. Nanotechnology has proven capabilities that are valuable in packaging food, including improved mechanical, thermal and biodegradable barriers. Intelligent food packaging technologies (e.g. microchipping) that contain sourcing, safety and traceability information on food production, processing and environmental footprint are becoming available (Herrero *et al.*, 2020).

Harnessing circular economies for natural resources

Current food production and consumption patterns are primarily built around a linear economic model involving extracting natural resources to make products, using them for a limited period and discarding them into landfill as waste. This is an inefficient way of using natural resources; in 2011, it had an estimated annual cost to the global food system of USD 1 trillion (FAO, 2011b).

The global food system already generates significant environmental impacts (Springmann *et al.*, 2018). It is vulnerable to environmental changes (e.g. severe droughts), floods and diseases, and land degradation caused, in part, by climate change. The idea of a circular economy is receiving increasing attention worldwide to promote sustainable consumption and production patterns, including food systems (Ghisellini, Cialani and Ulgiati, 2016).

A circular economy brings together all the issues of waste and inefficiency. It encourages businesses and households to change practices so production and consumption


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are consistent with environmental sustainability. This means "closing the loop" of resource use to decouple economic activity from consuming finite and limited resources (Ellen MacArthur Foundation, 2015). It includes searching for resource-efficient agricultural practices, encouraging regenerative agriculture, prioritizing renewable energy, preventing resource leakages (e.g. carbon, nitrogen, phosphorus and water), and stimulating reuse and recycling resource losses in a way that adds the highest value to the food system (Jurgilevich *et al.*, 2016).

The European Commission has already developed a circular economy action plan that includes specific measures for the food system (Box 5.23).

Innovative agricultural practices are improving resource-use efficiency on farms. Precision agriculture combines geomorphology, satellite imagery, global positioning and smart sensors to provide farmers with decision-support systems based in real time for whole-farm management (Lowenberg-DeBoer and Erickson, 2019). Global positioning system enabled autonomous farm machinery can operate continuously, reduce labour inputs, and minimize planting and harvesting costs. Smart sensors using drone technology can measure soil and plant characteristics, thus enabling efficient use of fertilizers, pesticides and water. By combining precision agriculture with no-tillage farming, farmers reported a 10–20 percent reduction in fertilizer and pesticide use and as much as a 75 percent reduction in machinery and input costs (Ellen MacArthur Foundation, 2015).

BOX 5.23
EUROPEAN COMMISSION'S CIRCULAR ECONOMY ACTION PLAN AND FOOD LOSS AND WASTE

In 2015, the European Commission adopted an ambitious circular economy action plan that included measures to help stimulate Europe's transition towards a circular economy, boost global competitiveness, foster sustainable economic growth and generate new jobs. The proposed actions aimed to "close the loop" of product life cycles through more recycling and reuse, thus bringing benefits for the environment and the economy.

Food waste prevention was identified as a priority. The European Union Platform on Food Losses and Food Waste, established in 2016, brings together all key actors representing public and private interests from farm to fork to advance European Union progress towards SDG target 12.3. Members include international organizations (FAO, OECD and UNEP), European Union institutions, experts from European Union member states and stakeholders from the food supply chain, including food banks and other NGOs.

The platform aims to support all actors in defining measures to prevent food waste, including possible recommendations for action at the European Union level, sharing best practices and evaluating progress. The European Commission has adopted European Union guidelines to facilitate food donations and redirecting food no longer fit for human consumption into feed.

Measurement is critical to food waste prevention. Revised European Union waste legislation adopted in 2018 has introduced specific measures, which provide the European Union with new and consistent data on food waste levels. In 2019, the European Commission adopted a delegated act laying down a common food waste measurement methodology to help member states quantify food waste at each stage of the food supply chain and ensure coherent food waste monitoring at all levels across the European Union.

Source: Adapted from **FAO**. 2019. *The state of food and agriculture 2019. Moving forward on food loss and waste reduction.* Rome. www.fao.org/3/ca6030en/ca6030en.pdf

The potential to recover resources from waste streams along the entire agrifood chain can be significant. By-products from production and consumption include crop residues, coproducts from industrial food processing, food waste, and animal and human excreta.

Closing resource loops requires new interactions among food system components, such as between cities and rural food-producing areas. Cities are sources of large amounts of food waste and human excreta, which could provide valuable nutrients for food production in farming systems that combine plant, insect and fish production.

The benefits of a circular economy are just as applicable to agricultural water management as to the broader land-use and food systems. For water, this approach offers opportunities to use non-conventional waters that might otherwise go to waste, such as saline and brackish water, agricultural drainage, water containing toxic elements and sediments, and wastewater effluents. All are of poor quality and unsuitable for most purposes, but may be acceptable in some circumstances for agricultural use.

Wastewater remains a largely untapped resource; the treatment capacity for wastes generated by growing cities is inadequate in most countries. Most wastewater is discharged without treatment into the environment. It either runs to waste, or is diluted in the region's waterways and reused downstream in some countries to irrigate millions of hectares of cropland, often unintentionally posing serious risks to the health of farmers and consumers and the environment. The SDG target 6.3 for water quality, wastewater treatment and safe reuse requires halving the proportion of untreated wastewater and

BOX 5.24

WASTEWATER: A POTENTIAL WATER RESOURCE IN THE CENTRAL AMERICA AND CARIBBEAN REGION

Estimates indicate that the Central America and Caribbean region generates some 30 km^3 of municipal wastewater annually, but has the capacity to treat only 40 percent. However, the proportion actually treated is even lower because of inadequate maintenance. Pollution, including faecal matter, is causing serious degradation in 25 percent of the region's rivers. Only a marginal amount of treated water is directly reused for agriculture in a planned, productive and safe manner. Concerted action is needed to mitigate the health and environmental risks in the region's peri-urban hotspots and to capitalize on the opportunities that reuse brings. An analysis by FAO and the International Water Management Institute to assess the potential for water reuse in agriculture in the region, based on country experiences, demonstrated the opportunities to consider urban effluents as a resource and set out the principles and the stringent management required to evaluate and mitigate the risks.

While the region has made substantial investments in wastewater treatment in recent years, their effectiveness, efficiency and sustainability are far from guaranteed. Challenges include an excessive emphasis on developing new infrastructure, poorly developed legislation, lack of policy and regulatory mechanisms to allow gradual improvement, regulations that limit or forbid resource recovery, technology selection criteria biased towards expensive technologies, lack of adequate control of industrial discharges, and reliance on conventional financing.

Wastewater reuse can transform wastewater treatment plants from cost into profit centres. Using marginal quality water for irrigation liberates better quality water for higher-value uses and creates value beyond that due to its direct use. Creating such value is significant in dry areas that suffer from chronic water scarcity. Wastewater management represents the largest market for clean technologies in the region, with an estimated size of USD 160 billion in the decade to 2023.

Sources: **Martin-Hurtado, R. & Nolasco, D.** 2016. *Managing wastewater as a resource in Latin America and the Caribbean: Towards a circular economy approach.* Washington, DC.
https://programme.worldwaterweek.org/Content/ProposalResources/allfile/managing_wastewater_as_a_resource_in_lac.pdf **FAO**. 2017. *Reutilización de aguas para agricultura en América Latina y el Caribe: Estado, principios y necesidades.* Santiago.
www.fao.org/3/i7748s/i7748s.pdf

substantially increasing recycling and safe reuse. There is great interest in the safe reuse of wastewater, and many countries are now working to improve data collection to understand how best to make use of it (Box 5.24).

The International Water Management Institute and the Near East and North Africa ReWater programme (whose partners include FAO, the International Centre for Advanced Mediterranean Agronomic Studies and the International Centre for Agricultural Research in the Dry Areas) support capacity development on water reuse in agriculture, addressing barriers to reuse and promoting safe reuse practices that improve food safety, health and livelihoods (IWMI, 2021).

Wastewater reuse in agriculture can be attractive to farmers because the nitrogen and phosphorus contents in sewage can reduce the need for chemical fertilizers (Box 5.25). With increasing urbanization, larger volumes of municipal wastewater become available for peri-urban agriculture. However, wastewater requires treatment appropriate to its use to avoid posing environmental or public health risks. Moreover, strict and enforceable rules are essential when adapting cropping patterns to effluent use based on safe wastewater reuse and controls on contaminants at the water source.

BOX 5.25

VALUING WASTEWATER AS A SOURCE OF NUTRIENTS FOR AGRICULTURE

Interest in recovering nutrients from streams of wastewater is increasing as municipal wastewater volumes increase and methods of nutrient recovery are developed. A global assessment suggests that wastewater annually contains 16.6 million tonnes of nitrogen, 3.0 million tonnes of phosphorus and 6.3 million tonnes of potassium. If fully recovered, this could offset some 13 percent of the global demand for these nutrients in agriculture and generate revenues of USD 13.6 billion. An environmental benefit from reducing the pollution of municipal effluents is reduced eutrophication in water bodies.

Source: **Qadir, M., Drechsel, P., Jiménez Cisneros, B., Kim, Y., Pramanik, A., Mehta, P. & Olaniyan, O.** 2020. Global and regional potential of wastewater as a water, nutrient and energy source. *Natural Resources Forum*, 44(1): 40–51.

Water extracted from saline aquifers or captured from agricultural drainage offers options for irrigation when mixed/diluted with freshwater for traditional crops like rice. There is also potential to diversify cropping into marine plants, such as seaweed, with the potential for gains in land and water. Such practices can offset water scarcity in some areas, but there are risks of further soil salinization and degrading drainage water quality.

Integrating wastewater reuse with other options in the farming system can bring additional benefits. These include nutrient recycling, regenerating soil health, and reducing non-renewable energy and materials used in irrigation. This requires a multisector approach to agricultural ecosystems, as recognized by the water–food–energy nexus approach.

5.6 Action area IV: Investing in long-term sustainability

5.6.1 Trends from 2010 to 2018

Trends in investments in agricultural land and water resources in the period 2002–2010 relative to 2010–2018 broadly parallel the growth in GDP in countries eligible for funding from the International Bank for Reconstruction and Development and the International Development Association.

The OECD Development Assistance Committee classifies the control of soil degradation, salinization, erosion and desertification, as well as soil improvement, drainage, land surveys and land reclamation, under “agricultural land resources”. This includes irrigation, reservoirs, hydraulic structures and groundwater exploitation. However, within the committed funds for 2010–2018, less funding went to agricultural land and more to agricultural water. Specifically:

- investments in irrigation infrastructure ranked highest in terms of number of projects and level of investment;
- there was an increase in projects that address climate change; and
- the level of investment in ecosystems and land/landscape management was relatively low but was gradually increasing.

The main scope of international investment in agriculture sectors has included agricultural development and governance, irrigation and drainage improvement, water resources management, climate change and, to a lesser extent, land and soil resources management. Many projects also seek to improve agribusiness, have an ecological or environmental focus, or focus on poverty alleviation and community development. Conventional funding has aimed to maximize agricultural efficiency and find competitive advantage, which has meant that in land- and water-scarce areas in particular, food self-sufficiency has been given a lower priority than that of producing exports of high-value crops.

Against this trend, land-based subsidies to agriculture are generating undesirable externalities (FAO, UNDP and UNEP, 2021). Removing distorting support measures and decoupling subsidies and production to direct subsidies toward public goods and services is a trend observed in developed economies but less so in developing economies where emissions from land are accelerating (Crippa *et al.*, 2021). There is still time to "repurpose agricultural support to drive a transformation towards healthier, more sustainable, equitable and efficient food systems" (FAO, UNDP and UNEP, 2021).

There are three broad categories of financing instruments common to most international financing institutions (IFIs): investment lending, results-based lending and policy-based lending. While IFIs use a broad spectrum of financing instruments for public sector projects, they primarily choose some form of investment lending (debts, grants, loans, etc.) for agricultural land and water projects.

Five key points emerge from an assessment of the performance of IFIs relative to FAO objectives:

- there is a need to understand the interdependence of urban and rural water requirements to achieve resilient water, food and land security;

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- low investment in agriculture is problematic according to the 2018 Asian Development Bank evaluation (ADB, 2018), but is even more so with the emergence of COVID-19 in 2020;
- there is scope for improving land and water productivity in rainfed areas to moderate the need for irrigation investment while contributing to smallholder livelihoods;
- environmental benefits and natural resource protection are emphasized to varying degrees by different IFIs in their impact evaluations, particularly in relation to distorting effects of direct payments to land productivity; and
- the unequal distribution of benefits and costs of irrigation and drainage investments exacerbates inequities.

Box 5.26 illustrates various approaches to financing NbSs, and Table 5.1 offers several case studies of investment in NbSs. Examples include the Nairobi Water Fund investment to improve the sustainability of small- and large-scale farming in the Upper Tana River basin, an Ecosystem Service Marketplace Consortium in the United States of America and the Qiandao Water Fund addressing non-point-source pollution in Qiandao Lake, which is an important drinking water source

BOX 5.26
FINANCING NATURE-BASED SOLUTIONS

Nature-based solutions are receiving increasing attention as an alternative solution to grey infrastructure. International financing institutions have shown interest in funding NbSs as part of climate financing, with varying degrees of success. The lack of a standardized methodology has slowed progress, but IUCN has introduced a global NbS standard (IUCN, 2020). Together with the European Green Deal (EC, 2019), it can be a game changer in making NbS investments attractive for private institutions and IFIs. The European Commission's definition of NbSs builds on and supports other closely related concepts, such as ecosystem approaches, ecosystem services, ecosystem-based adaptation/mitigation, and rainfed and irrigated infrastructure. For agriculture, this is in line with FAO policy recommendations for NbSs (FAO, 2018b), CFS (HLPE, 2015) and collaboration between FAO and IUCN (IUCN and FAO, 2020) for developing agroecological practices such as NbSs.

As a think tank based in the United Kingdom, E3G provides an account of the IFI alignment of NbS investments with climate financing (E3G, 2020). In its 2020 assessment, the picture looks promising but needs attention. Out of the nine multilateral development banks, only the Asian Development Bank has aligned NbS frameworks with the Paris Agreement. Six others (African Development Bank, Asian Infrastructure Investment Bank, European Investment Bank, Inter-American Development Bank, International Bank for Reconstruction and Development/International Development Association and International Finance Corporation) have made partial progress by including some biodiversity commitments and declaring the intention to scale up NbSs but without firm strategies. The three remaining (Asian Infrastructure Investment Bank, European Bank for Reconstruction and Development, and Islamic Development Bank) do not have explicit NbS policies.

The World Bank Group argues the financial sector has a crucial function in addressing the global biodiversity crisis, and that governments and regulators must mobilize private finance at scale to protect nature (World Bank Group, 2020). Its report presents the "Big Five": five ideas for actions that would help integrate biodiversity risk and opportunities into private sector decisions. These range from environment fiscal reform and better data collection to broad support of the recently announced Task Force on Nature-related Financial Disclosures.

in the Yangtze River delta in China (Hallstein and Iseman, 2021).

The Roundtable on Financing Water is a global public–private platform established by OECD, the Netherlands, the World Bank and the World Water Council. It draws upon political leadership and technical expertise to facilitate and increase investments that contribute to water security and sustainable growth. The round table engages a diversity of actors: governments and regulators in developed, emerging and developing economies; private financiers (e.g. institutional investors, commercial banks, asset managers and impact investors); development financing institutions; bilateral donors; international organizations; academia; and civil society organizations. It is focused on finding novel ideas and solutions. A brochure on financing a water secure future outlines OECD work in this area (OECD, 2021).

