GAR

Global Assessment Report on Disaster Risk Reduction

# Special Report on Drought 2021

United Nations

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# Foreword

The GAR Special Report on Drought 2021 comes at a pivotal moment as the world reflects on how it should deal with the threats various risks pose to sustainable development. As the Covid-19 pandemic has made tangible for so many, hazardous events that may have been thought of as being confined to a sector, or spatially and temporally limited, can quickly transform into crises with long-lasting, globally catastrophic social, ecological and economic consequences.

As with Covid-19, droughts affect all societies and economies – urban and rural – regardless of stages of development. Drought negatively affects the achievement of significant global agreements, underlining the imperative that risk reduction should be at the heart of accelerating action towards the 2030 Agenda for Sustainable Development, the Sendai Framework for Disaster Risk Reduction 2015–2030, the Paris Agreement, the Convention on Biological Diversity, the Convention to Combat Desertification, the New Urban Agenda and others.

The cost of drought to society and ecosystems is often substantially underestimated. It is borne disproportionately by the poor. As cultural historians warn, drought has been the single longest-term physical trigger of political change in 5,000 years of recorded human history. With its severe, wide-ranging and cascading impacts, the causal drivers of drought are rooted in the complex interactions of socioecological and technological systems. It is therefore imperative that addressing drought is included in national and international dialogues around poverty alleviation and sustainable development, including discussions on political insecurity and instability, which drought provokes and exacerbates.

This report explores the current understanding of drought risk, its drivers and the ways in which people, economies and ecosystems are exposed and vulnerable. It highlights that climate change is increasing the frequency, severity and duration of droughts in many regions across the world. It calls attention to the level of unreadiness across the world to respond effectively to the significant risks posed by drought.

Drawing on case studies from around the world, the report provides recommendations on how we can do better in reducing drought risks, thereby mitigating the devastating impacts on communities and economies. Failure to reduce the risk of and manage droughts differently in the future will result in dangerous consequences for lives, livelihoods, economies and ecosystems. The solutions and pathways towards more adaptive governance systems outlined in the report provide a foundation for building resilience across society, economies and the environment. These are needed urgently now more than ever.

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**Mami Mizutori**
Special Representative of the United Nations Secretary-General for Disaster Risk Reduction

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# Executive summary

The risks that drought poses to communities, ecosystems and economies are much larger and more profound than can be measured. The impacts are borne disproportionately by the most vulnerable people. Drought impacts are extensive across societies – they interconnect across large areas, cascade through socioecological and technical systems at different scales, and linger through time. A lack of awareness of such characteristics, including the consistent underestimation of the cost of drought impacts, can lead to ineffective response and systemic failure. As understanding of the globally networked aspects of drought and other complex risks improves, the changes required to reduce risk and improve the experience of drought become possible. This Global Assessment Report on Disaster Risk Reduction (GAR) Special Report on Drought 2021 aims to take a clear step forward in building that awareness.

While drought has always been a threat, climate change projections suggest many areas will experience droughts that are more frequent and more severe. This makes key issues such as how well society is coping with drought and the availability of governance, tools and approaches to reduce the cost of drought all the more pressing. This report aims to answer such questions by providing an in-depth exploration of the nature of drought risk, gathering experiences from responses and providing insights into new approaches to reduce and manage risk.

Drought risk is complex and has broad systemic impacts on societies, economies and the environment – all of which underpin future sustainable development. As outlined in the 2019 GAR, traditional and existing approaches are consistently overwhelmed by the systemic nature of drought risk, and so there is a need for new ways to tackle drought based on a systems and learning approach.

Addressing the full complexity of drought and reducing risk will require partnerships, greater public awareness and support, and participation and action at all levels. A transformation in the way the risk posed by drought is managed is essential to reduce this existential threat to many parts of the world.

This report is structured to build broad awareness of the nature of drought and the experience across the world of living with drought. It also builds the case for a new approach to drought risk management.

The new approach is based on effective models of governance where communities actively learn and adapt, while seeking to prevent and mitigate drought risk, and adapt and respond to drought. These processes build capacity across social, financial, institutional and scientific communities to recognize the complex nature of drought risk, devise risk reduction approaches and build the capacity to adapt as drought risk changes. This report also identifies enabling conditions that can transform drought management at local, national and global levels.

# Current understanding of drought

Chapter 1 presents the developing understanding of drought and also the drought risk equation: Risk = $f$ (Hazard, Exposure, Vulnerability). The breadth and complexity of drought impacts are described within the context of growing risks posed by human agency in a changing climate.

Droughts are recurrent events that affect large areas around the world each year. Their lengths are highly variable, from a few weeks to several years. They are challenging to characterize and manage due to their slow onsets (in most cases) and indeterminate ends.

**The damage and costs resulting from a drought are usually seriously underestimated due to widespread and cascading impacts, often not explicitly attributed to the drought.**

Droughts have always been part of human experience. Long and devastating droughts may have contributed to the demise of ancient cultures – reconstructive climatology indicates long dry periods during prehistory. Major droughts over the past century or so highlight the significant costs incurred by human society and the natural environment. The rapid evolution of human-induced climate change is likely to aggravate the risk of drought in many regions of the world.

### Defining and measuring drought

Drought is challenging to define clearly. Abnormally dry weather or an exceptional lack of water compared with normal conditions constitute the hazard posed by drought. Drought is not aridity or water scarcity. Drought risk and the considerable threat posed to people, societies and environments arise from the potential for dry weather to cause harm, the exposure of communities or environments, the vulnerability of those exposed to harm, and the capacity of society and ecosystems to undertake prospective, corrective or compensatory actions to reduce that risk.

Drought conditions arise from changes in atmospheric conditions. The El Niño Southern Oscillation, the Pacific Decadal Oscillation and the Interdecadal Pacific Oscillation are key indicators of low-frequency changes in persistent atmospheric circulation patterns associated with drought conditions over large areas of the world. Understanding the mechanisms of such climate features is key to improving capabilities for a timely seasonal prediction of drought events.

The drought hazard is more than a local shortfall in precipitation. It is a failure of whatever system drives the hydrological balance. This can include reduced rainfall over a certain period, inadequate timing or ineffectiveness of precipitation, and/or a negative water balance due to an increased atmospheric water demand following high temperatures or strong winds. Causes or exacerbating factors of drought include a lack of snow- or glacier-melt (following low winter precipitation) or increased temperatures.

**The drought hazard and human activities (e.g. land and water management) are strongly intertwined, such that these activities can exacerbate the hazard and increase the risk of severe socioeconomic and ecological impacts.**

Human actions interact with drought hazards to either exacerbate or limit the degree of risk and the severity of impacts. While land management and water management can mitigate drought impacts to a certain extent, they can also increase exposure and vulnerability and therefore increase future risks. Increased demand for water and extraction from natural and human-made reservoirs can increase vulnerability; some forms of conservative land-use practices can reduce soil moisture loss. A combination of drought and overabstraction from reservoirs and groundwater, for example, leads to decreasing buffers and reduced resilience to future drought.

Droughts are monitored based on hydrometeorological and land-surface indicators. They are usually termed meteorological, soil moisture (i.e. agricultural and/or ecological) or hydrological droughts; however, these are all progressive manifestations (or stages) of the same drought propagating through the hydrological cycle.

The onset of drought is usually slow, and so is difficult to measure until a certain threshold is reached. In addition, the end can be staggered. Nonetheless, defining discrete drought events is important for quantifying loss and damage from extreme events and for policy implementation. Droughts are monitored and quantified by sector-specific drought indicators, typically derived from hydroclimatic variables such as precipitation, climatic water balance, soil moisture, stream-flow and groundwater levels. Drought severity is communicated with indices assessed using meteorological, climatological and hydrological inputs including drought indicators. Important characteristics of droughts are frequency, severity (magnitude), intensity, duration, onset, cessation, end, peak month and area affected.

Droughts defined using these approaches range from flash droughts (with very fast onsets and which often end within a few days or weeks) to multi-decadal events. The notable damaging droughts of the last century have been multi-year events. Climate change may bring an increase in such long and severe events. In cold climates, different processes play a role in the development of droughts, where snow and glacier droughts are strongly influenced by climate change.

The hazard posed by drought can be compounded by exacerbating effects such as the co-occurrence of droughts and heatwaves, antecedent soil moisture deficits and the feedback and connections among droughts, heatwaves, wildfires and even floods.

### Drought trends

There is some confidence that climate change has already led to more-intense and longer meteorological droughts in some regions of the world, notably southern Europe and West Africa. Projections indicate droughts that are more frequent and more severe (even more severe than the worst droughts in the period 1981–2010) over wide parts of the world, in particular most of Africa, central and South America, central Asia, southern Australia, southern Europe, Mexico and the United States of America. The extent and severity of these projected droughts largely depend on the magnitude of the temperature rise. Other regions become wetter with less-frequent, less-intense or shorter meteorological droughts. The increase in drought hazard is larger when precipitation and temperature trends are combined.

### Drought impacts

**Drought impacts are intensifying as the world moves towards being 2°C warmer. When not adequately managed, drought is one of the drivers of desertification and land degradation, increasing fragility of ecosystems and social instability, especially in rural communities.**

Drought has a range of direct and indirect impacts. These can accumulate beyond the areas of drought, linger well after the drought ends and harm sectors in addition to agriculture (which is often the only sector economically assessed). Only some of these impacts are tangible (measurable and quantifiable); many are intangible and hidden.

**The direct and indirect impacts of drought across society, economy and ecosystems are often difficult to quantify.**

Direct impacts of drought occur through interaction among specific water deficiencies and environmental, social or economic components based on the dependence of livelihoods and economic sectors on water. Such impacts include agricultural production, public water supply, energy production, waterborne transportation, tourism, human health, biodiversity and natural ecosystems. Droughts may affect men and women differently, and their impacts often amplify existing structural inequalities across social groups, ages or other demographic categories.

Agriculture is harmed directly during drought because plant productivity is affected during all phases of growth. If this impact is sufficiently extensive in the world's "breadbaskets", drought can, and has, led to food prices rising globally and a range of significant cascading indirect impacts.

Such indirect impacts are the result of complex impact pathways. They cascade quickly through the economic system, affecting regions far from where the drought originated, and can linger long after the drought has ended. Thus, drought may result in temporary or permanent unemployment, business interruption, disrupted international trade, loss of income, disease due to poor water and air quality, food insecurity, malnutrition, starvation and widespread famine. In turn, this can trigger internal and cross-border migration, social unrest and even conflict in extreme cases.

Health impacts related to water and air quality and heatwaves can trigger physical harm to the well-being, and even death, of exposed and vulnerable people, especially the elderly. Impacts can also be felt through increased distress, leading to mental health issues, and shifting patterns of disease vectors, leading to disease outbreaks.

Ecosystems have complex relationships with the supply of water. Drought may cause reduced plant productivity, increased dehydration stress to wildlife, conversion of vegetation type or shifts in species range. There may be increases in disease in wild animals, and increased stress on endangered species or even extinction. Maintaining natural capital is crucial for resilience during drought cycles and to prevent land degradation and desertification. Vulnerability to land degradation increases due to drought (and the impact of subsequent floods and wildfires), and reduced resilience to future droughts arises from that degradation.

Large cities located in semi-arid to arid regions, and which rely mainly on reservoirs or groundwater for public water supply, are vulnerable to a sequence of dry years when water stocks are not sufficiently replenished. Furthermore, the quality of the water available to these cities (and all other users of water) can decline due to salinity, stratification, algal bloom and reduced dissolved oxygen. At least 79 megacities have suffered extensively across the world. Large urban centres (e.g. Brisbane in Australia, Cape Town in South Africa and São Paulo in Brazil) have come close to losing drinking water supplies and have had to mandate a high level of water efficiency and water diversions. Water scarcity has affected numerous other urban centres, and some small towns depend upon the trucking of water, among other emergency measures, to maintain water supply and survive.

Drought can impose choices, for instance among continued energy, water for food production or water for urban supply. This is because water is needed in power generation as a coolant or directly (as with hydropower).

**Vulnerabilities of the food, water and energy nexus are exposed by drought, and can spill over into a social vulnerability, stability and conflict nexus.**

Most drought impacts are indirect. They cascade through economies and communities and continue over time, dwarfing direct losses. They are not well documented or assessed.

Global estimates of costs offer only partial accounts and are deep underestimates; case studies suggest multiplicative impacts many times these costs. Estimates of some of the direct costs include annual losses due to drought in the United

States of America at approximately $6.4 billion per annum, and some €9.0 billion in the European Union. As a result of the Australian Millennium Drought, total factor agricultural productivity in Australia fell by 18% in the period 2002–2010. The effect of severe droughts on India's gross domestic product (GDP) is estimated at 2–5%.

The case studies summarized in Chapter 2 report crop failures, livestock deaths, mass migrations, hunger and health effects, impacts on food supply and markets, and conflict and various forms of severe social disruption in severe cases. There is clear disproportionate vulnerability of poor and marginalized populations (in many case studies and especially in Africa), where the cost of drought is measured in terms of lives, livelihoods and impoverishment.

**The better management of drought risk requires focusing on the identification and measurement of the full costs of drought.**

### Drought risks

Drought risks are complex, systemic and increasing. Such systemic risks are emergent and not obvious in prospect. Some elements can be modelled and quantified, some modelled and not quantified, and some remain unknown until experienced. Shocks in one or several parts of a system can ripple widely.

A drought becomes hazardous when water demands are no longer met. A drought becomes a risk when the drought hazard affects exposed and vulnerable societies and ecosystems with inadequate capacity to cope with the lack of water. Failure to manage this risk can result in dangerous consequences for lives, livelihoods, the economy and ecosystems. The size of the risk and thus the impacts of the realization of drought risk are dependent on the levels of exposure and vulnerability. Assessment of the drought hazard needs to be situation sensitive and to combine indicators; it is not necessary for all the characteristics of the drought hazard to be extreme for their composite impact to be extreme.

People and communities, livelihoods and ecosystems, as well as their services, infrastructure and basic services and other tangible assets, can be directly exposed to drought. Indirectly exposed elements include trade and financial systems that are affected by drought via teleconnection. Exposure is not static, so assessment of exposure requires composite and layered indicators.

Vulnerability is the predisposition to be harmed by drought because of the sensitivity of the elements of a system exposed to drought, coupled with a lack of coping and adaptive capacities.

Vulnerability assessment requires a socioecological systems perspective that can consider the susceptibility of ecosystems and deficits in coping capacities of the communities depending on them.

Improvements are needed in risk assessment and sustainable development approaches to identify dynamics and leverage points for understanding the underlying drivers of drought risk, for reducing impact, and to anticipate, adapt and move towards resilient sectors and societies.

## The lived experience of drought

Chapter 2 presents the lived experience of coping with and responding to drought from case studies around the world. Seventeen case studies have been developed that characterize a cross section of recent experiences of drought. The case studies are available in full in the digital edition of this report and can be accessed online at: https://www.undrr.org/publication/gar-special-report-drought-2021

The case studies have emerged from damaging droughts that have challenged existing drought policies and responses, and led to new plans and strategies. Notable droughts covered in the case studies are: the long cycle of droughts on the African continent and in the countries surrounding the Mediterranean Sea; the Australian Millennium Drought and the subsequent 2016–2020 drought; the Brazil multi-year drought of 2012–2018; the East Africa droughts of 2010–2011 and 2019; and recent experience of drought in North America.

The lived experience explores the impact of cycles of drought, the uncertainty of drought initiation, the importance of drought length and severity in terms of impacts, and the lack of clarity around when a drought ends.

Key questions remain around characterizing and predicting drought events, understanding the nature of vulnerability and resilience, and what constitutes an effective response to the risk of drought.

The costs of drought grow with increasing population, ineffective government policies and programmes, environmental degradation and fragmented authority in natural resources management. Impacts have grown due to the increasing frequency and severity of droughts, and are compounded with the increasing complexity and interconnectivity of economic, social and ecological systems, often incurring far-reaching social and environmental damage.

The broad range of direct and indirect impacts of drought test nations' wider economic and institutional systems and are especially complex when many nations share water resources or other impacts of drought. The impacts are most substantial in those countries with high reliance on rural economies and with large vulnerable populations. Cascading impacts noted in the case studies range from food price increases due to crop failures, through various forms of community health issues, to devastating conflict, either arising from drought impacts or exacerbated by them. These reports and issues inform the discussions of the systemic nature of risk in Chapter 3.

Drought effects are often felt initially at the landholder, farmer or grazier level. However, with time, the impacts propagate across communities, the economy and then beyond administrative or national borders. Vulnerability to the effects of drought is also unequal and follows a similar stratified pattern of severity. Across the African case studies, a hierarchy of vulnerability is clear (e.g. transhumance pastoralists, rain-fed crop farmers, irrigation farmers and then the broader elements of the community and economy). While vulnerability has many dimensions across the case studies, there are large numbers of people in fragile communities dependent on highly drought-sensitive activities like agriculture and livestock management, and which are further exacerbated by gender inequalities.

### Adaptation to drought

Local adaptations to drought are widely reported – essentially examples of adaptation from the ground up – sometimes supported by explicit government programmes. Examples include adapting crop variety or species choice, the mix of enterprises, planting dates, planting densities, irrigation strategies, agro-pastoralism, livestock species changes and delivery mechanisms. In Africa, adaptation strategies based on traditional knowledge (e.g. West African water harvesting) are increasing in importance, as are community networks (in Australia for example). Land regeneration, green belts and reforestation are key adaptive and mitigation actions in some case studies, and are especially important in the Aral Sea area.

Many of these local adaptations are not sufficiently connected to knowledge of the likelihood or current status of drought. While many case studies emphasize the need for empowered farmers and communities and an emphasis on preparedness tied into adequate early warning and monitoring, success is dependent on the effectiveness of policy support.

Policy support may include drought funds, rebates, tax measures and the like, which are now more common in many countries. However, the use of risk transfer and related financial instruments is rare due to a lack of knowledge or research into financial risk products, poor choice within expensive financial products and a small supplier pool and thus limited competition. Government-supported insurance schemes are in place in some countries (e.g. the Islamic Republic of Iran), while government farm subsidies feature in vastly different ways across countries.

### Drought risk management and governance

Drought spurs policy action, and cycles of policy development, review and restructure have emerged through the case studies. There are many national action plans, strategies, directives and similar initiatives, as well as new interministerial / departmental committees. These cycles reflect action when drought is severe and inaction when drought is no longer evident. Policy disconnects are common within and among governments. These challenge the general agreement that a move to prospective drought risk management is needed. While good examples exist in some parts of the world, many mechanisms and approaches have been overwhelmed by the length and complexity of severe droughts, and measures are currently in a reactive phase only.

**Almost all case studies identify the need for national drought policies to support drought risk reduction and avoid prevailing reactive models – shifting from dealing with drought impacts, to getting ahead of the curve to address underlying risk drivers to prevent and manage drought risk.**

International transboundary issues have additional complexities for governance. The case studies note that increasing pressures due to population and industrial development, unclear and poorly defined roles and responsibilities across institutions, increasing urgency of drought impacts during an event and knowledge gaps, challenge policy development and policy delivery. Conflict resolution and avoidance is a clear need, as water is becoming increasingly scarce and demand is growing.

In progressing beyond a reactive approach, some countries have adopted a three-pillar method to assess and respond to drought risk that includes: (a) monitoring and early warning systems, (b) vulnerability and impact assessment and (c) mitigation and response. Many countries are now connecting meteorological services to early warning, seasonal weather forecasts and status reports, with a focus on likely impacts on geographies and communities and livelihood / economic systems to improve targeting and support. There are opportunities to tie into and build monitoring systems that connect community "reporters" with remote-sensing technology and modelling (e.g. Drought Watch Danube Basin and DustWatch Australia), so that a resilient monitoring system takes shape.

Although the three-pillar approach is not prospective risk management, it is a step in the right direction towards prevention.

**The case studies show that countries' capacities to respond to drought-related impacts vary. They highlight how limited knowledge of possible impacts, poor assessments of vulnerabilities and costs, little coordination at national and regional levels, and lack of awareness on policy options are key impediments to effective drought management.**

## The change needed

The key aim of the Sendai Framework for Disaster Risk Reduction 2015–2030 (Sendai Framework) is to prevent new and reduce existing disaster risk. Prospective and proactive drought risk management is required to reduce and, where possible, avoid future risks and to increase resilience to the changing drought hazard. Early warning systems need to be re-imagined based on progress in understanding the physical processes underlying drought propagation and impacts, as well as the human role in exacerbating and mitigating drought. While some promising approaches do exist, these have not yet been replicated at scale. The capacity to explore plausible trends in drought risk needs to be expanded to support decision-making in the short to medium term, for example from a few weeks, to multiple seasons and decadal considerations. Scenarios of hazard and risk using integrated assessment tools can build on climate change and related socioeconomic pathways, along with context-specific models and gaming approaches. These approaches are essential but insufficient to prevent future risk.

Chapter 3 demonstrates how systemic risk management is fundamental to move from drought risk to resilience. It describes the transformation needed in governance to match the diversity of actors and viewpoints with the widely varying nature of drought. It develops the enablers, partnerships, capacities and strategies of a systemic approach to manage risk across scales and as scales and systems interact. While this report is neither a prescription nor does it claim solutions, it develops options to be explored and ways to navigate and negotiate through this complex, damaging risk.

### Enabling proactive and prospective responses to drought risk

The analysis of drought and the experiences explored in the case studies illustrate there are connected concerns requiring a transformation in approaches to managing drought risk.

**Successful integrated management requires a governance shift from reaction and bailout to risk reduction and resilience, in part based on improved knowledge of the climate mechanisms controlling the onset and termination of drought periods, other factors affecting drought initiation and cessation, and level of vulnerability of exposed communities, industries and ecosystems.**

This report argues for a more systemic approach to drought risk underpinned by nimble and adaptive risk governance, built around strengthened observation, learning where intervention is feasible and effective, all within adaptive and prospective drought risk management policies, plans and actions. This requires new forms of governance that are designed for the systemic nature of the risk and can respond to the extraordinary complexity of the drought experience.

Effective governance of drought-related systemic risks must be adaptive and multi-scale, in the context of anticipated risks and opportunities, for managing through a rapidly changing environment (i.e. across the full risk to resilience continuum).

### Transforming drought governance

Components of a systemic approach to drought risk include:

- Systemic innovation strategies founded on notions of complexity, ambiguity and diversity to manage present risks and adapt as new risks emerge
- A commitment to iterative analytical deliberation, monitoring, nesting of approaches, institutional variety and evaluation, where deviation from the target should not be seen as failure but rather as an opportunity to learn and adjust
- Substantially greater diversity of actors and viewpoints; more perspectives and visions may offer a broader portfolio of opportunities and solutions for problems
- System management that aims at the capacity of systems being able to adapt to and shape change, which is crucial to the resilience of socioecological and technological systems

Governance of such a systemic approach needs to include the actions, processes, traditions and institutions – formal and informal – by which collective decisions are reached and implemented. Managing the complexity of drought risk requires a transformation across the dimensions of risk management. Effective governance will deliver adaptive management that is aware of complexity, ambiguity and diversity.

**Transitions to new forms of governance can be enabled by enhancing the capabilities of public, private, civil society and financial institutions to accelerate national and local policy planning and implementation, along with accelerated and appropriate technological innovations.**

Transitions in governance can require incremental adjustments and rapid, sometimes disruptive, transformative changes. Managing the impact of those changes is part of appropriate policy action at all levels of governance. Promoting top-down and bottom-up processes of governance requires new mechanisms to promote dialogue among different levels and increased flows of information and resources. Enabling conditions are needed to: allow new effective multi-stakeholder partnerships where iterative learning with those most affected by drought is central, and which embrace systemic change; promote collaboration, shared responsibility and confidence; and support coordination, leadership and participatory learning.

Because much of the complexity in drought risk arises from the degree of exposure of vulnerable people, industries and ecosystems, this exposure and vulnerability needs to be reduced by transitioning systems at multiple scales.

Having initiated action in response to a complex threat like drought, it is not possible to assume those actions will always remain pertinent. Hence, iterative learning is required. Early warning is crucial to managing drought risk, and some impact can be mitigated. But the opaque, complex and coupled relationships that confound management of financial systems, for example, are matched or surpassed by the complexities of drought exposure and vulnerability.

## Towards adaptive governance of drought

A robust evidence and capability base is needed that provides: risk identification and mapping; participatory valuation and management of ecosystem services; mainstreaming of ecosystem approaches in drought risk management and reduction; social protection; social accountability; and aligned goals and investment for financing drought-related systemic risk reduction.

Existing strategies can be directed to address systemic risks. Early warning can be a proactive social process whereby networks of organizations conduct collaborative situational assessments. Indicators help to identify when and where local capabilities, human agency and policy interventions are most needed. Historical and institutional analyses help to identify the processes and entry points if vulnerability is to be reduced.

**Adaptive governance aims to deal with uncertainties and surprises that are inherent in transforming complex social, technological and ecological systems. It relies on iterative learning, planning, policymaking, implementation and evaluation over time.**

Adaptive governance of drought risk must cope with uncertainty, thresholds and surprises. It depends on innovation, reliable and accessible data, knowledge and decision-making tools – if these are people centred and used with vulnerable sectors and social groups to mitigate loss and damage through the introduction of their own local knowledge and experience. Moreover, taking local knowledge and practices into account promotes mutual trust and a community's sense of ownership and self-confidence.

Innovation requires transformative coalitions and partnerships. Research and the private sector are crucial, but "open innovation" policies can target users, civil society, communities and other actors. More support for social and grass-roots innovation can enable deeper and more transformative pathways. Innovation can be inspired through the effective use of scenarios and "serious" gaming – it does not predict future outcomes but guides choice between options by making likely trade-offs and synergies transparent.

**Future scenarios of drought risk need to consider the effects of adaptive or non-adaptive human behaviour and potential adaptation measures on future drought hazard, exposure and systems' vulnerabilities.**

Such transformative partnerships and a new paradigm for governance can then focus on tasks to improve adaptive management and governance of drought-related systemic risks (identified and described in detail in this report) and deliver them effectively. These include:

- Investing in drought risk identification, monitoring and mapping
- Employing horizontal partnership development to share visions, an architecture for participation and mainstreaming of resilience-based approaches in drought risk management and reduction
- Offering social protection through for example, resilience bonds and conditional cash transfer and temporary employment schemes, micro-insurance and loans
- Ensuring social accountability through increased public information and transparency
- Aligning goals and investment for financing drought-related systemic risk reduction to promote coherence in financing

Effective governance requires a process of systematic coordination at global to national scales, and national to local scales and back up the chain: (a) vertically at local, subnational, national, regional and global levels of government and (b) horizontally across sectors through collaboration across governments and intergovernmental organizations, the private sector, civil society organizations and citizens.

**Centralized and decentralized approaches can complement each other, especially when the actor network is broadened beyond a sender–receiver model of information communication.**

At national level, effective governance requires:

- Policies and directives for drought risk reduction and climate change adaptation and mitigation that are integrated with local development plans
- Information and incentives for government agencies to share the responsibility for sustainability across portfolios
- Re-enforcement, amplification and extension of existing regulatory measures and incentives, such as the promotion of water-saving practices, enforcement of sustainable land and water management, and environmental protection
- Building on international policy momentum to bring domestic attention and resources to the reduction of climate-related disaster risks, and specifically risk-prevention measures and the creation of centres of excellence where drought-related technical resources and capacities can be pooled

These changes require high levels of public awareness and support.

At the global level, support for national and local risk reduction requires an effective framework to:

- Understand and engage countries and communities
- Develop international collaboration and dialogue on drivers of globally networked risks
- Develop thematic working groups including industry and civil society actors focused on feasibility, capacity and accountability

Convergence among and integration of strategies within international mechanisms – including disaster risk reduction (DRR) (through the Sendai Framework), climate change adaptation and mitigation (Paris Agreement), reversing declining trends in biodiversity (Convention on Biological Diversity), combating drought and desertification (Convention to Combat Desertification) and sustainable development (Transforming our World: the 2030 Agenda for Sustainable Development) – provide this essential framework.

This report frames the prospective, corrective and compensatory dimensions of drought risk reduction as including the spectrum of activities described by the Paris Agreement as climate change adaptation and mitigation.

While increased coherence across these agreements brings gains in efficiency and effectiveness, it is not without costs. It can result in trade-offs between investing in DRR and climate change adaptation, mitigation and DRR and making progress on individual policy processes. The integration of both policy agendas can occur on a continuum, from strategic to operational and technical, where policy coherence is not viewed as an outcome but rather a process of coordination. With their mix of slow and fast onsets, fluctuating intensities and duration, even within the same event, droughts provide a useful analogue and practical experience for a much wider suite of complex and growing risks, including climate change.

**Two critical recommendations are made to achieve a shared vision and acceptable action-oriented development of drought resilience:**

- **Develop a national drought resilience partnership that works to ensure a seamless link between national and local levels with public, private and civil society partners.**
- **Support the establishment of a global mechanism for drought management focused on systemic risks.**

As no two droughts are the same, no simple formula to manage them is sufficient. The continuum and feedback among varieties of drought events and drivers, impacts, warnings and ongoing responses represent immense complexity. Risk assessment and management strategies have to change so resilience is built into the capacity to adapt to complex risk and learn from experiences.

# The call to action

Chapter 4 concludes the report with a call to action that applies to all stakeholders:

- Avoid growing human, ecological and financial costs by investing in risk preventative action through systemic drought management and adaptive governance.
- Take action now to better understand the causes of vulnerability that are a function of human agency, before inevitable drought hazards emerge (and intensify under climate change). Draw on the long history of research and practices within the DRR community together with knowledge enshrined in traditional and indigenous wisdom. With what we know, we must do better, and with what we learn, we must improve.
- Build enabling conditions for the transition to drought-related, systemic risk governance. These include drought resilience partnerships at the national and local levels, building on approaches such as the 10-step drought planning approach or the three-pillar approach developed through the Integrated Drought Management Programme while avoiding overly prescriptive planning that does not prioritize and allow iterative learning and innovation. Prospective drought risk management requires plans designed to be flexible with inbuilt capacity to learn to change.
- Move towards a new global mechanism to effectively address the complex systemic nature of drought across international, national and local levels. Vertical and horizontal governance and associated partnerships – based on shared values, roles and responsibilities – can then accelerate transitions towards systems-based and prospective approaches to drought risk management and reduction, and mobilize financial resources directed to grow systemic drought resilience. Inherent in these initiatives are improved international dialogue and collaboration around globally networked risks and more effective partnerships among public sectors, private sectors and civil society.

- Better knowledge of the complex nature of drought shared more broadly and with enabled, nimble and adaptive governance will lead to reduced drought risk to people and ecosystems. Systemic action to reduce and prevent drought risks provides an effective pathway for reducing a much wider suite of complex and proliferating risks, including the growing and real threat of climate change.
- Immediate action is required.

# 1. Modernizing current understanding of drought

## 1.1 Introduction

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

Before the start of instrumental records in the late nineteenth century, historical archives with written records of past weather and climate conditions, as well as paleoclimatic data (e.g. tree-rings, ice cores or lake sediments), provide proxy data that helps infer variations in climate conditions. Based on such data, long and devastating droughts supposedly contributed to the demise of a number of ancient cultures. Examples are the Mayan civilization in central America during the eighth and ninth centuries or the Akkadian empire in Mesopotamia around 2200 B.C.E.

In more recent history, repeated severe European droughts during the last thousand years, the well-known Dust Bowl in the central United States of America in the 1930s, the Sahel drought in the 1970s and 1980s, and the recent Australian Millennium Drought highlight the risks human societies face from this natural hazard (Kerr, 1998; Glaser, 2001; Sheffield and Wood, 2011; Cook et al., 2015a). While the risk of severe droughts will continue due to climate variability, the rapid evolution of human-induced climate change is likely to aggravate this risk in many regions of the world.

Drought impacts are far-reaching. They may affect agricultural production, water supply, energy production, waterborne transportation, tourism, human health, biodiversity and natural ecosystems. Related indirect and cascading impacts can affect employment rates, food prices, food security and international trade. In turn, these can lead to increased poverty, migration, social unrest and even conflict in extreme cases. Such impacts are often less directly linked to drought and can linger long after the actual event.

That water is a basic commodity for every individual, combined with an increased frequency and severity of droughts due to climate change, make droughts a major concern for communities and individuals alike (Prudhomme et al., 2014; IPCC, 2018; Lu et al., 2019; Spinoni et al., 2020). Droughts also pose a major challenge to achieving the United Nations Sustainable Development Goals (SDGs) in many parts of the world, as a result of direct and indirect impacts.

While droughts result in severe economic losses, environmental damage and human suffering, they are often less visible than other natural hazards such as floods or storms. The latter cause immediate damage linked to the hazardous event and are quantifiable in economic terms (UNISDR, 2011). However, the damage and costs resulting from droughts are often seriously underestimated due to their spatial and temporal characteristics and indirect nature.

A key challenge is to develop and implement adequate risk management strategies, enabling societies to adapt to the evolving drought risk in the context of global change, and which consider changes in climate, land and water management, exposure and vulnerabilities (Wilhite et al., 2014; WMO and GWP, 2014). Building an integrated understanding of drought is essential to its management. This needs to consider the physical processes and drivers behind droughts, their propagation through the hydrological cycle, and also the related societal and environmental vulnerabilities of different actors, sectors and systems as well as wide-ranging direct and cascading impacts. Such strategies need to address systemic risks resulting from compound events (e.g. co-occurring droughts and heatwaves, droughts and subsequent flooding, droughts and forest fires) and/or wide-ranging cascading impacts (e.g. droughts followed by food insecurity, migration and conflict) that can lead to systemic failures of entire societies.

Chapter 1 of this report first provides the physical and social context of drought. It discusses the related risk concept as a basis for the case studies in Chapter 2 and for the pathways towards resilience in Chapter 3. The report concludes with Chapter 4, which captures the main findings, recommendations and the call to action. Starting from the definition of a drought event and the variables to characterize drought, section 1.2 provides insight into the related climatological aspects (climate variability, past trends and future projections), special cases, possible confounding factors and the role of society. Section 1.3 gives an overview of the variety of drought impacts and discusses their tangible or intangible nature. Section 1.4 analyses the main components of drought risk (hazard, exposure and vulnerability), their drivers, spatial patterns, dynamics and importance, and discusses the current and future drought risk in the context of global change. Section 1.5 provides an introduction to the various aspects of risk management and risk reduction that aim to increase resilience to drought, which are further developed and discussed in Chapter 3.

This report employs the terminology adopted by the United Nations General Assembly in its *Report of the Open-Ended Intergovernmental Expert Working Group on Indicators and Terminology Relating to Disaster Risk Reduction* (United Nations, General Assembly, 2016), the *2009 UNISDR Terminology on Disaster Risk Reduction* (UNISDR, 2009) or the online glossary of the Integrated Drought Management Programme (IDMP, n.d.).

# 1.2

# The physical and social context of drought

**KEY MESSAGES**

- Droughts are a recurring feature of all climates.
- Droughts are to be distinguished from aridity, a seasonally or fully dry climate, and from water scarcity, when the climatologically available water resources are insufficient to satisfy long-term average water requirements, leading to a structural imbalance.
- Droughts are slow-onset events that can last from weeks to years. They are often defined as meteorological, soil moisture (i.e. agricultural and ecological) or hydrological droughts. In reality, these are progressive manifestations of the same drought propagating through the hydrological cycle.
- Recently, the concept of flash droughts has emerged, describing quick-onset, severe events of water stress due to high temperatures and a high evaporative demand.
- The risks resulting from droughts can be severely aggravated by compound events (e.g. droughts and heatwaves).
- Human activities resulting in water scarcity and feedback loops in the climate system play a key role in drought intensification and propagation.
- Typical mitigation responses are building more infrastructure or reducing exposure and vulnerability. However, more infrastructure can increase vulnerability by increasing demand or dependence on reservoir storage.

## 1.2.1

### Defining drought

Droughts are a recurring feature of all climates and are generally defined with respect to the long-term average climate of a given region (e.g. Heim Jr, 2002; Dai, 2013). Given the complex nature of droughts, their definition varies across climatic regions and has traditionally varied across affected sectors and scientific disciplines. It is therefore difficult to compare drought characteristics across time and space.

The Intergovernmental Panel on Climate Change (IPCC) defines drought as “a period of abnormally dry weather long enough to cause a serious hydrological imbalance” (IPCC, 2012). It results from a shortfall of precipitation over a certain period, from the inadequate timing or the ineffectiveness of the precipitation, and/or from a negative water balance due to an increased atmospheric water demand following high temperatures or strong winds. Furthermore, a lack of snow- or glacier-melt following a drop in winter precipitation can cause or exacerbate drought.

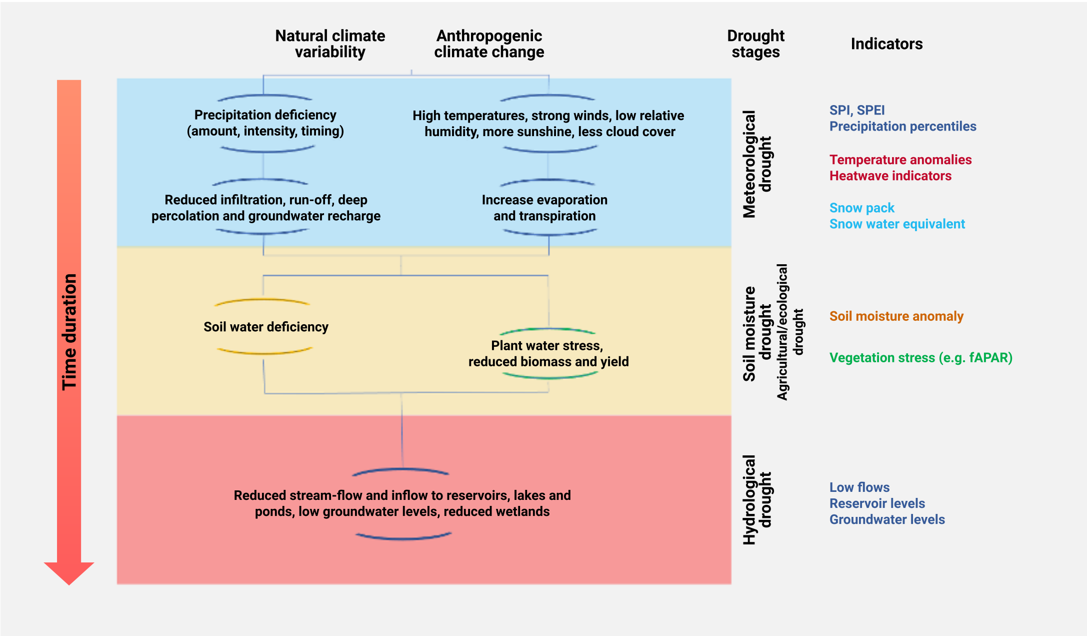
Droughts originate from extremes of the climate system like persistent anticyclonic conditions or the advection of hot and dry air masses. Van Loon et al. (2016) argued that droughts result from a complex interaction of natural and anthropogenic processes due to the strong influence of human activities on the water balance. High demand for water resources, for example, can exacerbate the severity of a drought. Mitigation responses like increased groundwater pumping for irrigation may alleviate water stress during an ongoing drought but can increase vulnerability for subsequent droughts. A generic definition of drought was therefore proposed as “an exceptional lack of water compared with normal conditions” (Van Loon et al., 2016). Note the stress here is on "exceptional", which distinguishes drought (a time-limited event) from water scarcity, a long-term structural imbalance between water availability and demand (i.e. an unsustainable overuse of water resources) and from aridity, a seasonally or fully dry climate (e.g. Tallaksen and van Lanen, 2004; van Lanen et al., 2017). Box 1.1 shows a further elaboration of the distinction between drought and water scarcity.

Droughts typically last from months to a few years, and may be exacerbated by antecedent dry conditions in soil moisture as well as by low reservoir and aquifer levels. As special cases, extreme and long-lasting "megadroughts" can persist for decades, while so-called "flash droughts" are short periods (usually less than 3 months) of high temperatures and/or strong winds, resulting in increased evapotranspiration and a fast depletion of soil moisture that can lead to major impacts, especially in the agricultural sector (Mo and Lettenmaier, 2016).

