OECD

# Global Drought Outlook

## Trends, Impacts and Policies to Adapt to a Drier World

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TRENDS, IMPACTS AND POLICIES TO ADAPT TO A DRIER WORLD

OECD
BETTER POLICIES FOR BETTER LIVES

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# Preface

Droughts may creep in stealthily, but their impacts are often more devastating and far-reaching than sudden storms or floods. In 2021, droughts in California led to agricultural losses exceeding USD 1 billion. Prolonged dry conditions in Central America resulted in severe water shortages in 2024 and halted ships on one of the world's most critical trade routes – the Panama Canal – leaving rivers and reservoirs across the region too dry to generate hydropower and prompting countries to restart emissions-intensive coal power plants. The human toll of droughts remains most severe in Africa, where extreme drought conditions left 23 million people in severe hunger in 2023.

Climate change has increased the land area exposed to droughts and worsened the impacts on communities and economies. In addition to more variable rainfall, rising temperatures accelerate evaporation, reduce soil moisture and increase stress on depleting freshwater resources. We estimate that the economic impacts of an average drought today can be up to six times higher than in 2000, and costs are projected to rise by at least 35% by 2035.

In light of these growing risks, countries must proactively and urgently adapt to droughts well before they strike. The OECD's *Global Drought Outlook* provides a comprehensive, evidence-based assessment of how drought trends and impacts are evolving under climate change and identifies policy responses for effective adaptation. The analysis demonstrates that drought resilience cannot be achieved through water management alone. It requires co-ordinated action across agriculture, land use, energy, transport, industry, construction and health systems. The report also underscores the need for sustained investment in risk prevention, robust data and monitoring systems, alongside inclusive governance that addresses the needs of vulnerable populations and ecosystems.

As climate pressures intensify, strengthening drought resilience must become a global priority. The OECD remains committed to supporting countries in advancing effective, forward-looking solutions that enable societies to anticipate, prepare for and adapt to increasing drought risks in a changing climate.

Jo Tyndall

Director

OECD Environment Directorate

# Foreword

The *Global Drought Outlook* is part of a substantial body of OECD work on climate change adaptation. This stream of work supports countries in navigating complex and rapidly-evolving scientific knowledge on climate change and translating it into actionable insights for policy makers. It also aims to identify the organisational and structural measures needed to strengthen climate resilience. This report follows earlier OECD studies on specific climate risks, including sea-level rise and extreme wildfires.

The *Global Drought Outlook* provides a global assessment of drought risks, impacts, and policy responses in the context of climate change. It distils recent scientific insights on how climate change amplifies drought impacts and presents new OECD estimates of their economic toll, including their ripple effects across value chains. Given the considerable warming already locked into the Earth's climate system, the increasing trend in drought occurrence is unlikely to reverse in the near future. Importantly, the report shows that water management alone is not sufficient. Building drought resilience requires all sectors to rethink their water use and contribute to restoring water supply capacity under changing climatic conditions.

This report was developed by the OECD Environment Directorate directed by Jo Tyndall. It was authored by Marta Arbinolo, Ioannis Tikoudis, and Simon Touboul, under the guidance of Walid Oueslati, Head of the Climate, Biodiversity and Water Division, and Catherine Gamper, Climate Adaptation Team Leader. It benefitted from valuable research support and contributions from Margaux Gabriel, Amélie Majnoni d'Intignano, Nicholas Poellinger, and Jiyul Shin. The authors are grateful for the input and feedback provided by OECD colleagues Alexandre Banquet, Marijn Kordenwal, Nicolina Lamhauge, Sophie Lavaud, Xavier Leflaive, Mikael Maës, Mikaela Rambali, Laura Smith, Lucy Watkinson, and Leigh Wolfrom. Administrative and communications support was provided by Sora Choi, Sama Al Taher Cucci, Beth Del Bourgo, and William Foster. The substantive review conducted by Michael Bruentrup (German Institute of Development and Sustainability), Benjamin Cook (NASA Goddard Institute for Space Studies and Columbia University), Richard Damania (World Bank), Caroline King-Okumu (Centre for Ecology and Hydrology), Yusuke Kuwayama (University of Maryland), Sergio Vicente-Serrano (Pyrenean Institute of Ecology), and Esha Zaveri (World Bank) is also gratefully acknowledged.

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# Abbreviations and acronyms

| | |
|---|---|
| CAP | Common Agricultural Policy |
| $CO_2$ | Carbon dioxide |
| DMP | Drought management plan |
| EU | European Union |
| EUR | Euro |
| GDP | Gross domestic product |
| IPCC | Intergovernmental Panel on Climate Change |
| MAR | Managed aquifer recharge |
| NAP | National Climate Adaptation Plan |
| NAS | National Climate Adaptation Strategy |
| NbS | Nature-based solutions |
| OECD | Organization for Economic Co-operation and Development |
| PDSI | Palmer Drought Severity Index |
| PPP | Public-private partnership |
| RBMP | River Basin Management Plan |
| RCP | Representative Concentration Pathway |
| SMA | Surface Soil Moisture Anomaly |
| SPEI | Standardised Precipitation Evapotranspiration Index |
| SPI | Standardised Precipitation Index |
| SSP | Shared Socioeconomic Pathway |
| UNCCD | United Nations Convention to Combat Desertification |
| US | United States |
| USD | US Dollars |
| WFD | Water Framework Directive |

# Executive summary

## Context

**Droughts are becoming increasingly frequent and severe worldwide**. New OECD analysis presented in this report shows that the global land area affected by drought doubled between 1900 and 2020, with 40% of the planet experiencing increased drought frequency and intensity in recent decades. Many of the most extreme droughts in recorded history have occurred in recent years, including the 20-year drought in Mexico and the devastating 2022 drought in Europe and the United States.

**The growing risk of drought stems from a combination of drivers, with climate change at the core**. Rising temperatures increase evaporation, disrupt precipitation patterns, and reduce snowpack and glacier reserves. For instance, climate change made the 2022 European drought up to 20 times more likely and increased the likelihood of the ongoing drought in North America by 42%. Projections suggest that under a +4°C warming scenario, droughts could become up to seven times more frequent and intense compared to a scenario with no climate change.

**Human activities like deforestation, urban expansion, and unsustainable agricultural practices further worsen drought risk by degrading ecosystems and water resources**. Irrigation accounts for 70% of global water withdrawals and, when practiced unsustainably, can exacerbate drought conditions by up to thirty times in some regions. Urban development facilitates soil sealing, reducing water infiltration and aquifer recharge in all OECD countries. These challenges will keep compounding existing climate pressures, further threatening freshwater availability.

**Droughts disrupt freshwater availability, with far-reaching effects on the ecosystems that rely on it.** New OECD analysis reveals that, since 1980, 37% of global land has experienced significant soil moisture decline. Similarly, groundwater levels are falling globally, with 62% of monitored aquifers in decline, while many rivers worldwide are experiencing significant decreases in stream flow. These changes in water availability accelerate soil degradation and negatively affect ecosystems such as forests and wetlands, affecting plants' biomass and distribution. This threatens biodiversity and disrupts essential ecosystem services, including water purification and carbon sequestration, exacerbating future drought risks through damaging feedback loops.

## The socio-economic implications of drought

**New OECD analysis highlights a sharp rise in the economic costs of drought, with losses and damages increasing globally at an annual rate of 3-7.5%**. As water scarcity constrains entire sectors and disrupts trade, the OECD projects that an average drought event in 2025 is at least twice as costly as in 2000, while by 2035, costs are expected to be at least 35% higher than today. Agriculture is the most affected sector: in particularly dry years, crop yields can decline by up to 22%, while a doubling of drought duration could reduce the production of key crops like soy and corn by up to 10%. In California, the 2021 drought alone caused USD 1.1 billion in agricultural losses, underscoring the vulnerability of even advanced economies. However, the economic impacts of drought extend far beyond agriculture. Severe droughts can reduce fluvial trade volumes by up to 40% and reduce hydroelectric production by more than 25%, affecting supply chains and energy availability. Yet, current estimates remain context-specific, and further analysis is needed to fully understand the effects of drought on different sectors.

**The human toll of drought is equally stark**. Despite accounting for only 6% of natural disasters, droughts cause 34% of all disaster-related deaths and exacerbate displacement and migration, especially in Sub-Saharan Africa. Prolonged droughts trap people in vulnerable situations in cycles of poverty, heightening social inequalities. Food security is also at stake, as observed in the Horn of Africa, where five consecutive years of low rainfall left 23 million people in severe hunger in 2023. Combined, these impacts can trigger political instability, social unrest, and geopolitical tensions over scarce resources.

## Key recommendations

**Growing drought risk underscores the need for proactive approaches to build resilience and adapt in the face of climate change.** Investments in drought resilience not only reduce the immediate costs of drought but can also deliver long-term economic, social, and environmental benefits. Evidence suggests that every dollar invested in drought prevention yields 2 to 3 dollars in benefits, with returns on resilience investments potentially up to ten times the initial costs.

**Effective water policy is essential for adapting to drought risk.** Integrated water resource management must ensure efficient water use, conservation, and the equitable allocation of water resources, while also improving supply resilience and restoring the balance between water withdrawal and renewal. Further efforts are needed to integrate climate change considerations into long-term planning and to protect ecosystems as vital water sources. For instance, water abstraction charges in Europe internalise only 2–3% of water scarcity costs, and many countries fail to integrate future climate impacts into their water allocation frameworks.

**Beyond water policy, effective drought management requires action across sectors.** Sustainable land-use, ecosystem restoration, and adaptive agricultural practices can help retain water in the soil, regulate hydrological cycles, and enhance resilience. For example, urban de-sealing projects in the United States have restored up to 780 million cubic metres of water annually. Globally, irrigation efficiency improvements could reduce global water use by up to 76%. Drought-tolerant crops have also demonstrated potential to lower water use and boost yields even in dry years. Additionally, adapting practices in sectors such as energy, transport, and buildings can further contribute to mitigating drought impacts while supporting broader climate resilience.

**Addressing drought risk requires decisive, coordinated, and proactive action across sectors and stakeholders.** Integrating robust risk assessments, strategic investments, and effective policies can protect communities, strengthen economic resilience, and preserve ecosystems from drought impacts. Collaboration and knowledge exchange across sectors is also essential to mitigate immediate drought impacts while ensuring long-term benefits, such as enhanced water efficiency, improved agricultural productivity, and the preservation of critical ecosystems. With the right strategies, these efforts can lay the foundations for sustainable development, ensuring water and food security, climate resilience, and healthy ecosystems for future generations.

# 1 Introduction

## 1.1. Droughts: a growing threat to people, ecosystems, and economies

Droughts are emerging as one of the most complex and significant environmental challenges of the 21st century. While periodic drought conditions are a natural occurrence in many regions, the nature of droughts is undergoing dramatic changes globally. What were once episodic events are becoming more frequent, prolonged, and severe (see Chapter 2), posing a growing challenge to societies across the globe. These unprecedented challenges exacerbate existing risks, particularly in arid and semi-arid regions that are already grappling with chronic water scarcity.

Recent scientific evidence underscores the alarming acceleration in drought trends. According to the Intergovernmental Panel on Climate Change (IPCC), global warming of 1.1°C above pre-industrial levels has already intensified hydrological extremes such as droughts (IPCC, 2023[1]). The global land area affected by dry conditions has more than doubled since 1900, and many regions have experienced more frequent extreme drought events in recent decades (see Chapter 2). Yet, unlike rapid-onset disasters such as storms or floods, droughts unfold gradually, silently eroding resilience and often catching communities, ecosystems, and economies unprepared.

The worsening of drought conditions is intrinsically linked to climate change. Rising global temperatures accelerate evaporation rates, reducing soil moisture and depleting freshwater resources, while shifting atmospheric circulation patterns are leading to irregular precipitation (IPCC, 2023[1]). As a result, some regions are now faced with increasingly prolonged dry spells while others experience extreme rainfall and flooding. Recent studies show that climate change made the ongoing megadrought[1] in North America 42% more intense and the 2022 drought in Western Europe up to six times more likely (Williams, Cook and Smerdon, 2022[2]; Schumacher et al., 2022[3]). In addition to these climatic factors, other drivers such as land-use changes, urbanisation, and unsustainable water use further exacerbate these challenges (see Chapter 2).

Drought impacts are cross-sectoral and ripple across boundaries, affecting the livelihoods and well-being of millions of people. The largest economic costs of droughts occur in the agricultural sector. In particularly dry years, crop volumes may drop by more than 20% compared to normal conditions (see Chapter 3). Even moderate drought episodes can substantially affect the income of agricultural areas. Yet, the economic impacts of drought extend much beyond the agricultural sector to affect energy production, industrial operations, and essential municipal services. For instance, extreme droughts in central Europe have recently reduced fluvial trade volumes by up to 40%, while hydroelectric production might suffer reductions of more than 25% during severe droughts (Rossi et al., 2023[4]; Tikoudis, Gabriel and Oueslati, 2025[5]).

The economic costs of droughts are projected to increase. Globally, economic losses and damages due to droughts are increasing with an annual rate of 3-7.5% (see Chapter 3). This implies that, with the most conservative estimates, a drought episode in 2025 could be at least twice as costly than it was in 2000, and that an episode in 2035 will be at least 35% more costly than it is today. The social impacts of drought are equally profound and disproportionately affect disadvantaged communities. Low-income populations and agricultural workers in water-scarce regions often lack the resources to adapt to prolonged dry spells and water shortages. In some cases, prolonged drought conditions may force families to migrate in search of water and livelihoods, destabilising entire communities and fuelling social unrest, political instability, and cross-border tensions over dwindling resources (see Chapter 3).

Beyond its socio-economic dimensions, droughts also have major ecological impacts. Since 1980, 37% of global land has experienced significant soil moisture loss, while declining river flows and groundwater levels have been reported in many regions (see Chapter 2). These shifts in water availability exacerbate soil degradation, affect vegetation productivity, and disrupt critical ecosystem services, such as water purification, creating feedback loops that may intensify future drought risks (see Chapter 3).

The impacts of droughts are not evenly distributed. Vulnerable regions such as sub-Saharan Africa, South Asia, and parts of Latin America bear a disproportionate burden, as they often lack the resources and infrastructure to cope with increasingly extreme drought events. Highly industrialised nations are also increasingly affected by growing drought risk. For instance, recent extreme droughts in Europe, North America, and Australia have severely strained water supplies, disrupted food systems, and inflicted billions of dollars in economic losses (see Chapter 3).

As the global climate continues to warm, the frequency and intensity[2] of drought are expected to further escalate, intensifying impacts and costs across most regions of the world. Rising temperatures, shifting precipitation patterns, reduced snowpack, and more frequent extreme weather events will exacerbate drought conditions. Projections suggest that, under future climate change, droughts could become up to seven times more frequent and intense compared to pre-industrial times (IPCC, 2021[6]). This growing risk threatens not only regions already vulnerable to water scarcity but also areas historically less prone to drought, amplifying the complexity and scale of future impacts.

## 1.2. A global momentum for adapting to drought

Amid growing risks and escalating impacts, the urgency to address drought has never been greater. Climate change mitigation efforts remain crucial to preventing the worsening of drought conditions. A growing body of scientific evidence shows that keeping atmospheric warming below 1.5°C above pre-industrial levels would significantly reduce the risk of extreme drought by reducing precipitation variability and soil moisture loss (IPCC, 2018[7]). Delivering on the 1.5°C pathway through sound climate change mitigation strategies is now more critical than ever.

At the same time, adaptation and resilience-building efforts must be significantly expanded to curb the growing toll of droughts. The increasing frequency, duration, and severity of droughts, fuelled by climate change, demand immediate and coordinated action to anticipate, prevent, and adapt to evolving drought risk (see Chapter 4). These efforts must leverage advancements in science, technology, and policy to focus on three core areas. First, understanding current and future risks is essential, which involves assessing drought trends and projections and identifying exposed and vulnerable areas. Second, efforts must aim at reducing losses and damages by mitigating the scale of drought impacts on people, ecosystems, and economies. Finally, empowering communities and enhancing their ability to withstand and recover from future droughts is crucial. Without targeted policies and long-term strategies, the cascading impacts of drought will continue to intensify, leaving societies, economies, and ecosystems unprepared for the challenges ahead.

Governments, organisations, and communities increasingly recognise the need to adapt to a more water-scarce future. Proactive and innovative solutions – such as sustainable water and land-use management, drought-resilient agricultural practices, and nature-based solutions – are gaining traction as viable pathways to mitigate the impacts of drought (see Chapter 4). Investments in early warning systems, risk transfer mechanisms, and transboundary cooperation have also proven critical in improving preparedness and minimising damages. These solutions, which draw on both technological and natural approaches, provide a blueprint for more effective drought management in the face of increasing uncertainty.

Despite these advances, significant gaps remain in the way drought risks are understood and addressed. Climate change is altering the dynamics of drought, with shifts in seasonality and exposure patterns creating new challenges that are not yet fully accounted for (see Chapter 2). Better tools and data are needed to refine risk assessments, identify the most vulnerable regions, and support decisions on adaptation strategies. At the same time, understanding the full costs of drought – including their indirect and long-term ripple effects such as food insecurity, economic disruptions, and migration – is essential for designing targeted and effective responses. As droughts in one part of the world increasingly trigger consequences across borders and sectors (see Chapter 3), a more comprehensive and interconnected approach to quantifying and addressing drought risk is urgently needed.

## 1.3. Objectives of this report

The growing global momentum to address drought risk offers a unique opportunity to close critical knowledge gaps, scale up innovative solutions, and foster partnerships that can drive transformative change. By investing in resilience today, governments and stakeholders can not only mitigate the immediate and long-term impacts of drought but also pave the way for a more secure, sustainable, and equitable future.

This report seeks to address these gaps by shedding light on the changing dynamics of drought in a warming world. Drawing on the latest scientific research and innovative data analysis, it explores observed and projected trends in drought risk, identifies the underlying drivers and impacts, and discusses the policies and practices that can help societies adapt effectively to this growing challenge. The aim is to provide actionable insights that empower decision-makers and stakeholders to respond to the multifaceted risks posed by drought.

The structure of this report is designed to systematically explore these key aspects of drought risk and management:

- ***Chapter 2*** focuses on current and future global drought conditions in the context of climate change. It delves into both the climatic and non-climatic factors contributing to drought, shedding light on the links between climate change, water use, land-use changes, and the increasing frequency and severity of drought events. The chapter also provides insights into the projected changes in drought frequency, duration, and intensity under different warming scenarios.
- ***Chapter 3*** focuses on the environmental, social, and economic implications of drought. It examines the wide-ranging physical and socio-economic impacts of drought events, quantifying observed and projected economic costs such as losses in gross domestic product (GDP) and agricultural income, as well as revenue losses in other key sectors. This chapter offers a detailed picture of how droughts disrupt ecosystems, livelihoods, and whole economies while also amplifying vulnerabilities across regions and sectors.
- Building on these foundations, ***Chapter 4*** examines the policies and strategies for improving drought resilience under a changing climate. It evaluates the policy measures and practices adopted in different contexts to adapt to evolving drought risk, with a focus on solutions that reduce vulnerability, enhance preparedness, and minimise long-term costs and damages. Drawing lessons from both successful adaptation efforts and existing policy gaps, this chapter provides insights and tools to help policymakers identify viable interventions and support the efficient allocation of resources in the face of this rapidly growing challenge.

Overall, this report aims to inform policymakers and stakeholders about the escalating risks of drought in a warming world and the solutions available to address this challenge. By providing scientific and policy insights, lessons learned, and novel data, it aims to support evidence-based decision-making to protect communities, economies, and ecosystems and ensure a more sustainable and climate-resilient future.

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## Notes

[1] Megadroughts are prolonged, multi-year drought events that are exceptionally extreme in their duration, severity, or spatial extent (Cook et al., 2022[8]).

[2] Drought intensity, which captures the degree of dryness at a specific location over a given period, is defined as the average value of a selected drought indicator (e.g. Soil Moisture Anomaly, Standardised Precipitation-Evapotranspiration Index (SPEI), river flow, or groundwater level) during the given timeframe.

# 2 Towards a drier world

This chapter examines current and future global drought conditions in the context of climate change, highlighting their climatic and other human-drivers. Drawing on original data analysis by the OECD and recent scientific literature, the chapter demonstrates how climate change is intensifying drought frequency and severity and shows how human development has exacerbated this risk in recent decades.

## 2.1. Introduction

Over the past decade, many regions of the world have faced extreme drought events that have caused severe economic and social consequences. The ongoing megadrought affecting Mexico and the United States – which has persisted for more than twenty years – is likely the most severe in 1 200 years (Williams, Cook and Smerdon, 2022[1]). In 2021, drought conditions in California caused economic costs of USD 1.1 billion for the agricultural sector alone (i.e. 2% of the sector's annual revenues) (Public Policy Institute of California, 2022[2]). In 2022, a third of Europe's territory experienced one of the worst droughts in the continent's history, which, combined with an abnormally hot summer, cost more than EUR 40 billion (EEA, 2023[3]). In the same year, the Rhine River (Germany) reached its lowest depth in thirty years, forcing ships to operate at only 25-35% of their loading capacity (European Space Agency, 2022[4]). In the Horn of Africa, the region's worst drought in forty years left 23 million people suffering severe hunger in 2023 (World Food Programme, 2023[5]). Overall, while droughts accounted for only 6% of all natural disasters that occurred between 1970 and 2019, they caused 34% of all disaster-related deaths, mostly due to famine in African countries (World Meteorological Organization (WMO), 2021[6]). Additionally, since 2010, over 3 million people have been displaced within their country to escape droughts (Internal Displacement Monitoring Centre, 2024[7]).

Climate change is set to worsen drought conditions, exacerbating other human pressures such as unsustainable land and water use. By increasing both temperature and precipitation variability, climate change facilitates periods of precipitation deficit and higher evaporation rates, leading to decreases in soil moisture, river flows, and groundwater levels (Vicente-Serrano et al., 2022[8]). The Intergovernmental Panel on Climate Change (IPCC) estimates that, under a +4°C warming scenario, average drought frequency and intensity may increase up to sevenfold in many regions compared to pre-industrial times (IPCC, 2021[9]). The causal link between climate change and specific drought events is increasingly demonstrated. For example, estimates suggest that climate change made the 2022 Northern Hemisphere drought twenty times more likely (Schumacher et al., 2022[10]) and has intensified the ongoing megadrought in North America by 42% (Williams, Cook and Smerdon, 2022[1]). These changes will compound existing pressures on water resources, such as increased water withdrawal for human consumption, industrial cooling, and irrigation, exacerbating the risk of water scarcity.

This chapter sheds light on the growing risk of drought in the context of climate change, showing the links between drought events and water availability and highlighting how human activities and climate change are intensifying drought risks. It includes existing scientific evidence and new analysis of various drought indicators by the OECD (see Annex B) to explore historical and future global trends in drought exposure in the context of climate change. The chapter outlines the key factors contributing to increasing drought risks, followed by an in-depth overview of how climate change is expected to exacerbate these conditions in the future.

## 2.2. Understanding drought risk

### *2.2.1. What is drought?*

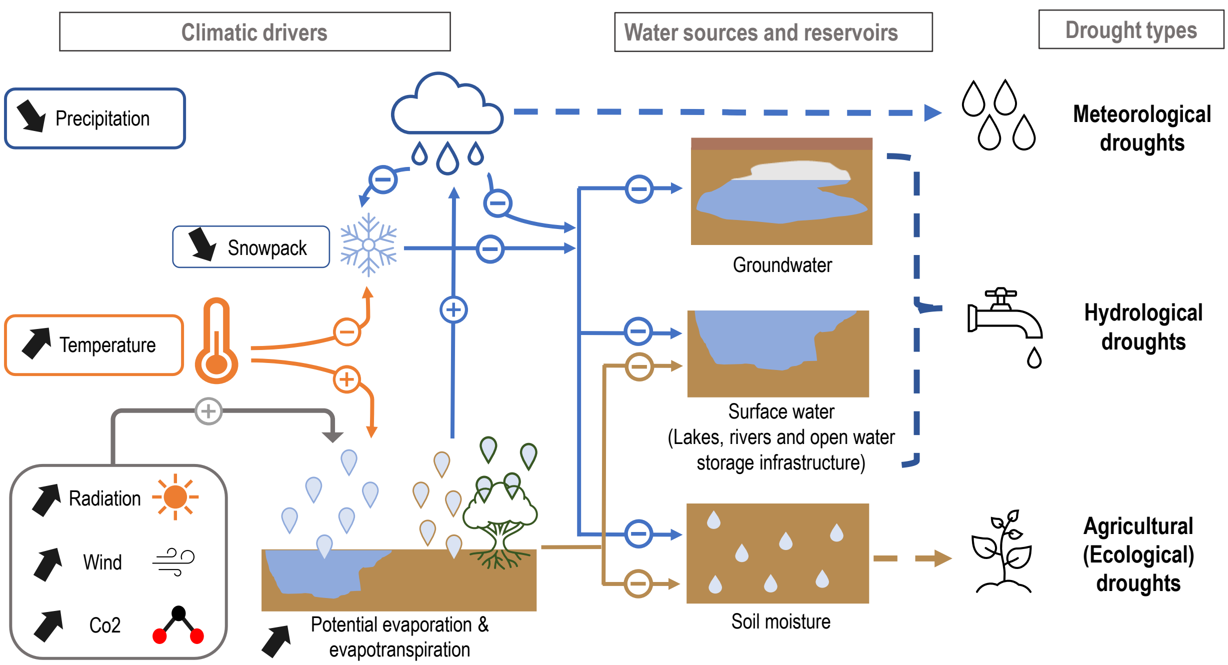
Droughts are periods characterised by a significant hydrological imbalance in water sources or reservoirs, typically marked by "drier-than-normal" weather conditions. These periods are primarily driven by low rainfall and can be further intensified by high temperatures or strong wind, which accelerate water evaporation, as well as human activities (e.g. land or water use) (IPCC, 2022[11]). This imbalance affects various components of the water cycle, including soil moisture, surface water (e.g. lakes and rivers) levels, and groundwater reserves. The complexity of these interactions has led to numerous definitions of drought

(Dracup, Lee and Paulson, 1980[12]; Wilhite and Glantz, 1985[13]), each emphasising an abnormal water deficit across different contexts and timescales.

Droughts are usually classified based on their main drivers and impacts (Figure 2.1):

- ***Meteorological drought*** refers to a prolonged period of low precipitation.
- ***Agricultural (or ecological) drought*** refers to a condition where soil moisture is insufficient to meet the needs of crops and vegetation.
- ***Hydrological drought*** occurs when surface or groundwater water levels drop below average over a prolonged period.

## Figure 2.1. Drought types and their drivers



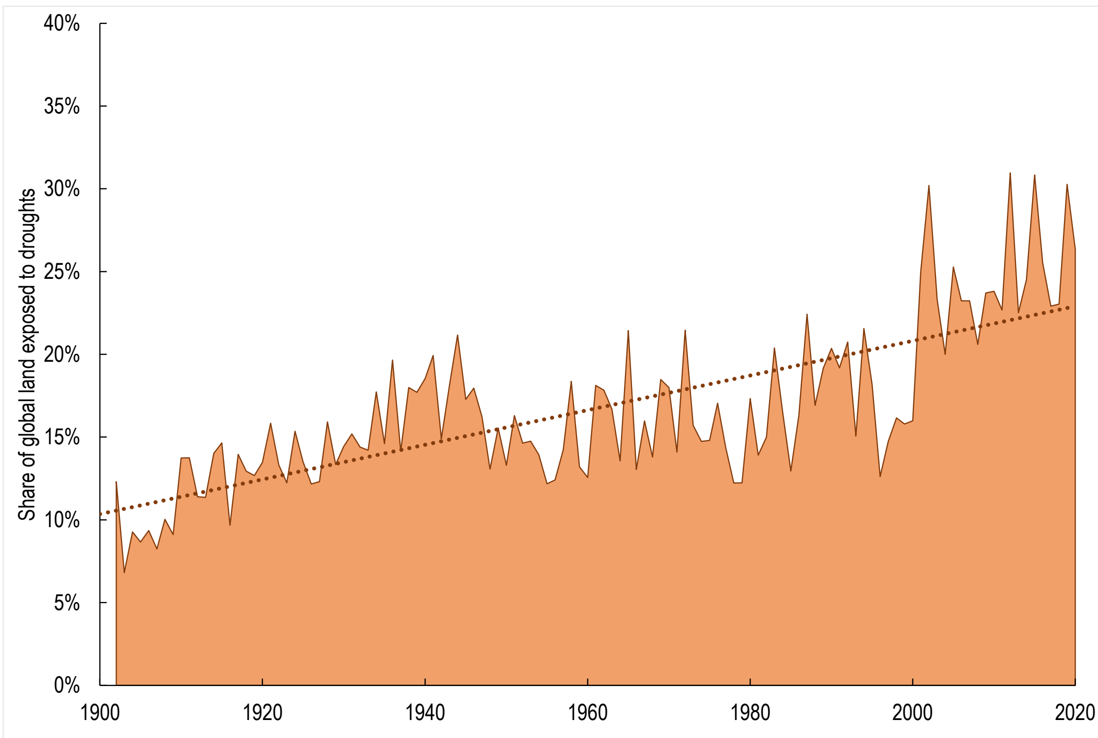

How to read this figure: This figure should be read from left to right, with "+" or "–" symbols indicating the effect of the elements at the base of the arrow on those at the arrow's head. Blue arrows represent the cascading effects of reduced precipitation and snow cover, orange arrows show the impact of rising temperatures, brown arrows indicate the effects of increased evaporation and evapotranspiration, and grey arrows represents the effect of radiation, wind, and $CO_2$ levels. For example, an increase in temperature reduces snowpack (–) and enhances evaporation and evapotranspiration (+). In turn, greater evaporation and evapotranspiration decrease soil moisture (agricultural drought) and surface water levels (hydrological drought).
Source: Author's own, based on IPCC (2021[9]).

While interlinked, droughts are distinct from water scarcity, aridity, and desertification. In fact, droughts are characterised by below-average water or precipitation levels, while water scarcity refers to an imbalance between water supply and demand (IPCC, 2022[11]). Water scarcity can thus arise independently of drought conditions, such as when water extraction surpasses the renewable supply, or as a result of water pollution and infrastructure failures. Drought and aridity differ in their temporal nature. Whereas drought is a temporary phenomenon, aridity is a permanent climatic feature of regions with low rainfall and high evaporative demand, such as deserts. Desertification, on the other hand, refers to the process of land degradation in arid regions, driven not only by droughts but also by unsustainable human activities such as agricultural expansion, deforestation, and urbanisation (UNCCD, 2022[14]).

### *2.2.2. Observed changes in drought conditions*

The share of global land exposed to droughts has significantly increased over the past decades, doubling between 1900 and 2020 (Figure 2.2). Regional observations show similar trends. For example, in Europe, drought-affected areas have expanded from the traditionally affected southern regions to encompass eastern and central parts of the continent (Joint Research Center, 2023[15]). In 2023, nearly half (48%) of the global land area experienced at least one month of extreme drought, the second-largest extent observed since 1951 (Romanello et al., 2024[16]).

**Figure 2.2. Share of global land area affected by droughts (1900-2020)**

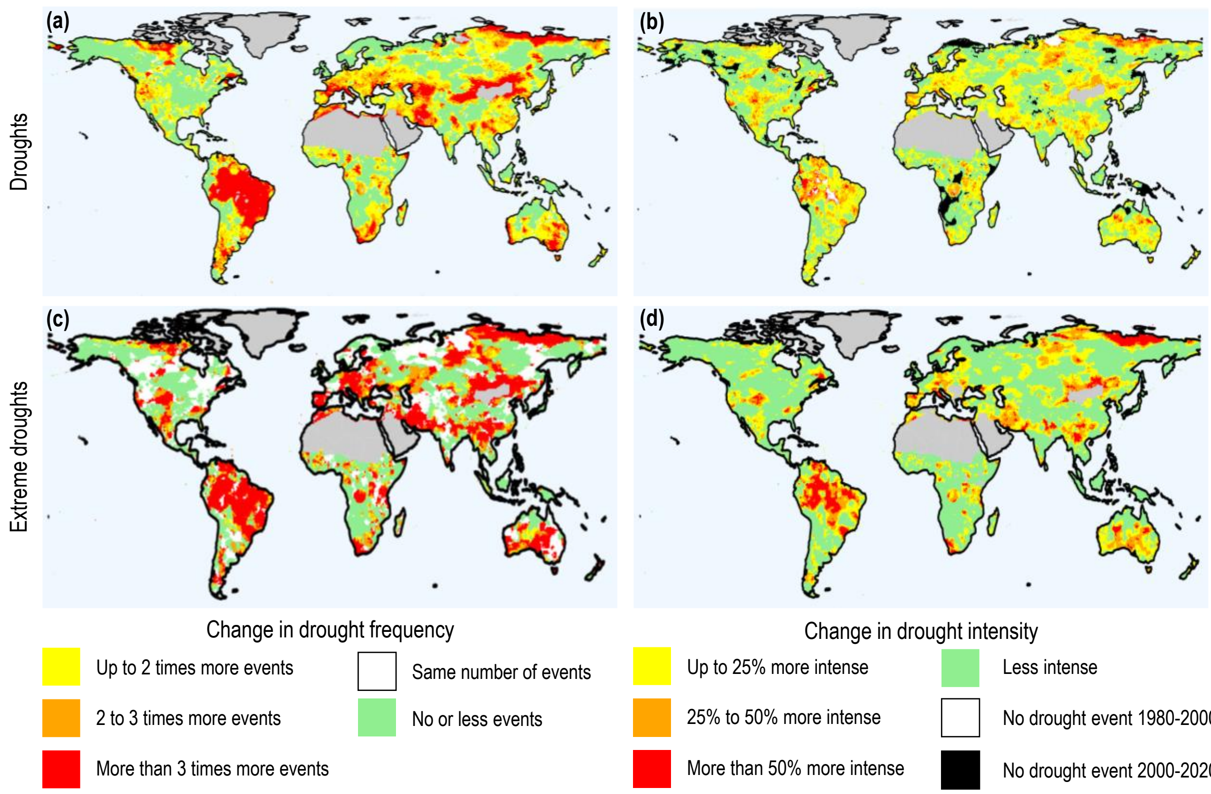



Note: Areas identified as affected by drought in a given year are those where the Standardised Precipitation Evapotranspiration Index (SPEI) value falls below -1 (Jain et al., 2015[17]). The analysis represented in this figure excludes the Sahara Desert, the Gobi Desert, the Arabic Peninsula, and polar regions. The trend line shown in the figure is derived from a linear regression analysis of the annual proportion of global land affected by droughts over time.
Source: Author's own, based on data from Beguería et al. (2023[18]).

Since the beginning of the 21st century, the frequency and intensity of drought events have increased in all continents. Around 40% of global land experienced an increase in both the average number of droughts and in their average intensity between the periods 1950-2000 and 2000-2020 (Figure 2.3 a and b). Extreme drought events – defined as years when the Standardised Precipitation Evapotranspiration[1] Index (SPEI) value is less than or equal to -2 – have also become more frequent and severe in many regions over the last two decades compared to 1950-2000 (Figure 2.3 c and d) (Jain et al., 2015[17]). Hotspots of increased drought frequency and intensity include the Western United States, South America, Southern and Eastern Europe, Southern Australia, Northern and Southern Africa, and Russia. Between 2000 and 2020, several of these regions experienced drought events with unprecedented intensities compared to the 1950-2000 period (Jain et al., 2015[17]) (Figure 2.3 d). OECD countries are not spared from these worsening drought conditions. In 27 of the 38 OECD member countries, at least 50% of the national territory has experienced an increase in drought frequency, while in 24 countries, at least 50% of the land has seen an increase in drought intensity (see Table A.A.1 in Annex A).

### Figure 2.3. Change in drought frequency and intensity (1950-2000 vs 2000-2020)

Change in the average number of drought events ((a) and (c)) and their intensity ((b) and (d)) in the period 2000-2020 compared to 1950-2000




How to read this figure: Graph (a) shows that South of France has experienced more than three time more drought events in the period 2000-2020 than in the period 1950-2000, while Northern Mexico experienced a decrease in the number of droughts over the same periods. Graph (b) shows that, in most of Northern Africa, the average intensity of all drought events (average SPEI values below -1) occurring during the period 2000-2020 was more than 50% more intense than the average of those occurring during the period 1950-2000. Graph (c) shows that Eastern interior Australia has experienced over three times more extreme drought events in the period 2000-2020 than in the period 1950-2000, while Indonesia experienced a decrease in the number of extreme droughts over the same periods. Graph (d) shows that, in most of Brazil, the most extreme event (event with the lowest SPEI value) during the period 2000-2020 was more than 50% more intense than the most severe event recorded during the period 1950-2000.

Note: Drought events are defined as years in which the average annual SPEI value falls below -1 (Jain et al., 2015[17]). Drought frequency (a and c) is calculated as the number of drought events occurring at each location during the two periods, divided by the duration (in years) of each period. Drought intensity (b) represents the average SPEI value of drought events at each location for each period. Panel (d) shows the change in the maximum intensity of extreme drought events, calculated as the ratio of the lowest SPEI value during 2000-2020 to the lowest SPEI value during 1950-2000 at each location. A drought year is considered as extreme if the annual SPEI value is below or equal to -2, based on the drought severity classification from Jain et al. (2015[17]).

Source: Author's own, based on data from Copernicus Climate Change Service (2022[19]).

### *2.2.3. Observed trends in freshwater availability*

The primary concern related to droughts lies in their impacts on freshwater availability, as most of the economic, environmental and social impacts of drought are linked to freshwater scarcity (see Chapter 3).

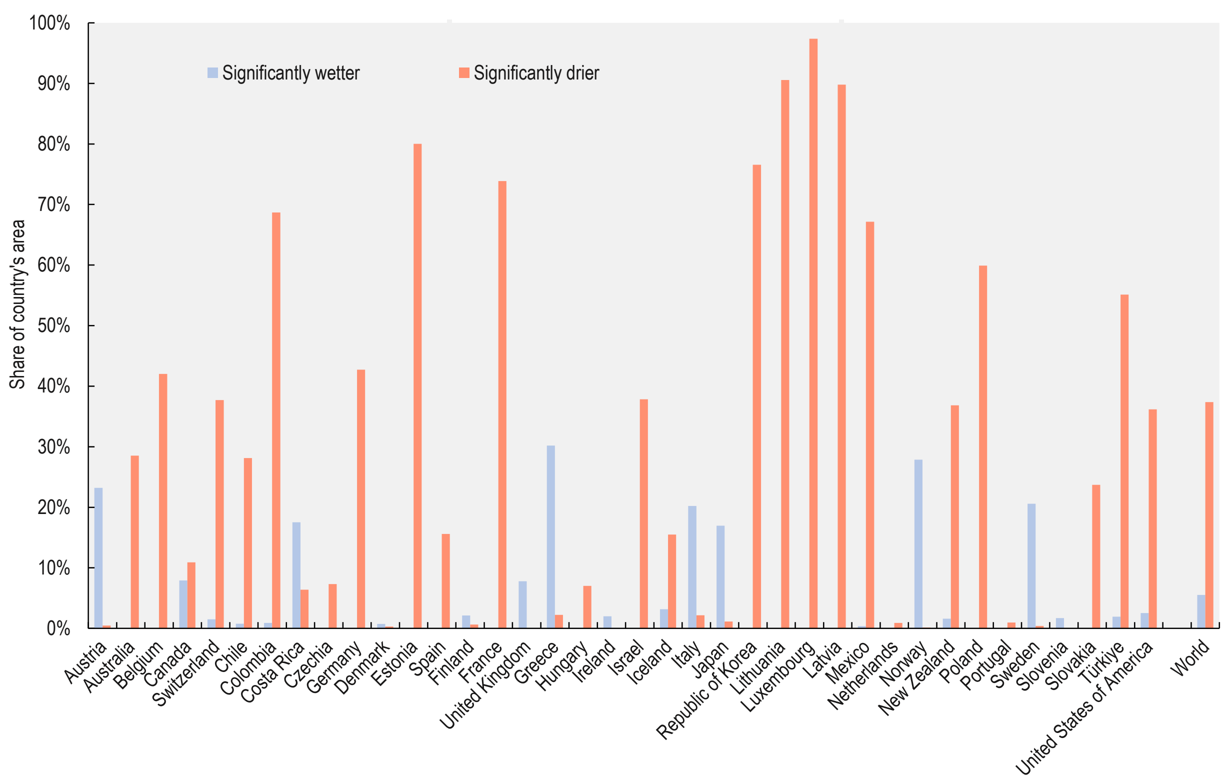
This section examines trends in freshwater quantity across major surface and groundwater reservoirs – including soils, rivers, glaciers, and aquifers – as well as the impacts of drought on freshwater quality.

### *Trends in soil moisture*

Decreasing levels of soil moisture due to drought have become a critical concern, with agricultural drought conditions affecting one-third of the global land area between 1980 and 2023. During this period, 37% of the world's soils experienced significant drying, while less than 6% of the global land surface saw a significant increase in average soil water content (Figure 2.4). Among OECD countries, over half reported that at least 20% of their territory experienced significantly drier soils over the same period. In contrast, only ten OECD countries experienced an overall increase in soil moisture. In particular, Figure 2.4 shows that Colombia, Estonia, France, Korea, Latvia, Lithuania, Luxembourg, and Mexico were particularly affected by decreasing soil moisture, with more than 60% of their land experiencing significant soil drying over the last forty years. It is important to note, however, that these annual averages can mask substantial seasonal fluctuations, which may be even more severe and concerning, especially when drying trends are observed during the growing season (see Chapter 3).