Farmer-led irrigation is a welcome initiative, pioneered by the World Bank (Izzi, Denison and Veldwisch, 2021). It aims to overcome the inability of the financial system, government schemes and market arrangements to enable smallholder farmers to establish their own irrigation systems. Scaling out farmer-led irrigation will unleash the entrepreneurial power of a large number of farmers to

TABLE 5.1 SELECTED NATURE-BASED SOLUTION INVESTMENT CASE STUDIES

PROJECT/LOCATION	PRACTICES	SCALE	BENEFITS	REPLICABILITY
Nairobi Water Fund: Watershed management for healthy forests, agriculture, water quality and hydropower	Riparian management/buffer zones; agroforestry adoption; terracing of hill slopes; reforestation for degraded lands; grass strips in farmlands; road erosion mitigation; soil conservation and water harvesting	One million ha watershed that supplies 95% of Nairobi's drinking water, food for millions of Kenyans and 65% of the hydropower of Kenya	A USD 10 million investment over ten years would yield USD 21.5 million in economic benefits, including up to USD 3 million/year in increased yield for farmers, over USD 600 thousand/year increase in hydropower revenue and a 50% reduction in sediment concentration	There are 41 water funds in 13 countries, and over 80% of cities globally can meaningfully reduce sediment or nutrient pollution through agriculture NbSs
Colombia Silvopasture: Using silvopastoral practices to help ranching and ecosystems	Scattered trees in pasturelands; timber plantations with livestock grazing; pastures between tree alleys, windbreaks, live fences and shrubs; fodder banks	Developed in 87 municipalities (12 states) in Colombia covering a total area of 159 811 ha	Twenty percent increase in milk and/or beef production; improved management on over 20 thousand ha and protection of almost 18 thousand ha; reduction of 1.5 million tonnes of GHG emissions	These practices could be deployed in cattle ranching across Colombia with scaling up to 1 million ha by 2030; they could also reduce grazed area by 30% for conservation or other purposes
Ecosystem Service Marketplace Consortium	Developing markets to enable farmer adoption of the NbS Ecosystem Service Marketplace Consortium, currently conducting pilots in key agricultural regions, including the great plains, corn and soy belts, and California fruit and nut areas		Market value of quantified ecosystem benefits could be as high as USD 13.9 billion, by reducing carbon emissions by 190 million tonnes, nitrogen runoff by 700 thousand tonnes and phosphorus runoff by 400 thousand tonnes	The goal is to launch a fully functioning national-scale ecosystem services market to sell carbon and water quality and quantity credits for agriculture by 2022
Qiandao Water Fund: Innovation plus tradition to engage smallholder farmers	Cooperative application of fertilizers and pesticides; mulching and burying fertilizer; planting cover crops; planting nectar source plants	Qiandao Lake watershed is a key drinking water source in the Yangtze River delta and for the Hangzhou metropolitan area; targeted subwatersheds to deploy best management practices on 333 ha in 2020	Reduced loss of nitrogen and phosphorus by 35–40%; increased farmer income by 30–40% for green tea	Currently expanding best management practices to a broader scale in the watershed and exploring other opportunities for a Water Fund model in China

Source: Adapted from **Iseman, T. & Miralles-Wilhelm, F.** 2021. *Nature-based solutions in agriculture: The case and pathway for adoption.* Rome, FAO and Virginia, The Nature Conservancy. https://doi.org/10.4060/cb3141en


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improve their livelihoods, build resilience, create employment, increase access to food and support the food supply chain against external shocks such as pandemics.

5.6.2 Innovation in agricultural support to land and water

Several innovations relate to financial instruments, emerging financing technologies and governance of investments. Internationally, there is a shift towards multigoal frameworks such as the 2030 Agenda and observing effective practices. International financing institutions have identified strategies for more closely tracking performance in complex projects. Two specific instruments have gained momentum:

- a multiphase programmatic approach, also called a "multitranche" approach, which seeks to reduce the complexity of implementing large, complex and long-duration projects by splitting interventions into multiple phases; and
- a performance-based lending approach, which holds funds back until performance criteria are met.

Investments are needed to move from infrastructure solutions and increasing production to sustaining productivity of rainfed and irrigated systems through improved governance, integrated interventions at scale and innovation in management and technology.

Governance is receiving increased attention, recognizing that an infrastructure focus is insufficient to address poverty, equity and sustainability. In view of increasing food demands, decreasing land and water availability, and environmental pollution challenges, the next generation of investments will need to focus on sustainably intensifying rainfed and irrigated agricultural production through improved data, technology, innovation, management and governance, and integrated interventions at scale.

Future investments are beginning to focus on increasing resilience, reducing risk, and enhancing connectivity and communication through better mechanisms for collecting and disseminating information, using modern technologies for improved production and inputs, and improving institutional capacity and governance. Improved connectivity is allowing smallholder farmers, for example, to use mobile phones to enhance connections to other farmers and other actors with a range of benefits. Like the African Development Bank, IFIs have noted that accelerating digitization across the agricultural sector is a long-term goal and will enable smallholders to access market information and transactions. More immediately, it has been invaluable during the COVID-19 pandemic when face-to-face interactions were limited. However, even today only 50 percent of the global population has access to the internet.

There are many efforts to improve the data value chain in the agricultural sector. This includes collecting and analysing production data on a large scale and then using the processed data to improve agricultural productivity and reduce land-related impacts.

For example, older technologies such as remote sensors are being deployed alongside new technologies like drones to collect more data faster. Machine learning helps process big data in a relatively short time to support decision-making. Sensors connected to controllers as well as mobile phones and apps enable a two-way flow of information. This helps government agencies to better understand what is happening in the field and also to improve their decision-making.

To ensure reliable harvests and livestock productivity and to respond to climate change and agricultural land expansion constraints, researchers are continually finding new and innovative methods to improve agricultural yields and product quality. Biotechnology continues to support yield increases and create crops that are more resilient. To complement advances in irrigated systems, innovations in land, soil and water management are focusing more on rainfed agriculture and SLM methods. These all deserve greater investment.

Rethinking investment in agriculture is needed to support integrated land and water resources management in rainfed and irrigated agriculture and to focus on policy coherence. The high costs of degradation and inaction highlight the urgency to increase investments in sustainable land, soil and water management and in restoring degraded ecosystems, including viable land and water management technologies, integrated landscape approaches in priority river basins and ecosystems at risk. Emerging events following the advent of COVID-19 in early 2020 also need to be part of future investments, as they have exposed vulnerabilities in global supply chains that are still playing out.

Investment in integrated interventions at scale shows great promise, and can be supported through innovative financing and incentive mechanisms. Public investment can help to develop capacities across producer associations, regulators and applied research. An effective land and water governance framework that mobilizes responsible investments and promotes the adoption of innovative management and technology in concert with sustainable land and water practices is a realizable goal. It requires understanding the trade-offs among sectors, the conflicts between land and water use for agriculture, forests and urban needs, and the urgent need to curb GHG emissions, through avoiding deforestation and enhancing carbon sequestration.

Investment from the private sector needs to complement investment from development banks and environmental funds. Governments can encourage consumers, NGOs and businesses to adopt responsible investments towards land and water management and sustainable food and agriculture systems.

Farmers and local communities are also key investors when productivity gains help to sustain livelihoods and improve income

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levels. Incentivizing farmers to become investors in sustainable land and water management can bring all-round environmental benefits. However, they will need support from innovative financing and instruments that reconcile production and environmental management. Instruments that support community-based land and water productivity improvements and adaptive management, capacity-building of producers' associations, small-scale infrastructure and access to microcredit are all likely to be effective.

5.6.3 Prospects for land and water investment

Meeting global food demand will continue to be a challenge, especially with growing social inequalities, conflicts, climate shocks and economic instabilities that affect food supply and distribution. Crises such as the COVID-19 pandemic will exacerbate this situation, as governments may reprioritize national funds towards more immediate economic recovery. International financing institutions can help ensure funds continue to flow towards SDG efforts in food security, resource management and rural livelihoods, so that investments are realized in terms of sustained social, economic and environmental benefits.

There is a continued need to engage farmers as investors in sustainable land, soil and water management, rather than them being passive beneficiaries, to help in enhancing productivity and sustainability. Investments in integrated landscape management show great promise in the form of ecocompensation (China), water funds (Africa and Central, Northern and Southern America) and PES (globally). These are critical to ensure sustainability and to achieve environmental benefits and natural resource protection. Soils have been seriously neglected in terms of investments. However, the Healthy Soils Trust Fund is a successful mechanism for mobilizing investment for technical support to the global and regional initiatives developed and supported through GSP. Several Green Climate Fund and GEF projects include soils to some extent. But it was only in 2019 that the GEF Council endorsed its first project concept focusing on soils – the Caribbean small island developing States multicountry soil management initiative for integrated landscape restoration and climate-resilient food systems – which is under development.

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Promoting innovative technologies can accelerate achieving SDGs related to land and water. These include genetic research and trials, precision agriculture, biotechnology, soil carbon sequestration and renewable energy systems in rural settings. Complementary investment is needed in data and information management to improve connectivity among all producers, markets and regulators. Early warning systems and performance monitoring will also improve on-farm decision-making, while information on adverse environmental and social impacts will help guide responsible investment.

Future investments are expected to improve resilience, thus reducing risk and enhancing connectivity and communication through better mechanisms for collecting and disseminating information, using modern technologies for improved production and efficient use of inputs and resources, and improving institutional capacity and governance.

5.7 Conclusions

Over the past century, the world has largely met the increasing demand for food, feed and fibre by expanding the cultivated area and intensifying the use of land, soil and water resources. However, increasing resource scarcity and inequalities of access are changing the global dynamics around food, climate, energy and allocation of financial resources to solve social and environmental problems. The ensuing economic tension has exposed the reality of shared dependency. The COVID-19 pandemic is another aggravating factor. Ensuring that land, soil and water resources are used in a sustainable manner requires careful balancing of competing goals such as economic growth, equity and a sustainable environment. These involve significant trade-offs as well as opportunities.

Land, soils and water feature in all five Action Tracks prioritized through the United Nations Food Systems Summit process and coalitions. Their instrumental role in access to food, sustainable consumption patterns, nature-positive and resilient production, and advancing equitable livelihoods must not be underplayed. The four action areas in this chapter complement the interlinked Food Systems Summit tracks and are an integral part of the FAO strategic framework. These signal the much-needed transformation of agricultural production from current performance, which is stagnant or experiencing low growth and still generating rising GHG emissions, to improved productivity, better nutrition and sustainable livelihoods in concert with positive environmental outcomes.

Land and water management can respond to meet the challenges of climate change based on "no regrets" investment in actions that are better planned, informed and implemented, but above all, better governed. Without doubt, governance is the most important element in successfully putting technologies into practice at territorial scale with all stakeholders for achieving significant social, economic and environmental benefits. Technologies will have little impact without strong and coherent governance at all levels of decision-making.


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Collaborative decision-making and learning require deliberate linkages across institutions, scales and sectors to capitalize on stakeholders' diverse knowledge, experiences and values to ensure negotiated trade-offs are realistic, innovative and equitable. Actions will also need to be inclusive across physical and economic landscapes.

Current levels of financing remain substantially inadequate to reach the international community's goal for life on land (SDG 15) and sustainable management of water (SDG 6). International funding and public and private investments are encouraged to improve the enabling environment and explore new approaches for investment in environmentally sustainable land, soil and water resources.

With well-adapted investments and actions by all stakeholders, unpredictable climate and socioeconomic shocks can be mitigated, and better food security, nutrition and environmental health achieved as a result. Taken together, the responses and actions outlined in this chapter can be expected to make positive contributions to the achievement of SDGs.


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Case study: Water accounting and auditing in the West Bank

There has been significant economic and agricultural development in the Al Moqatta sub-basin in northern West Bank in the last decade. This includes investment in greenhouses, drip irrigation, improved cropping systems, irrigation of fodder crops with treated wastewater, and the development of value chains that serve local and external markets. It is notable also that women farmers have invested in and are managing greenhouses, for example, to grow strawberries. These activities have benefited from FFSs and extension services supported by the Ministry of Agriculture and FAO, as part of a project funded by the Swedish International Development Cooperation Agency.

Water scarcity constrains agricultural production and economic development in the Al Moqatta sub-basin. Climate change and deteriorating water quality, linked to urbanization and agricultural intensification, add further constraints. These prompted the Palestinian Water Authority to adopt water accounting to assess and monitor trends in water supply, demand and consumptive use in the sub-basin, and to identify and quantify significant return flows at different scales to manage and improve water reuse.

The Palestinian Water Authority coordinates with the Ministry of Agriculture and other technical institutions to use water accounting and auditing to identify potential trade-offs and unintended consequences of investing in water management, such as constructing wastewater treatment plants that reduce water access for some farmers. Water auditing goes one step further than water accounting by placing trends in water supply in the broader context of governance, institutions, public and private expenditure, legislation and the Moqatta sub-basin's political economy within the West Bank.

Source: **FAO**. 2022. Water accounting and auditing. In: *Land & Water*. Cited 7 March 2022.
www.fao.org/land-water/water/water-managment/water-accounting/en


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Case study: Technology impacts on traditional water rights systems in the Near East and North Africa region

In the Near East and North Africa, the sustainability and equity of resources have long guided traditional water management systems, such as terracing, springs, aflaj/qanats and spate irrigation and their complementary rules and administrative procedures. However, the increasing demand for water for food production in the region has introduced new technologies, such as tube wells, spate irrigation and permanent surface water diversion structures. But engineering solutions are often inappropriate, participation is poor and the capacity to enforce new water regulations is weak. All these disturb traditional water rights and threaten resource sustainability.

Springwater rights under threat from groundwater pumping

Irrigation using groundwater pumped from tube wells expanded in many countries across the region during the 1960s and 1970s. However, legal and institutional frameworks set up to manage modern groundwater abstraction have rarely successfully incorporated traditional springs and oasis water rights and management systems. Many governments have been unable to confine agriculture within sustainable water resources limits, as groundwater abstractions were driven by individual interests that proved difficult for States to control. Clashes with traditional systems as springs ran dry have forced those who lost water rights to follow the trend and invest in wells.

A new power structure and consequently a de facto water rights system have emerged, reducing traditional spring and oasis water ownership and water rights in favour of open access to aquifers. This has limited groundwater abstraction to those who can afford it.

Most springs in the oases in Palmyra (Syrian Arab Republic), south Algeria, the Western Desert (Egypt), Al Kufrah (Libya) and Al Ahsa (Saudi Arabia), and the natural springs in Bahrain, Tozeur and Kebili (Tunisia) and Al Ahjar in Yemen, have all been lost or affected through excessive upstream pumping, which has lowered groundwater levels

Source: **United Nations Development Programme.** 2013. *Water governance in the Arab region: Managing scarcity and securing a future.* New York. www.undp.org/content/dam/rbas/doc/Energy and Environment/Arab_Water_Gov_Report/Arab_Water_Gov_Report_Full_Final_Nov_27.pdf

Modernizing traditional spate irrigation and social equity

In many countries in the region, spate irrigation has long been a vital method of exploiting flood flows in seasonal rivers and diverting water into fields for cropping. In Yemen, written records dating back some 600 years describe the complex arrangements for allocating water along the rivers. In Egypt, spate water from 26 wadis in the northwest coastal region has been used for irrigation since Roman times, and farmers in central Tunisia have practised this technique since the late 1800s. Other, more permanent water diversion structures have been introduced to modernize these traditional systems. In many cases, this shift has led to detrimental impacts on the original water allocation arrangements, especially for farmers in the middle and tail sections of the schemes. In Yemen, water abstractions upstream from some diversion sites have substantially increased, reducing wadi base flows to downstream users.