In addition, perceptions of what is to be called a drought and of its impacts vary to a large extent. A drought does not result in a sudden impact, unlike a flood or a storm. It is rather a slow-onset phenomenon that establishes itself over a long time period. Drought impacts are less obvious and spread over larger areas than damage resulting from other natural hazards (Wilhite et al., 2014). These spatial and temporal aspects and the complex interactions between environment and society make the cost of drought difficult to evaluate (Vogt and Somma, 2000).

Questions even arise with respect to the start and end of a drought event. Droughts are usually monitored based on a series of hydrometeorological and land-surface indicators (Figure 1.1). Droughts are often defined as being meteorological, soil moisture (i.e. agricultural and/or ecological) or hydrological droughts. However, these are progressive manifestations (or stages) of the same drought. A drought will likely have more-severe impacts as the propagation in the hydrological cycle advances. Exceptions

**Figure 1.1. Schematic representation of drought propagation through the hydrological cycle, related drought stages and key indicators**




*Note*: fAPAR: fraction of absorbed photosynthetically active radiation; SPEI: standardized precipitation evapotranspiration index; SPI: standardized precipitation index.

*Sources*: Adapted from the National Drought Mitigation Centre, United States of America; Wilhite et al. (2014)

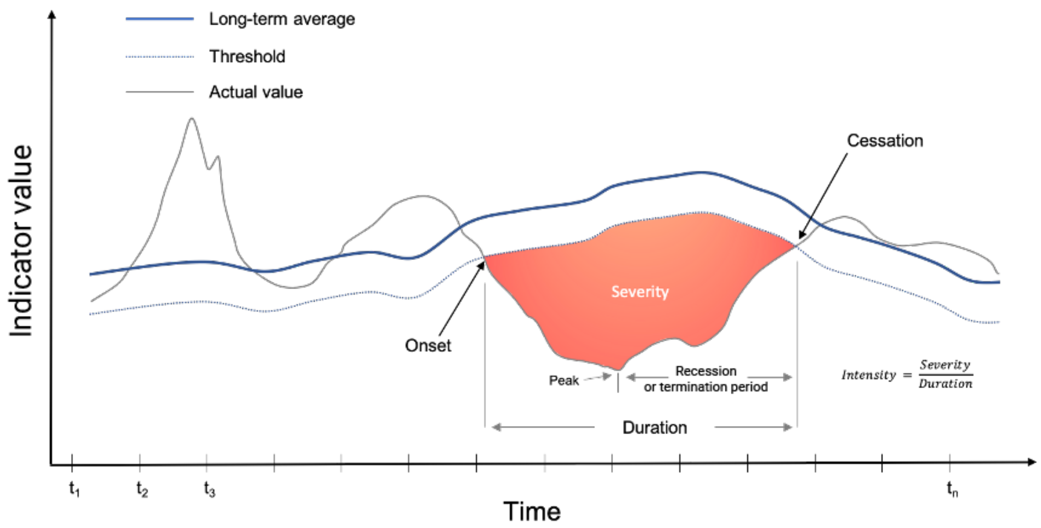
from this rule are flash droughts, which result in a rapid desiccation of the upper soil layer, and snow- and ice-related droughts, which originate from cold anomalies and a related late snow/ice melt (Staudinger et al., 2014; Van Loon et al., 2015).

A drought event is detected when one or several indicators fall below a given threshold for a defined period (e.g. 1 or 2 months). The threshold is often defined as a negative deviation in units of standard deviation from the long-term average or as a percentile (Figure 1.2). This threshold is variable during the year and depends on the indicator(s) monitored. The use of several indicators allows for consideration of drought propagation through the hydrological cycle and for monitoring impacts in different economic sectors and on the environment.

However, the detection of the end of a drought event is a more complex issue. Often, the return of indicators above the threshold or above the long-term average is used to determine the end of a drought, as that indicates the replenishment of water resources. However, different indicators may return to normal in a staggered process following gradual normalization in the different hydrological compartments. Therefore, the declaration of the end of a drought event may depend on the sector and related hydrometeorological indicators. To completely end a drought event, all indicators should return to normal, indicating a complete restoration of normal conditions. The duration of a termination (or recession) period from the peak severity to the crossing of the threshold (or long-term average) has been proposed as a more complete characterization of the restoration process from a drought (e.g. Parry et al., 2016; Margariti et al., 2019).

Drought impacts may linger for a significant time period, even after the hydrometeorological indicators return to normal. Defining discrete drought events is important for quantifying loss and damage from extreme climatic events and for policy implementation, especially with regards to the United Nations Framework Convention on Climate Change (UNFCCC), the Sendai Framework for Disaster Risk Reduction 2015–2030 (the Sendai Framework; United Nations, General Assembly, 2015a), and the Transforming our World: the 2030 Agenda for Sustainable Development (2030 Agenda; United Nations, General Assembly, 2015b) (WMO and GWP, 2016).

**Figure 1.2. Schematic representation of selected key drought parameters**



Not all droughts result in disasters. A drought becomes hazardous when water demands are no longer met and becomes a risk when there is a diminishing capacity to cope with the lack of water. This risk can result in dangerous consequences for people's livelihoods, the economy, ecosystems' health, and even the lives of humans and animals (see section 1.3). The loss of livelihoods has a strong impact on poverty, especially in less developed countries, and can lead to migration and aid dependency. The risk of long-term land degradation increases if droughts persist for long periods or occur frequently. In the worst cases, droughts can lead to a complete loss of ecosystem services when tipping points are passed (Vogt et al., 2011; Spinoni et al., 2015).

The risk of significant impacts from a drought is a function of the onset, duration and severity of the hazard itself. It also depends, to a large degree, on the spatial and temporal rate of exposure of affected actors, assets, economic sectors, and systems and their vulnerability. This vulnerability depends on susceptibility to impacts, a lack of coping capacity and the ability to adapt to changing conditions in the long term. The concept may be expressed by the risk equation:

Risk = $f$ (Hazard, Exposure, Vulnerability),

where

Vulnerability = $f$ (Susceptibility to impacts, Lack of coping capacity, Lack of adaptive capacity).

Section 1.4 provides a detailed discussion of the different components of the risk equation and their relationships, as well as the concepts and methodologies for assessment of the resulting risk, including a framework for understanding the relationships among various factors. These include drivers and impacts of drought that relate to areas remote from the drought-affected area but linked through global networks of production chains and trade, or teleconnections.

**Box 1.1. Drought and water scarcity**

Drought is different from water scarcity, where climatologically available water resources are insufficient to satisfy long-term average water requirements due to a structural imbalance (e.g. van Lanen et al., 2017). Both phenomena influence each other.

On the one hand, an increase in drought frequency or severity, or both, can threaten already water-scarce regions and create new or expand existing regions suffering from water scarcity. To reduce the threat, regional development planning should allow for timely adaptation to a changing climate. On the other hand, water scarcity significantly increases drought risk, as water-scarce regions lack adequate buffers to cope with droughts. Repeated, prolonged or severe droughts can severely damage the economy, society and natural ecosystems in such regions, with the risk of leading to land degradation and desertification (Cherlet et al., 2018).

Increased political engagement is required to address pressures on water resources such as population increase, irrigation, inadequate land and water management, and water availability under a changing climate.

## 1.2.2

### Drought indicators

Droughts are monitored and quantified by sector-specific drought indicators, typically derived from hydroclimatic variables such as precipitation, climatic water balance, soil moisture, stream-flow and groundwater levels. Related impacts such as reductions in greenness and vigour of vegetation are relevant indices. Indices are representations of drought severity, assessed using meteorological, climatological and hydrological inputs, including the indicators listed above. They aim to measure the state of droughts for a given period. Indices can also be considered as indicators. For this report, the term "indicators" will be used with the understanding that indices are included in this definition. The World Meteorological Organization (WMO) and the Global Water Partnership (GWP) have published an overview of widely used drought indicators and indices (WMO and GWP, 2016).

**Table 1.1. Main variables for characterizing drought events**

| Variable | Description | Relevance |
|---|---|---|
| **Frequency** | Number of drought events per defined time interval | More-frequent droughts can cause long-term impacts on ecosystems |
| **Severity (magnitude)** | Related to the water deficit; computed as the sum of the differences, in absolute values, between the drought indicator (DI) values and the threshold used to define the level of dryness: $S_i=\Sigma\ \lvert DI_i \rvert$ < threshold | Water deficit in relation to that needed for specific uses (e.g. irrigation, domestic water consumption or energy production) |
| **Intensity** | Severity divided by duration of the event | Characterizes the overall potential for impacts |
| **Duration** | Number of days, months or time steps of the event | Longer droughts propagate further through the hydrological cycle with a higher potential for cascading and secondary effects |
| **Onset** | First day, month or time step for which the indicator is below a given indicator and time-dependent threshold | Relevant if a drought starts in sensitive periods with greater water demand like seeding, flowering and ripening periods; relevant for drought management and declaration of drought emergencies |
| **Cessation** | Meteorological indices have returned to normal (i.e. within normal variability), soil moisture is restoring, pasture growth re-establishes, forest growth re-establishes, reservoirs and lakes refill | Relevant for management |
| **End** | Agricultural and natural ecosystem productivity returns to average pre-drought condition; lake and reservoir levels return to average pre-drought conditions; socioeconomic conditions return or stabilize to normal conditions | Relevant for management |
| **Peak month** | Day or month with the lowest value of the drought indicator | Period with the potentially strongest impact |
| **Area affected** | Area or percentage of a region (or country) with values of the drought indicator below a certain threshold | The wider the area, the more those assets that are exposed are affected |

*Source*: Vogt et al. (2018)

Drought indicators are most commonly presented in the form of standardized variables used to analyse droughts in different domains of the water cycle. Drought indicators are designed either for drought monitoring and awareness-raising or for water management (Beguería et al., 2014). However, they are also useful for drought forecasting (Dutra et al., 2014; Sheffield et al., 2014), climate change studies (Trenberth et al., 2014; Dai et al., 2018) and as input for drought impact modelling (Zampieri et al., 2017) and drought risk assessments (Svoboda et al., 2015).

Different drought stages require different indicators for their characterization (Figure 1.1). The standardized precipitation index (SPI; McKee et al., 1993) and the standardized precipitation evapotranspiration index (SPEI; Vicente-Serrano et al., 2010) are often used for meteorological drought analysis. Soil moisture indicators such as the soil moisture-based drought severity index (Cammalleri et al., 2016) or the Palmer drought severity index (Palmer, 1965) characterize drought impacts in terms of plant water stress. Hydrological indicators, such as flow percentiles or the standardized run-off index (Shukla and Wood, 2008), are used to quantify the volume of water deficit in rivers and reservoirs (Hisdal et al., 2004; Cammalleri et al., 2017) or to monitor whether a required ecological flow or a minimum flow regime is maintained. Remote-sensing-based indicators such as the normalized difference vegetation index or the fraction of absorbed photosynthetically active radiation are used to monitor drought stress on the vegetation canopy. In early warning and impact mitigation, the use of composite indicators reflecting regional climate conditions is recommended to adequately describe the progression of drought stages (WMO and GWP, 2016).

Combined indicators that blend several physical indicators into a single indicator have also been developed. The European Drought Observatory, run by the European Commission's Joint Research Centre (JRC), uses the combined drought indicator (Sepulcre-Canto et al., 2012) to monitor drought impacts on agricultural and natural ecosystems, while the JRC Global Drought Observatory (GDO) uses the risk of drought impact (RDrI) indicator to monitor risk in different sectors across the world. The RDrI indicator includes an evaluation of exposure and vulnerability for calculating risk (Naumann et al., 2014; Carrão et al., 2016).

To obtain an overview of the potential impacts of droughts, a set of characteristics is needed to represent different aspects of the water deficit. Key characteristics include frequency, severity or magnitude, intensity and duration (Table 1.1 and Figure 1.2).

Frequency describes the number of events per time interval, severity describes the accumulated deficit over the entire duration of an event and intensity describes the average degree of precipitation, soil moisture or water storage deficit during a drought. As depicted in Table 1.1, the duration and area affected are linked to the propagation in time and space of the water deficit. Longer and more-widespread events might trigger cascading effects, the magnitudes of which are directly related to the water deficit. The timing of the onset, cessation and end of a drought are particularly relevant during the growing season. Yet, the impacts as measured by reference indicators may be felt long after the drought has ended. Other similar characterizations have been developed for the various stages of the drought life cycle (WMO and GWP, forthcoming).

In summary, drought monitoring, assessment and forecasting for different economic or environment sectors requires diverse sets of indicators, depending on the sector and goal of the analysis.

## 1.2.3

### Climate variability, climate change and global trends in drought hazard

Droughts are caused by changes in persistent atmospheric circulation patterns usually connected to slowly varying atmospheric boundary conditions (e.g. changes in sea-surface temperature, sea-ice cover or land–atmosphere interactions). The El Niño Southern Oscillation (ENSO) is one of the main sources of episodic droughts globally, together with other low-frequency sources (Davey et al., 2014; Trenberth et al., 2014). Natural cycles of ocean–atmosphere interactions lead to recurring swings between anomalously warm (El Niño) and cold (La Niña) sea-surface temperatures in the equatorial Pacific. During an ENSO event, drought can occur nearly anywhere in the world, although researchers have found the strongest connections between ENSO and intense drought in Australia, Brazil, India, Indonesia, the Philippines, various parts of the United States of America, parts of eastern and southern Africa and central America, and the western Pacific basin islands (including Hawaii).

Droughts occur in each of the above regions at different seasons during a warm or cold event and to varying degrees of magnitude. Multi-year and decadal trend assessments are unreliable without base periods long enough to capture natural variability. Major uncertainties surround the degree to which ENSO, the Pacific Decadal Oscillation and the Interdecadal Pacific Oscillation are and will be affected by climate change and their effects on long-term evapotranspiration (Wood et al., 2015). Understanding the mechanisms behind low-frequency climate features like ENSO will be key to improving capabilities for a timely seasonal prediction of drought events.

In addition to natural variability, meteorological droughts are influenced by human-induced climate change. The IPCC special report on extreme events summarized with medium confidence that climate change has already led to more-intense and longer meteorological droughts in some regions of the world, notably southern Europe and West Africa (IPCC, 2012). The IPCC also predicts intensified meteorological droughts in the twenty-first century, again in southern Europe, but also in Mexico, north-eastern Brazil, central North America, southern Africa, central America and central Europe. This is due to reduced precipitation, increased evapotranspiration or a combination of both.

Other regions, especially at higher latitudes, have or will become wetter with less-frequent, less-intense or shorter meteorological droughts. Even in areas projected to become wetter on average, precipitation can be distributed unevenly – more water on average does not mean more water when it is needed. Climate change impacts in wetter regions can lead to more-severe soil moisture and/or hydrological droughts due to drier dry seasons or shorter, more-intense rainfall events. Such intense rainfall events can lead to flash floods or rapid surface run-off and less soil infiltration – meaning that even if more rain were to fall, it would not be necessarily retained or usable.

Recent studies have confirmed this regional difference in the climate change signal for meteorological droughts and the related uncertainties (e.g. Ficklin et al., 2016; Berg and Sheffield, 2018; Cook et al., 2018). On a global or continental scale, higher temperatures and related increases in evapotranspiration are the main driver of changes in meteorological and soil moisture droughts (Manning et al., 2019). The related reduction in snow accumulation is an additional driver for hydrological droughts (Hayhoe et al., 2007; Livneh and Badger, 2020).

On the global scale, recent climate change, characterized by global warming and climate extremes that are more frequent and more severe (IPCC, 2014a), has caused only a limited increase in the frequency of and area affected by meteorological drought events (Seneviratne, 2012; Sheffield et al., 2012; Dai and Zhao, 2017; Spinoni et al., 2019). However, this increase is more pronounced in the regions listed below and becomes larger when temperature is considered (Trenberth et al., 2014). In recent decades, several drought hotspots (areas particularly often or severely affected) have been identified as:

- The Mediterranean region (Hoerling et al., 2012)
- Southern Australia (Van Dijk et al., 2013)
- Sub-Saharan Africa (Greve et al., 2014)
- Southern South America (Penalba et al., 2014)
- Some areas in China (Xu et al., 2015)
- South-western United States of America (Diffenbaugh et al., 2015)
- North-eastern Brazil (Marengo et al., 2017)

Future drought hazard is predicted to show a globally steeper increase in the twenty-first century than in the recent past (Cook et al., 2014; Zhao and Dai, 2015). As the world will continuously get warmer, the role of temperature will become pivotal for drought projections (Ahmadalipour et al., 2017), especially over regions where future drought tendencies are variable in space, for example in Europe (Spinoni et al., 2018) and the United States of America (Jeong et al., 2014).

Carrão et al. (2018) mapped climate change effects on global patterns of drought hazard for the mid century (2021–2050) and late century (2071–2099) under three climate change trajectories, referred to as representative concentration pathways (RCPs)[1] (RCP2.6, RCP4.5 and RCP8.5). While model results do not show robust or significant changes in the near future, the drought hazard increases in all three RCPs towards the end of the twenty-first century, notably for the RCP with strong radiative forcing (RCP8.5).

Spinoni et al. (2020, forthcoming) analysed predicted changes in drought frequency and severity through to 2100 using SPI and SPEI, based on a combination of different circulation models from the Coordinated Regional Climate Downscaling Experiment data sets and input from RCP4.5 and RCP8.5 (van Vuuren et al., 2011). They showed that in the twenty-first century, and compared to the reference period 1981–2010, global drought hazard is likely to increase with increasing global warming level (GWL), confirming the trends identified by Carrão et al. (2018).

Projections indicate droughts that are more frequent and more severe (even more severe than the worst droughts in the period 1981–2010) over wide parts of the world, in particular Mexico, the United States of America, southern Australia, and most of Africa, central Asia, southern Europe, most of central and South America (Figures 1.3 and 1.4). Conversely, drought is projected to decrease at high latitudes (approximately > 60°) in both hemispheres, where precipitation increase will minimize the effects of rising temperatures. Cook et al. (2015a), Carrão et al. (2018) and Ahmadalipour et al. (2019) have reported similar tendencies.

The meteorological drought hazard projections shown in Figure 1.3 and Figure 1.4 refer to GWLs (Dosio and Fischer, 2018). The projections indicate the global temperature increase from pre-industrial values (1881–1910). GWLs are reached during slightly varying time windows, depending on the climate simulation. For the lower GWLs (1.5°C and 2°C), which are explicitly included as targets in the Paris Agreement (e.g. Rogelj et al., 2016), the time windows are centred approximately in the years 2025 and 2040 (median values from all combinations of global circulation models and regional circulation models). For the higher GWLs (3°C and 4°C), which correspond to high-emission scenarios with inadequate mitigation strategies, time windows are centred in the years 2060 and 2085, respectively (see Table 1.2).

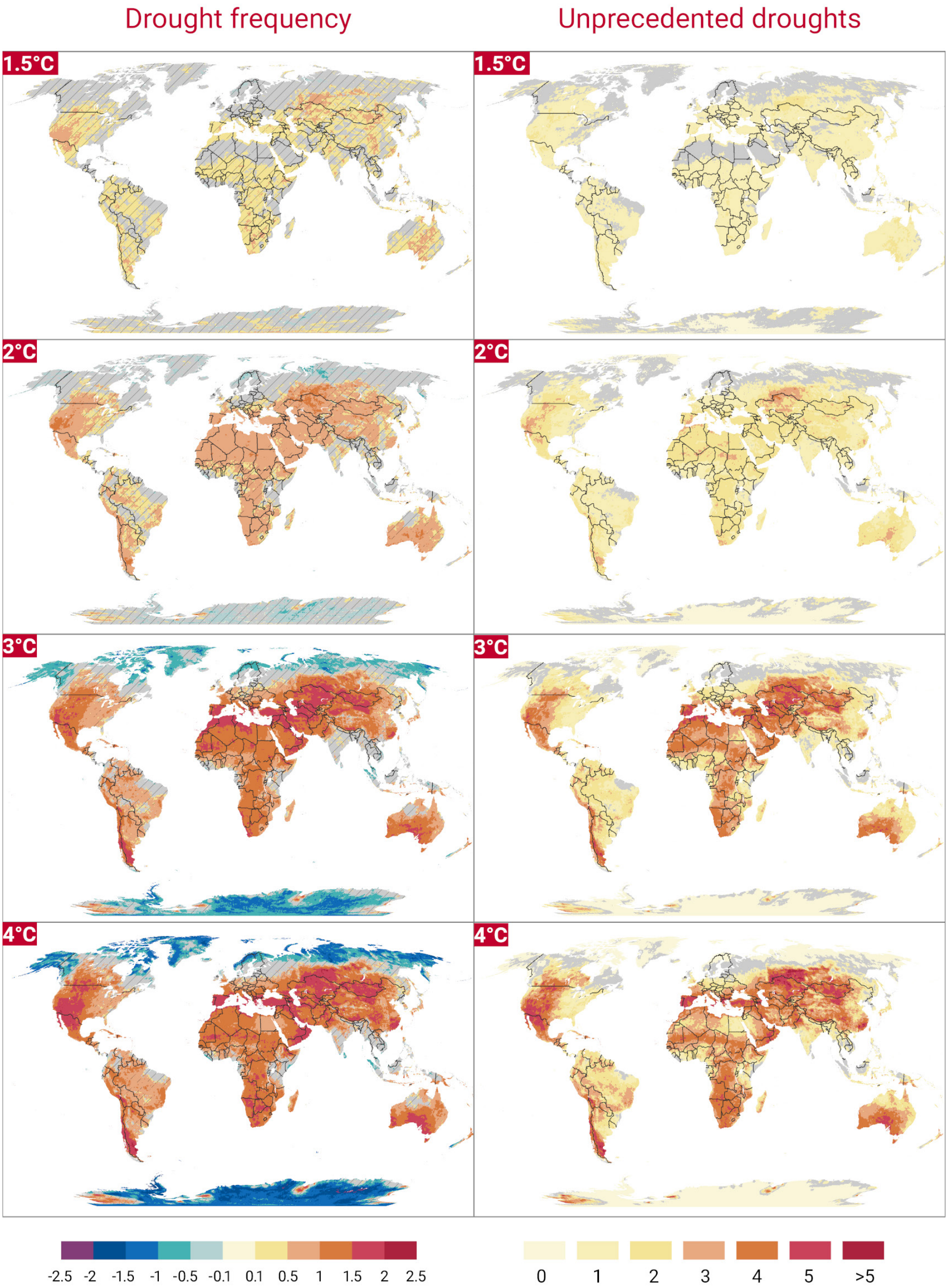
**Table 1.2. GWLs (according to Spinoni et al., 2020) and corresponding 30-year time windows**

| GWL (°C) | Central year of reaching GWL (median value from all simulations) | Corresponding 30-year time window |
|---|---|---|
| 1.5 | 2025 | 2011–2040 |
| 2.0 | 2040 | 2026–2055 |
| 3.0 | 2060 | 2046–2075 |
| 4.0 | 2085 | 2071–2100 |

*Source*: Vogt et al. (2018)

1 RCPs are time-dependent greenhouse gas (GHG) concentration trajectories. They describe different climate futures, which depend on the volume of GHGs emitted in the course of the twenty-first century. RCP2.6 is a strict mitigation pathway, likely to keep global temperature rise below 2°C by 2100. RCP4.5 is an intermediate scenario where emissions peak around 2040 and then decline. In RCP8.5, emissions continue to rise throughout the twenty-first century.

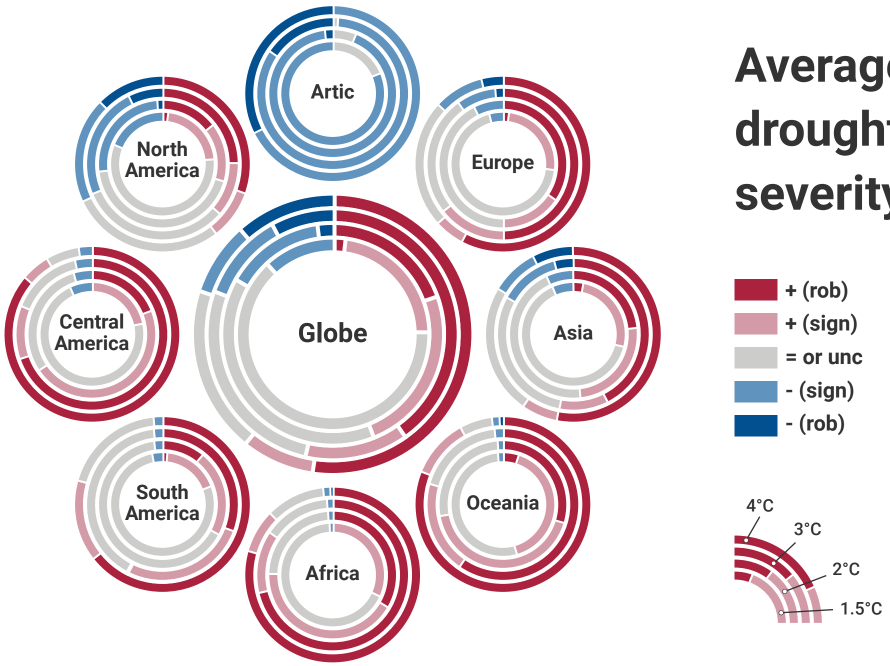
**Figure 1.3.** **Change in meteorological drought frequency (events/decade) from recent past (1981–2010) to 2100 for four projected warming levels of global surface air temperature (left) and number of drought events with stronger severity than ever recorded in the recent past (1981–2010) (right)**




The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.
Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.
Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined.

*Note*: Where less than two thirds of the simulations agree on the change, the areas are masked in grey; in the left panels dashed lines represent areas where the ensemble median of the change is smaller than the inter-model variability. Warming levels (1.5, 2.0, 3.0, 4.0°C): increase in global surface air temperature from the pre-industrial era (1881 to 1910). For corresponding time windows see text and Table 1.2.

**Figure 1.4.** **Percentage of areas with positive (red), null or uncertain (grey) or negative (blue) change in average severity of meteorological drought events from 1981 to 2010 for four warming levels of global surface air temperature; warming levels: increase in global surface air temperature from the pre-industrial era (1881 to 1910) to 2010**




*Note*: rob (robust): a change significant in sign and in magnitude, sign (significant): a change significant in sign, = or unc (equal or uncertain).

Table 1.3 presents past trends (Spinoni et al., 2019; JRC GDO, 2018) and future projections (Spinoni et al., 2020, forthcoming) of meteorological drought hazard. It shows that most of the global regions that experienced the highest hazard (assessed considering frequency and severity) in the last few years are also likely to face the highest hazard in the twenty-first century.

For soil moisture drought, Lu et al. (2019) simulated future drought hazard based on Coupled Model Intercomparison Project Phase 5 multi-model ensembles for four RCPs for the period 2071–2100 with similar spatial patterns as in Table 1.3. Their analysis shows statistically significant, large-scale drying for all scenarios for all world regions, most notably for scenarios with strong radiative forcing in central America, Europe and the Mediterranean, South Africa and tropical South America (Lu et al., 2019).

A similar trend has emerged for hydrological drought. Prudhomme et al. (2014) showed a likely increase in the global severity of hydrological drought by the end of the twenty-first century, with regional hotspots including central and western Europe and South America, in which the frequency of hydrological drought increases by more than 20%.

Droughts that are more frequent and more severe will have consequences in many sectors (Blauhut et al., 2015), but the severity will depend on the development strategies followed. Relying less on the use of fossil fuels and more on sustainable land management is fundamental to future sustainable development. Therefore, it is fundamental to account for socioeconomic scenarios (O'Neill et al., 2014, 2017) to quantify future exposure and vulnerability to drought hazard (see also section 1.4.2 for a more detailed discussion on future drought risk).

**Table 1.3.** GWLs (according to Spinoni et al., 2020) and corresponding 30-year time windows

| Macroregion | Hazard (2000–2019) | Projected hazard (GWL 3°C and 4°C) |
|---|---|---|
| **Alaska** | Severe | Very low |
| **North-eastern Canada** | Moderate | Low |
| **Greenland and Iceland** | Very low | Very low |
| **Central North America** | Low | Severe |
| **Eastern North America** | Low | Moderate |
| **North-western North America** | Severe | Severe |
| **South-western North America** | Severe | Very severe |
| **Central America** | Severe | Severe |
| **Caribbean islands** | Very Low | Moderate |
| **Amazonia** | Severe | Moderate |
| **Central South America** | Moderate | Moderate |
| **North-western South America** | Moderate | Moderate |
| **South-western South America** | Severe | Very severe |
| **Southern South America** | Very severe | Very severe |
| **South-eastern South America** | Low | Severe |
| **North-eastern Brazil** | Very severe | Moderate |
| **Central Europe** | Severe | Moderate |
| **Northern Europe** | Very low | Low |
| **Mediterranean region** | Very severe | Very severe |
| **Central Africa** | Low | Severe |
| **Central eastern Africa** | Moderate | Moderate |
| **North-eastern Africa** | Severe | Severe |
| **South-eastern Africa** | Very severe | Severe |
| **South-western Africa** | Very severe | Very severe |
| **Western Africa** | Very low | Severe |
| **Central Asia** | Severe | Very severe |
| **Eastern Asia** | Very severe | Severe |
| **North-eastern Asia** | Low | Very low |
| **North-western Asia** | Low | Low |
| **Southern Asia** | Severe | Moderate |
| **South-eastern Asia** | Low | Low |
| **Western Asia** | Very severe | Severe |
| **Tibetan Plateau** | Low | Severe |
| **Northern Australia and Oceania** | Severe | Moderate |
| **Southern Australia and New Zealand** | Very severe | Very severe |

*Note*: Macroregions follow the updated IPCC Working Group I reference regions (v4; Iturbide et al., 2020).

# 1.2.4

## Special cases of droughts

Droughts are commonly considered slow-onset hazards, of medium to long duration, and associated with warmer climates, but there are droughts that challenge these assumptions. This section thus introduces three special cases of drought.

### *Flash droughts*

Droughts are usually slow-developing and long-lasting climate-driven hazards, whose onsets are difficult to detect (Mishra and Singh, 2010). On the contrary, flash droughts rapidly evolve, often with strong impacts. Therefore, investigating flash droughts, which have a fast onset and often end within a few days or weeks (Mo and Lettenmaier, 2016), is not easy. As the largest impacts of drought events are generally associated with long-lasting events (Wilhite et al., 2007), recent studies on flash droughts tend to define such events by their rapid intensification, rather than their short duration (Otkin et al., 2018).

Flash droughts are generally driven by precipitation deficits, extremely high temperatures and a rapid increase in evaporative demand (Wang and Yuan, 2018). Therefore, they are usually considered summer events (Otkin et al., 2018). However, these variables often need to be assessed independently (Koster et al., 2019) and are not enough to describe flash droughts, so additional variables such as soil moisture (Otkin et al., 2016) and vapour pressure (Ford and Laboisier, 2017) are frequently used. The complexity of flash droughts and their seasonality and subseasonality makes their forecasting challenging (Pendergrass et al., 2020), but the ability to predict them is of great importance in early warning systems (Mo and Lettenmaier, 2020).

Global trends in the occurrence of flash droughts have been mixed in recent decades. Wang et al. (2016), Zhang et al. (2017) and Li et al. (2020) reported rapid intensification rates over different areas in China; Noguera et al. (2020) reported mixed trends over Spain; and Mo and Lettenmaier (2015) reported a decline in the United States of America. The anthropogenic influence is debated, with few studies pointing to its decisive role in recent and potentially future increases in flash droughts, for example in China (Yuan et al., 2019) and southern Africa (Yuan et al., 2018). However, it is difficult to obtain robust and reliable projections of flash droughts (Cook et al., 2018) due to the uncertainties of climate projections at daily and weekly scales (Murphy et al., 2004).

### *Megadroughts*

Megadroughts are defined as multi-decadal events (Dai, 2011), referring to long and abnormally dry periods, more severe than multi-year droughts registered since the 1880s with the onset of regular meteorological measurement (Williams et al., 2020). They are often observed in the last glacial period (the Pleistocene) (Fawcett et al., 2011) and the postglacial period (the Holocene) (Forman et al., 2001), including the last millennium (Stahle et al., 2012). Scientific literature has reported such megadroughts for all continents, for example in Europe (Helama et al., 2009; Cook et al., 2016a) and North America (Acuña-Soto et al., 2002; Stahle et al., 2007; Seager et al., 2008) during the Middle Ages, in Asia and Oceania in the last millennium (Cook et al., 2010; Sinha et al., 2011; Vance et al., 2015) and in Africa from the Holocene to the last millennium (Davis and Thompson, 2006; Scholz et al., 2007; Mulitza et al., 2008).

Historical megadroughts modified the structure of entire ecosystems (Hanson et al., 2009) or even led to their destruction (Cohen et al., 2007). Such epochal events can be forced by multiple – even concurrent – drivers: land surface or aerosol dust (Cook et al., 2013), long-term aridity changes and feedbacks (Cook et al., 2004), monsoon failures (Meehl and Hu, 2006), oceanic and radiative forcing (Steiger et al., 2019) or long-term climate anomalies due to ENSO, the Pacific Decadal Oscillation or the Atlantic Multi-decadal Oscillation (Cobb et al., 2003; Stahle, 2020).

Megadroughts and related impacts that occurred in the distant past should be carefully contextualized when compared to recent multi-year droughts (Cook et al., 2015b, 2016b), which in specific cases can be as severe or even worse than their historical precedents. An example is the drought in the 2010s in south-western United States of America, reported to be similar to the devastating megadrought in that area during the sixteenth century (Stahle, 2020). The severity of this recent drought can partly be attributed to human-induced climate change, while increases in exposure and vulnerability contributed to the increasing consequences (Diffenbaugh et al., 2015; Williams et al., 2020). This is also true for many other drought events in the recent past (AghaKouchak et al., 2015; Boisier et al., 2016; Samaniego et al., 2018).

Megadroughts are often reconstructed from various sources, generally paleoclimatic data such as tree-rings (Meko et al., 2007; Woodhouse et al., 2010). It is therefore difficult to provide statistics on their trends. Multi-year droughts within the last century show an overall slight tendency towards recent higher frequencies (Sheffield et al., 2012). However, events from the 1950s showed similar characteristics as those from the last two decades (Spinoni et al., 2019).

Remarkable multi-year droughts in the twentieth century include:

- The drought leading to famine in China in the early 1920s (Liang et al., 2006)
- The Dust Bowl in the United States of America in the 1930s (Schubert et al., 2004)
- Droughts in Mexico and the United States of America in the 1950s (Woodhouse and Overpeck, 1998)
- The Sahel drought in the 1970s and 1980s (Hulme, 2001)

The following events have been identified in the twenty-first century:

- The Australian Millennium Drought from 1996 to 2010 (Van Dijk et al., 2013), and the more recent drought from 2017 to 2020 (Nguyen et al., 2019)
- The droughts in California in the early 2010s (Seager et al., 2015)
- The drought in South Africa in the late 2010s (Masante et al., 2018)
- The megadrought in Chile from 2010 to 2018 (Garreaud et al., 2020)

Obtaining reliable projections of megadroughts is challenging because climate models estimate the future evolution of mega-events using atmospheric variability, sea-surface temperatures and greenhouse gas (GHG) emissions to simulate drivers that cannot be projected (Bolles et al., 2017). For multi-year events, a general tendency towards an increase in long and severe events has been reported by Spinoni et al. (2020), notwithstanding uncertainties inherent in all climate change projections (Orlowsky and Seneviratne, 2013).

### *Cold region droughts*

Different processes play a role in the development of droughts in cold climates compared to droughts in warmer climates. For example, temperature is a highly significant variable because it determines whether precipitation falls as rain or snow and whether water is available for use or locked up in frozen form.

In regions with seasonal snow cover, the amount of snow accumulation is crucial. A below-normal snow accumulation (or “snow drought”; Dierauer et al., 2019; Huning and AghaKouchak, 2020) depresses the tourism sector (Thomas et al., 2013), constrains downstream water use and weakens ecosystems dependent on snow-melt. The drivers of snow drought can be below-normal precipitation and/or above-zero temperatures during the winter season (Van Loon et al., 2015). Also, the timing of snow-melt is important. An earlier onset of the snow season can result in reduced winter low flows, whereas a delayed melt season can decrease hydropower production, which depends on a spring snow-melt peak (Van Loon et al., 2015). Drinking water supply and agriculture can also be affected if snow-melt is lower or later than normal.

In cold and semi-arid regions, like in the high mountainous areas of Asia, soil moisture can become critically low when periods of high climatic deficit (low precipitation and high evapotranspiration) are combined with or followed by periods of extremely low temperatures. In Mongolia for example, these events (called *dzud* locally) can cause massive losses of livestock (Middleton et al., 2015; Rao et al., 2015).

In regions where glaciers and ice sheets are present, river flow and groundwater are almost completely fed by glacier meltwater; thus, temperature plays a centrally important role (Van Tiel et al., 2018). Below-normal temperatures can lead to a decrease in glacier-melt and therefore to anomalies in river flow downstream, possibly resulting in low reservoir inflow (Van Loon et al., 2015). Interestingly, because glaciers have an opposite response to warm and dry periods than non-glacierized areas, increased glacier-melt in these periods can potentially compensate for a lower rainfall input in larger river basins. However, this process seems to be more complex than initially thought due to multiple additional factors that influence the relationship between glacier melt and river flow (Van Tiel et al., 2020a).

Climate change strongly influences snow and glacier droughts. Increased temperatures and changes in precipitation patterns affect snow accumulation and timing of melt (e.g. Diffenbaugh et al., 2013; Fontrodona Bach et al., 2018). Over recent decades, snow droughts have become longer and more intense in Europe, eastern Russia and the western United States of America (Huning and AghaKouchak, 2020). However, in the Hindu Kush Himalayan region and South America, snow droughts have become less intense (Huning and AghaKouchak, 2020). In many regions around the world, including central Europe, winter run-off has increased and late spring run-off decreased due to early snow-melt (Blahušiaková et al., 2020).

The methodology of analysing droughts in cold regions should be considered carefully. First, drought indices need to account for snow accumulation and/or melt, for example by using the standardized snow-melt and rain index (Staudinger et al., 2014) or the standardized snow-water equivalent index (Huning and AghaKouchak, 2020). Second, there are major challenges in modelling snow accumulation and melt (Van Loon et al., 2012) and glacier processes (Van Tiel et al., 2020b), which inherently increase the level of uncertainty in modelling results. Third, it is important to be aware that changes in the flow regime and related impacts can be accounted for in different ways, which can have a significant influence on results (Van Tiel et al., 2018).

## 1.2.5

### Confounding factors of drought: compound hazards

A further complication arises when different hazards occur simultaneously. A recent review by Zscheischler et al. (2020) proposed a classification of compound weather and climate events into four typologies: (1) preconditioned (a precondition aggravates the impacts), (2) multivariate (multiple drivers and/or hazards lead to an impact), (3) temporally compound (a succession of hazards leads to an impact) and (4) spatially compound (hazards in multiple connected locations cause an aggregated impact). While the boundaries between these types are blurred, the proposed classification should help differentiate and model the impacts of compound events across disciplines.

An example is the co-occurrence of droughts and heatwaves (type 2 in the above classification), where soil moisture deficits can significantly enhance heatwaves due to reduced evapotranspiration. In turn, heatwaves can reinforce droughts through feedback loops that are likely to intensify under climate change (Rasmijn et al., 2018). These feedback loops can severely aggravate the impacts of the heatwave and the drought. For example, the high evaporative demand of the atmosphere can lead to a rapid drying of the upper soil layer and the occurrence of a flash drought (Wang and Yuan, 2018; see section 1.2.4), with severe impacts on crops and natural vegetation.

Similarly, higher temperatures have significant impacts on human heat stress and related fatalities. An example is the 2003 drought and heatwave that affected large parts of central and northern Europe (Fink et al., 2004), with widespread impacts in various economic sectors and on the population. In addition to the heat, a drought-related increase in atmospheric dust load can trigger respiratory problems. When combined with increased heat stress, this can multiply the negative effects on human health (see section 1.3.4).