## Figure 2.4. Change in agricultural drought conditions in OECD countries and at the global level (1980-2023)

Percentage of land area that experienced significant change in average soil moisture over the period 1980-2023



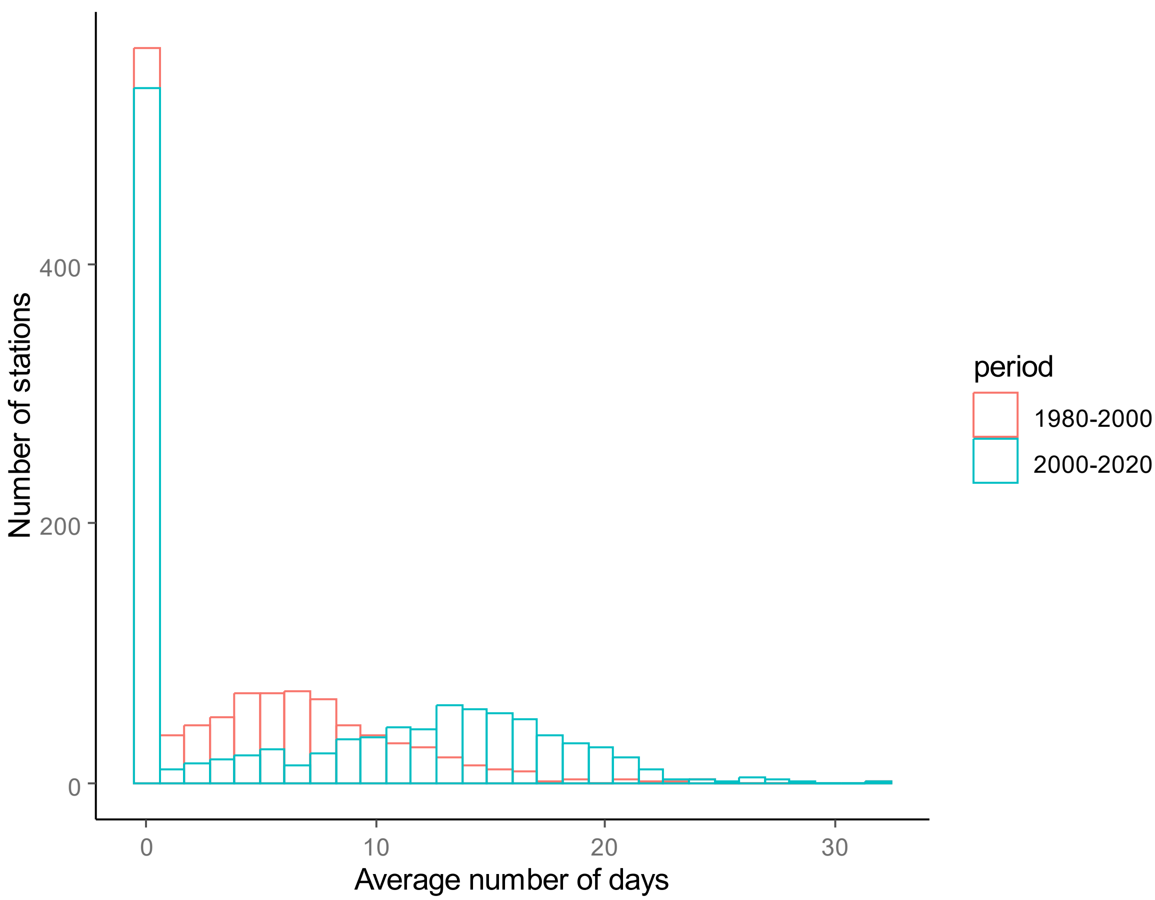

Note: The direction and statistical significance of changes in soil moisture are determined using a linear regression analysis, where annual average soil moisture (dependent variable) is regressed on the year (independent variable) for each location over the period 1980-2023. Statistical significance is assessed at a 10% level ($p < 0.1$). The percentage of a country's surface area experiencing significantly drier or wetter conditions is calculated as the ratio of grid cells (0.1° x 0.1° resolution) within the country showing a significant decrease or increase in average annual soil moisture to the total number of grid cells in that country.
Source: Author's own, based on data from Copernicus Climate Change Service (2022[19]).

### *Trends in river flows*

Decreasing average river flows have been observed in many regions of the world in recent decades. An analysis of global river streamflow trends shows that most rivers in Southern Europe, South Africa, Southern New Zealand, and Southern and Eastern Australia experienced decreases in average streamflow between 1951 and 2010 (Gudmundsson et al., 2019[20]; Amirthanathan, 2023[21]; Zhang, 2016[22]). In particular, 90% of rivers in Europe's Mediterranean region experienced declining average stream flows between 1950 and 2013 (Masseroni et al., 2021[23]), driven by climate change, revegetation, and increased water extraction for irrigation (Vicente-Serrano et al., 2019[24]). Recent data from over 1 000 river flow monitoring stations in Australia confirm these trends, with an increase in the annual average number of low-flow days – defined as daily flow below the 5th percentile of the monitored period – between 1980-2000 and 2000-2020 (Figure 2.5).

#### Figure 2.5. Number of river low-flow days in Australia (1980-2000 vs 2000-2020)

Average annual number of low-flow days across 1 174 river monitoring stations between the periods 1980-2000 and 2000-2020

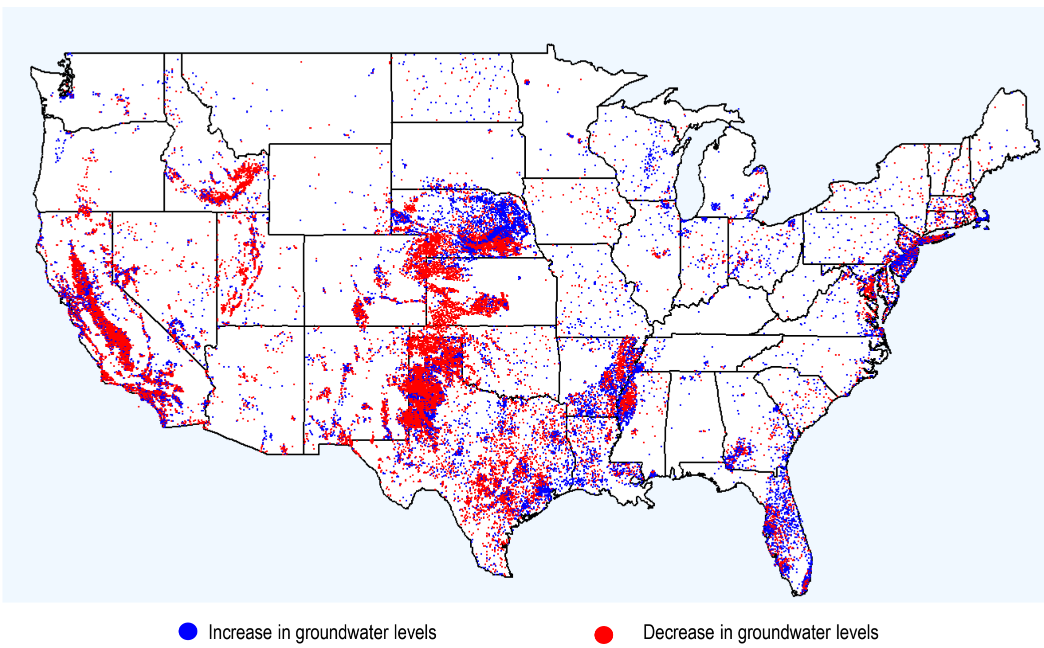



Note: Low-flow days are defined as days on which the average daily river flow is below the 5th percentile of the mean daily flow recorded at a given station over its entire monitoring period. The monitoring period varies by station but includes at least the period 1980-2020. Only river stations with fewer than five missing values for both the 1980-2000 and 2000-2020 periods are included in this analysis.
Source: Author's own, based on data from Chen et al. (2023[25]).

### *Trends in groundwater levels*

The majority of monitored groundwater table levels have also shown widespread declines in recent decades. A recent analysis of aquifers that supply over 75% of global water withdrawals found that 62% of monitored stations reported declining average water levels between 2000 and 2020. This decline is even more pronounced in non-OECD countries, where 73% of monitored stations recorded declining water levels, compared to 60% in OECD countries. In addition, 30% of these global monitored aquifers experienced faster declines in water levels during 2000-2020 compared to earlier periods (Jasechko et al., 2024[26]). However, these trends vary regionally within each country. For example, while most of the monitored stations in Florida indicated groundwater replenishment between 2000 and 2020, the majority of stations in Northern Texas, California, and Kansas showed consistent declines in water levels (Figure 2.6).

**Figure 2.6. Trends in monitored groundwater levels in the United States (2000-2020)**




Note: Each dot represents a single groundwater monitoring station. Alaska and Hawaii are excluded from the analysis.
Source: Author's own, based on data from Jasechko et al. (2024[26]).

### *Trends in glacier depletion*

Glacier depletion has significantly accelerated, with rising local temperatures and reduced snowfall driving faster melting and reducing annual replenishment. Between 2000 and 2020, glacier melt rates doubled, leading to widespread glacier retreat and threatening long-term water supply for many regions, as glaciers store around 70% of Earth's freshwater (Hugonnet et al., 2021[27]; Li et al., 2022[28]; Bhattacharya et al., 2021[29]). This accelerated melting has temporarily alleviated declines in river and groundwater levels in some drought-affected regions. For example, between 2010 and 2020, glacier melt in the Argentinian and Chilean Andes contributed up to 8% of local river flows during the driest months, partially offsetting the effects of the "megadrought" that has affected the region since 2010 (Dussaillant et al., 2019[30]). However, this mitigation is unlikely to continue, given the rapid and ongoing loss of glacier mass (see Section 2.3.1).

### *2.2.4. Observed trends in compound and consecutive climate events*

The observed increase in duration and frequency of extreme climate events amplifies the likelihood of droughts occurring concurrently or in succession with other extreme events. Globally, compound and consecutive weather events, such as heatwaves and droughts, have already become more common due to climate change, and this risk will continue to rise in the future as climate change intensifies (IPCC, 2023[31]).

Droughts can increase the likelihood and intensity of floods, particularly when dry conditions reduce soil absorption capacity. The occurrence of successive flood and drought events has increased in recent decades (Matano et al., 2023[32]). Prolonged droughts cause soil contraction, reducing water infiltration and increasing runoff (Matanó et al., 2024[33]), which can trigger landslides and flash floods when heavy rainfall occurs (Robinson, Vahedifard and AghaKouchak, 2017[34]). This is illustrated by the trends observed between 1980 and 2015, with 24% of global floods occurring during or immediately after drought periods (Matanó et al., 2024[33]). This pattern is particularly evident in South Africa and Mozambique, where river floods have been strongly correlated with preceding prolonged drought conditions (Franchi et al., 2024[35]).

Increasing drought severity and duration also heighten global wildfire risk. Droughts are a primary driver of extreme wildfires (OECD, 2023[36]), as demonstrated in studies linking droughts to large-scale fires in Türkiye and Mexico (Ertugrul et al., 2021[37]; Marín et al., 2018[38]). Some of the most devastating wildfires in recent history – including the 2018 Camp Fire in the United States (Hawkins et al., 2022[39]), the 2017 wildfires in Portugal and Chile (OECD, 2023[36]), and the 2020 wildfires in Arctic Siberia (Ciavarella et al., 2021[40]) – were fuelled by exceptionally dry conditions. In turn, forests exposed to wildfires become more susceptible to subsequent drought, raising concerns about their long-term sustainability in a changing climate. For example, forests affected by extreme wildfires tend to lose their ability to retain water, which makes them more sensitive to water shortages than mature forests (OECD, 2023[36]; Le Roux et al., 2022[41]).

Finally, climate change is set to drastically increase the frequency of compound drought and heatwave events. Low soil moisture exacerbates heatwaves through land-atmosphere feedback mechanisms, creating a self-reinforcing cycle of drought and extreme heat (Matanó et al., 2024[33]). The global frequency of these compound drought and heatwave events may increase tenfold by the end of the century (Yin et al., 2023[42]). The concurrence of these events is also particularly concerning as heatwaves significantly escalate water consumption, further compounding water scarcity issues (Cárdenas Belleza, Bierkens and van Vliet, 2023[43]).

## 2.3. The drivers of changing drought hazard

While droughts are natural phenomena driven by natural weather and climate variations, recent trends indicate they are increasingly driven by climate change and other anthropogenic factors. This section examines how shifting precipitation patterns, rising temperatures, and other non-climatic drivers have shaped and will continue to shape the occurrence and intensity of drought events.

### *2.3.1. Climatic drivers of drought*

Climate change amplifies drought risk through various interconnected drivers, including altered precipitation patterns and rising temperatures. A growing body of research increasingly provides evidence linking climate change to the intensification and frequency of drought events, quantifying how much more likely they become due to human-induced warming. For example, the 2022 droughts in the northern hemisphere were five to twenty times more likely and the ongoing drought in eastern Africa at least one hundred times more likely because of climate change (Schumacher, 2022[44]; Kimutai, 2023[45]).

*Changing precipitation patterns*

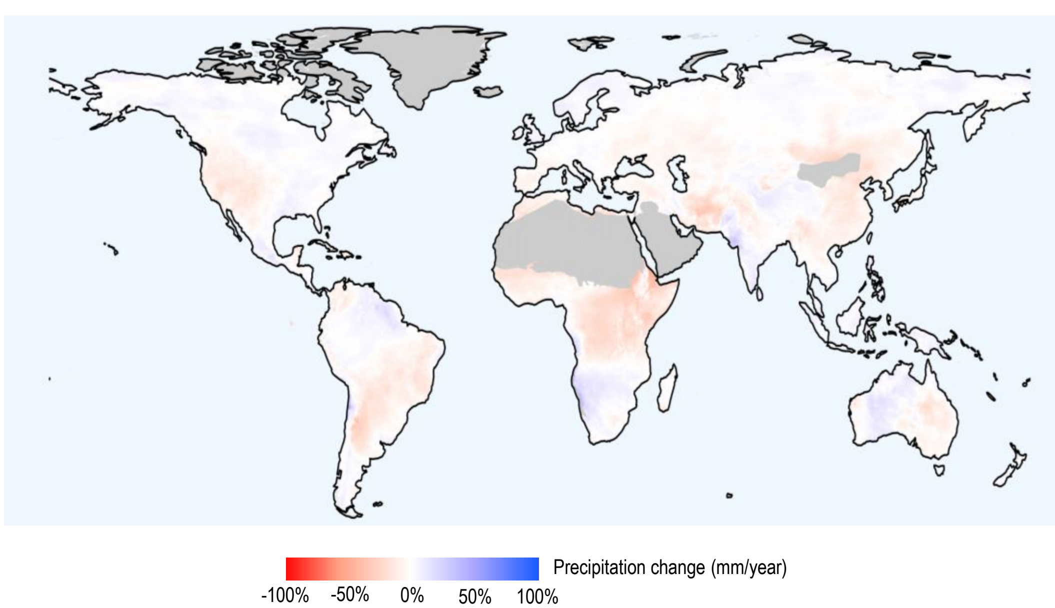
Climate change primarily influences drought occurrence by increasing annual and seasonal precipitation variability, which can lead to precipitation deficits in some regions. Since 1950, the inter-annual variability of average inland precipitation has increased considerably. Between 1950 and 2020, global maximum and minimum annual precipitation levels exceeded those recorded between 1900 and 1950 by a factor of six and five respectively, with extreme values up to three times higher (or lower) than those observed in the first half of the 20th century (Figure 2.8 a). There is broad scientific consensus that climate change has also altered interannual precipitation patterns. For example, France and Germany have experienced up to a 30% increase in average winter precipitation since pre-industrial times, coupled with an average 10% decrease in summer rainfall. Australia, on the other hand, has experienced reduced winter precipitation and increased summer rainfall (IPCC, 2022[46]).

Extreme precipitation patterns, driven by climate change, are also worsening drought risk. Heavy rainfall following prolonged dry periods can prevent effective water infiltration into the soil, worsening both agricultural and hydrological drought risks. Torrential rains, particularly on bare or compacted soils, can form a hard crust on the soil surface, leading to excessive runoff and preventing water infiltration into the soil. This process can reduce groundwater storage, soil moisture, and overall water availability (Eekhout et al., 2018[47]). As a result, even in areas experiencing episodic increases in precipitation, water availability may continue to decline.

Changes in precipitation patterns are not evenly distributed across the globe. While average global precipitation increased between 2000 and 2022 compared to 1950-2000, many areas experienced significant decreases in rainfall. For example, regions such as the Mediterranean, the Western United States, parts of South America, most of the African continent, the Middle East, and Eastern Australia all saw up to a 20% reduction in annual average precipitation during the period 2000-2020 compared to the previous fifty years (Figure 2.7).

### Figure 2.7. Global trends in average precipitation levels

Change in average annual precipitation (mm/year) between the periods 1950-2000 and 2000-2020




Source: Author's own, based on data from Copernicus Climate Change Service (2022[19]).

Additionally, extreme precipitation deficits[2] are also becoming more frequent in many regions due to climate change. Between 2000 and 2020, about 20% of global land experienced at least twice as many extreme annual precipitation deficit events compared to the previous fifty years (Figure 2.9). Combined with widespread increases in extreme temperatures, this trend has made regions such as South America, the western United States, northern East Africa, the Mediterranean, eastern Russia and eastern Australia particularly prone to drought.

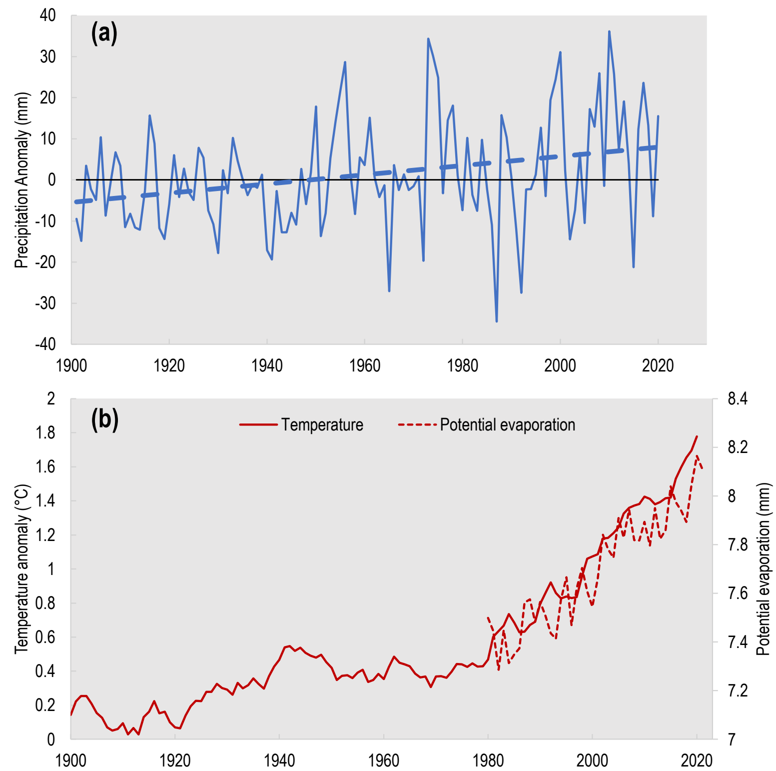
As illustrated in Figure 2.1, reduced precipitation leads to declines in river flow, soil moisture, and aquifer recharge (Taylor et al., 2012[48]). Between 2000 and 2020, precipitation deficits alone accounted for 25% of flash agricultural drought (Zeng et al., 2023[49]). Similarly, 80% of aquifers with declining water levels over the same period were linked to below-average precipitation (Jasechko et al., 2024[26]).

Beyond total rainfall amounts, the timing of precipitation is equally critical in defining drought risk. For example, winter precipitation plays a crucial role in aquifer recharge, as less abundant vegetation allows for more water to infiltrate the ground. Conversely, reduced winter precipitation limits snowpack storage in mountainous regions, increasing summer drought risk by reducing available meltwater (Han et al., 2024[50]).

### *Rising atmospheric temperatures*

The increase in global temperatures due to climate change is a key driver of higher evaporation rates, i.e. the transfer of liquid water from soil, rivers, and lakes into the atmosphere, which in turn amplify drought risk. Globally, continental surface temperatures have risen steadily since 1965, reaching an average of 1.8°C above pre-industrial levels by 2023 (IPCC, 2022[51]) (Figure 2.8 b). This warming trend is closely linked to the rising evaporation rates observed between 1980 and 2020 (Figure 2.8 b). In particular, heatwaves are an increasingly significant driver of flash droughts – i.e. a rapid-onset drought that develops over a short period –, with abnormally high temperatures having caused 50% more drought events during 2000-2020 compared to 1981-2000 (Zeng et al., 2023[49]). The effect of rising atmospheric temperatures is further compounded by solar radiation as well as wind, which further accelerates this process by disrupting the balance between atmospheric humidity and surface water (Vicente-Serrano et al., 2019[52]).

## Figure 2.8. Trends in global precipitation, temperature, and potential evaporation rates (1900-2020)



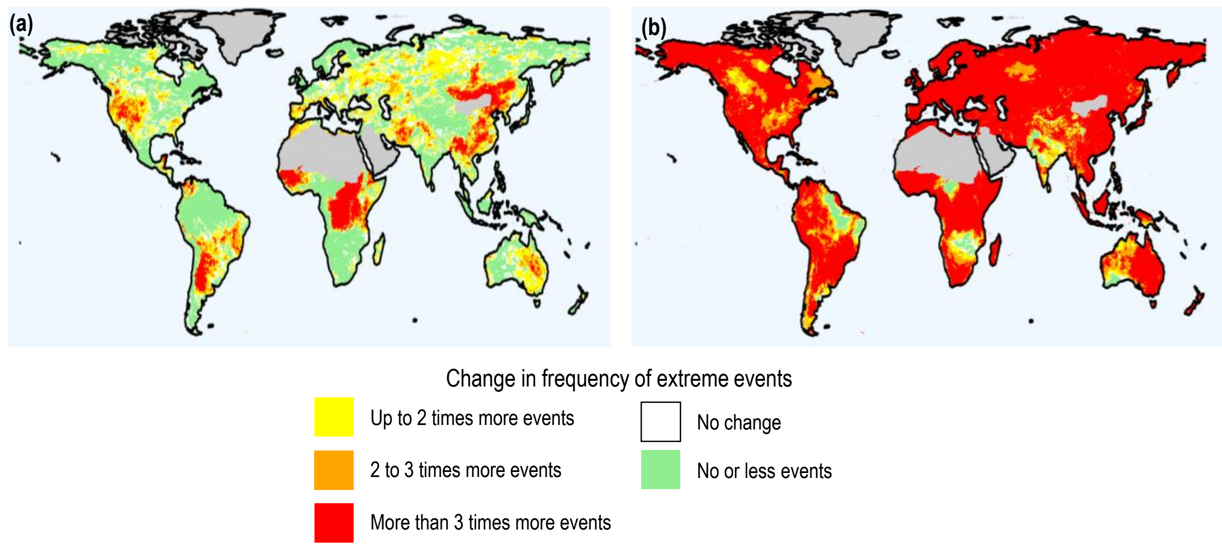

Note: The precipitation anomaly is calculated as the difference between total annual precipitation and the average annual precipitation for the period 1901-2000. The temperature anomaly is calculated as the difference between the global inland average annual temperature and the global inland average temperature of pre-industrial times (1980-1900). Annual temperature anomalies are derived from the average of four datasets: Berkeley Earth, GISTEMPv4 (NASA), HadCRUT5 (Met Office Hadley Centre), and NOAAGlobalTemp v6.0 (NOAA). Annual potential evaporation values represent the global inland average evaporation, calculated at a 0.1° x 0.1° resolution. Potential evaporation refers to the maximum amount of water that could evaporate from a given surface (e.g. soil, rivers, lakes) assuming an unlimited supply of water.
Source: Author's own, based on data from Blunden, Boyer and Bartow-Gillies (2023[53]) (Precipitation); (Rohde and Hausfather, 2020[54]; Lenssen et al., 2019[55]; Morice et al., 2021[56]; Huang et al., 2024[57]) (Temperature); (Copernicus Climate Change Service, 2022[19]) (Potential evaporation).

In parallel, rising atmospheric temperatures affect plant transpiration, i.e. the release of water vapour from plants during photosynthesis. Transpiration rates depend on atmospheric temperature, as well as on vegetation type and atmospheric gas concentrations, particularly carbon dioxide ($CO_2$) and ozone. Higher $CO_2$ concentrations affect plant photosynthesis by reducing stomatal openings and increasing leaf surface area, which can alter evapotranspiration rates (Skinner et al., 2017[58]; Swann et al., 2016[59]). Similarly, higher ozone concentrations can reduce plant transpiration, potentially mitigating drought risk (Arnold et al., 2018[60]).

Rising temperatures under climate change also disrupt the balance between solid and liquid freshwater, affecting both seasonal and long-term water availability. In mountainous regions, warmer temperatures reduce snowfall, increasing the proportion of rainfall and thus causing earlier snowmelt. This shift can deplete water reserves, leading to reduced water supplies during drier periods. In addition, global warming accelerates glacier melt and retreat. This poses a long-term threat to freshwater availability, as it reduces the ability of glaciers to sustain river flows and water supplies over time.

### Figure 2.9. Change in the frequency of extreme precipitation deficit and extreme temperature years

Change in the frequency of extreme annual precipitation deficit (a) and extremely hot year occurrence (b) between the period 2000-2020 and 1950-2000

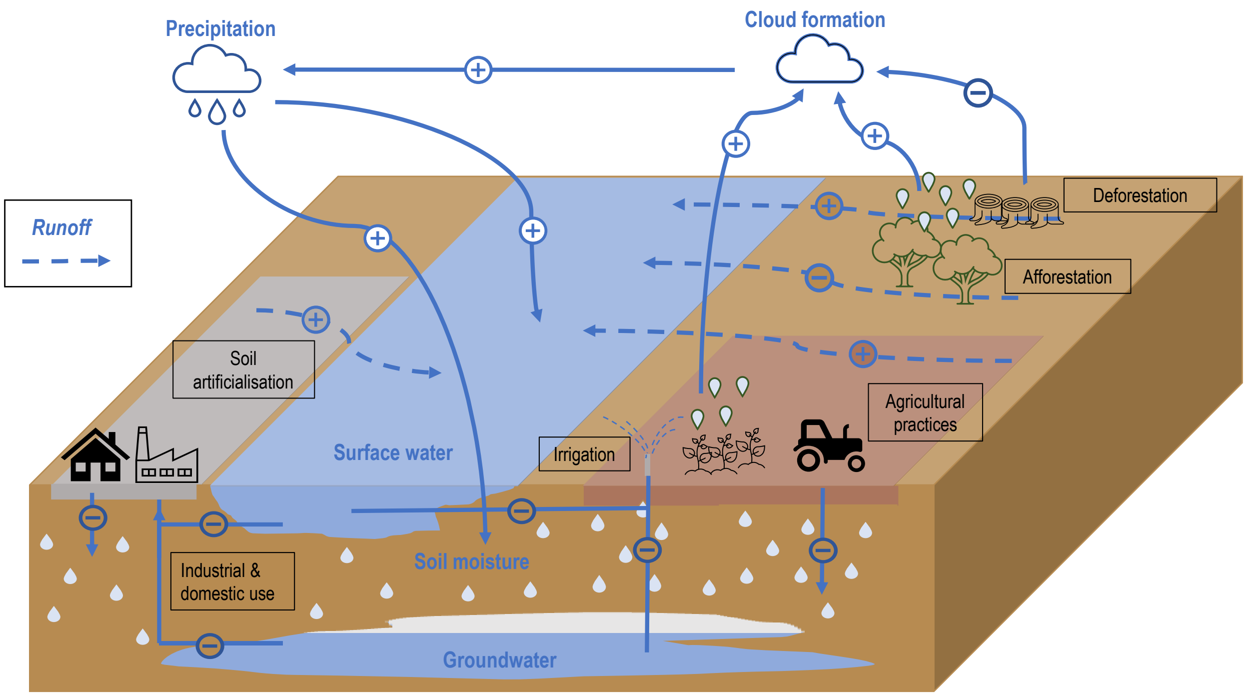



How to read this figure: Graph (a) shows that the Western United States experienced two to more than three times as many extreme precipitation deficit events on average during 2000-2020 compared to 1950-2000. In contrast, the United Kingdom saw a decline in the average number of extreme precipitation deficit episodes over the same period. Graph (b) shows that the global average number of extremely hot years more than tripled during 2000-2000 compared to1950-2000, except in some areas of South America, Australia, India, Mozambique, Botswana, and Zimbabwe.
Note: (a) A year is considered as experiencing an extreme precipitation deficit if its total annual precipitation falls below the 10th percentile of the annual precipitation distribution for that location during the 1950-2000 period. (b) A year is considered as extremely warm if its annual average temperature exceeds the 90th percentile of the annual average temperature distribution for that location during the 1950–2000 period.
Source: Author's own, based on data from Copernicus Climate Change Service (2022[19]).

### *2.3.2. Anthropogenic (non-climatic) drivers of drought*

In addition to climate change, human activities such as water withdrawal and land-use changes are other key drivers of growing drought risk. This section explores how growing volumes of water withdrawals – primarily for irrigation – and large-scale changes in land use due to deforestation, agricultural practices, and urbanisation – have exacerbated drought conditions in many regions and are expected to continue doing so in the future (Figure 2.10).

### Figure 2.10. Impact of human activities on drought risk




How to read this figure: The blue arrows represent water flows, with the direction of the arrow indicating the flow direction. The '+' and '-' symbols show the effects of specific activities or phenomena (shown in black) on water availability at the source. For example, evapotranspiration from forests contributes to cloud formation over land, so afforestation increases evapotranspiration and cloud formation, while deforestation reduces water flow to the atmosphere. Similarly, precipitation enhances soil moisture, replenishes groundwater and raises surface water levels, while water abstraction for industrial and domestic purposes reduces both surface and groundwater levels.
Source: Author's own.

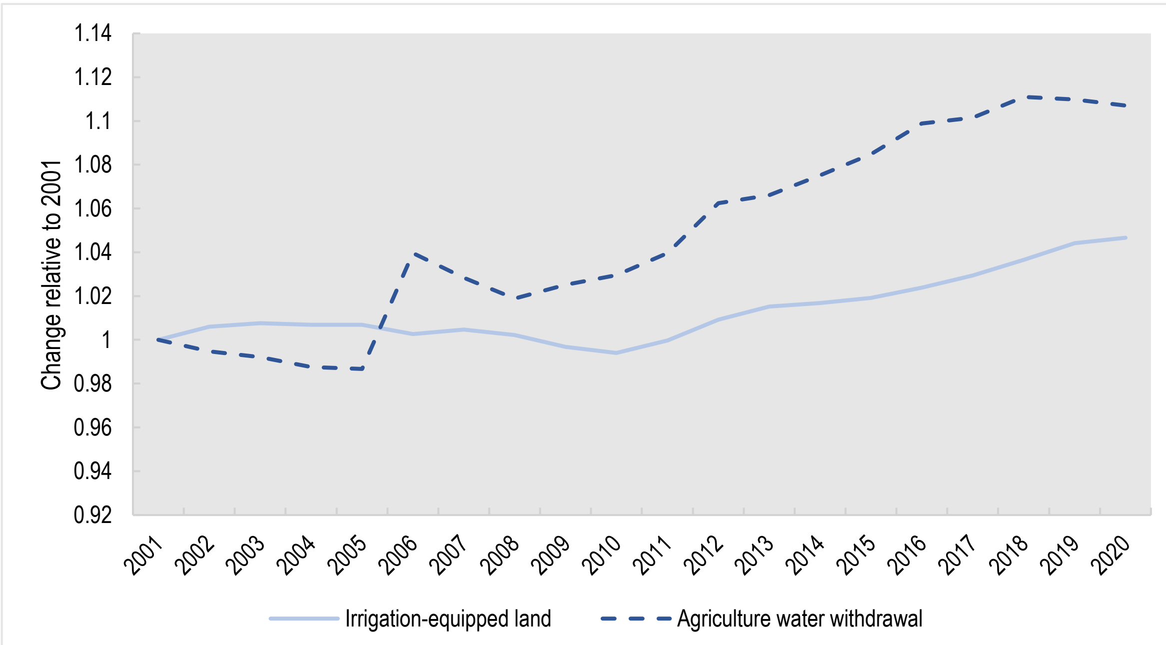
#### *Water withdrawals*

Water withdrawals significantly influence the occurrence and severity of drought events. By extracting water from surface and underground reserves, water withdrawals slow the replenishment of water bodies and reduce the availability of water during dry periods. Water extraction for irrigation plays a particularly large role in amplifying the severity and duration of drought, due to the large volumes usually extracted.[3] According to recent estimates, water pumping makes river droughts up to thirty times more severe and extends drought duration by ten times (Van Loon et al., 2022[61]; Ketchum et al., 2023[62]). Global expansion of irrigation in areas of high agricultural intensity explains much of the observed changes in groundwater levels (Scanlon et al., 2023[63]). For example, the shift from surface to groundwater irrigation in the High Plains region of the United States has been associated with significant declines in aquifer levels (Scanlon et al., 2021[64]).

Growing water withdrawals are closely linked to the expansion of irrigated agriculture as well as to climate change. Between 2001 and 2020, the surface of irrigated areas in OECD countries grew by 4% (Figure 2.11). This, together with the growing need for irrigation due increasingly dry conditions in many regions, has led to a 20% rise in water withdrawals for agricultural purposes (Figure 2.11).

### Figure 2.11. Irrigation capacity and water use in agricultural in OECD countries (2001-2020)

Relative change in the total area of agricultural land equipped for irrigation (solid brown line) and total agriculture water withdrawal (blue dotted line) in OECD countries (2001-2020)




Note: Ireland and Luxembourg are not covered in this analysis due to their very limited area of irrigated land.
Source: Author's own, based on data from FAO (2024[65]) (Surface of irrigation-equipped land) and FAO (2024[66]) (Total agriculture water withdrawal).

Excessive water abstraction for irrigation also degrades water quality, making drought episodes even more severe. Many aquifers and rivers worldwide have experienced higher salinity and pollutant concentrations during drought, partly due to increased water use for irrigation. For example, nitrate concentrations in California's Central Valley's monitored wells exceeded regulatory thresholds four to five times more frequently during drought periods, due to increased water pumping for agricultural purposes (Levy et al., 2021[67]). Similarly, water withdrawals for irrigation during the Millennium Drought in Australia (1997-2009) and the 2000-2001 and 2007-2009 droughts in Florida exacerbated water salinity- reaching record levels that exceeded regulatory thresholds – threatening water use for irrigation and drinking supplies for millions of people (Murray–Darling Basin Authority, 2023[68]; Haque, 2023[69]).

Water withdrawal is expected to increase in the future, further exacerbating drought conditions. By the middle of the century, global water withdrawal volumes are projected to increase by 20-30% compared to 2020 (Boretti and Rosa, 2019[70]). These trends will be driven by increased water demand in key sectors (e.g. water use in the manufacturing sector is projected to grow by 400% by 2050 (Boretti and Rosa, 2019[70])) as well as by rising temperatures and worsening droughts and heatwaves under climate change, which are likely to increase water demand for irrigation, energy production, and other uses (Labbe et al 2023; Wang et al 2016). Under a high-emission scenario (RCP 8.5), water demand for irrigation is projected to increase sharply in many dry regions, for example in the Pacific Southwest of the United States (Warziniack et al., 2022[71]). At the same time, in some European areas, drinking water consumption may increase by up to 10% on hot days (Fiorillo et al., 2021[72]; Dimkić, 2020[73]).

### *Land-use and land-cover changes*

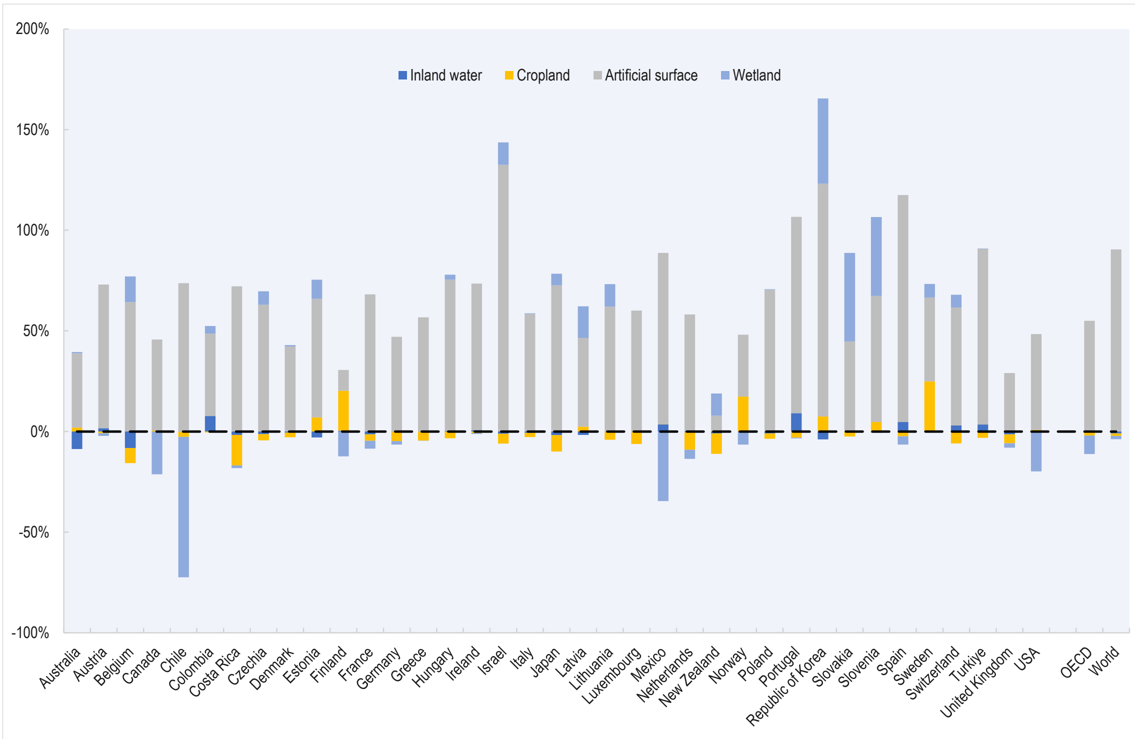
Land-cover changes such as deforestation are key factors contributing to drought occurrence. Forest and vegetation dynamics play a significant role in shaping the water cycle, affecting precipitation and runoff patterns at both the local and global level. For example, deforestation reduces evapotranspiration and – when performed on a large scale – can inhibit cloud cover, reducing precipitation and thus exacerbating drought conditions (The Global Commission on the Economics of Water, 2023[74]; Perugini et al., 2017[75]; Smith, Baker and Spracklen, 2023[76]). In the Amazon rainforest, deforestation has been associated with 4% of the increase in drought intensity observed between 2001 and 2014 (Staal et al., 2020[77]). Overall, a 1% reduction in tropical forest area is estimated to reduce rainfall by about 0.25 millimetres per month within a 200 kilometre radius around the deforested area (Smith, Baker and Spracklen, 2023[76]). Conversely, reforesting 14% of Europe's surface could lead to an 8% increase in average annual precipitation (Baker, 2021[78]; Meier et al., 2021[79]). However, when not carefully planned, afforestation can sometimes exacerbate local drought risk by reducing surface runoff and decreasing river flow downstream. For instance, intensive afforestation in the Pyrenees is estimated to reduce river streamflow by up to 50% during dry periods (Vicente-Serrano et al., 2021[80]).

In some agricultural areas, unsustainable agricultural practices have also diminished soil water infiltration and retention capacity, exacerbating drought risk. For example, the expansion of water-intensive crops, such as maize, have contributed to major declines in soil moisture in areas like Northern China (Liu et al., 2015[81]). Similarly, the continued use of traditional tillage practices has accelerated evapotranspiration and soil erosion, further affecting soil moisture. The use of heavy machinery has also been associated with reduced water infiltration and soil water retention capacity, with negative impacts on groundwater recharge (Chyba, 2014[82]; El-Beltagi et al., 2022[83]).

Finally, soil sealing driven by urbanisation and other land-use changes also contributes to worsening drought conditions. Throughout the 21st century, the pace of soil sealing has accelerated, with sealed surfaces increasing on average by 50% in OECD countries and nearly doubling globally (Figure 2.12). The surface area of inland waters, an important freshwater reservoir, also decreased in several OECD countries, such as Australia (-15%) and Belgium (-8%). During the same period, wetland areas in OECD countries declined by 18% on average, with losses peaking at 50% in Chile and between 20 to 30% in Canada, Mexico, and the United States[4] (Figure 2.12). The loss of such critical ecosystems, coupled with the artificialisation of riverbanks, have been associated with reductions in groundwater recharge, in addition to other ecological impacts such as loss of biodiversity, disruption of natural habitats, and diminished carbon sequestration capacity.

**Figure 2.12. Change in land cover in OECD countries**

Percentage change in land cover type between 2000 and 2020




Note: Iceland is excluded from the figure as the data show no change in land cover.
Source: Authors' own, based on data from Tesnière, Maes and Haščič (2024[84]).

## 2.4. Towards a drier world

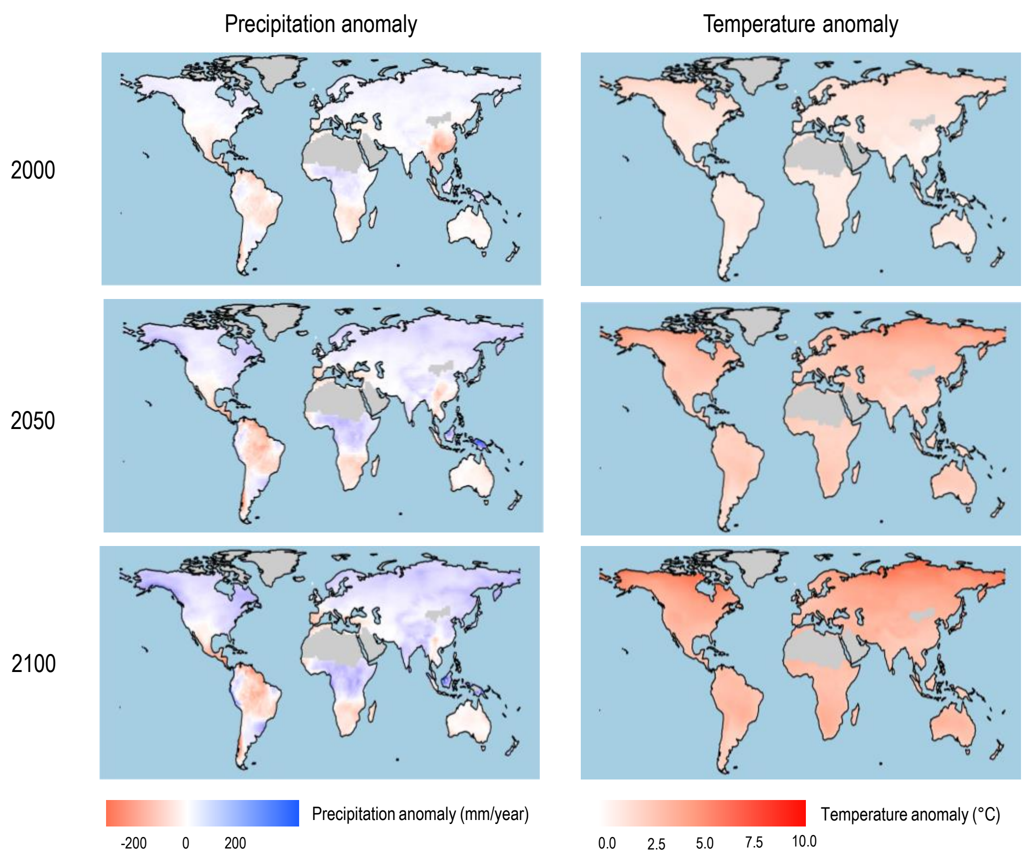
In the context of climate change, drought patterns will continue to evolve, affecting the frequency, duration, and severity of drought events. Rising temperatures and shifting precipitation trends will continue to disrupt soil moisture, groundwater levels, and river flows, with varying impacts across regions. At the same time, more people and land will be exposed to drought. Finally, climate change is projected to heighten the likelihood of compound and consecutive climate events, such as flash droughts and heatwaves. The following sections explore these evolving trends under different warming scenarios.