In Wadi Mawr in Yemen, a large-scale spate diversion system was constructed in the 1980s to enhance water-use efficiency and improve water supply for irrigation. However, following the construction of intake structures, sluices and canals to help manage the flood flows, upstream wealthy landowners prevented sluice and sediment-flushing facilities from working properly. Moreover, a new, and unauthorized, canal was constructed to divert and sell water to farmers outside the boundaries of the Wadi Mawr system. As a result, farmers downstream with original water rights entitlements lost access to their traditional water supply. Some adapted by investing in wells and exploiting groundwater, but those who could not afford to do this had to cope with the uncertainty of excess water from large floods that overflowed the diversion weir. This case highlights how public investment to improve a water diversion system for the benefit of all farmers can lead to changes in traditional water allocation arrangements for the benefit of a few.

Source: **FAO**. 2010. *Guidelines on spate irrigation.* FAO Irrigation and Drainage Paper 65. Rome. www.hydrology.nl/images/docs/dutch/key/2010_Guidelines_on_spate_irrigation.pdf

These examples demonstrate that introducing technologies without effective stakeholder participation and in the absence of suitable legal and institutional frameworks can lead to inequity in access to water and threaten the sustainability of water resources.


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Case study: Restoring rangeland productivity, biodiversity and ecosystems in Ethiopia and Jordan

Methods to protect degraded land from overgrazing and enabling grass and fodder crops to recover have evolved based on indigenous knowledge among farmers. In East Africa, they are called "area closures" and are widely used to rehabilitate millions of hectares of degraded lands. In Arab countries, they are called "Al Hima", which refers to enclosures to protect rangelands. The following examples in Ethiopia and Jordan highlight the benefits of protecting rangelands that are cost-effective, environmentally beneficial and widely accepted among local communities.

In Ethiopia, "area closures" describe areas of degraded land excluded from human activities and livestock grazing. Protection encourages natural regeneration through rich and diverse plant cover, including trees and shrubs, it improves soil health and reduces erosion, it increases productivity and it enhances economic and ecological benefits to local communities.

Many communities and institutions have reported that lost trees and shrubs species have re-emerged after two to three years from when areas were closed. Development begins with demarcating and fencing areas where productivity is poor, based on participatory decision-making involving men and women from beneficiary communities and local institutions. People and animals are excluded for three to five years, but this can increase to seven to ten years depending on the degree of degradation. In some circumstances, additional SLM measures such as terracing, enrichment plantation and oversowing of grass help accelerate restoration.

Maintenance activities include replanting, maintaining fences, pruning and weeding. Plant materials are prepared in nearby nurseries and local by-laws are used to regulate and protect enclosures from trespassers, livestock encroachment and deforestation. Violating the protection rules can result in punishment by the local authorities and confiscation of materials removed from the protected area.

Examples of degraded and restored landscapes in Ethiopia

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Medium- to long-term benefits include increased fuelwood, vegetation cover, availability of fodder for livestock feed, medicinal plants and bee forage, thus providing additional income sources and savings. Cash crops, trees and fodder bushes can also be grown on terraces. Wood for construction would be available after about seven years. Wider benefits can come from improving the productivity of downstream farmlands and protecting farmland and communities from flooding.

A cost–benefit analysis of area closures shows the practice has a positive net present value. The benefit–cost ratio varies between 4.6 and 54.3; that is, a USD 1 investment will bring at least USD 4 through carbon credits. These economic benefits are in addition to carbon dioxide sequestration benefits that accrue as the land becomes covered in vegetation.

Environmentally, area closures can significantly reduce sediment loads from upstream croplands and rangelands, reduce runoff coefficients and increase soil moisture. Highly erosive peak flows from steep slopes are reduced by area closures, and biomass increases carbon stocks. There are positive impacts on biodiversity, wildlife habitat, floral and faunal diversity, and natural regeneration through improved seed dispersal. Previously degraded farmlands or grazing lands have regenerated to either dense or open woodlands, with substantial improvement in the vegetation cover. Springs are also re-emerging after running dry two or three decades ago. The rise in groundwater tables has made irrigation more accessible. Farmers in some microwatersheds have dug wells and started small-scale irrigated cropping.

Involving farmers and communities in area closures and demonstrating the multiple benefits that come at low cost have encouraged farmers to implement closures on their own initiative and are helping to ensure sustainability.

*Sources***:** **FAO**. 2022. Rangeland restoration and sustainable pastoralism go hand in hand. In: *Pastoralist knowledge hub.* Cited 7 March 2022. Rome. www.fao.org/pastoralist-knowledge-hub/news/detail/en/c/1044677; **Gebrehiwot, T. & Veen, A.** 2014. The effect of enclosures in rehabilitating degraded vegetation: A case of Enderta District, northern Ethiopia. *Forest Research*, 3: 128; **Kasim, M., Assafaw, Z., Deraro, D., Melkato, M. & Mamo, Y.** 2016. The role of area closure in the recovery of woody species composition in degraded land and its socio-economic importance in central rift valley area of Ethiopia. *International Journal of Development Research*, 5: 3348–3358; **United Nations Convention to Combat Desertification.** 2015. *Ethiopia - Land degradation neutrality national report.* https://knowledge.unccd.int/sites/default/files/inline-files/ethiopia-ldn-country-report-final.pdf

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In Jordan, Al Hima or protected area is a traditional rangeland management system, similar to area closures, but developed by tribal peoples in Arab countries to survive under harsh climate conditions and scarce natural resources. Hima provides quick economic and environmental benefits liked by farmers, pastoralists and herders as the most preferred approach to support livelihoods. "HIMA" is also an abbreviation for the human integrated management approach, which emphasizes the role of human activities within this nature conservation system.

Harvesting and processing herbs before and after restoration using Hima


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Studies have shown that rangeland productivity in the Jordanian Badia has halved since the beginning of this century, and many indigenous plant species have disappeared. Hima was adopted in the Zarqa River basin in the Badia region to help restore the productivity of rangeland where rainfall is low and land is used mainly for domestic animal grazing. This included fencing selected areas of rangeland, participatory planning involving local communities, gender mainstreaming and developing alternative income-generating opportunities such as producing herbal medicines and making soap.

Sustainable land management was a central feature of restoring the rangelands. However, the legal framework for land tenure and land- and water-use rights initially hindered implementation. Local SLM knowledge was limited, and local communities were not usually involved in decision-making. All these issues changed as the project progressed, and communities became interested in SLM as they gained access to technical support from specialist advisers and began to participate in the project. Tenure issues were resolved by reclassifying barren and degraded land to rangeland and allocating land to the care of a cooperative.

Men and women were well represented in the project. Training topics included marketing, processing, packaging and collecting herbal/medicinal plants and grass for rotational grazing. Local institutions were established and strengthened. Women, in particular, were increasingly involved in training, engaging in income-generating activities and decision-making.

Following project completion, land users have taken responsibility for sustaining the gains made and monitored by the Ministry of Agriculture. A particular benefit is reducing soil erosion and the sediment-free runoff stored in downstream dams for domestic and farm use.

Hima has highlighted the importance of good governance at community, state and international levels in preventing and restoring rangelands. The project has also demonstrated the difference between nature reserves, which exclude people, and community-based natural resources management, which encourages participation and active involvement. The motivating force was increased profits and a growing awareness of the value of environmental sustainability.

Sources: **WANA Institute.** 2018. The concept of Al Hima. In: *WANA Institute*. Cited 7 March 2022. http://wanainstitute.org/en/fact_sheet/concept-al-hima; **Westerberg, V. & Myint, M.** 2015. *An economic valuation of a large-scale rangeland restoration project through the Hima system in Jordan.* Report for the ELD Initiative by International Union for Conservation of Nature. Nairobi. https://inweh.unu.edu/wp-content/uploads/2015/03/ELD_IUCN_Case_Study_Jordan.pdf

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Case study: Unconventional farming in marginal areas

Although some 83 percent of the global population will be living in developing countries by 2025, the capacity of available land resources and technologies to satisfy the growing demand for food and other agricultural commodities is far from certain. Exploiting marginal lands could provide a viable option.

Most agricultural policies favour agricultural lands with high potential, leading to a bias in policymaking that avoids marginal areas. A fresh policy outlook is needed that investigates options and innovative technological solutions to make the best use of marginal areas could be vital to meet future food demands.

Governments usually avoid marginal lands because of biophysical constraints, such as extreme weather, drought, salinity and socioeconomic conditions. Also, traditional agricultural cropping and practices may not be productive or economically feasible. Despite these problems, marginal areas offer territorial advantages and present an opportunity for alternative development models. The diverse and heterogeneous conditions, including spatial diversity and territorial capital, in marginal areas have a comparative advantage that can benefit the extreme poor, who are often overlooked and left behind.

Options in marginal areas include alternative crops that are resource efficient and climate smart. Regenerative technologies and practices best suited to areas affected by salinity, water scarcity and drought are options for sustaining marginal and salt-affected lands. Agricultural research has already documented how marginal lands can be sustainably cultivated with heat-/drought- and salt-tolerant crops such as barley, amaranth, types of millet, forages and halophyte (salt-tolerant) plants, mainly for human consumption and animal feed.

In areas where marginality is driven by salinity and waterlogging, agricultural planning involves a combination of salt-resistant crops and best irrigation management practices and methods to manage irrigation-induced salinity under the context of biosaline agriculture. Salt-friendly agriculture represents an opportunity to practice a new type of farming unconventionally by growing salt-tolerant varieties of conventional crops and halophytes using marginal water, such as drainage water, produced water and different types of saline water, including rejected brine and seawater. Improved climate-smart irrigation systems, applying models to improve agricultural water productivity, water accounting, air-to-water technologies, and water and crop modelling are innovative tools to respond to water scarcity in marginal environments. Additionally, climate-resilient, nutrient-dense agricultural schemes that combine fish and crop farming in a saline farming context can support sustainable food production in increasingly saline environments while contributing to the restoration and protection of productive natural capital affected by salinity and water scarcity. Such farming approaches benefit the "circular agriculture economy" models because they minimize the number of external inputs, close nutrient loops and reduce negative environmental impacts by eliminating discharges.

Quinoa (left) and salicornia (right) growing in a desert environment

Sources: **Shahid, S.A. & Al-Shankiti, A**. 2013. Sustainable food production in marginal lands—Case of GDLA member countries. *International Soil and Water Conservation Research,* 1(1): 24–38; **Ahmadzai, H., Tutundjian, S. & Elouafi, I.** 2021. Policies for sustainable agriculture and livelihood in marginal lands: A review. *Sustainability*, 13(16): 8692; **FAO**. 2022. WASAG – The global framework on water scarcity in agriculture. In: *FAO*. Rome. www.fao.org/wasag/working-groups/saline-agriculture/en

References

ADB (Asian Development Bank). 2018. *2018 Annual evaluation review: The quality of project design and preparation for efficiency and sustainability*. Manila. www.adb.org/sites/default/files/evaluation-document/388366/files/2018-aer.pdf

Albrecht, T.R., Crootof, A. & Scott, C.A. 2018. The water-energy-food nexus: A systematic review of methods for nexus assessment. *Environmental Research Letters*, 13(4): 043002.

Allouche, J., Middleton, C. & Gyawali, D. 2015. Technical veil, hidden politics: Interrogating the power linkages behind the nexus. *Water Alternatives*, 8(1): 610–626.

Atlin, G.N., Cairns, J.E. & Das, B. 2017. Rapid breeding and varietal replacement are critical to adaptation of cropping systems in the developing world to climate change. *Global Food Security*, 12: 31–37.

Balasubramanya, S. & Stifel, D. 2020. Viewpoint: Water, agriculture & poverty in an era of climate change: Why do we know so little? *Food Policy*, 93: 101905.

Batchelor, C., Reddy, V.R., Linstead, C., Dhar, M., Roy, S. & May, R. 2014. Do water-saving technologies improve environmental flows? *Journal of Hydrology*, 518(A): 140–149.

Biradar, C., Sarker, A., Krishna, G., Kumar, S. & Wery, J. 2020. Assessing farming systems and resources for sustainable pulses intensification. Conference presentation at Pulses the Climate Smart Crops: Challenges and Opportunities (ICPulse2020).

Biradar, C.M., Ghosh, S., Löw, F., Singh, R., Chandna, P., Sarker, A., Sahoo, R.N. *et al.* 2019. Geo big data and digital augmentation for accelerating agroecological intensification in drylands. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 42(3/W6): 545–548.

Bird, J., Dodds, F., McCornick, P.G. & Shah, T. 2014. Water-food-energy nexus. In: *On target for people and planet: Setting and achieving water-related Sustainable Development Goals*, pp. 9–12. Colombo, International Water Management Institute. https://digitalcommons.unl.edu/wffdocs/4

Burlingame, B., Charrondiere, R. & Mouille, B. 2009. Food composition is fundamental to the cross-cutting initiative on biodiversity for food and nutrition. *Journal of Food Composition and Analysis*, 22(5): 361–365.

Byagmugisha, F. 2013. *Securing Africa's land for shared prosperity: A program to scale up reforms and investments*. Washington, DC, International Bank for Reconstruction and Development/The World Bank. https://openknowledge.worldbank.org/handle/10986/13837

CFS (Committee on World Food Security). 2015. *Water for food security and nutrition: Policy recommendations*. Rome. http://www.fao.org/3/av046e/av046e.pdf

CFS & FAO. 2012. *Voluntary guidelines on the responsible governance of tenure of land, fisheries and forests in the context of national food security*. Rome, FAO. http://www.fao.org/3/i2801e/i2801e. pdf

Chaffin, B.C., Gosnell, H. & Cosens, B.A. 2014. A decade of adaptive governance scholarship: Synthesis and future directions. *Ecology and Society*, 19(3): 56.

Clinton, N., Stuhlmacher, M., Miles, A., Uludere Aragon, N., Wagner, M., Georgescu, M., Herwig, C. & Gong, P. 2018. A global geospatial ecosystem services estimate of urban agriculture. *Earth's Future*, 6(1): 40–60.

Cosens, B.A., Craig, R.K., Hirsch, S.L., Arnold, C.A., Benson, M.H., Decaro, D.A., Garmestani, A.S. *et al.* 2017. The role of law in adaptive governance. *Ecology and Society*, 22(1): 30.

Crawford, A. 2018. Big data suggests big potential for urban farming. In: *WIRED*. www.wired.com/story/big-data-suggests-big-potential-for-urban-farming

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F.N. & Leip, A. 2021. Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food*, 2(3): 198–209.

Dasgupta, P. 2021. *The economics of biodiversity: The Dasgupta review*. London, HM Treasury. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/962785/The_Economics_of_Biodiversity_The_Dasgupta_Review_Full_Report.pdf

Davies, J., Ogali, C., Slobodian, L., Roba, G. & Ouedraogo, R. 2018. *Crossing boundaries: Legal and policy arrangements for cross-border pastoralism*. Rome, FAO and Gland, International Union for Conservation of Nature. www.fao.org/3/ca2383en/CA2383EN.pdf

De Haan, C., Dubern, E., Garancher, B. & Quintero, C. 2016. *Pastoralism Development in the Sahel: A Road to Stability*? Washington, DC, International Bank for Reconstruction and Development/The World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/24228/K8813.pdf?sequence=2&isAllowed=y

Di Gregorio, M., Fatorelli, L., Pramova, E., May, P., Locatelli, B. & Brockhaus, M. 2016. *Integrating mitigation and adaptation in climate and land use policies in Brazil: A policy document analysis*. Centre for Climate Change Economics and Policy Working Paper No. 257. Sustainability Research Institute Paper No. 94. CIFOR Working Paper No. 194. www.cccep.ac.uk/wp-content/uploads/2016/02/Working-Paper-257-Di-Gregorio-et-al-2016.pdf

Diagnea, M., Demonta, M. & Diagneb, A. 2009. Adoption and impact of an award winning post-harvest technology: The ASI rice thresher in the Senegal River Valley. Conference presentation at International Association of Agricultural Economists Conference, 16–22 August 2009. Beijing, International Association of Agricultural Economists.