When droughts are followed by heavy rains (type 3), severe flooding can occur due to the reduced infiltration capacity of the crusted soil (e.g. Wang et al., 2017).

Wildfires can also be linked to prolonged drought when the accumulation of dry fuel in the soil litter layer facilitates ignition and the rapid spread of wildfires (type 1), often with catastrophic impacts. Strong and persistent winds are another aggravating hazard. Examples are the wildfires in Russia in 2011 and 2019 (Rudnitzky et al., 2019), the devastating fires during the 2011–2015 California drought (He et al., 2017a), the exceptional extent of forest fires seen in Scandinavia in 2019 (e.g. San-Miguel-Ayanz et al., 2019) and Australia 2019–2020 (e.g. Boer et al., 2020) or the 2020 fires in the western United States of America. Sutanto et al. (2020a) have recently reviewed the feedback and connections among droughts, heatwaves and wildfires.

Simultaneous crop failures across major crop production areas are an example of spatially compound hazards (type 4). The major failure of global maize production in 1983 is a compelling example of the influence of an El Niño event and the related droughts and heatwaves in different parts of the world, notably South Africa, North America and north-eastern Brazil (Anderson et al., 2019; Zscheischler et al., 2020).

Hillier et al. (2020) highlighted that spatial and temporal dependencies among different hazards can either aggravate or reduce the combined risk and related impacts as compared to independent analysis of the simultaneous occurrence of hazards.

## 1.2.6

### Human–environment interactions in drought propagation

The examples given above show that drought hazard, human activities, drought management and drought impacts are strongly intertwined, and that droughts cannot be perceived as purely natural hazards. For example, water shortage occurs when water demand is higher than water availability – a situation that can develop when there is a lack of water (drought) or when there is a high demand (e.g. during a heatwave). In addition, one of the aims of water management historically has been to alleviate drought by focusing on storing water to overcome dry periods and supplying it to dry areas. However, there are also unintended consequences of human activities on drought, for example, the effects of land-use change and overabstraction of water. Socio-economic systems are affected by drought and are also drivers of drought. Section 1.3 below discusses these impacts. Understanding and raising awareness on the role of society as a driver of drought and the complex interactions between society and drought is crucial for reducing drought impacts.

Meteorological droughts are projected to increase globally, mainly driven by higher temperatures due to climate change (see section 1.2.3). Soil moisture droughts and hydrological droughts, which may occur following meteorological droughts, are influenced by increasingly direct human interferences. For example, soil moisture is strongly influenced by different land-use practices. Increased tile drainage and tillage may worsen soil moisture droughts, although water conservation measures (e.g. mulching) and irrigation can mitigate effects. Irrigation is often used to cope with temporary water shortage, but it also affects surface water or groundwater storage from which the water is abstracted, which can potentially further aggravate hydrological drought.

Hydrological droughts are strongly affected by direct and indirect human influences, which can be long or short term. Human interactions may be designed with the purpose of drought management, but can either unintentionally alleviate or aggravate drought impacts. For example, reservoirs have a long-term, direct influence on drought. They are often built for overcoming dry periods or years, altering water balance and stream-flow seasonality of river basins for long periods of time. They can either aggravate or alleviate hydrological drought, depending on their purpose and the assessment methodology used. Reservoir management can provide short-term relief to mitigate hydrological drought downstream, but may also have drought intensifying effects and negative effects on river ecology (e.g. He et al., 2017b; Rangecroft et al., 2019).

Land-use change is an important long-term process that influences droughts indirectly by changing the water balance at the land surface, influencing evapotranspiration, infiltration and surface run-off fluxes. Hence, land-use change can affect local climate and change drought frequency and severity. For example, in the Amazon, large-scale conversion of rainforests to agricultural lands potentially leads to changes in regional precipitation patterns, leading to more-severe drought (Davidson et al., 2012). The impact of land-use change on hydrological drought via changes in infiltration and surface run-off is uncertain and relates strongly to local conditions. In addition, contrasting results between modelling and observation-based studies are reported. On the one hand, modelling studies show the increase in impermeable surface results in less infiltration and more surface run-off, leading to a more variable hydrological regime with lower low flows and more stream-flow droughts (e.g. Hurkmans et al., 2009). On the other hand, observation-based studies show higher low flows and less stream-flow droughts, possibly related to increased input into the hydrological system from urban areas, for example when treated sewage is released into urban rivers, or when leakage from water supply or sewage pipes recharges groundwater (e.g. Eng et al., 2013).

Water abstraction for irrigation or drinking water supply aggravates hydrological droughts (e.g. Van Loon et al., 2019), with impacts on ecosystems. Water can be abstracted from surface water, which has a direct influence on stream-flow drought, or from groundwater, which indirectly influences stream-flow via a reduction in groundwater discharge. As is the case for reservoir management, abstraction is not constant over time; it changes over the years, with the seasons and on shorter timescales, depending on the weather and socioeconomic variables. As droughts tend to be long, there is ample time for response during an event. Water demand often increases during drought, especially if it is combined with a heatwave and more water is needed for domestic and agricultural water supply. In addition, water-use restrictions or alternative water resources are often implemented during a drought. For example, Cape Town "day zero"[2] was averted by a combination of severe water restrictions and repurposing of agricultural water to domestic water use, with more water remaining in reservoirs.

The science–policy interface of the United Nations Convention to Combat Desertification (UNCCD) conducted a detailed assessment of the connections between sustainable land management and drought issues. This assessment reviewed 14 categories of sustainable land management measures in four land-use types (agriculture, grazing, forests and woodlands, and mixed land use), and the existing initiatives on land degradation neutrality. The outcomes of this assessment gave rise to a proposal for a new concept of drought-smart sustainable land management and practical guidance for its scaling up (Reichhuber et al., 2019).

2 Day zero is the day when municipal water supplies would largely be switched off and residents would have to queue for their daily ration of water at a limited number of distribution points.

The influence of human activities on drought may be felt at a later time than the event or even in a different location. Increased abstraction can influence downstream water users or affect the starting point for the next drought event. Furthermore, accelerated abstraction can decrease coping capacities and resilience if surface and groundwater reservoirs are not replenished in time. For example, in California, increased groundwater abstraction substantially lowered groundwater levels, which dried wells and triggered land subsidence (He et al., 2017b). Similar trends were reported in north-western India, where a combination of drought and groundwater overabstraction led to decreasing trends in groundwater levels and reduced resilience to future droughts (Pathak and Dodamani, 2019). Box 1.2 provides further insight into the relationship between drought and the management of groundwater reserves. Virtual water transfers are extreme cases of the temporal and spatial dependence of water management and drought impacts. Water is embedded in agricultural products that travel with global trade flows and is removed from the local hydrology. Remote coupling between local groundwater abstraction and global consumers can influence drought (Marston and Konar, 2017).

The influence of human activities varies in different parts of the world. The response to water shortage in most of the Global North is building more infrastructure, which strongly influences the soil moisture and hydrological drought hazards. A more common coping strategy to drought in most of the Global South is adaptation, for example, by planting different crops or migration to wetter or more job-secure regions. These strategies reduce drought risk by minimizing exposure and vulnerability. However the relationships among drought risk management strategies and vulnerability and exposure are complex. Increased infrastructure can increase vulnerability, for example, by increasing demand or dependence on reservoir storage (Di Baldassarre et al., 2018) or by decreasing resilience due to virtual water transfers (D’Odorico et al., 2010). Such feedback loops are often not considered when designing drought risk management measures.

**Box 1.2. Groundwater as a drought buffer under threat**

Groundwater is an important source of fresh water for domestic water supply and agricultural irrigation. Groundwater accounts for about 38% to 50% of global irrigation water demand, and partly satisfies the domestic needs of one third to one half of the world's population (Famiglietti, 2014; Rodell et al., 2018). Groundwater also serves as an important buffer for satisfying human and agricultural needs during drought. However, intensive pumping has led to a significant lowering of groundwater levels in several, often semi-arid to arid, regions of the world that are already water scarce and rely heavily on groundwater resources for their economic activities and public water supply. Examples of such regions include parts of Australia, the California Central Valley, north-eastern China, north-western and north-eastern India, the Middle East and the Tibetan Plateau (Chen et al., 2016; Rodell et al., 2018).

This depletion of groundwater resources, combined with moderate to severe droughts, poses significant risks to water and food security. Moreover, its unsustainable nature can lead to wide-ranging impacts including conflict over water resources (Robins and Fergusson, 2014). Environmental consequences include seawater intrusion, land-surface subsidence, stream-flow depletion, deterioration of water quality, loss of springs and wetlands, and ecological destruction (Famiglietti, 2014).

Rodell et al. (2018) studied changes and trends in total water storage as detected from Gravity Recover and Climate Experiment satellite measurements. They identified natural variability, climate change and human pressures as the key drivers with a clear human footprint in several regions around the world. Key drivers for the human pressures are population growth, rising quality of life, increasing demand for food and energy, inappropriate water legislation and lack of aquifer management across international boundaries (Famiglietti, 2014; Rodell et al., 2018).

In a changing climate, the situation is likely to deteriorate in many already water-stressed regions of the world. Water resource managers must reduce water demand by using more-efficient irrigation methods, cultivating drought-resistant crop varieties, ensuring adequate water pricing and encouraging domestic water savings. Success in introducing such changes requires raising public awareness, promoting water-saving practices, and developing policies to promote and enforce adequate land and water management.

# 1.3

# Drought impacts

**KEY MESSAGES**

- Droughts affect large areas and populations, with widespread impacts on society, economy, the environment and hence sustainable development. These impacts can be direct and indirect in nature, and are often difficult to quantify in economic terms.
- Drought impacts result from the complex interaction of drought hazards, exposure and vulnerability.
- The risks resulting from droughts can be severely aggravated by cascading impacts, which may also affect societies and economies far from the drought event.
- Far-reaching and long-lasting cascading impacts with a related increased probability for the co-occurrence of other risks are important factors for building up systemic risks.
- Reducing the impacts of drought will contribute to the achievement of SDGs, in particular poverty reduction, zero hunger, good health and well-being, gender equality, clean water and sanitation, and sustainable cities and communities.
- Estimates of economic damage should be interpreted with care – there is a significant gap between reported and real, direct and indirect impacts, and systematic quantification is extremely challenging.

Drought affects almost all dimensions of the environment and society, and directly influences achievement of SDGs. Drought conditions frequently remain unnoticed until water shortages become severe, and adverse impacts on the environment and society become evident. Drought impacts may be influenced by adaptive buffers (e.g. water storage or purchase of livestock feed) or can continue long after precipitation returns to normal (e.g. owing to groundwater or reservoir deficits). As elaborated in Box 1.3, the slow development and long duration of drought, among other characteristics, may combine with impacts beyond commonly noticed agricultural losses and complicate quantification and attribution of drought impacts.

## 1.3.1

### Direct versus indirect impacts

Drought impacts can be classified as direct or indirect (Vogt et al., 2018). Direct impacts occur through interactions among specific water deficiencies and environmental, social or economic components. Indirect or secondary impacts are those that are not a direct result of the water deficit and are often produced at a distance from the drought-affected region or as a result of a complex impact pathway.

Examples of direct impacts include limited public water supplies, crop loss, reduced forest production, limited commercial shipping capacities, drying up of wetlands, damage to buildings due to terrain subsidence and reduced energy production. However, drought impacts are often indirect because of the dependence of livelihoods and economic sectors on water. These indirect effects can cascade quickly through the economic system, affecting regions far from where the drought originated and lingering long after the drought ended.

Indirect impacts relate to secondary consequences on natural and economic resources that might also be directly affected. They affect ecosystems and biodiversity, human health, food prices and poverty. In extreme cases, drought may result in temporary or permanent unemployment, business interruption, loss of income, rising school dropout rates, and transmission of diseases due to poor water and air quality. Droughts can lead to food insecurity, malnutrition and, in extreme cases, starvation and widespread famine, resulting in internal and cross-border migration. The latter can increase the risk of social conflict in the host region or country (e.g. Adaawen et al., 2019). Table 1.4 shows the different sectors that are commonly affected by droughts.

Drought-related damage may further be classified as tangible (market related) or intangible (non-market related). While direct impacts are mostly tangible and can be evaluated in economic terms, many indirect impacts are intangible and not easy or even unsuitable for economic valuation. Examples are the loss of biodiversity because of the reduction or drying out of wetlands, increasing poverty among the affected population, ecosystem degradation and the loss of ecosystem services.

Figure 1.5 illustrates possible direct and indirect social, economic and environmental impacts, including migration, which is further developed in Box 1.4. Indirect exposure refers to losses due to disruption of local and global supply chains of production activities.

Drought is one of the most damaging and costly climate-related disasters in many parts of the world. The estimate of direct annual losses due to drought in the United States of America is approximately \$6.4 billion; this figure includes only those events with losses greater than \$1 billion in the period 1980–2019 (NOAA-NCEI, 2021). In the European Union, annual losses were estimated recently to be around €9 billion (Cammalleri et al., 2020; Naumann et al., 2021). In Europe, economic losses were worsened by recent prolonged heat and dryness, resulting in unprecedented drought impacts for farmers, private households and wildlife. During the 2018 and 2019 summers, raging wildfires in southern and northern Europe, severe restrictions for shipping on major rivers, severe restrictions on irrigation and reduced power supplies have raised concerns about a possible increase in the severity and frequency of droughts due to climate change. For a scenario of 4°C of global warming in 2100, direct annual drought losses in Europe are projected to increase to more than €65 billion per year (Naumann et al., 2021), if apparent increases in severity and frequency of drought continue in the absence of climate action.

The severe drought in California during 2006 caused direct losses of up to \$4.4 billion. Reported losses were estimated to be \$3.6 billion during the 2013–2015 drought in the midwest of the United States of America. The 2013–2015 drought that affected central eastern Brazil (Minas Gerais, Rio de Janeiro and São Paulo) caused reported losses of about \$5 billion. In Argentina during the 2008–2009, 2011–2012 and 2017–2018 agricultural seasons, the country suffered sharp declines in soybean and maize production with total accumulated direct losses estimated to be at least \$12 billion. The 2010–2011 drought in the Horn of Africa was estimated to have caused up to 250,000 deaths and to have left over 13 million people dependent on humanitarian aid, according to the United Nations Office for the Coordination of Humanitarian Affairs (OCHA, 2011). In response, some \$1.3 billion was spent on drought-relief measures.

Drought impacts are often excluded from loss estimates because they are difficult to quantify. Reports have stressed that direct impacts of a single drought could cost several billion dollars, and indirect impacts would add costs to the overall direct impacts. For example, for the Ebro River Basin in Spain, Gil et al. (2013) found indirect impacts were greater than direct impacts in absolute terms. However, indirect impacts can be compensated for at the macro level by market fluctuations or trends. Indirect impacts are more related to the direct impacts of drought than to the driving water deficit, as they result from transmission processes across sectors. Nevertheless, such figures should be interpreted with care since they represent just a small fraction of total losses (e.g. Poledna et al., 2018).

**Box 1.3. Assessing the economic impacts of drought: a cautionary note**

The characteristics of droughts are significantly different from those of other natural hazards such as floods or storms. This makes their impacts harder to assess. Such characteristics include: (a) spatio-temporal variation – droughts can occur over multiple timescales from a few months to decades and from small watersheds to entire continental regions; (b) multidimensionality – drought impacts are cross-sectoral and cascading; and (c) indirectness – drought impacts are usually of limited immediate visibility.

The task of comprehensively and accurately determining the cost of a drought is highly challenging due to: the difficulty of determining the onset and end of a drought; the complex, slow and creeping nature of its impacts; the site dependence of the impacts; and the diffuse nature of associated damage. While the social and economic impacts of droughts are recognized to disproportionally affect poor, rural households (UNISDR, 2011), such impacts remain poorly understood and are difficult to quantify.

The extent of drought impacts in urban environments has only recently been recognized (Singh et al., 2021). This is despite the far-reaching social and economic impacts of droughts, which can include reduced hydropower generation, food insecurity and famine, poverty, negative short- and long-term health effects, gender disparities, emerging civil unrest, conflict and migration (Benson and Clay, 1998; Logar and van den Bergh, 2011).

Existing damage and loss estimates are thus likely to be conservative, as they often fail to take all impacts into account (Logar and van den Bergh, 2011; UNISDR, 2011). It is often difficult to distinguish whether the costs of a drought stem from drought severity (i.e. the extent and intensity of the precipitation deficit) or inadequate land and water management (e.g. water-intense agriculture, overextraction of groundwater or landscape degradation).

Even when data is available, major barriers for accurate cost assessment are the multiple levels of advanced sector-specific expertise and the interdisciplinary character of the knowledge required (Damania, 2020). The magnitude of impacts depends on several issues such as the mobility of factors of production across sectors, the availability of food imports, the relative size of the drought-affected sector and the relative price of factors of production (Hertel and Liu, 2019).

A significant and persistent knowledge gap concerns the distribution of relative drought costs – and, to a lesser extent, benefits – among different economic sectors and social actors. Mathematical modelling approaches, such as computable general equilibrium models, have been applied to assess the economic gains from large infrastructure investments, such as dams, or significant policy shifts, such as reallocation of water to higher-valued uses (Damania, 2020). However, the results are conditional upon the variety of assumptions essential for computational feasibility.

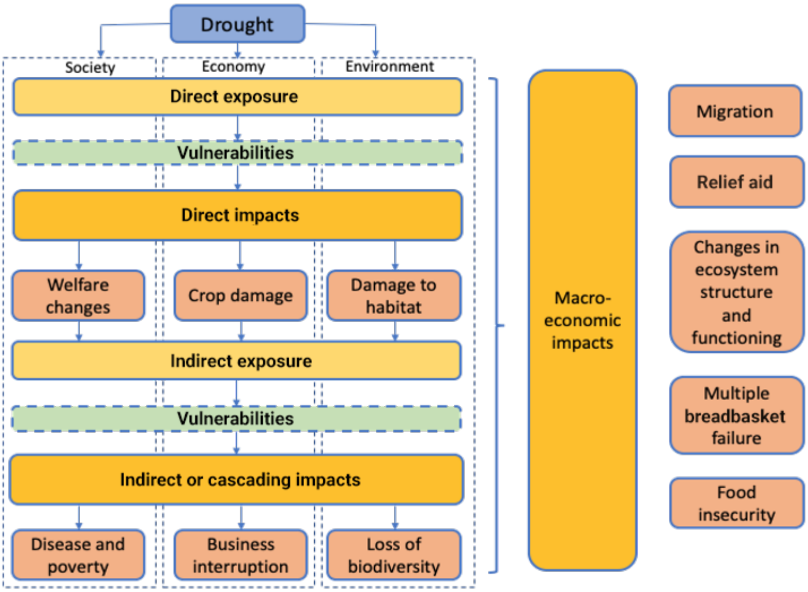
While the evidence cited above is informative and can provide a level of guidance, an accurate assessment of even a single sector that is usually assumed to be well understood, such as agriculture, provides little evidence of impacts on aggregate measures of economic activity. For example, reduced crop, rangeland and forest productivity, and associated lower income for farmers and agricultural businesses, can lead to: increased unemployment; food and timber price change; trade balance deficits through decreased exports and/or increased imports; reduced national, regional or local government tax revenues; increased pressure on financial institutions (credit risks); losses of farmers through bankruptcy due to foreclosures; and losses of industries related to the agricultural sector, for example, producers and distributors of fertilizers and machinery (Logar and van den Bergh, 2013; Damania, 2020).

**Table 1.4. Main sectors affected by droughts**

| Environment (e.g. forests, wildfires, wetlands, biodiversity) |
|---|
| Drought affects the environment in many ways. Plants and animals depend on water; under drought conditions, their food supply can shrink and their habitat can be damaged. Sometimes, the damage is only temporary and their habitat and food supply return to normal when the drought is over. But other times, drought impacts on the environment can endure or may lead to permanent land and ecosystem degradation or desertification. |
| **Agriculture (including crop and livestock production) and forestry** |
| Agriculture can be adversely affected if a drought damages crops and other related losses. Farmers may spend more money due to increasing irrigation costs, drilling new wells or feeding and providing water to their animals. Industries linked with farming activities, such as companies that produce tractors and food, may lose business. Forestry is affected by reduced fibre production and increased vulnerability to pests and insect attacks (e.g. bark beetle). |
| **Public water supply** |
| Drought conditions decrease water supply and increase demand for various uses (e.g. industrial, agriculture, residential, sanitation and wastewater management). Co-occurrence with heatwaves can aggravate impacts due to increased demand. Reductions in the available quantity of water can have secondary effects on water quality due to reduced dilution of pollutants. |
| **Power generation: hydro, thermal and nuclear** |
| Hydroelectricity production depends on river flow or water stored in upstream reservoirs. Consequently, the production level can be lower during a drought. Peak demands for electricity then need to be satisfied by other means available (e.g. gas turbines). The amount of losses depends on hydroelectricity infrastructure and drought severity. Reduced availability of cooling water can force the reduction of power generation and even shutdown of thermal or nuclear power plants during droughts. |
| **Buildings and infrastructure** |
| Soils swell and shrink with moisture changes, depending on their composition. Serious damage to buildings and infrastructure can occur if soil shrinkage is pronounced under drought conditions. For instance, in France, soil subsidence has caused as much damage as floods in recent years. The effects of drought can be aggravated due to aquifer overexploitation. |
| **Tourism and recreation** |
| Droughts can bring critical losses, as many activities in the tourism sector are water related. Droughts might affect summer and winter activities. |
| **Commercial shipping** |
| During low-flow conditions, barges and ships may have difficulty in navigating streams, rivers and canals, which affects businesses that depend on water transportation for receiving or delivering goods and materials. People may pay higher prices for food or fuel as a result. |
| **Industry** |
| A water deficit induced by droughts affects production, sales and business in a variety of sectors such as agriculture, energy production and water-intensive industries. |
| **Social impacts** |
| Welfare changes experienced by humans should be included in relief packages to mitigate socioeconomic impacts of drought. The social impacts of drought can affect people's health and safety, lead to a poverty trap, cause conflict between people when water restrictions are required and may result in changes in lifestyle. |

*Source*: Adapted from Vogt et al. (2018)

**Figure 1.5.** Schematic representation of direct and indirect drought impacts and their interrelations




*Note*: Direct exposure refers to a system, sector or community in a drought-affected area; indirect exposure refers to an element of a system that is affected by a drought occurring elsewhere.

### Box 1.4. Drought and migration

Migration is a possible response to disasters or changes in climatic and landscape conditions. However, the interrelations among prolonged drought, soil degradation, desertification and migration are complex and not well documented (Adaawen and Schraven, 2019; Adaawen et al., 2019; IOM and UNCCD, 2019). While available data on human migration due to land degradation and drought is rather sparse, numerous studies point out it is hard to directly attribute mass migration to crop failure or water deficits resulting from persistent droughts (Obokata et al., 2014). Instead, forced migration is especially widespread in regions characterized by political instability, such as in the Horn of Africa. In such a situation, drought may be a catalyst to trigger migration, the root cause of which is the socio-economic and/or political situation (Adaawen et al., 2019).

Migration is not an option open to all, and some populations are considered trapped (IOM and UNCCD, 2019). Migration requires human and financial assets that are not often available to all. Furthermore, some socioeconomic and political barriers can impede migration. Many smallholder households and pastoralists are consigned to living in a state of immobility due to the lack of resources required for migration. As a response to compensate for losses after prolonged droughts, some affected families adopt circular migration, commonly within their home country or in a neighbouring country. In that sense, individual family members migrate for a limited period, to earn money in informal sectors in cities or in commercial agriculture. For example, one of the first studies on drought and migration conducted in Mali showed it is often circular and short distance movements that increase at times of drought (Findley, 1994).

# 1.3.2

## Cascading effects and feedback loops

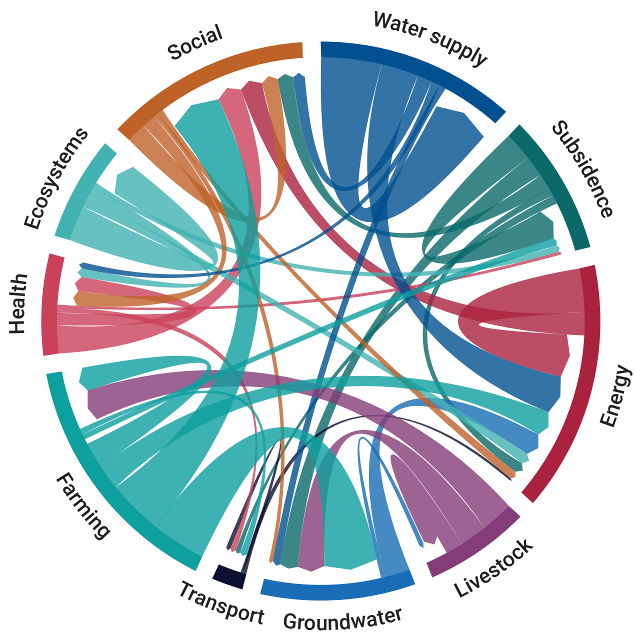
Complex interactions among different economic sectors make it difficult to monitor the overall impacts of droughts. Certain demographic, socio-economic or ecological factors worsen the intrinsic vulnerability to drought-related impacts. Therefore, losses from drought are likely to be underestimated and inaccurate. Indirect losses from impacts such as farm foreclosures are not counted, and even direct losses such as the damage to annual crops are difficult to attribute because of fluctuations in commodity markets.

Reports of drought impacts are available from multiple sources, for example: media outlets, farming associations, (re-)insurance companies, governmental reports and scientific literature. There are several different platforms that collect information on drought losses, including: the European Drought Impact Inventory (EDII), the Drought Impact Reporter and the Billion-Dollar Weather and Climate Disasters platform in the United States of America. Other global-level platforms such as the Emergency Events Database (EM-DAT) or DesInventar collect impacts of various environmental hazards including droughts. Each of these platforms provide valuable, publicly available information; however, drought losses remain particularly underreported (Svoboda et al., 2002; Gall et al., 2009).

It is extremely difficult to retrieve spatially and monetarily accurate loss estimates for the economic systems affected. This is due in part to the fact that only part of drought loss and damage is insured or of direct and tangible nature. Thus, such economic damage should be interpreted with care as there is still a significant gap between reported and real impacts that hinders systematic quantification.

Indirect impacts and interconnections among different economic sectors and ecosystems are particularly difficult to quantify as they include, for example, ecosystem degradation or the costs of

**Figure 1.6. Schematic representation of potential interconnections among different sectors affected by droughts**




*Note*: Each sector is represented by a fragment on the outer part of the circular layout. Arcs are drawn between each sector with the size of the arc being proportional to the importance of the trade-off.

mitigation and long-term adaptation measures. Figure 1.6 presents a schematic representation of possible interconnections among different sectors affected by a drought shock. It demonstrates the inherent complexity of the interactions and feedback loops among socioecological and technological systems. For instance, water deficits causing crop losses will subsequently prevent farmers from investing in new machinery, resulting in losses to the farm equipment dealer and producers in the business chain. Farmers may also experience shortages of inputs needed for their production process and may be forced to find alternative suppliers, thus increasing production costs. Consequently, governments are often ultimately the de facto risk bearer in larger droughts and are called upon to provide aid to the different sectors. As droughts often affect large areas, sometimes over several years, these cascading impacts can affect large parts of society and economic sectors distant from the drought event. Detailed analysis of compound and cascading drought impacts are available, for example for the 2018–2019 drought in Germany (de Brito, 2021). Section 1.3.4 covers the direct and indirect impacts on human health and well-being, including consequences for mental health.

Drought impacts on global food supply are usually managed through substitution. Under normal circumstances, the global food system can compensate for losses from a particular drought through grain storage and trade. For instance, precipitation-based risks for soybean losses in India and the main croplands in South America are negatively correlated, which means soybean losses in India can mostly be compensated for by imports from South America (Gaupp et al., 2020). However, simultaneous events affecting connected breadbaskets like Argentina, Australia, Brazil, Europe and the United States of America could lead to food price crisis and potentially trigger other systemic risks. In view of climate variability at the global scale, there is increased probability of multiple global breadbasket failures (Gaupp et al., 2020). The pressure on food systems will be high, with projections of a likely increase of water stress over most of the breadbaskets (Naumann et al., 2018). In particular, projected wheat, maize and soybean yields in the global breadbaskets will see a significant decrease within the 1.5°C and 2°C IPCC global warming scenarios of the IPCC (Gaupp et al., 2019).

# 1.3.3

## Society and the environment

### *Agricultural production and food security*

Agriculture is one of the sectors most affected by drought. Significant losses affect the local economy and also global commodity markets and food prices, which could lead to food insecurity in vulnerable countries (Maxwell and Fitzpatrick, 2012). Drought-related reductions in food production in major agricultural countries can strongly influence global food trade and pricing, with repercussions especially on poorer populations in areas distant from the drought. Such imbalances highlight global risks related to drought. In the worst case, synchronous failures in several core food producing areas can lead to severe repercussions with systemic risks and social unrest (e.g. Gaupp et al., 2020). Hence, the imperative to address systemic risks in national drought risk management plans so as to better cope with external pressures.

The Food and Agriculture Organization of the United Nations (FAO) reviewed 78 post-disaster needs assessments undertaken in the aftermath of medium- to large-scale disasters, to identify economic trends of disasters on crops, livestock, fisheries and forestry (FAO, 2015). The study covered 48 developing countries in Africa, Asia and Latin America over the period 2003–2013. FAO found agriculture absorbed approximately 84% of the economic losses due to climate-related disasters in these countries. Crop production was the most affected subsector, accounting for 42% of all agricultural losses, followed by livestock production with 36%. Almost 86% of reported loss and damage was due to drought events.

Environmental conditions affect plant productivity during all phases of growth. Such conditions include water availability, solar radiation, temperature and soil properties like acidity. Studies show biomass production of a barley crop decreased due to droughts of various timing and duration (Jamieson et al., 1995; Stallmann et al., 2020). More directly, moisture stress in all growth stages reduces grain yield significantly. Severe droughts are correlated with significant reduction in yields of the main cereals and other crops in most drought-prone regions.

Climate change is likely to increase the frequency and severity of agricultural droughts in many areas of the world, where water stress will be further exacerbated due to strain from overexploitation and land degradation (IPCC, 2014b). A decrease in soil moisture and increase in atmospheric evaporative demand will likely increase the risk of agricultural drought in drylands and threaten extensive pastoralism, leading to an increased risk of food insecurity.

### *Pests*

Drought stress can promote outbreaks of plant-eating fungi and insects. Agriculture and forestry can be seriously damaged as droughts favour the proliferation of pests through different mechanisms:

- Droughts provide a more favourable thermal environment for growth of phytophagous insects
- Drought-stressed plants are behaviourally more attractive or acceptable for insects
- Drought-stressed plants are physiologically more suitable for insects
- Droughts favour mutualistic microorganisms but not natural enemies of phytophagous insects

Droughts alter the nutritional quality of tissues consumed by herbivores, which affects herbivore performance. However, drought impacts on tree resistance to pest insects vary, depending on the feeding guild of insect herbivores (Gely et al., 2020). Generally, primary pests feeding on tree trunks are adversely affected by drought, whereas bark beetles, leaf chewers, leaf miners, gall makers and sap feeders benefit from drier conditions (Jactel et al., 2019).

During drought conditions, less complex vegetation (e.g. urban forests versus natural forests) may reduce biological control of pests, as plant stress creates a favourable environment for pests. Higher temperatures can directly increase pest fitness and abundance. This is particularly true in urban forests where increased temperatures from urban heat islands and reduced water availability favour herbivorous arthropod pests more than in rural areas (Dale and Frank, 2017).

### *Public water resources and water quality*

Water supply systems are operated by guidelines based on historical inflow, storage capacity and quality criteria, to meet target water demand. Most operations are adequate under normal weather patterns, but are unlikely to be sufficient during extreme circumstances such as prolonged droughts and sudden increases in water demand. Rapid changes in spatial and temporal water consumption patterns, as recently seen during the Covid-19 pandemic, may put additional stress to water supply systems that can exacerbate drought impact (Cooley et al., 2020).

During extreme drought conditions, normal operating procedures may result in single periods of severe shortage of supply or sequences of consecutive shortage of supplies, either of which may induce additional impacts. Improved policies for managing water supply systems that include drought planning and operation should be introduced and regularly updated, to avoid these water shortages (Dilling et al., 2019).

A case of severe limitation in public water supply was experienced in the metropolitan area of São Paulo, which had to impose restrictions on public water supply due to the 2014–2015 drought in south-eastern Brazil (see section 1.3.5). This and other similar cases point to the exposure of large cities around the world located in semi-arid to arid regions and which rely mainly on reservoirs or groundwater for public water supply. Such cities, which normally experience high water demand, are vulnerable to a sequence of dry years when water stocks are not sufficiently replenished.

Changes in water quality might also be associated with reduced river flows and reservoir levels. Such a reduction can lead to increased water salinity due to decreased dilution. Air temperature increases during dry periods, and can lead to abnormally high water temperatures and stratification. This effect can also be exacerbated due to longer hydraulic residence times and low water levels.

Such changes affect water availability for domestic use and ecosystem maintenance. Increased water temperatures can favour the production of algae, promote toxic cyanobacterial blooms and lower dissolved oxygen concentrations (Mosley, 2015). In contrast, nutrients and turbidity often decrease during droughts due to lack of catchment run-off and increased sedimentation.

### *Energy production at the water–energy nexus*

Thermal electricity generation from fossil fuels (coal, gas and petroleum) and non-fossil-fuel sources like nuclear power plants requires water for cooling. Simultaneously, water extraction, treatment and distribution consume energy. This interdependency is called the water–energy nexus and is part of planning for water security.

Power generation may depend on water availability directly (e.g. hydropower) or indirectly (e.g. cooling systems for power generators). Hydropower uses water directly and is a function of the hydraulic head (height difference between the input and output of water) and volumetric flow rate. Consequently, insufficient water levels lead to a reduction or even a cessation in energy production. As most power plants access nearby shallow waters, they are further affected by high water temperatures caused by hydrological droughts and high air temperatures. In such situations, discharging relatively warm cooling water to rivers might be restricted due to negative effects on river ecology and fish habitats.

Examples are the significant reduction in hydropower production in south-eastern Brazil in 2014–2015, or the reduction in thermal and nuclear power production in Europe in 2003 (Fink et al., 2004; Van Vliet et al., 2016). The latter was due to the lack of cooling water and the need for ensuring a minimum ecological flow in the rivers while not surpassing maximum allowed water temperatures. Thermal power plants can be made more resilient by improving their cooling technology.

Adopting an economy with net-zero GHG emissions is a potential solution for water depletion resulting from pressure on the water–energy nexus. Under this scenario, water consumption and withdrawal by thermal power plants may be reduced by more than 95% by 2050 (Lohrmann et al., 2019). The water that is freed could be used by aquatic ecosystems or allocated to other purposes such as food production.

### *Ecosystems*

Droughts can affect ecosystems and, in turn, their services. Impacts have a wide spectrum of severity, from small-scale, temporary responses to widespread and persistent ecosystem transformations (Crausbay et al., 2017; Figure 1.7). Examples of impacts on ecosystems are reduced plant productivity, increased dehydration stress in wildlife, vegetation type conversion or species range shifts, increased disease in wild animals and increased stress on endangered species or even extinction.

Drought can also have a major impact on wetlands. Reduced precipitation and increased evapotranspiration lead to reduced interception, less infiltration and percolation. Together with a reduction in water tables, these changes in the water cycle will reduce the valuable ecosystem services performed by wetlands such as water purification.

Prolonged droughts in coniferous forests can cause direct physiological damage and increase the susceptibility of pines to fungal diseases. Droughts can cause widespread tree mortality due to failure of the plant hydraulic system (Choat et al., 2018). Apart from alterations to the critical ecological role of trees, tree mortality (particularly large trees) causes a net loss of carbon dioxide into the atmosphere and reduces the capacity of forests to mitigate climate change.

Drought management and policy often do not consider effects on ecosystems nor how an ecosystem under drought stress may diminish services provided to human society. Integrating human and natural water requirements into drought planning processes is based on the understanding that an investment in water for nature may finally be an investment in water for society. Mutually beneficial solutions require proactive measures tailored to reduce drought risk over short and long time-horizons. Ecological drought vulnerability may be successfully reduced through proactive natural resource management strategies that work with and support natural processes, rather than employing engineering solutions that may degrade natural systems in the long term (Crausbay et al., 2017).

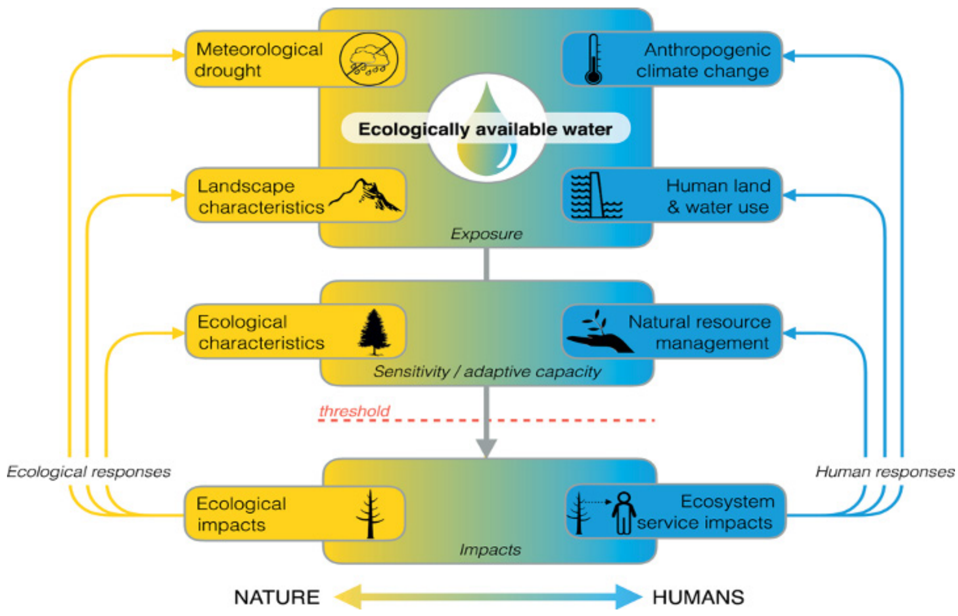
## 1.3.4

### Human health

The health of human populations is sensitive to shifts in weather patterns and other aspects of climate change, including droughts. While accurately quantifying direct, let alone indirect, affectation and mortality is extremely challenging, for the period 1900–2019, an estimated 2.7 billion people worldwide were directly affected by droughts, leading to an estimated 11.7 million deaths (CRED, 2019).

Accounting for approximately 58% of the total deaths caused by extreme weather events in the period 1900–2008, drought is by far the biggest cause of mortality in this category (Goklany, 2009; based on EM-DAT data). The peak, in absolute numbers and in death rates (deaths per million population per year), was reached in the 1920s with a declining trend since. This is attributable to a rapid increase in food production and improved emergency response (Goklany, 2009). Similar downward trends are noted for all other weather-related disasters except heatwaves, which show

**Figure 1.7.** **Conceptual diagram of ecological drought**




*Source*: Crausbay et al. (2017). © American Meteorological Society. Used with permission.

an increasing trend in mortality, particularly when combined with droughts in some regions (Smith, 2021). However, it should be noted that EM-DAT records deaths only directly attributable to drought (i.e. starvation), while all indirect health effects, for example due to water and air quality, are not included (McCann et al., 2011).

Drought is an example of a complex event that can be a current hazard while also directly and indirectly influencing future vulnerability. Droughts can cause impacts directly, resulting in water shortages and heatwaves, which can trigger physical harm and death to elderly and vulnerable populations. Impacts can also be felt indirectly through crop failures or shifting patterns of disease vectors, which can lead to malnutrition, famine or disease outbreaks (IPCC, 2014a). The most vulnerable populations may also find themselves even more at risk due to socioeconomic factors such as poverty, which may force people to live on lands with poor soil fertility or in ecosystems that are already drought prone (Van Lanen et al., 2017). They may even be forced to migrate in extreme cases (IPCC, 2014a; van Lanen et al., 2017). Trapped populations unable to migrate may be at even greater risk (Government Office for Science, 2011).