### *2.4.1. Growing drought frequency, duration, and intensity*

The observed trends in rising atmospheric temperatures and shifting precipitation patterns due to climate change are expected to persist in the future. Global warming is projected to reach between 1.8°C and 4°C by 2100 compared to pre-industrial levels under low-emission (SSP1-2.6) and high-emission (SSP5-8.5) scenarios, respectively (IPCC, 2021[9]) (see Box 2.1 for more details on these scenarios). Global average precipitation is estimated to increase by 1-2% for every additional degree of global warming (Trenberth et al., 2007[85]). However, these changes are projected to vary significantly across regions. Most notably, areas such as Latin America, the Mediterranean, Southern Africa, the Middle East, parts of Australia, and China are projected to experience notable decreases in average annual rainfall by 2050 and 2100 (Figure 2.13). Additionally, parts of South America, the Mediterranean, and Southern Africa could experience up to a fourfold increase in extreme low-rainfall episodes by the end of the century (compared to pre-industrial levels) across all climate scenarios (Cook et al., 2020[86]). At the same time, the frequency and intensity of extreme heat events is projected to rise sharply. By the end of the century, extreme heat events are projected to be 14 times more likely under a low-emission scenario (SSP1-2.6) and nearly 40 times more likely under a high-emission scenario (SSP3-7.0). The average intensity of these heatwaves could increase by up to 5°C compared to 1850-1900 levels (IPCC, 2021[9]).

### Figure 2.13. Projected changes in annual temperature and precipitation levels over time

Average annual precipitation anomaly (mm/year) and temperature anomaly (°C) for 2000, 2050, and 2100 under a moderate-emission scenario (SSP2-4.5), relative to the 1850–1949 baseline



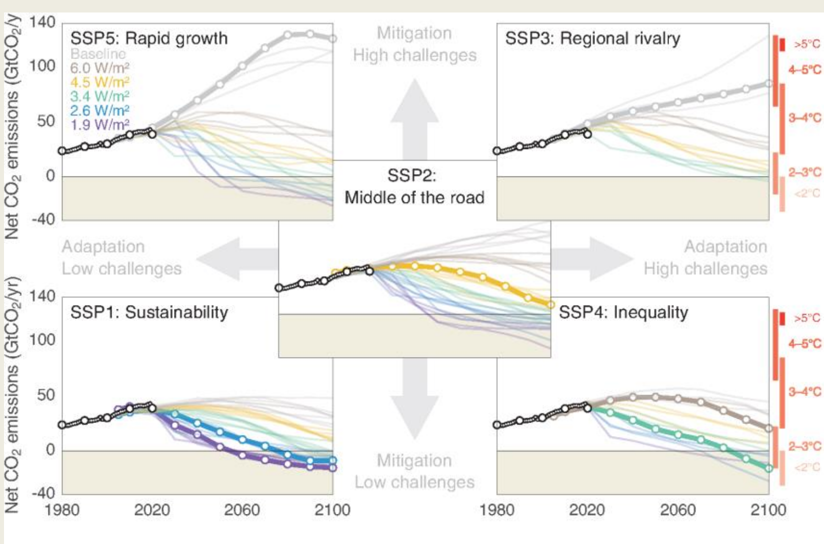

Note: The values shown are the averages of the annual median gridded anomalies projected by the model ensemble for the periods 2000-2020 (2000), 2036-2064 (2050), and 2071-2099 (2100).
Source: Author's own, based on data from Cook et al. (2020[86]).

## Box 2.1. Projecting drought risk under different climate and socioeconomic scenarios

To project future climate outcomes, the IPCC's Sixth Assessment Report introduced five scenarios – known as SSP-RCP – that combine socioeconomic development pathways with different greenhouse gas concentration trajectories. These scenarios serve as inputs for the Sixth Coupled Model Intercomparison Project (CMIP6), which models future greenhouse gas emissions and associated climate change projections until 2100. The SSP-RCP framework combines two major scenario systems:

- ***The Shared Socioeconomic Pathways (SSPs)*** outline five global development narratives (SSP1 to SSP5) based on different assumptions about economic development, population trends, technological advancement, education, and energy use. Each scenario is labelled SSPx-y, where "*x*" indicates the socioeconomic pathway and "*y*" the associated radiative forcing level (W/m²) by 2100, indicating the intensity of climate change under different emission mitigation scenarios.
- This approach builds on the ***Representative Concentration Pathways (RCPs)*** used in the IPCC's Fifth Assessment Report. RCPs are greenhouse gas concentration trajectories associated with specific radiative forcing levels. They range from strong mitigation scenarios (RCP2.6) to high-emissions (RCP8.5) pathways – reflecting a range of possible climate futures depending on the degree of global mitigation ambition.

### Figure 2.14. Global temperature change and greenhouse gas emission across SSP scenarios



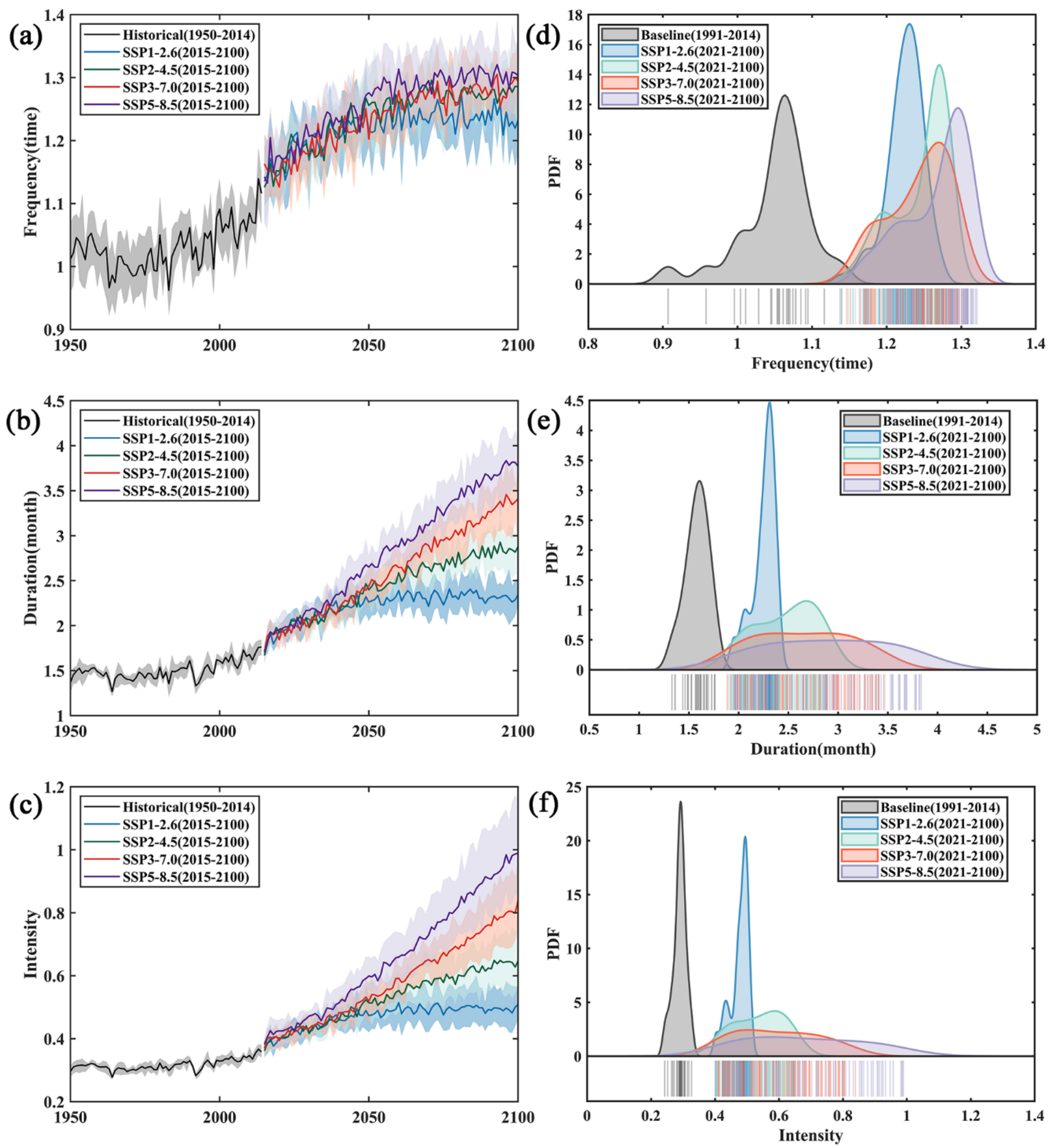

Source: (Andrew, 2016[87]).

By linking socioeconomic narratives with emissions trajectories, the SSP-RCP framework helps capture how both human development patterns and mitigation efforts shape future drought exposure and severity. Future drought conditions are assessed using three of the five SSP-RCP scenarios. The "middle of the road" scenario (SSP2-4.5) serves as the baseline, while the "sustainability" scenario (SSP1.2-6) and the "regional rivalry" scenario (SSP3-7.0) provide lower and upper bounds of potential drought risk under different emission pathways.

Source: (IPCC, 2021[9]; Andrew, 2016[87]).

These shifts in precipitation patterns, combined with rising atmospheric temperatures, are expected to make droughts more frequent, prolonged, and intense in many regions. By the end of the century, global drought frequency could increase by 30%, with average drought intensity more than doubling under moderate- to high-emission scenarios (SSP2-4.5 and SSP3-7.0), compared to 1991-2014 (Figure 2.15). Global average drought duration is also projected to rise by 50% under SSP2-4.5 and by 130% under SSP3-7.0 by 2100, relative to the 1950-2000 period (Zhou et al., 2023[88]).

## Figure 2.15. Projected change in average global drought frequency, duration, and intensity




Note: The SPEI is used to assess projected change in average global drought frequency, duration, and intensity.
Source: (Zhou et al., 2023[88]).

Climate change is also projected to increase the frequency of extreme drought events, i.e. drought episodes characterised by exceptional intensity and duration. These shifts in the occurrence of extreme events will be more pronounced than changes in average drought conditions (IPCC, 2022[46]). For example, in Canada, the United States, and Mediterranean Europe, the frequency of extreme agricultural droughts is projected to double or triple under 2°C of warming (IPCC, 2022[46]). The share of global land and population exposed to extreme drought events is projected to increase from 3% today to 7% and 8%, respectively, by 2100 (Pokhrel et al., 2021[89]). Climate change may also increase the frequency of long, multi-year droughts[5] up to fivefold (Wu et al., 2022[90]).

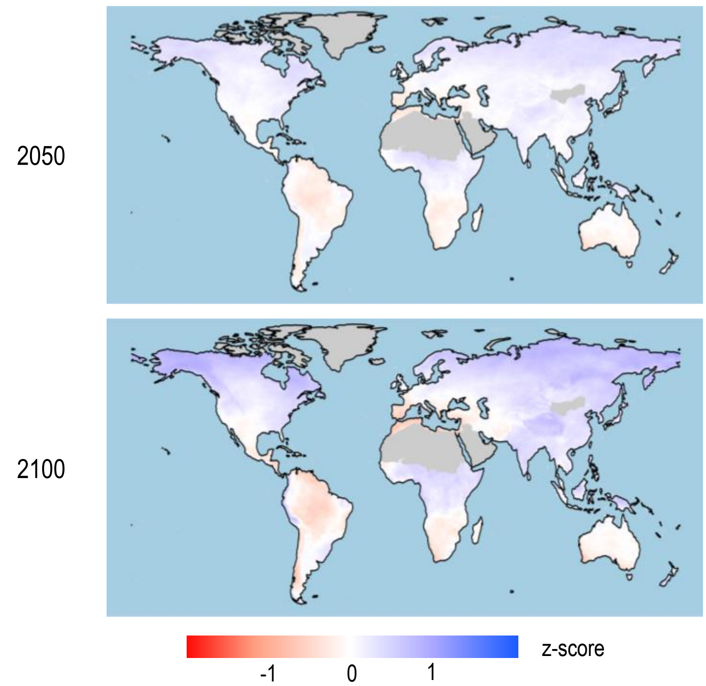
In addition, the increasing coincidence of heatwaves and extreme precipitation deficits is expected to intensify the risk of flash droughts. These events are particularly concerning because they develop suddenly and with limited warning, making them challenging to predict and mitigate. Based on trends from 2000-2020, the frequency of flash droughts is projected to rise by around 20% in Europe, Indonesia, and China, and up to 25% in Latin and North America by 2100 (compared to 2015) under a moderate-emission scenario SSP2-4.5 (Christian et al., 2023[91]).

As drought conditions worsen, both the human population and agricultural lands will face increasing exposure to average and extreme drought conditions. By 2050, more than 1.6 billion people – including nearly 20% of the African population – will be exposed to severe and extreme droughts (Thow et al., 2022[92]), with up to 700 million people potentially forced to migrate due to droughts by 2030 (UNCCD, 2022[93]). Under a 2°C warming scenario, the global population exposed to agricultural droughts every year will more than triple (Lange et al., 2020[94]). Additionally, by the end of the century, the annual area of agricultural land exposed to flash droughts may rise by 20% in North America and 30% in Europe under a moderate-warming scenario (SSP2-4.5) (Christian et al., 2023[91]).

Overall, climate change will exacerbate existing inequalities in drought exposure, intensifying drought risk in regions that are already severely affected. Drought hotspots identified in Section 2.2, such as the Mediterranean, Southern North America, Latin America, Southern Africa, and parts of Australia are projected to experience severe drought conditions more frequently by 2050 and 2100 under a moderate-emission scenario (SSP2-4.5) (Figure 2.16).

**Figure 2.16. Projected changes in global drought conditions by 2050 and 2100**

Average annual SPEI values for 2050 and 2100 under a moderate emission scenario (SSP2-4.5), relative to the 1995–2014 baseline



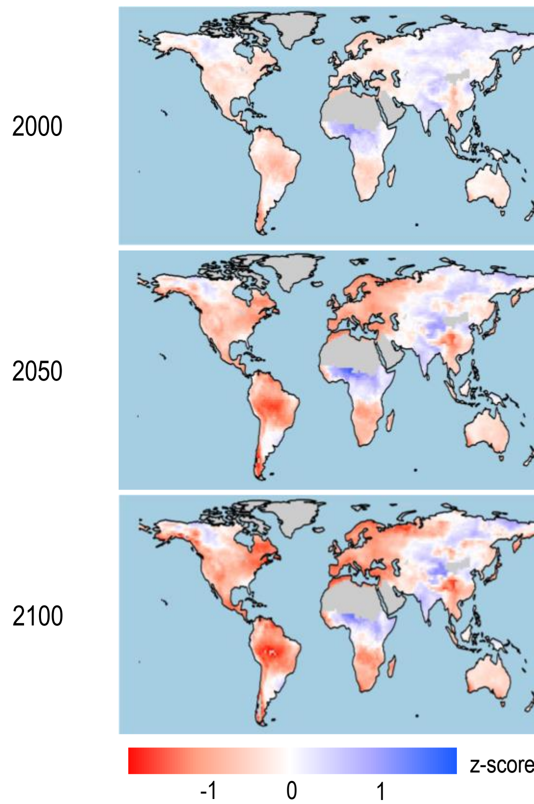

Note: The values shown in this figure represent the average of the median annual gridded SPEI values projected by the model ensemble for the periods 2036-2064 (2050) and 2071-2099 (2100).
Source: Author's own, based on data from World Bank (2024[95]).

### *2.4.2. Projected impacts on soil moisture, groundwater levels, and river flows*

Despite an expected increase in global average precipitation, agricultural droughts – driven by worsening soil moisture deficits – are projected to become significantly more severe (Figure 2.17). By the middle of the century nearly 70% of global land area could experience declining soil moisture under a moderate-emission scenario (SSP2-4.5), relative to pre-industrial levels under a SSP2-4.5 scenario. In addition to the drought hotspots identified in the previous paragraph, India, the United States, Europe, eastern Russia, and China are also projected to experience substantial reductions in soil moisture. Even in regions where meteorological droughts are projected to intensify, such as the Mediterranean and South America, drought impacts on agriculture may be even more severe due to rapid soil moisture depletion (Gimeno-Sotelo et al., 2024[96]).

### Figure 2.17. Projected changes in average agricultural drought conditions over time

Average annual standardised surface soil moisture anomaly for 2000, 2050 and 2100, under a moderate emission scenario (SSP2-4.5), relative to the 1850–1949 baseline



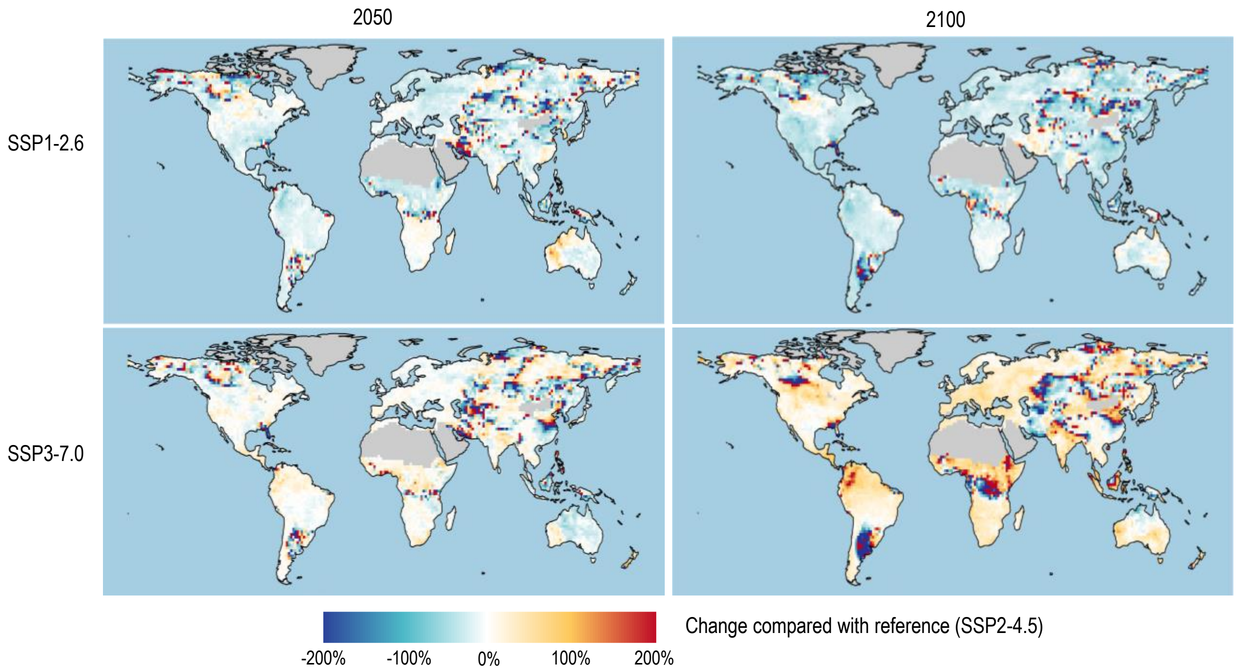

Note: The figure shows surface soil moisture levels at a depth of 0-30 centimetre. The values shown are the averages of the annual median gridded anomalies projected by the model ensemble for the periods 2000-2020 (2000), 2036-2064 (2050) and 2071-2099 (2100).
Source: Author's own, based on data from Cook et al. (2020[86]).

Under climate change, groundwater levels and river flows in many regions are also likely to decline, though projections remain uncertain due to varying water use and withdrawal trends. Most aquifers are projected to experience declining levels (Amanambu et al., 2020[97]), with depletion rates potentially doubling by 2100 compared to the early 21st-century trends (Wada, 2015[98]). Similarly, while future river flow projections vary across models, most models anticipate increases in river flow in Canada and Northern Europe and declines in the Mediterranean and Southern Africa (IPCC, 2022[46]).

While climate models indicate a clear trend of increasing drought risk, significant uncertainties remain. A key source of uncertainty is the substantial variability across models and emission scenarios (IPCC, 2023[99]). For example, soil moisture projections for 2050 and 2100 under SSP1-2.6 and SSP3-7.0 (Figure 2.18) show considerable regional variation. This highlights the complex interaction between climate change, local conditions, and water management policies. Additional sources of uncertainty arise from differences in the definitions and indicators used to assess drought, the limited historical data available for model calibration, and differing statistical methods used in model development (see (Gimeno-Sotelo et al., 2024[96]) for a review), as well as future water management policies and practices.

## Figure 2.18. Projected changes in drought conditions across different climate scenarios

Percentage change in average surface soil moisture by 2050 & 2100 under a low-emission scenario (SSP1-2.6) and a high-emission scenario (SSP3-7.0), compared to a moderate emission scenario (SSP2-4.5)




Note: The values shown are the ratio between the averages of the annual median gridded anomalies projected by the model ensemble for the periods 2036-2064 (2050) and 2071-2099 (2100) under SSP1-2.6 or SSP3-7.0 scenarios and SSP2-4.5.
Source: Author's own, based on data from Cook et al. (2020[86]).

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## Notes

[1] Evapotranspiration refers to the combined loss of water that occurs through evaporation – i.e. the transfer of liquid water from soil, rivers, and lakes into the atmosphere – and the release of water vapour from plants.

[2] In the context of this analysis, extreme precipitation deficits are defined as years when total annual precipitation falls below the 10th percentile of 1950-2000 levels.

[3] Irrigation accounts for about 72% of the global volume of water withdrawals, followed by industry (16%) and domestic and municipal uses (13%) (United Nations, 2024[100]).

[4] Changes in wetland surface should be interpreted with caution, as most of the observed loss corresponds to a conversion to forest land between these periods. In some cases, definitions of wetlands and forests overlap, making the distinction between them ambiguous.

[5] Wu et al. (2022[90]) defines long, multi-year droughts as droughts that persist for more than ten years.

# 3 Impacts and costs of droughts

This chapter examines the economic, social, and environmental impacts of droughts, highlighting their widespread and interconnected consequences. It shows how droughts affect agriculture while also disrupting economic sectors such as energy and transportation, leading to significant economic damage and macroeconomic instability. Beyond economic effects, the chapter also explores how extreme droughts can affect ecosystems and exacerbate social tensions. Drawing on scientific evidence and novel data analysis by the OECD, it underscores the far-reaching consequences of droughts and the need for proactive resilience strategies.

## 3.1. Introduction

Droughts have profound and wide-ranging impacts on the environment, the economy, and society. They impose a considerable burden on vegetation and wildlife, disrupting ecosystem processes and threatening biodiversity. In the economic sphere, droughts can severely undermine the performance of water-intensive sectors such as agriculture, power generation, and fluvial transport. In regions heavily dependent on agriculture, drought-induced water scarcity weakens macroeconomic performance, disproportionately affecting the most vulnerable socioeconomic groups. Beyond economic consequences, severe drought episodes pose a threat to food security and water sustainability, which are fundamental to social well-being and economic stability. These conditions may generate discomfort and social unrest, potentially jeopardising political stability and social cohesion. Consequently, the impacts of droughts often transcend national borders, contributing to increased migration flows and fuelling conflicts.

The balance of ecosystems are intrinsically tied to water availability and thus particularly vulnerable to the effects of droughts. Droughts disrupt vegetation in critical ecosystems such as forests and wetlands, compromising their ability to capture and store carbon. In turn, this weakens their role in climate regulation. Droughts also threaten native species, often forcing them to migrate or adapt to survive. Compounding this, drought conditions can foster the proliferation of invasive species, further disrupting ecological balance and threatening biodiversity in key ecological corridors.

The adverse effects of droughts on ecosystems translate into significant economic consequences. Agriculture is particularly affected, with droughts causing substantial losses in both crop quantity and quality. These losses drive up food prices and ripple through other areas of the economy. Droughts also disrupt industrial processes that depend on water, resulting in increased production costs for critical sectors such as fluvial transport, power generation, manufacturing, and mining. Given the central role of these sectors to many economies, prolonged and intense droughts can have far-reaching economic repercussions. Macroeconomic effects include inflationary pressures, recessions, slower long-term GDP growth, job losses, and fiscal deficits as governments allocate resources to emergency relief efforts and infrastructure restoration.

Droughts affect not only tangible economic indicators but also societal cohesion and geopolitical dynamics, often in ways that are difficult to quantify. By threatening food and water security – two cornerstones of social stability – droughts exacerbate social pressures and inequalities. Prolonged droughts significantly reduce human well-being, amplify income and spatial disparities, and may force communities to relocate. These dynamics can weaken political institutions, erode social trust, and reduce civic engagement, contributing to political instability. Although scientific evidence remains inconclusive regarding the exact magnitude of these effects, growing research suggests that they are significant and may persist over time. At the international level, droughts can exacerbate competition over transboundary water resources and may contribute exacerbating cross-border migration, potentially intensifying geopolitical tensions.

The impacts and costs of droughts are projected to intensify under climate change. Rising global temperatures are expected to increase the frequency, duration, and severity of droughts in many regions, exacerbating existing vulnerabilities (see Chapter 2). As extreme drought events become more common, agricultural losses are likely to rise, food price volatility may increase, and disruptions to energy production and industrial processes will become more severe. The socioeconomic consequences will also worsen, with heightened risks of displacement, inequality, and political instability. These escalating effects underscore the urgency of integrating drought resilience into climate adaptation strategies, ensuring that policies account for the growing risks posed by climate change.

In this context, understanding and quantifying the environmental, social, and economic implications of droughts is crucial to shaping proactive and informed policy responses. Unlike rapid-onset disasters such as floods, droughts unfold slowly, presenting unique challenges for climate change mitigation and adaptation. Their extended duration and cascading effects can lead to complex, far-reaching consequences that are still not fully understood, especially when compared to the more immediate impacts of rapid-onset events. Therefore, enhancing the understanding of these impacts is essential. Such knowledge can guide the development of more targeted adaptation strategies, enabling policymakers to prioritise measures that reduce vulnerability and build long-lasting resilience (see Chapter 4). Furthermore, quantifying the economic and social impacts of droughts can inform the design of adaptation policies that allocate resources more equitably and efficiently. Finally, disseminating data on drought exposure and vulnerability can foster civic engagement, strengthen trust in institutions, and support collective efforts to address these challenges.

This chapter serves these objectives by bringing together evidence on the impacts of droughts on ecosystems (Section 3.2), the economy (Section 3.3), and society (Sections 3.3 and 3.4). Section 3.2 examines how drought-related variables, such as reduced soil moisture, lower precipitation, and increased heat stress, affect vegetation and animal biodiversity. Section 3.3 provides a deep dive into the economic costs of droughts by compiling reported losses and damages from past drought events, as documented in scientific and institutional literature. It also explores the role of key drought indicators on GDP, agricultural income, and the productivity of water-intensive sectors. Finally, Section 3.4 reviews recent literature on the societal impacts of drought-induced water scarcity, including its effects on social unrest, political stability, and international migration.

## 3.2. Impacts of droughts on ecosystems

Droughts are among the most severe environmental stressors, as they disrupt ecosystems by altering precipitation patterns, soil moisture, and surface or groundwater levels. These prolonged dry periods have far-reaching consequences and can severely affect vegetation, wildlife, and water quality. This section explores the main environmental impacts of droughts, examining how droughts reshape and disrupt the delicate balance of natural systems.

### *3.2.1. The impact of droughts on vegetation*

Droughts cause significant changes in both the lifecycle and morphology of plants. First, intense droughts can shorten the lifetime of several species by reducing their likelihood of survival during drought episodes. Second, droughts often result in a decrease in the overall size of plants. Numerous studies suggest that the effects of water scarcity on plant size are non-linear and vary considerably across species. Furthermore, as water becomes scarcer, plants tend to reallocate biomass from their stems and leaves to their roots to enhance water absorption (Eziz et al., 2017[1]).[1]

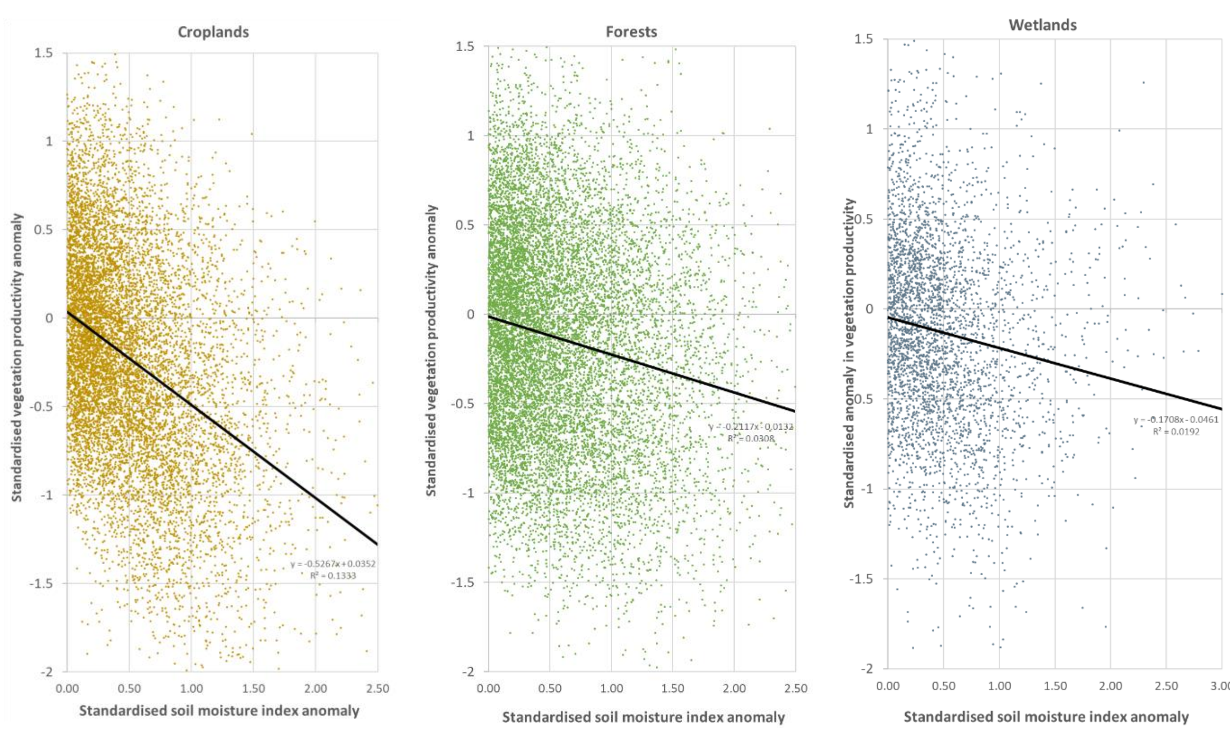
The longer droughts last, the more severe their impact on vegetation. Both plant biomass (i.e. their overall size) and survival rates decrease non-linearly as droughts become longer. A meta-study by Garssen, Verhoeven and Soons (2014[2]) shows that drought episodes exceeding 30 days cause significant reductions in plant size. In most of the studies they examine, at least 50% of plant biomass is lost during droughts that last between 40 and 80 days. Moreover, drought episodes longer than one month can substantially reduce the probability of plant survival, especially if drought intensity is high. For example, a plant exposed to a mild 30-day drought has 75% of the survival probability of a plant not exposed to drought conditions. Under severe drought conditions, this figure falls to 32%.

Herbaceous plants are much more sensitive to droughts than woody plants. Wilschut et al. (2022[3])[2] examined the above-ground biomass (i.e. the biomass of stems and leaves) of plants exposed to droughts and those that were not. They found that the above-ground biomass of exposed plants falls short of those that were not exposed, and that reduced precipitation increases that difference. Most importantly, the study indicates that interaction effects between temperature and drought conditions are substantially stronger in herbaceous plants than in woody plants. The finding that woody plants are less vulnerable to droughts is empirically consistent with the findings of the research conducted by the OECD in the context of this report, presented below.

Soil moisture declines (see Chapter 2) may reduce plant health and biomass across all types of ecosystems. New econometric analyses conducted by the OECD for the purpose of this report show that, while croplands are most severely affected by low soil moisture, forests and wetlands are also significantly impacted.[3] This finding aligns with existing literature suggesting that woody plants are less vulnerable to droughts than herbaceous plants (Wilschut et al., 2022[3]). Figure 3.1 illustrates the correlation between soil moisture anomalies and vegetation productivity across croplands, forests, and wetlands.

The effects of droughts on vegetation can vary from year to year and may persist over time. Drought impacts on vegetation productivity were found to be stronger during the period 2006-2010 and weaker in the years that followed. Vegetation levels can be influenced by soil moisture shocks that occurred up to two years prior. This pattern seems to hold especially in forests and wetlands, where vegetation cycles are long and less affected by human activity. While the delayed effects of past-year soil moisture losses are significantly weaker – approximately ten times smaller – than same-year effects, this gap narrows in forests and wetlands. In these ecosystems, the ratio of same-year to past-year effects drops to 6 in forests and 4 in wetlands, indicating greater vulnerability to persistent drought impacts. Unlike cultivated plants, which are typically harvested within a one-year period, vegetation in forests and wetlands affected by drought is more likely to remain in place and continue exhibiting stress. Soil moisture shocks that occurred two or more years prior are not found to have a significant effect on current vegetation productivity.

## Figure 3.1. Soil moisture anomalies and their impacts on vegetation productivity

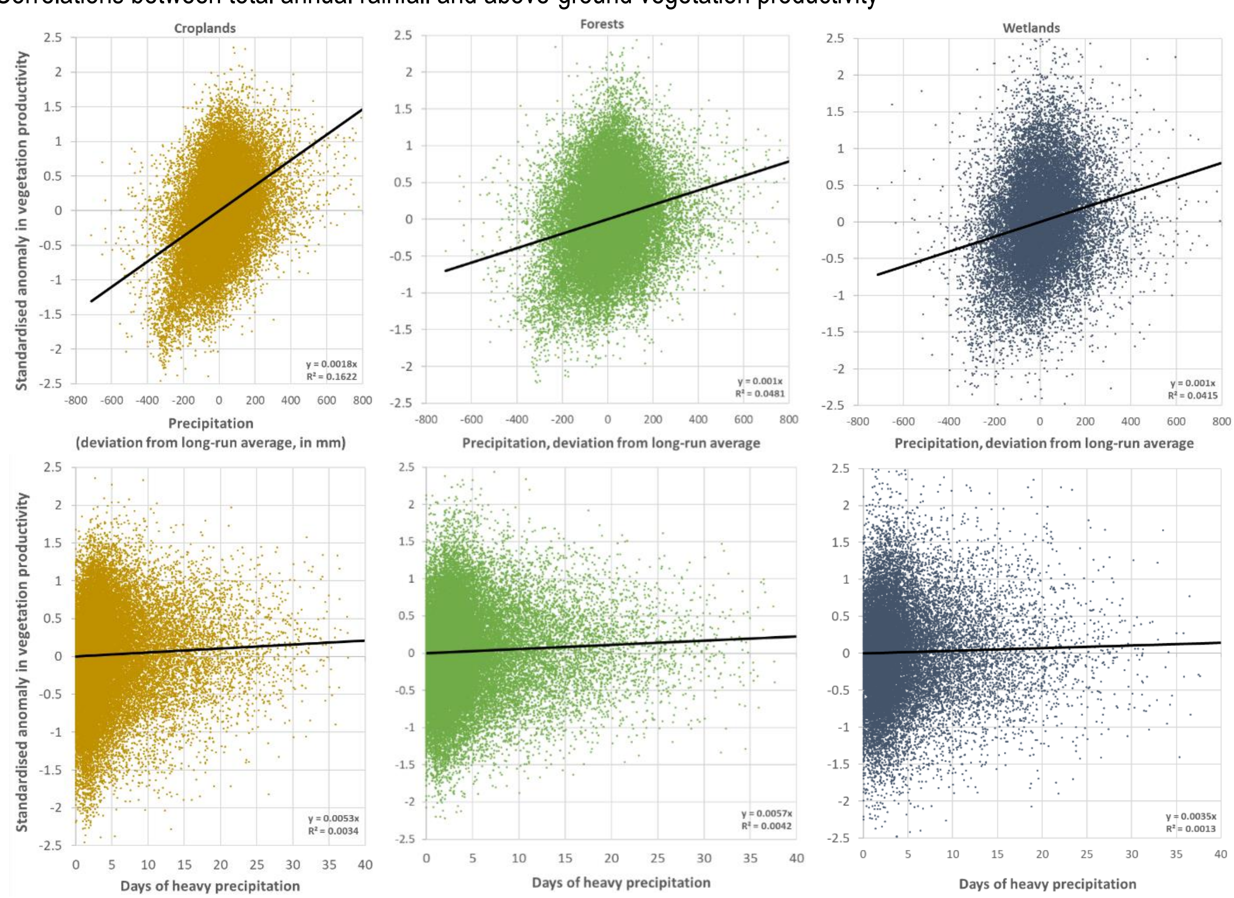



Notes: Each dot in the three panels above represents the standardised biomass productivity (vertical axis) and the standardised negative shock in soil moisture (horizontal axis) in a European NUTS-3 region during the same year. The fitted lines illustrate the estimated statistical relationship between biomass productivity and soil moisture within the same year. For technical details, the reader is referred to Tikoudis, Gabriel and Oueslati (2025[4]).
Source: Author's own, based on data from EEA (2024[5]).

In addition to soil moisture, precipitation and its variability substantially affect croplands, influencing crop growth, yield stability, and the timing of planting and harvesting (Figure 3.2). They also exacerbate drought stress when rainfall patterns become erratic.[4] However, the effect of additional rainfall varies by region: it is much stronger in areas that receive insufficient rainfall, weaker in relatively wet regions, and negative in areas with high precipitation. The type of cultivated crops and their water requirements also play a key role. These findings align with several studies detecting non-linear effects of precipitation on crop volumes, particularly Damania, Desbureaux and Zaveri (2020[6]). Lastly, rainfall variability may be more important than total rainfall, as heavy precipitation events have strong negative impacts on both forest and cropland vegetation. In fact, ten days of heavy precipitation can be as damaging as a substantial reduction in soil moisture.

## Figure 3.2. The relationship between precipitation and vegetation productivity

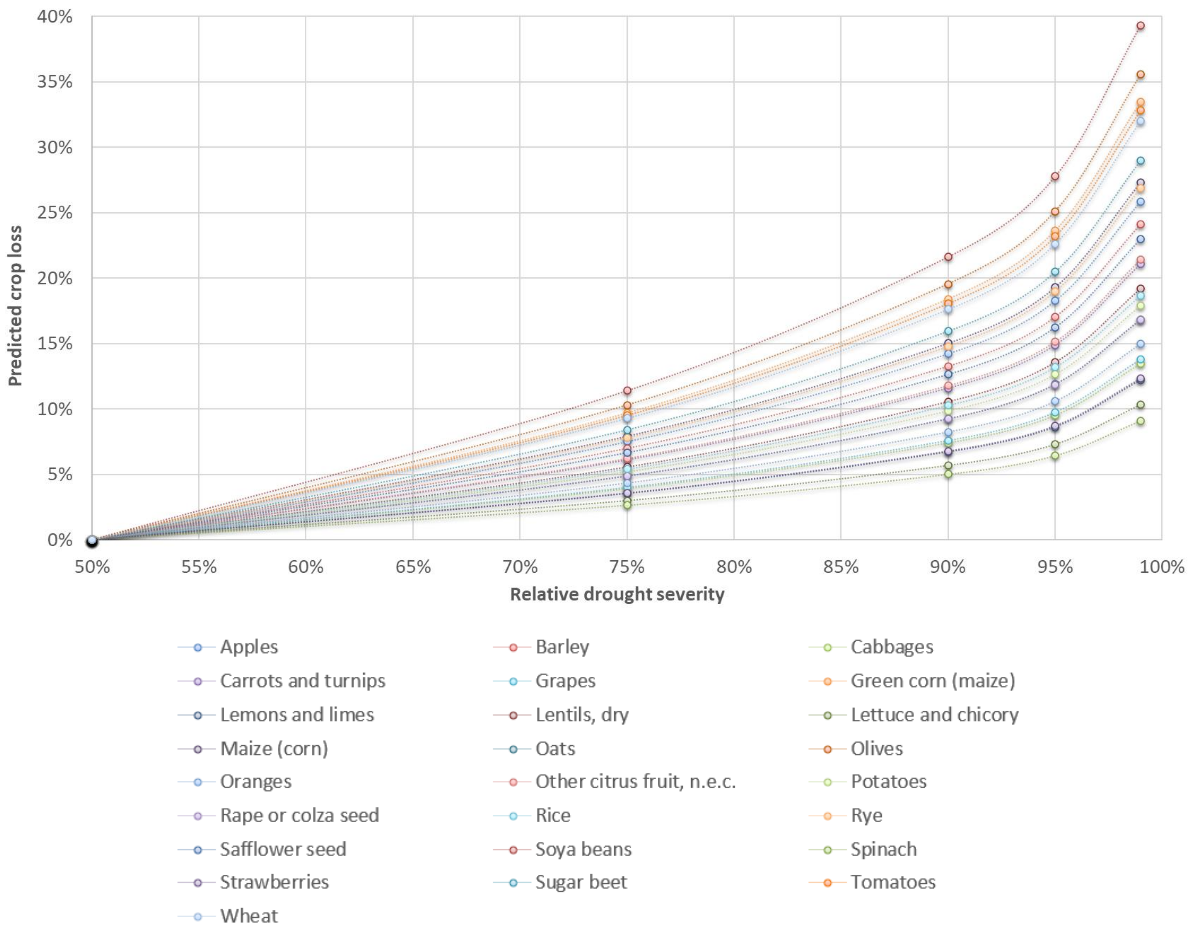
Correlations between total annual rainfall and above-ground vegetation productivity




Notes: The upper panels show the correlation between vegetation productivity anomalies and total precipitation. The lower panels illustrate the correlation with heavy precipitation days. The correlation between vegetation productivity and precipitation is stronger in croplands compared to forests and wetlands. Extreme precipitation events are excluded from the figure, as their correlation patterns are similar to those observed for heavy precipitation. For technical details, the reader is referred to Tikoudis, Gabriel and Oueslati (2025[4]).
Source: Author's own, based on data from EEA (2024[5]).