Dillon, P., Escalante, E.F., Megdal, S.B. & Massmann, G. 2020. Managed aquifer recharge for water resilience. *Water 2020*, 12(7): 1846.

Doss, C. & Meinzen-Dick, R. 2020. Land tenure security for women: A conceptual framework. *Land Use Policy*, 99: 105080.

Duong, N.T.B. & De Groot, W.T. 2020. The impact of payment for forest environmental services (PFES) on community-level forest management in Vietnam. *Forest Policy and Economics*, 113: 102135.

EC (European Commission). 2019. A European green deal. In: *EC*. Cited 13 July 2021. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

Economic Commission for Latin America and the Caribbean. 2021. Natural resources and development. In: *Economic Commission for Latin America and the Caribbean*. www.cepal.org/en/publications/type/natural-resources-and-development

E3G. 2020. Public bank climate tracker matrix. In: *E3G*. Cited 13 July 2021. www.e3g.org/matrix

Ellen MacArthur Foundation. 2015. *Growth within: A circular economy vision for a competitive Europe*. https://ellenmacarthurfoundation.org/growth-within-a-circular-economy-vision-for-a-competitive-europe

FAO. 2007a. *Modernizing irrigation management – the MASSCOTE approach: Mapping system and services for canal operation techniques*. FAO Irrigation and Drainage Paper 63. Rome. www.fao.org/3/a1114e/a1114e.pdf

FAO. 2007b. *Irrigation management transfer: Worldwide efforts and results.* FAO Water Reports 32. Rome. www.fao.org/3/a1520e/a1520e00.pdf

FAO. 2011a. Biotechnologies for agricultural development. Conference presentation at Agricultural Biotechnologies in Developing Countries: Options and Opportunities in Crops, Forestry, Livestock, Fisheries and Agro-industry to Face the Challenges of Food Insecurity and Climate Change (ABDC-10). www.fao.org/biotech/abdc/backdocs/en

FAO. 2011b. *Global food losses and food waste: Extent, causes and prevention*. Rome. www.fao.org/3/i2697e/i2697e.pdf

FAO. 2014a. *Water and the rural poor: Interventions for improving livelihoods in Asia.* Bangkok. www.fao.org/3/i3705e/i3705e.pdf

FAO. 2014b. *The water-energy-food nexus: A new approach in support of food security and sustainable agriculture*. Rome. www.fao.org/3/bl496e/bl496e.pdf

FAO. 2014c. *Turning family farm activity into decent work*. Rome. www.fao.org/fileadmin/user_upload/fao_ilo/pdf/FF_DRE.pdf

FAO. 2016a. *Le rôle des femmes dans la gestion des ressources en eau agricole – Phase 2*. Rome. www.fao.org/3/i5680f/i5680f.pdf

FAO. 2016b. *Water accounting and auditing: A source book.* FAO Water Reports 43. Rome. www.fao.org/3/i5923e/i5923e.pdf

FAO. 2017a. *Watershed management in action: Lessons learned from FAO field projects.* Rome. www.fao.org/3/i8087e/i8087e.pdf

FAO. 2017b. Sustainable land management (SLM) in practice in the Kagera Basin: Lessons learned for scaling up at landscape level. In: *Kagera Agro-ecosystems*. Rome. Cited 3 March 2022. www.fao.org/in-action/kagera/news-archive/news-detail/en/c/901665

FAO. 2017c. *Sustainable land management (SLM) in practice in the Kagera basin: Lessons learned for scaling up at landscape level – R*esults of the Kagera Transboundary Agro-ecosystem Management Project (Kagera TAMP). Rome. www.fao.org/3/i6085e/i6085e.pdf

FAO. 2017d. *Land resource planning for sustainable land management.* Land and Water Division Working Paper 14. Rome. www.fao.org/3/i5937e/i5937e.pdf

FAO. 2017e. *Climate-smart agriculture sourcebook: Summary.* 2nd edition. Rome. www.fao.org/3/i7994e/i7994e.pdf

FAO. 2017f. *The future of food and agriculture: Trends and challenges.* Rome. www.fao.org/3/a-i6583e.pdf

FAO. 2017g. *Does improved irrigation technology save water? A review of the evidence.* Rome. www.fao.org/3/I7090EN/i7090en.pdf

FAO. 2018a. *Climate-smart agriculture: Case studies 2018. Successful approaches from different regions.* Rome. www.fao.org/policy-support/tools-and-publications/resources-details/en/c/1177071

FAO. 2018b. *Nature-based solutions for agricultural water management and food security.* Land and Water Discussion Paper 12. Rome. www.fao.org/3/ca2525en/ca2525en.pdf

FAO. 2018c. *Water accounting for water governance and sustainable development.* Rome. www.fao.org/3/i8868en/i8868en.pdf

FAO. 2018d. *Handbook for saline soil management*. Rome. www.fao.org/3/i7318en/I7318EN.pdf

FAO. 2018e. *Integrated natural resources management in drought-prone and salt-affected agricultural production systems in Central Asia and Turkey*. FAO/GEF Regional Project CACILM-2. www.fao.org/3/CA1423EN/ca1423en.pdf

FAO. 2019a. Water and gender. In: *Land & Water*. Cited 3 March 2022. www.fao.org/land-water/water/watergovernance/water-gender/en

FAO. 2019b. *Water use in livestock production systems and supply chains: Guidelines for assessment.* Rome. www.fao.org/3/ca5685en/ca5685en.pdf

FAO. 2019c. *The international code of conduct for the sustainable use and management of fertilizers.* Rome. www.fao.org/3/ca5253en/ca5253en.pdf

FAO. 2019d. *The state of food and agriculture 2019. Moving forward on food loss and waste reduction.* Rome. www.fao.org/3/ca6030en/ca6030en.pdf

FAO. 2020a. *Unpacking water tenure for improved food security and sustainable development.* Land and Water Discussion Paper 15. Rome. https://doi.org/10.4060/cb1230en

FAO. 2020b. *The state of food security and nutrition in the world 2020. Transforming food systems for affordable healthy diets*. Rome. https://doi.org/10.4060/ca9692en

FAO. 2020c. *The state of food and agriculture 2020. Overcoming water challenges in agriculture.* Rome. https://doi.org/10.4060/cb1447en

FAO. 2020d. *Peatland mapping and monitoring: Recommendations and technical overview.* Rome. https://doi.org/10.4060/ca8200en

FAO. 2020e. *Environmental performance of feed additives in livestock supply chains: Guidelines for assessment, Version 1.* Rome. https://doi.org/10.4060/ca9744en

FAO. 2020f. *A protocol for measurement, monitoring, reporting and verification of soil organic carbon in agricultural landscapes: GSOC MRV protocol.* Rome. https://doi.org/10.4060/cb0509en

FAO. 2022a. Global Soil Partnership. In: *FAO*. Rome. www.fao.org/global-soil-partnership/en

FAO. 2022b. Incentives for ecosystem services . In: *FAO*. Rome. www.fao.org/in-action/incentives-for-ecosystem-services/resources/case-studies/en

FAO. (forthcoming). *Water auditing/water governance analysis: A methodological guide.* Rome.

FAO & IHE Delft Institute for Water Education. 2019. *Water accounting in the Litani River basin: Remote sensing for water productivity.* Water Accounting Series. Rome. www.fao.org/3/ca6679en/CA6679EN.pdf

FAO & ITPS (Intergovernmental Technical Panel on Soils). 2015. *Status of the world's soil resources: Main report.* Rome. www.fao.org/3/i5199e/i5199e.pdf

FAO & ITPS. 2017. *Voluntary guidelines for sustainable soil management.* Rome, FAO. www.fao.org/3/a-bl813e.pdf

FAO & ITPS. 2020. *Protocol for the assessment of sustainable soil management.* Rome, FAO. www.fao.org/fileadmin/user_upload//GSP/SSM/SSM_Protocol_EN_006.pdf

FAO & IWMI (International Water Management Institute). 2018. *More people, more food, worse water? A global review of water pollution from agriculture,* J. Mateo-Sagasta, S. Marjani & H. Turral, eds. Rome. www.fao.org/3/ca0146en/ca0146en.pdf

FAO, UNDP (United Nations Development Programme) & UNEP (United Nations Environment Programme). 2021. *A multi-billion-dollar opportunity: Repurposing agricultural support to transform food systems.* Rome. https://doi.org/10.4060/cb6562en

FAO, International Fund for Agricultural Development, United Nations Children's Fund, World Food Programme & World Health Organization. 2018. *The state of food security and nutrition in the world 2018. Building climate resilience for food security and nutrition.* Rome, FAO. www.fao.org/3/i9553en/i9553en.pdf

FAO, International Fund for Agricultural Development, United Nations Children's Fund, World Food Programme & World Health Organization. 2021. *The state of food security and nutrition in the world 2021. Transforming food systems for food security, improved nutrition and affordable healthy diets for all.* Rome, FAO. https://doi.org/10.4060/cb4474en

FAO, ITPS, Global Soil Biodiversity Initiative, Convention on Biological Diversity & EC. 2020. *State of knowledge of soil biodiversity: Status, challenges and potentialities.* Rome, FAO. https://doi.org/10.4060/cb1928en

Foley, J.A. 2018. No, vertical farms won't feed the world. In: *GlobalEcoGuy.org.* https://globalecoguy.org/no-vertical-farms-wont-feed-the-world-5313e3e961c0

Folke, C., Hahn, T., Olsson, P. & Norberg, J. 2005. Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources*, 30: 441–473.

Foster, S. & Loucks, D., eds. 2006. *Non-renewable groundwater resources: A guidebook on socially-sustainable management for water-policy makers.* Paris, United Nations Educational, Scientific and Cultural Organization. https://fr.ircwash.org/sites/default/files/Foster-2006-Nonrenewable.pdf

Franco, A. 2009. Fixação biológica de nitrogênio na cultura da soja no Brasil: Uma lição para o futuro. (Biological nitrogen fixation on soybean crop in Brazil: A lesson for the future.). Jan–Apr: 23–24.

Garg, M., Sharma, N., Sharma, S., Kapoor, P., Kumar, A., Chunduri, V. & Arora, P. 2018. Biofortified crops generated by breeding, agronomy, and transgenic approaches are improving lives of millions of people around the world. *Frontiers in Nutrition*, 5: 12.

Ghisellini, P., Cialani, C. & Ulgiati, S. 2016. A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, 114: 11–32.

Global Donor Platform for Rural Development. 2022. Land governance programme map & database. https://landgov.donorplatform.org

Gonzalez Fischer, C. & Garnett, T. 2016. *Plates, pyramids and planets. Developments in national healthy and sustainable dietary guidelines: A state of play assessment.* Rome, FAO and Oxford, University of Oxford. www.fao.org/3/I5640E/i5640e.pdf

GWP (Global Water Partnership) & IWMI. 2021. *Storing water: A new integrated approach for resilient development*, W. Yu, W. Rex, M. McCartney, S. Uhlenbrook, R. Von Gnechten & J.D. Priscoli, eds. Stockholm, GWP. www.gwp.org/globalassets/global/toolbox/publications/perspective-papers/perspectives-paper-on-water-storage.pdf

Haacker, E.M.K., Kendall, A.D. & Hyndman, D.W. 2016. Water level declines in the high plains aquifer: Predevelopment to resource senescence. *Groundwater*, 54(2): 231–242.

Hallstein, E. & Iseman, T. 2021. *Nature-based solutions in agriculture: Project design for securing investment.* Rome, FAO and Virginia, The Nature Conservancy. https://doi.org/10.4060/cb3144en

Herrero, M., Thornton, P.K., Mason-D'Croz, D., Palmer, J., Benton, T.G., Bodirsky, B.L., Bogard, J.R. *et al.* 2020. Innovation can accelerate the transition towards a sustainable food system. *Nature Food*, 1(5): 266–272.

HLPE (High Level Panel of Experts on Food Security and Nutrition). 2014. *Food losses and waste in the context of sustainable food systems. A report by The High Level Panel of Experts on Food Security and Nutrition.* HLPE Report 8. Rome. www.fao.org/3/i3901e/i3901e.pdf

HLPE. 2015. *Water for food security and nutrition. A report by The High Level Panel of Experts on Food Security and Nutrition.* HLPE Report 9. Rome. www.fao.org/fileadmin/user_upload/hlpe/hlpe_documents/HLPE_Reports/HLPE-Report-9_EN.pdf

Hoogeveen, J., Faurès, J.M., Peiser, L., Burke, J. & Van De Giesen, N. 2015. GlobWat – A global water balance model to assess water use in irrigated agriculture. *Hydrology and Earth System Sciences*, 19(9): 3829–3844.

Horst, L. 1998. *The dilemmas of water division: Considerations and criteria for irrigation system design.* Colombo, IWMI. https://publications.iwmi.org/pdf/H023588.pdf

IIASA (International Institute for Applied Systems Analysis). 2019. *The digital revolution and sustainable development: Opportunities and challenges. Report prepared by The World in 2050 Initiative.* Laxenburg. http://pure.iiasa.ac.at/id/eprint/15913/1/TWI2050-for-web.pdf

IPCC (Intergovernmental Panel on Climate Change). 2019. *Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.* Geneva. www.ipcc.ch/srccl

IUCN (International Union for Conservation of Nature). 2020. *IUCN global standard for nature-based solutions: A user-friendly framework for the verification, design and scaling up of NbS.* 1st edition. Gland. https://doi.org/10.2305/IUCN.CH.2020.08.en

IUCN & FAO. 2020. 008 - Developing agroecological practices as nature-based solutions. In: *IUCN*. Cited 9 September 2021. www.iucncongress2020.org/motion/008

IWMI. 2021. IWMI and ReWater MENA support online course on water reuse for agriculture. In: *ReWater MENA.* https://rewater-mena.iwmi.org/2021/06/08/iwmi-and-rewater-mena-supports-online-course-on-water-reuse-for-agriculture

Izzi, G., Denison, J. & Veldwisch, G. 2021. *The farmer-led irrigation development guide: A what, why and how-to for intervention design*. Washington, DC, International Bank for Reconstruction and Development/The World Bank.
https://pubdocs.worldbank.org/en/751751616427201865/FLID-Guide-March-2021-Final.pdf

James, C. 2014. Brief 49: Global area of commercialized biotech/GM crops. In: *International Service for the Acquisition of Agri-biotech Applications (ISAAA)*. Cited 3 March 2022.
www.isaaa.org/resources/publications/briefs/49

Jurgilevich, A., Birge, T., Kentala-Lehtonen, J., Korhonen-Kurki, K., Pietikäinen, J., Saikku, L. & Schösler, H. 2016. Transition towards circular economy in the food system. *Sustainability,* 8(1): 69.

Karimi, P., Bastiaanssen, W.G.M. & Molden, D. 2013. Water accounting plus (WA+) – A water accounting procedure for complex river basins based on satellite measurements. *Hydrology and Earth System Sciences*, 17(7): 2459–2472.