The broad health impacts of drought can be organized into five main categories (WHO, 2012):

- Malnutrition (including micronutrient malnutrition and anti-nutrient consumption)
- Waterborne diseases (including algal bloom, cholera and *Escherichia coli*)
- Vector-borne diseases (including dengue, malaria and West Nile virus)
- Airborne diseases (including coccidioidomycosis, Covid-19 and silo gas exposure under reduced water availability for sanitation)
- Mental health (including distress and other emotional consequences)

Table 1.5 summarizes evidence on the direct and indirect effects of drought on these areas of health.

Multiple reviews on health risks associated with droughts indicate drought effects occur primarily through indirect pathways (Stanke et al., 2013; Sena et al., 2014; Yusa et al., 2015; Ebi and Bowen, 2016) – meaning they are linked to other circumstances, for example, loss of livelihoods.

Berry et al. (2018) reported there is a growing apprehension about the effects of current and future climate change on human health, particularly mental health, in some of the world's most vulnerable regions. Mental health issues have been observed in some rural populations subjected to drought, often in the form of anxieties, which may lead to suicide in extreme cases (van Lanen et al., 2017). Since drought-affected communities may be forced to migrate as their best survival option, members may experience high rates of psychiatric morbidity and mental health problems. Furthermore, as the risk of violence is high, the drought can exacerbate mental health decline (Berry et al., 2018).

Berry et al. (2018) considered that a systems approach can help insert this emerging threat into existing research and policy agendas. They reviewed the work of Vins et al. (2015) that identified several different pathways linking drought to mental health and further developed a causal process diagram for the mental health impacts of droughts (Amelung et al., 2016; Figure 1.8).Figure 1.8 shows associations among drought, disproportionately vulnerable persons[3] and compromised mental health are real. Understanding these associations could promote mental well-being and minimize harm.

Droughts can also exacerbate chronic illnesses and leave individuals less able to cope with and recover from their condition, which may have a potentially significant impact on individual and community vulnerability and resilience to further shocks.

3 These may include, for instance, migrants, women, youth, minorities, or persons with a specific ethnic status, poor family or social support and a history of mental illness.

However, attribution of some of the more indirect associations can be challenging because of the slow-moving, longer durational nature of droughts. For example, wildfires are more common during droughts, but injuries or deaths are typically linked only to the wildfire and not to the drought as the root cause of the wildfire (Stanke et al., 2013).

Unfortunately, there is little documented evidence on the economic impacts that droughts can have on health systems overall. Research looking at health coverage in Viet Nam found drought-related health shocks caused financial burden for many households, with health expenditures increasing by 9–17% of total consumption (Lohmann and Lechtenfeld, 2015).

Surprisingly, there is a paucity of data on the adverse health impacts of droughts, including complex and long-lasting issues such as famines (Taye et al., 2010). There is a need to better identify and quantify the impacts of droughts on health systems, which could be made possible through surveillance

**Table 1.5. Direct and indirect consequences of drought on human health**

| Category | Description |
|---|---|
| **Malnutrition** | Malnutrition can occur through a reduction in the quantity and stability of food, leading to increased morbidity and mortality (Stanke et al., 2013; Friel et al., 2014; Sena et al., 2014). Water shortages may result in reduced food production (crop failure and livestock loss), leading to malnutrition and health risks, such as starvation, low birth weight (WHO, 2012) and stunting (Cooper et al., 2019). Vulnerable groups, such as pregnant women, children aged < 5 years and people living in shelters, are mostly affected (Gitau et al., 2005; Singh et al., 2006; Black et al., 2008). |
| **Waterborne diseases** | Drought-induced stress in livestock and livestock use of human water resources may lead to high concentrations of pathogens and increase the risk of human exposure and infection, particularly after heavy rain following a drought (Effler et al., 2001). Poor hygiene and poor water quality for human consumption may result in the transmission of diarrhoeal diseases (Burr et al., 1978; WHO, 1985; Smoyer-Tomic et al., 2004; Sena et al., 2014). |
| **Vector-borne diseases** | In addition to increases from more precipitation, mosquito densities may also increase dramatically following a drought (habitat rewetting) because of the reduced number of competitors and aquatic predators (Chase and Knight, 2003). Drought may boost the density of birds and mosquitoes around any water sources remaining and thus may accelerate the transmission of pathogens such as West Nile virus within these populations, thereby increasing the risk of West Nile virus outbreaks in humans (Shaman et al., 2005; Wang et al., 2010). Mosquitoes may adapt to drought in urban environments and exploit artificial aquatic habitats (e.g. water containers), thus elevating the risk of infection in humans of diseases such as chikungunya and dengue (Brown et al., 2014). |
| **Airborne diseases** | Drought-related processes can result in atmospheric dust loadings and dispersion of associated microorganisms at various scales, which may have significant implications for human health. Models for premature mortality due to fine dust exposure project an increase of between 24% and 130% depending on the scenario (Achakulwisut et al., 2018). Dust-storms and winds can also facilitate the transport of microorganisms favouring meningococcal meningitis seasonality, which can have serious consequences for public health, although the mechanisms are not clear (Griffin, 2007; Agier et al., 2013; WHO, 2015). An association between respiratory and cardiovascular diseases has been shown in several regions, but little attention has been paid to West Africa, where desert winds and storms may cause more diseases (De Longueville et al., 2013; García-Pando et al., 2014). In addition, Covid-19 can spread more easily in conditions of reduced water availability by preventing the population from meeting water, sanitation and hygiene needs (e.g. Bellizzi et al., 2020). |
| **Mental health** | Fear and anxiety among rural populations are the most often reported mental health symptoms in response to drought, although suicidal thoughts have been recorded as more critical symptoms (Carnie et al., 2011; Polain et al., 2011; Hanigan et al., 2012). Droughts are also linked to higher emotional distress in rural communities, especially for farmers (Austin et al., 2018). |

*Source*: Vogt et al. (2018)

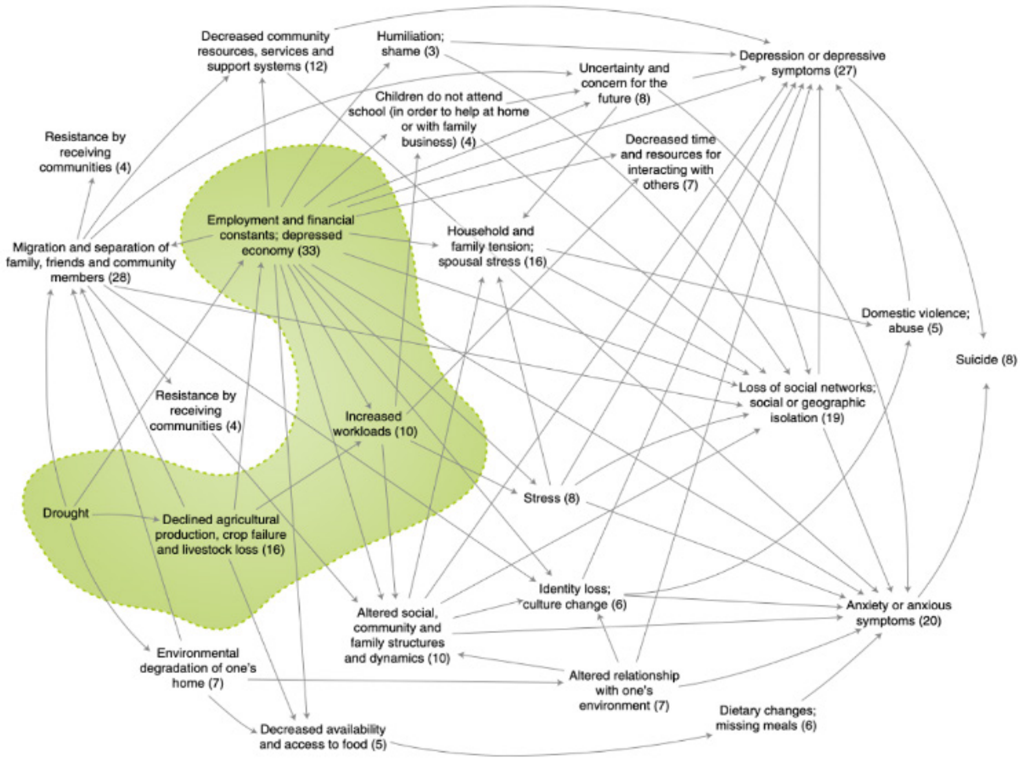
systems. There are few studies that assess and compare the performance of different drought indicators to quantify potential health impacts. Therefore, it is still necessary to better understand which drought characteristics are the best predictors of health effects (Balbus, 2017). To do so, different forms of drought, levels of exposure and periods of time in which these effects are manifested should be considered (Belesova et al., 2019; Salvador et al., 2020).

## 1.3.5

### Cities and urban environments

As major centres of population and infrastructure, cities are particularly vulnerable to extreme climate events and other effects of climate change. Water shortages during drought events affect domestic water supplies by decreasing the availability of fresh water. As dense urban areas are often significantly warmer than the surrounding countryside, compound drought and heatwave events can exacerbate the impacts in these areas due to increased demand.

**Figure 1.8.** **Causal process diagram for the mental health effects of drought based on a systematic review**




*Note*: Numbers in brackets indicate the quantity of papers meeting the search criteria located for each factor. The shaded area shows how the systems diagram can be used to isolate meaningful subsystems for research and analysis, such as drought-related socioeconomic factors and pathways that ultimately affect mental health.

*Source*: Berry et al. (2018), adapted from Amelung et al. (2016). Reprinted by permission from Springer Nature Customer Service Centre GmbH: Springer Nature, *Nature Climate Change*, Berry et al. (2018), The case for systems thinking about climate change and mental health, © 2018.

Globally, a quarter of all cities are already water stressed and exposed to perennial water shortages (McDonald et al., 2014). Exacerbated by climate and land-use changes, river basins with important reserves of fresh water, such as those that serve Melbourne (2000–2010), Barcelona (2008), Los Angeles (2012–2016), Perth (2014), São Paulo (2014–2015), Cape Town (2015–2018) or Chennai (2018), have experienced major water shortages due to droughts over the last few years (LaVanchy et al., 2019; Zhang et al., 2019).

In Cape Town in 2018, the city's water supply was close to being shut off as its freshwater reservoirs hovered at about 13% of full capacity (NASA, 2020) following a sequence of several dry years (Simpkins, 2018; Ziervogel, 2019). The complete cessation of municipal water supply was avoided only by reallocation of water from agriculture and severe restrictions on the use of tap water for several months. Effective water rationing and collective water savings efforts fostered by the local government as well as some precipitation events, meant the so-called "day zero" was avoided.

**Table 1.6. Examples of impacts, actions taken and lessons learned from four recent urban droughts across the world**

| | Melbourne (2000–2010) | Los Angeles (2012–2016) | São Paulo (2014–2015) | Cape Town (2015–2018) |
|---|---|---|---|---|
| **Water supply** | Melbourne water consisted of 10 storage reservoirs | Complex and highly decentralized with over 400 utilities | Cantareira reservoir system | Six reservoirs of around 900 million $m^3$ total capacity |
| **Impacts** | Poor rainfall during the cool season and rainfall declines during the warm season, water storage fell to below 30% | Record high temperature, reduced water stored in the Sierra Nevada snowpack; below-normal reservoir level; agricultural sector (especially rangeland grazing) in the first 2 years; then urban life | Two dry rainy seasons, lowest 3% capacity of reservoir, daily life and violent incidents | Three consecutive years (2015–2017) of below-average precipitation; below 20% of reservoir capacity; local daily life and tourist industry |
| **Actions taken** | Intervention that prompted an almost 50% reduction in water demand per capita | Declared drought emergency; urban water-use report; 20% voluntary conservation; mandate 25% water conservation; extend mandatory conservation regulations | Initial actions to prevent social disorder were implemented, official water countdown | Enforced suburban restrictions of 50 l per person per day; 25 l a day when "day zero" approached |
| **Lessons learned** | Prioritize conservation efforts; use electronic billboard messaging to encourage water saving; purchase water rights for the environment; tax water authorities and use the money to promote sustainable water management and address adverse water-related environmental impacts | Coordinate water shortage contingency planning and implementation; foster water system flexibility and integration; improve water suppliers' fiscal resilience; address water shortages in vulnerable communities and ecosystems; balance long-term water-use efficiency and drought resilience | Avoid pollution in reservoirs and rivers; detect urban droughts in real time; conduct long-term planning that integrates climate change and variability across all sectors of urban development | Reduce water consumption; increase water storage; improve the management of existing resources |

*Source*: Vogt et al. (2018)

Had day zero been triggered, it would have been the first instance of a major city running completely out of water in modern times.

Table 1.6 provides further details on impacts, actions and lessons learned from recent urban droughts.

The main challenge cities face is the balancing of urban demand and water sourcing, which is particularly relevant today in regions where freshwater access is restricted by geographic and climatic conditions. As droughts and heatwaves are projected to likely increase in many areas of the world (see section 1.2.3), water shortages will become more common. Together with the increasing levels of urbanization, many megacities in semi-arid and arid environments will be particularly threatened. Section 2.2.3 gives detailed information on the role of cities in a climate-resilient future.

Bottom-up initiatives like the Mayors Adapt, the Global Covenant of Mayors or ICLEI – Local Governments for Sustainability are cities' response to foster sustainable urban development. Those initiatives aim to support local activities by fostering greater engagement and networking among cities, as well as raising public awareness about mitigation and adaptation of the measures needed to cope with climate change.

## 1.3.6

### Livelihood stability, food prices and volatility risk

The negative impacts of drought on food security, water availability or human health have further consequences on the stability of livelihoods. Drought can push people into humanitarian crises in which households experience gaps in consumption and access to food, especially in low-income countries. Such situations lead to additional burdens, particularly on women, who, in many cases, are responsible for the household, including the collection of drinking water. This is further elaborated in Box 1.5.

Droughts are considered root causes of global food price fluctuations as they lead to crop failure and reduced global food supply. The co-occurrence of multiple breadbasket failures poses a risk to global food price stability (McKinsey Global Institute, 2020). Even small fluctuations in food prices can lead to food insecurity and malnutrition in low-income countries. For example, between 2006 and 2008, the food price crisis was a major factor in the increase of the global number of hungry people to more than 1 billion (FAO, 2011).

Food price volatility is a global concern for consumers and producers (Kalkuhl et al., 2016). Even in high-income countries, price volatility is ranked as one of the most important risks by farmers. In a survey of 500 farmers in Austria, heat and drought were identified as the most important threats, followed by commodity price volatility and volatility of farm input prices (Hanger-Kopp and Palka, 2020). Additionally, farmers face political and institutional risks from inadequate policy as well as financial risk from expensive loans to finance their operations.

The Group of Twenty (G20) developed an action plan to reduce food price volatility for all countries, because of food price shocks in the early 2000s. This included the establishment of the Agricultural Market Information System – hosted by FAO – so as to increase market information and transparency (G20, 2011). It builds data-collection capacity in participating countries, promotes international policy coordination and creates alerts of food price surges to strengthen global early warning capacity.

Further policy measures against the impacts of drought include disaster response and also investments in infrastructure or technology to prevent or mitigate future drought risks and to maintain livelihoods. There are several ex ante policy measures to increase resilience: providing information to improve drought risk management, improving planning for a more-effective drought response, investing in disaster risk reduction (DRR) and providing an overall risk-minimizing environment (OECD, 2020a). More recently, ex ante cash transfers have begun to be used as a measure to stabilize livelihoods and prevent food price crises.

In forecast-based financing mechanisms, people in drought-prone regions are paid a predetermined amount of money if drought forecasting models pass a certain warning threshold. These ex ante cash transfers are designed to prevent populations from becoming undernourished and have been shown to be more cost-effective than ex post disaster relief, for example in reducing stressors resulting from food price volatility (Nobre et al., 2019).

Ex post policy measures preventing the loss of livelihoods include early disaster response. The United States Agency for International Development estimated that an early response to drought in Ethiopia, Kenya and Somalia would have saved $1.6 billion in humanitarian response and nearly $2.5 billion in avoided losses over a period of 15 years (USAID, 2018). In the Horn of Africa, monitoring systems indicated a severe drought in 2017. Due to early action from the Special Fund for Emergency and Rehabilitation Activities, livestock feed and other assistance were provided that reduced livestock mortality and improved household welfare (FAO, 2018).

**Box 1.5. Drought impacts and gender imbalance**

Drought can have differential economic, social and environmental effects on women in developing countries. Unequal power relations, gender inequalities and discrimination mean women and girls are often hit hard during a crisis and are often required to take on significant extra work to recover from drought in such countries.

Women are especially vulnerable because their social roles, responsibilities, limitations and capacities are different from those of men (UNCCD, 2019). Women often face discrimination, resulting in unequal pay, fewer educational opportunities, and exclusion from political, community and household decision-making processes. Recurrent drought can put additional pressure on single-parent households, or those caring for elderly or ill family members.

Studies have shown women are at greater risk of sexual violence during drought in refugee camps, as they have to walk further or walk during the night to collect water. For instance, reported cases of sexual violence quadrupled among refugees during the 2011 drought in the Horn of Africa (Reliefweb, 2011).

Women and men often deploy different skills and coping mechanisms during droughts (FAO, 2010). As illustrated in a case study in Patía, Colombia, women assume proportionally greater additional responsibilities to cope with drought than men, with no discernible reduction in daily pre-drought activities and tasks to which men make little or no contribution. Pre-drought, men's labour participation is focused on pasture management, livestock care, production of meat, and buying and selling of animals; women work more on milk production, cleaning of equipment and utensils, milking and processing activities. This is partly due to the ease of combining these activities with household responsibilities. Such competing claims on women's time can result in a significant deterioration in women's well-being (Arora et al., 2017).

Policy development must address the direct and indirect contributions of women and men to crop and livestock production. Policies need to value women's labour both in the home and outside of it. Gender-responsive approaches in drought preparedness, policymaking and programming are essential to effective drought risk management initiatives (UNCCD, 2019).

# 1.4

# Drought risk assessment

**KEY MESSAGES**

- Drought risk depends on the drought hazard and on the interactions between socioeconomic and ecosystem vulnerability of exposed systems.
- A better understanding of the drivers, spatial patterns and dynamics of drought risk is key for building resilience to droughts. Risk assessments should go beyond mapping current patterns of vulnerability drivers and systematically explore root causes, as they can be influenced by adequate management and policy.
- To understand current drought risk, it is important to consider current susceptibilities and lack of coping capacities.
- Future scenarios of drought risk need to consider the effects of adaptive or non-adaptive human behaviour and potential adaptation measures on future drought hazard, exposure and systems' vulnerabilities.

This section introduces a novel conceptual framework for characterizing systemic drought risk (see Box 1.6), followed by an introduction to approaches and recent advances in assessing present-day and future drought risk in all dimensions of drought hazards, exposure and systems' vulnerabilities.

## 1.4.1

### Conceptualizing drought risk

Droughts and their adverse impacts are putting livelihoods at risk and are hampering the achievement of SDGs – notably SDG1 (no poverty), SDG2 (zero hunger), SDG3 (good health and well-being) and SDG15 (life on land). While there is ambiguity regarding drought trends in the past century (Sheffield et al., 2012; Trenberth et al., 2014), and despite the uncertainty in climate projections, it is likely that the frequency, severity and duration of droughts will increase in many regions across the world due to climate change (IPCC; 2018; UNDRR, 2019). At the same time, exposure of people, assets and ecosystems has increased in the past decades faster than vulnerability has decreased, thus generating new risks and leading to a steady rise in overall drought-related losses and damage (UNDRR, 2019).

Identifying pathways towards more resilient societies and sustainable development is hence high on the global political agenda. Cross-sectoral, cross-scale and impact-specific assessments of who and what are at risk to what (e.g. soil moisture for agriculture or stream-flow drought for energy), as well as where and why, will be key for the development of baselines that can inform prospective and proactive risk management (IPCC, 2014c), as well as targeted response.

A proactive approach to drought risk management includes appropriate measures being designed in advance, with related planning tools and stakeholder participation. The proactive approach is based on short-term and long-term measures and includes monitoring systems for a timely warning of drought conditions, identification of the most vulnerable part of the population and tailored measures to mitigate drought risk and improve preparedness. The proactive approach entails the planning of necessary measures to prevent or minimize drought impacts in advance. This approach is reflected in the three pillars of integrated drought management (see section 1.5.2).

It is no surprise that the need to understand, assess and monitor the drivers, complexities and spatio-temporal dynamics of present-day and future drought risk has been underscored by several recent international agreements and initiatives, including the Sendai Framework, the UNCCD 2018/19 Drought Initiative and the 2019 United Nations Global Assessment Report on Disaster Risk Reduction (GAR; UNDRR, 2019).

Tremendous progress has been made over the past few decades in understanding the physical processes underlying drought propagation (Hao and Singh, 2015), as well as the human role in enhancing and mitigating droughts (Van Loon et al., 2016). Countries have implemented drought monitoring and early warning systems based on their ability to monitor and predict drought events (Pulwarty and Sivakumar, 2014).

At the same time, conceptual approaches to understanding risk associated with climate change and natural hazards have undergone paradigm shifts. Early conceptualizations focused primarily on understanding and assessing key characteristics of the hazard, such as frequency, intensity, duration or extent. The choice and frequent use of the term "natural disasters" reflects the thinking of that time when disasters were understood as being random, exceptional events, or purely natural phenomena (Hewitt, 1983; Burton, 2005).

Emphasizing the role of agency (the action people take to reduce their vulnerability) and structure (the social, economic or political structures that place people in vulnerable conditions), criticism emerged in the 1970s of these hazard-oriented explanations of risk, and called for the consideration of vulnerability as a key driver of risk (O'Keefe et al., 1976; Hewitt, 1983; Blaikie et al., 1994; Lewis, 1999). More holistic risk concepts have been advanced that integrate social, economic, political, environmental, physical and governance-related drivers of climate and disaster risk by considering hazard, exposure and vulnerability (Turner et al., 2003; Birkmann et al., 2013; IPCC, 2014c; UNDRR, 2019).

As a result, new conceptual foundations and frameworks on how to define disaster and drought risk coexist, and are used to inform drought risk assessments (Hagenlocher et al., 2019; Blauhut, 2020). Previously, while vulnerability and risk were conceptualized differently by DRR and climate change adaptation communities, efforts of the past decade, such as the IPCC special report on extreme events or the IPCC Fifth Assessment Report, have made a contribution to reconciling contrasting definitions (IPCC, 2012, 2014; Giupponi and Biscaro, 2015).

It is widely acknowledged today that risk (i.e. the potential for adverse consequences) is more than just the likelihood and severity of hazardous events and potential impacts. Recent severe droughts have shown that the risk of negative impacts associated with drought is not linked only to the severity, frequency, onset and duration of drought events. Rather, drought risk is complex, multifaceted and dynamic (Brüntrup and Tsegai, 2017; Van Lanen et al., 2017), resulting from the complex and non-linear interactions of drought events with exposure of humans, infrastructure and ecosystems, to systems' vulnerabilities across multiple scales, sectors and systems (IPCC, 2014c; UNDRR, 2019).

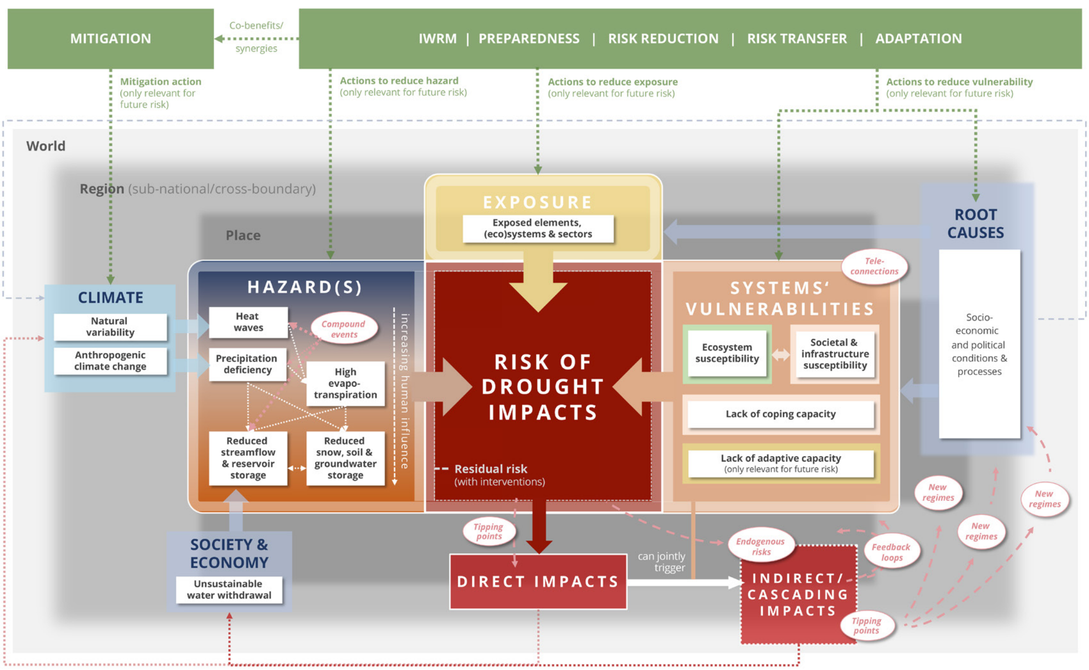
Figure 1.9 shows that the risk of direct drought impacts for one system results from the complex, non-linear, cross-scale interaction of compounding drought hazards, exposure and systems' vulnerabilities. Failures in one or multiple parts of the system can also trigger cascading impacts on other sectors or systems, in the same region or far from the area affected by droughts. Mitigating anthropogenic climate change can help to reduce drought hazards. Furthermore, integrated water resources management (IWRM), risk reduction (including risk transfer, e.g. through insurance solutions) and adaptation, aiming to reduce current and future exposure and vulnerabilities, are instrumental to reduce the risk of direct and cascading drought impacts. Residual risk is the risk that remains unmanaged after considering the effects of risk reduction, risk management and adaptation.

Persistent anomalies in large-scale atmospheric circulation patterns can lead to meteorological droughts, and in turn to reduced water storage in the form of snow and in soils (soil moisture drought), as well as to reduced stream-flow, declining groundwater tables and decreased storage in lakes and reservoirs (hydrological drought) (Van Loon et al., 2016; Manning et al., 2018). This is especially true when combined with an elevated atmospheric evaporative demand exacerbated by global warming (Dai, 2011; Trenberth et al., 2014) and compound effects of precipitation deficiencies with hot temperature extremes (Hao et al., 2018; Sharma and Mujumdar, 2017), unsustainable water abstraction (Mehran et al., 2017; Di Baldassarre et al., 2018; Veldkamp et al., 2017; Ashraf et al., 2019) and anthropogenic modifications of catchment properties altering hydrological processes (e.g. soil compaction, degradation of ecosystems and their services, and urbanization).

The presence of people, livelihoods, species, ecosystems and their services, infrastructure, basic services and other tangible assets in places and settings that could be adversely affected by droughts determines exposure. Like the other two risk components (drought hazards and system vulnerabilities), exposure is not static, but subject to constant spatio-temporal dynamics (UNDRR, 2019). Some of the key factors contributing to these dynamics include population growth, tourism, mobility and changes in agricultural land and ecosystems resulting from human influences (e.g. increasing demand for land for housing and food production), political priorities and economic development.

Analysing the root causes of system vulnerabilities is necessary to understand why households, communities, regions, systems or sectors facing the same drought event may experience fundamentally different impacts (Blaikie et al., 1994; Wens et al., 2019). System vulnerability also exhibits a dynamic and non-linear nature (Wisner et al., 2004; Birkmann et al., 2013; IPCC, 2014c; Jurgilevich et al., 2017; Ford et al., 2018), for example driven by changes in social, economic, physical or natural capital and their complex interrelations across spatial and temporal scales. Particularly

**Figure 1.9. Characterizing the systemic nature of drought risk**



**Box 1.6. Systemic risks**

Systemic risks are defined as interdependent failures in different parts of a system that might lead to cascading events or even to breakdown of the entire system. Failure can arise through one or several external shocks, but can also be embedded in the system itself and have cumulative risk potential when some characteristics of a system change (Helbing, 2013; UNDRR, 2019). Droughts contain a range of systemic risk characteristics that need to be acknowledged in drought risk analysis and management. These include:

- Interconnected, complex, causal structures: Droughts and heat-related extremes such as heatwaves are among the most-severe impacts of climate hazards, potentially resulting in agricultural production losses, human health stresses or damage to infrastructure. In particular, the non-linear interplay among various climate extremes such as hot and dry conditions and system vulnerabilities pose a risk.
- Compound events: A combination of interacting physical processes such as climate drivers or hazards across multiple spatial and temporal scales (Zscheischler et al., 2018, 2020), which may include (a) preconditions that aggravate impact, (b) compounding impacts as a result of multiple drivers and/or hazards, (c) impacts resulting from a succession of hazards or (d) aggregated impacts provoked by hazards in multiple connected locations.
- Non-linear dynamics and tipping points: Tipping points occur in non-linear dynamic systems when an incremental change in a specific variable leads to a sudden, often catastrophic, shift into a new equilibrium state. Droughts can have highly non-linear effects on other systems such as the food system. Although droughts might gradually develop over many months, they might also act as a sudden, dramatic trigger to famine and consequent food riots when a social tipping point is crossed.
- Globally networked risks: The globalized world consists of highly interdependent social, environmental and technical systems. The economic system is characterized by an increasing number of trade connections and trade volume. While global economic integration can strengthen resilience to smaller shocks like drought-induced crop losses in one region through trade adjustments, large or multiple shocks can propagate through global networks and lead to ripple effects such as price spikes around the world.
- Cascading events and feedback loops: Droughts can act as trigger events for cascading events and feedback loops that further exacerbate the initial hazard (Zuccaro et al., 2018). In particular, the interdependence among hazards such as heatwaves and prolonged droughts can generate different event chains that, exacerbated by system vulnerabilities, can cause damage to different exposed elements such as agricultural production, critical infrastructure or service networks (for more details, see section 1.3.2).

in settings where livelihoods rely on ecosystems and their services, a social–ecological systems perspective is imperative to understanding system vulnerabilities; a perspective that considers the susceptibility of ecosystems and their relationship to the susceptibility and lack of coping capacities of the communities that depend on them (Sebesvari et al., 2016; IPCC, 2019).

## 1.4.2

### Assessing drought risk

Drought risk assessments should have a systems perspective of the spatial and temporal scales on which the drought-prone sectors, systems or user groups at risk operate (risk of who and to what) (World Bank, 2019). This systemic approach is not fixed on a single discipline or sector, rather it needs to be based on a transdisciplinary and holistic approach involving networking and partnership across different scientific disciplines, policymakers, practitioners and citizens. The assessment should be tailored to specific user needs so drought risk management, adaptation policies and plans can be developed to reduce risk and impacts (Vogt et al., 2018; UNDRR, 2019; World Bank, 2019). Therefore, it should be co-designed in close collaboration with local stakeholders and citizens.

The interdependence of different risk variables – hazard, exposure and vulnerability – must be represented to avoid underestimating the compounding effect that can occur if risk is measured based on a single variable or risk component (Zscheischler and Seneviratne, 2017; He et al., 2020). The root causes, spatial patterns and dynamics of exposure and vulnerability need to be considered alongside climate variability in an integrated and consistent manner (Hagenlocher et al., 2019; Spinoni et al., 2019; He et al., 2020; Meza et al., 2020).

Composite-indicator approaches are commonly used for drought risk assessments. They are valuable for aggregating multiple underlying factors and identifying generic leverage points for reducing impacts from the local to the global scale (Beccari, 2017; de Sherbinin et al., 2017, 2019; UNDRR, 2019). However, when assessing drought risk with index-based approaches, composite indicators are often static in time and space, and do not fully capture the inherent system dynamics (e.g. non-linear relationships, feedback loops, and cross-scale and cause–effect interactions).

Considerable efforts have been made in recent decades to improve drought risk monitoring, modelling and assessment across scales and sectors, ranging from global (e.g. Dilley, 2005; Carrão et al., 2016; He et al., 2020; Meza et al., 2020), to transboundary (e.g. Mohammed and Scholz, 2017; Sušnik et al., 2018), to national (e.g. Frischen et al., 2020) to local (e.g. Chou et al., 2019) level risk assessments. These improvements help to identify dynamics and leverage points to anticipate, adapt, reduce impact and move towards resilient sectors and societies.

#### *Current drought risk*

**Drought hazard**

Drought hazard assessment should evaluate the evolution of spatio-temporal drought patterns, including drought climatology, monitoring, seasonal forecasting and future projections (see section 1.2.1). Hao et al. (2018) assessed the interdependence and non-linear interactions between drought and other climate extremes such as heatwaves. These extremes can contribute to and amplify impacts on society and ecosystems (e.g. agricultural production, changes in vegetation growth, energy security, human health and migration).

As discussed in section 1.2.2, different drought types require different indicators for their characterization. One of the main difficulties of using indices is setting the context, benchmarks and threshold below which the dynamic nature of droughts and their interrelated characteristics are defined (He et al., 2020; Wilhite, 2000). This process requires the gathering of historical climate/hazard trend data along with a broad range of indicators selected according to the impact to be assessed (UNDP, 2011).

Combining indicators will provide further insight into the range of potential levels of drought severity and the frequency and occurrence of drought hazards (World Bank, 2019). Several combined indicators that integrate physical indicators into one index have been developed, for example, to monitor drought impacts on agricultural and natural ecosystems (Sepulcre-Canto et al., 2012) or to measure drought hazard for agricultural systems (Meza et al., 2020; section 1.2.2).

Another relevant consideration is the seasonality of drought. While seasonal droughts are frequent and predictable, megadroughts and flash droughts (lasting less than 3 months) are aberrant and unpredictable (Bond et al., 2008; UNDRR, 2019; section 1.2.4). The case studies summarized in Chapter 2 highlight the relevance of the seasonality of drought on assessments. Understanding and monitoring each hazard component in the different sectors is crucial, as it is not necessary for all the characteristics of the drought hazard to be extreme for their composite impact to be extreme.

**Exposure**
Exposure is generally defined as the elements of a system located in areas that could be adversely affected by the drought hazard (IPCC, 2014c). It comprises all assets, sectors, infrastructure, species or ecosystems and people located in a drought-prone area (Vogt et al., 2018). In addition to directly exposed elements, there are indirectly exposed elements such as trade and financial systems that are affected by the drought elsewhere via teleconnection (Figure 1.5). Sections 1.2.5 and 1.3 describe examples of sectors that are susceptible to drought impacts and therefore relevant to exposure, and Chapter 2 provides examples of how exposure assessment is operationalized at a local scale. Exposure is not static as it is subject to constant spatio-temporal dynamics including political priorities and economic development (UNDRR, 2019).

Understanding the characteristics of exposed elements is important, as they influence the magnitude of the potential drought impact (World Bank, 2019). For instance, the larger the share of agricultural land exposed in a given country, the larger the potential impact of drought on crops, leading to a potential cascading effect on food availability. Approaches can be different depending on the sector and temporal and spatial scales at which RDrI is assessed. Vogt et al. (2018) provide a good example with emphasis on agriculture and primary sector impacts. Table 1.7 considers the exposure layers and their relevance to specific sectors seeking to assess exposure to drought. Their model was computed and validated based on spatially explicit geographic layers. This comprehensive approach considers the spatial distribution of several physical elements or proxy indicators (Carrão et al., 2016). Furthermore, using this methodology ensures dominance in one indicator cannot be compensated for by inferiority in another (UNDRR, 2019).

**Vulnerability**
A better understanding of the vulnerabilities of people, livelihoods, sectors or systems towards drought is essential in designing targeted drought risk reduction and adaptation strategies and measures (Vogt et al., 2018). Building on the IPCC definition, the United Nations defines vulnerability as the conditions determined by physical, social, economic and environmental factors or processes that increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards (here: drought) (IPCC, 2014c; United Nations, General Assembly, 2016). IPCC and the United Nations identify (the lack of) coping and adaptive capacities as central to determining vulnerability.

Vulnerability to droughts is difficult to quantitively measure due to its multidimensional nature, and is often best assessed by considering relevant drivers of vulnerability. Context-specific vulnerability drivers need to be considered – such as social (e.g. demographic characteristics), economic (e.g. gross domestic product (GDP) per capita), physical/infrastructural (e.g. hydropower), governance and environmental (e.g. land and soil degradation) factors – and employed subject to the target of the drought risk assessment. Different vulnerability drivers might be relevant when assessing drought risks for public water supply or for agricultural livelihoods, for example.

These factors are dynamic and change over time and space. To capture this complexity, assessments should allow interactions between one or multiple drought hazards and the multiple associated vulnerabilities of different exposed elements to emerge. This approach is often described as being multi-risk (Garcia-Aristizabal et al., 2015) or multi-vulnerability (Gallina et al., 2016). As the socioecological system develops, the sectors or users that are affected may also change (Wilhite et al., 2014; Hagenlocher et al., 2018; World Bank, 2019). Therefore, droughts in the same region will have different impacts on the exposed elements, even if hazard characteristics are identical because the drought event is coupled with a socioecological system that is complex and dynamic.

The magnitude of drought impact depends on the vulnerability of the exposed assets, sectors and systems (World Bank, 2019). Some sectors are more vulnerable than others to drought. Agriculture, energy production and industry, drinking water/ domestic water supply, navigation and ecosystems are among the most susceptible, due to their heavy dependency on water (World Bank, 2019).

As different sectors are affected in distinct ways, different indicators and variables need to be used to characterize and assess their vulnerability according to the geographical and socioecological context (Peduzzi et al., 2009; World Bank, 2019).

**Table 1.7. Exposure layers, description and relevance to sectors assessing drought exposure**

| Exposure layers | Description | Sectors |
|---|---|---|
| **Gridded population data** | Used to account for the spatial distribution of population exposed to droughts | Agriculture, energy, industry, water supply, navigation, ecosystems, tourism, forestry, aquaculture and fisheries, and financial |
| **Land use** | Used to represent the proportion of land area used as cropland, settlements, pastures and managed woods | Agriculture, energy (biomass), water supply, ecosystems, forestry, aquaculture and fisheries, and financial |
| **Agricultural crop type** | Used to identify crop types more sensitive to droughts | Agriculture |
| **Gridded livestock of the world** | Used to model livestock densities of the world | Agriculture, water supply, ecosystems and financial |
| **Highly valued and/ or protected nature areas** | Used to spatially localize and identify the size/density of protected areas and species as well the highly valued and rare ecosystems | Ecosystems, tourism, forestry and financial |
| **Baseline water stress** | Used to represent the relative water demand (ratio of local water withdrawal/ available water supply) | Agriculture, energy, industry, water supply, navigation, ecosystems, tourism, forestry, aquaculture and fisheries, and financial |
| **Location and density of industrial activities** | Used to identify the capacity and type of industries | Energy, industry, water supply and financial |
| **Hydropower capacity production** | Used to represent the location and capacity (water, energy production) of reservoirs used for hydropower generation | Agriculture, energy, industry, water supply, ecosystems, tourism and financial |
| **River network and navigation activities** | Spatial information used to identify the main navigation transportation routes or most important harbours and the shipping density and specific shipping characteristics | Navigation and shipping, energy, industry and financial |

*Source*: Vogt et al. (2018)

Due to its complexity, the most common method to assess drought vulnerability uses composite indicators or index-based approaches (Beccari, 2017; de Sherbinin et al., 2019; Hagenlocher et al., 2019). A handbook on constructing composite indicators was published in 2008 (OECD, 2008), the indicators of which have been implemented and adapted to different drought assessments at global and local levels (Naumann et al., 2014; Carrão et al., 2016; Núñez et al., 2017; Meza et al., 2020).

However, vulnerability cannot be fully assessed by quantifiable variables only. There are other root causes of vulnerability that cannot be "quantified" with a simple indicator, such as beliefs, awareness, social capital or accepted risk thresholds. In addition, due to the static nature of index-based approaches, they do not capture inherent complexities and dynamics of drought vulnerability completely.