The impacts of droughts on crops are worse if combined with heat stress. For example, under extremely dry conditions, an additional degree of temperature may decrease yields in maize and wheat by more than 9% (Matiu, Ankerst and Menzel, 2017[7]). Heat stress, which often accompanies droughts, has a region-specific effect on crops, forests and wetlands. In general, croplands in North Europe are found to be more vulnerable to the exposure in temperatures over 32 °C, than those in South Europe, reflecting systematic differences in the cultivated species and their heat resilience. Severe heat stress has a detrimental effect in the croplands and wetland vegetation of all regions, as well as in the forest vegetation of most of the regions.

## Figure 3.3. Estimated crop losses due to soil moisture anomalies




Notes: A relative drought severity of 50% indicates average conditions; 75% corresponds to one of the 25% driest years; 90% to one of the 10% driest years; 95% to one of the 5% driest years; and 99% to one of the 1% driest years. The full set of results are presented in Tikoudis, Gabriel and Oueslati (2025[4]). This analysis is based on crop productivity data from the Food and Agriculture Organization (FAO, 2024[8]) covering the period 1961-2022, combined with econometric estimates by the OECD using data from the European Environment Agency (EEA, 2024[5]).
Source: Author's own, based on OECD analysis reported in Tikoudis, Gabriel and Oueslati (2025[4]).

The expected impact of droughts on crops is substantial, with impacts on wheat, rice and maize being among the most studied. Zhang et al. (2018[9]) collect estimates from 55 and 60 primary studies on rice and wheat, respectively, which examine the effect of droughts on the above-ground biomass, height and yield of rice and wheat respectively. They find that the average loss of biomass due to a drought episode is 25% in wheat and 27.5% in rice, and that the corresponding numbers for yield loss are 25.2% and 25.4%. Controlling for drought intensity, Zhang et al. (2018[9]) show that biomass losses in both crops lie below 13% for mild drought episodes and above 34% for severe episodes. In line with the literature, OECD estimates suggest that droughts may substantially affect the productivity of almost all crops (Figure 3.3). Compared to the year in which soil moisture is at its mean level, producing in a year among the 25% driest implies an average quantity loss of 6.3%. Being among the 10%, 5% and 1% driest years gradually increases that loss to 12%, 15.5% and 21.9% respectively, with direct and profound implications for crop production and food security.

The impact of droughts on crops is largely uncertain and heterogeneous. In the 10% driest seasons, expected losses may range from 5% to 22% depending on the crop. However, the most conservative econometric estimates suggest losses between 3.6% and 15.4%, and the strongest estimates losses in the range 6.4-27.8%. The largest source of uncertainty is the volume of the drought (moisture shock). Moving from the 25% to 5% driest conditions increases the expected losses of the various crops from 2.6-11.4% (former case) to 9.1-39.3% (latter case). The far-reaching implications of droughts on agricultural sector are examined in Section 3.3.1.

To the extent that wood production resembles agriculture, the analysis conducted here for croplands could be replicated to estimate the impact of a drought episode on wood production. However, only a small part of the above ground biomass present in forests and wetlands is commercial. Rather, its primary functions relate to ecosystem service provision and carbon storage. In that sense, the analysis presented in this section could utilise primary data measuring forest and wetland biomass (e.g. per unit of area covered by forests and wetlands), as well as their variance across time. This could enable the conversion of the estimated effects, expressed in terms of standard deviations, to percentages of biomass lost due to a drought episode.

### *3.2.2. The impact of droughts on fauna*

Droughts affect animal communities, with impacts varying widely across ecosystems and species. Reduced access to surface water directly influences reproduction rates and survival probabilities, while indirect effects typically cascade through the food chain. Bottom-up impacts begin with disruptions to vegetation (see Section 3.2.1) and extend to herbivores, omnivores, and carnivores. Additionally, drought-induced declines in water availability and food sources can lead to increased competition, habitat loss, and higher mortality rates, further destabilising ecosystems. The full consequences of a drought episode on fauna may take years to materialise, as the progression of these effects unfolds over time.

A species' sensitivity to droughts appears closely linked to its dependence on water abundance. Aquatic ecosystems are particularly vulnerable to drought conditions, with substantial declines observed in fish stocks and other aquatic fauna during prolonged dry periods. In contrast, terrestrial and arboreal species tend to exhibit greater resilience, though they remain affected by the long-term impacts of sustained droughts. For example, Bodmer et al. (2018[10]) investigated the effects of the 2010 drought on animal populations in the Amazon, focusing on terrestrial, arboreal, and aquatic species in flooded forests. Their study revealed significant declines in aquatic fauna, with fish stocks decreasing by 12% and pink river dolphins by 45%. In contrast, terrestrial and arboreal species showed no significant population declines during this period. Aquatic populations began recovering only after two years of intensive flooding, illustrating the prolonged effects of drought on water-dependent species and ecosystems.

Differences in feeding behaviours significantly influence animal sensitivity to droughts, even among closely related species. For instance, white rhinos are believed to be more vulnerable to droughts than black rhinos (Ferreira, le Roex and Greaver, 2019[11]). The key difference lies in their feeding habits: white rhinos are grazers, feeding primarily on grass and ground-level vegetation, which becomes scarce during droughts. In contrast, black rhinos are browsers, consuming leaves, shoots, and twigs from shrubs and trees, often above ground level. As a result, browsing herbivore species are better adapted to cope with drought-induced food scarcity.

Despite these figures, there remain substantial knowledge gaps on the extent to which a drought episode may affect different species. Prugh et al. (2018[12]) studied how California’s severe drought (2012–2015) affected 423 species, including arthropods, birds, reptiles, and mammals. They found that the drought is highly likely to have reduced the population of 25% of the species they study, and to have reduced the population of 4% of these species. The population changes observed in the remaining 71% of the species were not large enough to be attributed to the drought episode. Overall, there continues to be a lack of studies observing the population dynamics of multiple species before and after a drought, while controlling for factors that may also be subject to change during a drought episode. Such studies may provide important insights on the fragility of animal species under drought episodes of different duration and intensity.

### *3.2.3. The impact of drought on water quality and land degradation*

#### *Impacts on water quality*

By reducing freshwater quantity in water bodies, droughts affect the dilution capacity of aquatic environments, facilitating the concentration of pollutants, nutrients, pathogens, salt, and heavy metals in lakes, rivers, and other freshwater bodies (Mosley, 2015[13]). For example, during the 2018 drought in Europe, the concentration of pharmaceutical residues in the Rhine and Meuse rivers increased by up to 30% (Wolff and van Vliet, 2021[14]). Similarly, the 2005-2006 drought in Salamanca (Spain) led to a significant increase in groundwater pollution levels, with a fourfold increase in water samples exceeding drinking water standards for arsenic levels (García-Prieto et al., 2012[15]). Similarly, in Germany and Poland, consecutive droughts exacerbated the impacts of industrial pollution in the Oder River, leading to severe ecological collapse in 2022 (JRC, 2023[16]).

In turn, high levels of water contamination reduce the amount of freshwater available for safe use. This was observed for example in Denmark, where high pollutant and nutrient concentrations have led to the closure of 30% of existing wells (EEA, 2017[17]). Prolonged droughts can also exacerbate salinisation in coastal aquifers, posing risks to human health, aquatic ecosystems, and the reliability of water supplies. For example, high salinity levels in the Colorado River have reduced agricultural yield and damaged infrastructure, causing USD 348 million per year in damages (Miller et al., 2024[18]). Globally, water contamination is projected to intensify water scarcity by 2050, complicating efforts to ensure water security in drought-affected regions (see Chapter 4).

Finally, drought-induced declines in freshwater levels, coupled with rising average and extreme temperatures, are also warming rivers and groundwater reserves. Reduced flow speeds also contribute to increasing river temperatures (Mosley, 2015[13]). Sixteen out of twenty studies examining river temperature changes during droughts in the United Kingdom report increases in maximum and/or average monthly water temperatures – which have risen by as much as 12°C during low-flow periods compared to normal years (White et al., 2023[19]).

#### *Impacts on land degradation*

By reducing soil moisture and affecting biodiversity and vegetation cover, drought plays a critical role in accelerating land degradation. Prolonged drought periods leave soils exposed to wind and water erosion, leading to the depletion of organic matter and essential nutrients. Between 2015 and 2019, global land degradation increased by 4%; currently, it affects more than 15% of the world's land area, with direct impacts on 1.3. billion people (UNCCD, n.d.[20]). These processes undermine soil fertility, reduce water retention capacity, and limit the ability of land to sustain vegetation. Consequently, they exacerbate global water and food security challenges, compounding the issues discussed in Section 3.2.1.

Through these processes, drought can also facilitate desertification. Desertification arises from the combined effects of climatic factors, such as prolonged drought, and unsustainable human activities, including overgrazing, deforestation, and unsustainable land management practices. It can lead to irreversible declines in land productivity, with significant impacts on ecosystems and livelihoods. It accelerates biodiversity loss, intensifies water scarcity, and contributes to climate change by diminishing the land's ability to sequester carbon.

## 3.3. The economic impacts of droughts

Droughts impose a series of quantifiable costs on the economic system. Direct economic effects are mostly pronounced in the agricultural sector. The analysis in Section 3.2.1 indicated that precipitation and soil moisture deficits have a substantial effect on vegetation productivity. This section provides insights on how losses of plant biomass translate into reduced crop volume and agricultural income (Section 3.3.1). It also investigates the impacts of droughts on two other water-intensive sectors of the economy: fluvial transport and power generation (Section 3.3.2).

Several questions arise from observing the economic impacts from droughts. A central question is whether these impacts have a significant upward trend, or whether they remain constant or decrease, indicating effective adaptation to climate change. Another question is whether an upward trend in economic impacts is driven by a growing frequency, a growing duration or a growing intensity of drought episodes. This section provides new relevant insights by exploring the evolution of drought-related losses and damages worldwide and in the United States (US) (Section 3.3.3). The section also explores the extent to which droughts have a substantial impact on GDP (Section 3.3.4).

### *3.3.1. Impacts on the agricultural sector*

A large body of literature suggests that the impact of reduced precipitation on crop volume is considerable (Table 3.1). Qin et al. (2023[21]) review more than 1 800 simulations from 68 modelling studies on the impact of climatic conditions on the volume of rice, maize and wheat production. Their meta-estimate from these studies is that a positive precipitation shock of 10% increases crop volume by more than 4%. Challinor et al. (2014[22]), using a similar number of primary studies and estimates, find a slighlty larger effect (above 5%). Wilcox and Makowski (2014[23]) find that a 10% increase in precipitation has an even larger effect on crop volume (7.0 - 7.5%), but their meta-analysis focuses only on wheat. The three meta-studies control for the corresponding effects of temperature. Both Wilcox and Makowski (2014[23]) and Challinor et al. (2014[22]) agree that the effect of an additional degree Celsius in average termperature is negative (-3.3% and -5.0% respectively). Another study by Troy, Kipgen and Pal (2015[24]) offers richer drought-relevant controls, such as dry-spells, precipitation intensity and maximum rainfall, but reports its effects in standard deviations.

Meta-studies agree that adaptation measures in agriculture are effective in mitigating droughts impacts. However, they widely diverge regarding the volume of this contribution: Challinor et al. (2014[22]) find that common adaptation strategies increase yields by up to 15%, while Qin et al. (2023[21]) find this effect to be much larger (64%).

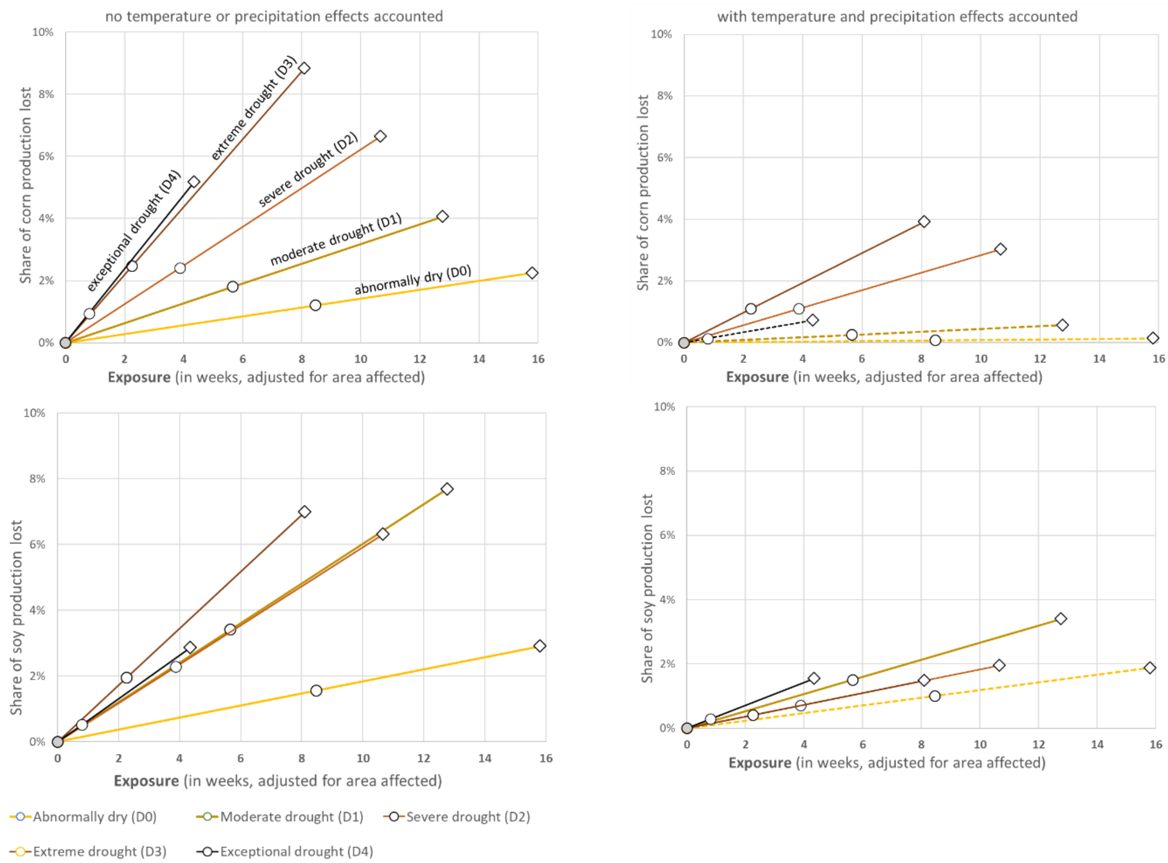
Studies on the impact of drought-specific indicators on crop volumes are remarkably scarce. Kuwayama et al. (2019[25]) is one of the few empirical studies simultaneously accounting for the presence of a drought episode, its intensity and duration alongside temperature and precipitation effects. This allows for distinguishing between the effect of U.S. Drought Monitor index (which contemplates soil moisture, daily streamflow and vegetation health) and the additional effects of temperature and precipitation. The U.S. Drought Monitor is reported in five levels, D0-D4, with D0 describing a mild drought and D4 an exceptional drought (Figure 3.4).

## Table 3.1. Studies on droughts, precipitation shocks and crops

| Study | Information | Controls | Main findings |
|---|---|---|---|
| Qin et al. (2023[21]) | **Inputs:** Meta-analysis of 68 published modelling studies, each reporting multiple results under various climate scenarios, giving rise to 1842 simulations<br>**Crops:** rice, maize and wheat | Precipitation | An increase of 1% in *average precipitation* is associated with an increase of 0.43% in crop yield (elasticity = 0.43) |
| | | Drought-relevant controls | An increase of 1% in *maximum temperature* is associated with an increase of 4.21% in crop yield (elasticity = 4.21). Effect of minimum temperature is insignificant |
| | | Other controls | Adaptation measures increase crop volume by 64% |
| Wilcox and Makowski (2014[23]) | **Inputs:** Meta-analysis of 90 simulation-based studies<br>**Crops:** wheat | Precipitation | An increase of 1% in total precipitation is associated with 0.70-0.75% increase in crop yield. A decrease of 1% in total precipitation is associated with a decrease of up to 0.90% in crop yield |
| | | Temperature | An increase of 1 °C in *average temperature* is associated with a decrease of crop volume by 3.3% |
| | | Other controls | An increase of atmospheric concentration of $CO_2$ by 100 parts per million (ppm) is associated with an average yield increase 8%. Sowing adaptation increases yield by up to 6% |
| Challinor et al. (2014[22]) | **Inputs:** Meta-analysis of 1700 published simulation-based estimates<br>**Crops:** wheat, rice and maize | Precipitation | An increase of average rainfall by 1% is associated with an increase in the crop volume by 0.53%. A 1°C increase of average temperature decreases crop volume by 4.9%. An increase of atmospheric concentration of $CO_2$ by 100 ppm increases crop volume by 6%. Adaptations (change in variety, sowing dates, irrigation, residue management) increase simulated yields by 7-15% |
| Troy, Kipgen and Pal (2015[24]) | **Inputs:** Crop yield data from the United States Department of Agriculture<br>**Spatial coverage:** United States<br>**Temporal coverage:** 1948-2020<br>**Crops:** corn, soy, wheat, rice | Rainfall: Dry-spells[a], precipitation intensity[b], max 5-day precipitation[c], average precipitation | Substantial deviation-to-deviation[f] relations are visualised for: dry-spells on corn, soy and spring wheat ($\approx -1.0$), reduction in total precipitation on corn and soy ($< -1.0$), max 5-day precipitation on corn and soy (between $0$ and $+1.0$). Soil moisture and drought-specific indexes are not considered |
| | | Temperature: minimum, maximum, average, heat stress[d], heatwaves[e] | Substantial deviation-to-deviation[f] are visualised for heatwaves and heat stress on corn and soy (between $-1$ and $-2$) |
| Kuwayama et al. (2019[25]) | Empirical analysis of the effect of droughts on farm income.<br>**Inputs:** U.S. Drought Monitor Index<br>**Spatial coverage:** United States (3 080 counties)<br>**Temporal coverage:** 2001-2013<br>**Crops:** corn, soy | Drought-specific: U.S. Drought Monitor Index | Point elasticities of production with respect to exposure to drought conditions vary in the range $(-0.012, -0.002)$, but reduce to the range $(-0.002, 0.000)$ when rainfall and average precipitation conditions are considered. Reduced rainfall by one standard deviation reduces corn and soy production by $5.4\%$ and $15.4\%$ respectively[g]. Irrigation drastically reduces precipitation impacts on soy production, and renders precipitation and drought-indexes statistically insignificant on corn production |
| | | Rainfall: Precipitation | |
| | | Temperature: days of moderate (10-30 °C) and extreme heat (30+ °C) | |

Notes: [a]Dry-spells: maximum number of days without rain; [b]Precipitation intensity: average precipitation in days with rain; [c]Maximum rainfall in a 5-day period; [d]Heat stress: total number of days with temperature above 25 °C; [e]Heatwaves: number of consecutive days with temperature at least 5 °C above the mean climatology; [f]Deviation-to-deviation estimates refer to the effect of one standard deviation in the value of $x$, on the value of variable $y$ (measured in standard deviations); [g]Effect calculated using the estimates, sample means and standard deviations reported in Kuwayama et al. (2019[25]).
Source: Author's own, based on Qin et al. (2023[21]), Wilcox and Makowski (2014[23]), Challinor et al. (2014[22]), Troy, Kipgen and Pal (2015[24]), Kuwayama et al. (2019[25]).

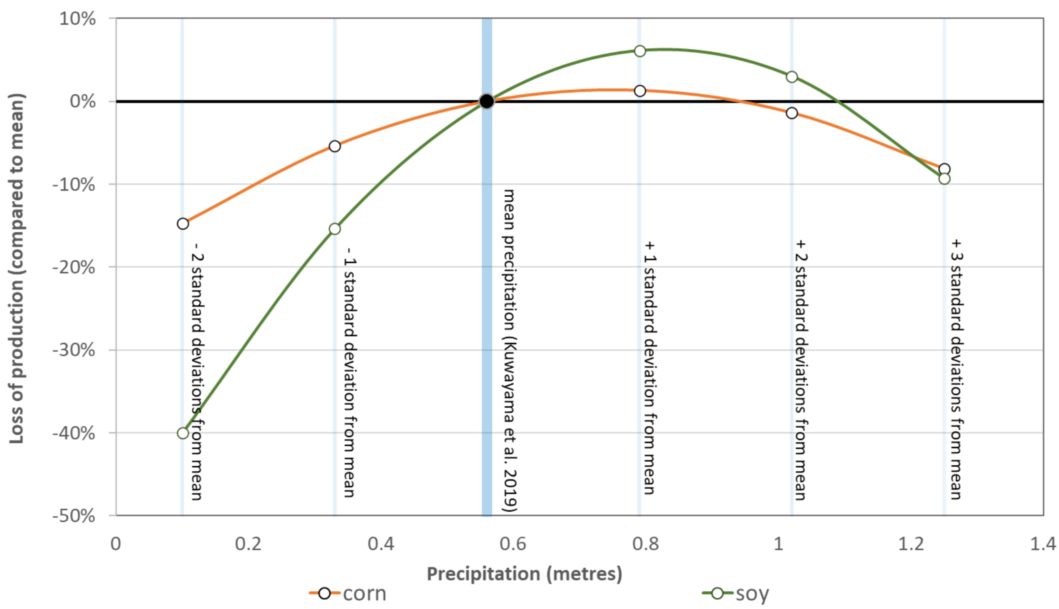
## Figure 3.4. Agricultural production loss from drought conditions in the United States




Notes: Losses estimated in Kuwayama et al. (2019[25]) for soy and corn. All graphs use estimates from dryland US counties. Upper and lower panels display, respectively, effects for corn and soy production. Left panels display effects based on econometric models that do *not* control for temperature and precipitation. Right panels show estimates for the effect of drought-characterising episodes from models that control for temperature and precipitation. Circles indicate the mean annual exposure of US counties to each drought category (D0, D1, D2, D3, D4), adjusted for the percentage of cropland exposed to drought. Diamonds indicate exposure levels one standard deviation away from the mean. Dashed lines indicate that the p-value of the background estimated effect exceeds 10% (insignificant estimate). The respective impacts of drought exposure on agricultural production in irrigated counties are insignificant for corn cultivations and substantially smaller than those displayed in the lower panels for soy. The U.S. Drought Monitor categories include abnormally dry (D0), moderate (D1), severe (D2), extreme (D3) and exceptional (D4) drought. For technical details, the reader is referred to Tikoudis, Gabriel and Oueslati (2025[4]).
Source: Author's own, based on the estimates and summary statistics reported in Tables 2, 3, and 4 of Kuwayama et al. (2019[25]).

Soil moisture shortages have a strongly negative impact on agricultural production. In dryland areas of the United States, drought conditions have reduced corn and soy production by 2.2-2.6% compared to normal years.[5] If these drought conditions worsened significantly, these losses could increase to 6.9-10.2%. Under a broader definition including precipitation and temperature shocks, the historical cost of droughts increases to 9-10% of production, and the future cost under substantially worsened conditions reaches 27% of production.

**Figure 3.5. Agricultural production loss from precipitation shocks**




Note: Losses estimated in Kuwayama et al. (2019[25]) for soy and corn. The graph is based on estimates of the effect of precipitation on agricultural production in dryland US counties. The estimates used to produce the graphs originate from models that control for exposure to drought conditions. Crop-maximising precipitation levels are comparable to those reported in other studies, e.g. 0.64 metres for corn and 0.69 metres for soy reported in Schlenker and Roberts (2009[26]). For technical details, the reader is referred to Tikoudis, Gabriel and Oueslati (2025[4]).
Source: Author's own, based on the estimates and summary statistics reported in Tables 2, 3 and 4 of Kuwayama et al. (2019[25]).

Positive precipitation shocks in one region cannot make up for the production loss in regions experiencing decreased precipitation (Figure 3.5). A considerable increase in precipitation is predicted to increase corn crop volume by 1.4%. A decrease of the same magnitude in precipitation is predicted to reduce corn crop volume by 5.4%. In soy, the difference is even larger: increased precipitation increases crop volume by 6.1%, while decreased precipitation decreases precipitation volume by 15.3%. Larger shocks can also generate larger asymmetries. For example, a very large increase in rainfall may increase soy crop volume by 3%, while a severe drop in rainfall can eliminate 40% of it. Consequently, the anomalies that droughts introduce to the hydrological cycle can substantially lower agricultural production. The above findings suggest that this may hold even if the water scarcity introduced during a drought episode is later offset by a period of excessive rainfall.

In areas where irrigation systems are widely available, the negative effects of droughts are substantially smaller. Droughts and precipitation shocks do not seem to significantly reduce corn production. Irrigation does not seem eliminate the negative impact of soil moisture and rainfall deficits in soy production. However, the reported effects of these deficits are substantially smaller. This is a strong indication that irrigation technologies can be particularly effective when it comes to the adaptation of the agricultural sector to climate change. The potential of irrigation and other adaptation measures is examined in Chapter 4 of this report.

### *3.3.2. Beyond agriculture: impacts of droughts on other economic sectors*

While agriculture is often the most visible sector affected by droughts, drought impacts extend far beyond farming systems, disrupting industries that rely on water for production, cooling, or transportation. This section explores these broader economic consequences, with a particular focus on the observed and projected impacts of drought on energy systems and fluvial transport.

### Impacts on energy production

Droughts have been shown to cause significant negative impacts on hydropower production. They reduce the surface water in lakes, rivers and other bodies that supply hydroelectric plants with water. Water is required to set turbines in motion and to cool down the steam. Declines in its availability during droughts can force these plants to operate at lower capacities or shut down temporarily. Economic repercussions may include temporary shocks in energy prices, especially in regions that are heavily dependent on hydroelectric power. Consequently, this may have environmental repercussions, as the excess energy demand may be met with electricity produced by fossil fuels. In the long term, repeated droughts may necessitate investments in alternative energy sources or improved water management strategies.

Observed hydrological drought episodes had notable impacts on hydropower generation. The severe drought in California (2012-2016) lowered water levels in major reservoirs, leading to a 48% decrease in hydroelectric power generation compared to the 2011-2020 average (U.S. Energy Information Administration, 2024[27]; U.S. Energy Information Administration, 2022[28]). Consequently, California had to rely more on natural gas, which implied increased electricity costs and $CO_2$ emissions. Similarly, Eyer and Wichman (2018[29]) find that an increase of the Palmer Drought Severity Index (PDSI) value by one standard deviation[6] is predicted to cause a 27% decrease in the electricity generated by hydroelectric stations. The authors estimate the monthly social cost for each plant that experiences a one-standard deviation decrease in water availability to be $USD_{2015}$ 330 000. Similar impacts were observed during the 2002-2003 drought in the Nordic countries, which lowered water inflows to hydropower reservoirs, causing a significant decline in hydropower production. Furthermore, Rodriguez and Madrigal (2014[30]) mention cases of water-related disruptions in the operations of hydroelectric power stations in North America, South Africa, India and Australia, suggesting that more than 50% of the world's energy companies faced water-related business impacts.[7]

By impacting hydropower production, droughts threaten electricity affordability and decarbonation strategies. Gleick (2017[31]) estimates the direct economic cost on electricity users at $USD_{2016}$ 2.45 billion and reports a 10% increase in the $CO_2$ generated by the state's power plants. Eriksson, del Valle and De La Fuente (2024[32]) estimate that the replacement of hydropower by fossil fuels due to drought-induced water scarcity in Latin America and the Caribbean increased fine particulate matter by more than 5%. Between 2014 and 2017, Brazil experienced one of its worst droughts, severely impacting the functioning of hydroelectric stations. Hydropower generation, which accounts for 64% of the electricity mix (Cuartas et al., 2022[33]), was drastically reduced. This led to energy rationing and increased use of more expensive and polluting thermal power plants. Beyond hydropower, nuclear power production can also be heavily affected by drought. Linnerud, Mideksa and Eskeland (2011[34]) estimate a 2% loss in the production capacity of nuclear power plants for each degree Celsius of warming during droughts and heatwaves.

### Impacts on fluvial transport

Fluvial transport is particularly sensitive to droughts. Severe droughts may lower water levels in rivers, hampering fluvial navigation in different ways. Lower water levels force boats to dock far from riverbanks, making passenger mobility and logistic operations more difficult. Routes may be adjusted and navigation may slow down in order to reduce the risk of running aground. Such adjustments lead to delays and additional costs. The Mississippi river in North America, Amazon in South America, and Rhine in Europe are among the most drought-sensitive fluvial systems. This sensitivity is due to the substantial volume of commodity trade that takes place using their waters and the strategic position of several supply chain hubs along their shores. Europe relies on 40 000 kilometres of waterways to accommodate supply chains that may not be sufficiently elastic to the choice of transport mode. The waterways of the Mississippi river in the United States are used to transport more than 450 million tonnes, according to the United States Department of Transportation (2019[35]).

Drought-related water scarcity may substantially lower fluvial trade volumes, but the magnitude is region-specific. For example, the severe drought conditions that affected the Panama Canal in recent years have forced authorities to restrict ship transit and cargo volumes, causing a 49% reduction in monthly traffic between December 2021 and January 2024 (UNCTAD, 2024[36]). The European Drought Risk Atlas (Rossi et al., 2023[37]) estimates that droughts reduce the volume of expected trade by up to 2.5% in several European countries, and up to 5% in Poland and Croatia. The same report finds that during extreme events, including droughts of very high intensity, the losses increase up to 10% of the expected trade volume in Western Europe and can reach up to 40% in Central and Eastern Europe. The authors attribute this difference to the smaller basins available in rivers traversing these countries, a morphological difference that implies more bottlenecks and therefore larger parts of the network affected.

The estimated costs associated with fluvial transport disruptions are remarkable. In Europe, droughts lowered the water levels of the Rhine River in 2018 and 2022, disrupting the voluminous trade that takes in it. Ships were authorised to sail with cargo capacity below 25%, steeply increasing the cost of fluvial trade and causing ripple effects on industrial production and the supply chain. For instance, 30 consecutive days of water level below a critical threshold (0.78 metres) is estimated to reduce freight transport by 24% over two months (Kara, van Reeken-van Wee and Swart, 2023[38]). Ademmer, Jannsen and Meuchelböck (2023[39]) estimate that 30 days of inland waterway disruptions in Rhine decrease industrial production by 1%, which roughly corresponds to a reduction of 0.3% in German GDP, i.e. more than $USD_{2021}$ 15 billion. Therefore, it is possible that the 2018 and 2022 droughts may have had a substantially negative effect on German GDP, in particular due to their duration. The numbers are comparable to those presented for the United States. In the context of the ongoing 22-year mega-drought, disruptions in the fluvial transport system of Mississippi have been estimated to cause total losses and damages of USD 20 billion.[8]

### *3.3.3. Losses and damages*

While the sectoral impacts presented in the previous sections highlight the direct costs of droughts, they represent only a part of a broader picture. Figures presented in this section may encompass direct and indirect costs due to damages on income-generating entities (e.g. crops), human health (e.g. due to water scarcity), and losses of physical capital and land (e.g. buildings due to soil erosion). Losses and damages reflect wider quantified impacts that span various aspects of economic activity with profound welfare impacts, such as production, labour supply and physical asset values. Due to the strong links between capital stock, productivity, employment and income, losses and damages bear significant relevance for the overall economic performance of a country. However, drought-induced losses and damages should not be confused with macroeconomic effects, and in particular with the negative impact that a drought may have on the level and the growth rate of GDP. The latter effects are examined in detail in Section 3.3.4.

#### *Ad-hoc evidence and challenges in measuring and comparing drought costs*

Measuring, benchmarking, and comparing damages from droughts is a challenging task. Losses and damages measured as percentages of national GDP may simply reflect the size of a country's economy, rather than the extent of the losses. Damages expressed in direct monetary terms expressed at the national level or in a time-average manner may hide considerable impacts from events that were spatially limited or did not last for a long time. Moreover, historically aggregated or time-averaged costs in long periods may not fully reflect the toll of droughts. The European Commission reports a long-run annual cost that ranges between EUR 2 billion and EUR 9 billion (European Commission, n.d.[40]), a figure that translates to 0.014-0.062% of the European Union (EU)'s GDP.

Time-averaged costs *during drought-intense years* can provide a clearer picture of the economic shocks induced during an episode. For example, Wheaton et al. (2008[41]) report total economic costs of Canadian Dollar (CAD) 2.13 and 3.65 billion due to the drought that affected Canada in 2001 and 2002 respectively. These represent 0.19% and 0.31% of the Canadian GDP during those years. Ziolkowska (2016[42]) reports that the total economic cost of the drought episode of 2011 for Texas (United States) was USD 16.9 billion, or 1.26% of the state's GDP. Felbermayr and Gröschl (2014[43]) follow disaster events and measure their intensities using geophysical and meteorological information. They estimate that the droughts in Syria (1983) and Guatemala (1998) caused a GDP per capita loss of 0.16% and 0.27%, respectively. The same study reports a high-intensity drought (above the 95$^{th}$ percentile) is statistically associated with a GDP loss of 0.34%.

When expressed relative to GDP, drought costs may appear much larger in less advanced economies or countries of low population. For example, damages from drought episodes in the Caucasus and Central Asian countries, as reported by Duenwald et al. (2022[44]), all exceed 5% of GDP.

Expressing the costs relative to the surface of the affected area adds further precision to the estimates. The primary effects of droughts can be spatially concentrated in an area that is much smaller than the administrative unit in which total economic costs are measured. This is particularly true for regional episodes within large countries. For instance, the damages of 0.19-0.31% of Canadian GDP reported in Wheaton et al. (2008[41]) increase to 0.6-1.2% of the combined GDP of Alberta, Saskatchewan and Manitoba, i.e. the provinces that were mostly affected by the 2001-2002 droughts. Zooming in further in Saskatchewan, the damages climb to 1.6-2.6% of the province's GDP. Another example of how spatial aggregation can compress substantial local effects of droughts is the 2008 episode recorded in Spain. Martin-Ortega, González-Eguino and Markandya (2012[45]) report an economy-wide cost of EUR 1.61 billion, i.e. less than 0.1% of the country's GDP in 2008. However, almost all of the impacts were manifested around Barcelona, where the economic costs amounted to 0.5% of the regional GDP.

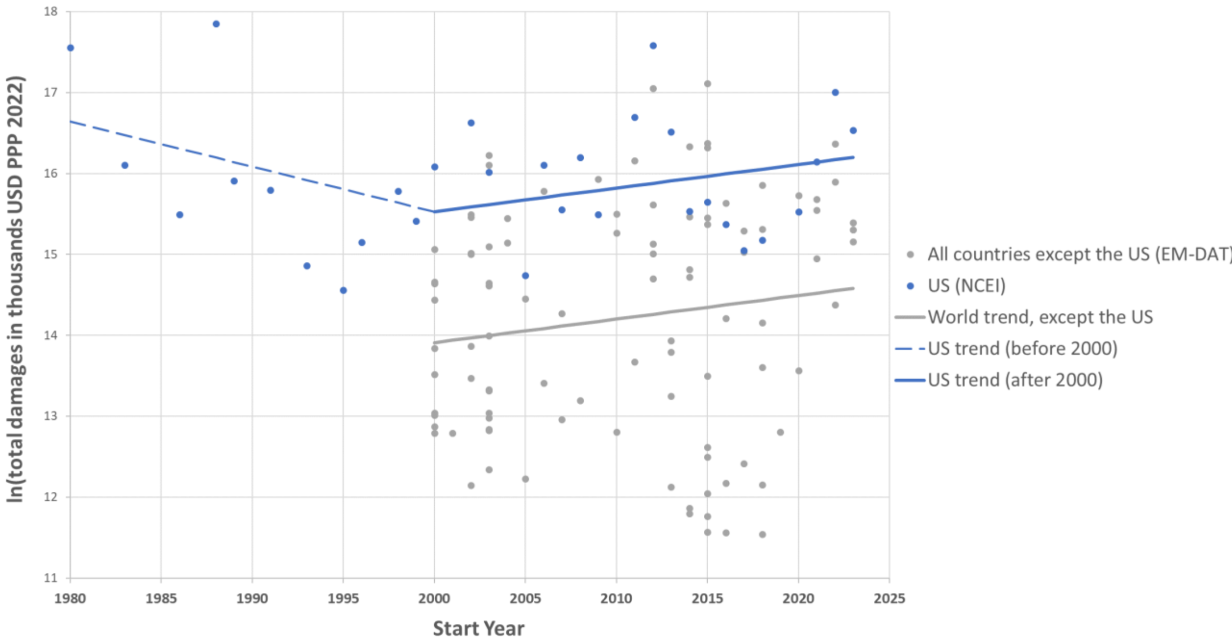
### *Systematic evidence*

The analysis that follows uses systematic information (datasets) on drought losses and damages to assess:

- if drought episodes become more costly with time
- if an upward trend in costs could be attributed to longer and more frequent episodes
- if an upward trend could be attributed to more intense episodes
- whether the recorded damage of the average drought episode in an OECD country differs significantly from that in a developing country.

The following findings were obtained with analysis conducted by the OECD for the purposes of this report. All technical details are available in Tikoudis, Gabriel and Oueslati (2025[4]).

## Figure 3.6. The economic costs of drought episodes




Explanatory notes: The overall damage levels reported in the International Disaster Database (EM-DAT) and the National Centers for Environmental Information (NCEI) datasets differ, as the latter dataset reports the aggregate damages observed in the entire United States, while the former dataset provides observations from systematically smaller administrative entities. This difference is captured by the distance between the grey and the blue line. The grey line designates the average cost of a drought episode, of any duration or affected area, anywhere in the world (excluding the United States). The blue line represents the expected aggregate cost of all episodes that took place in the United States within a year of the sampling period. For technical details, the reader is referred to Tikoudis, Gabriel and Oueslati (2025[4]).
Technical notes: Both US and global trends are statistically significant, confirming an increasing trend in losses and damages.
Source: Author's own.

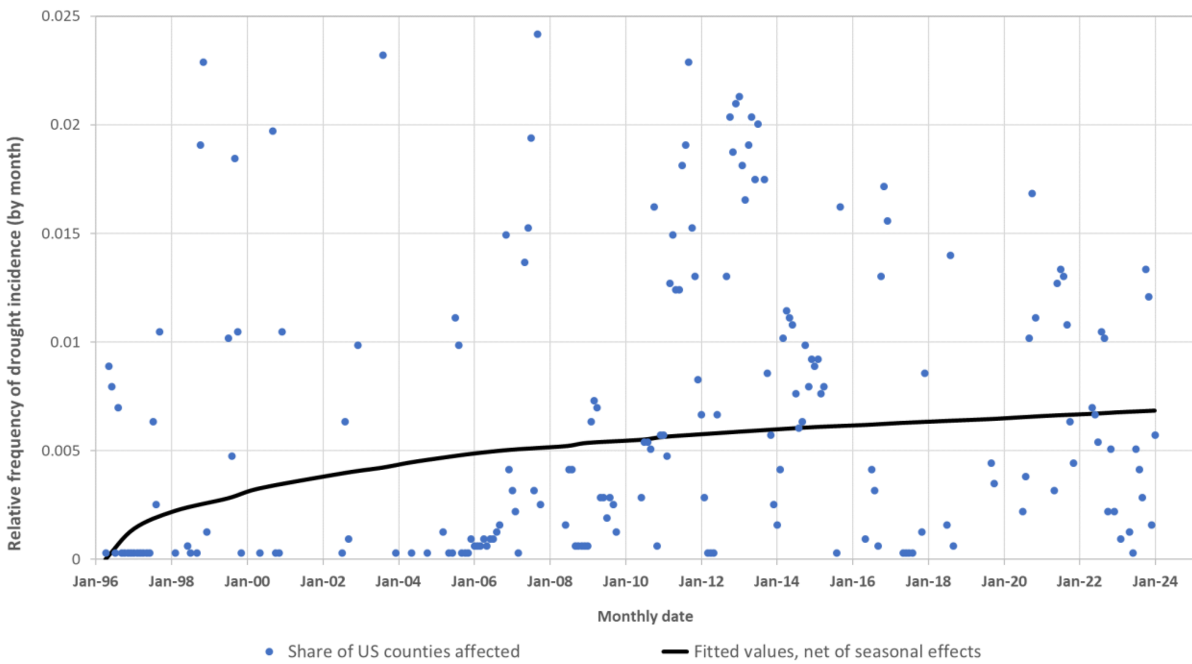
The economic cost of drought episodes has been increasing, at least since 2000, at an annual rate that exceeds 3% and could be as high as 7.5% (Figure 3.6). With the most conservative estimates, the average drought episode today costs at least twice what it did in 2000, and in 2035 it will cost a national economy almost 40% more than it does today. Overall, no significant differences are observed between OECD and non-OECD countries. The *level* of losses and damages from an episode occurring in an OECD country cannot be statistically differentiated from those occurring in a non-OECD country. Furthermore, there is no significant evidence that the *rate* at which droughts become more costly differs between OECD and non-OECD countries.

The upward trend is driven more by a longer duration, rather than an increasing intensity of drought episodes. The estimates indicate that the duration of droughts may have increased at an annual rate of 6%, implying that drought episodes are now four times longer than they were in 2000. Current data do not allow for systematic assessment of the degree to which drought intensity evolves.

At least in the US, there is limited evidence that droughts have become more intense. The incidence of droughts in US counties has substantially increased in the last 20 years. Today, it is much more likely that a US county would be facing a drought episode that causes losses and damages, than it was 30 years ago. Figure 3.7 displays the share of US counties that reported positive losses and damages due to a drought episode at any given month in the period 1996-2024. The increasing trend translates also to *longer episodes*, as counties are now more likely to report losses and damages for a larger number of consecutive months. On the other hand, the level of losses and damages reported by US counties during a month of a given episode do not have a clear trend (Figure 3.8). Instead, they had a decreasing trend between 2001 and 2017, before starting to increase again. This pattern could potentially reflect a simultaneous intensification of droughts and a proliferation of adaptation measures, and its complexity renders any forward projection speculative.