Kassam, A., Friedrich, T. & Derpsch, R. 2018. Global spread of conservation agriculture. *International Journal of Environmental Studies,* 76(1): 29–51.

Kaune, A., Droogers, P., Van Opstal, J., Steduto, P. & Perry, C. 2020. *REWAS: REal WAter Savings tool: Technical document.* FutureWater Report 200. Rome.
www.futurewater.nl/wp-content/uploads/2020/06/FAO_REWAS_v08.pdf

Kay, M. 2020. *Improving irrigation water use efficiency: A synthesis of options to support capacity development.* Istanbul, Turkish Water Institute. www.suen.gov.tr/Suen/en/catdty.aspx?val=456

Kay, M.G. & Renault, D., eds. 2004. *Capacity development in irrigation and drainage: Issues, challenges and the way ahead.* FAO Water Report 26. Rome, FAO.
www.fao.org/3/y5524e/y5524e00.htm

Keene, S., Troell, J. & Ginsburg, C. 2020. *Whose water? A comparative analysis of national laws and regulations recognising peoples indigenous peoples', afro-descendants', and local communities' water tenure.* Washington, DC, Rights and Resources Initiative and Environmental Law Institute. https://rightsandresources.org/wp-content/uploads/2020/02/WhoseWater.pdf

Kibblewhite, M.G.G. 2018. Contamination of agricultural soil by urban and peri-urban highways: An overlooked priority? *Environmental Pollution*, 242(B): 1331–1336.

Kristensen, P. 2004. The DPSIR framework. Presented at Workshop on a comprehensive/detailed assessment of the vulnerability of water resources to environmental change in Africa using river basin approach. Nairobi, UNEP.
https://wwz.ifremer.fr/dce/content/download/69291/913220/.../DPSIR.pdf

Kummu, M., De Moel, H., Porkka, M., Siebert, S., Varis, O. & Ward, P.J. 2012. Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. *Science of the Total Environment*, 438: 477–489.

Lausche, B. 2019. *Integrated planning: Policy and law tools for biodiversity conservation and climate change.* IUCN Environmental Policy and Law Paper No. 88. Gland, IUCN.
https://doi.org/10.2305/IUCN.CH.2019.EPLP.88.en

Lehner, B., Liermann, C.R., Revenga, C., Vörömsmarty, C., Fekete, B., Crouzet, P., Döll, P. *et al.* 2011. High-resolution mapping of the world's reservoirs and dams for sustainable river-flow management. *Frontiers in Ecology and the Environment*, 9(9): 494–502.

Lobos, **V.** 2021. *Gobernanza del agua en territorios agrícolas: Estudio de caso en Chile: Subcuenca del río Tinguiririca.* Santiago, FAO. www.fao.org/3/cb3617es/cb3617es.pdf

Löw, F., Biradar, C., Dubovyk, O., Fliemann, E., Akramkhanov, A., Vallejo, A.N. & Waldner, F. 2017. Regional-scale monitoring of cropland intensity and productivity with multi-source satellite image time series. *GIScience & Remote Sensing,* 55(4): 539–567.

Lowenberg-DeBoer, J. & Erickson, B. 2019. Setting the record straight on precision agriculture adoption. *Agronomy Journal*, 111(4): 1552–1569.

Lubell, M., Blomquist, W. & Beutler, L. 2020. Sustainable groundwater management in California: A grand experiment in environmental governance. *Society & Natural Resources,* 33 (12): 1447–1467.

Lundqvist, J. & Unver, O. 2018. Alternative pathways to food security and nutrition – Water predicaments and human behavior. *Water Policy*, 20(5): 871–884.

Lundqvist, J., Malmquist, L., Dias, P., Barron, J. & Wakeyo, M.B. 2021. *Water productivity, the yield gap, and nutrition: The case of Ethiopia*. Land and Water Discussion Paper 17. Rome, FAO. http://www.fao.org/3/cb3866en/cb3866en.pdf

Mansourian, S., Dudley, N. & Vallauri, D. 2017. Forest landscape restoration: Progress in the last decade and remaining challenges. *Ecological Restoration,* 35(4): 281–88.

Munroe, R. & Mant, R. 2014. *REDD+ and adaptation: Identifying complementary responses to climate change.* www.unep-wcmc.org/resources-and-data/un-redd-programme-launches-info-brief-on-redd-and-adaptation

McCartney, M., Foudi, S., Muthuwatta, L., Sood, A., Simons, G., Hunink, J., Vercruysse, K. & Omuombo, C. 2019. *Quantifying the services of natural and built infrastructure in the context of climate change: The case of the Tana River Basin, Kenya.* IWMI Research Report 174. Colombo, IWMI. www.iwmi.cgiar.org/publications/iwmi-research-reports/iwmi-research-report-174

McElwee, P., Huber, B. & Nguyễn, T.H.V. 2020. Hybrid outcomes of payments for ecosystem services policies in Vietnam: Between theory and practice. *Development and Change,* 51(1): 253–280.

Naranjo, L. & Willaarts, B.A. 2020. *Guía metodológica: Diseño de acciones con enfoque del Nexo entre agua, energía y alimentación para países de América Latina y el Caribe*. Serie Recursos Naturales y Desarrollo, no. 197 LC/TS.2020/117. Santiago, Comisión Económica para América Latina y el Caribe. www.cepal.org/es/publicaciones/46078-guia-metodologica-diseno-acciones-enfoque-nexo-agua-energia-alimentacion-paises

Nizzetto, L., Futter, M. & Langaas, S. 2016. Are agricultural soils dumps for microplastics of urban origin? *Environmental Science and Technology,* 50(20): 10777–10779.

OECD (Organisation for Economic Co-operation and Development). 2015. *OECD principles on water governance.* Paris. www.oecd.org/cfe/regionaldevelopment/OECD-Principles-on-Water-Governance.pdf

OECD. 2017. *Guiding principles of effective environmental permitting systems.* Paris. www.oecd.org/env/outreach/37311624.pdf

OECD. 2018. *Implementing the OECD principles on water governance: Indicator framework and evolving practices.* OECD Studies on Water. Paris. https://doi.org/10.1787/9789264292659-en

OECD. 2021. *Financing a water secure future.* Paris. www.oecd.org/water/brochure-financing-a-water-secure-future.pdf

OECD. 2022. *The OECD principles on water governance.* Paris. www.oecd.org/governance/oecd-principles-on-water-governance.htm

O**strom, E.** 2005. *Understanding institutional diversity.* Princeton, Princeton University Press.

Ostrom, E. 2010. Beyond markets and states: Polycentric governance of complex economic systems. *American Economic Review*, 100(3): 641–672.

Otoo, M. & Drechsel, P. 2005. *Resource recovery from waste: Business models for energy, nutrient and water reuse.* London, Earthscan.

Oweis, T. 2016. *Effective mechanised rainwater harvesting: Coping with climate change implications in the Jordanian badia.* Amman, International Center for Agricultural Research in the Dry Areas. www.icarda.org/publications/6061/effective-mechanized-rainwater-harvesting-coping-climate-change-implications

Oxfam & ILC (International Land Coalition). 2016. *Common ground: Securing land rights and safeguarding the earth.* Briefing Paper. Oxford, Oxfam. https://policy-practice.oxfam.org/resources/common-ground-securing-land-rights-and-safeguarding-the-earth-600459

Pahl-Wostl, C. 2015. *Water governance in the face of global change: From understanding to transformation.* Springer. https://link.springer.com/content/pdf/10.1007%2F978-3-319-21855-7.pdf

Pahl-Wostl, C., Mostert, E. & Tàbara, D. 2008. The growing importance of social learning in water resources management and sustainability science. *Ecology and Society,* 13(1): 24.

Pahl-Wostl, C., Sendzimir, J., Jeffrey, P., Aerts, J., Berkamp, G. & Cross, K. 2007. Managing change toward adaptive water management through social learning. *Ecology and Society,* 12(2): 30.

Pahl-Wostl, C., Arthington, A., Bogardi, J., Bunn, S.E., Hoff, H., Lebel, L., Nikitina, E. ***et al.*** 2013. Environmental flows and water governance: Managing sustainable water uses. *Current Opinion in Environmental Sustainability,* 5(3–4): 341–351.

Pfitzer, M. & Krishnaswamy, R. 2007. *The role of the food & beverage sector in expanding economic opportunity.* Corporate Social Responsibility Report No. 20. Cambridge, MA, Kennedy School of Government, Harvard University. www.issuelab.org/resources/1708/1708.pdf

Pham, T.T., Thi, M.N.B., Thi, L.C.Đ., Hoàng, T.L., Pham, H.L. & Nguyen, V.D. 2018. *The role of payment for forest environmental services (PFES) in financing the forestry sector in Vietnam.* Center for International Forestry Research.

Plummer, R., Crona, B., Armitage, D.R., Olsson, P., Tengö, M. & Yudina, O. 2012. Adaptive co-management: A systematic review and analysis. *Ecology and Society,* 17(3): 11.

Plusquellec, H. 2014. Improving performance of canal irrigation systems is long overdue. http://fliphtml5.com/pjhk/uwyq/basic

Reed, M. & Massie, M. 2013. Embracing ecological learning and social learning: UNESCO biosphere reserves as exemplars of changing conservation practices. *Conservation and Society,* 11(4): 391–405.

Renault, D. & Wallender, W.W. 2000. Nutritional water productivity and diets. *Agricultural Water Management,* 45(3): 275–296.

Roobroek, D., Van Asten, P.J.A., Jama, B., Harawa, R. & Vanlauwe, B. 2015. *Integrated soil fertility management: Contributions of framework and practices to climate-smart agriculture.* Climate-smart Agriculture Practice Brief. Copenhagen, CGIAR Research Program on Climate Change, Agriculture and Food Security. https://ccafs.cgiar.org/resources/publications/integrated-soil-fertility-management-contributions-framework-and

Rosa, L., Chiarelli, D.D., Rulli, M.C., Dell'Angelo, J. & D'Odorico, P. 2020. Global agricultural economic water scarcity. *Science Advances,* 6(18).

Ros-Tonen, M.A.F., Reed, J. & Sunderland, T. 2018. From synergy to complexity: The trend toward integrated value chain and landscape governance. *Environmental Management,* 62(1): 1–14.

RRI (Rights and Resources Initiative). 2017. *Securing community land rights: Priorities and opportunities to advance climate and Sustainable Development Goals.* https://rightsandresources.org/wp-content/uploads/2017/09/Stockholm-Prorities-and-Opportunities-Brief.pdf

RRI & ELI (Environmental Law Institute). 2020. *Whose water? A comparative analysis of national laws and regulations recognising indigenous peoples' and local communities' rights to freshwater.* Washington, DC. https://rightsandresources.org/wp-content/uploads/2020/03/Whose-Water.pdf

Searchinger, T., Waite, R., Hanson, C. & Ranganathan, J. 2019. *Creating a sustainable food future: A menu of solutions to feed nearly 10 billion people by 2050.* World Resources Report. Washington, DC, World Resources Institute. https://files.wri.org/d8/s3fs-public/wrr-food-full-report.pdf

Seckler, D. 1996. *The new era of water resources management: From "dry" to "wet" water savings.* Research Report No. 1. Colombo, International Irrigation Management Institute. www.iwmi.cgiar.org/Publications/IWMI_Research_Reports/PDF/pub001/REPORT01.PDF

Settle, W. & Garba, M.H. 2011. Sustainable crop production intensification in the Senegal and Niger River basins of francophone West Africa. *International Journal of Agricultural Sustainability,* 9(1): 171–185.

Shafiee-Jood, M. & Cai, X. 2016. Reducing food loss and waste to enhance food security and environmental sustainability. *Environmental Science and Technology,* 50(16): 8432–8443.

Shah, T. 2009. *Taming the anarchy: Groundwater governance in South Asia.* Washington, DC, Resources for the Future and Colombo, IWMI.

Shah, T. 2022. *Water-energy-food nexus in action: Global review of policy and practice.* Thematic Background Report for SOLAW 2021. Rome, FAO. www.fao.org/land-water/solaw2021/en

Sjoerd, E., Stofberg, S.F., Yang, X., Liu, Y., Islam, M.N. & Hu, Y.F. 2017. Irrigation and drainage in agriculture: A salinity and environmental perspective. In: *Current Perspective on Irrigation and Drainage.* IntechOpen.

Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B.L., Lassaletta, L., de Vries, W. ***et al.*** 2018. Options for keeping the food system within environmental limits. *Nature,* 562(7728): 519–525.

Tripathi, V., Edrisi, S.A., Chaurasia, R., Pandey, K.K., Dinesh, D., Srivastava, R., Srivastava, P. & Abhilash, P.C. 2019. Restoring HCHs polluted land as one of the priority activities during the UN-International Decade on Ecosystem Restoration (2021–2030): A call for global action. *Science of the Total Environment,* 689: 1304–1315.

UNECE (United Nations Economic Commission for Europe). 2021. UN Watercourses Convention. In: *UNECE.* Cited 3 March 2022. https://unece.org/environment-policy/water/un-watercourses-convention

UNEP. 2015. *Building inclusive green economies in Africa: Experience and lessons learned 2010-2015.* Nairobi. www.unep.org/resources/report/building-inclusive-green-economies-africa-experience-and-lessons-learned-2010-2015

UNEP. 2019. *Environmental rule of law: First global report.* Nairobi. https://wedocs.unep.org/handle/20.500.11822/27279

UNEP. 2021. *First draft of the Post-2020 Global Biodiversity Framework.* CBD/WG2020/3/3. www.cbd.int/doc/c/abb5/591f/2e46096d3f0330b08ce87a45/wg2020-03-03-en.pdf

United Nations. 2015. *Transforming our world: The 2030 agenda for sustainable development.* New York. A/RES/70/1. www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_RES_70_1_E.pdf

United Nations. 2018. *Sustainable Development Goal 6: Synthesis report 2018 on water and sanitation.* New York. www.unwater.org/publications/sdg-6-synthesis-report-2018-on-water-and-sanitation

USAID (United States Agency for International Development). 2016. Fact sheet: Land tenure and women's empowerment. In: *LandLinks.* Cited 3 March 2022. www.land-links.org/issue-brief/fact-sheet-land-tenure-womens-empowerment

Varshney, R.K., Ribaut, J.M., Buckler, E.S., Tuberosa, R., Rafalski, J.A. & Langridge, P. 2012. Can genomics boost productivity of orphan crops? *Nature Biotechnology,* 30(12): 1172–1176.

Venkatesh, M. & Hurrell, R., eds. 2018. *Food fortification in a globalized world.* Academic Press.

Viña, C.S.-L. 2020. Beyond title: How to secure land tenure for women. In: *World Resources Institute.* Washington, DC. Cited 3 March 2022. www.wri.org/insights/beyond-title-how-secure-land-tenure-women

Whitehead, A.L., Kujala, H. & Wintle, B.A. 2017. Dealing with cumulative biodiversity impacts in strategic environmental assessment: A new frontier for conservation planning. *Conservation Letters,* 10(2): 195–204.

WMO (World Meteorological Organization) & GWP. 2017. *Selecting measures and designing strategies for integrated flood management: A guidance document.* Geneva, WMO. https://www.floodmanagement.info/publications/guidance%20-%20selecting%20measures%20and%20designing%20strategies_e_web.pdf

WOCAT (World Overview of Conservation Approaches and Technologies). 2013. *Water harvesting: Guidelines to good practices.* https://www.wocat.net/library/media/25/

World Bank Group. 2020. *Mobilizing private finance for nature.* Washington, DC. http://pubdocs.worldbank.org/en/916781601304630850/Finance-for-Nature-28-Sep-web-version.pdf

WWF (World Wide Fund for Nature). 2017. *Natural and nature-based flood management: A green guide.* https://files.worldwildlife.org/wwfcmsprod/files/Publication/file/538k358t40_WWF_Flood_Green_Guide_FINAL.pdf

Zhang, Y., Massel, K., Godwin, I.D. & Gao, C. 2018. Applications and potential of genome editing in crop improvement. *Genome Biology,* 19: 210.