The selection of relevant vulnerability indicators depends on the impact, sector, scale and unit of analysis. There are different approaches to identifying the most-relevant indicators; the most common are expert judgment, literature review or a mixture of both. One of the most sensitive steps in index construction is the weighting scheme. A wide variety of approaches have been developed to identify and incorporate the relevance and contribution of factors and indicators to vulnerability and risk in the context of droughts (OECD, 2008).

These approaches can be classified as based on statistical models (e.g. regression analysis, principal component analysis or factor analysis) or expert or participatory community consultation (e.g. ranking, budget allocation, analytic hierarchy processes and Delphi methods).

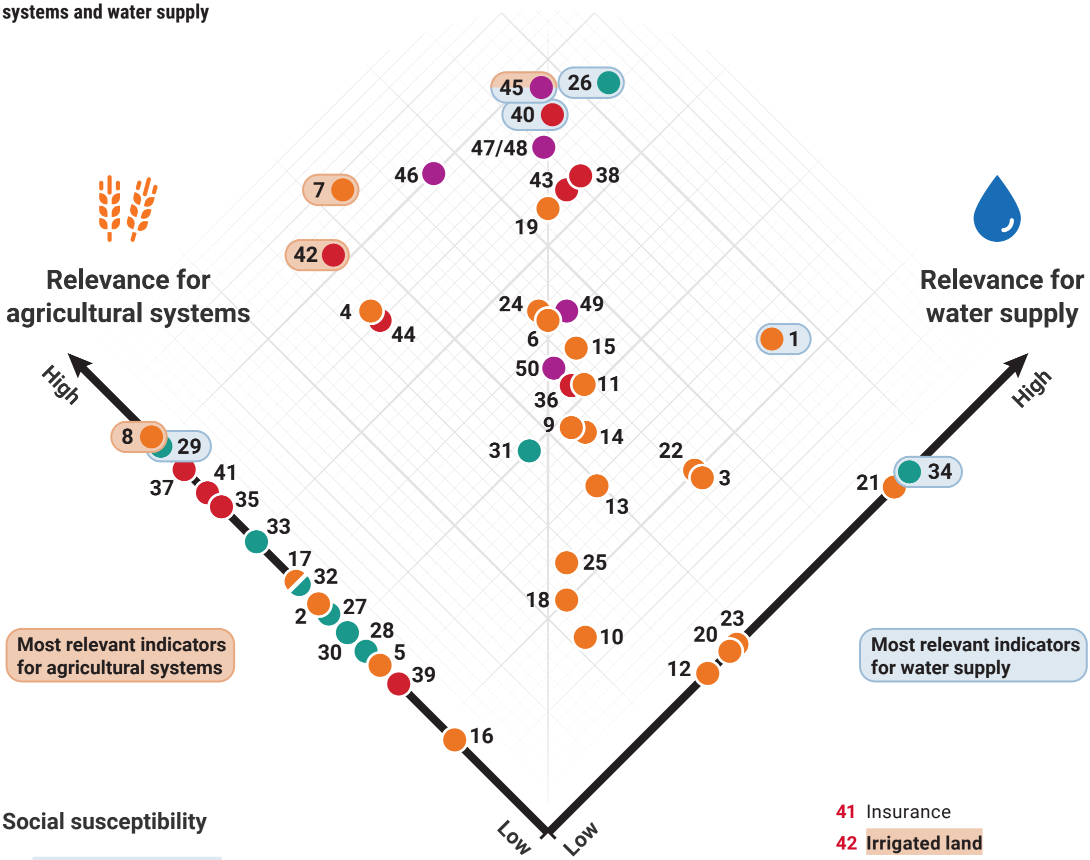
Meza et al. (2019) performed a global expert survey with the aim to identify the most-relevant drought vulnerability indicators for global-scale drought risk assessments for water supply and the agricultural sector. They found the relevance of indicators varies strongly according to the sector, as different drivers are relevant for different impacts. Furthermore, this relevance, even within the same sector, might vary for different contexts and scales. Figure 1.10 shows the most-relevant indicators and their weights according to experts.

The foregoing analysis on vulnerability and risk drivers can be refined at higher spatial resolution, allowing for an improved assessment of the spatial distribution of the drought risk within a given area of interest (e.g. farm, province, river basin, country, region or continent). An example is the vulnerability assessment developed for the UNCCD Drought Toolbox, launched at the fourteenth meeting of the Conference of the Parties to UNCCD. In the toolbox, the drought vulnerability assessment relies on the methodology and assessment developed by JRC (Vogt et al., 2018). It is calculated as the propensity of exposed elements to suffer adverse impacts when affected by a drought event, and is derived from a combination of social, economic and infrastructural indicators (Carrão et al., 2016). Figure 1.11 shows the implementation of the vulnerability assessment in the UNCCD Drought Toolbox (UNCCD, 2020). The framework is data driven and thus the main limitation for obtaining reliable estimates is the availability and accuracy of relevant information at different administrative levels.

An uncertainty and sensitivity analysis should be conducted before results are visualized, as the development of composite indices has inherent uncertainties due to the subjective decisions made in the process (e.g. the mechanism to include or exclude an indicator, the normalization approach, the imputation of missing data and the weighting scheme) (OECD, 2008). Uncertainty and sensitivity analysis will provide useful insights into the process of building composite indicators, thereby increasing transparency and giving meaning to the associated policy message.

The examples above highlight the relevance of the vulnerability assessment and identify its key drivers, as vulnerability shapes the risk of current and future droughts for the different sectors. Chapter 2 presents local examples on how vulnerability assessments are performed.

**Figure 1.10.** Differing relevance of vulnerability indicators to drought impacts on agricultural systems and water supply




### Social susceptibility

1 **Access to clean water**
2 Access to fodder
3 Access to sanitation
4 Agricultural GDP
5 Agricultural machinery
6 Conflict and insecurity
7 **Dependency on agriculture**
8 **Drought-resistant crops**
9 GDP
10 Gender inequality
11 GINI index
12 Health expenditure
13 Hydroelectricity
14 Ill-health
15 Illiteracy
16 Life expectancy
17 Market fragility
18 Population ages 15-64
19 Poverty
20 Refugee population
21 Risk Perception
22 Rural population
23 Tourism
24 Undernourishment
25 Unemployment

### Environmental susceptibility

26 **Baseline water stress**
27 Fertilizer use
28 Insecticides and pesticides
29 Land degradation and desertification
30 Livestock health
31 Protected areas and biodiversity
32 Soil depth
33 Soil organic matter
34 **Water quality**

### Lack of coping capacity

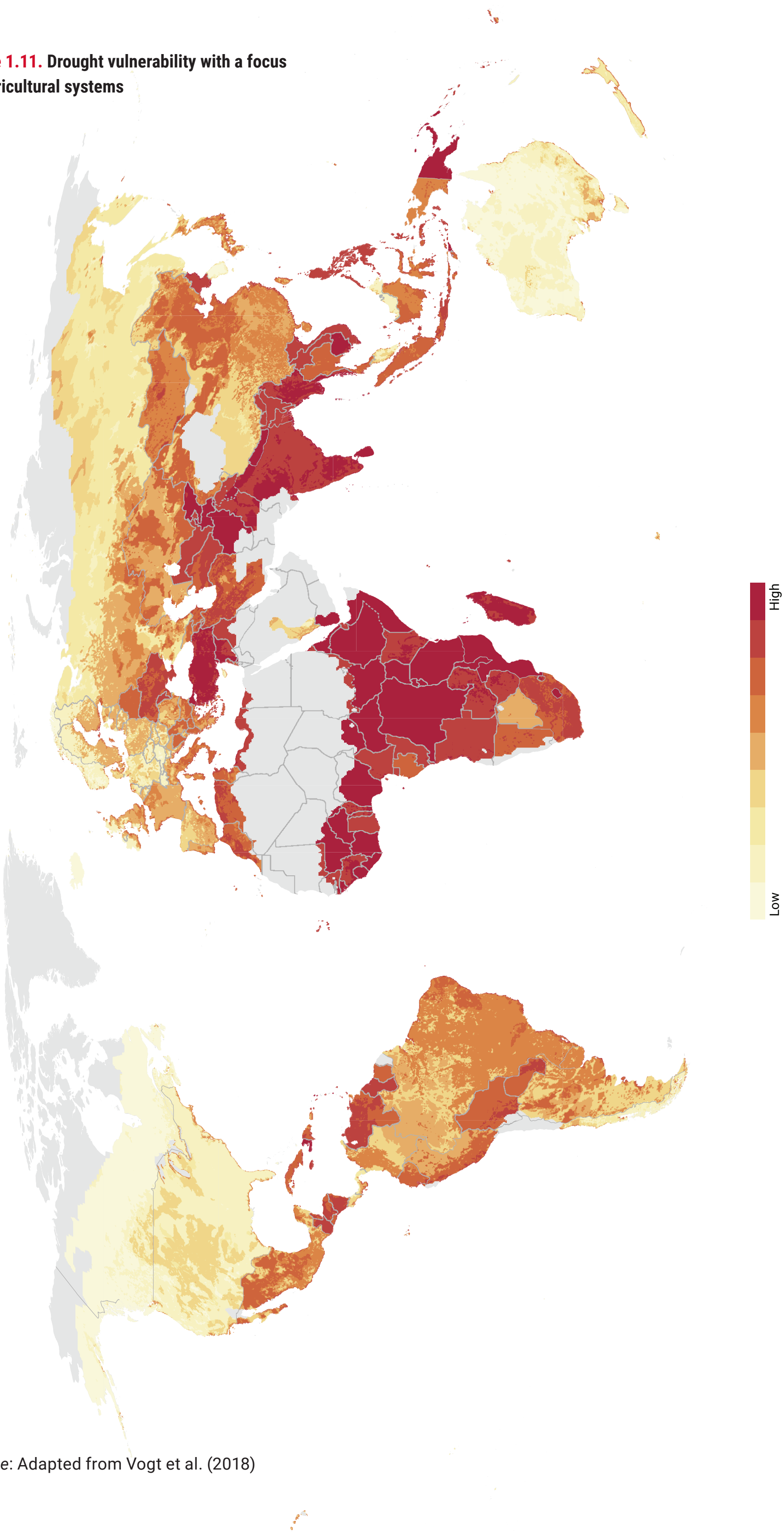
35 Access to credit
36 Corruption
37 Crop varieties
38 Dam capacity
39 Distance to markets
40 **Government effectiveness**
41 Insurance
42 **Irrigated land**
43 Retained renewable water
44 Savings

### Lack of adaptive capacity

45 Adaptation **policies**/**plans**
46 Adaptation projects
47 Disaster prevention and preparedness
48 Disaster risk policies
49 Public participation in local policy
50 Research and development expenditure

*Source*: Adapted from Meza et al. (2019)

**Figure 1.11. Drought vulnerability with a focus on agricultural systems**




The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.
Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.
Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined.
A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas).

*Source*: Adapted from Vogt et al. (2018)

**Risk of drought impacts**

The risk of drought impacts is the result of the interaction of drought hazards with exposure of human and natural systems and their vulnerabilities, which depend on changing socioeconomic pathways and socioecological conditions (IPCC, 2014c). As discussed in section 1.2.1, this concept is commonly expressed in a mathematical form where Risk = $f$ (Hazard, Exposure, Vulnerability).

Drought risk is characterized by numerous feedback loops among the different risk components. As part of a system, these could be aggravated by previous or parallel events. In cases of severe disruption of the exposed and vulnerable elements (people, assets, sectors and systems), the hazard may materialize as a disaster. Different approaches have been developed to determine the overall drought risk. It may be assessed through a factor approach, based on a conceptual framework of drought risk (Naumann et al., 2014; Carrão et al., 2016), or through a probabilistic approach where risk is commonly understood as the probability of a drought event happening multiplied by its impact (Van Lanen et al., 2017; Rajsekhar and Gorelick, 2017; World Bank, 2019). However, such probabilistic approaches need to be considered with care, especially when assessing risks associated with climate-related hazards such as droughts, where climate change might affect the frequency and severity of droughts, as well as on the occurrence of drought events in places where droughts occur infrequently (Diffenbaugh, 2020).

Estimating the risk of drought impacts requires the development of models that combine drought hazard with relevant indices or metrics of drought exposure and vulnerability (Van Lanen et al., 2017). For instance, Carrão et al. (2016) and Meza et al. (2020) used a factor approach at the global level and developed composite-indicator approaches to determine global drought risk for the agricultural sector. In this approach, the evolution of the hazard is dynamic, while the social, infrastructural, governance and environmental factors underlying exposure and vulnerability assessments are less dynamic (and in most instances are updated irregularly).

Blauhut et al. (2015, 2016) assessed drought risk in Europe through a static and probabilistic impact model for diverse sectors such as energy, industry and water quality. Chen and Yang (2011) performed an assessment of impacts on agricultural systems in Hunan Province, China, using a matrix approach that weighted risk factors, and was considered useful in designing effective drought prevention and mitigation measures. Wens et al. (2019) developed an agent-based modelling framework to integrate human behaviour dynamics into drought risk assessment by simulating local-scale dynamics. The framework allows simulation of dynamic drought risk as a result of the evolution of the drought and the dynamic mitigation and adaptation decisions of exposed farmers, water managers, urban populations or administrative and government bodies involved.

Composite indicators, matrix and impact models represent alternative but complementary ways of approaching drought risk assessment at different scales, and for different assets, sectors and systems. Moreover, composite indicators are the most common approach as they can identify generic leverage points for reducing drought impacts at the regional to global scales while allowing for comparability across countries or regions (Van Lanen et al., 2017). For example, the case study of central southern Africa in Chapter 2 presents a probabilistic drought risk assessment for Angola (livestock/livelihoods impacts), the United Republic of Tanzania (crop impacts) and Zambia (hydropower impacts).

More efforts are required to integrate the dynamic nature of drought risk into current assessments so future adaptation strategies can be improved (He et al., 2020). In addition, incorporating the uncertainties and sensitivity of the assessment, which may inevitably involve various trade-offs, is needed. Improvements could be achieved with the availability of more spatially explicit vulnerability information (i.e. at subnational levels) and the availability of standardized drought impact information that can serve as quantitative validation of risk level.

### *Future drought risk in the context of global change*

In the context of global environmental change, societal change, sustainable development and transformation, future risk scenarios are useful tools to illustrate different potential development pathways and associated risk trends. Risk scenarios can also help identify policies and measures to prepare for a range of possible futures (Birkmann et al., 2015). Preventing future risk, a key goal of the Sendai Framework, and enabling risk-informed, climate-resilient development require a solid understanding of which areas might be affected by drought hazards in the future, alongside possible future exposure and vulnerability pathways.

RCPs (Moss et al., 2010) and shared socioeconomic pathways (SSPs; Kriegler et al., 2012; O'Neill et al., 2014) provide a framework for the assessment of future risks and options for their management (van Ruijven et al., 2014). RCPs describe four different twenty-first century pathways of GHG emissions and atmospheric concentrations, including a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one high-end scenario with high GHG emissions (RCP8.5). SSPs provide narratives describing plausible alternative trends in the evolution of societies and natural systems and their associated challenges for mitigation and adaptation over the twenty-first century (Kriegler et al., 2012). Together, these two challenges span a challenge space of five SSPs: low challenges for mitigation and adaptation (SSP1), moderate challenges for mitigation and adaptation (SSP2), high challenges for mitigation and adaptation (SSP3), high challenges for adaptation, low challenges for mitigation (SSP4), and high challenges for mitigation, low challenges for adaptation (SSP5) (O'Neill et al., 2014).

While RCPs and SSPs were initially developed at the global level, in recent years, an increasing number of studies have been published aimed at extending SSPs to regional (e.g. Williges et al., 2017), national (e.g. Chen et al., 2020a) and subnational (e.g. Absar and Preston, 2015; Frame et al., 2018; Kebede et al., 2018) scales, strengthening scenario development within drought risk assessment at different administrative scales.

To gain a better understanding of possible future exposure to drought, some recent studies have used SSPs to identify scenarios of future population growth (Jones and O'Neill, 2016; KC and Lutz, 2017) and land use (Popp et al., 2017; Chen et al., 2020b). Integration of future drought hazard scenarios based on RCPs and future exposure scenarios based on SSPs at the global scale is still lacking. However, Smirnov et al. (2016) integrated future drought hazard scenarios using SPEI for four RCPs with one population growth scenario to simulate future exposure of the world's population to drought hazards until the end of the twenty-first century. Their study shows that by 2081–2100, under the high-emissions scenario RCP8.5, the average worldwide monthly population exposed to extreme drought (SPEI < −2) would possibly increase from 85.5 million at present to 472.3 million at the end of the century. Furthermore, according to their simulations, at the end of the century, 129 countries will experience an increase in drought exposure mainly due to climate change alone, 23 countries primarily due to population growth, and 38 countries primarily due to the interaction between climate change and population growth (Smirnov et al., 2016).

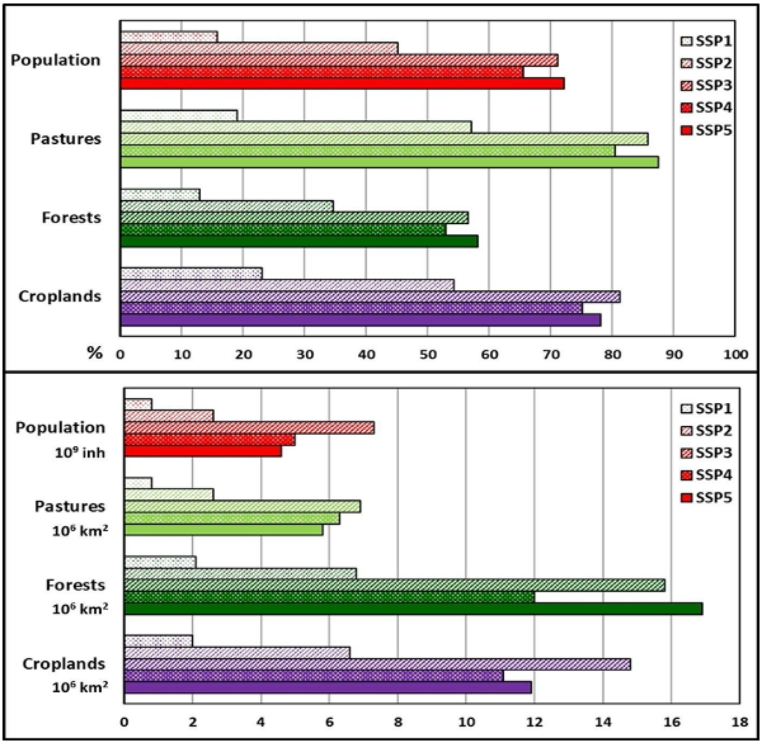
Combining the drought hazard projections discussed above with population (Jones and O'Neill, 2020) and land-use projections under five SSPs (Hurtt et al., 2018), Spinoni et al. (forthcoming) found population exposure to meteorological droughts is expected to increase towards the end of the century. This finding is also valid for pastures, forests and croplands (Figure 1.12). However, drought exposure of population and land use is limited with SSP1 (green growth), medium with SSP2 (middle of the road), and large with SSP3 (regional rivalry), SSP4 (deepening inequality) and SSP5 (fossil-fuelled development).

Globally, using temperature and precipitation as drought drivers, Spinoni et al. (forthcoming) report that by the end of this century, more than 2 billion people are projected to be exposed to increased drought frequency and severity with any SSP except SSP1.

At a global scale, more than 60% of forests, croplands and pastures will be exposed to higher drought frequency and severity with less-sustainable SSPs (SSP3, SSP4 and SSP5). As the feedbacks induced by global warming and drought stress are known to affect population (Miyan, 2015), increase forest mortality (Allen et al., 2010) and have devastating impacts on agriculture (Parry et al., 2005; Leng and Hall, 2019), there is urgent need for national (Wilhite et al., 2014) and transnational actions (UNDRR, 2019) to cope with drought, implying strong efforts are required immediately to limit global warming to below 2°C (Lehner et al., 2017).

Future vulnerability is much more difficult to predict and model due to its multidimensional, dynamic and complex nature. SSPs have been used to develop future scenarios of population by age, sex and level of education (KC and Lutz, 2017), urbanization (Jiang and O'Neill, 2017) and GDP (Cuaresma, 2017; Dellink et al., 2017; Leimbach et al., 2017) at the global scale (Riahi et al., 2017), and to project drivers of social vulnerability using extended SSPs at regional level (e.g. Rohat, 2018). However, few studies have developed future vulnerability scenarios to simulate future drought risk (Fraser et al., 2013; Ahmadalipour et al., 2019). This absence is also in line with findings from two reviews of existing climate (Jurgilevich et al., 2017) and drought vulnerability and risk (Hagenlocher et al., 2019) assessments.

**Figure 1.12. Percentage of areas (above) and total population and extent of land-use classes (below) subject to an increase in meteorological drought frequency and severity from 1981 to 2100 to the highest warming level allowed by five SSPs (1.5°C with SSP1, 2°C with SSP2, 3°C with SSP4, and 4°C with SSP3 and SSP5)**



Fraser et al. (2013) used a global hydrological model to simulate future soil moisture and integrate agricultural, meteorological and socioeconomic data to develop models of adaptive capacity for 2050 and 2080 for wheat and maize. Their study identified five wheat-growing regions (south-eastern United States of America, parts of central Asia, the north-eastern Mediterranean and south-eastern South America) and three maize-growing regions (parts of southern Africa, north-eastern Mediterranean and south-eastern South America) likely to be exposed to worse droughts compared to present-day conditions and having a reduced capacity to adapt. Using an ensemble of 10 regional climate models and a multi-scalar drought index, Ahmadalipour et al. (2019) assessed drought risk scenarios in Africa at the national scale using SPEI for two RCPs (RCP4.5 and RCP8.5), three population scenarios and three vulnerability scenarios for three periods until 2100 (2010–2040, 2040–2070 and 2070–2100). Their analysis shows drought risk is expected to increase across Africa at varied rates for different models and scenarios, with the highest risk in central African countries.

The above assessment reveals two challenges warranting further action and research:

- Existing scenarios tend to focus on longer timescales (e.g. end of century) and show stronger signals when projecting long-term changes rather than expected changes in the short to middle terms. While such long-term scenarios are relevant to demonstrate long-term pathways, they do not coincide with most policy and planning mechanisms of relevant stakeholders, which require robust short-term to midterm scenarios (e.g. projected changes and scenarios until 2030).
- Future scenarios of drought risk need to consider the effects of adaptive or non-adaptive human behaviour and potential adaptation measures on future exposure and system vulnerabilities (Palmer and Smith, 2014; Wens et al., 2019).

# 1.5

# Drought risk reduction and risk management

**KEY MESSAGES**

- The governance and management of droughts must shift from prevailing reactive crisis management to prospective and proactive drought risk management.
- Policy and planning mechanisms demand robust short-term to midterm scenarios (i.e. 20–30 years), rather than for longer timescales (e.g. end of century).
- Risk reduction requires prospective and proactive drought risk management, including drought monitoring, forecasting, early warning and measures to reduce vulnerability, coupled with adaptation to a changing climate and actions to increase societal and environmental resilience.
- Climate change demands urgent adaptation action to reduce water demand, for example, by more-efficient irrigation methods, cultivating drought-resistant varieties and adequate water pricing.
- Public awareness-raising and development of water-saving practices and policies to promote and enforce sustainable land and water management are needed for successfully introducing required changes.

The governance and management of drought has traditionally been dominated by a reactive crisis management approach (i.e. trying to mitigate the impacts of ongoing droughts). Instead, prospective and proactive drought risk governance and management that aim to prevent or reduce future and existing risks, and to increase resilience to the changing nature of drought, are urgently required.

Nations have defined prospective disaster risk management as distinct from corrective and compensatory (or residual) risk management; it includes activities that address and seek to avoid the development of new or increased risks (United Nations, General Assembly, 2016). Prospective disaster risk management addresses risks that may develop in future if risk reduction policies are not put in place (United Nations, General Assembly, 2016), rather than existent risks that can be managed and reduced now. Activities can include structural or non-structural measures (e.g. better land-use planning) that are established by inter alia a community, local government, national agency to promote sustainable development by avoiding or minimizing the generation of new risks.

The foregoing discussions have demonstrated the complexity of the nature of drought hazard and the multitude of factors that determine the vulnerabilities and risks associated with drought for society and the environment. Policy and management actions commensurate to the scale of the threat are required, to significantly reduce these debilitating risks. These actions should ideally be based on a deep knowledge and understanding of the key drivers, spatial patterns and dynamics of drought hazard, exposure and vulnerability.

## 1.5.1

### Drought risk reduction policies

Drought policies and frameworks promote drought risk avoidance and reduction by developing better awareness and understanding of the drought hazard and the underlying causes of societal and ecosystem vulnerability, and by setting the framework for prospective and proactive planning and action.

Effective drought risk management relies on enabling national (and where relevant regional or global) drought (risk reduction) policies and frameworks to establish clear principles and guidelines to manage drought. As an example, under the 2016 Windhoek Declaration for Enhancing Resilience to Drought in Africa, countries at the African Drought Conference 2016 committed to a drought-resilient and prepared Africa, based on six principles:

1. Drought policy and governance for drought risk management
2. Drought monitoring and early warning
3. Drought vulnerability and impact assessment
4. Drought mitigation, preparedness and response
5. Knowledge management and drought awareness
6. Reducing underlying factors of drought risk[4]

To move from a reactive to a prospective and proactive approach, local or regional environmental conditions must be considered, including legislative and administrative frameworks. An effective drought management plan should provide a dynamic framework for an ongoing set of actions to prepare for and effectively respond to drought, including: periodic reviews of achievements and priorities; readjustment of goals, means and resources; and strengthening institutional arrangements, planning and policymaking mechanisms for drought mitigation (e.g. EC, 2007; Poljanšek et al., 2019).

At the 2013 High-level Meeting on National Drought Policy (HMNDP), the final declaration encouraged governments to develop and implement national drought management policies guided by the following principles (UNCCD, FAO and WMO, 2013):

- Develop proactive drought impact mitigation, preventative and planning measures, risk management, fostering of science, appropriate technology and innovation, public outreach and resource management as key elements of effective national drought policy
- Promote greater collaboration to enhance the quality of local/national/regional/global observation networks and delivery systems
- Improve public awareness of drought risk and preparedness for drought
- Consider, where possible within the legal framework of each country, economic instruments and financial strategies, including risk reduction, risk sharing and risk transfer tools in drought management plans
- Establish emergency relief plans based on sound management of natural resources and self-help at appropriate governance levels
- Link drought management plans to local/national development policies

HMNDP policy guidance further recommended the following essential elements of a national drought policy (UNCCD, FAO and WMO, 2013):

- Promote standard approaches to vulnerability and impact assessment
- Implement effective drought monitoring, early warning and information systems
- Enhance preparedness and mitigation actions
- Implement emergency response and relief measures that reinforce national drought management policy goals

Introduced in 2014, the National Drought Management Policy Guidelines of the Integrated Drought Management Programme (IDMP) have provided countries with a template of 10 guiding steps for developing drought policies and management plans (WMO and GWP, 2014; Figure 1.13).

Over time, and as a follow-up of HMNDP, IDMP and its many partners have refined the above concepts into an Integrated Drought Management Framework with three pillars that can lead to proactive national drought management policies and plans (WMO and GWP, forthcoming).

4 Principles 2, 3 and 4 correspond to the three critical pillars of integrated drought risk management as described in section 1.5.2. Principles 1, 5 and 6 are cross-cutting principles.

**Figure 1.13.** **Ten steps of the drought policy and preparedness process**


*Sources*: WMO and GWP (2014); IDMP (https://www.droughtmanagement.info/drought-policies-and-plans/)

While such guidelines and frameworks provide countries with useful guidance in seeking to address drought risk more effectively, their use and application should always be determined by the context in which they are employed. Chapter 3 discusses the problems of rigidly following such methods without full consideration of new learning opportunities provided by adaptive governance and also the unique nature of each drought event.

## 1.5.2

### Drought risk management – from policies to plans to action

Drought risk management that includes long-term adaptation to a changing climate and considers possible interdependencies and compound risks is essential if societies are to be better prepared to cope with drought and avoid major impacts.

While it is impossible to prevent the occurrence of droughts or eliminate residual risk (reduce risk to zero), the resulting impacts may be mitigated to a certain degree through appropriate surveillance and management strategies such as water supply increase, demand reduction and drought impact minimization. These are measures that should be agreed and laid down in a drought management plan by reducing vulnerability and being prepared to manage residual risk.

Most countries currently employ reactive crisis management in response to droughts. This entails measures and actions initiated after a drought event has started and been detected. However, there is little time to evaluate best options once a drought has started. With stakeholder participation often limited, such emergency actions often result in inefficient solutions. Crisis management places little or no attention on addressing drought risk drivers or impacts caused by future drought events.

The IDMP approach offers a common way of structuring an integrated approach to drought management (Pischke and Stefanski, 2018), and includes appropriate measures being designed in advance, including related planning tools and stakeholder participation. It is based on short-term and long-term measures and includes monitoring systems for a timely warning of drought conditions, identification of the most vulnerable part of society, and tailored measures to mitigate drought risk and improve preparedness.

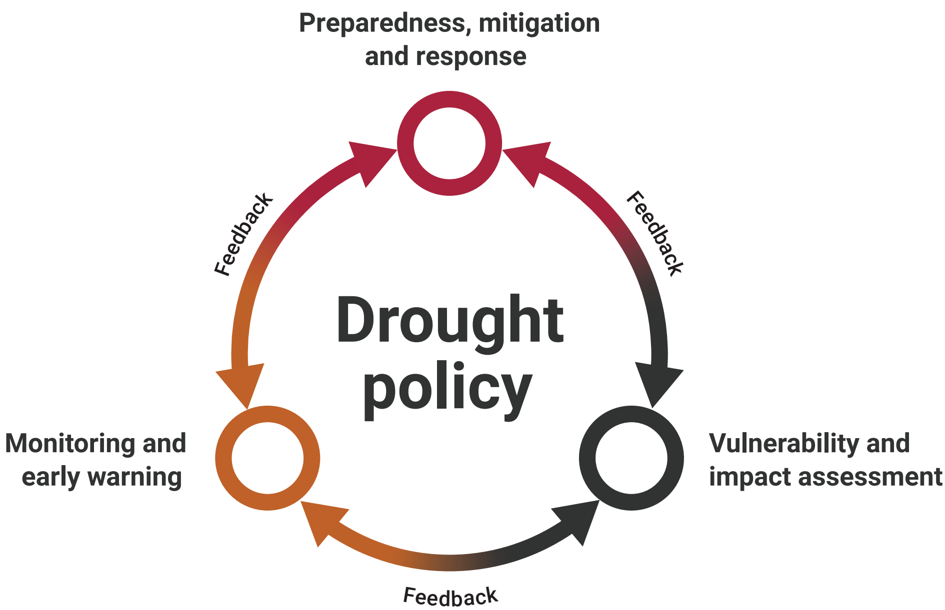
The IDMP approach comprises three pillars of integrated drought management (Figure 1.14):

1. Drought monitoring and early warning systems;
2. Drought vulnerability and impact assessment;
3. Drought preparedness, mitigation and response.

A drought monitoring and early warning system (Pillar 1; see also Box 1.7) is the foundation of proactive drought policies. As they are more than scientific and technical instruments for monitoring and forecasting hazards and issuing alerts, if used effectively, early warning systems can be the basis for reducing vulnerability and improving mitigation and response capacities of people and systems at risk.

Improved early warning systems[5] support a prospective and proactive social process whereby networks of organizations conduct collaborative analyses and develop indicators that can help to identify when and where policy interventions are most needed, specific to geographic and stakeholder requirements (Pulwarty and Verdin, 2013). As such, early warning systems facilitate formal and informal decision-making in a way that empowers vulnerable sectors and social groups to assess and mitigate potential loss and damage (Pulwarty

**Figure 1.14.** **Three pillars of integrated drought management**




*Source*: Adapted from Pischke and Stefanski (2018)

5 For example, the European Commission's drought observatories (European Drought Observatory and GDO), IDMP, the National Integrated Drought Information System, FEWS NET and the UNCCD Drought Initiative.

and Sivakumar, 2014; Seager et al., 2015). Historical and institutional analyses performed in this context help to identify the processes and entry points needed to reduce vulnerability.

Early warning systems must communicate reliable information in a timely manner to water and land managers, policymakers and the public through appropriate communication channels to implement the drought management plan. They can provide scientifically credible, authoritative and accessible knowledge that integrates information about and coming from areas at risk. The governance context in which early warning systems are embedded is critical, in particular with respect to communication and acceptance of the information generated – especially to the end user (Pulwarty and Sivakumar, 2014). A mixture of centralized and decentralized activities, including different communication channels, is required.

Vulnerability and impact assessment (Pillar 2; see also sections 1.3 and 1.4) aims to determine the historical, current and likely future impacts associated with drought. In this context, drought vulnerability and impact assessment aims to improve the understanding of the natural and human processes and drivers associated with drought and its impacts, as well as the interlinkages and feedback loops among processes, drivers and impacts. The outcome of such assessment is a depiction of who and what is at risk and why.

The work related to drought preparedness, mitigation and response (Pillar 3; see also Chapter 3) determines appropriate mitigation and response actions aimed at risk reduction and building resilience, identification of appropriate triggers to phase in and phase out mitigation actions during drought onset and termination, and to identify appropriate institutions to develop and implement mitigation actions.

Prospective risk management goes further than the proactive approaches described above by seeking to prevent the development of new or increased risks before they are realized. If DRR policies are not put in place, prospective risk management activities focus on addressing disaster risks that may develop in the future (United Nations, General Assembly, 2016). Among other goals, such activities promote adaptation planning as part of increasing the resilience of socioecological systems. An example is the development and implementation of improved land-use planning with a focus on long-term sustainability.

Prospective and proactive drought risk management is dependent on active involvement and support from all stakeholders – including national and local governments, appropriate sectoral representatives, citizens and private sector actors. Combining local knowledge and practices with modern approaches promotes mutual trust, acceptability, common understanding, and community sense of ownership and self-confidence (e.g. Giordano et al., 2014; Masinde, 2015).

An integrated approach to drought management that looks at the costs of inaction and the benefits of action and identifies the political window of opportunity is advocated (WMO and GWP, 2017). Examining costs and benefits can also provide an entry point for including financial services, including the (re-)insurance industry, more broadly in integrated drought management. The World Bank and WMO and GWP (as part of IDMP) have jointly developed guidance on this process by proposing a framework to perform economic analyses (Venton et al., 2019).

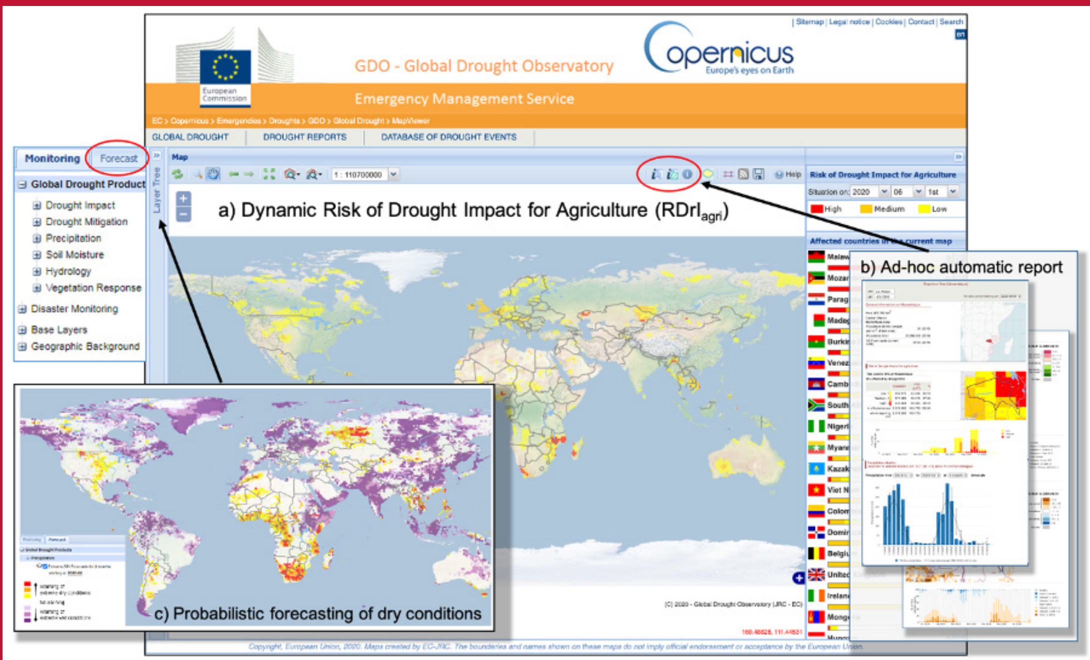
Chapter 3 discusses these aspects of prospective and proactive risk management in more detail within the development and implementation of appropriate governance arrangements, policies and drought risk management frameworks (as briefly introduced above).

## Box 1.7. Monitoring and forecasting drought hazard and risk

Adequate early warning (forecasting) and continuous monitoring during a drought event are central pillars of effective drought risk management (Pischke and Stefanski, 2018). Combined with information on exposure and vulnerability, they assess the evolution of drought risk and possible impacts on different sectors (WMO, 2006; Bailey, 2013; Wood et al., 2015).

Drought early warning systems (DEWSs) have been implemented over a number of decades, across spatial scales ranging from the local level to the global level, and addressing the variety of users and their needs. DEWSs comprise many components (Figure 1.15) and require cooperation from National Meteorological and Hydrological Services and key users such as water managers and decision makers at different levels. Ideally, all the components are included in the design and implementation of such systems. Near-real-time, historical and forecast data should be at the top of the system.

**Figure 1.15. Main components of GDO**




The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined.

*Note*: The main panel shows an example of the global map of the risk of drought impact for agriculture (RDrIagri). The bottom-left panel shows the forecast of subseasonal dry conditions and the bottom-right panel an example of the automatic reporting tool.

*Source*: GDO (European Commission, JRC)

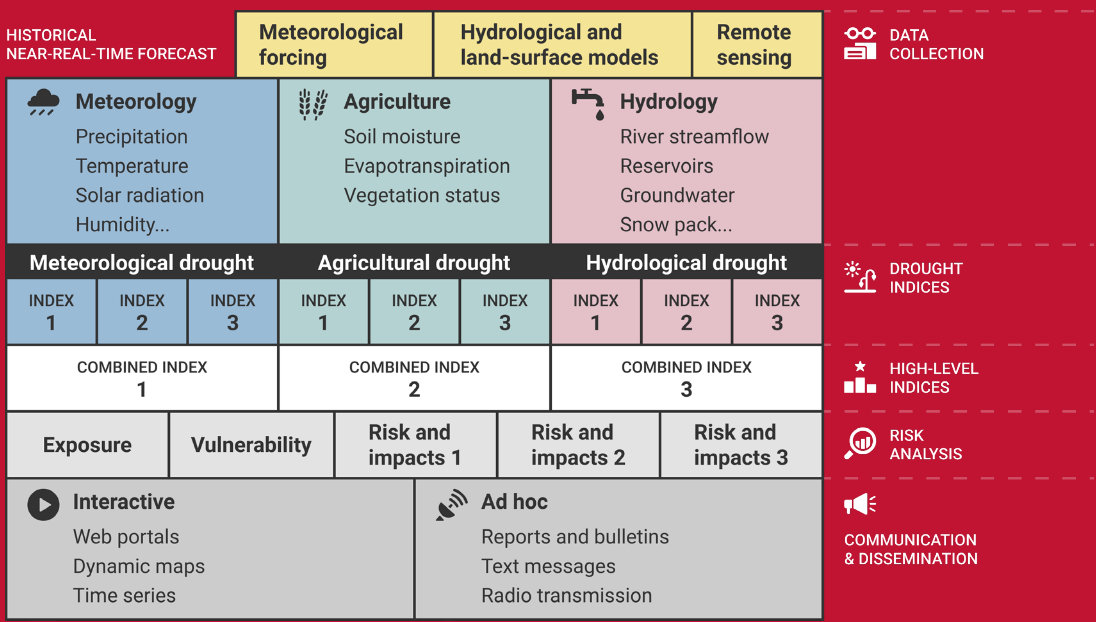
Drought indicators range from single indices, relevant to water and land managers at local scales, to high-level combined indicators, targeted to raise awareness with policymakers and high-end decision makers or the general public.