## Figure 3.7. The relative frequency of recorded losses and damages in the United States

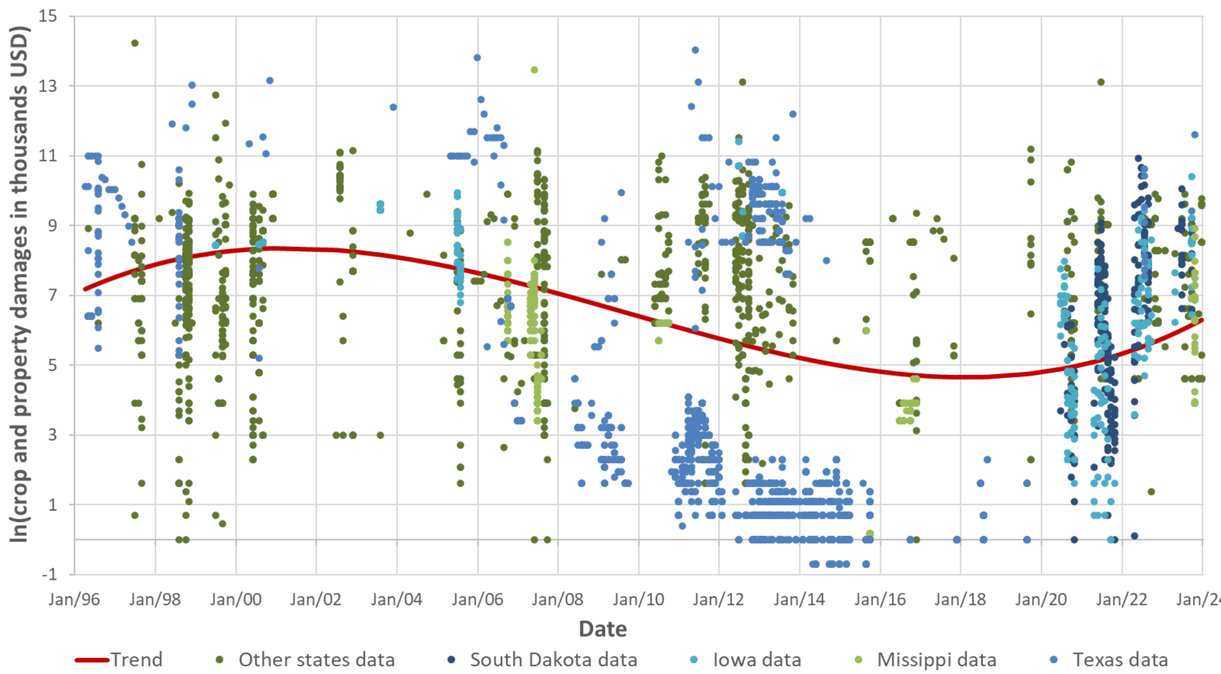
Share of US counties recording damages from a drought episode in the period 1996-2024, by month




Notes: Each dot represents a month of a given year in the period 1996-2024. The vertical axis reports the share of US counties ($S_{y,m}$) in which crop and property damages from droughts were positive in a given month ($m$) of a year ($y$), e.g. 0.01 indicates that 1% of US counties were affected. The fitted values originate from the model: $S_{y,m} = \alpha \ln(y) + \beta_s D_{m.s} + \beta_f D_{m.f} + \varepsilon_{y,m}$, where $D_{m.s}$ and $D_{m.f}$ are dummies that equal 1.0 if month $m$ is a summer and fall month, respectively, and zero otherwise. Seven outlier observations are included in the estimations but are excluded from the graph for reasons of legibility. Used data originate from the Storm Events Database of (NOAA, n.d.[46]). For technical details, the reader is referred to Tikoudis, Gabriel and Oueslati (2025[4]).
Source: Author's own.

**Figure 3.8. Trends in drought-related costs in the United States**

The cost-intensity of a given drought episode does not have a distinct trend




Notes: The analysis controls for seasonal effects, which are found to be particularly strong in the summer months, and unobserved factors that vary across states (state fixed effects). After controlling for seasonal and regional effects, the analysis suggests that the losses and damages from a drought episode do not have a distinct intertemporal trend. The average losses and damages per episode had a decreasing trend between 2001 and 2017, before starting increasing again. This pattern could potentially reflect a simultaneous intensification of droughts and a proliferation of adaptation measures, and it is complexity renders any forward projection speculative. For technical details, the reader is referred to Tikoudis, Gabriel and Oueslati (2025[4]).
Source: Author's own.

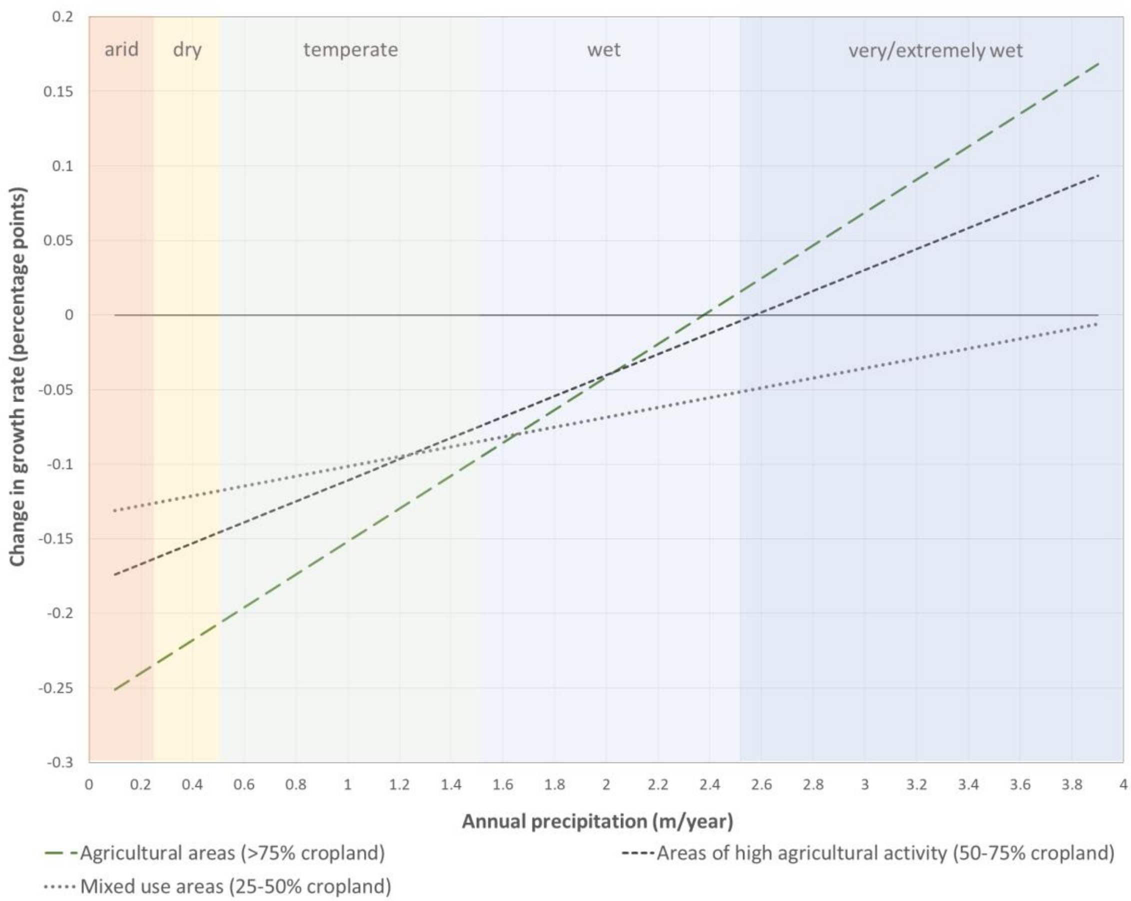
### *3.3.4. Macroeconomic effects*

There is currently limited evidence on the *direct* impact drought episodes exert on GDP levels and growth rates. A study from the International Monetary Fund (Fuje et al., 2023[47]) finds that a weighted Palmer Drought Severity Index value below -2.0, which indicates a moderate-to-severe drought episode, during the three most critical crop-growing months is linked to a 1.4 percentage point slowdown in the GDP growth rate of the same year. The effect is short-term and is confined to developing economies, with no significant long-term effects observed in subsequent years. Felbermayr and Gröschl (2014[43]) show that, all else equal, if rainfall lies 50% below its long-run monthly mean for at least 3 consecutive months, per capita growth rate of GDP is expected to be lower by 1.3 percentage points.

There is a voluminous literature on the impact of precipitation on GDP. This literature examines the continuous evolution of GDP and several climatic variables that strongly correlate with drought episodes. Apart from rainfall, these variables include mean temperature, days of heavy or extreme precipitation and heat stress. The significant advantage of this literature is that climatic variables are observed with much higher spatiotemporal frequency than drought episodes.

The impact of precipitation on *national* GDP is much more likely to go undetected than that of temperature. The study by Damania, Desbureaux and Zaveri (2020[6]) highlights how spatial aggregation may blur the substantial impact rainfall has on *local* GDP.[9] The study links local GDP, temperature and precipitation data, reporting that the within-country variation of precipitation is two times that of temperature. It demonstrates that averaging precipitation at the country level may render the impact of national rainfall average on national GDP statistically insignificant. Therefore, the spatial aggregation of precipitation may be the reason why the impact of rainfall shocks on GDP goes undetected in studies at the country level. In sharp contrast, estimating the impact of *local rainfall* on *local GDP* allows a robust relationship to emerge. The key findings reported below stem from the estimates of Damania, Desbureaux and Zaveri (2020[6]), which is one of the studies overcoming this issue.

### Figure 3.9. Negative precipitation shocks and their potential effects on regional GDP




Notes: Computed effects of 100 mm less rainfall, based on the estimates of Damania, Desbureaux and Zaveri (2020[6]). The position in the horizontal axis represents the average precipitation of a region.
Source: Author’s own, based on data from Damania, Desbureaux and Zaveri (2020[6]).

A severe dry shock has a pronounced negative impact on the GDP growth rate of the affected region. A significant reduction in annual rainfall – equivalent to one standard deviation – can halve the region's GDP growth rate. If the shock is temporary, the growth rate recovers to its normal level. However, if the rainfall deficit becomes permanent, the region's GDP by 2050 could be 30% lower than it would have been under normal conditions.

Smaller rainfall shocks also have noticeable impacts. A 100-millimetre reduction in annual rainfall can lower GDP growth by 0.2 percentage points in arid zones but has minimal effect in regions with high precipitation (above 2.5 metres annually). In very wet areas, this reduction may positively impact GDP growth, especially if it reflects fewer episodes of extreme rainfall (Figure 3.9). A substantial wet shock has a positive, but smaller effect. While a substantial dry shock halves an area's GDP growth rate, a substantial wet shock of the same magnitude —one standard deviation— may increase that GDP growth rate by one third.

Rainfall deficits have a stronger negative impact on the GDP of dry and temperate regions whose economy depends on agriculture. The drier an area is, the more detrimental the effect of a decrease in annual rainfall is (Figure 3.9). Furthermore, the larger the dependence of the local GDP on agriculture, the larger the sensitivity of the GDP to negative precipitation shocks, at least in dry and temperate areas. In very humid areas, negative precipitation shocks may increase GDP, e.g. by reducing the probability of flooding. In a temperate region with annual rainfall of about 1000 millimetres, a drought episode reducing rainfall to 900 millimetres could lower GDP growth by 0.10–0.15 percentage points.

Precipitation impacts on GDP are more pronounced in developing countries. In these economies, agriculture constitutes a larger share of GDP and income, making their economic performance more dependent on climatic conditions. Damage to agricultural crops, such as reduced yields during droughts, translates directly into measurable economic losses. In contrast, developed economies have more diversified economic structures, which reduce the relative importance of agricultural shocks to overall GDP. Another reason why GDP is impacted in different ways by rainfall is the adoption of adaptation strategies, such as irrigation systems. The gap in resilience measures between developing and developed countries is significant and well documented in the work of Barrios, Bertinelli and Strobl (2010[48]). As examined earlier in this chapter and further discussed in Chapter 4, the uptake of irrigation systems mitigates the economic impacts of reduced rainfall during drought episodes, making GDP effects less detectable (see Section 3.3.1).

Dry shocks may boost the GDP of wet areas if they reduce extreme rainfall episodes. The study by Kotz, Levermann and Wenz (2022[49]) accounts for heavy and extreme precipitation. They find that significant decrease in annual rainfall (one standard deviation) reduces GDP growth rates at all levels of annual rainfall. However, the effect of fewer episodes of heavy and extreme rainfall is predominantly positive, as fewer such episodes translate to lower flooding risks.

The literature is not conclusive on how long the negative GDP effect of a dry shock may last. Berlemann and Wenzel (2018[50]) find that a negative precipitation anomaly of one standard deviation keeps GDP growth rates 0.05 to 0.15 percentage points below their baseline levels for up to 14 years. This implies that 14 years after a moderate rainfall deficit shock, the GDP *level* of a country whose baseline growth rate (i.e. in absence of the shock) is 2%, would be 1.1% below its baseline level.

Dry shocks may be less detrimental if green water is abundant. The work by Zaveri, Damania and Engle (2023[51]) indicates that the negative impact of a dry shock in areas of high forest cover is less than 50% of the impact dry shocks can have in areas of low forest cover. This finding suggests that forests could possibly act as a natural adaptation mechanism to droughts.

## 3.4. Beyond the economy, beyond borders

Persistent and intense drought episodes produce far-reaching effects that extend beyond the economic domain and are often difficult to confine within national borders. They may disrupt existing migration patterns or trigger new ones, forcing populations to relocate to more resource-abundant areas. This relocation can place significant strain on resources and infrastructure in receiving regions, potentially fuelling social tensions and instability. In drought-affected areas, the social costs of fundamental needs like drinking water and food can rise sharply, creating lasting disruptions to social well-being and economic stability. In extreme cases, recurring droughts of prolonged duration and high intensity may weaken political institutions, foster instability, and contribute to internal violence and armed conflicts (OECD, 2023[52]).

Moreover, the impacts of droughts can cross borders. Competition for scarce resources such as water and arable land may intensify tensions both within and between nations. Historical evidence suggests that, in some instances, prolonged droughts have contributed to precipitate violent conflicts, as communities and countries compete for dwindling resources. In other areas, the unsustainable use of water resources has played a key role in exacerbating cross-border issues. These interconnected effects emphasise the need for policymakers to approach droughts not merely as environmental challenges but as pressing geopolitical concerns.

### *3.4.1. Droughts and migration flows*

Migration and displacement figure among the most concerning effects of climate-related disasters. The increasing interest in climate-relevant migration is well reflected in the frequency with which the word *migration* appeared in the text of past IPCC assessment reports. While *migration* was mentioned only twice in the First Assessment Report of 1990, this number raised to 185 in the 5$^{th}$ assessment report in 2014.[10] The interest in the impacts of climate change on migration has also been inscribed into a voluminous scientific literature, with publications accumulating at an annual rate of 18.5% between 2003 and 2020.[11] The volume of environmental migration literature is also well reflected in the various meta-studies on the field, including systematic literature reviews, meta-analyses and bibliometric studies. These meta-studies are summarised in Table 3.2.

**Table 3.2. Meta-studies in climate change and migration**

| Meta-study | Information |
|---|---|
| Black et al. (2013[53]) | Qualitative synthesis of the evidence accumulated until 2013. Conceptualisation of mobility, displacement and climate change |
| Millock (2015[54]) | Systematic literature review focusing on empirical and theoretical environmental migration studies with a strong economic component |
| Berlemann and Steinhardt (2017[55]) | Literature review |
| Hoffmann et al. (2020[56]) | Meta-analysis utilising 1803 estimates of climate-relevant impacts on migration from 30 studies published between 2006 and 2019<br>**Central meta-estimate:** 1.0 standard deviation change in the environmental conditions increases migration by 0.021 standard deviations<br>**Drought-relevant control variables:** precipitation level, precipitation variability<br>**Relevant findings:** Estimates of precipitation effects are systematically weaker than these of temperatures and rapid-onset events and precipitation anomalies (by 0.015 to 0.018 standard deviations) |
| Beine and Jeusette (2021[57]) | Meta-analysis utilising 1355 estimates from 51 studies attempting to explain (i) why some studies do obtain significant results while others not, (ii) the probability that a study detects a direct effect and (iii) the probability to detect a significant positive displacement effect. Some of the most important findings are:<br>(a) Studies that focus on developing countries are 19% more likely to detect a positive displacement effect;[a]<br>(b) Studies that control for *rainfall levels* and *rainfall variability* are 12-17% and 19-24% more likely to detects migration effects;[b]<br>(c) No rainfall variable makes a study more likely to detect positive migration effects (emigration);[b]<br>(d) Studies controlling for droughts are less likely by 0-5% to detect migration effects.[c] |

Notes: (a) Beine and Jeusette (2021[57]) Tables 5-9; (b) Beine and Jeusette (2021[57]) Table 16; (c) Beine and Jeusette (2021[57]) Table 19.
Source: Author's own, based on Black et al. (2013[53]), Millock (2015[54]), Berlemann and Steinhardt (2017[55]), Hoffmann et al. (2020[56]) and Beine and Jeusette (2021[57]).

There are few conclusions to extract from the existing literature on the impacts of climate change on migration and displacement, with relevance to the specific role of droughts. The meta-analysis by Hoffmann et al. (2020[56]), which uses more than 1800 estimates from 30 country-level studies on the impact of various climate factors (including drought-relevant variables) on migration. Across studies, migration is reported in various forms that are not directly comparable (nominal flows, relocation probability or migration probability odds). To overcome these comparison barriers, the study standardises its primary estimates.[12] The meta-analysis suggests that the average impact of climate factors on migration across studies is seemingly low, i.e. $0.021$ standard deviations. To the extent this finding is valid for droughts, it suggests that people tend to migrate in response to warmer and drier climate conditions, though such response is rather weak.

Understanding the link between droughts and migration remains challenging due to data gaps, limited bibliographic evidence and methodological diversity. Only a narrow subset of the existing literature on the impacts of climate change on migration refers to droughts (Table 3.3). A small amount of studies control for drought-specific variables, such as precipitation and soil moisture, and an even smaller subset reports statistically significant effects. Comparability across findings is further hampered by the diversity of methodological approaches. Some studies employ aggregate empirical models to estimate how conditions in origin and destination regions, such as unemployment rates or water scarcity, influence migration flows. Other studies use microdata and event-history models to isolate the migration impact of drought episodes from individual (e.g. education, age) and household (e.g. family size) characteristics. Aggregate models face additional challenges, as migration flows often alter the demographic and skill composition of a region, which they assume to be exogenous. Migration is studied at different levels, with some studies focusing on international migration, while others explore internal movements, such as rural-to-rural or rural-to-urban relocations.

## Table 3.3. Migration studies involving drought-relevant explanatory variables

| Primary study | Methodological Information | Key findings |
|---|---|---|
| **Studies controlling for *rainfall level (one-side)*[1]** | | |
| Backhaus, Martinez-Zarzoso and Muris (2015[58]) | Gravity model estimated with data from 142 immigration-origin countries between 1995 and 2006 | An 10% decrease in precipitation decreases migration flows by 0.55 percentage points |
| Marchiori, Maystadt and Schumacher (2012[59]) | Theoretical migration model estimated with migration flows between Sub-Saharan African countries | The annual weather-induced *international* migration rate is estimated at 0.03%, and 53% of this (0.016%) is attributed to rainfall anomalies. Within the sampling period of 40 years (1960–2000) it accumulates to 0.64% |
| Barrios, Bertinelli and Strobl (2006[60]) | Econometric model predicting urbanisation rates at the country level using data from the United Nations' World Urbanisation Prospects | The elasticity of urbanisation with respect to rainfall is estimated to be between $-0.3$ and $-0.6$ in Sub-Saharan African countries |
| **Studies controlling for *rainfall level (both sides)* [2]** | | |
| Bohra-Mishra, Oppenheimer and Hsiang (2014[61]) | Econometric study following 7185 Indonesian households from 13 provinces for over 15 years | $1\%$ *increase* in precipitation (from the mean) affects the interprovincial migration rate by $-1.8\%$ to $+1.6\%$;<br>$1\%$ *decrease* in precipitation increases the interprovincial migration rate by to $0.6-4.0\%$ |
| Henry, Schoumaker and Beauchemin (2003[62]) | Retrospective migration survey recording the complete locational history of more than 8500 individuals in Burkina Faso | For male population, the odds of **rural-to-rural migration** increase by more than 200% in annual rainfall decreases from a level exceeding $0.9$ metres to a level between $0.2$ and $0.5$ metres.<br>For female population, the change is smaller (70%), but the shock also decreases the odds of **international migration** by up to 50% |
| **Studies controlling for *rainfall anomaly and/or rainfall variability*** | | |
| Henry, Schoumaker and Beauchemin (2003[62]) | Retrospective migration survey recording the complete locational history of more than 8500 individuals in Burkina Faso | For male population, the odds of **rural-to-rural migration** increase by almost $60\%$ if annual rainfall falls $15\%$ below its historical annual mean. The odds of **international migration** decrease by 30%. No statistically significant effects are detected for female population |

| | | |
|---|---|---|
| Coniglio and Pesce (2015[63]) | Gravity model estimated on bilateral international migration flows from emerging and developing countries toward OECD countries in the period 1990–2001 | Level of rainfall does not explain **migration to OECD countries**. A one standard deviation increase in *rainfall variability* is associated with a 13.7% increase in average bilateral migration. Floods (positive rainfall anomalies) cause larger migration outflows than droughts (negative rainfall anomalies) |
| Mastrolillo (2016[64]) | Gravity model for migration flows between 52 zones in South Africa (1997-2011) | A 10% increase in the occurrence of negative precipitation anomalies increases **inter-regional** migration flows by 2.2 percentage points.<br>A 10% increase in the occurrence of positive precipitation anomalies increases **inter-regional** migration flows by 1.0 percentage point |
| Thiede, Gray and Mueller (2016[65]) | Event history model estimated on 21 million observations from 25 censuses conducted in 8 South American countries | $-1.0$ standard deviation in precipitation increases emigration probability by $7\%$ at young age but has no impact at mid-age or older people |
| **Studies controlling for *Standardised Precipitation Index (SPI)*** | | |
| Dallmann and Millock (2017[66]) | Gravity model estimated on inter-state migration flows in India | An additional month in which a drought is at least moderate $\mathrm{SPI} < -1.0$ increases **inter-regional migration** probability by 1.3 percentage points. An additional drought episode that is at least "moderate" increases migration probability by 1.7 percentage points. Decreasing $\mathrm{SPI}$ by 1.0 point within a drought episode increases migration probability by 0.8 percentage points. The mean migration rate in the sample is 0.2% |
| Gray and Mueller (2012[67]) | Event history model estimated with panel data from Ethiopian Rural Household Survey (1 500 households, 15 rural communities, 15-years) | A severe drought almost doubles labour mobility rates, and almost triples the probability of out-of-district immigration |
| **Studies controlling for s*oil moisture levels*** | | |
| Mastrolillo (2016[64]) | Gravity model for migration flows between 52 zones in South Africa (1997-2011) | A 1.0 percentage point increase in soil moisture decreases migration flows by 5.0 percentage points |
| Mueller, Gray and Kosec (2014[68]) | Event history model estimated with individual level data collected for Pakistan Panel Survey (1986–1991, 2001, 2011) | + 1.0 standard deviation in soil moisture decreases probability of internal migration by $27-29\%$ |
| Henderson, Storeygard and Deichmann (2017[69]) | Econometric model of urbanisation estimated with Census data of 29 African countries collected from various sources | A decrease in the growth rate of moisture by $1.0$ standard deviation increases the growth rate of urbanisation by up to $1.5$ times. The finding is conditional to the presence of industries in the district |
| **Studies with indirect drought-related controls** | | |
| Feng, Krueger and Oppenheimer (2010[70]) | Instrumental variables regression. Stage 2: gravity equation with crop yield explaining immigration; Stage 1: crop yield is explained by climatic variables, including rainfall | A 10% decrease in crop yield increases the emigration rates by 2% |
| Ezra and Kiros (2001[71]) | Event history model estimated with data from 2000 Ethiopian households | All else equal, migration from Ethiopia was 30% lower in 1987-90, compared to 1984, which was characterised by a drought-induced famine |

Type of control: (1) the study does not distinguish the effects of rainfall increases or decreases, (2) the impact of rainfall increments is differentiated from that of rainfall reductions.

Studies controlling for drought-related variables with insignificant or partial effects: Beine and Parsons (2015[72]), Cattaneo and Peri (2016[73]), Cai et al. (2016[74]), Drabo and Mbaye (2015[75]), Findley (1994[76]), Gröschl and Steinwachs (2017[77]), Koubi et al. (2016[78]).

Source: Author's own, based on primary studies and back-of-the-envelope calculations detailed in Tikoudis, Gabriel and Oueslati (2025[4]).

In a dedicated global study on the impacts of drought on migration, the World Bank reports that water scarcity induces out-migration, but in a way that is highly context-specific (Zaveri, Damania and Engle, 2023[51]). The study combines microdata from 189 different census, which contain 442 million migration cases in 64 countries in the period 1960-2015, with high-granularity weather data. The analysis distinguishes the effects of rainfall deficits from those of other climate factors and individual characteristics. Rainfall shocks are found to have 40% of the explanatory power education has, and almost 10% of the explanatory power of age, which is the strongest predictor. The likelihood of migrating due to a dry shock is about five times higher for individuals with incomes above the median compared to those with lower incomes. This pattern reverses for wet shocks, highlighting potentially contrasting distributional effects of droughts and floods.

Some studies show that water scarcity may prompt displacement (OECD, 2016[79]) and hamper migration flows out of the country that experiences it (Backhaus, Martinez-Zarzoso and Muris, 2015[58]). Part of the literature attributes this finding to the existence of a *poverty trap effect*. While there are several arguments that may support this hypothesis, studies that confirm it may be subject to considerable methodological limitations.

The effects seem to be mostly confined to developing countries or low-income provinces depending on agriculture. For example, Barrios, Bertinelli and Strobl (2010[48]) follow rainfall and urbanisation rates in 78 countries between 1960 and 1990. Controlling for several covariates and unobserved heterogeneity, they find that a 1% increase in rainfall decreases the urbanisation rate by 0.3-0.6%. The effect is confined to sub-Saharan African countries and is not significantly different from zero for other developing countries. Currently, there is limited evidence for the effect of drought episodes on relocation trends within OECD countries, or cross-country migration flows between them.

Finally, there is some evidence that rural relocation is more responsive to droughts than international migration is. For example, from the estimates of Henry, Schoumaker and Beauchemin (2003[62]) it can be inferred that droughts in Burkina Faso affect within-country rural-to-rural migration flows by 20-300% more than they do affect migration flows to another country.

### *3.4.2. Droughts, environmental security and conflicts*

It is well documented that climate disasters may limit accessibility to important resources, and droughts constitute no exception. During drought episodes water is scarcer and dryland becomes less arable. Conflict may arise not only because water and food become scarcer, but also because some population groups and geographic locations are in a more vulnerable position than others. Environmental migration and displacement constitutes another channel via which drought episodes may contribute to tensions and conflict in regions not directly affected by droughts (OECD, 2023[52]). Violence can take various forms, from property crime at the individual level to armed conflict between organised groups. It is theoretically possible that drought episodes negatively affect political stability and social order, and that they may fuel tensions between neighbouring nations, even if they do not affect them at the same time.

Plenty of case-study and anecdotal evidence supports the hypothesis that droughts can contribute to conflicts, though this evidence is not conclusive. A visual analysis of conflict locations reveals their spatial coincidence with dry shocks and negative anomalies in rainfall and soil moisture. However, a substantial portion of conflicts take place in wet locations. Climate Diplomacy (n.d.[80]) presents more than 138 case studies on clashes and conflicts that occurred around the world and can be attributed to climate change. Out of these 138 incidences, 105 relate to water scarcity. Further filtering reveals that 70% of the conflicts that are jointly related to climate change and water scarcity simultaneously constitute conflicts driven by local or international competition, food security concerns and migration. Table 3.4 summarises a sample of conflicts whose occurrence could be attributed, at least partially, to persistent or gradually worsening anomalies in precipitation and temperature. All explored incidences pertain to developing countries, with the majority of them having occurred or currently occurring in Sub-Saharan Africa.

The geographic concentration of drought-related conflicts in certain regions, such as Sub-Saharan Africa, poses significant challenges to conducting rigorous scientific analyses. Resource scarcity frequently arises in Sub-Saharan Africa during drought episodes, creating a consistent overlap between drought conditions and scarcity-related unrest. This overlap makes it difficult to separate the direct effects of climate disasters—such as increased mistrust in institutions and social panic—from the indirect effects driven by intensified competition for increasingly scarce resources. Moreover, resource scarcity in Sub-Saharan Africa often coincides with economic and political institutions unique to the region, which differ substantially from those found in developed economies. These overlapping factors complicate efforts to isolate the specific role droughts play in triggering conflicts. Similar challenges in detecting causal relationships also apply to other developing regions, where resource scarcity and institutional vulnerabilities often coexist with drought conditions, further complicating the analysis.

### Table 3.4. Droughts as a potential contributing factor to recorded conflicts

| Countries involved | Period | Key findings |
|---|---|---|
| **Local competition for resources** | | |
| Mali | Since 2012 | Northern Mali faces warming and shifts in rainfall patterns that have resulted in crop losses and political exclusion of local communities. By exacerbating inequalities, droughts are believed to increase support for separatist groups and recruitment for armed extremist group |
| Yemen | Since 1990 | Numerous local conflicts occurring at various levels (individuals, tribal groups, villages). Internal migration and land sales further exacerbate conflicts, as cohabiting tribes with diverging interests vie for access to dwindling water resources |
| Sudan | Since 2003 | The severe droughts recorded in 1970s and 1980s may have contributed to hostility between local groups and the government, which culminated with the civil war in Darfur |
| Nigeria, Niger, Chad, Cameroon | Since 2009 | The rise of terrorist groups is preceded by a complex nexus of policy failures and the occurrence of recurrent droughts in the Chad and Niger |
| Niger | Since 1944 | Ethnic violence at a local scale reflected is reflected upon conflicts of herders and farmers, which tend to exacerbate under drought and famine conditions |
| South Sudan | Since 1944 | Increasing variability of rainfall in South Sudan may be linked to various conflicts between communities |
| **Cross-border competition for resources** | | |
| Ethiopia, Kenya | Since 1944 | Since 1960, droughts occurring with higher frequency and intensity in the Omo-Turcana basin. Droughts intensify resource competition of between communities located at different sides of the border causing 600 deaths due to conflicts recorded between 1989 and 2011 |
| Tajikistan, Kyrgyzstan, Uzbekistan | Since 1991 | The recorded disputes may be exacerbated by upward trends in water consumption which occur simultaneously with temperature rises and a decrease in the average rainfall |

Source: Author's own, based on data from Climate Diplomacy (n.d.[80]).

As a result of these methodological barriers, the statistical evidence on the effect of climate change on conflict remains largely inconclusive.[13] One of the earliest studies in the field (Burke et al., 2009[81]) predicted a significant effect of temperature (but not of rainfall) on the incidence of civil war in Sub-Saharan African countries. Two closely related studies (Hsiang, Burke and Miguel, 2013[82]; Hsiang and Burke, 2014[83]) collected estimates from various scientific studies from disciplines including psychology, archaeology, paleo-climatology, political science and econometrics. Using meta-analytic techniques, the latter study postulates that significant temperature or precipitation shocks (i.e. one standard deviation) increase interpersonal conflict by 4% and intergroup conflict by 11%. However, several other experts in the field (Buhaug et al., 2014[84]) expressed concerns about the methodological barriers that could limit the validity of the study by Hsiang, Burke and Miguel (2013[82]). The lack of consensus is well reflected in Chapter 12 of the IPCC's Fifth Assessment Report dedicated to human security (Agder et al., 2014[85]). This stresses that: "*Some of these* (i.e. studies) *find a weak relationship*, *some find no relationship, and collectively the research does not conclude that there is a strong positive relationship between warming and armed conflict*".[14] In agreement with this statement, several literature reviews stress this lack of consensus. However, one of the latest reviews on the field (Koubi, 2019[86]) concludes that there is substantial consensus on the role of climate in the onset of conflict, but the impact is subject to several conditions. Notably, less developed regions that rely on agriculture are susceptible to conflict arising from climatic conditions, especially when political marginalisation is present.

Some analyses support the hypothesis that droughts contribute to conflict, but only when the necessary preconditions for the outbreak of violence are present (Table 3.5). Harari and Ferrara (2018[87]) use unique data spanning 2 700 cells ($1° \times 1°, approx. 12000\ \text{km}^2$), 46 African countries and 24 years. Their estimates indicate that a transitory dry shock that occurred three years ago increases the probability of conflict today by 3 percentage points. If the same dry shock endured until now, its effect would grow to 6.3 percentage points. The magnitude of the estimate is large, as a location in the sample had a 17% probability of experiencing some kind of conflict at any point in time. The study predicts that a location that was in a state of conflict during the previous year has an additional probability of 12-34 percentage points of being in a state of conflict in the current year as well. Also, Harari and Ferrara (2018[87]) find significant spatial spill-over effects. A location is more likely by 2.3 to 4.5 percentage points to experience conflict if a neighbouring location is currently in a state of conflict. Most importantly, Harari and Ferrara (2018[87]) show that the effects are confined to growing seasons only, as dry shocks occurring outside the time windows that are critical for crop growth have no effect on conflict incidence. While the preconditions highlighted by Harari and Ferrara (2018[87]) are crop failure and loss in agricultural production, the study by Almer, Laurent-Lucchetti and Oechslin (2017[88]) stresses the importance of water scarcity and the presence of multiple ethnic groups as similar preconditions to conflict.

## Table 3.5. Environmental security studies spotlighting drought-relevant drivers

| Study | Methodological information | Key findings |
|---|---|---|
| **Indirect impact of precipitation on conflict and violence, via income** | | |
| Hidalgo et al. (2010[89]) | Brazil, Precipitation anomalies are used as a predictor[1] of agricultural income, which in turn affects land invasions | $1.0$ standard deviation in rainfall (both sides) increases land invasions by $2.6 - 4.1$ standard deviations |
| **Direct impact of Standardised Precipitation Evapotranspiration Index (SPEI) on conflict** | | |
| Harari and Ferrara (2018[87]) | African continent, 1997-2011. Spatial econometric study following conflicts with high spatial resolution data (2700 cells, 46 countries) | Depending on its duration, a $1.0$ standard deviation decrease in SPEI values (i.e. a mild drought) during a growing season increases the likelihood of conflict in the subsequent two years by $0.09$ to $0.26$ standard deviations |
| Almer, Laurent-Lucchetti and Oechslin (2017[88]) | African continent, 1997-2011. Spatial econometric study following conflicts with high spatial resolution data (2700 cells, 46 countries) | On average, $1.0$ standard deviation decrease in SPEI values (i.e. a *mild* drought) increases the probability of the overall onset of conflict by $8\%$ or $0.002$ standard deviations |
| Abel et al. (2019[90]) | World, 2006-2015. Study exploring the nexus of climatic change, conflict and asylum seeking | Droughts had limited or no impact on conflicts, except for North African and Middle East countries during 2010-2015 |
| **Direct impact of precipitation on conflict** | | |
| Sofuoğlu and Ay (2020[91]) | 18 countries in the Middle East and North Africa region, 1985-2016. Panel causality analysis using data on temperature and precipitation | Causal relationships from temperature to political instability and conflict are detected for at least 15 of 18 countries in the sample. Causal relationships from precipitation to political instability and conflict are detected for 3 out of 18 countries in the sample |
| Miguel (2005[92]) | Tanzania, 1992 - 2002. Study analysing differences in murders rates across villages, controlling for observed and unobserved heterogeneity across them (fixed effects) | Droughts and floods (almost) doubled the incidence of murders and attacks |

Source: Author's own, based on primary studies and back-of-the-envelope calculations detailed in Tikoudis, Gabriel and Oueslati (2025[4]).

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## Notes

[1] All three channels (plant survival rates, plant size, ratio of above-to-below biomass) are relevant for agricultural production. While the first may appear as trivial, the third is less straightforward. Stems and leaves are crucial for photosynthesis and the development of fruits, grains and other harvestable parts. With less biomass going to these structures, the overall growth and yield of the crop may decrease.

[2] For instance, the survival probability of Salix trees (e.g. willows and osiers) exposed to a 30-day drought episode is half of those not exposed to it. In sharp contrast, tamarisc trees exposed to 30 days of a drought have almost 90% probability of survival, relative to non-exposed tamarisc trees.

[3] The key numerical findings are as follows. Reducing soil moisture by 1.0 standard deviation reduces cropland vegetation during the same year by approximately 0.4 standard deviations, as most of the used models predict an effect between 0.30 and 0.55. For forests and wetlands, the central estimates are 0.25 and 0.20 respectively. Econometric model specifications and research details are provided in (Tikoudis, Gabriel and Oueslati (2025[4]).

[4] The central numerical finding is that 400 millimetres less rain per year may have an effect that is equivalent to a 1.0 standard deviation reduction in soil moisture.

[5] Here, the reported estimates originate from back-of-the envelope calculations using the summary statistics in Table 2 and the econometric estimates for dryland US counties that do not control for temperature or precipitation (Table 4, column 1) in Kuwayama (2019[25]). The average exposure was 8.5 weeks in mild droughts (D0), 5.7 weeks in moderate droughts (D1), 3.9 weeks in severe droughts (D2), 2.3 weeks in extreme droughts (D3), and 0.8 weeks in exceptional droughts (D4).

[6] The authors report the standard deviation to be 2.7 units of the PDSI.

[7] However, droughts and water stress are not the only reasons behind vulnerabilities in the supply of energy from thermoelectric power stations. A branch of literature stresses the general problem of water scarcity and water allocation across residential consumption, industrial use, energy and food systems. See for example, Zheng et al. (2016[93]) for China, Hejazi et al. (2023[94]) for the Middle East and North Africa region.

[8] This number was originally reported by AccuWeather (2022[95]) and has been cited by World Economic Forum (2023[96]).

[9] A related reference empirically examining the effect of rainfall on GDP is the paper by Zaveri, Damania and Engle (2023[51]).

[10] Šedová, Čizmaziová and Cook (2021[97]) and Minx et al. (2017[98]).

[11] Cipollina, De Benedictis and Scibè (2024[99]). For other bibliometric reviews of the field see Maretti, Tontodimamma and Biermann (2019[102]); Milán-García et al. (2021[100]); Priovashini and Mallick (2022[101]).

[12] Therefore, each observation in the meta-analysis represents the (reported) effect of a 1.0 standard deviation change in a climate variable on migration, with that reported effect expressed also in standard deviations.

[13] The contribution and limitations of qualitative approaches in the general environmental security literature are investigated by Bernauer, Böhmelt and Koubi (2012[103]).

[14] Agder et al. (2014[85]) attributes this to Theisen, Gleditsch and Buhaug (2013[104]).

# 4 Adapting to drought risk for long-term resilience

This chapter makes the case for drought adaptation action, examining how policy frameworks, instruments, and financing mechanisms can strengthen resilience to drought in the face of climate change. It explores strategies for integrating drought resilience into national policies, managing water demand and supply, protecting ecosystems, and adapting key sectors to increasing drought risk. Through case studies and best practices from OECD countries and beyond, the chapter illustrates how countries are enhancing their capacity to mitigate drought impacts and build long-term resilience.

## 4.1. Introduction

The increasing risks and impacts imposed by droughts underscore the urgent need for stronger policy action to build resilience against increasingly dry conditions, protect communities, and ensure the sustainable use of resources in the face of climate change. Without decisive policy action, the socio-economic and environmental costs of drought will continue to rise globally, with cascading and potentially irreversible consequences for societies, economies, and ecosystems in all continents (see Chapters 2 and 3).

In response to the rising frequency of drought episodes, many countries have scaled up the use of emergency measures, most notably water use restrictions (Gerber and Mirzabaev, 2017[1]; UNW-DPC, 2015[2]). For instance, in France's Île-de-France region, the average number of days per year subject to water use restrictions increased from 0.7 days/year in 2011-2016 to 21.7 days/year in 2017-2022 (OECD, 2025[3]).[1] Similarly, some of Spain's most drought-prone regions have increasingly relied on water use restrictions (Agència Catalana de l'Aigua, 2020[4]).

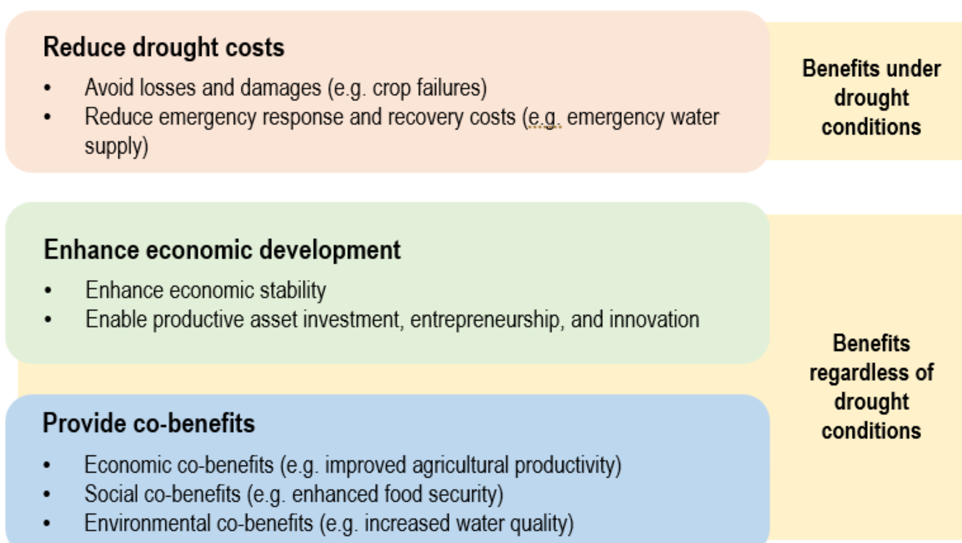
While these measures can effectively curb water consumption during acute shortages, their limitations are becoming evident as droughts become more frequent and severe. Water use restrictions are typically short-term responses aimed at reducing immediate surface water consumption, but they do little to enhance long-term resilience. Once restrictions are lifted, water use usually rebounds to pre-restriction levels (Climate ADAPT, 2023[5]). Sometimes, water use restrictions can even be counterproductive from a climate resilience perspective, as they can trigger mechanisms that further increase vulnerability to drought. For example, if groundwater extraction is not strictly regulated, users may turn to groundwater sources as an alternative for surface water, accelerating aquifer depletion. Moreover, by limiting water use, these restrictions can reduce the surface runoff that naturally replenishes groundwater, further hindering aquifer recharge. Moreover, while cutting water use could alleviate scarcity in the short term, the economic efficiency cost of such measures can be considerable when compared to other management strategies such as water pricing, and affects users across the residential, commercial and industrial sectors (Woo, 1994[6]; de los Angeles Garcia Valiñas, 2006[7]). Equity concerns also arise, as the users most affected by these restrictions are not always those responsible for water scarcity.