Zhang, H., Zhou, Y., Huang, H., Wu, L., Liu, X. & Luo, Y. 2016. Residues and risks of veterinary antibiotics in protected vegetable soils following application of different manures. *Chemosphere,* 152: 229–237.

Ziadat, F., Bunning, S. & De Pauw, E. 2017. *Land resource planning for sustainable land management: Current and emerging needs in land resource planning for food security, sustainable livelihoods, integrated landscape management and restoration.* Land and Water Division Working Paper 14. Rome, FAO. www.fao.org/3/a-i5937e.pdf

6

CONCLUSIONS AND RECOMMENDATIONS

The land and water resources behind global food supply systems are rarely recognized as critical pathways to the transformation advocated by the 2021 United Nations Food Systems Summit. Yet more than 95 percent of food is directly dependant on land and freshwater, and 68 percent of aquaculture production is derived from inland waters. The FAO outlook for 2050 projects that agricultural production will need to add 50 percent more food, fibre and biofuel to satisfy human demand than in 2012. The implications for land and water are profound. Over 33 percent of agricultural land is degraded, and any expansion will necessarily involve further deforestation or recovery of degraded land. With climate change factored in, global agricultural freshwater withdrawals would need to increase by as much as 30 percent above the level in 2012. This would take total global withdrawals to within 10 percent of the annually renewable freshwater resources generated on land.

Land suitability is expected to shift poleward under climate change. In addition, the impacts of climate change on agriculture are felt through water. Changing patterns of rainfall and relative humidity determine all aspects of crop growth. The management of soil moisture and its deficits lies at the centre of agricultural adaptation.

It is for these reasons that SOLAW 2021 makes the case that immediate threats to land and water can be addressed by transforming approaches to land and water governance and adaptive management to keep productive land in play while contributing towards zero net GHG emissions. The functions of these systems have to be safeguarded.

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6.1 The state of play offers no room for complacency

The current state of land, soil and water resources and the trends in their use reflect the pressures and drivers imposed by growing populations and expanding economies. World food demand is predicted to increase by 50 percent over the next 30 years, with the greatest needs in developing countries. While it is expected that production will respond to rising demand, this will not be the only measure of success. The environmental sustainability of the productive land and water systems and their capacity to satisfy the livelihood requirements of urban and rural populations will be essential criteria.

Since SOLAW 2011, most of the growth in global agricultural production has been derived from input intensification, particularly on prime agricultural land equipped for irrigation. By contrast, rainfed systems in the tropics and mountain regions have exhibited slower increases in productivity. Many uses of land and water systems are continuing to impose negative impacts on ecosystem services.

There is little room for expanding the productive land area. Deforestation and land drainage continue to deplete protected areas, despite attempts to limit encroachment. The local impact of physical water scarcity and freshwater pollution on food production is spreading and accelerating in low-income countries. In addition, without well-designed land policy and enforcement, rapid urbanization in developing countries often takes over some of the most productive arable land.

Current patterns of agricultural intensification are not sustainable. Agricultural production remains far below sustainability levels. Changing land-use patterns and concentrating inputs are producing unacceptably high levels of pollution and GHG emissions. These patterns of production stretch the productive capacity of agricultural systems to the limit and severely degrade their associated environmental services.

The combination of land degradation and water scarcity threatens food security. Agricultural intensification degrades soil structure and water for other uses, and depletes nutrients. These are reversible by reducing agriculture pollution, restoring the land, improving water quality, and remediating soils to maintain productivity and reduce GHG emissions. Groundwater is in crisis due to overexploitation from irrigation and pollution derived from agricultural inputs and untreated urban waste. Groundwater depletion and degradation is the first sign of water scarcity, affecting vulnerable rural populations that depend on access to land and water for subsistence and then spreading at scales that affect national food security.

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6.2 Socioeconomic development pathways are diverging

Demographic and economic growth increase food demand, placing unprecedented pressures on ecosystems and limited renewable land, soil and water resources. Socioeconomic trends, including urbanization, migration and technological change, will continue to drive the distribution of these pressures on available natural resources. Higher incomes and urban lifestyles change food demand towards more resource-intensive consumption of animal proteins, fruits and vegetables. At the same time, malnutrition persists among the urban and rural poor who are disconnected from markets or have limited access to productive land due to poverty or geography.

Increasing population means there are reduced natural resources available per capita. Underlying the patterns of economic growth, competition for land and water resources is intensifying. Increasing population is reducing the amount of natural resources available per capita. In 2018, more than 733 million people lived in countries with high (70 percent) and critical (100 percent) water stress areas, accounting for almost 10 percent of the global population. Over the past two decades, sub-Saharan Africa experienced a 40 percent reduction in water availability per capita between 2000 and 2017. West Africa, Northern Africa and Southern Africa now have less than 1 700 m^3 of agricultural land per capita, which is considered to be a level that compromises a nation's ability to meet water demand for food. Similarly, there was a 22 percent decline in arable land per capita between 2000 and 2019.

Farming systems are becoming polarized. The social and economic structure of most populations is finely tuned to natural resource access, even as populations concentrate in urban areas. Large-scale commercial holdings dominate agricultural land use to supply global food. Land tenure patterns restrict and concentrate up to 500 million smallholdings (less than 2 ha) in subsistence farming on lands susceptible to climate change, degradation and water scarcity.

Globally, 80 percent of the extreme poor live in rural areas. Most live in the developing world; their livelihoods are disproportionally dependent on agriculture, which is highly exposed to current and future climate risks. Ensuring equitable access to land and water resources is key for promoting inclusive rural development. The lack of adequate access and user rights and increasing disparities in capacities to take advantage of land and water endowments are exacerbating rural poverty.

Policy and legal frameworks governing land and water resources are fragmented, lack implementation or have proven ineffective. Many are not adapted to cope with the range and depth of environmental shocks that are anticipated in the future under climate change. They also risk perpetuating the current trends that concentrate land under large commercial concerns and fragment tenure among smallholder communities.

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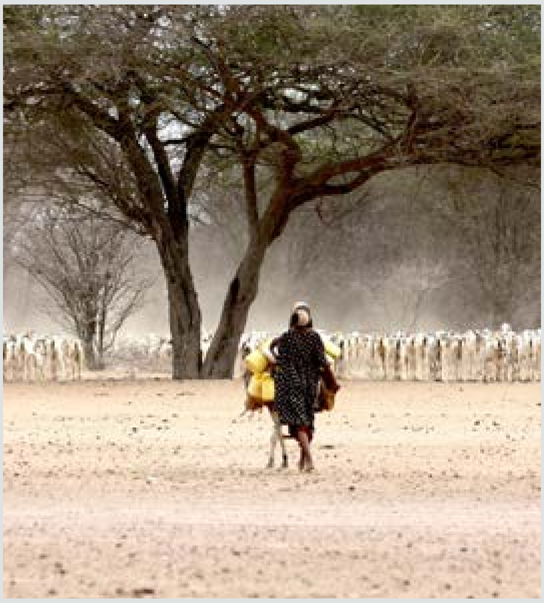
The depth of the socioeconomic trade-offs between agricultural production and environmental services depends on land-use management. Such trade-off decisions will require sound data and information to fully understand the consequences of socioeconomic outcomes and environmental impacts. Decisions taken will need to include ways of reducing the risks and their impacts to avoid further degrading natural resources while maintaining food security and poverty targets. There may be important synergies and trade-offs that cannot be addressed by single sector strategies and investments alone. Initiatives in the water–food–energy nexus approach can help to optimize resource-use efficiency, but ultimately land-use planning and the process of water allocation will need to become truly inclusive.

Overall recommendation: Inclusive and effective land and water governance will need to be applied, to underpin the required productivity gains to meet global food demand. Governance over land and water resources can perform if there is an enabling environment in which land- and water-management actions take place at multiple levels of decision-making. Social, agricultural and environmental policies need to be mutually reinforcing if they are to reconcile competition over land and water. There is progress in land tenure initiatives, but land and water allocation adjustments will be possible only when explicit instruments are joined up and resources management decision-making becomes inclusive. Integrated land and water planning is urgently needed to guide land and water use and not just to promote sustainable resources management. To establish a realistic scope for reducing GHG emissions, land-use planning will need to become much more inclusive and focus on alternative strategies for crop fertilization and soil management.

6.3 The risks to a food-secure future are proliferating

Land and water systems are under pressure – and some are at breaking point. There are mounting pressures on productive land, soil and water resources that are creating comprehensive land degradation and water scarcity. Unprecedented heat and shifting rainfall patterns already affect agricultural production. Long-term adaptation to climate change is necessary. Limits on the global food system need to be recognized, and alternative land- and water-management approaches taken to avoid, mitigate or manage risks.

Pressures on land and water systems are compromising agricultural productivity, precisely at times and in places where growth is most needed to meet global food security targets. Land degradation and water scarcity raise risk levels for agricultural production and ecosystem services. A converging range of economic drivers and climate variability are affecting the long-term viability of global food systems.



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Climate change adds uncertainty to the agro-climatic risks facing producers, particularly those who are least able to buffer shocks and who are food insecure. Climate volatility and extreme hydrological and temperature events will affect all producers, but risks are greater in areas with minimal resource endowments, a growing population and limited economic power to adapt local food systems or find substitutes. Specifically, climate change is expected to increase evapotranspiration from cropped land and alter the quantity and distribution of rainfall, leading to changes in land/crop suitability. Greater variations in river runoff and groundwater recharge are expected, and will affect rainfed and irrigated agriculture. At the same time, changes in overall temperature and rainfall regimes are expected to result in poleward shifts in land suitability.

Looking to the future. FAO estimates that by 2050, agriculture will need to produce almost 50 percent more food, fibre and biofuel than in 2012. Agricultural production in sub-Saharan Africa and South Asia will need to more than double (increase of 112 percent) to meet estimated calorific requirements. The rest of the world will need to produce at least 30 percent more. Achieving this will mean increasing crop yields and cropping intensities, as there are limited options for expanding the cultivated area. The current annual cereal yield growth rate remains below 1 percent and is a warning that staple food production can fall behind growing demand.

The risk to agricultural production from land degradation is significant. However, it is rarely factored in until cropland soils and pastures are significantly depleted or lost because of human-induced erosion, salinization and pollution. Climate change is expected to further hamper growing conditions for crops and natural ecosystems in subtropical developing countries, whereas warming in temperate latitudes could extend growing seasons for some cereals. Sustainable land and water management across all agroclimatic zones will become a priority to reduce GHG emissions and increase food production.

Water scarcity increases agricultural production risks as water supply, storage and conveyance systems reach their design limits. In many areas with high water stress, farmers manage their production risks by abstracting shallow groundwater for irrigation; in some cases, they use non-renewable groundwater. However, competition for diminishing quantities of high-quality groundwater is intensifying as aquifers suffer from overabstraction and saline intrusion. Many aquifers also suffer from agricultural and industrial pollution. Droughts are slow to develop and not easily recognized at first, but they can quickly become a crisis when severe and damaging impacts emerge that are widespread and have underestimated impacts on societies, ecosystems and economies.

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Water pollution from agriculture is proliferating, as is pollution from domestic and industrial processes. New and emerging pollutants are adding to clean-up costs and challenging technological solutions on land and in lacustrine and nearshore marine environments.

Overall recommendation: The operational decisions for agricultural production should be better informed of economic and environmental consequences. The risk to food production can be mitigated by changing agricultural and land-management practices to reduce impacts on livelihoods, human health and the delivery of ecosystem services. Using LRP tools together with climate models provides invaluable insights into how these changes will redistribute land available for production for different crops and livestock, and identifies potential impacts on productivity and yield gaps. However, none of this can be done without the land planning process engaging with urban development and poverty reduction strategies that affect spatial planning including water governance.

6.4 Responses should be better planned – the tools are in place

Taking stock of land and water assets is necessary to address the range of adaptive management processes and attain national emission targets for agricultural land. It is therefore important to consider realistic forms of spatial planning for agricultural land use for which economic trade-offs can be evaluated, and policies in public subsidies can be directed.

Acquiring the data to support planning is vital. The tools for sustainable land, soil and water planning and management are available to assess the potential impacts of climate change on crop production and to tackle the growing pressures on freshwater ecosystems and degrading land, soil and water quality. Data collection needs to be comprehensive and smarter if it is to provide the basis for transparent water accounting for agricultural water use and the quality of return flows. Monitoring the accumulated impact of climate change in relation to agroecological suitability will prove essential for planning resource use along the entire food value and supply chains.

Integrated multisectoral approaches need not be complex, they can be intuitive. Solutions require close collaboration across sectoral boundaries where interests align. Planning and implementing measures that sustain productivity, reduce pollution, sequester carbon and mitigate emissions can be straightforward. Tested technologies in SLM can be combined with inclusive planning approaches at scale when good land and water governance is in place.

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Resource planners and policymakers can respond to the challenge using a mix of policy tools (e.g. incentives, impact investments and regulations), remote sensing, big data and innovative analytical methods that are revolutionizing approaches to resource assessment and planning. A wide range of resource assessment and planning tools and approaches support decision-makers, planners and practitioners, working at global, national and local levels to plan, take action, and scale out SLM and sustainable water-management options.

Models are now essential tools for land-use planning and land and water resources planning. They are increasingly being used together with participatory approaches to develop better-adapted food and agricultural systems. Combining land and water resource assessment and planning tools, including GAEZ methods, with the latest climate models provides invaluable insights into how changes will redistribute land available for agricultural production and affect water availability. These include shifts in areas suitable for different crop and livestock species and farming systems, and identifying potential impacts on productivity and yield gaps. In particular, shifting to a risk management approach can significantly lessen drought risks and impacts.

The tools for sustainable land, soil and water planning and management are available. Planning tools can define critical thresholds in natural resource systems, leading to the reversal of land degradation when wrapped up as packages or programmes of technical, institutional, governance and financial support. In this respect, LDN under the UNCCD Global Mechanism can help governments set targets and plan interventions based on the principle of Avoid > Reduce > Reverse land degradation.

Preventing degradation is far less costly than restoration. The LDN approach is advocated to find pathways out of human-induced cycles of land degradation and water scarcity.

Overall recommendation: Land resources planning is needed at all levels of decision-making to address challenges set by changing human demands. When matched with appropriate financing mechanisms and combined with environmental regulation, LRP can provide the essential impetus to reverse trends in land degradation.

6.5 Channel actions in four response areas

The governance of land and water resources underpins productive food systems. Demanding that these systems are, at the same time, efficient, resilient and inclusive of those who produce them and those who depend upon them is a tall order. Actions in four key response areas can enable and facilitate a transition by all actors to sustainable land and water management. Taken together, this set of responses can transform current patterns of land and water management in agriculture and reduce GHG emissions from land.