DEWSs support water management and water-saving strategies, trigger immediate and long-term mitigation actions, and support adaptation measures to increase medium- and long-term resilience. Information provided must be easily accessible and understandable, enabling timely actions. Where relevant, the information should be combined with traditional knowledge (e.g. Masinde, 2015).

Web-based portals provide an entry point to DEWSs from which drought bulletins and reports, maps and direct communications to stakeholders are delivered to achieve timely and effective action (Bordi and Sutera, 2007; Akwango et al., 2017). DEWSs routinely use statistical approaches (Kim and Valdés, 2003; Mishra et al., 2007) integrated with downscaled weather models (Fleig et al., 2011; Kingston et al., 2013; Lavaysse et al., 2018) and dynamic precipitation and hydrological forecasts (Dutra et al., 2014; Nobre et al., 2019; Sutanto et al., 2020b).

Recent developments such as GDO include sector-specific vulnerabilities for assessing the risk of drought impacts (e.g. RDrIagri; main panel in Figure 1.16) based on the temporal evolution of the drought hazard, and sector-specific exposure and vulnerability. Continuous improvement of these systems requires close interactions with key users (Pulwarty and Verdin, 2013). Therefore, GDO includes a tool to produce ad hoc automatic reports for decision makers (Figure 1.16, bottom-right secondary panel). Detailed analytical reports are sent to customers during severe events.

**Figure 1.16. Main components of a DEWS as part of proactive integrated drought risk management**




*Source*: Adapted from Vogt et al. (2018)

# 2. Droughts: the lived experience

This chapter provides a link between the presentation of drought and related hazards, exposure and vulnerabilities in Chapter 1 and the options and pathways for avoiding risks and building resilience in Chapter 3. Through the lived experience of coping with and responding to drought, this chapter explores the current understanding of drought, supplemented where necessary with accounts of the wide range of impacts, response and adaptation actions. It looks at the extent to which society understands and manages drought, and its systemic characteristics, causes, impacts and lingering effects, including the efficiency of drought planning, responsive actions, support services and the adaptive learning challenge that this presents. This chapter also analyses the key features of hazard, exposure and vulnerability through the lens of climate change and related drivers. The case studies and the challenges described in this chapter explore the historical, current and prospective policies and practices applied in recent droughts.

The case studies (summarized below) present geographical examples, and are supplemented with a desk review of cases from river basins, agricultural food-basket regions, cities and mountain communities. The case studies highlight successes and challenges for a systems approach to managing drought risks. They are taken from the interaction among people, communities and decision makers, and point to the need for a growing public awareness of climate change and its relationship with drought. While public awareness of climate change has grown, the lack of understanding of drought as a serious and systemic risk creates concerns regarding potential impacts.

The case studies are available in full in the digital edition of this report and can be accessed online at: https://www.undrr.org/publication/gar-special-report-drought-2021

# 2.1

## Case studies of this GAR Special Report on Drought 2021

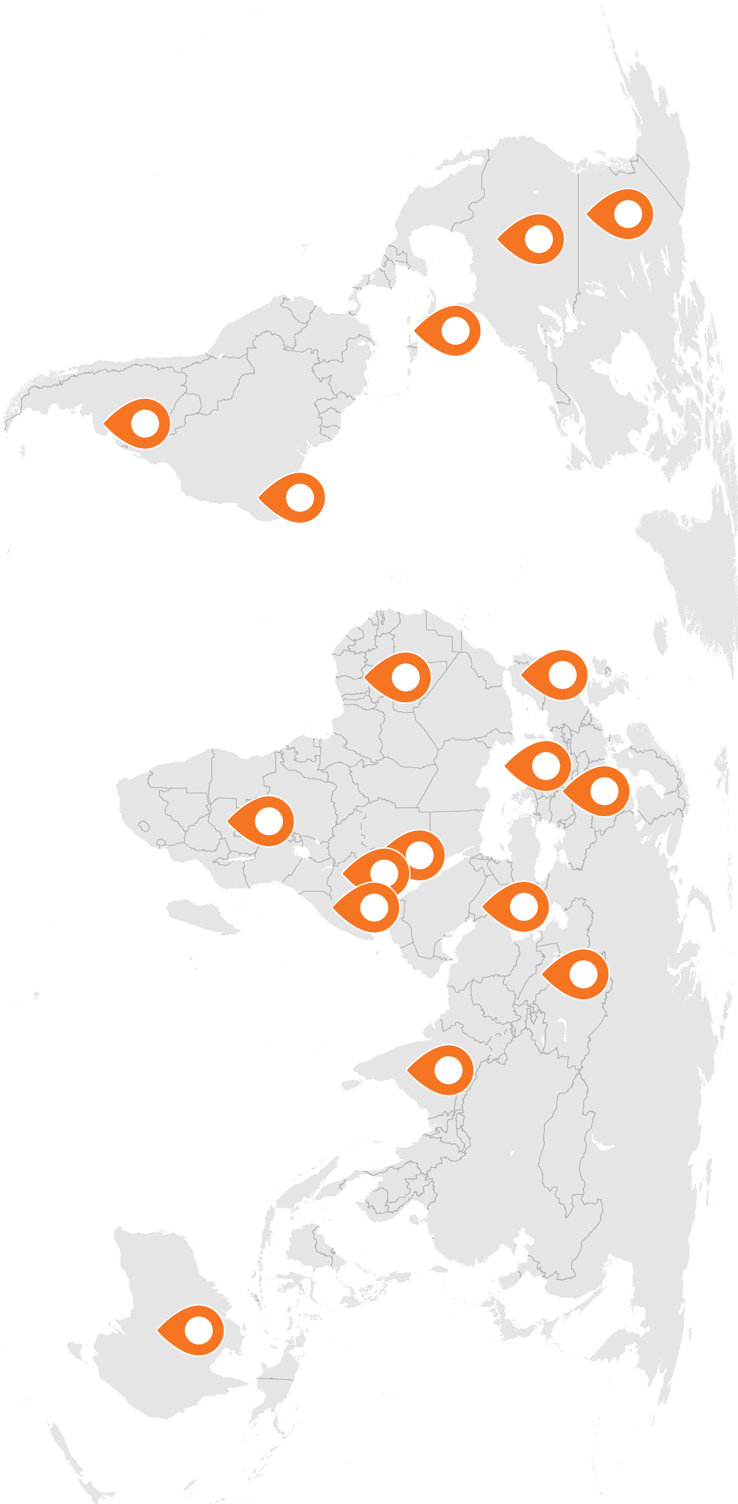
The case studies explored in this chapter show that countries' capacities to respond to drought-related impacts vary. They highlight how limited knowledge on possible impacts, poor assessments of vulnerabilities and costs, little coordination at national and regional levels, and lack of awareness on policy options are key impediments to effective drought management. Figure 2.1 demonstrates the global distribution of the case studies and Table 2.1 summarizes the studies.

**Table 2.1. Summary of case studies**

| Case study | Context | Description |
|---|---|---|
| **Argentina** | Agriculture in the Pampas region of Argentina; relevant to similar landscapes and communities in neighbouring countries | Lessons learned from significant drought events in 2008–2009 and 2017–2018; complexities arising from food production and processing interdependencies; need for more proactive governance |
| **Australia** | General background to Australian droughts and progression in drought risk management | Millennium Drought 1997–2009; multiple and multiplicative impacts across all sectors and ecosystems; evolution in policy, governance and financial strategies (including risk transfer) |
| **Brazil** | North-eastern Brazil in the context of drought in the wider region | Compares governance and experience in the region with wider initiatives and potential solutions; institutional capacity issues; identifies required improvements in governance and preparedness |
| **Canada** | Flash droughts in the Canadian Prairies | Impact on agriculture and landscapes, particularly during the 2017 drought; cascading impacts including wildfires; clarity needed in roles across government and communities |
| **Caribbean** | Countries in the archipelago | Response to the impacts of the 2009–2010 drought and the level of preparedness for the 2014–2016 drought; describes successful risk management approaches credited in part to the effective operation of the Caribbean Drought and Precipitation Monitoring Network; novel collaborations needed in the development and integration of drought risk prevention |
| **Central southern Africa** | Drought risk in Angola, United Republic of Tanzania and Zambia | The 2010–2011 East African drought, a strong La Niña event aggravated by human actions; combined exploration of drought-affected populations in Angola; drought-induced crop yield losses in the United Republic of Tanzania; drought-related hydropower losses in Zambia |
| **Danube River Basin (DRB)** | 19 European countries sharing DRB | Explores and characterizes drought management in DRB; Danube water supply connections, communities, irrigation, hydropower generation and industry, transportation, tourism and fishing; enhanced drought management model – the DriDanube project |

| Case study | Context | Description |
|---|---|---|
| **East Africa** | Principally in Intergovernmental Authority on Development (IGAD) countries | Comprehensive discussion of recent drought experience across countries of the region; drought resilience management often proves insufficient to protect lives; regional cooperation success stories are emerging |
| **Euphrates–Tigris Basin** | Drought impacts and risk throughout the Euphrates–Tigris Basin | Describes impacts and responses in areas shared by six countries exposed and highly vulnerable to drought; complexity grows from impacts on agriculture, through the whole economy and environment to turmoil and conflict; need for better coordination across the Euphrates–Tigris Basin but constrained by geopolitical realities |
| **Horn of Africa** | Drought risk over an area of 5.2 million $km^2$; 230 million people | Drought risk, impacts and increasing vulnerability – emphasis on arid and semi-arid lands (ASALs); drought risk composed of complex and interacting components; need to increase equality in access to drought risk management opportunities |
| **Iberian Peninsula** | Guadiana River Basin that spans Portugal and Spain | Issues of sharing a river basin crucial to urban and rural water supply and irrigated agriculture; experience of implementing the European Union Water Framework Directive and European Union Drought Policy; different mechanisms for implementation and resultant tensions between countries |
| **India** | Deccan Plateau region (about 43% of southern and eastern India) | Impacts and risk governance; substantial variance in the quality of drought monitoring; exacerbation of pre-existing vulnerabilities during droughts |
| **Mediterranean Basin** | Lands typical of the Mediterranean bioclimate | Middle East and North Africa region, which is expected to be more severely affected in future projections; a 10-step drought mitigation approach is recommended, but not yet widely adopted; complexity due to competition for water among agriculture, energy and urban water supplies |
| **Nile Basin** | Blue Nile region | Diversity leads to substantially varying drought impacts; absence of transboundary drought management policies, plans or agreed legislation; need to strengthen institutional mechanisms for collaboration, data collection, monitoring and data sharing |
| **United States of America** | Flash droughts across agricultural areas | A shift in urgency for early warning and preparedness; Subseasonal Experiment, a Climate Test Bed project focused on improving subseasonal prediction |
| **Uzbekistan** | Drought risk management | Natural ecosystems of the country's arid and semi-arid regions; salinization, spread of moving sands, dust-storms and dry winds, exacerbated by lack of water resources; national action plan for drought management to be developed |
| **West Africa** | Recent drought experience in West African countries | Likely impacts from projected increased dryness; drought cascades to migration, conflict, deaths, hunger and malnutrition, and natural resources depletion |

**Figure 2.1.** **Global distribution of the case studies of the GAR Special Report on Drought 2021**



The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.
Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.
Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined.

## 2.1.1

## Case studies

### *Argentina*

This case study focuses on agriculture in the Pampas region of Argentina (Figure 2.2) and is also relevant to similar landscapes and communities in neighbouring countries.

It draws lessons from significant drought events in 2008–2009 and 2017–2018. Droughts in the region are driven by ENSO variations, with additional influences from humidity transport from the Amazon forest, the displacement of the Inter-Tropical Convergence Zone, the position and strength of the south Atlantic anticyclone, and the Antarctic Oscillation. An increase in annual precipitation that started in the 1970s has apparently reduced the frequency of strong droughts. However, recent droughts have been extremely damaging.

The droughts have devastated crops, dried rivers and springs, caused livestock losses, and affected the society and economy of productive communities and regions. Water deficits translated to economic losses of more than $4 billion from the 2008–2009 drought and effects continued into 2011–2012 as substantial reductions in corn yields and declines in soybean production were recorded, with a consequent loss in exports and challenges to processing infrastructure. Extensive forest fires followed with more than 500 persons evacuated, 40,000 ha of forest burned and the death of an unknown number of wildlife.

The case study focuses on the agricultural sector in Argentina and the interactions with processing structures and markets. Therefore, exposure includes dryland cropping, beef and dairy cattle, and the limited irrigation areas. Recent droughts have driven increased use of marginal lands, which are then more prone to drought impacts. Government subsidies supporting exposed sectors are limited, and there is a dominance of farm rental. There appears to be limited government awareness of the level of exposure to drought impacts.

**Figure 2.2. Pampas region of Argentina**


Drought management has therefore been reactive and taken the form of a declaration of agricultural emergency. A fund for prevention and mitigation exists, but it is inadequate (it currently covers 1% of Argentinean agricultural areas). Proactive measures are being developed but are not sufficiently coordinated. A drought information system may emerge from a combination of the Sistema Nacional para la Reducción del Riesgo de Desastres y la Protección Civil (an institutional framework for coordination and planning for a broad spectrum of risks) and the drought information system for southern South America (a regional initiative that operates within the framework of the regional climate centre for southern South America). Improvements in Argentinean drought risk management rely significantly on regional sharing of early warning and drought monitoring information.

A drought monitoring round table is playing a crucial role in coordinating the separate, sometimes overlapping, efforts of governmental and academic institutions involved with drought. However, this information is provided mainly to governmental agencies, and there has not yet been any broad public dissemination. Micro-level actions by individuals, households and firms are perceived as the comprehensive – and possibly, the most effective – set of actions combating drought in the Pampas.

The case study describes the many and varied examples of the complexity that arise in managing drought risk in Argentina, even with the focus limited to agriculture. Argentina is a major global breadbasket. The same ENSO extreme that leads to drought in the Pampas also decreases production in other breadbaskets, producing a correlated risk for global production and world food prices. Argentina has large grain-processing facilities; with drought, their capacity is idle, without imports from other countries, thus adding complexity to the local supply chain.

### Australia

This case study gives a general background to Australian droughts and the progression in drought management, with a particular focus on the Millennium Drought that ran from 1997 to 2009 (Figure 2.3).

Australian droughts are frequent. Many are intense and protracted; differences between events are significant, and the nature of the impacts and the societies and economies affected vary greatly. Drought in Australia is associated with multi-year ocean and weather cycles in the Pacific and Indian Oceans. There is growing evidence that climate change will increase the frequency and severity of droughts. Droughts have direct impacts on agricultural production and profitability, urban and regional water supply, irrigation systems, and the state and dynamics of ecosystems. A range of confounding and cascading connections then produce highly complex impacts. Australian landholders are not, in general, subsidized, and so are subject to market forces that reduce options and flexibility in drought preparedness and management. Large cities have increasingly been exposed to drought; and in recent droughts, small towns have often been at crisis point for water supply. The fragile landscape suffers substantial degradation. After drought, there has been a trend towards damage from wildfire and flooding.

**Figure 2.3. Australia**


The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Australia develops drought policy through a federal system with responsibilities shared among state and national agencies. Policy and scientific support are focused on: understanding and managing the coincident effects of climate change; better measuring and communicating the onset, progress and impact of drought; further development of financial and social support for drought preparedness and response; and broadening the tools available to farmers, irrigators and regional managers to identify and respond to drought impacts and short-term opportunities (including through technology and genetic revolutions).

Cascading impacts include land degradation, challenged social support systems, effects on human physical and mental health, dust-storms that damage supply and receiving areas, water quality decline, and challenges to the public and private sectors in developing and delivering effective responses. Initial plans and actions therefore need to be changed as each drought develops.

There are currently evolving policy, governance, insurance and financial strategies that prepare for drought risk and then respond to the emerging characteristics of each drought in place or in development. Integrated risk management and risk transfer approaches are needed for resilience but are only partly in place.

### *Brazil*

This case study focuses on drought in north-eastern Brazil (Figure 2.4).

Brazil has records of droughts in 1877–1879, 1888–1889, 1898, 1900, 1903, 1915, 1919–1920, 1931–1932, 1942, 1951, 1953, 1958, 1970, 1979–1983, 1987, 1992–1993, 1997–1998, 2002–2003, 2010 and the latest one, 2012–2018. ENSO drives drought in Brazil. The frequency, severity and duration of droughts are likely to change in the future, in combination with traditional, and often unsustainable, economic development plans for the region.

Large rural and urban populations in the region are exposed to drought. There are major impacts on production and yields of summer crops (maize and soybean) and on livestock production. As a result of the 2014-2015 drought, São Paulo had less than 4% of its capacity in the main reservoir, and the city of over 21.7 million inhabitants was less than 20 days away from running out of water. The 2012–2018 drought led to devastating widespread impacts on water storage, agriculture, livestock and industry (CGEE, 2017). In 2016, in the state of Ceará, water supply ceased from 39 of 155 monitored reservoirs.

Most of the measures adopted by the government to deal with the occurrence of drought in the region can be characterized as reactive, with an emphasis on infrastructure overshadowing the importance of preparedness. While economic losses due to the reduction in agricultural and livestock production affect the region as a whole, especially the most vulnerable people, there are other compounded social and environmental impacts that are also substantial. These include

**Figure 2.4. North-eastern Brazil**


an increase in unemployment, a rise in hunger in vulnerable communities, a growth in the number of cases of water-related diseases due to the poor quality of water supplied to the population, migration of the most affected and vulnerable people from rural areas to large urban centres, and the triggering of land degradation (Magalhães, 2017). States have registered several water conflicts. For the most part, these conflicts are local and related to a specific water system or reservoir.

The case study describes inadequate institutional capacity (including a lack of qualified human resources), a myopic view of the problem in the political arena due to short-term perspectives, infrastructure vulnerability and inadequate logistics.

Elements needed to improve the policy and governance environment include:

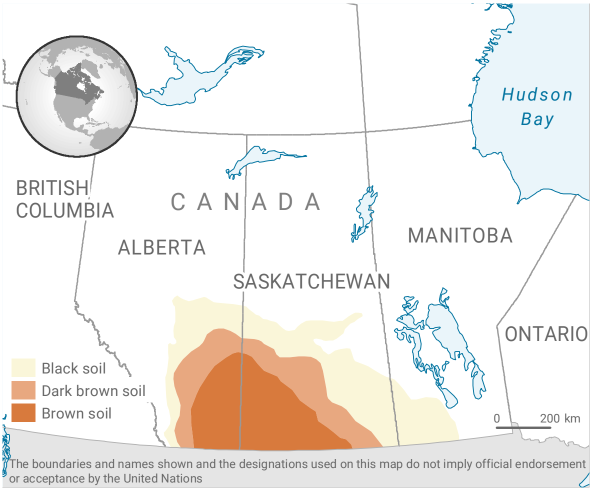
- Improving and developing explicit drought strategies such as drought preparedness policies, national drought management programmes, national action plans and drought mitigation planning
- Building resilience of production systems against shocks
- Developing comprehensive basin-wide agreements, regional basin water policy frameworks and flexible water allocation strategies
- Capacity-building and training, and raising political and public awareness
- Making investments in dams, canals, pumping stations and wells, with structures to manage water supply and demand during drought
- Preparing emergency measures to support those affected by drought

### Canada

This case study focuses on flash droughts in the Canadian Prairies and the impact on agriculture and landscapes, in particular, for the 2017 drought. The 2016–2017 winter season in Canada was abnormally dry throughout much of the southern prairies (Figure 2.5).

The value of farm assets in the prairie provinces was estimated at $280 billion in 2016. Those assets generated gross receipts of $38.3 billion in 2016 and accounted for close to 4% of Canada's total GDP in 2016. Droughts therefore can have devastating economic and social impacts in the prairie provinces. In 2017, crops were affected by poor germination, stunted growth and early maturation. Drought resulted in poor pasture production and unreliable water supplies.

**Figure 2.5. Canadian Prairies**




Federal and provincial governments collaborate on monitoring and developing appropriate responses. Both levels of governments have established or enacted programmes and policies to assist those affected by drought. These actions include water testing for livestock, opening land for livestock grazing and providing assistance for uninsurable losses from wildfires. Agriculture and Agri-Food Canada provides continuous near-real-time monitoring and assessments of weather and climate conditions that affect the agricultural sector. In addition, the Canadian Drought Monitor follows the drought monitor process first established by the United States of America. There is also a livestock tax deferral provision.

Following drought, there have been abnormally high numbers of wildfires on rangeland in Alberta and Saskatchewan. These fires have destroyed homes, ruined agriculture machinery and infrastructure, damaged crops, reduced feed supplies and resulted in significant livestock loss.

There is an identified need for increased investment in drought monitoring, analysis and planning. Drought response plans need to be improved to help guide decisions and triggers during a drought event. The 2017 drought highlighted the need to improve or update drought plans to ensure the various administrations know their roles and avoid causing unnecessary delays in programmes or actions.

### *Caribbean*

This case study focuses on the response to the impacts of the 2009–2010 drought across countries in the Caribbean archipelago (Figure 2.6) and the level of preparedness for the 2014–2016 drought.

The severe 2009–2010 drought event, one of the worst droughts in the region in almost 50 years, was followed by the 2014–2016 drought and another one in 2019–2020. ENSO was identified as the single most-important factor.

The droughts led to reductions in crop yields, losses of livestock, increases in food prices (with resulting riots in Haiti), increases in plant pests and diseases, low reservoir levels and reduced stream-flows resulting in water shortages and rationing, hotel cancellations in Tobago due to water shortages, significant increases in the number of wildfires and areas burned, and significant numbers of landslides on overexposed slopes when the rains returned.

The health sector was also affected, with poor water storage contributing to gastroenteritis in Barbados (Trotman et al., 2018) and *Aedes aegypti* mosquito (the vector responsible for transmission of chikungunya, dengue and Zika viruses) proliferation in Barbados (Lowe et al., 2018) and Dominica (Government of Dominica, 2016).

Energy data provided by St. Vincent Electricity Services Limited illustrates the impact the decline in rainfall during 2014–2016 had on hydropower generation in Saint Vincent and the Grenadines, which produced 11,858,670, 16,757,832 and 15,932,020 kWh in 2014, 2015 and 2016, respectively, compared to the 9 year (2011–2019) average of 20,982,164 kWh per year.

The case study describes successful risk management approaches credited in part to the effective operation of the Caribbean Drought and Precipitation Monitoring Network – a regional operational

**Figure 2.6. Caribbean**


network of National Meteorological and Hydrological Services coordinated by the Caribbean Institute for Meteorology and Hydrology. These are supplemented by a suite of technical drought early warning (monitoring and forecasting) tools and products geared towards multisectoral decision support, using primarily SPI, and more recently SPEI (for monitoring only), and a drought forecast/alerting system that issues threat levels using 6 and 12 month SPI forecasts updated every month.

Strategic drought partnerships have been formed, but only a few Caribbean countries have approved the national multisectoral drought plans/documents.

The complex interplay among traditional hazards like drought and new transboundary threats such as the Covid-19 pandemic can compound an emerging health crisis. Such impacts are observed in the Caribbean case study (and further discussed in section 1.2.5).

The cascading and compounding multisectoral impacts of drought require novel collaborations in the development and integration of drought risk prevention, preparedness and response. Across scales, this collaboration will include local communities, non-governmental organizations (NGOs) and community-based organizations connected to national and regional governance and science platforms, with an aim to facilitate broad public education and risk awareness.

The region now looks to progress beyond meteorological forecasting of the drought hazard alone to extend into forecasting the cascade of potential climate-sensitive outcomes that may occur due to drought. The Caribbean Climate Impacts Database (an open-source geospatial inventory) provides and mainstreams sector-specific impacts-based forecasting information for drought.

### *Central southern Africa: Angola, United Republic of Tanzania and Zambia*

This case study combines exploration of drought-affected populations in Angola, drought-induced crop yield losses in the United Republic of Tanzania and drought-related hydropower losses in Zambia (Figure 2.7). The focus is on the 2010–2011 East African drought – a strong La Niña event aggravated by human actions.

Agricultural sectors in central southern regions of Africa have a large share of the population and are exposed to drought. The region has a high dependence on hydroelectricity (e.g. hydropower constitutes ~85% of Zambia's overall electricity generation). Drought has moved over 1.2 million people into food and livelihood insecurity due to related losses of main crops.

**Figure 2.7. Angola, United Republic of Tanzania and Zambia**


Climate change projections vary across the region, but suggest possible losses of approximately $600 million every 20 years. This is equivalent to almost 10% of the total value, with many families losing their livelihoods. Predictions for hydropower losses increase substantially, to about 25% for drought events with a return period of 10 years or more.

In Angola, on average, 1.9 million people per year are currently affected by droughts, with this projected to rise to 7.9 million people per year. More than 40% of livestock, which is a significant livelihood source and accounts for 31.4% of the agricultural GDP nationwide, is currently exposed to droughts, rising to 70% under projected climate conditions.

Across all three countries, drought management has a focus on climate change policies and building resilience, promoting drought-tolerant food crops and improving water availability in drought-stricken communities. Angola has coordinated the approach with the United Nations Office for Disaster Risk Reduction (UNDRR), aimed at short-term response measures and medium-term prospective risk-reducing measures for nine sectors that are dependent upon external donor investment. Some national stakeholders suggest drought risk transfer mechanisms should be established, utilizing probabilistic risk assessments, and connected to improved disaster risk sensitive investment and funding in agriculture to foster climate-resilient agricultural practices.

Droughts in the region often escalate family abandonment, domestic violence and diseases (e.g. yellow fever), with impacts on food security at the subnational level. Farm labour opportunities decline, and there are connected impacts on food security. Land degradation and deforestation from increased charcoal production are compounding impacts.

### *Danube River Basin*

This case study includes 19 European countries where the River Danube is crucial for water supply for communities, irrigation, hydropower generation, industry, transportation, tourism and fishing (Figure 2.8).

Significant parts of DRB have been affected by drought in recent years – notably in 2003, 2007, 2012, 2015 and 2017. This has affected various water-dependent economic sectors, vegetation and the aquatic environment. Drought frequency is expected to increase and resultant low water levels in the region expected to be more commonplace, especially in summer and particularly in the south-eastern parts of DRB. Drought frequency in the period 2041–2070 is expected to increase by at least one event per decade, especially in the downstream half of DRB. The spatial distribution of drought-affected areas will continue to extend from the south-east to the north-west.

**Figure 2.8. Danube River Basin**


A range of aquatic and associated ecosystems are especially vulnerable to drought, in addition to water-dependent industries and communities. Species with low reproduction rates and limited mobility seem to be the most affected.

The case study characterizes drought management in the basin as essentially crisis management. Such a reactive approach activates institutions only when drought intensity is already alarming. At the political level, drought is still not considered an issue of high priority. Existing legislation and policies, and stakeholder roles and responsibilities, including those of lead institutions, are either unclear or overlapping or both. Co-responsibility without a functional inter-institutional agreement on data exchange, shared responsibility and communication flow negates the combined institutional response. While some good practices and agreements can gradually be negotiated, improved and maintained, relevant policies are mostly non-binding.

Quantitative knowledge of the environmental and socioeconomic impacts of drought is often missing in drought planning and management. Post-drought estimation of damage is usually the primary way to quantify impacts, but it misses many costs.

Examples exist in DRB where inadequate drought policies could be improved by amending existing policies, such as climate change or water management policies, with applicable drought-related components.

Drought impacts in DRB are a result of a complex, often cascading, set of dynamic factors that include snow-melt, drying soils, surface and groundwater reductions, and increased wildfire risk. These result in diverse outcomes including: agricultural decline; less snow negatively affecting winter tourism; poor water quality; soil loss; inflation; market changes; public health issues; waterway freight restrictions; reduced hydropower; and environment water loss.

An enhanced drought management model has been developed in the form of the DriDanube project, which promotes a proactive approach that encompasses monitoring, an impact database and drought management tools. It also promotes cooperation among stakeholders, sectoral experts and decision makers to enhance the capability of society to better cope with droughts in the long term.

### *East Africa*

This case study is a comprehensive discussion of recent drought experience across the countries of the region, principally in IGAD countries and with a focus on ASALs (Figure 2.9).

The region has experienced extreme droughts and increasing risk throughout the twentieth and twenty-first centuries. However, climate projections suggest increased rainfall in the region and fewer dry periods, which is in contrast to recent experience (perhaps a reflection of the spatial and temporal limitations of the models).

Droughts have reduced food security (decreases in food quantity and quality). They have even caused famine, provoked by losses in agricultural and livestock production and in income, and compounded by already low income and lack of income diversification. There are additional impacts on water quantity and quality, and disruption to weak local and national food markets.

While some countries have diverse agroecological conditions, much of the area in the region is ASAL, with consequent high national drought vulnerability. The ASAL areas have large populations of pastoralists practising transhumance and which contribute 6–10% of the GDP of these economies, most of which are low- or low-middle-income countries. Generation of electricity in the region relies heavily on hydropower, which provides 83% of the total electricity generated in Ethiopia, 75% in Uganda, 65% in Sudan and 27% in Kenya, for example (UNEP, 2017).

**Figure 2.9. IGAD member states**


Early warning systems have been adopted in the whole region, but they require more bottom-up linkages with local communities. They need to be connected with constant monitoring of ever-changing vulnerabilities. While drought resilience management exists at various governance layers, it often proves insufficient to protect lives, thereby highlighting the need to better synchronize and harmonize sectoral drought preparedness and emergency interventions.

Drought in the region has deep impacts. When combined with low local coping capacities and state failure, civil war and political interference, the impacts have provoked some of the worst humanitarian disasters of the twenty-first century. There are medium- and long-term cascading impacts, such as loss of scarce assets, stunted human (child) development, conflict and migration. Challenges to hydroelectric generation, and deterioration of sensitive aquatic and terrestrial ecosystems, can have repercussions on development, food security and tourism.

Drought risk management in this region is dependent upon several important components, including regional organizations (e.g. IGAD), large NGOs and international early warning systems (e.g. the Famine Early Warning Systems Network; FEWS NET). There are some regional cooperation success stories, but cooperation is still less than optimal.

### *Euphrates–Tigris Basin*

This case study describes drought impacts and risk through the Euphrates–Tigris Basin (Figure 2.10), and covers land in Iraq, the Islamic Republic of Iran, Jordan, Saudi Arabia, the Syrian Arab Republic and Turkey (approximately 880,000 km$^2$). The climate of the region is arid and semi-arid, and drought is a recurring phenomenon.

Droughts in recent decades have been more severe in length and intensity, and IPCC projections suggest increasing severity superimposed on a drying trend and higher temperatures. Damaging droughts occurred in 1998–2001 and 2006–2010 across the Islamic Republic of Iran and the Syrian Arab Republic.

**Figure 2.10. Euphrates–Tigris Basin**


Rain-fed and irrigated cropping and pastoralism are the first sectors exposed to drought across the region. Vulnerability is highest where rain is essential for agriculture, where pressures exist on water resources, where subsistence farming is a dominant land use, or where safety nets and other forms of public support are lacking.

The region has seen many examples of cascading impacts from this initial exposure. Recurring social and economic losses have led to loss of rural livelihoods, increased pressures on cities through migration, breakdown in food production and supply chains, and consequent social and political unrest. Drought cycles and stretched human capacity have led to increased land degradation and desertification, soil salinity and reduced soil fertility, with resultant broader ecosystem impacts.

Complexity grows with such a combination of stress and vulnerability. Forced migration due to drought is compounded in the region with other displacement of populations (e.g. from the draining of marshlands in Iraq), resultant pressures on receiving populations and increased demand for limited water and food.

Each country in the area has initiated steps to respond to drought risk. For example: a Higher Committee for Drought in Iraq, designed to work across government agencies; a National Strategy and Action Plan on Drought Preparedness, Management, and Mitigation in the Agricultural Sector in the Islamic Republic of Iran; a national drought strategy in the Syrian Arab Republic, with integrated drought monitoring; and a drought management system in Turkey, integrated across government with plans for drought mitigation, alleviation and improved preparedness. However, the case study concludes that to varying degrees, all Euphrates–Tigris Basin countries have weaknesses in the elements of a systemic response to drought risk. Although there has been a series of bilateral agreements over the shared basin dealing with droughts, political turmoil, conflict and instability have constrained effective whole-of-basin agreements.

The case study also concludes there are numerous opportunities for better policies integrating risk reduction in the region.

### *Horn of Africa*

This case study discusses drought risk and impacts across an area of 5.2 million km$^2$ in the Horn of Africa (Figure 2.11), in which approximately 230 million people live. It has an emphasis on ASAL.

Droughts have occurred intermittently in the area, with large-scale impacts recorded during 1973–1974, 1984–1985 and 2010–2011 events. Drought frequency and intensity are projected to increase (IPCC, 2012; IGAD, 2013).

This is an area with a high level of exposure to drought and increasing vulnerability, notably in ASALs, with less than 600 mm of rainfall annually and high numbers of pastoralists. Many communities' livelihoods depend on rainfall for farming (animal husbandry, crop farming and cash crops). Drought impacts reinforce impacts from other hazards including floods, pests and diseases that reduce agricultural production and increase human-induced land degradation within a context of weak institutional capacity.

**Figure 2.11. Horn of Africa**


Drought affects agricultural areas with loss of livestock and reduction in livestock production, decreased resistance of livestock to diseases and reduced yields or crop failure. Groundwater and surface water has reduced in quantity and quality. Habitat and species stress under high temperatures leads to low biological productivity and degradation of ecosystems, which reduce buffer functions. This leads to loss of important ecosystem services. Tourism declines as wildlife communities reduce, leading to a reduction in an important contributor to national income. Competition for resources and water among communities leads to increased conflict and hostility.

Local adaptation approaches to drought risk are in evidence, for example Kikuyu soil and water conservation measures. In support, individual countries are adopting the 10-step process of drought management. Across the region, IGAD has developed a Drought Resilience and Sustainability Initiative framework, with support from IDMP in the Horn of Africa, itself supported by WMO, GWP and UNCCD. In addition, the Drought Resilience and Sustainable Livelihoods Programme, established in 2012, seeks to strengthen resilience by reducing dependency on rainfall. FEWS NET is providing early warning information and useful analysis on food insecurity.

The complex and interacting components of drought risk are evident in this region. Poverty, inconsistent and malfunctioning markets, and human diseases considerably minimize labour availability for food production during droughts. Pastoralists practice transhumance in ASALs where livestock management is extremely vulnerable to drought, potentially intensifying conflict between farmers and pastoralists. The burden of water collection falls disproportionately on women and girls, who in some cases spend as much as 40% of their calorific intake carrying water.

Drought is exacerbated by deforestation and poor agricultural practices, leading to a significant reduction in water retention and loss of soil cover. Widespread poverty constrains many communities' abilities to address water issues, even when significant opportunities such as irrigation, rainwater harvesting, groundwater exploitation or sanitation infrastructure exist. In some countries, electricity generation relies strongly on hydropower and is a competitor for water during drought.

There is an outstanding need for improved connection between policy and science to better respond to drought realities. The case study highlights the need to increase equality in access to drought risk management opportunities, promoting the possibility of resilience by explicitly empowering women, developing equitable credit schemes and equal access to information.

### *Iberian Peninsula*

This case study focuses on the Guadiana River Basin that spans Portugal and Spain (Figure 2.12); an area with annual average precipitation below 600 mm. The basin is crucial to urban and rural water supply and irrigated agriculture, and is subject to intensifying water use.

The longest drought periods across the basin came in 1981–1984 and 1991–1995, with the driest year in 2005 (Maia and Vicente-Serrano, 2017). The most-severe drought period, in terms of duration and intensity, occurred in the Spanish part of the Guadiana River Basin in the years 1991–1995, when the reduction of precipitation led to significant decreases (over 70%) in the mean annual run-off, with reservoir reserves reducing to nearly 10% of the total capacity.

Droughts have had detrimental impacts on agriculture, water resources and ecosystems in the region (Vicente-Serrano, 2006; López-Moreno et al., 2009; Lorenzo-Lacruz et al., 2010). Due to the prioritization of urban water supply during drought, the region has suffered significant reductions of

**Figure 2.12. Guadiana River Basin**

irrigated agricultural output (e.g. losses of €370 million in 1994–1995). In Portugal, drought has led to urban water supply restrictions, to the search for new sources of water supply (collective hole drilling) and, in some regions, to the continuing supply through water trucking (Vivas, 2011). Drought in the region has caused a degradation of water quality and quantity in rivers, and a deterioration in the conditions required for flora and fauna to flourish. The increased dryness of the vegetation cover has also fostered the occurrence of wildfires (Vivas, 2011; GPP, 2017a, 2017b). Projections suggest that temperature is likely to increase and precipitation decrease.

Both countries are implementing the European Union Water Framework Directive and the European Union Drought Policy. They can access EDII and the European Drought Reference – both housed within the European Drought Centre. EDII allows a search of reported drought impacts and submission of new impact reports for Europe, while the European Drought Reference summarizes historical droughts for Europe and provides a tool to visualize SPI data for any date within the period 1958–2009.

Improved transboundary cooperation in drought planning and management has resulted in the development of a sound drought and water scarcity indicator system, and a range of related measures. Drought management measures have contributed to reduced vulnerability and impacts in agriculture and livestock sectors, and improved water management during critical drought periods (Maia and Vicente-Serrano, 2017).

International drought management is challenged in ways common to transboundary risk management (most of the population bordering the Mediterranean lives in transboundary river basins). Portugal depends on the quantity and quality of water flowing from Spain, but the water policies and related institutions of each country have been developed independently.

Despite agreements and improvements, the different mechanisms for implementation can lead to tensions in implementation between the two countries. The case study notes the absence of a common or coordinated framework for drought risk management between Portugal and Spain.

### *India*

This case study focuses on the Deccan Plateau region of India (about 43% of southern and eastern India; Figure 2.13).

Major droughts have occurred across the region and over large areas of India in 1876–1878, 1899–1900, 1918–1919, 1965–1967, 2000–2003 and 2015–2018. Significant drought conditions occur once in 3 years (Mishra and Singh, 2010). The Deccan region sees the highest frequency (>6%) of severe droughts (SPI of −1.5 to −1.99) in all of India.

Rain-fed agriculture in a low rainfall area is the dominant source of food production, and droughts are ingrained into society and the economy. In 2019, villages in the heart of the Deccan Plateau in Maharashtra and Karnataka were deserted as families left due to the acute water crisis. The village of Hatkarwadi, in the Beed district of Maharashtra state, was effectively abandoned, with only 10–15

**Figure 2.13. Deccan Plateau region of India**


The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

families remaining out of a population of more than 2,000 (Relph, 2019). Subsistence farmers are often affected first and often most severely, even in seemingly mild droughts.

The impact of severe droughts on India's GDP is estimated to be about 2–5% per annum, despite substantial decreases in the contribution of agriculture to GDP over the period 1951–2003 (Gadgil and Gadgil, 2006). Furthermore, the socioecological damage can also be significant, as was the case in the 2002 drought, which caused large-scale ecological damage, mass migration and death (UNDP, 2002).

Drought-related decisions and policies are made at national and state levels. The Government of India is the main authority at national level to: collate information to monitor drought conditions; issue advisories; and coordinate with other ministries of the central government, state governments and relevant agencies to respond and mitigate drought impacts. "Drought declaration" is the most important step in governmental response to a drought situation and arises from information in the national agricultural drought assessment and monitoring system.

The case study notes substantial variance in the quality of drought monitoring and the methodology and parameters adopted in the declaration of drought among states. Monitoring, early warning and technical improvements to drought management systems – ongoing and planned – need to focus on "practical" tools that can be embedded and sustained in operational systems that capture dynamic vulnerability and strengthen existing systems. In terms of drought preparedness in agriculture, crisis management plans and drought contingency plans are prepared each season, which, to varying extents, connect with coping strategies at farm level (e.g. choice of crop variety).