Addressing the challenges posed by drought requires a decisive shift towards preventive action that mitigates and adapts to changing conditions. Effective drought adaptation involves a broad range of proactive efforts designed to reduce the occurrence of drought and drought-induced water scarcity *ex ante* while minimising their impacts on communities, ecosystems, and economies. The far-reaching impacts of drought – on food security and prices, public health, energy systems, transport, agriculture, and even peace and security – underscore the need for integrated, cross-sectoral approaches. These efforts must include sustainable water management, soil and ecosystem conservation, as well as sector-specific adaptive practices to enhance resilience in affected areas. While these efforts cannot eliminate drought risk entirely, they can minimise impacts. Importantly, these adaptive measures must operate both domestically and across borders to address the complex, interconnected nature of drought risks effectively.

Proactively adapting to drought risk has the potential to deliver a "triple dividend of resilience", yielding significant socio-economic benefits (Figure 4.1). Firstly, preventive measures can reduce the impacts and costs of drought, including the financial and welfare burdens resulting from emergency response and recovery efforts. Secondly, proactive adaptation reduces economic uncertainty associated with drought impacts, enabling long-term planning and encouraging greater economic activity and investment in productive assets, especially in regions where risk perception is high. Finally, proactive adaptation generates socio-economic and environmental co-benefits, such as improved farmer productivity, reduced vulnerability to poverty, and better human and ecosystem health. As such, proactive adaptation not only mitigates the effects of drought but also enhances overall resilience and economic performance, benefitting countries and communities regardless of whether they are experiencing drought conditions at a given time (Tanner et al., 2015[8]; OECD, 2024[9]).

The triple dividend of drought resilience highlights that the potential returns on investing in resilience far outweigh the associated costs. Cost-benefit ratios vary depending on each country's specific risk profile and socio-economic conditions. In some cases, resilience-building efforts may yield lower returns during non-drought periods or in areas only sporadically affected by drought (Kusunose and Lybbert, 2014[10]). Despite these variations, the overall benefits of investing in drought resilience and adaptation tend to be positive, with potential returns up to ten times greater than the initial investment (FAO, 2021[11]; IDRA, 2024[12]; IDMP, 2022[13]). The need for increased investment in drought resilience is further emphasised by the substantial impacts of reduced water availability on economic growth (see Chapter 3) (Zaveri, Damania and Engle, 2023[14]). Moreover, due to the slow-onset nature of drought, the benefits of preventive measures accumulate over time, providing significant long-term returns on investment.

## Figure 4.1. The triple dividend of adapting to drought




Source: Author's own, remodelled after Tanner et al. (2015[8]).

This chapter aims to outline the range of available strategies, policies, and practices available to adapt to drought risk and assess the extent to which countries are adopting them. It provides an overview of how policy strategies (Section 4.2) and policy measures (Section 4.3) across sectors have evolved to adapt to growing drought risk. This is followed by a discussion on the enabling environment required for effective drought adaptation (Section 4.4). While the analysis primarily focuses on the experiences of OECD countries, it also includes examples and lessons from other drought-prone countries and regions. By exploring different contexts, the chapter aims to provide a comprehensive overview of the diverse policy gaps and opportunities posed by drought. Ultimately, while the strategies and measures proposed throughout the chapter offer promising solutions to strengthen resilience to drought risk, their prioritisation will depend on each country's unique socio-economic and risk profile.

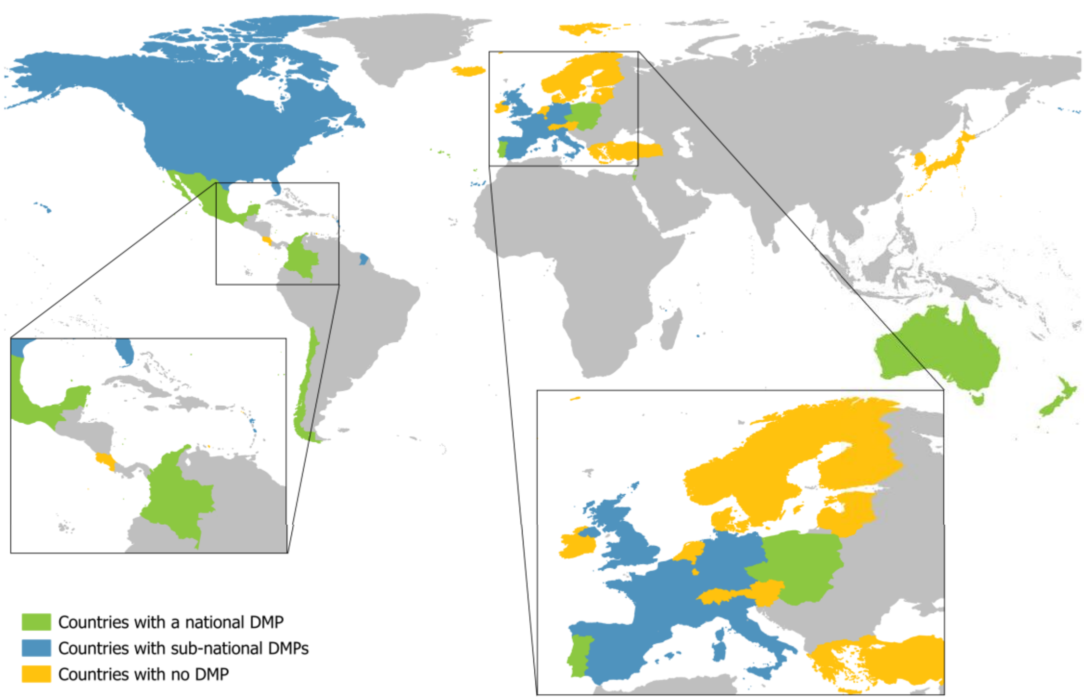
## 4.2. Adapting to growing drought risk through strategic planning

### *4.2.1. National policy frameworks for drought resilience*

In response to the escalating risks and impacts of drought, countries are increasingly embedding drought resilience into their national policy frameworks. These frameworks emphasise the need for preventive action across sectors and policy domains to address the multifaceted nature of drought risks. This reflects a growing recognition of the importance of long-term planning to mitigate drought impacts on ecosystems, economies, and communities.

Dedicated drought management plans (DMPs) serve as a cornerstone for building resilience by setting clear policy objectives, co-ordinating policy efforts, and reducing resource-related conflicts in drought-prone regions. These plans typically outline strategies, measures, and institutional frameworks to prevent and respond to drought, ensuring an integrated, cross-sectoral approach. Globally, at least 70 countries have established national DMPs, with significant adoption in Africa, Latin America and the Caribbean, and South-East Asia (UNCCD, 2024[15]). Among OECD countries, half have implemented either national or subnational DMPs (Figure 4.2). Subnational plans often complement – and in some case substitute – national DMPs, with scopes ranging from state level (e.g. in the United States (US)) to river basin level (e.g. in Mexico and Spain). These subnational frameworks often serve as laboratories for innovative approaches to drought resilience, as highlighted by examples such as Catalonia's Special Drought Action Plan and Cape Town's urban drought management strategy (Box 4.1).

#### Figure 4.2. Drought management plans in OECD countries




Note: This map shows sub-national DMPs only for countries that do not have a national DMP. It is to be noted that countries without any dedicated DMPs typically address drought risk through water resource management, climate adaptation, or other sectoral or local strategies.
Source: Author's own.

Some countries have developed sector-specific DMPs and broader strategies to enhance resilience in vulnerable sectors. For instance, Türkiye has developed a national strategy specifically addressing agricultural drought (OECD, 2021[16]), as well as a strategy and action plan that promote water efficiency and climate adaptation in water-dependent sectors (Republic of Türkiye, 2023[17]). Similarly, Poland's State Water Holding Polish Waters integrates risk reduction and climate adaptation into its recently adopted DMP for water management (European Commission, 2023[18]). In some cases, broader water strategies and agriculture development plans also address drought risk. Germany and Slovakia, for example, integrate drought risk reduction into their long-term water strategies, while France's National Water Plan and its basin-level water management frameworks explicitly prioritise reducing drought risk in the management of water resources (OECD, 2023[19]; Deltares, 2022[20]; FAO, 2016[21]; FAO, 2021[11]; OECD, 2025[3]). Emerging policies in other sectors, including energy, transport, biodiversity, and urban planning, are also beginning to address drought resilience, reflecting the interconnected nature of drought risks across economies.

### Box 4.1. Innovative approaches to drought resilience in subnational policy frameworks

Cities and regions prone to drought have long been at the forefront of developing strategies to address water scarcity. For instance, Catalonia's (Spain) Special Drought Action Plan relies on hydrological indicators (e.g. rainfall, reservoir and aquifer levels) to define drought alert levels, which in turn trigger response measures focused on water use restrictions, strengthened water supply, and water transfers. In contrast, other local strategies take a longer-term perspective. For example, the urban drought management strategy developed in Cape Town (South Africa) in the wake of the severe 2015-2017 drought integrates projections of long-term water demand into its water management measures and combines them with awareness campaigns, water efficiency regulations, and investments to diversify water supply and enhance resilience against future droughts.

These and other strategies have traditionally concentrated on blue water resources – i.e. rivers, lakes, and groundwater – to address water scarcity during droughts. Common measures to this end include water use restrictions, infrastructure development for water storage, and improving water distribution systems. However, in recent years, these has been growing recognition of the importance of green water – i.e. the water stored in soil as moisture – in comprehensive drought management, some governments are beginning to integrate green water management into their drought strategies. Integrating green water considerations involves practices like sustainable land management, improved agricultural techniques, and ecosystem restoration to enhance soil moisture retention. For example, Scotland's policy framework on water incorporates natural water retention measures to manage surface water while creating water-resilient landscapes, signalling a shift toward more holistic and integrated approaches to drought resilience.

Source: (GCEW, 2024[22]; Agència Catalana de l'Aigua, 2020[4]; Deltares, 2022[20]; Shimabuku, Diringer and Cooley, 2018[23]; City of Cape Town, 2024[24]; World Bank Group, 2023[25]; Scottish Government, 2021[26]).

National climate adaptation strategies (NAS) and plans (NAPs) have also become vital tools for aligning drought resilience efforts with broader climate policies. These frameworks provide a strategic basis for integrating adaptation into policy planning across sectors and levels of government. The extent to which drought risks are addressed in NAPs and NAS varies, reflecting each country's unique risk profile and policy priorities. NAPs often identify specific regions, ecosystems (e.g. wetlands, forests), and sectors (e.g. agriculture, energy) as priorities for adaptation, with agriculture and water management frequently highlighted as critical areas. Across OECD countries, these plans emphasise the need for proactive drought management, supporting a transition from reactive responses to anticipatory, long-term solutions (Table 4.1).

### Table 4.1. Drought risk focus in NAPs and NAS of selected OECD countries

| Country | Sectoral focus for drought risk |
|---|---|
| Australia | Focuses on water security and diversification including desalination and funding to enhance resilience in agricultural systems |
| Canada | Emphasises proactive drought adaptation and integration into water management considerations in agriculture and forestry; highlights importance of reforestation and climate-resilient infrastructure |
| France | Touches on drought-induced damages to buildings, vulnerability assessments for water supply, adaptation-mitigation linkages, and bridging the gap between water supply and demand |
| Germany | Highlights drought risk reduction through sustainable land-use planning, agricultural and forest management, and water resource strategies. The 2024 draft of Germany's Adaptation Strategy further introduces measurable targets for resilience against drought-related impacts among others |
| Hungary | Refers to nature-based-solutions (NbS) to target drought risk as well as river and urban flooding |
| Spain | Promotes the integration of adaptation and drought risk management considerations into water management and planning |
| United States | Incorporates comprehensive drought resilience assessments and sector-specific adaptation measures, highlights drought-resilient vegetation and watershed protection projects |

Source: Author's own, based on information from Commonwealth of Australia (2021[27]), Environment and Climate Change Canada (2023[28]), Ministère de la Transition écologique (2024[29]), Ministère de la Transition Écologique et Solidaire (2017[30]), BMUV (2020[31]; 2024[32]), OECD (2020[33]), MITECO (2020[34]) and EPA (2024[35]).

Despite progress, national policy frameworks face persistent challenges in effectively building drought resilience. Limited financial resources, capacity constraints, and weak coordination across sectors and administrative levels undermine implementation. Although many countries have developed DMPs, their effectiveness is often hindered by gaps in enforcement, monitoring, and stakeholder engagement. Many frameworks fail to account for the impacts of climate change under different scenarios, and it remains unclear if observed improvements (e.g. declines in water abstraction) translate into reduced vulnerability to water scarcity. The lack of appropriate indicators (e.g. for soil health) further hampers the effective assessment of actions taken (Climate Change Committee, 2021[36]). Furthermore, the insufficient integration of green water management (Box 4.1) and the lack of alignment between drought risk strategies and broader development priorities reduce their overall impact. Addressing these limitations requires improving the comprehensiveness of drought management frameworks and accelerating their implementation through sustained investment, stronger cross-sectoral coordination, and better alignment between drought resilience efforts and national development objectives.

### *4.2.2. Informing drought management with climate risk assessments*

Increased strategic planning on drought management has been accompanied by strides to better understand the evolving nature of drought risk under climate change. Climate risk assessments are key tools to characterise drought hazard, identify geographic and sectoral vulnerabilities, and inform adaptation needs. These assessments evaluate observed and projected climate risks, including drought, analysing current and future hazards, exposures, and vulnerabilities (Table 4.2) to provide a forward-looking basis for adaptation planning (OECD, 2024[37]). Early warning systems further complement these assessments, offering real-time data and forecasts that enable dynamic interventions and support long-term resilience as risks evolve.

### Table 4.2. The three components of drought risk assessment

| Component | What is assessed | How it is assessed |
|---|---|---|
| Hazard assessment | Likelihood of drought occurrence, including frequency, severity, and duration | • Analyse climate and hydrological data (e.g. precipitation, temperature, water availability);<br>• Assess land use (e.g. vegetation cover, urbanisation, agricultural practices) and water demand (e.g. groundwater extraction);<br>• Assess type of drought, seasonal patterns, linkages with other hazards (e.g., heatwaves, floods, wildfires), and cascading risks (e.g. desertification, soil erosion, ecosystem tipping points) |
| Exposure assessment | Presence of people, assets, ecosystems or systems in directly or indirectly affected areas | • Map the spatial distribution of exposed elements (e.g. settlements, infrastructure, ecosystems) that could be directly or indirectly exposed to drought |
| Vulnerability assessment | Characteristics of exposed elements that increase susceptibility to drought impacts | • Assess factors influencing the susceptibility and fragility of the exposed elements, including their coping and recovery capacity (e.g. demographics, socio-economic conditions, soil health, water use, critical infrastructure, ecosystems) |

Source: Author's own.

Many OECD countries use climate risk assessments to shape drought management policies and strategies, though their depth and sophistication vary. Most assessments focus on changes in drought hazard. Countries such as Australia, the United Kingdom, and the United States use global and regional climate models to project future drought frequency and distribution under different climate scenarios. Similarly, the EU has developed high-resolution models to assess future hydrological drought under different warming scenarios (Clark et al., 2024[38]; DOE, 2022[39]; JRC, 2020[40]; EEA, 2024[41]). Some countries complement hazard assessments with evaluations of drought exposures, vulnerabilities, and potential impacts. For example, Spain and the United Kingdom assess water demand trends under different climate scenarios to estimate future risks of drinking water deficits (OECD, 2025[3]). Belgium's Flanders region conducts regional drought impact assessments under climate change (European Commission, 2023[18]; Klimaatportaal Vlaanderen, 2024[42]), while Lithuania and Slovenia undertake drought impact assessments for specific sectors, such as forestry (GWP and WMO, 2015[43]; GWP CEE, 2015[44]).

Despite significant advancements in data modelling, comprehensively assessing drought risk under climate change remains a challenge. The slow-onset and complex nature of drought makes long-term projections difficult, as even minor changes in its drivers can influence occurrence and severity. The diverse and cumulative impacts of drought complicate the evaluation of exposures and vulnerabilities. To date, only a few countries systematically records drought events including their severity, duration, and impacts (IDMP, 2023[45]), which undermines the accuracy of predictive models reliant on historical data. Gaps in hydrological and socio-economic vulnerability data persist (OECD, 2025[3]),[2] along with low capacity to assess drought risk at subnational level (IDMP, 2022[13]) and limited cross-agency co-ordination on data integration and harmonisation. Expanding the integration of early warning systems into these assessments could help address some of these challenges by offering continuous updates, improving data harmonisation, and strengthening subnational and sector-specific monitoring. Addressing these obstacles is key to advancing effective drought risk assessments (OECD, 2025[3]).

## 4.3. Policy measures and instruments for enhancing drought resilience

To effectively prevent drought risk, drought management and climate adaptation plans highlight the need to develop a wide range of measures across multiple sectors and policy domains. While sustainable water management is central to building drought resilience, it alone is insufficient to address the increasingly complex challenges posed by drought and the interconnected impacts of different policy measures. Hence, measures to manage water demand and supply (Section 4.3.1) need to go hand in hand with measures focused on the sustainable management of land and ecosystems (Section 4.3.2) and on adapting sectoral practices to climate change (Section 4.3.3).

### *4.3.1. Managing water demand and supply for drought resilience*

Efficient water resource management is essential for reducing drought risk. As climate change increases the frequency and severity of droughts, measures to reduce and optimise water demand must be coupled with efforts to enhance freshwater availability and diversify water supplies. Only by addressing both water demand and supply in an integrated manner, in accordance with local needs and hydrological conditions, can countries effectively prevent, prepare for, and build resilience to drought.

#### *Policy measures for managing water demand*

Reducing water demand is crucial for adapting to drought risk in the context of climate change, as it directly addresses the growing pressure on limited water resources. Water demand management entails a broad range of policy measures to minimise water waste and encourage water conservation. These include the regulation of water use and abstraction, incentives for water efficiency, water pricing, and awareness-raising efforts directed to households, farmers, and other water users.

##### **Regulating water use and abstraction**

In light of the sharp increase in freshwater abstraction in recent decades (Box 4.2), regulating water use and withdrawals has become paramount. Effective regulatory frameworks typically integrate water allocation regimes, permitting systems, and economic instruments to manage water resources sustainably. Water allocation regimes provide a strategic framework for distributing water rights among users and prioritising essential uses (e.g. agriculture, drinking water, sanitation, ecosystem preservation) during periods of scarcity. Permitting and registration systems set limits on the quantity, timing, and purpose of individual withdrawals, including provisions on return flows. Economic instruments such as water markets enable the trading of water permits, promoting flexibility and efficiency in water use. When implemented effectively, these regulations help balance immediate water demand with long-term resilience, promoting water conservation and aligning water use with local ecological needs (Box 4.3) and broader climate adaptation goals.

### Box 4.2. The challenges posed by unsustainable water abstraction

Water resources are over-exploited in many regions of the world. Over the past century, global freshwater use has increased sixfold, driven primarily by growing demand for irrigation and electricity production. In Europe, water over-abstraction affects 10% of rivers and 17% of groundwater resources.[3] On a global scale, 21 of the world's 37 largest aquifers are being depleted faster than they can recharge. The over-exploitation of water resources is particularly severe in urban, industrial, and agricultural areas, where demand for water is highest.

By depleting aquifers and river flows, the over-abstraction of water exacerbates the impacts of climate change, increasing vulnerability to drought in the long term. For instance, in Europe, eliminating water over-abstraction could reduce the number of days with very low river discharge levels by 50-90% in many areas. In addition to intensifying drought risks, excessive water abstraction damages ecosystems and the critical services they provide. For example, in Spain's Doñana National Park, over-abstraction was associated with reduced water quality and lower carbon storage capacity, in addition to diminished stream flows, falling groundwater tables, and slower aquifer recharge rates. Such degradation not only threatens biodiversity but also undermines the natural resilience of ecosystems to climate change.

Source: (IDMP, 2022[13]; OECD, 2024[46]; EEA, 2021[47]; WWF, 2023[48]; European Commission, 2013[49]; Richey et al., 2015[50]; Sun et al., 2021[51]).

Most OECD countries employ water allocation regimes and permitting systems to manage water resources. For example, Australia, the United States, and many European countries have comprehensive water management frameworks in place that include both allocation and permitting systems. The design of these frameworks – including the conditions for water use limits, efficiency requirements, and seasonal restrictions – vary depending on regional contexts, ultimately defining whether or not these allow to adapt to changing climate conditions and fluctuating water availability. For example, in Australia's Murray-Darling Basin, water allocation plans dynamically adjust water rights based on actual water availability, ensuring the prioritisation of essential services during drought (Murray-Darling Basin Authority, 2023[52]). In its recent Water Code update, Chile also tied allocated water volumes to water availability and made new water rights revokable in case of under- or inefficient use, though challenges linked to over-allocation and permanent water rights remain (Ministerio de Obras Públicas, 2022[53]; OECD, 2024[54]). Provided compliance is respected, linking water allocation to availability and efficiency can incentivise shifts toward less water-intensive activities or crops and encourage relocation to areas with more reliable water sources (Ramirez, 2022[55]). Formal water markets are in place in various countries, including Australia (see Section 4.3.3), Chile, and Spain (OECD, 2021[56]).

Nonetheless, many water use and abstraction regulations remain insufficiently adapted to the challenges posed by climate change. Quantitative restrictions on water withdrawal are often employed only as reactive measures during drought emergencies, limiting their potential to strengthen long-term resilience.[4] While short-term restrictions may help overcome temporary water scarcity, they do not enhance resilience, as they do not trigger the long-term changes needed to foster adaptation. Besides, even in drought-prone countries such as France, individual permits are issued without sufficiently considering their cumulative impact on long-term water resources (OECD, 2025[3]). Moreover, water use regulations often fail to appropriately incorporate the effects of climate change and over-abstraction on future water availability, as observed for example in Chile, France, Spain, and California (Ramirez, 2022[55]; OECD, 2025[3]; Gómez Gómez and Pérez Blanco, 2012[57]; Gleick et al., 2014[58]). A 2015 OECD survey found that only 57% of country respondents integrate considerations on future climate impacts into their water allocation regimes (OECD, 2015[59]). This gap is likely to become more pressing as climate change enhances agricultural potential in traditionally water-abundant regions, heightening competition for freshwater among sectors.

This further underscores the importance of integrated, forward-looking, and climate-resilient water allocation frameworks that balance economic and food security objectives with equitable access and the preservation of essential ecosystem functions.

### Box 4.3. Integrating ecological flow considerations in water allocation regimes

Integrating ecological flows into water allocation regimes is key to ensure drought resilience and maintain the health of aquatic ecosystems. Ecological flows define the amount, timing, and quality of water needed in rivers or lakes to sustain healthy ecosystems and the services they provide to humans and nature. Neglecting ecological flows in water allocation and permitting frameworks can lead to the degradation of river ecosystems and wetlands, disrupting biodiversity and weakening the natural resilience of ecosystems to droughts and other environmental stresses.

Many governments have recognised the importance of preserving ecological flows. For example, South Africa's National Water Act, the Swiss Federal Act on the Protection of Waters, and the EU Water Framework Directive all include provisions for ecological flows. In Australia, the Murray-Darling Basin Plan sets abstraction limits to protect river health and allocates proportional water entitlements to ecosystems, ensuring minimum ecological functions even during drought. The federal government further supports this approach by buying back water entitlements from water markets to restore freshwater ecosystems. In response to a 2019 OECD survey, 78% of respondents[5] reported incorporating minimum environmental flows or sustainable diversion limits in their water allocation regimes. The amount of water needed for ecological functions is often defined before allocating the remainder to other users, either through pre-allocated shares for ecosystems (e.g. Australia) or based on minimum flow requirements meant to maintain ecological functions regardless of other allocations (e.g. Israel and Switzerland).

Despite progress, there is scope to better align abstraction levels and ecological flows and to further prioritise ecological flows in water regulation. For example, in many OECD countries, minimum flow requirements are suspended during water scarcity, undermining their ability to protect ecosystems. Aligning other water-dependent activities, such as hydropower operations, with ecological flow requirements is also critical to maintaining ecosystem health and resilience.

Sources: (OECD, 2024[46]; European Commission, 2000[60]; WWF, 2023[48]; Republic of South Africa, 1998[61]; Murray–Darling Basin Authority, 2023[62]; Fedlex, 2023[63]; OECD, 2021[56]).

One additional challenge is that illegal water use remains a significant issue in water-scarce regions due to limited monitoring, weak enforcement, and outdated regulations. As of 2019, illegal groundwater abstractions were reported to occur in 12 OECD countries (OECD, 2021[56]). In France and Bulgaria, illegal water use accounts for approximately 13% of total abstraction, while in Spain's Castile-La Mancha region, it exceeds 22% (European Court of Auditors, 2021[64]). This highlights the need to strengthen regulatory frameworks and improve their enforcement, as well as to scale up the water flow monitoring systems to help detect illegal connections and leaks. Many EU countries, for example, are adopting advanced monitoring systems to identify unauthorised water use (EEA, 2022[65]).

#### Incentives for water efficiency

Improving water use efficiency can significantly help enhance resilience to drought, as it helps conserve limited water resources and ensure their sustainable use across sectors. By adopting water-efficient technologies, communities can reduce water waste, mitigate the impacts of water scarcity, and maintain essential activities during dry periods. At the household level, devices such as low-flow faucets and flow reducers can lower water use by up to 20% (OECD, 2025[3]). In agriculture, technologies like drip and sprinkler irrigation and soil moisture sensors offer significant potential to boost drought resilience, provided it is combined with regulations limiting water use (see Section 4.3.3). Water metering technologies further support efficient water use by enabling households, farmers, and businesses to monitor consumption, raise awareness, and encourage billing based on actual use. Overall, strengthening water use efficiency is key to address the challenges posed by climate variability and ensure long-term water security for agriculture, industry, and households.

Governments have developed various regulatory and financial incentives to promote the adoption of water-saving technologies. While these often focus on irrigation (discussed in depth in Section 4.3.3), they sometimes also extend to households. For example, in California, the Model Water-Efficient Landscape Ordinance establishes water efficiency and irrigation design standards for large development projects and encourages local governments to provide financial incentives for water-saving technologies (City of Vallejo, 2024[66]). In Australia, rebate programmes encourage households to install water-efficient appliances (Australian Government, 2013[67]). Some local governments and water operators in France have also distributed water-saving kits to households, helping to limit flow rates and improve water use efficiency (OECD, 2025[3]). Israel has developed a comprehensive water metering system for domestic and agricultural use, which relies on a combination of regulatory instruments, financial incentives, and awareness-raising campaigns (OECD, 2023[68]).

The effectiveness of water use efficiency measures ultimately depends on how the volumes of water saved are managed. Without proper oversight, efficiency gains can encourage increased water demand, negating the intended benefits (OECD, 2024[46]; OECD, 2016[69]). This “rebound effect” has been observed in Australia, where irrigation efficiency improvements were linked to a 21-28% increase in water use (OECD, 2025[3]). Mitigating such risks requires the establishment of robust and adaptive water allocation regimes that regulate how and under what conditions saved water can be used. This approach ensures that water savings contribute to reducing drought risk rather than inadvertently increasing demand.

#### Water pricing

Water pricing is a key mechanism for encouraging water saving. It can consist of abstraction charges for withdrawing water from natural sources or tariffs imposed on water users to pay for water services such as water supply or wastewater treatment. These pricing mechanisms can provide incentives for sustainable water management, reflecting the economic costs of water services, the environmental costs of water abstraction, and the opportunity costs from competing uses (Farnault and Leflaive, 2024[70]; Leflaive and Hjort, 2020[71]; OECD, 2017[72]). Overall, by signalling scarcity, water pricing can promote water use efficiency and incentivise investment in water-saving processes and technologies.

Water pricing is widely implemented but varies significantly in design, objectives, and price levels (Figure 4.3). For instance, charges and tariffs can be based on volumetric use or be differentiated based on usage tiers, regions, seasons and other factors (Table 4.3). Among the countries adhering to the OECD Council Recommendation on Water, 74% have abstraction charges for surface- and groundwater. Half apply charges to energy producers and industrial users, and 45% to agricultural users (OECD, 2021[56]). Different types of tariffs are also widely used. For instance, progressive tariffs are used in countries like Germany, France, and Italy (EEA, 2024[73]; OECD, 2025[3]). Seasonal or regional pricing has been implemented in countries like Greece, Hungary, and Spain (OECD, 2024[46]; Tortajada et al., 2019[74]).

### Table 4.3. Selected water pricing mechanisms relevant for drought prevention

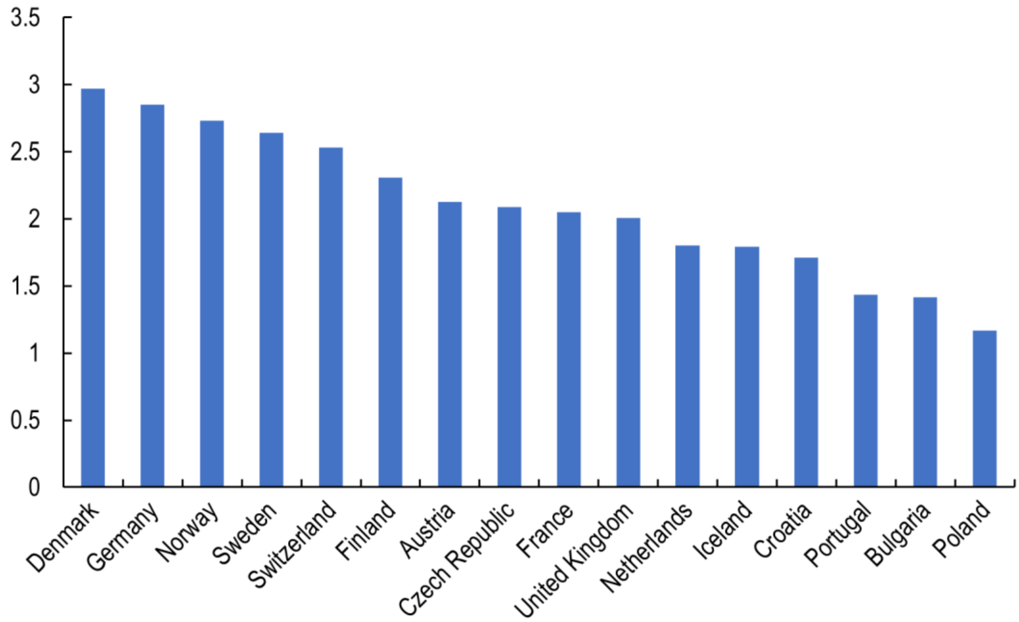
| Pricing mechanism | What it is | Key benefits |
|---|---|---|
| Volumetric tariffs or charges | Prices are based on the actual volume of water used or abstracted | Encourage conservation by linking cost to consumption/abstraction, discourage waste, support efficient use |
| Seasonal/regional tariffs or charges | Prices fluctuate based on seasonal or regional water availability, with higher rates in water-scarce periods/regions | Reflect water scarcity, incentivise efficient use, support equitable distribution, adapt to local conditions |
| Progressive (block) tariffs | Prices increase with higher usage tiers (e.g. low rate for essential use, higher rates for excessive use) | Ensure affordability for basic needs while discouraging excessive consumption, promote a culture of conservation |
| Two-part tariffs | Prices combine a fixed charge (for infrastructure) with a variable charge based on water consumption | Balance cost recovery and user accountability |
| Capped abstraction charges | Fees apply up to a predefined abstraction limit, with penalties or significantly higher charges for exceeding it | Prevent overextraction, promote compliance, protect long-term resource sustainability |
| Differentiated charges | Fees vary based on specific factors, such as source of water (e.g. higher rates for groundwater) or sectors of use (e.g. agriculture, industry) | Reflect environmental impacts (e.g. groundwater depletion), incentivise conservation in high-impact sectors, promote fair use |

Note: This table does not include pricing mechanisms that do not incentivise long-term conservation, e.g. flat-rate tariffs, fixed charges, or dynamic tariffs and charges.
Source: Author's own.

The effectiveness of pricing instruments depends on price levels and on users' ability to adjust their demand. Household consumption tends to be inelastic due to the lack of substitutes for drinking water, with demand estimated to decrease by 0.1% to 1% for every 1% increase in water prices (Reynaud and Romano, 2018[75]; Sebri, 2013[76]). In contrast, agricultural and industrial users are generally more responsive to price changes, though this can lead to unintended social costs. Demand elasticity also varies based on local geography and specific sub-sectors, crops, and productive practices. Along with demand elasticity, water scarcity considerations are also crucial to inform the design of abstraction charges. Yet, in many contexts, abstraction charges primarily function as revenue-generating fees rather than tools to promote efficiency, failing to internalise the full costs of water scarcity (OECD, 2025[3]; OECD, 2024[46]). For example, existing abstraction charges in Europe only internalise an average of 2-3% of water scarcity costs (IEEP, 2021[77]).[6] Moreover, in many countries, the exemptions of certain sectors (e.g. agriculture) from water charges often undermine their effectiveness (OECD, 2018[78]).

While water pricing is an effective tool for promoting water conservation, it has limitations. Distributional impacts are a major concern for domestic consumption, as higher water prices may disproportionately affect low-income households. Progressive tariffs can mitigate this by keeping essential water use affordable (Ruijs, Zimmermann and van den Berg, 2008[79]), though they must be carefully designed to account for different consumption patterns and ensure cost recovery (Leflaive and Hjort, 2020[71]).[7] Raising water prices to reflect scarcity costs can be politically sensitive and challenging, especially in regions where water use is heavily subsidised. Additionally, water pricing alone may not be sufficient to address challenges such as groundwater over-abstraction or ecosystem deterioration. Combining pricing measures with non-pricing instruments – such as regulations, incentives, and awareness campaigns – can enhance their effectiveness. Accurate water metering is also needed to calibrate price levels to actual demand and consumption trends, ensuring that pricing schemes are fair and aligned with sustainability goals (OECD, 2024[46]).

**Figure 4.3. Average price for drinking water in selected countries (EUR/m3), 2022**




Note: To allow comparability, the calculations are based on a consumption level of 15m³ per month. Country averages are calculated by weighting the prices charged by operators based on the population they serve. Therefore, the price levels displayed for each country do not represent the average of all prices charged domestically. Price levels must be considered in the context of each country's specific conditions (e.g. water scarcity levels, income per inhabitant, and changes over time or during periods of scarcity).
Source: adapted from OECD (2025[3]), based on data from the International Benchmarking Network (IBNET).

### Awareness raising

Awareness raising measures aim to reduce water use by promoting less water-intensive and more water-efficient behaviours. These low-cost, no-regret measures often have high benefit-to-cost ratios, though their effectiveness depends on factors such as baseline consumption levels, resource availability, and local contexts (e.g. urban vs rural environment). Awareness-raising campaigns can reduce water consumption by approximately 9.5-32.5%, while labels and standards have the potential to achieve reductions of 6-10% (OECD, 2025[3]).

Over the past decades, governments and water operators have implemented numerous awareness-raising initiatives at various territorial levels. Successful urban examples include efforts in Saragossa and Sevilla (Spain), Melbourne (Australia), Tallin (Estonia), Copenhagen (Denmark), and Atlanta (United States). These campaigns have raised awareness about drought risk and encouraged sustainable water-use behaviours (OECD, 2025[3]; EMASESA, 2022[80]). For instance, in Barcelona, awareness-raising campaigns contributed to a 10% reduction in domestic water consumption between 2006 and 2011 (EEA, 2020[81]). In Sevilla, similar measures resulted in a 39% reduction per capita (EMASESA, 2023[82]). Along with the uptake of water-saving technologies, awareness-raising efforts have been among the most effective tools for reducing water demand in Spain (Tortajada et al., 2019[74]).

Labels and standards for water-efficient appliances and buildings have been introduced in some countries to encourage sustainable water-use behaviours. For example, water-saving labels for selected household appliances in Australia have reduced household water consumption by 6% (equivalent to 0.8% of the country's total consumption) in just one year. In France, water-efficiency labels are already in use, but broader adoption could reduce household water consumption by an estimated 22% in the Paris region

(OECD, 2025[3]). Such measures not only guide consumer choices but also incentivise manufacturers to improve the water efficiency of their products, further driving long-term reductions in water demand.

### *Policy measures for enhancing water supply*

Efforts to reduce water demand must be paired with strategies to enhance water supply. These can focus on improving infrastructure efficiency, facilitating groundwater recharge, and diversifying water sources by tapping into unconventional resources such as rainwater, treated wastewater, and desalinated water (Table 4.4). Integrating these innovative approaches with existing supply systems enhances resilience to climate variability and can help communities secure sustainable water resources and strengthen their resilience to prolonged droughts. Other supply and storage solutions – such as the use of artificial reservoirs – also exist, though their role in building long-term resilience to climate change is contentious (Box 4.4). Water supply enhancements must also be at the heart of governments' economic planning efforts, to ensure that development ambitions are underpinned by adequate, sustainable, and climate-resilient water resources.

## Table 4.4. Overview of selected water supply measures and their benefits

| Intervention | Description | Benefits |
|---|---|---|
| Water network efficiency | Enhancing the efficiency of water distribution systems to minimise leaks and optimise performance | Reduce water loss, lower operational costs, extend infrastructure lifespan, decrease energy consumption |
| Managed aquifer recharge | Replenishing groundwater reserves using infiltration basins, recharge wells, or nature-based solutions | Maintain groundwater levels, increase water supply resilience, mitigate drought impacts |
| Rainwater harvesting | Capturing and storing rainwater from rooftops or other surfaces for future use during dry periods | Increase water availability, reduce urban heat and runoff, lower costs associated with stormwater management systems and water treatment and distribution |
| Water reuse | Recycling greywater and treated wastewater for non-potable uses | Increase water availability, minimise wastewater discharge and associated pollution, reduce wastewater treatment costs |
| Desalination | Using technology to remove salt and other minerals from seawater or brackish water to produce freshwater | Increase freshwater availability, generate employment for plant construction, operation, and maintenance |

Note: The measures included in this table entail economic and ecological costs that must be carefully balanced against their benefits on a case-by-case basis, considering local contexts and long-term resilience and sustainability.
Source: Author's own.

### Box 4.4. Avoiding maladaptation: The controversial role of reservoirs and water transfers

Artificial water reservoirs have historically played a critical role in buffering water scarcity, though their effectiveness under climate change is uncertain. Water reservoirs can store water for drinking, industrial, agricultural, and energy production purposes. Less predictable precipitation patterns and higher temperatures may limit the ability of these costly infrastructures to maintain sufficient water storage in the future. For example, if a drought similar to that of 1921 were to occur in the Paris metropolitan region, existing reservoirs would recharge to only 28%[8] of their capacity. Moreover, depending on their location, local climate conditions, and the type of water withdrawal, artificial reservoirs can reduce the annual flow of rivers by 7-35%, potentially harming downstream ecosystems and water availability. Given these challenges, building new reservoirs might not be the most effective strategy for enhancing water security in all drought-prone regions. Instead, new reservoir projects should be approached as complementary measures and undergo comprehensive resilience and impact assessments to evaluate their feasibility and long-term effectiveness. Equally important is ensuring proper maintenance and retrofitting of existing assets and integrating them with natural water storage solutions to enhance their overall resilience and long-term effectiveness.

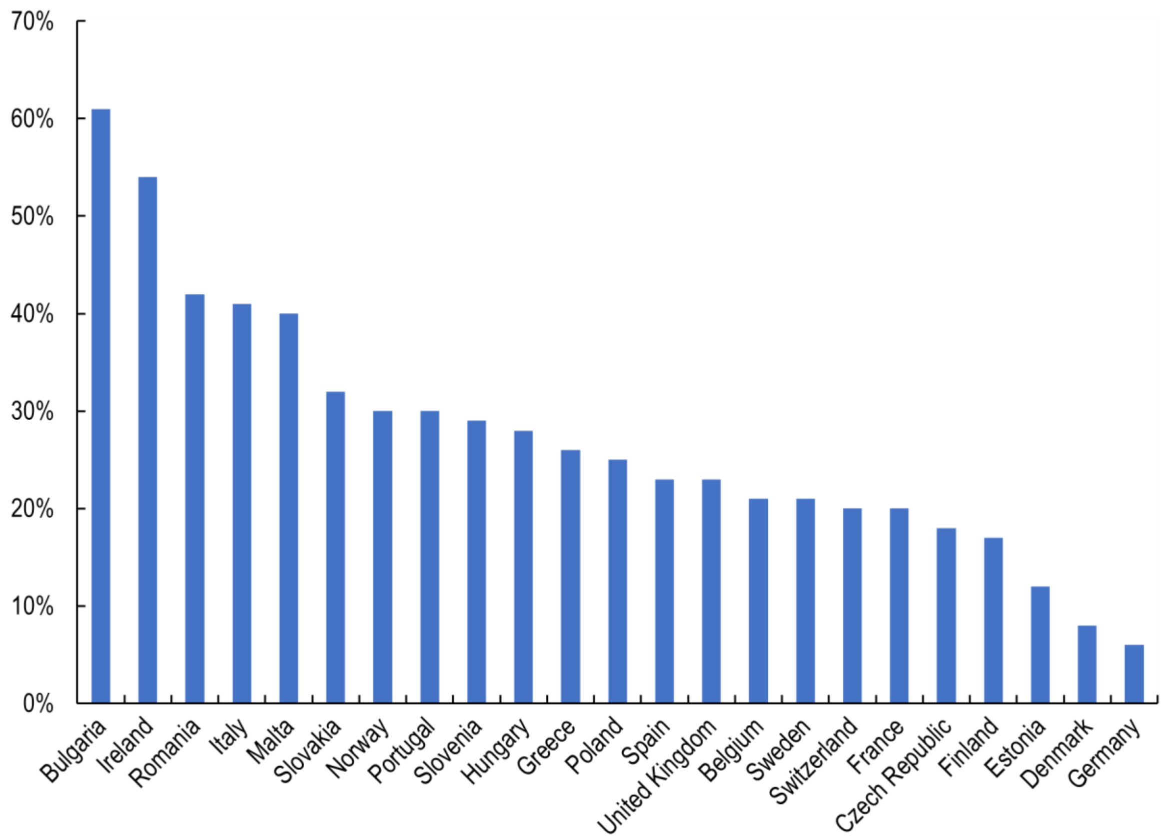
The use of water transfers has also been questioned. Such infrastructures involve diverting water from one basin to another. They have been used in countries like China, Korea, Spain, and the United Kingdom to support agricultural, industrial, and municipal water needs in regions with insufficient water supply. While these infrastructures can provide short-term relief, they raise concerns regarding their high construction and maintenance costs, their environmental impacts and climate resilience, and their actual water supply benefits given evaporation during transport and storage. In fact, growing water scarcity may undermine the effectiveness of transfers and exacerbate territorial conflict over shared water resources. Additionally, these infrastructures themselves risk exerting excessive pressure on the basins they rely on, potentially worsening drought risk. These challenges are exemplified by the Chavimochic water transfer project in Peru. While the project has delivered significant socio-economic benefits, including improved well-being and development, its reliance on shrinking glacier resources threatens its long-term sustainability. Such cases underscore the need for careful planning and impact assessments when considering large-scale water transfer projects.