The world has largely met the increasing demand for food, feed and fibre over the past century by expanding the cultivated area and intensifying the use of land, soil and water resources. However, increasing resource scarcity and inequalities of access are changing the global dynamics concerning food, climate, energy and the allocation of financial resources to solve social and environmental problems. The ensuing economic tension has exposed the reality of shared dependency. The ongoing COVID-19 pandemic is another complicating factor, together with the suppression of agricultural production due to armed conflict. Ensuring land, soil and water resources are used in a sustainable manner requires careful negotiation of competing interests in economic growth, equity and a healthy environment. Negotiations will inevitably involve trade-offs among interests, but more importantly, they should open the way for improved forms of agricultural practice on land. Land and water management can respond to meet the challenges of climate change through environmental, social and governance approaches to investment in actions that are better planned, informed and implemented, but above all, better governed. Without doubt, governance is the most important element in putting technologies into practice at territorial scale with the consent of all interests. Improved practice and technology will have little impact without it.

6.5.1 Action area I: Adopting inclusive land and water governance

Effective and inclusive governance is essential for building capable and informed institutions and organizations. However, advances in land and water governance require coherent and integrated policies in the various sectors to deliver on the multiple objectives related to natural resources management, trade-offs, and related ecosystems and services. Coherence is needed across all levels of government and policy areas, as decisions outside the water and land domain can significantly affect natural resources. Understanding and recognizing the relationship of customary and statutory land and water rights and the role of hybrid legal systems for inclusive water and land tenure regimes can form the basis for achieving a diverse array of policy and development goals.

Collaborative decision-making and learning requires deliberate linkages across institutions, scales and sectors to capitalize on stakeholders' diverse knowledge, experiences and values to ensure negotiated trade-offs are realistic, innovative and equitable. Actions will also need to be inclusive across physical and economic landscapes.

Land and water governance needs to shift up a gear. Reducing pressures on productive land and water systems and adjusting their allocation will be possible only when explicit land and water policy instruments are collaborative and resources management decision-making is inclusive.

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6.5.2 Action area II: Implementing integrated solutions at scale

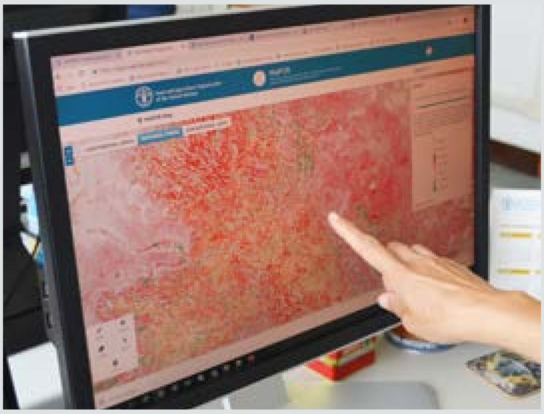
Agriculture's "solution space" has expanded. Advances in agricultural research have broadened the technical palette for land and water management. Nature-based solutions can address pest control, water quality and quantity attainment, crop phenology and biodiversity. Applied at scale, they can reduce the build-up of environmental pressures and obtain LDN.

There is no "one size fits all" solution – a "package" of solutions is envisaged. Increasing land and water productivity is crucial for achieving food security, sustainable production and SDG targets. A "package" of workable solutions is now available to enhance food production and tackle the main threats from land degradation, increasing water scarcity and declining water quality. But these will succeed only when there is a conducive enabling environment, strong political will, sound policies and inclusive governance, and full participatory planning processes across all sectors and landscapes.

Measures to adapt to and mitigate the impacts of climate change in agriculture are part of a continuum ranging from addressing the drivers of vulnerability to explicitly targeting climate change impacts. The landmark KJWA places soil- and water-management practices within a systems approach for tackling mitigation and adaptation in agriculture. This emphasizes improved management of soil carbon, soil health and soil fertility under grassland, cropland and integrated systems, including water quality and watershed management.

6.5.3 Action area III: Embracing innovative technologies and management

Technical responses are now better targeted across agriculture to significantly improve the sustainable management of land, soil and water. Digital agriculture needs to be accessible to all, and combined with advances in farming hardware to target production and improve the environmental footprint of agriculture. Mobile technologies are spreading rapidly across the agricultural sector, together with innovative on-farm mechanization. Combining these with remote-sensing services, cloud-based computing, and open access to data and information ("big data") on crops, natural resources, climatic conditions, inputs and markets already benefits smallholder farmers by integrating them into digitally innovative agrifood systems. However, care is needed to avoid a "digital divide" among those with different levels of access to new technologies.



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Sustainable land-management techniques can address the ten main soil degradation threats while conserving water resources, vegetation and biodiversity. These include controlling soil erosion through rainfall and runoff management, and replenishing SOM, SOC and nutrient balance in soil systems. The WOCAT database offers over 1 500 tried and tested technologies to support SLM and contribute to LDN targets in avoiding and reducing degradation and restoring degraded lands. The network enables practitioners and technical experts worldwide to select, document and share their best practices and experiences from specific socioeconomic and biophysical contexts that support SLM and restoration.

Reducing chemical inputs and the concentration of animal waste on land and water should be a global priority. The mobility and persistence of many agricultural nutrients and chemicals in soils, surface water and groundwater are affecting human health and ecosystem function. Input control and use of alternative conservation methods need to be mainstreamed in all farming systems and targeted in priority river basins and catchments. Integrated pest management and the Fertilizer Code are some of the instruments designed to counter the trend towards unsustainable agricultural intensification and the potential for increased use and harmful effects of fertilizers, pesticides and herbicides. The Fertilizer Code offers guidance to tackle misuse, underuse and overuse of fertilizers. Management of animal waste through controlled spreading on agricultural lands can be incentivized through an appropriate mix of governmental incentive and regulatory policies, including the treatment of biosolids and climate-smart biodigesters.

Responses to drought can shift to a risk management approach and reduce impacts on rainfed and irrigated production. This will require investment in early warning and monitoring systems to be combined with outreach of climate-smart agriculture techniques, especially in areas where rural communities are particularly vulnerable.

Water scarcity is driving renewed interest in irrigation. The modernization of irrigation to focus attention on farmer demand for more flexible and reliable water supplies will raise productivity. New planning, design and evaluation technologies, water accounting and auditing, ICT and automation have to be part of a package of modernization if they are to result in real water savings per unit of production. Traditional methods of improving water-use efficiency in crop production to "save" water are being challenged. Research shows that so-called "efficient technologies", such as pressurized, sprinkler and drip irrigation and canal lining, can increase evaporative consumption, reduce recharge and return flows to others.

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At river basin level, freshwater storage provides an essential buffer for managing climate uncertainty and variability while juggling differences in supply and demand and building overall societal resilience. As ageing infrastructure is being repaired or replaced, a new agenda is changing the current thinking about storage to address all forms of freshwater storage, natural and built, in an integrated system that provides multiple benefits.

Overall, the agricultural sector needs to better manage environmental risks – and at scale. The circular economy concept is just as applicable to agricultural land and water management as it is to the broader global food system. It offers opportunities to use non-conventional waters that might otherwise go to waste, such as saline and brackish water, agricultural drainage water and reclaimed water. Other aspects of reuse within the farming system include nutrient recycling, regenerating soil health, and reducing non-renewable energy and materials and inputs used in rainfed and irrigated systems. In this sense, agriculture NbSs can provide a low-impact green development strategy for transforming the agricultural sector into a beneficiary and a custodian of ecosystems.

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6.5.4 Action area IV: Investing in long-term sustainability

Future investments will need to move away from pure hardware solutions to sustaining rainfed and irrigated production systems through improved governance, integrated interventions at scale, and innovation in management and technology. Investment is needed in data and information collection and management, to improve connectivity among all producers, markets and regulators. On-farm decision-making will then improve dramatically, and agronomic innovation can be combined with early warning systems and performance monitoring offered by advances in near-real-time dissemination of environmental data.

Private investment in land management will prove decisive. Farmers can be incentivized to become investors in sustainable land and water management when supported through innovative financing and instruments that reconcile production and environmental management.

Public investment will be essential to develop capacities across producer associations and applied research institutions. A well-regulated land and water governance framework that can promote the adoption of innovative management and technology with targeted financing for impact is a realizable goal.

Land and water management can respond to meet the challenges of climate change based on investment that is compliant with environmental, social and governance approaches through actions that are better planned, informed and implemented, but above all, better governed.

This report has taken a global view of the available land and water data derived from national statistical sources where measures of land and water resource use have been reported up to 2019. It is not prescriptive about specific regions or entry points. Rather, the report recommends a set of mutually reinforcing responses to address the critical issues of human-induced land degradation and water scarcity. Observations on the state of land and water systems give rise to policy recommendations generally applicable in agriculture programmes. These recommendations reflect the key messages developed for each chapter.

ANNEX: COUNTRY GROUPINGS

CONTINENT REGIONS	SUBREGION	COUNTRIES
Africa		Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cabo Verde, Central African Republic, Chad, Comoros, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Djibouti, Egypt, Equatorial Guinea, Eritrea, Eswatini, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Togo, Tunisia, Uganda, United Republic of Tanzania, Zambia, Zimbabwe
Northern Africa		Algeria, Egypt, Libya, Morocco, Tunisia
Sub-Saharan Africa		Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cabo Verde, Central African Republic, Chad, Comoros, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Djibouti, Equatorial Guinea, Eritrea, Eswatini, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Togo, Uganda, United Republic of Tanzania, Zambia, Zimbabwe
	Sudano-Sahelian	Burkina Faso, Cabo Verde, Chad, Djibouti, Eritrea, Gambia, Mali, Mauritania, Niger, Senegal, Somalia, Sudan
	Gulf of Guinea	Benin, Côte d'Ivoire, Ghana, Guinea, Guinea-Bissau, Liberia, Nigeria, Sierra Leone, Togo
	Central Africa	Angola, Cameroon, Central African Republic, Congo, Democratic Republic of the Congo, Equatorial Guinea, Gabon, Sao Tome and Principe
	Eastern Africa	Burundi, Ethiopia, Kenya, Rwanda, Uganda, United Republic of Tanzania
	Southern Africa	Botswana, Eswatini, Lesotho, Malawi, Mozambique, Namibia, South Africa, Zambia, Zimbabwe
	Indian Ocean Islands	Comoros, Madagascar, Mauritius, Seychelles

CONTINENT REGIONS	SUBREGION	COUNTRIES
Americas		Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bolivia (Plurinational State of), Brazil, Canada, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, French Guiana, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, United States of America, Uruguay, Venezuela (Bolivarian Republic of)
Northern America		Canada, Mexico, United States of America
	Northern America	Canada, United States of America
	Mexico	Mexico
Central America and Caribbean		Antigua and Barbuda, Bahamas, Barbados, Belize, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, Grenada, Guatemala, Haiti, Honduras, Jamaica, Nicaragua, Panama, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago
	Central America	Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama
	Greater Antilles	Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico
	Lesser Antilles and Bahamas	Antigua and Barbuda, Bahamas, Barbados, Dominica, Grenada, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago
Southern America		Argentina, Bolivia (Plurinational State of), Brazil, Chile, Colombia, Ecuador, French Guiana, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela (Bolivarian Republic of)
	Guyana	French Guiana, Guyana, Suriname
	Andean	Bolivia (Plurinational State of), Colombia, Ecuador, Peru, Venezuela (Bolivarian Republic of)
	Brazil	Brazil
	Southern America	Argentina, Chile, Paraguay, Uruguay
Asia		Afghanistan, Armenia, Azerbaijan, Bahrain, Bangladesh, Bhutan, Brunei Darussalam, Cambodia, China, Democratic People's Republic of Korea, Georgia, India, Indonesia, Iran (Islamic Republic of), Iraq, Israel, Japan, Jordan, Kazakhstan, Kuwait, Kyrgyzstan, Lao People's Democratic Republic, Lebanon, Malaysia, Maldives, Mongolia, Myanmar, Nepal, Occupied Palestinian Territory, Oman, Pakistan, Papua New Guinea, Philippines, Qatar, Republic of Korea, Saudi Arabia, Singapore, Sri Lanka, Syrian Arab Republic, Tajikistan, Thailand, Timor-Leste, Turkey, Turkmenistan, United Arab Emirates, Uzbekistan, Viet Nam, Yemen
Middle East–Western Asia		Armenia, Azerbaijan, Bahrain, Georgia, Iran (Islamic Republic of), Iraq, Israel, Jordan, Kuwait, Lebanon, Occupied Palestinian Territory, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Turkey, United Arab Emirates, Yemen
	Arabian Peninsula	Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates, Yemen
	Caucasus	Armenia, Azerbaijan, Georgia
	Islamic Republic of Iran	Iran (Islamic Republic of)
	Near East	Iraq, Israel, Jordan, Lebanon, Occupied Palestinian Territory, Syrian Arab Republic, Turkey

CONTINENT REGIONS	SUBREGION	COUNTRIES
Central Asia		Afghanistan, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan
Southern and Eastern Asia		Bangladesh, Bhutan, Brunei Darussalam, Cambodia, China, Democratic People's Republic of Korea, India, Indonesia, Japan, Lao People's Democratic Republic, Malaysia, Maldives, Mongolia, Myanmar, Nepal, Pakistan, Papua New Guinea, Philippines, Republic of Korea, Singapore, Sri Lanka, Thailand, Timor-Leste, Viet Nam
	South Asia	Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka
	East Asia	China, Democratic People's Republic of Korea, Japan, Mongolia, Republic of Korea
	Southeast Asia	Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Papua New Guinea, Philippines, Singapore, Thailand, Timor-Leste, Viet Nam
Europe		Albania, Andorra, Austria, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Faroe Islands, Finland, France, Germany, Greece, Holy See, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Monaco, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Republic of Moldova, Romania, Russian Federation, San Marino, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom of Great Britain and Northern Ireland
Western and Central Europe		Albania, Andorra, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Faroe Islands, Finland, France, Germany, Greece, Holy See, Hungary, Iceland, Ireland, Italy, Liechtenstein, Luxembourg, Malta, Monaco, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, San Marino, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom
	Northern Europe	Denmark, Faroe Islands, Finland, Iceland, Norway, Sweden
	Western Europe	Andorra, Austria, Belgium, France, Germany, Ireland, Liechtenstein, Luxembourg, Netherlands, Switzerland, United Kingdom
	Central Europe	Bosnia and Herzegovina, Bulgaria, Croatia, Czechia, Hungary, Montenegro, Poland, Romania, Serbia, Slovakia, Slovenia
	Mediterranean Europe	Albania, Cyprus, Greece, Holy See, Italy, Malta, Monaco, North Macedonia, Portugal, San Marino, Spain
Eastern Europe		Belarus, Estonia, Latvia, Lithuania, Republic of Moldova, Russian Federation, Ukraine
	Eastern Europe	Belarus, Estonia, Latvia, Lithuania, Republic of Moldova, Ukraine
	Russian Federation	Russian Federation
Oceania		Australia, Cook Islands, Fiji, Kiribati, Micronesia (Federated States of), Nauru, New Zealand, Niue, Palau, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu
Australia and New Zealand		Australia, New Zealand
Pacific Islands		Cook Islands, Fiji, Kiribati, Micronesia (Federated States of), Nauru, Niue, Palau, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu

CONTINENT REGIONS	SUBREGION	COUNTRIES
World		Afghanistan, Albania, Algeria, Andorra, Angola, Antigua and Barbuda, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahamas, Bahrain, Bangladesh, Barbados, Belarus, Belgium, Belize, Benin, Bhutan, Bolivia (Plurinational State of), Bosnia and Herzegovina, Botswana, Brazil, Brunei Darussalam, Bulgaria, Burkina Faso, Burundi, Cambodia, Cameroon, Canada, Cabo Verde, Central African Republic, Chad, Chile, China, Colombia, Comoros, Congo, Cook Islands, Costa Rica, Côte d'Ivoire, Croatia, Cuba, Cyprus, Czechia, Democratic People's Republic of Korea, Democratic Republic of the Congo, Denmark, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Eritrea, Estonia, Eswatini, Ethiopia, Faroe Islands, Fiji, Finland, France, French Guiana, Gabon, Gambia, Georgia, Germany, Ghana, Greece, Grenada, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Holy See, Honduras, Hungary, Iceland, India, Indonesia, Iran (Islamic Republic of), Iraq, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Kiribati, Kuwait, Kyrgyzstan, Lao People's Democratic Republic, Latvia, Lebanon, Lesotho, Liberia, Libya, Liechtenstein, Lithuania, Luxembourg, Madagascar, Malawi, Malaysia, Maldives, Mali, Malta, Mauritania, Mauritius, Mexico, Micronesia (Federated States of), Monaco, Mongolia, Montenegro, Morocco, Mozambique, Myanmar, Namibia, Nauru, Nepal, Netherlands, New Zealand, Nicaragua, Niger, Nigeria, Niue, North Macedonia, Norway, Occupied Palestinian Territory, Oman, Pakistan, Palau, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Portugal, Puerto Rico, Qatar, Republic of Korea, Republic of Moldova, Romania, Russian Federation, Rwanda, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Samoa, San Marino, Sao Tome and Principe, Saudi Arabia, Senegal, Serbia, Seychelles, Sierra Leone, Singapore, Slovakia, Slovenia, Solomon Islands, Somalia, South Africa, Spain, Sri Lanka, Sudan, Suriname, Sweden, Switzerland, Syrian Arab Republic, Tajikistan, Thailand, Timor-Leste, Togo, Tonga, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Tuvalu, Uganda, Ukraine, United Arab Emirates, United Kingdom, United Republic of Tanzania, United States of America, Uruguay, Uzbekistan, Vanuatu, Venezuela (Bolivarian Republic of), Viet Nam, Yemen, Zambia, Zimbabwe

GLOSSARY

Agricultural land: Agricultural area as the sum of areas under: (a) arable land, (b) permanent crops (land cultivated with long-term crops that do not have to be replanted for several years) and (c) permanent meadows and pastures.