Cascading impacts of drought continue to evolve as Indian society transforms. For example, in recent major droughts in Tamil Nadu state, a 20% reduction in the primary sector caused an overall 5% drop in industry and a 3% reduction in the service sector (UNDP, 2013). The water demands of rapid urbanization and industrialization in recent years have seen groundwater systems dry up without appropriate aquifer replenishment. Overdependence on groundwater resources and lack of water-retaining structures have significantly increased vulnerability in Indian cities during severe drought events. Under pressure of drought, farmers feel the need to raise and harvest one crop. This leads to repeat plantings and cost spirals.

Pre-existing vulnerabilities are exacerbated during droughts. People manage drought as an integral part of risk, as observed in subsistence agriculture where water conservation and efficiency measures combined with drought-resistant seeds are central to rural livelihoods and food security in many countries. However, institutions treat drought as discrete, episodic and outlier events, choosing to respond only when drought emergencies arise. This leads to perpetuation and aggravation of drought vulnerabilities, agrarian crisis and natural resources degradation.

### *Mediterranean Basin*

The case study includes the lands typical of the Mediterranean bioclimate. It places a particular focus on the Middle East and North Africa region (Figure 2.14), for which projections expect droughts to be increasingly severe.

**Figure 2.14. Mediterranean Basin**


The region has a long and varied history of drought, with notable events including the Syrian Arab Republic's drought in 2007–2010 and a 15 year drought in the Levant from 1998 to 2012. Recent droughts have been centred in Greece, the Levant and the western Mediterranean. IPCC projects increased risk of desertification and soil degradation, sea-level rise, an increase in the duration and intensity of droughts, changes in species composition, habitat losses, and agricultural and forests production losses. These will result in an increased risk of coastal erosion, infrastructure damage, and threatened water and food security. The Middle East and North Africa region already has one of the lowest water availabilities per capita worldwide.

Across such a large area, there are diverse ranges of exposure and vulnerability to drought. For example, in North African countries, there is high population pressure on land and water resources, urban sprawl, overexploitation of forests and overgrazing.

Droughts can be recurrent across Algeria, southern France, Greece, northern Italy, Spain and Turkey, with impacts that include crop yield and livestock losses, irrigation shortfalls, wildfires, reduced hydroelectricity, unstable house foundations due to shrinkage and swelling of clay soils, and drinking water shortages (requiring water imports in some cases). In Spain, the 1991–1995 megadrought caused a significant reduction in agricultural output in 1994–1995, with losses of €370 million, as irrigation water was diverted to urban use. The 2005–2009 drought reduced agricultural output because of restrictions placed on water extraction from overexploited aquifers and reservoirs, and reduced hydroelectric energy output. In Portugal, economic growth in 1994–1995 was negative or null for 6 months.

At the European Union level, the Water Framework Directive is available, but the development of drought management plans by member states is not compulsory. A range of other frameworks either directly address drought or are inclusive of drought issues, for example the Mediterranean Drought Preparedness and Mitigation Planning. Implementation of strategies for IWRM in water-deficient regions is needed. The 10-step drought mitigation approach is recommended, but not yet widely adopted.

The situation in the region is made more complex due to competition for water among agriculture, energy and urban water supplies, with prioritization granted to urban water supply. Compounding impacts include the degradation of water quality and quantity in rivers, reduction of flora and fauna, and more wildfires due to the increased dryness of the vegetation cover. Food cooperation during drought events is emerging as a key issue among the southern and eastern Mediterranean countries.

### *Nile Basin*

This case study concentrates on the Blue Nile (Figure 2.15) – a climatologically diverse region with rapid population growth and historically at risk from climate-induced agricultural shocks.

Heat and drought years have become more common over the past four decades; a projected increased frequency of hot and dry years (by a factor of 1.5–3) will increase the likelihood of multi-year hot and dry spells, during which impacts on agriculture may increase.

The region is experiencing rapid population growth. Many people depend on rain-fed and irrigated crops for livelihoods; 250 million people rely on the Nile for water. Despite the large number engaged in subsistence agriculture and thus vulnerable to drought, the diversity of the region leads to substantially varying drought impacts. These include famine in Ethiopia, reduced hydropower generation, and risks of food shortages and socioeconomic impacts in Egypt and Sudan.

Despite attempts, the three countries sharing the Blue Nile have not yet developed transboundary drought management policies, plans or agreed legislation. However, water demand has increased, and diversions upstream (e.g. the Grand Ethiopian Renaissance Dam) have exacerbated the potential impacts of drought risks for downstream countries. The region has a history of geopolitical instability and migration, conflict and humanitarian disaster.

The case study notes the need for strengthening institutional mechanisms for collaboration, data collection, monitoring and data sharing.

**Figure 2.15. Nile River Basin**

### *United States of America*

This case study has a focus on flash droughts across agricultural areas of the United States of America (Figure 2.16), in part because they have meant a shift in urgency of early warning and preparedness.

The country has experienced costly and extensive droughts in the past, for example the Dust Bowl drought of the 1930s. The Northern Plains have been in an active drought cycle over the past two decades. The short-lived flash drought of 2012 was widespread and costly. Moderate to exceptional drought conditions (D1–D4 according to the United States Drought Monitor) affected over 65% of continental United States of America at its peak. This was followed by a similar event in 2017. The country suffered harvest failure for corn, sorghum and soybean crops, among others, incurring $34.5 billion in losses (NCEI, 2021). The 2017 Northern Plains flash drought resulted in an economic impact of approximately $2.6 billion (NCEI, 2021), and the associated summer heatwave also caused 123 direct deaths. The case study does not exhaustively follow through cascading impacts but observes that drought was followed by wildfires that burned just under 2 million ha across the United States of America and neighbouring Canada (Jencso et al., 2019).

**Figure 2.16.** **United States of America**


Early warning is provided by the United States Drought Monitor, which reports impacts through the Drought Impact Reporter – an online, comprehensive database and user interface dedicated to operationally monitoring and archiving impacts of all types of drought. The Drought Impact Reporter is freely available and accessible to the public.

Coordination among local, state, tribal and federal levels has grown, and connects systems such as Condition Monitoring Observer Reports on Drought, U.S. Agricultural Commodities in Drought and several new satellite-based products (e.g. evaporative stress index, evaporative demand drought index, QuickDRI and next-generation soil moisture models of the North American Land Data Assimilation System). The early warning system will benefit from recent increased investment for better forecasting and monitoring of flash droughts and the Subseasonal Experiment – a Climate Test Bed project focused on improving subseasonal prediction.

## *Uzbekistan*

This case study describes drought in Uzbekistan (Figure 2.17). It focuses on the natural ecosystems of the country's arid and semi-arid regions prone to salinization and threatened by the spread of moving sands, dust-storms and dry winds, and exacerbated by the lack of water resources. The country is united by common sources of water supply – the Amudarya and Syrdarya Rivers.

The most prolonged droughts occurred in 2000–2001, 2014–2015 and 2017–2018, with more than half of the territory of the country being affected by desertification and drought. With drought, reductions of 2–5% in stream-flow in the Syrdarya River Basin and of 10–15% in the Amudarya River Basin were recorded, as well as an increase in the inter-annual variability of flow in the rivers. In extremely warm and dry years, the run-off in the basins of the Syrdarya and Amudarya Rivers may decrease by 25–50%. The expected reduction in river run-off will lead to an acute water deficit, especially in dry years.

**Figure 2.17.** **Uzbekistan**


The Aral Sea was the fourth-largest lake in the world until the 1960s. There are now only two fragments of the sea left – in the north and west, with a remaining water volume of about 10% compared to 1960. The contraction of the Aral Sea is a disaster that concerns all countries of the drainage basin – the Islamic Republic of Iran, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan. It is the result of many years of human activity, including water diversion for agriculture, and is an ecological and socioeconomic problem for communities living along its former banks.

Uzbekistan has experienced increasing occurrence of severe droughts – with more predicted – entailing negative impacts on all types of water bodies, so disrupting their natural functions, as well as the health and well-being of the population and economy. The agriculture sector is especially vulnerable. The 2000–2001 drought was a catalyst for desertification and environmental degradation. Hydrological and socioeconomic effects of drought were felt until the end of 2003, while precipitation and agricultural production returned to normal in most areas in 2002. The buffering from mountain glaciers is also under threat; from 1957 to 2010 the rate of reduction in the area of glaciation varied from 0.1% to 1.65% per year.

Drought suppresses crops, and provokes crop shortages and loss over large areas of the country. In response, extraordinary measures were introduced in 2000–2001, including the banning of the cultivation of water-intensive rice in some areas. Losses of grain crops during the years of severe drought in 2000–2001 accounted for a loss of 14–17%, and for other crops, on average from 45% to 75% in the lower reaches of Amudarya River. Orchards and vineyards are particularly susceptible to reduced yields when water is scarce.

In the cattle breeding sector, drought affects pasture productivity, fodder stocks, grazing conditions and animal health. During the 2000–2001 and 2011 severe droughts, overgrazed pastures around rural settlements and villages were completely deprived of water supply. As a result, the harvesting of forage grasses was reduced by more than half. In some of the affected areas of Karakalpakstan, drought forced farmers to sell a significant portion of their herds or agricultural equipment.

Drought disrupts the aquatic biota of lake systems and wetlands, and reduces the productivity of terrestrial ecosystems. This is visible in lakes and wetlands in the lower reaches of the Amudarya River and the Aral Sea region, which in turn makes the delta *tugai* forests vulnerable.

Rural populations are particularly vulnerable to the lack of water in years of drought. Combined with high temperatures, this leads to the death of plants, a decrease in yield, the drying up of small reservoirs, fish die-off and problems with grazing, with a consequent drop in income. Populations are prone to exacerbation of cardiovascular diseases and acute intestinal diseases.

During the severe drought of 2000–2001, approximately 600,000 people in the most affected regions of Uzbekistan required food, drinking water and assistance in the supply of agricultural resources, at a cost of $19 million (OCHA, 2001). Unemployment of farmers in 2001 was rife, with about 79,000 in Karakalpakstan and 21,000 in Khorezm affected, prompting a marked increase in those migrating beyond the borders of Uzbekistan to seek better living conditions.

In 2015, the Government of Uzbekistan committed to implementation of the 2030 Agenda, and the Paris Agreement prioritizing mitigation and adaptation to climate change, with a special focus on the Aral Sea region, conservation and careful use of water, land and energy resources, as well as biodiversity conservation (SDG13, SDG14 and SDG15). Uzbekistan also adopted a national action plan for implementation of the Sendai Framework. Implementation will shift the emphasis from reactive crisis response to proactive measures building drought preparedness.

A DEWS, developed by Uzhydromet, assesses, monitors, warns, alerts and supports decision-making in the event of low water levels and drought in the basins of the Amudarya and Syrdarya Rivers. It informs the adoption of action plans to mitigate the consequences of drought and supports authorities in adjusting strategies for managing available water resources.

A road map has been developed for 2019–2023 to combat desertification and drought in the country, together with a national action plan that includes a programme of replanting and reforestation. A national action plan for drought management is to be developed in the near future, supported by analysis of drought impacts recorded in the national disaster loss database that is currently under development.

## *West Africa*

This case study focuses on recent drought experience in West African countries (Figure 2.18), and examines projections for increased dryness.

A number of droughts are listed, particularly the 1970s and 1980s Sahelian droughts and the damaging drought of 2003–2004. Drought frequency and intensity is projected to increase, further threatening the dominant agriculture sector.

There are a wide range of drought impacts and associated costs, including wheat yield loss and decline in area planted, more general agricultural production losses, grain quality decline, rising food prices, and increased hunger and malnutrition. Conflicts are prevalent between nomadic herders and sedentary farmers, connected to the massive migration of people (e.g. outmigration reached 40% in some villages of Burkina Faso during the 1973 drought).

Exposure and vulnerability to drought in West Africa arises from chronic food insecurity, inadequate water security, and poor and inadequate infrastructure in all key sectors. When extreme, food shortages can prompt calls for food aid and international assistance.

Policy initiatives on drought are rare and are usually built into agricultural and economic development policies. Several climate-smart solutions, including climate information services, improved soil and water conservation practices, and rainwater harvesting, have been developed for farmers to adapt to and mitigate drought-related risks on natural resources, food, water and livelihoods. Regional and national strategies have been adopted as a response to the UNFCCC call for action, including national communications and a national adaptation programme of action.

The drought risk in the region is pervasive. Drought can lead to multiple stressors such as rising agriculture input prices, increased incidence of pest and diseases or declining infrastructure, which then disrupt agriculture production and weaken livelihoods. Such stress on the agriculture and food system has at times led, through cascading

**Figure 2.18. West Africa**


The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations

connections, to migration, conflict, deaths, hunger, malnutrition and natural resources depletion.

There are prospects for an increased focus on adaptation through a poverty alleviation lens and drought control. The West African drought monitoring centre now provides downscaled seasonal forecast information through mobile phone technology and rural radio broadcasts to farmers in some areas.

# 2.2

## Case study drought impacts

Drought displays widely different effects across the regions and countries of all case studies. Impacts vary across scale: effects are initially felt at the landholder, farmer or livestock manager level, but with time, the impacts are broader across communities, the economy and even beyond borders.

Drought vulnerability is also unequal and follows a similar pattern of severity. For example, across the African case studies, there emerges a hierarchy of vulnerability, in which are found pastoralists, rainfed crop farmers, irrigation farmers and broader parts of the community and economy. The case studies describe crop failure, livestock death, mass migration, hunger and health effects, and impacts on food supply and markets. Conflict and various forms of severe social disruption may also occur in situations with compounding political and ethnic factors. The studies illustrate the disproportionate vulnerability of the poor and marginalized, where the cost of drought is measured in terms of lives, livelihoods, malnutrition and impoverishment.

While those closest to agriculture are affected first, the case studies also detail challenges to urban water supplies. Many large urban centres are affected by water scarcity, while some small towns depend upon the trucking of water, among other emergency measures, to maintain water supply and survive. Related issues of water quality and the need for effective wastewater management and recycling have been identified.

More generally, drought challenges the resilience of water infrastructure. Ageing water infrastructure is common across the developed and the developing worlds. The case studies note some large reservoirs are less effective than expected as drought cycles intensify. Irrigation becomes more important to the survival of agriculture, but in severe drought, the dependence of large food systems can be threatened by a loss of water security (e.g. the Murray–Darling Basin in Australia). Interestingly, some case studies (e.g. Australia, the Mediterranean Basin and southern Africa), note the gradual development of a culture of water efficiency in urban, rural and farming communities as water scarcity worsens.

Most case studies in some way note the importance of natural capital for resilience during drought cycles. Many countries report that vulnerability to land degradation increases with drought and that reduced resilience for future droughts arises from that degradation, and increased use of buffers such as groundwater and forested lands. Cascading impacts include forest loss, soil erosion and degradation, sandstorms and dust-storms (SDSs), floods and wildfires. Some case studies observe there have been investments in reforestation, land fallow and conservation, but the protection of natural capital is missing in most policies. There is a common expectation that implementation of SDGs would reduce vulnerabilities in many countries.

A historical and continuing reliance on hydroelectricity has meant this sector is especially vulnerable to water scarcity and drought. However, this is a protected user in many countries, which limits access for less-valuable users and increases vulnerability within lower-priority sectors.

While the case studies cover significant elements of the global experience with drought (the full case studies are available online), the coverage of exposure, vulnerability and geographies is incomplete. The following sections explore these elements in more detail.

## 2.2.1

### Hydrological cycles

#### *Mountain glaciers and snow-fields*

Mountain glaciers occur on all continents except Australia. The world's glaciers have an estimated total area of about 525,000 km$^2$, excluding the large Greenland and Antarctica ice sheets and the surrounding smaller ice caps (Raup et al., 2007; Kargel et al., 2014). High mountain areas – including all glacier regions in the world except those in Antarctica, Greenland, the Canadian and Russian Arctic, and Svalbard – include ~170,000 glaciers covering an area of ~250,000 km$^2$ (RGI Consortium, 2017).

Over half of the world's population lives in watersheds of major rivers originating in mountains with glaciers and snow, which thus shape cultures, food production, livelihoods and biodiversity.

Glaciers and their role in drought mitigation are under threat from climate change. The rate of ice loss has increased substantially in many regions since the beginning of the 1980s (Kaser et al., 2006; Lemke et al., 2007). The snowpack acts as a natural reservoir by providing water throughout the drier summer months. A reduction in snowpack storage or a shift in the snow-melt release can be a challenge for drought planning.

Examples of severe events include:

- Snowpack loss from the Sierra Nevada mountains from 2013 to 2015
- A series of droughts over the last century in the high mountainous areas of Asia that constitute the most damaging natural hazard in the region, with more than 6 million deaths and an estimated 1.1 billion people affected (National Research Council, 2012)
- Cyclical patterns of drought in the high mountains of Europe, which have a return period of approximately 30 years, thus affecting high mountain populations and causing winter droughts downstream

Populations in mountain regions of the world are familiar with environmental change, and many have developed strategies for dealing with a dynamic context. Considerable adaptive capacities are in evidence, for example, increasing food and water storage to better prepare for floods and droughts (Dekens and Eriksson, 2009). However, accelerating climate change will exceed the adaptive capacities of many. Improved land management and enhanced storage methods, embedded in traditional knowledge, may provide solutions such as (Shrestha, 2009):

- Increased water and irrigation efficiency (Schild and Vaidya, 2009) based on comprehensive water risk assessments to document water availability, deficits in time and space, and availability scenarios relative to climate change and drought predictions
- Water harvesting and watershed management based on traditional knowledge and improved local governance
- Investments in efficient, environmentally friendly small-scale irrigation systems, designed to match water supply to crop demand
- Probabilistic forecasting of soil moisture to inform local managers and decision makers about available options

#### *Transboundary river basins*

Some transboundary issues are discussed in the case studies, but given their ubiquity and the complexity of drought and its impacts, Table 2.2 further explores the drought risk and impacts experienced by countries sharing significant rivers.

**Table 2.2. Examples of drought stress in transboundary river basins**

| | |
|---|---|
| **Amudarya River Basin** | |
| **Countries** | Afghanistan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan |
| **Exposure** | Extensive irrigation networks, diversions and reservoirs |
| **Vulnerabilities** | Precipitation of 200 mm/year; natural water flow is generated mainly by snow- and glacier-melt; in low-water years, the region operates in a water-deficit regime, vulnerable to future potential decrease in water availability; drought alters the relative run-off contributions from snow- and glacier-melt and rain; currently, 78% is from snow-melt and 14–16% from glacier-melt; the glacial area shrunk by 13.1% from 1957 to the 1980s |
| **Hazard trends** | Recurring droughts and floods; severe drought (2000–2001): significant crop losses, shortages of drinking water, flood in 2005 damaged settlements and irrigation infrastructure; climate change could substantially affect the water resources of the Amudarya if precipitation decreases; glacier-melt's contribution to run-off is expected to be reduced by 6% before 2030, and by 15% before 2050–2075 |
| **Source** | Agaltseva (2005) |
| **Danube River Basin** | |
| **Countries** | 19 European countries |
| **Exposure** | Water supply for communities, irrigation, hydropower generation and industry, transportation, tourism and fishing |
| **Vulnerabilities** | Significant parts of DRB have been affected by drought in recent years (e.g. 2003, 2007, 2012, 2015, 2017), thus affecting various water-dependent economic sectors, vegetation and the aquatic environment; drought frequency and low water levels in the region are expected to increase, especially in summer and in the south-eastern parts of DRB; drought frequency in the near future (2041–2070) is expected to increase by at least one event per decade, especially over the downstream half of DRB, where an even more severe drought is expected; the spatial distribution of drought-affected areas will continue to extend from the south-east to north-west |
| **Hazard trends** | Stressed aquatic and associated ecosystems |
| **Source** | DRB case study |
| **Euphrates–Tigris Basin** | |
| **Countries** | Iraq, Syrian Arab Republic and Turkey |
| **Exposure** | Agriculture dependent on surface water and groundwater |
| **Vulnerabilities** | Agriculture on the Syrian Arab Republic side of the Khabur Basin is becoming increasingly uncertain in nearly half of the production area, affecting farmer livelihoods |
| **Hazard trends** | Projected significant declines in stream-flow and discharge in the Euphrates–Tigris Basin in Iraq, and increases in water and basin soil salinity |
| **Source** | Smith et al. (2000); Cullen et al. (2002); Evans (2009); Kitoh et al. (2008); World Bank (2012) |
| **Guadiana River Basin** | |
| **Countries** | Portugal and Spain |
| **Exposure** | Urban and rural water supply; irrigated agriculture |
| **Vulnerabilities** | Dependence of Portugal on quantity and quality of water flowing from Spain; most of the population around the Mediterranean lives in transboundary river basins |
| **Source** | Maia and Vicente-Serrano (2017); Iberian Peninsula case study |

| | |
|---|---|
| **Jordan River Basin** | |
| **Countries** | Israel, Jordan and the Palestinian territories |
| **Exposure** | People, livelihoods and ecosystems |
| **Vulnerabilities** | Palestinian populations rely almost entirely on transboundary water in one of the world's most water-scarce areas; current water-use rules lock in unequal access to shared aquifers, and drought brings in added tensions |
| **Hazard trends** | Due to drought, Israel reduced the quantity of water piped to Jordan by 60% in 1999, triggering the type of dispute likely to recur in the future |
| **Source** | World Bank (2018) |
| **Khabur River Basin** | |
| **Countries** | Syrian Arab Republic and Turkey |
| **Exposure** | Agriculture dependent on surface water and groundwater |
| **Vulnerabilities** | Agriculture in the Khabur River Basin on the Syrian Arab Republic side is becoming uncertain in nearly half of the production area, affecting farmer livelihoods |
| **Hazard trends** | Increased drought and expansion in agriculture investment has exhausted groundwater, causing reduction in river flow and groundwater levels; in the absence of a diversified economy, people are forced to migrate |
| **Source** | Erian et al. (2013) |
| **Lower Mekong Basin** | |
| **Countries** | Cambodia, Lao People's Democratic Republic, Thailand and Viet Nam |
| **Exposure** | Intense land use (rice, aquaculture, vegetables); irrigation in north-eastern Thailand and the Mekong Delta; large rural and urban populations |
| **Vulnerabilities** | Rural economy based on rain-fed agriculture |
| **Hazard trends** | Reduced hazard as average monthly precipitation may increase in most months |
| **Sources** | Shimizu et al. (2006); Adamson and Bird (2010); Thilakarathne and Sridha (2017) |
| **Mexico–United States of America river basins** | |
| **Countries** | Mexico and United States of America |
| **Exposure** | Population growth, rapid industrialization and urbanization |
| **Vulnerabilities** | More intensive patterns of water consumption and use and high demand of water for agriculture; the 1944 treaty on the utilization of waters of the Colorado and Tijuana Rivers and of the Rio Grande does not explicitly address groundwater use, which is increasing with growing urban centres along the Rio Grande (Rio Bravo), where the river becomes the international boundary |
| **Hazard trends** | Increasing drought risks |
| **Source** | Mumme et al. (2018) |

| Nile Basin | |
|---|---|
| **Countries** | Many inhabitants of the region are engaged in subsistence agriculture |
| **Exposure** | Some 250 million people rely on the River Nile for water; population growth; dependence on rain-fed and irrigated crops for livelihoods |
| **Vulnerabilities** | Climatologically diverse, rapid population growth; historically at risk for climate-induced agricultural shocks; history of geopolitical instability and migration, conflict and humanitarian disaster; increasing frequency of hot and dry years (by a factor of 1.5–3) will increase the likelihood of multi-year hot and dry spells, during which impacts on agriculture may increase |
| **Hazard trends** | Climate extremes in the region (sweltering and dry years) are coupled with periodic water and food insecurity; heat and drought years have become more common over the past four decades; in the upper Nile Basin (including western Ethiopia, South Sudan and Uganda), threats to water security and drought triggered conflict potentially to grow; nearly all recent regional crop failures have occurred in hot and dry conditions and under low run-off |
| **Sources** | Lobell et al. (2011); Rowell et al. (2015); Burrows and Kinney (2016); Lesk et al. (2016); Kent et al. (2017); Matiu et al. (2017); Zscheischler et al. (2018); Coffel et al. (2019); Nile Basin case study |
| **Orange-Senqu River Basin** | |
| **Countries** | Botswana, Lesotho, Namibia and South Africa |
| **Exposure** | Crop and livestock water requirements; water availability for urban areas, industrial centres and electricity production |
| **Vulnerabilities** | Small-scale farmers with limited technical and financial resources; subsequent floods could increase soil erosion, causing agricultural land loss and dam siltation |
| **Hazard trends** | The Orange-Senqu system is projected to have less rainfall in most midstream and downstream areas and more in the Lesotho Highlands |
| **Sources** | Knoesen et al. (2009); ORASECOM (2011); Schulze (2015) |
| **Orontes River Basin** | |
| **Countries** | Lebanon, the Syrian Arab Republic and Turkey |
| **Exposure** | Shared water resources |
| **Vulnerabilities** | Intensive use of groundwater by agriculture in the last decade has depleted the aquifers' water storage, lowered the groundwater table and reduced the spring yield |
| **Hazard trends** | Water quality is good in the headwaters but deteriorates in the middle section of the river due to inputs from agricultural, urban and industrial activities |
| **Source** | UNESCO-IHE (2002) |
| **Paraná-La Plata Basin** | |
| **Countries** | Argentina (northern), Plurinational State of Bolivia (south-eastern), Brazil (southern and central), Paraguay and Uruguay |
| **Exposure** | Large rural and urban populations |
| **Vulnerabilities** | Major impacts on production and yields of summer crops (maize and soybean) and on livestock production; crop losses |
| **Hazard trends** | The Paraguay River, the Paraná River and the Uruguay River, extending over 3.1 million km$^2$, have drought and flood conditions closely connected to El Niño and La Niña events; during the La Plata drought of 2008–2009 and the El Niño flooding of 2009–2010, hydrological anomalies were in the southern, central and eastern parts of the basin |

| | |
|---|---|
| **Sources** | Diaz et al. (1998); Codromaz de Rojas (2000); Chen et al. (2010); Abelen et al. (2015); Argentina case study |
| **Senegal River Basin** | |
| **Countries** | Guinea, Mali, Mauritania and Senegal |
| **Exposure** | High population growth, declining economy, unstable food security and numerous mass migration, mainly to Dakar |
| **Vulnerabilities** | People leave the valley with consequent starvation and conflict; the utility of the important Manantali Dam is threatened |
| **Hazard trends** | High frequency of dry climatic periods over a long period of time; Senegal River stream-flow reductions at Bakel from 1904 to 1990 |
| **Sources** | Bass et al. (1996); Rasmussen et al. (1999); UNDP (2006) |
| **Syrdarya Basin** | |
| **Countries** | Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan |
| **Exposure** | Uzbekistan's primary surface water source; large Toktogul reservoir on the Syrdarya River producing hydropower and irrigation water |
| **Vulnerabilities** | Energy production requires water release in winter, leading to a flood peak and less supply for summer irrigation, especially in drought years |
| **Hazard trends** | There is a need for better agreement around country cooperative arrangements |
| **Comments** | Focus has been on creating water-use agreements at the local level and basin management levels at the international level |
| **Sources** | Teasley et al. (2011); Wegerich et al. (2015); Uzbekistan case study |

# 2.2.2

## Ecosystems

### *Ecosystems and biodiversity*

Environmental degradation, deforestation and overexploitation of natural resources all result in increased vulnerability of ecosystems to drought. Drought then places pressure on fragile ecosystems, with increased risk of depletion of soil, vegetation and water resources (IPCC, 2001; Archaux and Wolters, 2006).

Vegetation sensitivity results in rapid land-cover changes and increased vulnerability to land degradation. When the drought ends, vegetation recovery may follow, but such recovery may take longer than a non-drought situation. With growing population pressure, the opportunity for biodiversity loss is high, especially in species-poor ecosystems (Hooper et al., 2005). The case studies document specific threats to aquatic ecosystems, the ecosystems connected to river and stream corridors. There is observed loss of key species and vegetation communities throughout terrestrial and aquatic ecosystems.

There is an associated loss of regulating function. Beyond the range of ecosystem services lost to human communities, the buffering function of key ecosystems is lost. Forests in particular are vulnerable to the direct impact of water depletion and the further threat of wildfire.

Such biological losses may intensify societal vulnerability, especially in regions where economies are highly dependent on natural resources (Chape et al., 2008).

### *Land degradation, desertification and soil loss*

Land degradation is a critical driver of agricultural drought risk. Soil water deficiency can increase land degradation through loss of vegetation cover. Areas experiencing land degradation and drought are more at risk of desertification, which represents an often-irreversible loss of natural capital (WMO, 2005; Erian et al., 2012).

The percentage of the Earth's land area afflicted by serious drought more than doubled from the 1970s to the early 2000s. The world's drylands continue to be vulnerable and threatened by desertification, land degradation and drought. Land degradation is a global phenomenon, with 78% of total degraded land located in terrestrial ecosystems other than drylands (United Nations, General Assembly, 2011).

Land degradation also occurs with an increase in soil salinity in arid and semi-arid regions, for example when the source of irrigation water from groundwater or reused water has a high saline concentration.

An FAO study estimates that drought accounts for over 34% of crop and livestock production loss in least developed countries and lower-middle-income countries, costing the sector $37 billion overall for the period 2008–2018, with corollary increases in poverty and hunger (FAO, 2021a).

SDSs are widespread natural phenomena in many parts of the world. They occur when unchecked, intense or turbulent winds act on exposed loose dry soil surfaces (UNEP, WMO and UNCCD, 2016). A non-linear relationship of increasing dust-storms with aridity in Australia shows drought influences spatial and temporal occurrence (McTainsh et al., 1989).

The areas most affected by SDSs are located in a broad "dust belt" that extends from the west coast of North Africa, over the Middle East, central and south Asia, to China (Prospero et al., 2002). As a result of more-extreme drought conditions in the SDS sources of Afghanistan, the Islamic Republic of Iran and south-eastern Turkey (APDIM ESCAP, forthcoming), SDS risk is expected to increase in south-west Asia, with associated socioeconomic impacts on various sectors such as agriculture, energy, environment, transport and human health.

The African Sahel experienced extended drought conditions from the late 1960s to the early 1970s, and drought conditions have further intensified since. Land was abandoned in many regions, as fields became covered with sand and invasive plants. Out of 3.16 million ha of wheat, 639,720 ha suffered losses of about 10 cm of topsoil, with an estimated reduction in wheat yield of 290,300 tonnes – equivalent to $58 million, based on 2016 wheat prices (Abraham et al., 2016).

### *Wildfire*

Drought combined with hot and dry summers increases the susceptibility of forests and grasslands to wildfire. Many terrestrial ecosystems are fire climax communities, and need regular fires for seed propagation and germination, weed control and forest renewal. However, wildfire that is more intense or which occurs in other ecosystems may result in loss of ecosystem services, economic downturn, and loss of human health and life.

The number of wildfires has grown by a factor of 4 in the United States of America since the mid-1980s, and this increase is expected to continue. The economic impact of wildfires is significant, for example, damage caused by wildfires in the United States of America reached $665 million per year between 2000 and 2009 (Esri, 2016).

Wildfire risk is expected to increase as a result of substantial warming and exceptional weather conditions – more-frequent heatwaves, droughts and dry spells – across much of the Mediterranean (Rossi et al., 2020). Length and severity of fire seasons, as well as the size of the area at risk, are expected to increase, with adverse effects on human health, principally through: direct exposure to flames and radiant heat; exposure to materials or substances dispersed through the air; use of land contaminated by chemical substances after a wildfire or other geologically meditated impacts such as exposure to airborne dust; and water contamination (Finlay et al., 2012).

Australia has frequent fires, which are a significant part of many of its terrestrial ecosystems. Dangerous wildfires are less frequent but can be devastating. In February 2020, fires spread rapidly across large areas of the country and were among the most catastrophic on record. About 10.3 million hectares were burned, destroying more than 3,000 homes, and killing at least 28 people and millions of wild animals. Airborne particulate matter from these fires caused health impacts in regions far from the sites of the blazes.

## 2.2.3

## Societies

### *Socioeconomic impacts*

The socioeconomic impacts of drought have grown in recent years, because of the increasing frequency and severity of droughts, and also because of the complexity of economic impacts and far-reaching social and environmental damage. Notwithstanding the inability to accurately quantify direct impacts, let alone indirect impacts, costs have escalated due to increasing population, ineffective government policies and programmes, environmental degradation and fragmented authority in natural resources management. In addition, the negative impacts of weather-related disasters further erode natural capital, reducing overall wealth and competitiveness. Table 2.3 reviews some of the socioeconomic impacts.

### *Social vulnerability*

Case studies show the nature of vulnerability varies substantially among and within countries. Subsistence farmers and many pastoralists in arid areas are vulnerable to the point where livelihoods, and even their very survival, is threatened by drought.

Gender inequality and discrimination have been shown to increase during periods of drought stress. For example:

- During droughts, the wage gap between men and women has been shown to increase
- Women with children are less able to shift to non-farm, income-generating activities or to move, due to household care responsibilities (UNDP, 2014)
- Fetching water, fuelwood or fodder becomes more challenging and time-consuming, which increases health and mobility risks, and curtails income-generating activities (UNFPA, 2002; Singh et al., 2013; UNDP, 2014)
- There is a negative impact on girls' school attendance (Jones et al., 2010)
- Food and income insecurity creates increased psychosocial stress and health risks within households (Zimmermann, 2011; UNDP, 2014)

### *Human health*

The connection between drought and health is complex. It depends on the exposure to drought impacts and the increased vulnerability of communities to health threats. The same water deficits may produce different outcomes depending on exposure, and differences in vulnerability. The potential impacts of drought on human health are wide and varied; examples include:

- Food, nutrition and public health: Beyond the direct impact of reduced moisture, crop yield can fall due to insect and disease infestation, leading potentially to food shortages and malnutrition. Livestock may also suffer disease and low production.
- Air quality: The dusty, dry conditions and wildfires that often accompany drought can harm health by increasing airborne particulate matter such as pollen, smoke and fluorocarbons. These substances can irritate the bronchial passages and lungs and worsen

Table 2.3. **Review of socioeconomic impacts and related case studies**

| Africa | |
|---|---|
| Given the breadth and diversity of Africa, socioeconomic impacts are discussed in broad groupings below. Nearly 30% of the African continent has experienced drought since 2000, 15% severely (Erian et al., 2014). General impacts include shortages in food production, increased agricultural uncertainty and instability in affected rural communities bringing political stressors, increased migration and possible conflict. | |
| **Central southern Africa** | |
| **Countries** | Angola, United Republic of Tanzania and Zambia |
| **Background and significant impacts** | The 2010–2011 East African drought, attributed to a strong La Niña event and aggravated by human actions, was the worst in 60 years; it provoked food and livelihood insecurity for over 1.2 million people due to drought-related losses of main crops; under current scenarios, a loss may occur every 20 years of approximately $600 million, equivalent to almost 10% of the total value of crop production |
| **Exposure** | The agricultural sectors in central southern regions of Africa account for most of the potentially affected people; there is a high dependence on hydroelectricity as hydropower constitutes ~85% of Zambia's overall electricity generation |
| **Vulnerabilities** | Given the large share of the population depending on agriculture for survival, families may lose their livelihoods during droughts; droughts often escalate family abandonment, domestic violence and diseases such as yellow fever, with potential impacts on food security at the subnational level |
| **Hazard trends** | Climate projections give varying scenarios of crop failure with some systems more vulnerable to increased temperatures and rainfall decrease; as an example, in Angola, on average 1.9 million (current) people per year are affected by droughts, rising to 7.9 million per annum when future climate and socioeconomic projections are factored in; livestock is a significant livelihood source in Angola and accounts for 31.4% of the agricultural GDP nationwide, and yet each year on average almost 50% of livestock is exposed to droughts – rising to 70% under projected climate conditions; predictions for hydropower losses increase substantially, to about 25% for drought events with a return period of 10 years or more |
| **Comments** | Land degradation and deforestation from increased charcoal production are likely confounding impacts |
| **Sources** | OCHA (2015); central southern Africa case study |
| **Horn of Africa** | |
| **Countries** | Djibouti, Eritrea, Ethiopia, Kenya, Somalia, South Sudan, Sudan and Uganda |
| **Background and significant impacts** | Regional agricultural sectors (animal husbandry, crop farming and cash crops) operate in an estimated 8% of the region's territory; severe impacts from different hazards (e.g. droughts, dry spells, floods, pests and diseases) reduce agricultural production and increase human-induced land degradation within a context of weak institutional capacity |
| **Exposure** | Many livelihoods depend on rainfall for farming or grazing (ICPAC and WFP, 2017); Sudan has the highest number of pastoralists in the Horn of Africa region (over 70%), with similarly high numbers in Somalia (70%), Eritrea (33%), Djibouti (20%) and Ethiopia (10–12%); two thirds of Kenya's livestock population are in ASALs; the burden of water collection falls disproportionately on women (72%) and girls (9%), who, in some cases, spend as much as 40% of their calorific intake carrying water |
| **Vulnerabilities** | Poverty, inconsistent and malfunctioning markets, and human diseases considerably minimize labour availability for food production during droughts; pastoralists practice transhumance in ASALs where livestock management is vulnerable to drought; drought is exacerbated by deforestation and poor agricultural practices, leading to a significant reduction in water retention and soil cover loss; widespread poverty constrains many communities' abilities to address water issues even when significant opportunities such as irrigation, rainwater harvesting, groundwater exploitation or sanitation infrastructure exist; in some IGAD countries, electricity generation relies strongly on hydropower |

| | |
|---|---|
| **Hazard trends** | The Horn of Africa experienced mild to moderate droughts throughout the period 1930–2014, with severe to extreme droughts in 1943, 1984, 1991 and 2009 |
| **Sources** | Africa Development Fund (2002); IGAD (2007); World Bank (2015); Horn of Africa case study |
| **West Africa** | |
| **Countries** | Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone and Togo |
| **Background and significant impacts** | The drought of 2003–2004 led to reduction in the wheat yield of 39% due to smaller areas of planting (12%) and lower yields; reservoir water levels were, on average, 25% lower, with many running dry |
| **Exposure** | Rural communities dependent on rainfall or irrigation for cropping |
| **Vulnerabilities** | Production losses, rising food prices, and increased hunger and malnutrition; conflicts are prevalent between nomadic herders and sedentary farmers |
| **Hazard trends** | Increased variation in temperature and precipitation in the subregion; while the coastal and western Sahel areas such as Côte d'Ivoire, Ghana, Guinea and Senegal have shown a 0.2–0.5°C temperature rise per decade, the southern Sahara and northern Sahel areas like southern Mauritania, Mali and the Niger and northern Burkina Faso have shown no significant changes; for precipitation, studies have shown a significant increasing trend of about 0.2–1.0 mm/day per decade in parts of the Sahel (e.g. Burkina Faso, Senegal and certain parts of Chad, Mali, southern Mauritania and the Niger) |
| **Sources** | Theunissen (2004); West Africa case study |
| **Australia** | |
| **Background and significant impacts** | Major multi-year droughts reduce agricultural production and profitability, urban and regional water supply, irrigation systems, and ecosystems' states and dynamics; they also hasten land degradation, stretch social support systems, reduce human physical and mental health, and challenge public and private sector capacities to develop and deliver effective responses |
| **Exposure** | Rain-fed agriculture, irrigation schemes (e.g. the Murray–Darling Basin) and urban water supplies; increased urban and peri-urban populations |
| **Vulnerabilities** | High levels of water extraction from irrigation schemes based on "normal" years; increased temperatures and moisture deficits in rain-fed agriculture; export market and price signals may drive production increases at times of climate vulnerability |
| **Hazard trends** | Increasing severity and frequency of multi-year droughts covering significant areas of the continent; declining annual rainfall in southern and south-western Australia; compounding impacts due to land degradation, wildfire hazard and vulnerability to flooding when droughts end; system changes have included a market in irrigation water so prices increase with scarcity; increasing emphasis on financial strategies |
| **Sources** | Freund et al. (2017); Nguyen et al. (2019); Australia case study |
| **Canada** | |
| **Background and significant impacts** | Droughts are a recurring feature in the Canadian Prairies; the 2016–2017 winter season was abnormally dry throughout much of the southern prairies; at the end of April 2017, the southern prairies continued to be drought free with only a small area classified as abnormally dry; but, by the time soil temperatures had risen enough to begin agricultural seeding, many of the region's soils had dried considerably, leaving producers reliant on insufficient precipitation for germination; precipitation across much of the southern prairies was below 60% of average rainfall, with large regions in southern Saskatchewan below 40% |
| **Exposure** | Agricultural regions throughout the southern prairies, especially in southern Saskatchewan |

| | |
|---|---|
| **Vulnerabilities** | Uneven crop development resulted in crops growing at different stages within the same field, making it hard to time herbicide and fungicide application as well as harvest; warm dry conditions resulted in stunted crops and early maturity in many regions |
| **Hazard trends** | Increased current and future drought risk |
| **Comments** | Despite drought conditions, overall crop production fared better than initial expectations, given the severity and extent of drought across the region |
| **Source** | Canada case study |
| **India** | |
| **Background and significant impacts** | Significant drought conditions occur once in 3 years (Mishra and Singh, 2010); the impact of severe droughts on India's GDP is estimated to be about 2–5% per annum, despite substantial decrease in the contribution of agriculture to GDP over the period 1951–2003 (Gadgil and Gadgil, 2006) |
| **Exposure** | As agriculture-based livelihoods form a considerable proportion of the economy, India is one of the most vulnerable and drought-prone countries |
| **Vulnerabilities** | Changing drought ecosystems of poor farmers and the trend in agricultural development |
| **Hazard trends** | Changing morphology of droughts in the Indian context (large-scale slow-onset low- to high-frequency localized impact); flash droughts in Andhra Pradesh |
| **Comments** | In 2019, villages in Maharashtra and Karnataka's districts in the Deccan Plateau were deserted as families left due to the acute water crisis; specific press reports mentioned the village of Hatkarwadi, in the Beed district of Maharashtra state, which was abandoned with only 10–15 families remaining out of a population of more than 2,000 (Relph, 2019) |
| **Source** | India case study |
| **Mediterranean Basin including the Guadiana River Basin** | |
| **Background and significant impacts** | In Spain, the 1991–1995 megadrought caused a significant reduction in agricultural output in 1994–1995, with losses of €370 million, as irrigation water was diverted to urban use; the 2005–2009 drought reduced agricultural output because of restrictions placed on water extraction from overexploited aquifers and dam reservoirs; reduced hydroelectric energy output; in Portugal, economic growth in 1994–1995 was negative or null for 6 months |
| **Exposure** | Rain-fed and irrigation agriculture, urban water supplies and hydropower dams |
| **Vulnerabilities** | Competition for water between agriculture and urban water supplies (prioritization granted to urban water supply); livestock water demand |
| **Hazard trends** | Increased current and future drought risk |
| **Comments** | Compounding impacts include the degradation of water quality and quantity in rivers, which has resulted in the removal of flora and fauna; increased dryness of vegetation cover has led to wildfires |
| **Source** | GPP (2017, 2018); CH Guadiana (2018); Iberian Peninsula case study; Mediterranean Basin case study |

chronic respiratory illnesses like asthma. Airborne particulate matter can also increase the risk of acute respiratory infections like bronchitis and bacterial pneumonia. Other drought-related factors affecting air quality include the presence of airborne toxins originating from freshwater blooms of cyanobacteria. When airborne, these toxins are associated with lung irritation and adverse health effects.