Source: (Sun et al., 2021[51]; OECD, 2025[3]; IDMP, 2022[13]; OECD, 2024[46]; SIGAL, 2020[83]; WRI, 2021[84]; EPTB Seine Grands Lacs, 2021[85]; OECD, 2018[78]; World Bank Group, 2023[25]).

#### Efficiency of water supply networks

Reducing leakage in water distribution networks has significant potential to improve water-use efficiency and safeguard resources. Currently, 24% of potable water in the EU is lost due to pipeline leakages (Ociepa-Kubicka, Deska and Ociepa, 2024[86]) (Figure 4.4), with losses reaching up to 50% in some countries (European Commission, 2013[49]). These losses are often linked to insufficient investment in urban water infrastructure – including in their operations and maintenance, as observed in countries like Costa Rica and Italy (OECD, 2023[87]; JRC, 2023[88]). Upgrading irrigation conveyance infrastructure also offers considerable water savings, with potential reductions in agricultural water use of up to 25% in the EU (EEA, 2021[47]).

**Figure 4.4. Share of wasted water in selected European countries' water distribution systems**




Source: adapted from OECD (2025[3]), based on data from EurEau (2021[89]).

Governments are implementing various measures to improve drinking water infrastructure efficiency. This includes setting efficiency targets for leakage reduction, infrastructure upgrades, and using surveillance technologies such as water meters and sensors to identify leaks. Some municipalities provide inspiring examples in this field. For instance, Sevilla (Spain) reduced pipeline losses by 68% between 1991 and 2021, while Paris (France) maintains a network renewal rate of 1.19% per year, i.e. nearly double the national average. In London (United Kingdom), local water operators also have set leakage reduction targets (OECD, 2025[3]). In Korea, the Smart Water Management initiative uses real-time data to detect leaks and promote household water use efficiency (OECD, 2017[90]). While infrastructure improvements costs vary depending on whether networks run above or below ground, increasing water distribution efficiency is a no-regret measure, insofar as the socio-economic and environmental benefits outweigh the implementation costs (OECD, 2025[3]). However, in some countries, underinvestment caused by poor cost-recovery mechanisms in water supply and sanitation agencies remains a significant barrier.

**Managing aquifer recharge and water quality**

Managing groundwater recharge and water quality is pivotal to ensure reliable water supplies on the long term. Aquifer recharge can occur naturally through soil infiltration (see Section 4.3.2) or artificially via human interventions. Complementing this, water quality policies safeguard the usability of these resources, preventing aquifer (as well as surface water) contamination and ensure a sustainable supply of clean water for future use.

Managed aquifer recharge (MAR) entails the replenishment of groundwater by allowing water to infiltrate aquifers, enabling the storage of excess water during wet periods for use during dry spells. This can be achieved through recharge basins, injection wells, and nature-based solutions (NbS) that enhance natural infiltration processes. In the context of climate change, MAR is becoming increasingly important to ensure water sustainability, particularly in regions where surface water is scarce or highly variable. Without such interventions, many countries, including Greece, Portugal, and Spain, are projected to experience significant reductions in groundwater recharge rates (JRC, 2018[91]). In parallel, MAR can also contribute to flood protection.

OECD countries have been progressively adopting MAR practices, with the United States, Australia, and several European countries leading the way. In Europe, more than 220 MAR sites are operational, and adoption is projected to grow (Sprenger et al., 2017[92]). For example, Spain's Pedrajas-Alcazarén MAR site raised the water table by 0.75 metres between 2012 and 2016 (Deltares, 2022[20]). With 26% of the global MAR capacity, the United States have extensively implemented MAR in Arizona and California, successfully reversing declining groundwater levels (Dillon et al., 2019[93]; Scanlon et al., 2016[94]). In Australia, subnational governments (e.g. Western Australia) have developed frameworks and tools to facilitate MAR adoption across the state (Government of Western Australia, 2021[95]). In recent decades, MAR techniques have also gained traction in Africa. Countries like Kenya, Morocco, Namibia, Somalia, and South Africa have implemented MAR to enhance water security in drought-prone regions and areas facing groundwater stress.

Managing the interaction between drought and water quality is also paramount for building drought resilience. Poor water quality reduces the availability of clean water sources, while drought, in turn, often exacerbates water quality issues by concentrating salinity and pollutants in freshwater supplies. The impact of this interplay was observed for example in Denmark, where high pollutant and nitrate concentrations in freshwater have led to the closure of 30% of existing wells (EEA, 2017[96]), as well as in several other instances in Colorado (United States), Germany, and Poland (see Chapter 3). Globally, water contamination is projected to intensify water scarcity by 2050, affecting thousands of surface and groundwater bodies (Wang et al., 2024[97]) and imposing additional treatment costs (EEA, 2024[73]).

Addressing these challenges requires maintaining ecological flows and establishing robust water quality standards. It also involves tackling key pollution sources such as agricultural runoff, industrial discharges, and urban wastewater, e.g. through permitting systems, monitoring requirements, adoption of best available technologies to improve water quality. Innovative approaches, such as salinity credit trading in Australia, have also helped protect critical water resources by regulating industrial discharges in freshwater (NSW EPA, 2024[98]). Coupled with investments in water treatment infrastructure and enhanced monitoring and enforcement, these measures help safeguard freshwater resources and ensure resilience to growing drought risks.

### Rainwater harvesting

Rainwater harvesting is an effective strategy to meet water needs by capturing and storing excess rainwater for later use. It can be applied for household and irrigation purposes, as well as municipal uses such as street cleaning, green space irrigation, climatisation. By reducing reliance on surface and groundwater resources, rainwater harvesting helps alleviate pressure on these vital resources. For example, rainwater harvesting has the potential to meet up to 90% of household and recreational water demand, with substantial savings recorded even in low-precipitation areas such as Barcelona (Spain) (OECD, 2025[3]; Domènech and Saurí, 2011[99]). This approach is particularly valuable in regions with limited freshwater availability or subject to saltwater intrusion, such as small islands and arid or semi-arid areas. Regions with distinct wet and dry seasons, and those reliant on unpredictable rainfall for crop growth, can also benefit significantly by storing surplus water for use during dry periods.

The adoption of rainwater harvesting systems has been supported by a combination of regulatory requirements and economic incentives. In many cases, building codes and regulations primarily focus on promoting adoption in new buildings or renovation projects, while grants and subsidies are sometimes used to encourage retrofitting of existing structures (Table 4.5). This is the case in Barcelona (Spain), where rainwater and greywater collection is mandatory for new buildings and subsidies for retrofitting private buildings are in place (OECD, 2025[3]). In San Francisco (United States), legal requirements for rainwater harvesting in new buildings have reduced drinking water consumption by up to 50% in some areas (Shimabuku, Diringer and Cooley, 2018[23]). A careful balance of regulatory requirements and financial incentives is key to encourage the uptake of rainwater collection systems while minimising financial burdens on property owners.

## Table 4.5. Country experiences in government support for rainwater harvesting

| Country | Policy instrument | Description |
|---|---|---|
| Australia | Financial incentive | Rebates are available at national, regional, and local levels to support homeowners who install rainwater harvesting tanks on their properties |
| Barbados | Regulations | Minimum rainwater harvesting capacity is required for both residential and commercial buildings |
| Belgium | Regulations | In Flanders, rainwater collection is mandated for new constructions and renovation projects exceeding a certain surface area |
| Czech Republic | Grants | The national "Dešťovka" programme provides subsidies to homeowners and construction companies for rainwater harvesting in both new and existing buildings |
| France | Subsidies | In Île-de-France, financial support covers 50% of the cost for installing water collectors on existing properties |
| Germany | Fiscal incentives and subsidies | In most of the country, incentivise rainwater harvesting by calculating wastewater fees based on properties' impermeable surface area. In Bremen, subsidies cover 40% of installation costs (up to EUR 5 000) |
| New Zealand | Regulations | Rainwater collection is required in several urban areas across the country |
| Poland | Subsidies and reimbursements | In Wrocław, homeowners can claim up to 80% reimbursement (up to EUR 1 100). In Kraków, subsidies cover 50% of costs for installing rainwater collectors |
| Spain | Regulations and subsidies | In Barcelona, rainwater collection is required for new constructions and renovations exceeding a certain size and in certain neighbourhoods. Subsidies for retrofitting existing properties are available |
| Türkiye | Regulations | New buildings constructed on plots larger than 2 000 square meters must incorporate rainwater collection systems. Local municipalities have the discretion to extend this requirement to smaller plots |
| United States | Regulations | In Tucson (Arizona), rainwater harvesting is mandated under the Land Use Code. San Francisco (California) mandates the installation and maintenance of stormwater capture in certain developments |

Source: Author's own, based on information from OECD (2025[3]), EEA (2020[81]), FAO (2016[21]), UNCCD (2022[100]), Australian Government (2013[67]), Shimabuku, Diringer and Cooley (2018[23]), City of Tucson (2024[101]), Esin Attorney Partnership (2022[102]).

To ensure the sustainability of rainwater harvesting, it is important to regulate when and how rainwater can be collected and used. For example, in areas where downstream stakeholders or local water cycles depend heavily on rainwater, harvesting may need to be limited. Conversely, rainwater harvesting could be encouraged during periods of heavy precipitation as a substitute for groundwater abstraction, helping to preserve groundwater resources. Urban areas with high runoff and coastal areas where rainwater is often discharged into the sea could particularly benefit from expanded rainwater harvesting practices (UNCCD, 2023[103]; Gleick et al., 2014[58]; EEA, 2020[81]). Altogether, adapting rainwater harvesting strategies to local contexts is essential to maximise its benefits while avoiding unintended consequences for water systems and stakeholders.

### Water reuse

Water reuse (or recycling) is an effective strategy for expanding water supply by recycling greywater and treated wastewater.[9] This practice can help ensure supply for irrigation, industrial, and municipal uses and can also contribute to aquifer recharge and domestic non-potable uses. Recent analysis suggests that reusing treated wastewater in urban areas and industrial parks could reduce drinking water consumption by 26-48% (Bauer, Linke and Wagner, 2020[104]).[10] In the EU, water reuse for irrigation alone could save up to 50% of water use (EEA, 2021[47]).

Many governments have introduced regulations and incentives to support water recycling (Table 4.6). In Israel, 85% of wastewater is reused, accounting for 45% of agricultural consumption and 21% of total water consumption. This success is attributed to supportive regulations combined with water tariffs and significant investments in technology. Similar wastewater reuse rates (90%) are found in Cyprus (OECD, 2024[46]), which aims to reuse 100% of urban wastewater for non-potable uses such as irrigation and aquifer recharge (EEA, 2020[81]). In Australia, the adoption of water reuse is increasing, supported by national guidelines and monitoring efforts that are often complemented by subnational recycling targets (OECD, 2018[105]; OECD, 2021[56]). Despite these advancements, water recycling still constitutes a small share of total water use globally. For example, in the EU, recycled water accounted for only 2.4% of treated wastewater and 0.4% of annual freshwater withdrawals in 2015 (European Commission, 2018[106]).

## Table 4.6. Country experiences in supporting water recycling

| Government | Policy instrument | Description |
|---|---|---|
| Australia | Guidelines and quantitative targets | Water quality guidelines and monitoring in place for various uses (e.g. agriculture, industry, municipal, drinking water, MAR). State and city-level targets for waste- and stormwater recycling have been established. For example, Perth aims to recycle 30% of its metropolitan wastewater by 2030 |
| Germany | Subsidy | In Bremen, the local government subsidises greywater reuse systems, covering 40% of installation costs (up to EUR 5 000) |
| Israel | Public investments in wastewater treatment facilities | Significant national investments in wastewater treatment expansion. The Greater Tel Aviv Wastewater Treatment Plant provides about 400 000 $m^3$ of treated water daily, serving 11 cities and 2.5 million people |
| Japan | Regulations | The reuse of greywater is mandatory for buildings larger than 30 000 m2 and when potential greywater volumes exceed 100 $m^3$ per day |
| Singapore | Awareness raising | Singapore's Public Utilities Board engages in public education and outreach campaigns to promote the use of reclaimed water |
| Spain | Regulations and guidance | The Royal Decree 1620/2007 sets water quality requirements and establishes a framework for water reuse authorisation. The National Plan of Water Treatment, Sanitation, Efficiency, Savings and Water Reuse promotes the increased use of reuse water. Catalonia's special drought plan mandates emergency measures to be implemented, including water recycling |
| Tunisia | Subsidy | The government provides subsidies covering 20% of the full price to make water reuse tariffs significantly lower than those on conventional water |
| United States | Tax credit | In California, homeowners who install greywater reuse systems in their properties are eligible for tax credits |

Source: Author's own, based on information from OECD (2025[3]; 2024[46]; 2018[105]; 2023[68]; 2021[56]), EEA (2020[81]), Navarro (2018[107]), Agència Catalana de l'Aigua (2020[4]), Singapore's National Water Agency (2024[108]) and Chenini (2010[109]).

The broader adoption of water reuse is inhibited by several challenges. In some countries, regulations restrict water reuse for specific purposes (e.g. household use in France (OECD, 2025[3]). In others, the lack of guidance and standards hinders investment in recycling technologies. The EU Water Reuse Regulation addresses this by setting minimum water quality, monitoring requirements, and risk management provisions (European Union, 2020[110]). Developing or retrofitting advanced treatment facilities requires significant upfront investments, which can deter local governments despite long-term savings. Financial incentives are thus key to support adoption, particularly in water-intensive sectors like agriculture (OECD, 2025[3]; OECD, 2024[46]). Finally, public hesitance about potential health risks associated with the use of recycled water (e.g. possible water contamination during domestic use) further inhibits adoption (Morris et al., 2021[111]; European Union, 2020[110]). Targeted awareness-raising campaigns have successfully enhanced public acceptance of water recycling, as seen in Türkiye (Taher et al., 2018[112]).

Regulating when and how water can be reused is vital to ensure the sustainability of this practice. For instance, water reuse might need to be restricted where wastewater discharges support ecological flows or groundwater recharge (OECD, 2025[3]; EEA, 2024[73]). This is the case of the Seine River (France), where treated wastewater accounts for up to 70% of the river flow (Agence de l'Eau Seine Normandie, 2022[113]). Conversely, in coastal regions where treated wastewater would otherwise be discharged into the sea, encouraging reuse could be prioritised (OECD, 2025[3]). By tailoring water reuse regulations to local contexts, countries can optimise its benefits while minimising environmental and socio-economic risks.

**Desalination**

Desalination can offer a viable solution for regions with limited or shrinking freshwater supply, provided negative side-effects are addressed. This practice involves removing dissolved salts from seawater and brackish water to produce freshwater and is thus often used in areas with scarce freshwater resources but abundant seawater access. For example, in the Middle East, up to 90% drinking water comes from desalinated seawater (Eyl-Mazzega and Cassignol, 2022[114]). Israel has invested significantly in desalination technologies, with over 80% of its urban water supply now sourced from desalination plants (OECD, 2023[68]). In Europe, desalination is widely used in the Mediterranean region (e.g. Greece, Italy, and Spain) as a supplementary source, primarily for addressing seasonal or localised water scarcity in coastal areas. Australia, Chile, and Egypt have also adopted desalination. Egypt has launched a series of five-year plans to 2050 to expand desalination capacity to meet drinking water needs (IDMP, 2019[115]; Elsaie et al., 2023[116]).

Governments use various policy instruments to support the adoption and advancement of desalination technologies. These include financial incentives such as subsidies, grants, and tax breaks to encourage investment in desalination plants and technologies, as well as regulations to ensure the environmental sustainability of desalination processes. Research and development funding is also provided to support innovation in energy-efficient and environmentally sustainable desalination technologies, such as solar-powered desalination. For instance, the US federal government has recently provided USD 250 million in funding to support the construction of desalination plants (White House, 2024[117]). Germany has also launched funding programs for research and development (R&D) projects targeting water reuse and desalination to increase water availability (BMBF, 2024[118]).

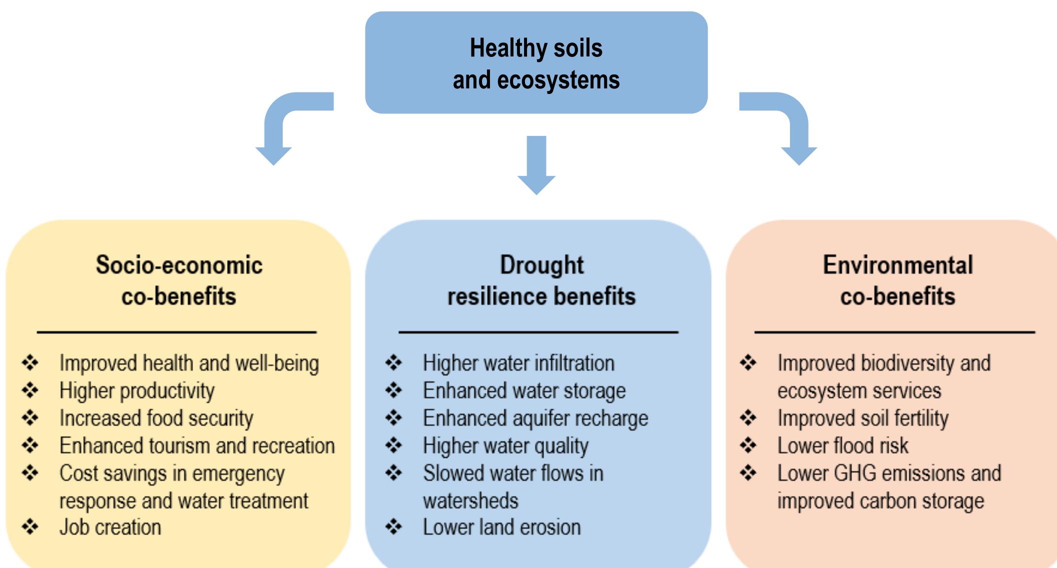
Despite its potential to increase freshwater availability, desalination faces several challenges. Although the costs of desalination technologies have decreased significantly in recent years, they remain high compared to other water supply solutions. Costs depend on plant size and the technology used.[11] Desalination is also highly energy-intensive (Shokri and Sanavi Fard, 2022[119]) and raises concerns about impacts on marine ecosystems and water quality due to the risk of chemical contamination and brine discharge. Whereas recent technological advancements have improved plant efficiency (Hidalgo González et al., 2020[120]) and reduced environmental impacts, further technology development and investments are needed to enhance environmental safeguards and sustainability, including measures to minimise ecological risks and optimise energy use (Bdour et al., 2023[121]; Berenguel-Felices, Lara-Galera and Muñoz-Medina, 2020[122]; EEA, 2020[81]; EEA, 2021[47]).

### *4.3.2. Managing land and ecosystems for drought resilience*

Managing land and ecosystems sustainably is fundamental to enhance resilience to drought in the context of climate change (see Chapter 2). Healthy soils and ecosystems improve water retention in the landscape, enhancing the availability of surface and groundwater resources and regulating hydrological flows. The benefits of sustainable land and ecosystem management range from improved water availability at the farm, city, or river basin level achieved through locally-implemented interventions, to shifts in hydrological cycles (e.g. enhanced precipitation) when larger-scale interventions are implemented at regional level. At all scales, sustainable land and ecosystem management reduce drought risks while strengthening the resilience of both human communities and natural ecosystems. Furthermore, NbS offer additional co-benefits such as water purification, climate mitigation, biodiversity conservation, and improved air quality (Figure 4.5). To maximise their effectiveness and avoid the risk of maladaptation, NbS must be adapted to local socio-economic, climatic, and environmental conditions (OECD, 2021[123]; Li et al., 2023[124]).[12]

Governments have increasingly reflected the importance of conserving and restoring land and ecosystems to reduce drought risk, in their policy and regulatory frameworks. For example, the restoration of surface water bodies is explicitly encouraged in Spain's national adaptation plan and Switzerland's law on water resource protection (Fedlex, 2023[63]). NbS have also been consistently promoted through EU legislation as a key approach to addressing climate and environmental challenges. Globally, more than 120 Parties to the United Nations Convention to Combat Desertification (UNCCD) have committed to halting land degradation by integrating restoration targets into national legislation, aiming to rehabilitate 450 million hectares of degraded land. The following sections explore the benefits and extent of NbS adoption at landscape and urban level (Section 4.3.2). A further discussion on the role of sustainable agriculture practices for soil and ecosystem health is included in Section 4.3.3.

**Figure 4.5. The benefits of sustainable soil and ecosystem management**




Source: Author's own.

### *Managing ecosystems at landscape level*

Protecting and restoring ecosystems at the landscape level is essential for enhancing resilience to drought. Healthy ecosystems, such as rivers, forests, wetlands, and grasslands, play a key role in retaining moisture, recharging groundwater, and regulating hydrological flows (OECD, 2021[123]). For instance, wetlands can store up to 15 000 cubic metres of water per hectare (Office Français pour la Biodiversité, 2012[125]), while plant transpiration contributes to more than half of land-derived atmospheric moisture (UNDRR, 2021[126]). Recognising these functions, governments have increasingly promoted the protection and restoration of these ecosystems, focusing primarily on sustainable landscape and vegetation cover management (Table 4.7).

**Table 4.7. Overview of landscape-wide ecosystem management practices and their benefits**

| Practice | Description | Benefits |
|---|---|---|
| Integrated landscape management | Reconnecting rivers to floodplains, protecting and restoring riparian buffers and natural floodplains, protecting sensitive water ecosystems, removing invasive species | Reduce runoff, enhance water storage and groundwater recharge, maintain streamflow during dry periods, reduce erosion and flood risk, improve water quality, support biodiversity |
| Vegetation management | Protecting or restoring land ecosystems, creating green belts, increasing native vegetation cover | Improve water storage and flow regulation, ensure water availability downstream, reduce erosion, enhance water quality, support biodiversity |

Source: Author's own.

Policy efforts in recent years have focused on enhancing landscape management to improve hydrological connectivity. Key measures include reconnecting rivers to floodplains, protecting sensitive ecosystems, and restoring riparian buffers (i.e. vegetation along river and wetland banks). In Europe and the United States, incentive schemes encourage the creation of vegetated buffer zones along rivers and wetlands to enhance water filtration and retention (OECD, 2024[46]). In China, the Sloping Lands Conversion Programme compensates farmers for converting cropland on eroding slopes into forests or grasslands, to reduce drought and flood risks along major rivers (Liu and Lan, 2015[127]). In Estonia and Germany, efforts such as dam removal and levee setbacks have significantly improved river and floodplain connectivity, delivering hydrological and ecological benefits such as enhanced water storage and ecosystem resilience (EEA, 2024[73]; Serra-Llobet et al., 2022[128]). Protecting peatlands and other wetlands from drainage, maintaining minimum water flows (see Box 4.3), and supporting restoration initiatives where needed have also helped restore water balances and preserve water availability in the landscape. For instance, in Israel's Hula Valley, government support for wetland restoration through regulations, public investments, and ecotourism incentives for local stakeholders successfully enhanced water storage and stabilised local water cycles (Hambright and Zohary, 1999[129]).

National and local authorities have also invested heavily in conserving and restoring vegetation in drought-prone areas. Healthy vegetation cover retains soil moisture, regulates humidity levels during dry periods, and enhances drought resilience while reducing the risks of land degradation (OECD, 2021[123]; Browder et al., 2019[130]). For example, in Mexico's Izta-Popo National Park, the reforestation of over 300 hectares has improved groundwater recharge, with the potential to store 1.3 million cubic metres of water annually (Oppla, 2023[131]). In Türkiye's Konya region and Seyhan Basin, local authorities have integrated climate-resilient forest management and drought adaptation considerations into regional forest management plans (Oppla, 2023[132]; IUCN, 2019[133]). An innovative NbS example to minimise drought risk comes from Quito (Ecuador), where a local water fund (the *Fondo para la Protección del Agua*) has supported the restoration of 2 500 hectares of degraded land and the protection of 33 000 hectares of high-altitude vegetation, ensuring freshwater availability downstream (Browder et al., 2019[130]). Water funds targeting ecosystem regeneration have also been established in Costa Rica and in Scotland (United Kingdom) (Water Conservation Costa Rica, 2023[134]; SEPA, 2024[135]). In recent years, initiatives for vegetation and land restoration at landscape level have also gained momentum at the international level (Box 4.5).

### Box 4.5. International initiatives to address drought risk through land and ecosystem restoration

In response to growing drought risk, several multilateral initiatives have been launched to promote large-scale land and ecosystem restoration. These efforts focus on combating desertification, enhancing soil health, and improving drought resilience in affected regions through collaborative partnerships. Key initiatives include:

- The ***G20 Global Land Initiative*** aims to reduce global degraded land by 50% by 2040 through ecosystem restoration, reforestation, and sustainable land management. Activities include knowledge sharing, civil society engagement, and private sector involvement.
- The ***Great Green Wall Initiative*** targets the restoration of 100 million hectares across 22 Sahelian countries to combat land degradation, desertification, and drought. By 2030, it aims to enhance climate resilience and food security, while also sequestering 250 million tons of carbon and creating 10 million green jobs. By 2020, 4 million hectares of degraded land had been rehabilitated.
- The ***African Forest Landscape Restoration Initiative (AFR100)*** unites 34 African governments, as well as businesses and NGOs, to restore 100 million hectares of land by 2030. The initiative promotes agroforestry, pastoralism, and best practices for landscape restoration to improve food security, climate resilience, and rural development.

Source: (UNCCD, 2022[136]; G20 Global Land Initiative, 2023[137]; UNCCD, 2024[138]; UNCCD, 2022[139]; UNCCD, 2021[140]).

To inform effective and efficient landscape-level interventions, governments are increasingly using costs-benefit analyses. For example, Cape Town (South Africa) identified invasive plant removal from seven priority catchments as a cost-effective measure to enhance water availability, as the proliferation of such species is associated with lower river flows and aquifer recharge. For example, invasive tree species were found to allow only 16% of annual rainfall to recharge groundwater, whereas native vegetation, such as Fynbos, enable up to 40% groundwater replenishment (FAO, 2021[11]). With yearly savings of 2 million litres per hectare, this intervention could save 100 billion litres of freshwater per year by the middle of the century at one-tenth the unit cost of alternative water supply options (Stafford et al., 2019[141]). Similarly, in the Netherlands, cost-benefit assessments undertaken as part of the Delta Plan allowed to identify the most impactful measures for freshwater supply, such as protecting Lake IJsselmeer (OECD, 2025[3]).

Despite some progress in ecosystem management, challenges persist and the potential of land-based interventions remains untapped. Effective ecosystem management often requires limiting or altering land use, which can lead to sectoral or public opposition due to competing interests or perceived trade-offs (OECD, 2021[123]). For example, in Spain, conflicting land-use priorities have driven public administrations to support the expansion of industrial agriculture around the Doñana protected area, significantly reducing water availability within the protected area (WWF, 2023[48]). This challenge is often compounded by the tendency to underestimate the economic benefits of conservation, as these are not as easily monetised or quantified compared to other uses. Moreover, the implementation of large-scale NbS requires co-ordination and integrated planning among multiple stakeholders, which remain major challenges in many cases (see Section 4.4.1) (OECD, 2021[123]). Another challenge is the frequent prioritisation of water for drinking, infrastructure, and key economic sectors over ecosystem needs. This imbalance often undermines ecosystem health and their ability to maintain essential functions during water scarcity periods. Ensuring a balance between human and ecosystem needs (e.g. by regulating water abstraction and fostering cooperation among users, see Sections 4.3.1 and 4.4.1 respectively) is thus fundamental for sustainable ecosystem management.

*Harnessing urban NbS for drought resilience*

Nature-based solutions are increasingly recognised as vital tools for enhancing drought resilience in cities. In recent decades, urban sprawl and soil sealing have reduced soil permeability and disrupted aquifer recharge and the natural flow of rainwater. For instance, in Paris, where 21% of the metropolitan area is built-up, only 30% of rainfall infiltrates the soil on average (OECD, 2025[3]). Similar challenges affect many large urban areas globally. By integrating permeable surfaces – such as urban green spaces, green roofs, and permeable paving – into urban planning, NbS slow runoff, enhance rainwater infiltration, and improve groundwater recharge (Table 4.8). In Southern California and the San Francisco Bay, permeable paving and stormwater harvesting systems in urban areas supply an additional 518 to 777 gigalitres of water annually (Gleick et al., 2014[58]). Besides mitigating drought impacts, urban NbS also enhance resilience to other extreme events (e.g. floods and heatwaves), support biodiversity, and improve urban liveability (OECD, 2021[123]).

Many OECD countries have expanded the use of urban NbS for enhanced hydrological connectivity through land-use policies, fiscal incentives, and urban regeneration projects. For example, in Bremen (Germany), financial contributions are offered to homeowners for de-sealing paved areas on their properties (EEA, 2020[81]), to reduce surface runoff and improve water infiltration. Similarly, the Paris metropolitan region enforces stormwater management regulations and funds interventions such as de-sealing, tree planting, green roofs, and renaturation projects on both public and private land. The region aims to de-seal 5 000 hectares by 2030. Currently, nearly 16% of non-potable water use in Paris is sourced from drainage water (OECD, 2025[3]). An innovative approach to urban water management has emerged in Rotterdam (the Netherlands), where an artificial wetland has been developed to collect and treat rainwater, which is then purified and stored beneath a sand layer for non-drinking purposes (EEA, 2020[81]).

**Table 4.8. Overview of urban NbS for drought resilience and their benefits**

| Practice | Description | Benefits |
|---|---|---|
| Urban green spaces and tree planting | Parks, green belts, and street trees that provide shade, reduce urban heat, and support biodiversity | Improve urban water flows, reduce runoff, enhance urban microclimates, reduce heat stress, improve air quality, support biodiversity, enhance resilience to droughts |
| Rain gardens and bioswales | Vegetated depressions or channels designed to capture and filter stormwater runoff | Enhance groundwater recharge, reduce runoff, mitigate local flooding, provide localised irrigation during dry periods |
| Artificial wetlands | Engineered systems using native vegetation to treat stormwater runoff and enhance groundwater recharge | Regulate water flow during droughts, improve water quality, support biodiversity, treat wastewater, provide flood mitigation |
| Permeable paving | Porous surfaces that allow rainwater to infiltrate into the ground and reduce soil sealing | Reduce surface runoff, replenish groundwater, mitigate the urban heat island effect, improve urban drainage |
| Green roofs | Vegetated roof systems that retain rainwater | Retain rainwater, reduce runoff and peak flows, improve water quality, enhance building insulation, support biodiversity, mitigate the urban heat island effect |

Source: Author's own.

### *4.3.3. Adapting sectoral practices to climate change*

In a changing climate, effective drought management requires strategies that extend beyond water and land management to encompass the role of critical sectors in building long-term resilience to drought. This section explores the need and opportunities for sectoral adaptation in three selected sectors: adapting agricultural practices to sustain productivity and food security under changing climate conditions; ensuring continuity in river transport to maintain trade and communication channels; and preventing risks to physical assets to protect essential services and communities from the impacts of drought.

*Adapting agricultural practices to a changing climate*

The agricultural sector is highly vulnerable to drought risk under climate change, as rising temperatures and shifting precipitation patterns jeopardise crop yields and food security (see Chapter 3). Strengthening the resilience of farmers, farming communities, and agricultural economies is pivotal. This requires improving irrigation water use efficiency; enhancing the drought resilience of crops, livestock, and farming systems; and promoting sustainable land and water management to alleviate the sector's pressure on increasingly scarce water resources. The following subsections examine key practices available and their current adoption.

**Enhancing irrigation efficiency**

As climate change intensifies variability in precipitation patterns, irrigation has become increasingly central to ensuring reliable water supply for crops, thus ensuring resilience to prolonged dry periods. Over the past fifty years, global irrigated area has doubled, and today, irrigation supports 20% of the world's harvested area and 40% of global crop yields (IPCC, 2022[142]). Yet, irrigation accounts for 70% of global freshwater withdrawals, significantly driving groundwater depletion in many regions (United Nations, 2024[143]). Projections indicate that, as water scarcity intensifies, large-scale shifts from rain-fed to irrigated agriculture will occur, further increasing agricultural water demand until the end of the century (IPCC, 2022[142]). While this shift is vital for adaptation, it must be accompanied by considerations regarding the sustainability of water resource use, especially as most water abstracted for agriculture is not returned to the surrounding environment.

Enhancing irrigation efficiency is thus necessary to alleviate groundwater pressures and promote sustainable water use. Research shows that upgrading irrigation systems can cut inefficient water use by up to 76% globally (Jägermeyr et al., 2015[144]) and lower overall water consumption by 15-20% in some countries (OECD, 2025[3]). Governments worldwide have implemented various measures to encourage the adoption of water-efficient irrigation technologies. Key solutions include micro and drip irrigation systems, which use 20-50% less water than conventional sprinklers (UNCCD, 2023[103]), as well as advanced technologies like sensors, drones, and water metering systems. In Europe, the Common Agricultural Policy (CAP) promotes these technologies through water efficiency requirements and subsidies for water-saving investments (European Court of Auditors, 2021[64]). Hungary provides irrigation subsidies contingent on a water-saving objective, while in the United States, the federal government supports the modernisation of irrigation infrastructure, including off-farm water conveyance systems (OECD, 2021[56]).

Effective water governance, including water allocation frameworks, groundwater regulations, and water pricing schemes, is also key to improving irrigation efficiency. These measures can prevent over-extraction and ensure equitable and efficient water use, particularly during droughts, while incentivising farmers to adopt water-saving technologies and practices (see Section 4.3.1). For example, well-designed water pricing schemes promote conservation by reflecting the true value of water, ensuring its sustainable use in agriculture and other sectors. Examples of policy support in this area include the establishment of water markets in Australia, which has improved irrigation efficiency at the farm level (OECD, 2019[145]; Kirby et al., 2014[146]), and Colorado's (United States) compensation programme for farmers who permanently forgo irrigation water rights in designated areas (USDA, 2017[147]).

Emerging digital tools can further enhance irrigation efficiency by enabling precise water management. Remote sensing technologies provide real-time data on soil moisture, crop health, and water distribution, optimising irrigation practices, while Internet of Things (IoT) devices – such as smart sensors and automated valves – monitor and regulate water use dynamically, reducing water waste. Additionally, weather-based scheduling systems leverage meteorological data to adjust irrigation timing and volumes, ensuring alignment with actual crop water needs. Policy instruments that support the adoption of these tools, such as subsidies for smart irrigation systems or data-sharing platforms, can accelerate their implementation. For instance, in France, regional subsidies are available for technologies aimed at improving environmental performance, including water efficiency, as part of several *Plan Végétal Environnement* (Nouvelle-Aquitaine, 2021[148]). Similarly, in Hungary, irrigation subsidies are contingent on meeting water saving targets (OECD, 2021[56]).

Despite recent advancements, more robust enforcement of water efficiency requirements and better-aligned incentives are needed. For example, in the EU, exemptions from requirements for water withdrawal authorisation allow the agricultural sector to over-abstract water, while CAP funds are often allocated to new irrigation projects rather than improving existing systems' efficiency (European Court of Auditors, 2021[64]). These exemptions and misaligned incentives risk exacerbating pressures on already stressed water resources, undermining efforts to enhance sustainability in agricultural water use. Moreover, improving irrigation efficiency without proper safeguards can lead to a rebound effect, where water savings are offset by expanded irrigation or increased water consumption. Additionally, the integration of climate change considerations into agricultural water management lags behind, with only a minority of OECD countries having increased their focus on climate adaptation in the last decade (OECD, 2021[56]).

Enhancing the resilience of farming systems to drought Enhancing the resilience of agri-food systems to drought is essential for safeguarding food security and rural livelihoods amid increasing climate variability. By adopting drought-tolerant crop varieties, adjusting cropping calendars, improving livestock management, and diversifying income sources, farmers can reduce vulnerability, maintain productivity, and ensure the sustainable use of resources (Table 4.9).

Governments have actively supported the adoption of practices that improve crop and livestock resilience to drought through incentives, public investments, and information campaigns. In the EU, the CAP promotes eco-schemes to support the cultivation of less water-intensive crop varieties and adjustments to planting and harvesting schedules (OECD, 2024[46]). Recent estimates suggest that the use of drought-tolerant crops in the EU could save up to 50% of water use (EEA, 2021[47]). Sectoral agencies, as well as international research organisations, have also played relevant roles in research and development. For example, the Drought Tolerant Maize for Africa project has significantly enhanced the adoption of drought-tolerant maize varieties in sub-Saharan Africa, achieving yields up to 40% higher than conventional varieties during drought years while performing similarly in non-drought years (Shiferaw et al., 2014[149]). Efforts to improve livestock management practices have been implemented in Tajikistan through the Livestock and Pasture Development Project, which provides partial grants and capacity building to communities. These initiatives have resulted in co-benefits such as enhanced food security and increased household incomes, among others (IFAD, 2022[150]).

Some countries have also encouraged farmers in drought-prone areas to diversify their livelihoods, with a view to stabilising incomes and reducing vulnerability (UNDRR, 2021[126]; De Boni et al., 2022[151]). Measures include incentives for diversifying agricultural production as well as for engaging in non-agricultural activities such as agri-tourism. Governments have supported these efforts with financial incentives, training programmes, and market access initiatives. For example, in Australia, government programmes provide trainings and resources to support farmers in diversifying their income sources beyond traditional agriculture (Department of Agriculture, n.d.[152]). Agricultural insurance programmes in some countries further encourage income diversification (see Section 4.4.3). For instance, the United States' Whole-Farm Revenue Protection insurance programme ties premium rate discounts and subsidies to farm revenue diversification and only offers its highest coverage levels to farms cultivating at least three commodities (USDA, n.d.[153]; Kokot et al., 2020[154]).

Despite these efforts, significant challenges remain. For example, as of 2024, only two EU countries provide funding for drought-resilient crops as part of their national strategic plans on agriculture (EEA, 2024[41]). Moreover, some CAP incentives continue to support water-intensive crops and livestock expansion without adequately considering water efficiency, potentially exacerbating drought vulnerability (WWF, 2023[48]). While exposed and vulnerable farmers are increasingly aware of drought risk (Durrani et al., 2021[155]; van Duinen et al., 2015[156]), adopting drought-resilient practices often entails trade-offs with other pressing concerns, such as the labour intensity of new practices, potential income reductions, missing value chains for rotation crops, or the need for investments in specialised machinery. Thus, addressing these barriers requires providing financial incentives, developing infrastructure development, and strengthening value chains, ensuring that financial support encourages proactive resilience measures and long-term drought adaptation while avoiding the reinforcement of maladaptive practices that inadvertently increase vulnerability.

## Table 4.9. Overview adaptive practices to enhance the resilience of farming systems

| Practice | Description | Benefits |
|---|---|---|
| Using drought-adapted crops | Planting water-efficient or drought-tolerant varieties (e.g. early-maturing or saline-tolerant crops) | Reduce vulnerability to low rainfall, stabilise yields and income, optimise water use, enhance soil health |
| Adjusting cropping calendars | Modifying planting and harvesting schedules to adapt to changing rainfall patterns or minimise irrigation needs | Minimise crop failure risk, optimise water and resource use, increase yields and profitability |
| Adapting livestock production | Using drought-resistant breeds, adjusting stocking density (e.g. through extensive and/or rotational grazing), improving feed and forage systems | Reduce livestock loss, improve water efficiency, enhance productivity and income, improve livestock welfare, improve soil moisture, structure and organic matter, reduce erosion, support carbon storage |
| Diversifying livelihoods | Expanding income sources through mixed farming (e.g. mixing crops and animal breeds) or off-farm activities | Reduce reliance on single income sources, improve economic stability, boost resilience to shocks |

Source: Author's own.

### Promoting soil health and water retention for enhanced resilience

Sustainable land and water resource management in agricultural areas is critical for enhancing drought resilience and supporting long-term agricultural sustainability. Strategies such as agroforestry, natural water retention systems, and sustainable soil management practices conserve natural resources, safeguard biodiversity, and improve soil quality and water retention (Table 4.10). These practices contribute to increasing soil organic carbon, which drives improvement in soil water retention capacity, infiltration properties, and overall soil health, while also serving as a powerful carbon storage mechanism and a biodiversity hub for microorganisms. By adopting these practices, farmers not only enhance resilience to climate variability but can also achieve higher crop yields and often maximise benefits even during non-drought years (UNCCD, 2019[157]).[13]

Countries are increasingly supporting agroforestry and water retention systems through incentives and education programmes aimed at promoting sustainable land use and improved water management. In the EU, the CAP finances agroforestry and supports the afforestation/restoration on over 60 0000 hectares (European Commission, 2022[158]). The new CAP requires that 25% of national funding for farmers target eco-schemes designed to support sustainable agricultural practices (EEA, 2024[41]). In France, the education initiative *Enseigner à Produire Autrement* fosters drought resilient agricultural practices by integrating adaptation and sustainability considerations into agricultural education (OECD, 2025[3]).