Agroforestry: Land-use systems or practices in which trees are deliberately integrated with crops and/or animals on the same land management unit.

Arable land: Land under temporary agricultural crops, temporary meadows for mowing or pasture, market and kitchen gardens, and land temporarily fallow (less than five years). The abandoned land resulting from shifting cultivation is not included in this category. Data for "arable land" are not meant to indicate the amount of land that is potentially cultivable.

Biodiversity: The variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.

Carbon sequestration: The process of removing carbon from the atmosphere and depositing it in reservoirs such as oceans, forests or soils through physical or biological processes.

Conjunctive use (of surface water and groundwater): The integrated management and use of surface water and groundwater supplies.

Conservation agriculture: An approach to managing agroecosystems for improved and sustained productivity, increased profits and food security, while preserving and enhancing the resource base and the environment. Conservation agriculture is characterized by three principles: continuous minimum mechanical soil disturbance, permanent organic soil cover and diversification of crop species grown in sequences or associations.

Conservation tillage: An approach to soil management that excludes conventional tillage operations that invert the soil and bury crop residues. There are five types of conservation tillage systems: no-tillage (slot planting), mulch tillage, strip or zonal tillage, ridge tillage (including no-till on ridges) and reduced or minimum tillage.

Consumptive use of water: The part of water withdrawn from its source for use in agriculture, industry or domestic purposes that has evaporated, transpired or been incorporated into products. The part of water withdrawn that is not consumed is called return flow.

Contaminant: Any substance not intentionally added to food, which is present in such food as a result of production (including operations carried out in crop and animal husbandry), manufacture, processing, preparation, treatment, packing, packaging, transport or holding of such food or as a result of environmental contamination. The term includes chemical and biological substances not desirable in food but does not include insect fragments, rodent hairs and other extraneous matter.

Cropland (or cultivated land): The land that is under agricultural crops. In statistical terms, cropland is the sum of arable land (see definition above) and permanent crops.

Desertification: The degradation of land in arid, semi-arid and dry subhumid areas resulting from various factors, including climatic variations and human activities.

Dry lands: Arid, semi-arid and dry subhumid areas (other than polar and subpolar regions) in which the ratio of mean annual precipitation to mean annual reference evapotranspiration ranges from 0.05 to 0.65.

Ecosystem: A dynamic complex of plant, animal and microorganism communities, and the non-living physical components of the environment (e.g. air, soil, water and sunlight), interacting as a functional unit.

Ecosystem services (or environmental services): The benefits people obtain from ecosystems. These include provisioning services (e.g. food and water), regulating services, supporting services (e.g. soil formation and nutrient cycling) and cultural services (e.g. recreational, spiritual, religious and other non-material benefits).

Erosion: The wearing away of the land by running water, rainfall, wind, ice or other geological agents, including such processes as detachment, entrainment, suspension, transportation and mass movement.

Eutrophication: The enrichment of freshwater bodies by inorganic nutrients (e.g. nitrates and phosphates), typically leading to excessive growth of algae.

Evapotranspiration: The combination of evaporation from the soil surface and transpiration from the plants.

Fertilizer: A substance that is used to provide nutrients to plants, usually via application to the soil, but also to foliage or through water in rice systems, fertigation, hydroponics or aquaculture operations.

Freshwater: Naturally occurring water on the Earth's surface in glaciers, lakes and rivers, and underground in aquifers. Its key feature is a low concentration of dissolved salts. It excludes rainwater, water stored in the soil, untreated wastewater, seawater and brackish water. In this report, when not otherwise specified, the term *water* is used as a synonym of freshwater.

Groundwater: All water which is below the surface of the ground in the saturation zone and in direct contact with the subsoils.

Institution: The laws and regulations governing the management, development, protection from pollution and use of water resources; the governmental bodies at all levels, in charge of the administration and enforcement of the laws and regulations; the judiciary; and the formal or informal water user-level organizations.

Integrated pest management: An ecosystem approach to crop production and protection that combines different management strategies and practices to grow healthy crops while minimizing the use of pesticides.

Integrated water resources management: A process that promotes the coordinated development and management of water, land and related resources to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. Sustainable Development Goal target 6.5 measures the degree and implementation of integrated water resources management.

Internal renewable water resources: The conventional measure of freshwater available to a nation (surface water and groundwater), comprising resources deriving from the rainfall within a nation's boundaries. It excludes transboundary and fossil water resources.

Land degradation: The reduction in the capacity of the land to provide ecosystem goods and services over a period of time for its beneficiaries.

Land degradation neutrality: A state whereby the amount and quality of land resources necessary to support ecosystem functions and services to enhance food security remain stable, or increase, within specified temporal and spatial scales and ecosystems.

Modernization: In irrigation, modernization is a process of technical and managerial upgrading (as opposed to mere rehabilitation) of irrigation schemes combined with institutional reforms, if required, with the objective to improve resource utilization (e.g. labour, water economics and environment) and water delivery service to farms.

Nutrient imbalance: An excess or lack of nutrients (mainly nitrogen, phosphorus and potassium) in the soil as a consequence of bad land use and management. It may result in soil contamination when nutrients are in excess and in loss of inherent fertility when nutrients are mined.

Payment for ecosystem services: A voluntary transaction whereby a service provider is paid by (or on behalf of) beneficiaries for land-use practices that are expected to result in continued or improved environmental service provision beyond what would have been provided without the payment.

Rangeland: Land on which the indigenous vegetation (climax or subclimax) is predominantly grasses, grass-like plants, forbs or shrubs that are grazed or have the potential to be grazed, and which is used as a natural ecosystem for the production of grazing livestock and wildlife.

Return flow: The part of the water withdrawn from its source that is not consumed and returns to its source or to another body of groundwater or surface water. Return flow can be divided into non-recoverable flow (flow to salt sinks, uneconomic groundwater or flow of insufficient quality) and recoverable flow (flow to rivers or infiltration into groundwater aquifers).

Riparian: Relating to land adjoining a stream or river.

Runoff: Part of the water from precipitation, melted snow or irrigation that flows over the land surface in stream flow and is not absorbed into the ground.

Salinization: The process by which salt accumulates in or on the soil. Human-induced salinization is mostly associated with poor irrigation practices.

Sodic soil: A soil that contains sufficient sodium to adversely affect the growth of most crop plants (sodic soils are defined as those soils which have an exchangeable sodium percentage of more than 15).

Soil acidification: The lowering of the soil pH of the build-up of hydrogen and aluminium ions in the soil and the leaching of base cations such as calcium, magnesium, potassium and sodium. Soil acidification negatively affects soil fertility and compromises the production capacity of most agricultural soils.

Soil biodiversity loss: The decline in the diversity of (micro- and macro-) organisms present in a soil. It prejudices the ability of soil to provide critical ecosystem services.

Soil compaction: The increase in density and a decline of macro-porosity in a soil that impairs the functions of both the top- and subsoil, and impedes roots penetration and water gaseous exchanges.

Soil degradation: The decline in soil quality caused by its improper use by humans, usually for agricultural, pastoral, industrial or urban purposes. Soil degradation may be exacerbated by climate change and encompasses physical, chemical and biological deterioration.

Soil health: The capacity of soil to function as a living system. Healthy soils maintain a diverse community of soil organisms that help to control plant disease, insect and weed pests, form beneficial symbiotic associations with plant roots, recycle essential plant nutrients, improve soil structure with positive repercussions for soil water and nutrient-holding capacity, and ultimately improve crop production.

Soil organic carbon loss: The decline of organic carbon stock in the soil affecting its fertility status and climate change regulation capacity.

Soil pollution: The presence of a chemical or substance out of place and/or present at higher than normal concentration that has adverse effects on non-target organisms.

Soil salinization: The increase in water-soluble salts in soil which is responsible for increasing the osmotic pressure of the soil. This negatively affects plant growth because less water is made available to plants.

Sustainable development: The development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Sustainability is a paradigm for thinking about the future in which environmental, societal and economic considerations are balanced in the pursuit of an improved quality of life.

Wadi: The ravine or valley of a seasonal stream in arid or semi-arid areas that is usually dry except for a short time after spate flow events (a few hours to a few days).

Water accounting: A systematic acquisition, analysis and communication of information relating to stocks, flows and fluxes of water (from sources to sinks) in natural, disturbed or heavily engineered environments.

Water auditing: A systematic study of the current status and future trends in water supply and demand, with a particular focus on issues relating to accessibility, uncertainty and governance in each spatial domain.

Water governance: The processes, actors and institutions involved in decision-making for the development and management of water resources and for the delivery of water services, encompassing the political, administrative, social and economic domains along with the formal and informal systems and mechanisms involved.

Water harvesting: The process of collecting and concentrating runoff water from a runoff area into a run-on area, where the collected water is either directly applied to the cropping area and stored in the soil profile for immediate use by the crop (i.e. runoff farming) or stored in an on-farm water reservoir for future productive uses (i.e. domestic use, livestock watering and aquaculture irrigation).

Waterlogging: The state of land in which the water table is located at or near the soil surface, affecting crop yields.

Water productivity: The ratio between the amount or value of output (including services) provided by water, in relation to the volume of water used to produce the output. Crop water productivity refers to the ratio between crop yield and water supply. Economic water productivity is expressed as the ratio between added value of a product and water supply.

Water scarcity: An imbalance between supply and demand of freshwater in a specified domain (e.g. country, region, catchment or river basin) as a result of a high rate of demand compared with available supply, under prevailing institutional arrangements (including price) and infrastructural conditions. Symptoms are unsatisfied demand, tensions between users, competition for water, overextraction of groundwater and insufficient flows to the natural environment. Artificial or constructed water scarcity refers to the situation resulting from overdevelopment of hydraulic infrastructure relative to available supply, leading to a situation of increasing water shortage.

Water scarcity (absolute): An insufficiency of supply to satisfy total demand after all feasible options to enhance supply and manage demand have been implemented. It is measured as the level at which all freshwater resources available is less than 500 m^3/capita annually.

Water scarcity (chronic): The level at which all freshwater resources available are being used. Beyond this level, water supply can be made available only through the use of non-conventional water resources such as agricultural drainage water, treated wastewater or desalinated water, or by managing demand. The level at which all freshwater resources available ranges between 500 and 1 000 m^3/capita annually.

Water security: The reliable availability of an acceptable quantity and quality of water for health, livelihoods and production, coupled with an acceptable level of water-related risks, while ensuring that the environment is protected and enhanced.

Water shortage: A shortage of water supply of an acceptable quality and/or low levels of water supply at a given place and a given time, relative to design supply levels. This may arise from climatic factors, or other causes of insufficient water resources, such as a lack of, or poorly maintained, infrastructure, or a range of other hydrological or hydrogeological factors.

Water stress: The symptoms of water scarcity or shortage, such as widespread, frequent and serious restrictions on use, growing conflict between users and competition for water, declining standards of reliability and service, harvest failures and food insecurity. Sustainable Development Goal indicator 6.4.1 measures water stress as the ratio of freshwater withdrawals by all major sectors to the available freshwater resources after taking into account environmental water requirements.

Water tenure: The relationship, whether legally or customarily defined, between people, as individuals or groups, with respect to water resources.

Water-use efficiency: The ratio of the amount of water used for a specific purpose to the amount of water withdrawn or diverted from its source to serve that use. In irrigation, water-use efficiency presents the ratio between estimated irrigation water requirements (through evapotranspiration) and actual water withdrawal. It is dimensionless and can be applied at any scale (plant, field, irrigation schemes, basin, country). Sustainable Development Goal indicator 6.4.2 measures water-use efficiency as the ratio of the gross value added per unit of water used (in USD/m^3).

Water-use right: In its legal sense, a legal right to abstract or divert and use water from a given natural source; to impound or store a specified quantity of water in a natural source behind a dam or other hydraulic structure; or to use or maintain water in a natural state (ecological flow in a river, and water for recreation, religious/spiritual practices, drinking, washing, bathing or animal watering).

Water withdrawal: Water abstracted from streams, aquifers or lakes for any purpose (e.g. irrigation, industrial, domestic or commercial). It includes conveyance losses, consumptive use and return flow. It can include water from renewable freshwater resources as well as water from overabstraction of renewable groundwater or withdrawal from fossil groundwater, direct use of agricultural drainage water, direct use of (treated) wastewater and desalinated water.

THE STATE OF THE WORLD'S LAND AND WATER RESOURCES FOR FOOD AND AGRICULTURE 2021

Systems at breaking point

Satisfying the increased demand for food is placing pressure on the world's land, soil and water resources. Agriculture has its part to play in alleviating these pressures and contributing positively to climate and development goals. Sustainable agricultural practices can lead to direct improvements in the state of land, soil and water, and generate ecosystem benefits as well as reduce emissions from land. Accomplishing all these requires accurate information and a major change in how we manage the resources. It also requires complementing efforts from outside the natural resources management domain to maximize synergies and manage trade-offs.

The objective of *The state of the world's land and water resources for food and agriculture 2021* (SOLAW 2021) report is to build awareness of the status of land and water resources, highlighting the risks, and informing on related opportunities and challenges. It also aims to underline the essential contribution of appropriate policies, institutions and investments. Recent assessments, projections and scenarios point to the accelerated depletion of land and water resources and associated loss of biodiversity. The SOLAW 2021 report highlights the major risks and trends related to land, soil and water resources, and presents the means for resolving competition among users and generating the desirable benefits. The report provides an update of the knowledge base and presents a suite of responses and actions to enable decision-makers to make an informed transformation from degradation and vulnerability towards sustainability and resilience.

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