Governments have also advanced policies to promote soil conservation practices, such as mulching, conservation tillage,[14] and crop rotation, to improve soil health, water retention, and overall drought resilience. These practices are particularly effective in enhancing soil organic carbon, further improving soil's ability to retain water and nutrients. For instance, the United Kingdom's Sustainable Farming Incentive compensates farmers for adopting sustainable practices like no-till farming and companion cropping, while also providing guidance for implementation (UK Government, 2024[159]). Similarly, Ireland's Results-Based Environmental Agri Pilot reward farmers for achieving measurable improvements in soil health and water retention (Government of Ireland, 2021[160]). In the United States, programmes like the Environmental Quality Incentives Program and the Conservation Reserve Program prioritise practices such as crop rotation, conservation tillage, and cover cropping through subsidies and annual rental payments (OECD, 2024[46]; USDA, 2017[147]). The latter has seen higher enrolment in drought-prone areas (controlling for other regional differences), suggesting drought resilience as a key driver for participation (USDA, 2017[147]).

These land and water management practices have been linked to improvements in drought resilience, water efficiency, soil health, and productivity, though their effectiveness varies depending on local climate, environmental and socio-economic factors.[15] For example, in Spain's Segura river catchment, mulching and conservation tillage reduced water stress and improved soil moisture (UNCCD, 2019[157]), while earth-banked terraces in Murcia enhanced water infiltration (WOCAT SLM Database, 2011[161]). In southern Africa, crop rotation increased soil water infiltration by 70-238%. Drought-resilient practices have also boosted productivity in some regions. In Zambia, agroforestry increased maize yields during drought years by up to 12 times compared to non-agroforestry systems (UNCCD, 2019[157]). Similarly, in Mexico, sustainable farming practices like conservation and precision agriculture, improved maize and wheat yields by 20.5% and 2.8% respectively (CIMMYT, 2024[162]).

Despite progress, significant barriers remain in scaling up these practices. Limited capacity and engagement among private stakeholders often hinder adoption, particularly in regions where smallholder farmers face immediate financial constraints (UNCCD, 2019[157]). The medium- to long-term benefits of sustainable land management practices may not align with the short-term needs and constraints of low-income farmers. Addressing these challenges requires stronger incentives, targeted capacity building, and financial support as well as further research to ensure broader adoption of drought-resilient agricultural practices.

### Table 4.10. Overview of sustainable land and water management practices and their benefits

| Practice | Description | Benefits |
|---|---|---|
| Agroforestry and agropastoralism | Integrating trees or shrubs with crops or livestock | Improve soil health, enhance moisture retention and water infiltration, sequester carbon, provide shade, support biodiversity |
| Natural water retention systems | Building earth-banked terraces, stone bunds, or planting buffer strips on sloped land | Enhance water retention, promote uniform water distribution, reduce soil erosion, improve crop yields |
| Mulching | Applying organic materials to the soil surface | Improve soil moisture and structure, enhance carbon storage and nutrient cycling, regulate soil temperature, minimise erosion, increase crop yields |
| Conservation tillage | Using reduced or no-till practices to minimise soil disturbance | Improve soil moisture and structure, reduce erosion, increase organic matter, boost water infiltration |
| Crop rotation and diversification | Alternating crops seasonally (crop rotation) or intercropping; includes cover cropping for soil protection during fallow periods | Enhance soil fertility, reduce soil erosion, improve water infiltration, break pest and disease cycles, reduce water use |

Source: Author's own.

#### *Ensuring continuity in river transport*

Drought conditions can severely disrupt inland waterway transport by lowering water levels, which in turn reduce ship capacities, cause delays, and increase transportation costs (see Chapter 3). To address these growing challenges, governments have developed policies and initiatives to upgrade fluvial infrastructure and maintain navigability during drought periods. Key strategies include the development of new river channels and dredging, deepening, or widening of existing ones, as seen in the Rhine (Germany) and Mississippi (United States) basins (Gobert, 2023[163]; Guo, 2023[164]). Investments in reservoir lakes, locks and pumping stations to regulate water flows during drought also play a key role, as observed along the Seine river (France) and the Rhine-Meuse-Scheldt river system (Belgium, the Netherlands) (OECD, 2025[3]; Climate-Adapt, 2016[165]; Havinga, 2020[166]) (Table 4.11).

In parallel, some countries have introduced or adjusted regulatory frameworks to adapt vessels and shipping operations to changing water levels. For example, in Germany, regulations set limits on vessel draft based on water levels to ensure safe navigation on the Rhine River (Vinke et al., 2024[167]). A federal funding programme also supports the modernisation of inland vessels to optimise ship operations during low-water conditions (PLATINA3, 2022[168]). Similarly, Austria has launched a subsidy scheme to enhance the efficiency of inland vessels (BMK, 2022[169]).

Despite these advancements, the effectiveness of current policies and investments is often limited by the evolving nature of drought risk under climate change. Many measures and strategies rely on historical drought trends and only few account for yet unprecedented or future drought conditions. This is exemplified by Germany's experience with the Action Plan Low Water Rhine (*Aktionsplan Niedrigwasser Rhein*) released after the 2018 drought. While the plan includes long-term low-flow forecasting and projection services that were activated in the years 2019 and 2020, other measures of the plan – such as infrastructure measures – were not yet in place when the next severe low-flow event occurred in 2022 (OECD, 2023[19]). To address these limitations, policies and strategies must be grounded in forward-looking risk assessments based on a range of climate scenarios to improve preparedness. Furthermore, wetland restoration and riverbank reforestation are effective options for maintaining navigable water levels during droughts (see Section 4.3.2). These measures also provide co-benefits, such as enhanced biodiversity, water quality, and socio-economic resilience.

## Table 4.11. Overview of adaptive waterway transport practices and their benefits

| Measure | Description | Benefits |
|---|---|---|
| Upgrade of grey waterway infrastructure | Channeling rivers, dredging, widening, or deepening existing canals, upgrading reservoir lakes, locks, dams, and pumping stations | Maintain navigability during periods of low water levels, reduce delays, ensure the continuity of waterway transport |
| Regulations and incentives for vessel adaptation | Regulatory requirements and financial incentives to encourage adapted ship design (e.g. reduced draft, improved propulsion systems, lighter materials) | Ensure safe navigation during low water levels, optimise vessel efficiency, reduce operational costs. |
| Adaptive supply chain management | Investments in modal shifts and alternative modes of transportation | Ensure the transport of goods even during prolonged drought or low water levels |
| Nature-based solutions | River restoration, managing vegetation in forests and along watercourses, restoring wetlands to maintain natural water flows and regulate streamflow | Maintain minimum streamflow during dry periods to maintain navigability, enhance biodiversity, improve water quality |

Source: Author's own.

### *Preventing risks to physical assets from clay shrinkage and land subsidence*

Prolonged drought conditions and excessive groundwater abstraction contribute significantly to clay shrinkage and land subsidence, causing structural damages to infrastructure and buildings.[16] In France alone, clay shrinkage and swelling caused nearly EUR 2 billion in damages between 1995 and 2019, with annual costs averaging 1.5 times higher than those of floods (DRIEAT, 2023[170]; CCR, 2020[171]). Across Europe, drought-induced subsidence has increased substantially in recent decades and is projected to rise further under climate change (Swiss Re, 2011[172]). Additionally, subsidence can permanently reduce the storage capacity of aquifers, further exacerbating drought risk (OECD, 2025[3]).

Governments have adopted various regulatory measures to strengthen asset resilience in areas prone to clay shrinkage and subsidence. In some cases, construction is restricted in high-risk areas and mandatory soil analyses are often required to identify clay content and shrink potential before development. Building codes in affected areas sometimes include requirements for deeper foundations, ground stabilisation techniques, or building materials that can accommodate land movements. Many of these measures have been implemented in France (DRIEAT, 2023[170]), which has also integrated damage from clay shrinkage into its national compensation system (see Table 4.13). The European Commission has issued guidelines for adapting buildings to climate change impacts, including clay shrinkage and subsidence (European Commission, 2023[173]).

Efforts have also been made to maintain soil moisture levels and facilitate groundwater recharge in areas prone to soil shrinkage or drought-induced subsidence. For example, Tokyo has implemented bans on groundwater abstraction to reduce land subsidence (Cao et al., 2021[174]), while regulations promoting practices like planting vegetation[17] farther from buildings to maintain constant soil moisture levels are in place in France (DRIEAT, 2023[170]). Nature-based solutions that support aquifer recharge and soil water retention (see Section 4.3.2 and Table 4.12) can also help mitigate clay shrinkage and subsidence while delivering additional environmental and policy benefits.

## Table 4.12. Overview adaptive practices to prevent damage to physical assets and their benefits

| Practice | Description | Benefits |
|---|---|---|
| Building regulations | Restrictions on land development, requirements for resilient construction practices or retrofitting (e.g. on building materials, foundations, ground stabilisation) and vegetation use near structures | Reduce exposure to clay shrinkage and land subsidence; enhance structural resilience, prevent property damage during drought |
| Groundwater management | Regulation of groundwater abstraction, managed aquifer recharge to prevent excessive drawdown | Reduce risk of land subsidence, maintain aquifer storage capacity, increased groundwater levels, support long-term water availability and quality |
| Nature-based solutions | Use of permeable surfaces, soil conservation practices, streamflow regulation, protection and restoration of critical ecosystems (e.g. wetlands) | Improve water infiltration and storage, reduce the risk of soil shrinkage and subsidence; enhance groundwater recharge; deliver co-benefits such as flood mitigation and biodiversity protection |

Source: Author's own.

## 4.4. Building institutional and financing frameworks for drought resilience

Creating the enabling conditions for effective drought risk prevention is indispensable to drive the adoption of policies, practices, and investments that strengthen resilience. Achieving this requires establishing institutional networks that promote policy alignment and stakeholder engagement within and across national borders (Section 4.4.1), ensure adequate financial support for resilience-building measures (Section 4.4.2); and promote private stakeholder resilience through insurance schemes (Section 4.4.3).

### *4.4.1. Strengthening collaboration for drought resilience*

#### *Institutional co-ordination within national borders*

To address growing drought risk, many countries have developed coordination mechanisms that facilitate policy alignment and collaboration across authorities, sectors, and levels of government. For example, in the United States, the Drought Resilience Interagency Working Group brings together 14 federal departments to facilitate coordination and a whole-of-government approach (White House Drought Resilience Interagency Working Group, 2022[175]). Its work is complemented by the National Drought Resilience Partnership, which coordinates federal resources and information to support state, tribal, and local efforts on long-term drought resilience (NIDIS, n.d.[176]; NDRP, 2019[177]). In Kenya, a permanent body for drought management (i.e. the National Drought Management Authority) was established to improve coordination across national, sub-national, and international levels (FAO, 2021[11]). In Australia, the National Soil Action Plan promotes coordinated efforts to protect and improve soil health, e.g. by supporting collaborative frameworks for soil monitoring, promoting policy alignment, and enabling joint investment in soil initiatives. This approach ensures that national priorities are addressed while responding to regional and local conditions (Australian Government, 2021[178]).

Institutional collaboration at the river basin level has also advanced, facilitating the shared management of freshwater resources and mitigating drought risk and impacts downstream. Co-operation mechanisms include river conventions and river basin management plans. River conventions are binding agreements among governments (domestic or cross border; for the cross-border discussion, see next subsection) that outline long-term objectives for shared water resources. For example, Canada's Mackenzie River Basin Transboundary Waters Master Agreement establishes a cooperative framework for sustainable water management among the federal government and the provinces and territories that are part of the basin (Government of Canada, 1997[179]). River conventions are sometimes supplemented by non-binding river basin management plans, which provide technical guidance for managing shared water resources within the basin, often addressing drought and water scarcity. This is the case in Mexico, where 26 basin-level drought prevention plans were developed as part of the National Program Against Drought (Deltares, 2022[20]). These plans support coordinated water allocation (e.g. preventing over-abstraction upstream, ensuring minimum flows), infrastructure investments (e.g. water storage), and drought prevention measures. However, rising drought risk due to climate change calls for periodic assessments and updates of existing agreements and plans.

Despite progress, significant gaps remain in institutional frameworks. Responsibilities for drought management are sometimes unclear or fragmented, complicating co-operative efforts and in some cases leading to misaligned policies and incentives. Cross-agency and intersectoral collaboration mechanisms are often weak, even within key sectors such as water management, as observed in Chile and France, among others (OECD, 2024[54]; OECD, 2025[3]). To strengthen drought resilience, it is fundamental to reinforce coordination mechanisms and other co-operative frameworks that promote collaboration and alignment across sectors and government levels.

### *Addressing drought risk across borders*

With a large share of the water resources being transboundary, the growing threats posed by drought present complex management challenges that go beyond national borders. These challenges are expected to intensify as climate change exacerbates water scarcity and variability (see Chapter 2). Developing coordinated approaches to water allocation and abstraction, infrastructure management, risk assessment and monitoring, and ecosystem management may significantly help address these issues. Such an approach may reduce water availability and quality issues in downstream countries and facilitate the equitable and effective utilisation of transboundary waters among riparian countries (IDMP, 2022[13]; UN Water, 2024[180]).

Cross-boundary agreements, plans, and initiatives have been established to facilitate cooperation at river basin level, mirroring similar approaches used within national borders (see subsection above). Examples include the Danube River Convention in Europe, as well as the Nile River Basin Management Plan in Africa, which regulate transboundary water governance, aiming to enhance water sustainability and reduce drought risk under changing climatic conditions (Slovenian Environment Agency, 1994[181]; Nile Basin Initiative, 2023[182]). Bilateral agreements – such as those between Portugal and Spain, or Mexico and the United States – regulate flow regimes and co-operation at the basin level (UNECE, 2009[183]; Interreg España Portugal, 2024[184]). In the EU, the River Basin Management Plans developed under the Water Framework Directive also play a role in addressing drought risk and ensuring sustainable water management across transboundary basins within Europe (Box 4.6).

### Box 4.6. The EU River Basin Management Plans (RBMPs)

Developed by EU Member States and managed by dedicated river basin commissions, RBMPs define common frameworks for riparian countries to coordinate water resources and ecosystem management at the basin level. Each RBMP outlines measures to achieve the objectives of the EU Water Framework Directive (WFD), including managing water availability, maintaining water balances,[18] and ensuring ecological flows. To support effective planning and implementation, RBMPs must include assessments of the WFD's objectives for the relevant water body, including evaluations of their quantitative status.

RBMPs often acknowledge the increasing risk of drought and its pressures on water resources in the context of climate change, though they rarely include dedicated strategies to address this issue comprehensively. Although RBMPs often incorporate sectoral scenarios for managing water availability and use, these are not always consistent with the timeframes of widely accepted climate projections. In the second RBMP cycle (completed in 2021), 16 countries reported significant pressures from water abstraction on surface or groundwater resources in parts of their territories. However, only eight countries reported having a dedicated DMP for the affected basins, and the level of detail and comprehensiveness of existing DMPs varies significantly (see Section 4.2.1). Finally, in various instances, drought conditions have justified exemptions from existing requirements on the ecological and quantitative status of water bodies, allowing for the temporary deterioration of ecological flows.[19]

To better meet the WFD's objectives regarding water availability and minimum flow requirements, future RBMPs must more prominently incorporate drought adaptation measures. Good practice examples can be found in Belgium's Flanders, Wallonia, and Brussels regions, where climate impacts have been integrated into river basin management plans. Notably, Brussels has made adaptation to climate-induced drought risk a core priority in its water management strategy.

Source: (European Commission, 2000[60]; EEA, 2021[47]; GWP and WMO, 2015[43]; European Commission, 2023[18]).

In some cases, basin-specific drought management and adaptation initiatives are also in place. For instance, the Danube River Basin has developed a dedicated drought management strategy and a climate adaptation strategy, ensuring climate resilience considerations are integrated into river management across riparian countries (Danube Transnational Programme DriDanube, 2019[185]). In Africa, the Volta Basin Flood and Drought Management Project promotes the integrated drought and flood management across six riparian countries, also fostering co-operation and resilience at the basin level (UNCCD, 2023[103]). These initiatives highlight the potential for transboundary co-operation to address shared drought risks effectively.

Supranational initiatives can also go a long way in fostering knowledge exchange, disseminating best practices, and advancing innovative approaches to drought management. Several cross-border efforts have supported joint risk assessments, data-sharing monitoring systems, and the development of early warning systems. For example, the European Drought Observatory, managed by the European Commission's Joint Research Centre, collects and shares data on drought conditions, including precipitation and soil moisture, across EU member states, providing a unified understanding of drought risks and supporting informed decision-making. The Mediterranean Drought Information System facilitates cross-border collaboration among Mediterranean countries, enabling the sharing of drought-related data and the development of early warning systems. In addition to these regional initiatives, several global initiatives for drought resilience have also emerged (Box 4.7). Altogether, these efforts have strengthened collective capacity to address drought challenges and implement sustainable solutions at scale.

### Box 4.7. International initiatives for integrated drought management

Several international initiatives on drought management and resilience are in place to facilitate mutual learning, data sharing, and the scaling up of effective drought resilience strategies. By harnessing peer learning and knowledge exchange, these initiatives provide policy guidance, technical support, and capacity-building to governments and other stakeholders worldwide. Key examples include:

- The ***United Nations Convention to Combat Desertification (UNCCD)'s Drought Initiative***, which supports countries in developing national drought plans and strengthening capacity for proactive and integrated drought management;
- The ***International Drought Management Program***, jointly led by the World Meteorological Organization and the Global Water Partnership, which provides policy guidance, tools, and capacity-building resources globally, while also operating regional programs (e.g. in Central and Eastern Europe and Western Africa) to address localised needs;
- The ***Food and Agriculture Organization's Drought Portal***, which serves as a knowledge-sharing global platform, providing tools, capacity building resources, and good practices to shift from crisis-driven responses to proactive drought management, with a particular focus on agriculture and food security; and
- The ***International Drought Resilience Alliance (IDRA)***, which has mobilised political and financial support for drought resilience by creating a coalition of countries and organisations dedicated to proactive drought management. It fosters international collaboration and advances strategies to build long-term resilience to water scarcity and climate impacts.

Together, these initiatives have promoted a transition from reactive drought response to risk-based and adaptive strategies. They have also helped mobilise political and financial support for drought resilience, aligning national and subnational efforts with regional and global policy priorities.

Despite progress, significant gaps remain. Currently, 60% of transboundary river basins lack any formal cross-country agreement on water use. Even where agreements exist, their implementation often lags behind, undermining their effectiveness (UNICEF, 2021[186]). Global initiatives and coalitions also face challenges, including limited funding, uneven implementation, and coordination gaps among national, subnational, and international stakeholders. To address these issues, scaling up coordinated planning and implementation efforts is key to enhance the effectiveness of existing initiatives and mitigate shared risks. At the same time, increasing financial support for drought resilience projects and initiatives is fundamental to achieving lasting results.

#### *Engaging private stakeholders*

Engaging private stakeholders can go a long way to strengthen drought management, as they play a central role in managing water resources and implementing practices that can either reduce or exacerbate drought risk and resilience. By collaborating with farmers, industry, citizens, and other private entities, governments can foster efficient resource use and accelerate the adoption of innovative solutions to mitigate and adapt to drought risk.

Voluntary agreements between water users, or between users and governments, are important for fostering collaboration and accountability in managing water resources during droughts. These agreements typically involve commitments to reduce water consumption, adopt sustainable practices, or share resources equitably among stakeholders. For instance, in France, the "*contrats de milieu*" are agreements aimed at preserving water resources through collective action. These contracts, which also exist at the aquifer level ("*contrats de nappes*") bring together farmers, industries, and local authorities to implement measures that reduce over-extraction, ensure water supply, and protect ecosystems (SYMCRAU, 2024[187]). In the United States, significant efforts in California's Bay-Delta Watershed have sought to establish voluntary agreements to improve water management and ecosystem restoration. These agreements encourage stakeholders to take proactive measures, align resource use with sustainability goals, and promote drought resilience through co-operative action. However, evidence from California shows that prioritising voluntary agreements alone is insufficient for securing consistent action, and is thus better suited as complements to, rather than replacements for regulatory frameworks (Center for Law, Energy & the Environment, 2024[188]). Such agreements encourage stakeholders to take proactive measures, align resource use with sustainability goals, and promote resilience to drought impacts through cooperative approaches.

Involving citizens and local groups in decision making is also integral to effective drought prevention. Bottom-up and inclusive approaches ensure that interventions are tailored to local needs and do not inadvertently exacerbate pre-existing challenges. For instance, in the United States, the government has issued guidance documents to help authorities incorporate Indigenous knowledge on drought and other challenges into research and decision-making across various policy fields (The White House, 2022[189]). Similarly, in Australia, the National Soil Action Plan emphasises bottom-up approaches by supporting regionally tailored projects and promoting collaboration with local communities, Indigenous groups, and land managers to co-design sustainable soil and drought resilience solutions (Australian Government, 2021[178]).

### *4.4.2. Scaling up finance for drought resilience*

Public finance is a critical enabler of building long-term resilience to droughts, as it supports action on both immediate needs and long-term, proactive adaptation measures. These investments – ranging from ecosystem restoration and water infrastructure development to capacity-building and the promotion of climate-resilient agricultural practices – are vital for ensuring sustainable drought resilience (OECD, 2024[9]). Although such measures may not yield immediate financial returns, they are indispensable for protecting communities, ecosystems, and economies in the long run. By prioritising and mobilising public resources for adaptation, governments can address the root causes of vulnerability, reduce future costs, and foster a more resilient and sustainable future.

Adequate financial resources are key to promote effective water and land use, upgrade water infrastructure, incentivise sustainable agricultural practices, strengthen risk assessments, and enhance community resilience against droughts. Recent studies have highlighted the cost-effectiveness of investments in drought prevention compared to reactive approaches. The economic returns of building drought adaptation and resilience can be up to ten times greater than the initial investment. At the same time, prevention can cost up to three times less than response and recovery measures (IDRA, 2024[12]; IDMP, 2022[13]). While cost-effectiveness varies by investment type and based on each country's specific risk profile and socio-economic context, every dollar invested in drought prevention is estimated to generate 2 to 3 dollars in benefits from avoided losses and recovery costs (IDRA, 2024[12]; UNCCD, 2023[190]; UNCCD, 2021[140]).

The funding landscape for drought resilience varies significantly across countries, with national governments typically serving as the primary providers of finance for drought prevention. In recent years, notable advancements have been made in public drought risk financing. Governments at both national and subnational level have increased resources for drought prevention through dedicated funds, grants, and investments in climate-resilient infrastructure (UNCCD, 2023[190]). For example, the Flemish government (Belgium) allocated about EUR 223 million for investments in NbS such as wetland restoration and green-blue infrastructure, with a view to enhance soil water retention and mitigate drought-induced water scarcity (Interlace Hub, 2023[191]). Similarly, in France, water agencies subsidise the implementation of NbS, in some cases offering higher funding rates for NbS compared to grey infrastructure. In Germany, a national fund finances climate adaptation, including water retention measures in forested areas (European Commission, 2014[192]). In some cases, drought risk assessments are used to inform financing decisions. This is the case of Sri Lanka, whose Climate Resilience Improvement Project integrates drought and flood risk modelling to inform investment plans for major river basins (Ministry of Environment, 2020[193]).

Nonetheless, significant challenges remain in securing adequate public financing for drought prevention. While drought prevention requires sustained funding, some the benefits often take years to materialise. This makes droughts less urgent in the eyes of policymakers compared to immediate disasters like floods or storms. Thus, limited public funds are frequently allocated to more visible hazards or more short-term needs. Additionally, drought prevention spans multiple sectors and activities, complicating budget allocation and coordination across agencies. In addition to a gap in the financing available, misaligned investments can in some cases hinder drought resilience. This was observed in France's Île-de-France region, where local water management financing is over-shadowed by agricultural sector funding, which has less stringent drought prevention standards (OECD, 2025[3]).[20] Altogether, these barriers underscore the need for improved prioritisation and alignment of public investments to enhance drought resilience.

Complementing public finance with private sector resources is key to bridging financing gaps and easing the burden on public budgets. Private sector involvement can be harnessed through mechanisms such as trust funds and public-private partnerships (PPPs). Trust funds, for example, can mobilise sustained funding for conservation, innovation, and infrastructure projects. A notable case is offered by Ecuador's Quito Water Fund, which successfully secured sustained financing for NbS by engaging private companies, public utilities, and international donors (Browder et al., 2019[130]). Additionally, including climate resilience objectives and water use efficiency conditions in contracts can enhance the effectiveness of these partnerships (GCEW, 2024[22]). PPPs, on the other hand, enable joint investments in water infrastructure, technological innovation, and community resilience. While PPPs are widely applied in sectors like energy and transport, their use in water and agriculture remains limited (UNCCD, 2021[140]). One example of PPPs in agriculture is offered by Zambia, where smallholder farmers have formed liability companies to expand irrigated agriculture, leading to increased income, employment, and rural development (German Development Institute, 2017[194]). By expanding private sector participation through innovative financing mechanisms, drought resilience can be strengthened, and the sources of funding for critical interventions diversified.

### *4.4.3. Harnessing insurance for drought resilience*

Insurance can offer a key tool for enhancing resilience to drought risk in sectors highly vulnerable to water scarcity. By providing payouts for drought-induced losses, it helps mitigate financial risks for private stakeholders, allowing them to recover more quickly and reducing the potential need for government funding in the aftermath of severe droughts (OECD, 2021[195]). Moreover, insurance can incentivise investments in *ex ante* adaptation and risk reduction by offering benefits such as lower premiums to policyholders who adopt preventive measures. Linking eligibility or premium rates to drought-resilient practices – e.g. the use of drought-resistant crops or efficient irrigation systems – can encourage investments in risk reduction, ultimately reducing vulnerability (Mahul and Stutley, 2010[196]). For instance, in the United States, the government-backed Whole-Farm Revenue Protection insurance programme ties eligibility and premium rates to on-farm commodity diversification, thus promoting adaptive agricultural practices (USDA, n.d.[153]; Kokot et al., 2020[154]).

Yet, the slow-onset, and complex nature of drought makes insurance provision technically and financially challenging for insurers. Assessing the timing and severity of drought is difficult, and the far-reaching and gradual impacts of drought are harder to quantify compared to rapid-onset events like floods or storms. This complicates loss assessments and leads to extended claims processes, besides creating challenges in setting accurate premiums. This has long challenged the sustainability of traditional insurance models (Bielza et al., 2006[197]). These challenges are exemplified by Türkiye's Agricultural Insurance System

(TARSİM), a government-backed insurance programme that has long excluded drought from the range of natural hazards covered. Only in recent years has a drought insurance product been introduced, specifically for wheat (OECD, 2019[198]; Republic of Türkiye, 2022[199]).[21]

To address these challenges, governments have increasingly stepped in to ensure the availability of drought insurance where private markets alone may not be viable. In some cases, they provide direct coverage; in others, they subsidise premiums for vulnerable stakeholders (OECD, 2015[200]). These schemes typically focus on agricultural losses, though in some countries they also cover other impacts, such as clay shrinkage-induced building damage in France (Table 4.13). Public-private partnerships are used to enhance the affordability and accessibility of insurance products (OECD, 2016[69]), as seen for example in Austria, Mexico, and Türkiye. Notably, Austria's Drought Index Insurance (Table 4.13) relies on two parameters – water shortages and heat – more accurately capturing the complex nature of drought impacts on crops (Austrian Hail Insurance VVaG, 2025[201]). Broader risk-sharing arrangements can also help address the challenges of drought complexity and limited coverage. An example is the African Union's African Risk Capacity, a regional insurance pool for drought and food security emergencies that also offers capacity building to its 39 member countries (ARC, 2023[202]). Many of these government-backed initiatives rely at least partially on index-based mechanisms (Box 4.8). However, public support must be carefully designed to promote proactive resilience measures; without such safeguards, subsidies and insurance coverage may inadvertently reduce incentives for farmers to adopt preventive actions.

## Table 4.13. Government-supported insurance schemes for drought resilience in selected countries

| Country | Scheme name | Coverage | Description |
|---|---|---|---|
| Austria | Austrian Hail Insurance (Österreichische Hagelversicherung VVaG - ÖHV) | Crops. livestock | This programme offers index-based insurance against drought and other weather-related hazards for arable land, grassland, orchards, vineyards, and livestock. Premiums are subsidised at through the Austrian Natural Disaster Fund, jointly financed by the federal government and the federal states |
| France | Assurance Récolte, CatNat | Crops, buildings | L'Assurance Récolte subsidises premiums for crop insurance against drought and other climatic hazards. The national catastrophe insurance system (CatNat) includes coverage for building damages due to natural hazards, including clay shrinkage |
| India | Pradhan Mantri Fasal Bima Yojana | Crops | This scheme subsidises premiums for crop insurance against drought and other hazards |
| Kenya | Kenya Livestock Insurance Program | Livestock | This programme subsidises premiums to protect pastoralists from drought-related livestock losses, covering 18 000 households in high-risk areas |
| Mexico | Fondos de Aseguramiento Agropecuario | Crops, livestock | Through the government reinsurer AGROASEMEX, Mexico supports these funds by subsidising premiums for drought and other weather-related hazards |
| Thailand | Rice Disaster Relief Top-up Crop Insurance Scheme | Rice | The government covers 50% of premiums for drought and other hazards. This scheme complements compensation offered by the national Disaster Relief Program |
| Türkiye | TARSİM | Crops, livestock, aquaculture | This subsidised agricultural insurance system provides coverage to farmers against a range of weather-related hazards, including drought |
| United States | Pasture, Rangeland, and Forage Insurance Policy (PRF); Whole-Farm Revenue Protection (WFRP) | Crops, livestock | The PRF insures crop and livestock losses on pasture, rangeland, and forage. The WFRP covers drought losses and ties eligibility and premium rates to drought-resilient practices like commodity diversification. Both are part of the Federal Crop Insurance Program |

Source: Author's own, based on information from Bundesministerium Finanzen (n.d.[203]), Climate ADAPT (n.d.[204]), Maina et al. (2024[205]), DGAL (2023[206]), OECD (2015[200]; 2025[3]), WOCAT SLM Database (2021[207]), FARM-D (2024[208]), Republic of Türkiye (2022[199]), SwissRe (n.d.[209]), Parthiban and Anjugam (2023[210]) and USDA (n.d.[153]).

Despite notable advancements, the availability and adoption of drought insurance remains limited in many countries. Key barriers include affordability issues for smallholder farmers, limited awareness of the potential benefits of insurance, and high transaction costs (OECD, 2016[211]). Designing insurance policies that balance affordability with comprehensive coverage is an ongoing challenge. This is only complicated by the fact that, while improving accessibility, subsidised risk premiums distort price signals, inadvertently reducing incentives for policyholders to invest in preventive measures (OECD, 2021[195]; Mahul and Stutley, 2010[196]). Finally, the technical complexities of setting accurate drought indices present another significant hurdle. Index-based insurance relies on clearly defined weather metrics for payouts, but drought impacts vary widely depending on local conditions, soil types, and regional climate dynamics. This variability complicates the development of reliable indices and can erode trust in insurance schemes if payouts are perceived as misaligned with actual losses. Addressing these challenges remains fundamental for expanding insurance coverage and strengthening resilience to drought risk.

### Box 4.8. Index-based insurance: evolving products for drought resilience in agriculture

Over the past two decades, advancements in technology, particularly high-quality Earth observation systems, have driven the growth of index-based insurance schemes. Index-based schemes address the limitations of traditional indemnity-based insurance, which compensate farmers for actual losses based on *ex-post* impact assessments. Instead, index-based schemes provide payouts based on observed changes in weather conditions (e.g. low rainfall levels), regardless of the occurrence or extent of damage. As index-based schemes reduce insurer costs such as underwriting and loss adjustment expenses, their emergence has improved insurance affordability, particularly for low-income farmers or regions where insurance is often inaccessible.

Index-based insurance plays a crucial role in enhancing resilience at the farm level. Unlike indemnity-based models, pay-outs are not tied to actual losses, incentivising farmers to adopt proactive risk reduction measures (e.g. investment in water efficiency). Moreover, these payouts also offer more flexibility to farmers, who can use them to address non-crop and non-livestock damages or recover from indirect impacts, such as disruptions to their livelihoods or farm operations. This adaptability makes index-based insurance an effective tool for fostering resilience in the face of drought.

Governments have widely supported the development and expansion of index-based insurance through public-private partnerships, premium subsidies, reinsurance programmes, and enabling policy and regulatory frameworks. These efforts have facilitated its adoption in several countries, including OECD members such as Austria, Mexico, Türkiye, and the United States. While access to accurate and reliable weather data – essential for calculating indices and determining payouts – remains a challenge in many contexts, some countries have established advanced data systems that support index-based insurance. For example, Austria’s recently established GeoSphere Austria Data Hub provides high-quality data for public, commercial, and research use, including for the Austrian Hail Insurance‘s drought insurance products. As governments continue to scale index-based insurance, further investments in meteorological infrastructure and data-sharing platforms will be critical to ensure its long-term viability and effectiveness.

Source: (UNCCD, 2021[140]; Gerber and Mirzabaev, 2017[1]; OECD, 2015[200]; Bielza et al., 2006[197]; Roberts, 2005[212]; GeoSphere Austria, n.d.[213]).

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## Notes

[1] These figures refer to the number of days affected by a "*arrêté sécheresse*" implying water restrictions (i.e. "*Alerte*", "*Alerte renforcée*", or "*Crise*") for the region's three major rivers.

[2] Information on hydrological trends includes data on long-term patterns in water cycles, including rainfall, river flows, groundwater levels, evapotranspiration, and water storage. Information on socio-economic vulnerabilities includes data on the level of dependency (of a region or population) on consistent water sources, the resilience of local water systems, and the availability of alternative water supplies.

[3] These figures include EU countries, Norway, and the United Kingdom.

[4] While short-term restrictions on water withdrawal may help overcome temporary water scarcity, they do not contribute to long-term resilience to climate change, as they do not trigger the long-term changes needed to foster adaptation.

[5] The survey focused on the implementation of the OECD Council Recommendation on Water. It gathered 27 responses received, including from 26 Adherents to the Recommendation.

[6] This figure is based on five case studies carried out in five European regions in 2017, namely Greece's Thessaly region; Italy's Mid-Apennine region; Bulgaria's Black Sea basin district; Spain's Júcar river basin district; and Germany's Weser river basin district (IEEP, 2021[77]).

[7] For an in-depth discussion on tariff structures, see Leflaive and Hjort (2020[71]).

[8] This represents the estimated average reservoir recharge considering the maximum capacity of each reservoir.

[9] Wastewater is used water from households, industries, and businesses, containing waste products such as chemicals, food scraps, and solid waste. Greywater is wastewater generated from household activities such as bathing, washing dishes, and laundry.

[10] This is confirmed by statistics form the city of Melbourne (Australia), where housing equipped with wastewater reuse systems use on average 30% less drinking water than conventional houses (Van Leeuwen, 2017[215]).

[11] For example, desalination costs are estimated at USD 0.49-2.86/$m^3$ of water when using reverse osmosis, i.e. the most widely-deployed desalination technique to date. Other technologies, such as multistage flash distillation and multi-effect distillation desalination, achieve production costs between USD 1.00-1.74/$m^3$ and USD 1.40-1.50/$m^3$ respectively (World Bank Group, 2019[216]).

[12] All these factors influence the response of ecosystems to conservation and restoration efforts. For example, soil conservation efforts may be undermined by intensive farming practices that erode topsoil or increase runoff. The scale of implementation also plays a key role. For example, large-scale reforestation can improve hydrological cycles at regional level, while on a small scale its effects may be limited.

[13] The results of adopting sustainable agricultural practices such as those described in this section vary significantly depending on the local climate, soil type, and the timeframes considered.

[14] Mulching is the practice of covering the soil surface with a layer of material to conserve moisture and regulate soil temperature. Conservation tillage minimises soil disturbance by reducing or eliminating the use of tillage and plowing.

[15] For example, soil characteristics such as texture and moisture retention capacity can determine how well agricultural practices like crop rotation and no-till farming perform.

[16] Clay shrinkage consists in the reduction in clay soil volume due to the evaporation of soil moisture. Drought-induced subsidence refers to the gradual sinking of the ground surface due to the compaction of aquifer layers. Both phenomena can cause cracking, structural damage, and potentially affect the stability of assets. Subsidence can also increase exposure to floods.

[17] E.g. restricting the planting of trees with root systems that facilitate soil drying or employing root blocking screens to make trees with deep root systems less likely to deplete moisture around buildings.

[18] Water balances consist in the equilibrium between water inputs and outputs within a catchment's area. It considers both surface water and groundwater systems and any interactions between them.

[19] The EU defines ecological flows as hydrological regimes consistent with the achievement of the Water Framework Directive's environmental objectives for natural surface water bodies (European Commission, 2015[214]).

[20] Such mismatch in funding is caused by the fact that the agriculture sector is financed via the EU's Common Agricultural Policy, while the local water agency is largely financed by revenues from pollution and abstraction charges levied on domestic users and actors from industry and agriculture.

[21] Natural hazards covered by TARSİM included hail, floods, storms, tornadoes, fires, earthquakes, landslides and frost. A District Based Drought Yield Insurance was introduced for wheat in dry agricultural areas in 2017 and first implemented in 2021.

# Annex A. Details on OECD countries' exposure to drought

### Table A A.1. Change in OECD countries' exposure to droughts

Share of land experiencing increased average drought frequency and intensity between the periods 1950-2000 and 2000-2020

| Country | Share of land with increased drought frequency | Share of land with increased drought intensity |
|---|---|---|
| Australia | 66% | 63% |
| Austria | 67% | 95% |
| Belgium | 77% | 29% |
| Canada | 41% | 38% |
| Chile | 63% | 43% |
| Colombia | 61% | 65% |
| Costa Rica | 69% | 81% |
| Czech Republic | 100% | 100% |
| Denmark | 53% | 30% |
| Estonia | 52% | 100% |
| Finland | 13% | 50% |
| France | 98% | 49% |
| Germany | 97% | 88% |
| Greece | 87% | 52% |
| Hungary | 100% | 100% |
| Iceland | 4% | 29% |
| Ireland | 0% | 22% |
| Israel | 100% | 50% |
| Italy | 100% | 94% |
| Japan | 65% | 32% |
| Korea | 39% | 60% |
| Latvia | 60% | 86% |
| Lithuania | 92% | 74% |
| Luxembourg | 100% | 0% |
| Mexico | 31% | 45% |
| The Netherlands | 35% | 94% |
| New Zealand | 53% | 51% |
| Norway | 6% | 22% |
| Poland | 100% | 86% |
| Portugal | 84% | 100% |
| Slovak Republic | 100% | 100% |

| | | |
|---|---|---|
| Slovenia | 100% | 100% |
| Spain | 99% | 95% |
| Sweden | 14% | 46% |
| Switzerland | 100% | 94% |
| Türkiye | 66% | 61% |
| United Kingdom | 5% | 49% |
| United States | 40% | 48% |

Source: Author's own, based on data from Copernicus Climate Change Service (2022[1]).

## References

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# Annex B. Details on drought indicators

Chapter 2 relies on a mix of indicators (observations) and indices to assess current and future hydrological and agricultural drought risk, along with their key drivers. The indicators used in this report meet the following three criteria: (i) they are normalised indicators (i.e. standardised indicators or anomalies) to track changes in drought conditions over time and across regions; (ii) they are widely used and recognised in scientific literature for their accuracy in monitoring agricultural and hydrological droughts; and (iii) they are available at a gridded level for both historical and projected periods.

To evaluate **changes in drought frequency, intensity, and extremes**, this report primarily relies on the Standardised Precipitation Evapotranspiration Index (SPEI), which measures the balance between precipitation and evaporation, a key driver behind the occurrence and severity of droughts. SPEI strongly correlates with both agricultural and hydrological droughts, making it a valuable proxy for assessing long-term trends. Agricultural droughts are further analysed using the Surface Soil Moisture Anomaly (SMA). Historical hydrological droughts are monitored using station-based measurements of river flow and groundwater levels. Finally, precipitation and temperature anomalies, along with potential evaporation indicators, are used to evaluate historical and projected climate change impacts on drought risk. Table A B.1 below summarises the key characteristics and sources of the climate indicators used in this analysis.

### Table A B.1. Indicators used to assess drought trends and their drivers

| Indicator | Description | Source |
|---|---|---|
| Surface Soil Moisture Anomaly (SMA) | Annual average water volume in the surface soil layer (0-7 cm), measured as the difference between the annual value and the reference period average. | (Copernicus Climate Change Service, 2022[1]) (historical)<br>(Cook et al., 2020[2]) (projected) |
| Standardised Precipitation Evapotranspiration Index (SPEI) | Standardised measure (z-score) representing the difference between precipitation and potential evapotranspiration | (Vicente-Serrano, Beguería and López-Moreno, 2010[3]) (historical)<br>(World Bank, 2025[4]) (projected) |
| Precipitation anomaly | Total annual precipitation, measured as the difference between the annual value and the reference period average | (Copernicus Climate Change Service, 2022[1]) (historical)<br>(Cook et al., 2020[2]) (projected) |
| Temperature anomaly | Annual average temperature, measured as the difference between the annual value and the reference period average | (Copernicus Climate Change Service, 2022[1]) (historical)<br>(Cook et al., 2020[2]) (projected) |
| Potential evaporation | Potential evaporation from land, assuming well-watered conditions (not constrained soil moisture availability) | (Copernicus Climate Change Service, 2022[1]) (historical) |

Source: Author's own.

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# Global Drought Outlook

## Trends, Impacts and Policies to Adapt to a Drier World

Droughts are becoming more frequent and severe, placing growing pressure on communities, ecosystems and economies across the globe. As climate change intensifies these trends, the need for proactive and adaptive responses to strengthen drought resilience has never been more urgent. This report provides a global assessment of drought risk, impacts and policy in the context of climate change. It examines observed and projected drought trends and their drivers, and explores how climate change influences the frequency, duration and intensity of drought events. It also highlights the wide-ranging economic, social and environmental consequences of drought, providing data analysis and new insights into the scale and scope of these challenges. Drawing on international experiences and good practices, the report identifies policy options and measures that can support adaptation and enhance long-term resilience to a drier future.

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