- Covid-19 pandemic: More familiar hazards like drought, and new transboundary threats like the Covid-19 pandemic, can interact and compound an emerging health crisis. Such a compounding impact is outlined in detail in the Caribbean case study and applies more widely. Impacts include:
  - Reduced funding for water utilities, following reduced income from travel and tourism and diversion of funds to combat the spread of Covid-19 (GWP-Caribbean, 2020); water rationing and trucking are required under drought conditions.
  - With limited access to safe water, communities are less able to engage in preventative hygiene to combat the Covid-19 pandemic; in some cases, the prioritization of water use for everyday domestic chores over handwashing becomes a life-threatening balancing act.
  - Saint Vincent and the Grenadines experienced one of its worst droughts in over 50 years, as farmers and fishers have had to adapt their daily routine to follow national advisories on Covid-19 health protocols.
  - In Grenada, the Covid-19 state of emergency and its associated restrictions on movement affected farmers who could not visit their farms to tend their crops.
  - In Belize, where farmers had already suffered millions of dollars in losses in 2019 due to drought, the Covid-19 pandemic brought economic activity to a halt, severely impeding farmers' abilities to export livestock across the border to Guatemala (News 5 Belize, 2020).

### *Energy generation*

While few of the case studies focus on energy generation, the complex relationship between energy, water and food production is clear. Water is central to hydropower, and is crucial for cooling in thermoelectric, geothermal and nuclear power plants. For example, from October 2011 to the end of 2015, California experienced a production decrease of around 57,000 GWh of hydroelectricity compared to average water years at a cost to ratepayers of approximately $2 billion. The combustion of natural gas was used to compensate for the shortfall, which led to a 10% increase in carbon dioxide emissions (Gleick, 2018a). In Australia, during the Millennium Drought, electricity generation at two power plants – Tarong (1,400 MW) and Tarong North (443 MW) that drew water from reservoirs shared with urban areas – was curtailed in 2007 in order to protect municipal water supplies. As a result, production and employment at the coal mine that fed the Tarong plants were cut. Operations at a third power plant – Swanbank B (500 MW) – were also curtailed, and electricity prices soared (Tellinghuisen, 2012).

In many case studies, it is clear that drought can impose choices between continued energy, water for food production or water to meet urban demand. This is because water is needed as a coolant in power generation or directly as with hydropower.

### *Cities and urban environments*

Almost half of the world's people now lives in cities, and the urban population accounts for more than 80% of today's global GDP. This requires considerable investment in water and energy infrastructure. The sustainable growth of cities depends on a reliable water supply, in quality and in quantity, that can cope with drought (Desbureaux and Rodella, 2019).

Direct impacts in cities and urban environments of increasing hydrometeorological hazards include:

- Shortage of water supply for drinking, washing and related hygiene, industry use, civic amenities, sewage and related systems

- Deterioration of water quality leading to water-borne and food-borne diseases and additional costs in water treatment

Indirect impacts include:

- Insecurity in food supply to cities due to local agricultural impacts and possible reduction in imports
- Rising food prices and increasing poverty levels among urban groups
- Increased and uncontrolled migration to urban areas due to a decline in rural livelihood options with a possible increase in illegal slums with little access to basic amenities
- Increased stress in support and community services in cities

The case studies describe where major water shortages in some large cities are emerging as a result of drought; this issue is becoming increasingly widespread. In the first two decades of the twenty-first century, 79 megacities suffered extensively (UCCRN, 2018; Zhang et al., 2019). Climate change has magnified urban drought in frequency and severity, putting pressure on urban water supply (Zhang et al., 2019). In Australia, at the end of the Millennium Drought, Brisbane had to employ major water-saving measures to find time for new water recycling systems, and small towns had to bring in drinking water.

High-resolution climate model outputs found the 2018 Cape Town "day zero" drought was five to six times more likely than it would have been in the nineteenth century (Pascale et al., 2020). Unless there are significant reductions in projected future GHG emissions, models project that such extreme droughts in the Cape Town region will become more frequent, moving from a rare event today to occurring every few years or almost every year by the end of this century.

### *Drought and climate insecurity*

Droughts accentuate risks where fragility is high, and can lead to violence, instability and conflict. Droughts can stretch societies' adaptive capacities, undermining national and international security. Recent examples where drought and climate insecurity have combined to exacerbate instability include the following.

**Chad**

This country is deeply susceptible to climate variability and drought. Lake Chad has contracted significantly in recent years. Communities around Lake Chad are subject to: (a) increased livelihood and food insecurity due to an increase in diseases related to changing temperatures and rainfall patterns, (b) decreased coping capacity to deal with unpredictable changes in lake levels and (c) new conflict over the dynamic nature of access to fertile land. Mass displacement and movement have left large population groups vulnerable and without access to land for subsistence agriculture. Hence, they are often dependent on humanitarian aid for survival. Pressure on natural resources has led to increased competition among host communities and displaced populations, with a consequent degradation of natural resources. Conflict and climate risks are high.

**Sudan**

The 2003 war in Darfur flared up after periods of drought (Suliman, 2005). Each consecutive drought was followed by more violent and extended conflict. In the 1970s and 1980s, prolonged droughts and environmental degradation forced about 4 million Sudanese to migrate to southern agricultural lands (Reuveny, 2007). As resources became scarcer, land became less fertile and demand for farmland continued to increase; tensions between farmers and pastoralists reached new highs. These tensions could not be mitigated through traditional means of community leaders seeking peaceful solutions. Therefore, war broke out, claiming 300,000 lives and displacing over 2 million people.

**Iraq**

Prolonged heatwaves, erratic precipitation, higher than average temperatures and increased disaster intensity are placing additional stress on Iraq's post-war environment (von Lossow, 2018). Although terrorism and corruption in the country receive international attention, climate-related security risks are growing. Around 2 million Iraqis are currently food insecure. With water depletion, there are security risks that could be worsened by drought and climate change (Hassan and Nordqvist, 2018).

**Syrian Arab Republic**

There have been six significant droughts in the Syrian Arab Republic in the period 1900 to 2005, in which the average monthly winter precipitation level dropped to around one third of normal. Five of these droughts lasted only one season, but the sixth lasted two (Mohtadi, 2012). There then followed (in the period 2007 to 2010) a multi-season, multi-year period of extreme drought that contributed to agricultural failures, economic dislocations and population displacement (Worth, 2010; IPCC, 2012). This period continued, and is now being described as the "worst long-term drought and most severe set of crop failures since agricultural civilizations began in the Fertile Crescent many millennia ago" (Femia and Werrell, 2012). The 2008 harvest loss accelerated migration to urban areas and increased extreme poverty levels in the country (United Nations, 2009; Sowers et al., 2011).

The devastating civil war that began in the Syrian Arab Republic in March 2011 resulted from complex, interrelated factors beyond the ostensible focus on regime change. Triggers included a broad set of religious and sociopolitical factors, erosion of the country's economic health, a wave of political reform through the Middle East and North Africa, and challenges associated with the availability and use of fresh water (Gleick, 2014). Factors related to drought, including agricultural failure and water shortages, contributed to the deterioration of social structures and led to migration of rural communities to cities (FAO, 2012; Femia and Werrell, 2012). These interactions intensified insecurity, leading to instability, heightened fragility and conflict.

**West Africa**

During the 1970s and 1980s, the Sahelian drought caused massive migration of people – out-migration reached 40% in some villages in Burkina Faso during the 1973 drought (Wouterse, 2006). Drought-induced conflicts can occur between groups of pastoralists and sedentary farmers, as competition for scarce vegetation for animals intensifies. Animals can damage farmlands, leading to farmer–herder disputes and clashes with indigenous populations (Ajaero et al., 2015). Such conflicts have caused six times more deaths than the Boko Haram insurgency (Prager and Samson, 2019). The implementation of climate-smart solutions for pastoralists seems essential for conflict resolution in north-east Nigeria.

The above cases support the linkage of resilience building to broader approaches addressing climate security. Effective solutions to drought, building resilience, can strengthen international cooperation in drought risk management, with the additional dividend of potentially reducing tension within and among communities and countries.

# 2.3

# Drought risk reduction and management

The case studies demonstrate the impact of cycles of drought, the uncertainty of drought initiation, the importance of drought length and severity on impacts, and the uncertainty around when droughts resolve. Debilitating impacts on livelihoods and vulnerability of drier periods that fell short of full droughts have been felt in many contexts – notably in Argentina and the United States of America – and the emergence of short-term subseasonal flash droughts with rapid intensification occurring during periods of peak demand is of growing concern (Hoell et al., 2019; Pendergrass et al., 2020).

These are some of the elements that characterize drought and its complexity; they have challenged existing policies and responses, leading to the framing of new plans, toolkits, decision-support platforms and strategies. The case studies reinforce the need for effective drought monitoring, assessment of vulnerability across scales and availability of mitigation measures to limit impacts during droughts.

## 2.3.1

### Risk reduction policies

The likelihood of increased drought severity in parts of Africa, Australia, the Mediterranean Basin, Portugal and Spain is well recognized, as are the social and economic dysfunctions that can result. However, no single case study has indicated a context that identified, much less implemented, the suite of integrated solutions to the complex and wide-reaching aspects of coupled human–ecological–technological systems.

The need in many countries for umbrella structures and better coordination across government departments – including weather, water, energy, agriculture and infrastructure – is apparent.

Successful integrated management requires a governance shift from reaction and bailout to risk reduction and resilience. This should be based on improved knowledge of the climate mechanisms controlling the onset and termination of drought periods, other factors affecting drought initiation and cessation, and level of vulnerability of exposed communities, industries and ecosystems.

Most studies describe cycles of policy development, review and restructure (e.g. the transitioning of the Intergovernmental Authority on Drought and Development to IGAD in East Africa), as well as various national action plans, strategies, directives and similar initiatives such as new interministerial / departmental committees. These cycles reflect action when drought is severe and inaction when drought is no longer evident.

The case studies identify many challenges to successful policy development. Policy disconnects are common, wherein drought risk management is often treated independently of policies for agriculture and food, water resource allocation, energy generation, conservation and climate change adaptation, among others (e.g. in the Caribbean). Few polices and plans have been found to be binding across international boundaries, and cycles of social disruption and conflict can fester.

Almost all case studies identify the need for national drought policies to support drought risk reduction and avoid prevailing reactive models. Some more progressive examples exist – in Australia (and its farm management deposits[6]) and East Africa, emergency response is connected to recovery and long-term development within a pre-drought strategy – although many have been challenged by recent significant droughts.

6 Income generated in one year can help with favourable tax treatment for withdrawal in a later year. It can also include direct support to farmers, rebates on emergency water infrastructure for watering animals and permanent plants, assistance to local councils and regions to fund structural improvements, and insurance systems to manage losses (Goodwin, 2001).

Adaptation and planning actions are needed that typically include a strategic framework to engage all sectors of the economy, and which is put in place before droughts occur. The framework develops and maintains governance, financing, risk management and preparedness systems to respond to needs as droughts progress, and provide the opportunity for prospective and proactive drought risk management before droughts occur.

The case studies identify a series of strategies in place or planned to identify and manage drought risk, which include, for example:

- Balancing multiple uses of water: This may be done by addressing the trade-offs and conflicts at the nexus among water and food, energy and ecosystems (Vaughan et al., 2016).
- Adaptive and shock-responsive social protection programmes: Social protection in the form of cash or food aid remains essential during intense droughts, as observed in the East Africa case study. Such programmes are entry points for identifying future drought impacts where poverty and lack of non-financial capacities limit local efforts.
- IWRM: Many elements of IWRM plans have drought risk reduction elements, including policies aimed at increasing exploitable potential through improved water and soil conservation (e.g. in the Mediterranean Basin), replenishment of water tables (e.g. in the Pampas region of Argentina), reutilization of wastewater in agriculture (e.g. in the Mediterranean Basin) and reducing transport losses and increasing efficiency in irrigation (e.g. in West Africa, as well as in Australia and the Mediterranean Basin). The European Union Water Framework Directive is a good example of an integrated approach. The directive is supplemented by implementation of SDGs with yearly reporting as part of accountability checks and water demand integration that analyses the socioeconomic and ecological impacts of water management on natural and artificial water reservoirs in coastal areas around the Mediterranean. Water treatment includes drinking water treatment, wastewater treatment, reuse of wastewater, reuse of sewage, and treatment and reuse of sludge (Barceló and Petrovic, 2011).
- Improved irrigation techniques: Yields and household income can increase with significant savings in water use possible over conventional irrigation (e.g. drip irrigation in Uzbekistan).
- Adaptation strategies in smallholder agriculture: These include: (a) diversified production through permanent or temporary agropastoralism, combining crop farming and livestock rearing within the same farm (observed in East Africa); (b) use of improved crop varieties and animal breeds (e.g. in West Africa); and (c) shift from cattle to sheep and goats because small ruminants are less costly, hardier, require less food, reproduce faster and are more resilient to drought than cattle (described in the West Africa case study). Most case studies emphasize the need for empowered farmers and communities and an emphasis on preparedness, benefiting from early warning and monitoring, but dependent on the effectiveness of policy support.
- Ecosystem-based DRR: As observed in the Mediterranean Basin and Uzbekistan case studies, ecosystem-based DRR covers sustainable management, conservation and restoration of ecosystems to reduce disaster risk, with the aim to achieve sustainable and resilient development (Nehren et al., 2014).
- National adaptation plans (NAPs) and nationally determined contributions: Better quantification of climate change risks at local scales has been identified as being necessary to be able to generate more fully integrated risk management approaches.
- Financial instruments: Several instruments, which must match local structures, are identified in the case studies. Beyond insurance and other risk transfer mechanisms that provide immediate relief to individuals and communities during drought, access to credit may be improved and savings supported to provide buffers against drought impacts before, during and after droughts as observed in Australia and East Africa.

- The shift to prospective drought risk management: NAPs that address the key drought risk elements of the Sendai Framework (as described in the East Africa and West Africa case studies) are exemplars of the shift from response measures to proactive and preparedness measures to prospective risk management. Chapter 3 discusses the development of more structured and proactive national drought policies pursuing better-coordinated, prospective disaster risk management across government institutions. The three-pillar framework (after Wilhite et al., 2005) is cited in a number of instances as helpful, and includes: (a) monitoring, early warning and prediction, (b) vulnerability/resilience and impact assessment and (c) mitigation and response planning (Gutiérrez et al., 2014).

### *Transboundary drought risk policies in practice*

Across transnational boundaries and administrative units within countries, the case studies note increasing pressures due to population growth and industrial development, unclear roles and responsibilities across institutions, and knowledge gaps that challenge policy development and implementation.

The complexity with which transboundary strategies must contend is shown in several of the case studies, with considerable differences observed among countries in terms of support and actions, which can trigger society-wide disruptions. There are working examples and historical successes; the European Union water policy framework is an example of a cross-boundary guidance and support mechanism for national cooperation, which has resulted in increased coordination between Portugal and Spain. There are promising developments in most studies, and evidence of new initiatives and plans emerging from the related imperatives of climate change adaptation and SDG implementation (including in DRB, as well as Portugal and Spain).

However, flexible water allocation strategies and water quality standards, including new transboundary agreements, are needed that adapt to altered timing and availability of flows, frequency and intensity of extreme events and effects on water demand (Hamner and Wolf, 1998). An amendment and review process will allow effective response to changes in social, economic, biophysical and climatic conditions, and incorporate new scientific knowledge (Fischhendler, 2004).

A framework for transboundary decision makers requires standard, robust and transparent scientific monitoring and assessment platforms that track basin-wide hydrological and water quality trends. The framework should include baselines to measure ecosystem benefits, which are central to developing management options (Vaughan et al., 2016).

Transboundary agreements are increasingly being developed around institutions that effectively foster cooperation over time, with well-funded, third-party support trusted by all factions (Hinrichsen et al., 1997; UNDP, 2006). Example agreements include:

- The Mackenzie River Basin Transboundary Waters Master Agreement (1997), which was agreed among Alberta, British Columbia, Northwest Territories, Saskatchewan, Yukon Territory and within the Commonwealth of Canada. Bilateral agreements were negotiated in which both sides shared their interests and worked towards an agreement that satisfied common interests and balanced opposing interests.
- Within the Senegal River Basin, Mali, Mauritania and Senegal are cooperating to regulate river flows and generate hydropower through co-owned infrastructure.
- The Rhine River Basin has an agreement between France, Germany, Luxembourg, the Netherlands and Switzerland. The International Commission for the Protection of the Rhine was established in 1950. Initially focused on research and data collection, it evolved to include targets for deep cuts in pollution. In 2001, the 2020 programme for sustainable development of the Rhine was adopted, and the International Commission for the Protection of the Rhine is now an active intergovernmental body to which member states must report their actions.

## 2.3.2

### Risk management in practice

Noting that drought commonly overwhelms traditional approaches, experiences from the Caribbean, DRB, the Horn of Africa and the Mediterranean Basin have identified that the cascading and compounding multisectoral impacts of drought require innovative collaboration in the development and integration of drought risk prevention, preparedness and response. Across scales, this collaboration should include local communities, NGOs, community-based organizations, local and national industries, agribusiness, and advisory firms connected to national and regional governance and science platforms. The aim is to facilitate broad public education and risk awareness to enable early action.

Many studies identify the need to support populations at local, regional, national and transnational scales, thus requiring an effective policy environment. The use of transformative tools in land management (e.g. information technology / digital agriculture) mostly focused on communication is identified as part of empowered local decision-making in some countries, especially where it connects to forecasting and monitoring. However, other tools (e.g. genetically modified crop varieties) are, in some case studies, seen as problematic.

Most of the case studies describe a reactive approach to alleviate crisis situations, historically in all cases and continuing in many cases. These responses include financial payments, provision of emergency water supplies, supply of fodder, construction of wells, and allowing access to land and infrastructure. This reactive approach is a result of the perceived costs of upfront proactive planning, an inadequate level of preparedness and a lack of access to information about the current and likely state of drought (Gerber and Mirzabaev, 2017).

The case studies do not provide consistent estimates of drought costs, despite covering almost a century of experience. Indeed, many countries lack systematic quantitative data on environmental and socioeconomic impacts. Nonetheless, there are accounts of large GDP losses to communities in many countries. In many developing countries, much of the impact falls on private actors – for instance, smallholder agriculture is increasingly developing a "cash crop" dimension supported by small local entrepreneurs using leap-frog information technology. Elsewhere, the farmer is actually a small business, and in many cases, the farmer is much larger than that (e.g. Australia). Drought therefore forces some challenging business decisions.

Many countries note large investments to deliver drought plans (e.g. $A10 billion in the Australian Murray–Darling Basin Plan), or large investments in water infrastructure and irrigation schemes all designed to "drought proof" nations and secure water into the future. However, many case studies demonstrate the trend is away from these investments in favour of investments in preparedness and resilience, but not at the multi-scale coordination and financing levels needed. In addition, emergency funding is short term and costly in most case studies where severe droughts have been experienced.

The case studies recognize the need to strengthen the implementation of SDGs through national and international partnerships, the development of analytical tools to solve global challenges and the promotion of multi-stakeholder partnerships. These include negotiating and implementing agreements across relevant regional institutions responsible for a range of climate services, and the active engagement of NGOs and community-based organizations to ensure drought early warning information systems target the people and communities at risk. The studies identify the importance of cultivating partnerships based on community participation in influencing policy and prioritizing needs, and building a culture of water saving and efficiency.

#### *The Integrated Drought Management Programme*

The three-pillar approach to drought risk management developed through IDMP is a notable development. This programme draws on the lessons learned and experience of the National Drought Mitigation Centre, the National Integrated

Drought Information System in the United States of America, the Consultative Group on Agricultural Research and UNCCD, among others. The Brazil case study outlines the need for an evolved version of the three-pillar approach to assessing and managing drought risk: monitoring, early warning and prediction; vulnerability, resilience and impact assessment; and mitigation and response planning. Similar needs are identified in most case studies.

### *Drought monitoring and early warning*

The need for frequent early warning before a drought, and monitoring during a drought, is common to all case studies, as is the call for improved seasonal weather and climate information and forecasts developed in ways that build stakeholder capacity. Examples are observed in Argentina, Australia, Brazil, the Caribbean and West Africa, where increasing emphasis is being placed on improving the connection of meteorological services to early warnings, seasonal weather forecasts and status reports. The case studies stress that focus on impact geographies, communities and livelihood systems are imperative to improve targeting and support.

Capacity-building should bring together stakeholders (including research institutions and the media), for example to ensure farmers receive effective advice that enables them to interpret information received and adopt climate-smart agriculture. Case studies identify it is also possible to build monitoring systems that connect community "reporters" with remote-sensing technology and modelling (e.g. Dust Watch Australia and Drought Watch Danube Basin).

Drought bulletins, drought maps, and other media and tools have been developed as communication aids. They produce information before and during droughts for the general public, for specific vulnerable sectors and as part of education systems. The system developed by the Research Institute for Meteorology and Water Recourses of Ceará state, north-east Brazil, is a good example of this. The case studies identify that these need to be connected to monitoring systems at meteorological offices and science agencies.

### *Adapting to drought*

The case studies also detail an abundance of local strategies of adjustments and adaptation from the ground up – sometimes supported by explicit government programmes. These involve adapting crop variety or species choice, the mix of enterprises, planting dates, planting densities, irrigation strategies, agropastoralism, livestock species and supply chains. These are supported by extension programmes in many cases.

Adaptation strategies in Africa based on traditional knowledge, for example water harvesting in West Africa, are increasing in importance as are community networks in Australia. Land regeneration, green belts and reforestation are key adaptive and mitigation actions in cases such as the Aral Sea Basin. There is concern that many of these local adaptations are not sufficiently connected to knowledge of drought likelihood or appropriate tools for risk mitigation.

### *Drought risk financing instruments*

The development of drought funds, rebates, tax measures and the like are now more common across countries, especially in rural areas. However, while improvements in understanding risk have propelled the development of innovative financing and risk transfer products in other sectors and for other risks, as noted in some case studies, drought financing by the private sector has generally been unsatisfactory.

Insurance and related financial instruments at the local level are rarely observed in the case studies. They note a lack of knowledge of financial risk products, financial products that are expensive and a small supplier pool with limited competition. Government-supported insurance schemes are in place in some countries (e.g. the Islamic Republic of Iran). Government farm subsidies play out in different ways across countries, and can produce perverse outcomes for drought management in almost all situations.

# 2.4

## Gaps, challenges and lessons identified

Significant progress has been made in recent years in improving the current understanding of drought and its effects on societies, ecosystems and economy. Nevertheless, significant gaps in research, management and policy remain.

Chapter 1 identified gaps concerning data, methodological challenges and weaknesses in policy and management which have been further illustrated in the lived experience of Chapter 2. Chapter 1 described the complex nature of the hazard of drought and the challenge to predict the onset, duration and resolution of each event, despite the growing knowledge of the climate system and an expanded set of observations and models. The case studies in this chapter exemplify the systemic nature of the risk that drought poses by exploring where exposure and vulnerability to drought and the capacity to adapt and respond have led to significant impacts.

The case studies and supplementary examples in this chapter note the impact of cycles of drought, the uncertainty of drought initiation, the importance of drought length and severity on impacts, the uncertainty around when droughts resolve and the emergence of short-term subseasonal flash droughts. Drought has had widely variable effects across regions and countries. Impacts vary across scale – effects are initially felt at the landholder, farmer or livestock manager level, but with time, the impacts are broader across communities, the economy and even beyond national borders.

Beyond the immediate impact of drought on rainfed agriculture, the case studies note the increased insecurity of irrigation systems, the increased tendency for many urban centres to be affected by water scarcity and decreases in water quality, the decline of natural capital (soils, freshwater sources, pests and diseases) and degradation of ecosystems and biodiversity. Land degradation and desertification reduce the resilience to future droughts. Cascading impacts include forest loss, soil erosion and degradation, SDSs, flood vulnerability, and more-frequent wildfires. Energy generation requires water. Consequently, the energy industry shares vulnerability to drought with competing users of water. The interdependencies among water, food and energy are made abundantly clear during drought. In all these impacts, the level of drought vulnerability is unequal; it has a disproportionate impact on the poor and marginalized where the cost of drought is measured in terms of lives, livelihoods and impoverishment. The case studies reinforce the message of the drought risk equation – the risk is greatest where the exposed are vulnerable and have the least capacity to cope.

Where societal fragility is high, the cascading impacts of droughts can lead to violence, instability and conflict. Examples from Chad, Sudan, Iraq, Syrian Arab Republic and West Africa demonstrate how droughts have stretched societies' adaptive capacities and undermined national and international security. Given the potential increase in drought risk imminent with climate change, the global community must pursue drought risk reduction and strengthened resilience and the dividends wrought in terms of reduced tension within and among communities and countries, even mitigating human conflict and forced migration.

Most case studies emphasize the need for empowered farmers and communities and an emphasis on preparedness, while benefiting from early warning and monitoring, but depending on the effectiveness of policy support. The case studies describe an abundance of local strategies and approaches. These involve adapting the crop variety or species choice, mix of enterprises, planting dates, planting densities, irrigation strategies, agropastoralism, livestock species and supply chains. They are supported by extension programmes in many cases. Connections to traditional knowledge are increasingly being sought.

Risk transfer and related financial instruments at the local level are rarely observed in the case studies, despite the clear need. They note a lack of knowledge of financial risk products, financial products that are expensive and a small supplier pool with limited competition.

Most case studies describe cycles of policy development, review and restructure that reflect action when drought is severe and inaction when drought is no longer evident. Policy disconnects such as drought and agriculture, water resource allocation, energy generation and conservation constrain action. Polices and plans across international boundaries are rarely binding.

Across transnational boundaries and administrative units within countries, the case studies note increasing pressures due to population growth and industrial development, unclear roles and responsibilities across institutions, and knowledge gaps that challenge policy development and implementation.

Given the complex and systemic nature of drought risk, it is perhaps not surprising that a "solution" has yet to emerge from the case studies. Key questions remain around characterizing and predicting drought events, understanding the nature of vulnerability and resilience, and what constitutes an effective response to the risk of drought.

Each case study demonstrates how societal structures, institutions, policies and actions determine the resilience of a community and its environment to drought risk and that, given sufficient drought severity or an increase in vulnerability, existing arrangements can be overwhelmed. Chapter 3 explores how societies and communities can develop systemic approaches and more-effective systems of governance to increase resilience in the face of growing drought hazard and reduce the risk.

The resolution of knowledge and practice gaps identified in Chapters 1 and 2 is an important component in exploring the enabling conditions required for the shift to a systemic approach to drought risk reduction. The following illustrate gaps identified in data and knowledge and access to existing and developing sources:

- It is rare within the case studies that sufficient data on past, present and projected impacts in vulnerable lands, ecosystems and communities is available to prioritize investments in building resilience and reducing exposure to drought. Communities need to be able to characterize and manage the relative importance and vulnerability of sectors affected by drought and access spatial and temporal data on impacts at a scale and resolution suitable for each sector via open, standardized, interoperable platforms.
- Wider and easier access to interlinked meteorological and hydrological drought hazard data, and exposure and vulnerability data, are crucial at sufficient spatial and temporal resolutions to allow risk assessments and to build understanding of the systemic nature of drought risk that applies in each region or country.
- There is a growing range of models, decision tools, monitoring systems and data stores. Guidance and support are needed to choose or access appropriate tools and capabilities to support effective horizontal and vertical communication and decision-making across the hydrological system[7] and relevant to specific climates and communities. Shared information on what approaches are being employed in development, or have been tested and appear most promising, is needed.

It is clear in many countries that adequate resources for the development and implementation of drought risk management plans are needed. That also requires resources for periodic review of their quality and efficacy and assessment of the relative benefits and costs of actions within the plans, with emphasis on ex ante drought risk prevention and mitigation of underlying risk drivers. Broader acceptance and therefore implementation of drought risk management plans requires improved models of participation in problem identification and design of solution pathways, and drought risk education and public awareness-raising programmes.

7 For example, glaciers and snowfields, springs, surface water, coastal systems, groundwater and reservoirs.

Chapter 3 examines these lessons, exploring prospective and proactive governance with in-built and forward-looking learning systems to better adapt to drought. It builds on the modernized understanding of drought risk and the lessons identified from the lived experience to bring out the enabling conditions that will allow new governance systems to emerge and take hold in daily lives and facilitate the broad changes needed to match societal responses to the systemic nature of drought risk.

# 3. Droughts: from risk to resilience

## 3.1 Introduction

Drought poses substantial risk to societies and ecosystems around the world. The case studies reviewed in Chapter 2 illustrate the challenge that communities and governments at local to global scales face in recognizing and responding to drought risk. No two droughts are the same; no single formula to manage them is sufficient. The continuum and feedbacks among varieties of drought events and drivers, impacts, warnings and ongoing responses are immensely complex. These include interactions at multiple time and space scales that range from global trade to the everyday insecurities and coping activities experienced by those people most at risk. Risk assessment and management strategies are increasingly challenged by such systemic and evolving impacts of extremes, variability and change across time and space.

In many cases, global integration can strengthen resilience to smaller shocks, for example through trade and other adjustments. However, increasingly integrated network structures can also expand vulnerabilities to existing and emerging systemic risks (UNDRR, 2019). Global networks, cascading climate events, poverty, rapid urbanization, weak governance, the decline of ecosystems and climate change are all driving disaster risk, and in some instances introducing new threats, around the world.

A system may be complex because:

- It comprises many parts connected in multiple ways
- Over time, cause and effect are hard to relate, and interventions produce unexpected consequences
- The emergent behaviour of the system is deeply unpredictable, even when the subsystem behaviours are known and predictable
- As a whole, it can carry out a unique function that cannot be performed by the constituent elements alone

Adaptive risk management and governance strategies are required as responses to complex risks such as drought. They are fundamentally different from individual risk management approaches in that they are founded on notions of complexity, ambiguity and diversity.

"Governance" refers here to actions, processes, traditions and institutions (formal and informal) by which collective decisions are reached and implemented. Transitioning to governance mechanisms that facilitate rapid responses to crises is a different challenge – monitoring slower changes and responding with longer-term measures (Kahneman, 2011; IPCC, 2012; Olson, 2016; IRGC, 2018).

Effective governance of drought-related systemic risks must be adaptive and multi-scale, in the context of anticipated risks and opportunities. It must also be prospective in avoiding the emergence of new threats and for managing through a rapidly changing environment across the full risk to resilience continuum.

This chapter outlines the lessons drawn from modernizing the current understanding of drought (Chapter 1) and the case studies from around the world (Chapter 2). It crafts a framework and process for the development and implementation of adaptive management and governance of drought-related systemic risks.

# 3.2

## Characterizing systemic risks and challenges for governance

**KEY MESSAGE**

- **Achieving the outcome and goal of the Sendai Framework will require the global community to better understand the dynamic nature of systemic risks such as droughts, and to support new structures to govern risk in complex, adaptive systems and develop new tools for risk-informed decision-making that allow human societies to live with uncertainty.**

### *The systemic nature of drought risk*

Disasters resulting from systemic risks such as drought may not fall into the traditional taxonomy of a sudden event or an event with clear start and end dates. Some feedbacks and potential state shifts can be modelled and quantified; others can be modelled or identified but not quantified; and some are probably still unknown. Indirect issues play a key role, and can be exposed or exacerbated. For example, technologies enhancing farm productivity, such as adding fertilizers, might improve adaptive capacity through higher incomes but at the same time drive emissions and lead to direct farm changes (e.g. soil acidification, and off-site impacts such as groundwater and surface water nutrient overload). In the case of drought, this might depend, for example, on the timing and quantity of precipitation and return flows (Harvey et al., 2014; Thornton et al., 2017).

The globalized economic system and networks of communication and trade have generated highly interdependent social, technical and biological systems. However, increasingly integrated structures also expand vulnerabilities to traditionally recognized and also novel systemic risks (UNDRR, 2019). This has practical implications for financing and implementation of prospective and proactive approaches.

Chapter 1 shows the impacts of cascading and compounding events can be greater than the sum of their parts. To further complicate matters, the spatial or temporal correlation among extreme events – including drought and land-cover degradation – remains poorly understood. There is considerable uncertainty about trigger events, shock propagation and remote, indirect impacts, especially within systemic risks.

Systemic drought risk characteristics include physical feedback loops, such as when spring droughts in Europe are connected to a higher probability of summer heatwaves. They also include non-linear dynamics in the agroclimatic system such as nutrient losses and crop failure after a prolonged heatwave during heat-sensitive plant growth stages, which can further lead to rapid and irreversible changes and impacts (Vogt et al., 2018; UNDRR, 2019; Chapter 1).

Effective governance of drought risks must therefore be able to cope with uncertainty, thresholds and surprises. This includes cross-scale trigger events such as (compound) climate hazards, cascading impacts such as crop losses and consequent price spikes, and resultant social vulnerabilities such as reduction in the economic strength of individuals, communities and nations.

#### *Governance of systemic risks*

Governance addressing systemic change requires iterative analytical deliberation, monitoring, nesting of approaches, and institutional variety and evaluation. Deviations from targets should not be seen as failures, but rather as opportunities to learn and adjust (Dietz et al., 2003; Lempert et al., 2018). A systems approach benefits from diversity, as more perspectives offer a broader portfolio of solutions. It requires that integrating an understanding of everyday activities and attendant vulnerabilities and capabilities is central. Identifying and acting on risks from so-called small events can reduce risks from larger ones.

Transformations that address future drought-related resilience as a systemic problem will require profound shifts in institutions, technologies, consumption patterns and personnel, as well as the ecological, economic and social processes they influence. Not all transformations work to achieve the intended outcomes; in some cases, they can further marginalize already vulnerable groups. Much of the risk governance literature has been limited in its ability to address competing values under which decision-making takes place.

## 3.2.1

### Drought in the context of systemic risks

**KEY MESSAGE**

- **Early warning is crucial in drought contexts, and some emergencies can be mitigated. However, drought management over the long term is confounded by complexities and uncertainties regarding drought exposure, vulnerability and attendant decision-making.**

Numerous assessments show drought remains a hidden risk, with non-linear secondary and higher-order impacts (e.g. UNISDR, 2011; IPCC, 2012; UNDRR, 2019; UNESCO, 2019). Micro-level actions and responses involving households, communities and individual businesses are often under-recorded but are the most important elements for drought risk mitigation (UNISDR, 2011; UNDRR, 2019). Systemic drought risk characteristics further influence cascading events such as price volatility, food insecurity and even food-related riots.

Drought raises additional questions about the capacity to measure, evaluate and respond to related risks. When does a drought start? Are drought conditions intensifying and/or spreading? When is a location in drought? What is the outlook? When will the drought end? Does the return of some rain signify an end to drought or transitory relief? Are any past droughts indicative of future droughts? How are attention and prospective risk management activity maintained between events?

Drought staging (Chapter 1) is an important characteristic for the present assessment, and can be considered analogous to medical disease staging. As in medical staging, intervention and support is less costly and more effective in early stages, and more costly and less effective in later stages as response capabilities and system buffers are depleted when communities move to relief and welfare.

As discussed in Chapters 1 and 2, the experiences of JRC, IDMP, the National Integrated Drought Information System in the United States of America, FEWS NET and IGAD illustrate that drought early warning can be a proactive social process whereby networks of organizations conduct collaborative situational assessments to guide action. The drought centres align observations, research, forecasts, risk assessment and communication, and embed information in drought response, albeit with varying levels of success (Pulwarty and Verdin, 2013; Vogt et al., 2018; Chapter 2).

Indicators of vulnerability help to identify when and where local capabilities, human agency and policy interventions are most needed. Historical and institutional analyses help to identify the processes and entry points for reducing vulnerability. Taking local knowledge and practices into account promotes mutual trust, a community sense of ownership and self-confidence (Dekens, 2007). As important as indicators and risk management tools are to such systems, it is the governance context that needs further attention. This is particularly so for people-centred strategies at the end-user interface – the so-called "last mile" (Singh, 2006; Birkmann et al., 2013), where increased inclusion and alignment of a mix of centralized and decentralized activities are required.

The term "emergent risk" has most commonly been applied to financial systems, for example when one significant financial institution fails and others collapse because of opaque, complex, coupled relationships that connect them. Governance of systemic risks requires new institutional structures and processes, as recognized after the global financial crisis in 2008. Before the crisis, early warning systems were in place to identify precursor signals and anomalies in the overall performance of the financial system. Yet they failed to detect what are now, in hindsight and ex post analyses, understood to have been clear signals. In addition, and as widely acknowledged, early warning does not necessarily lead to early action (Pulwarty and Sivakumar, 2014). Warnings of such system changes and an improved knowledge of their past behaviour are not sufficient to guide even initial actions. Moreover, having initiated action, it is not possible to assume those actions remain as viable solutions as events evolve.

## 3.2.2

### Challenges today and tomorrow

Risk drivers such as transboundary water tension, land degradation, international trade and climate change are increasingly occurring at larger scales and are affected by non-local and multilayered influences. Promising strategies for addressing these problems include dialogue and partnerships among interested parties and researchers; complex, layered and adaptive institutions incorporating intentional redundancies; investing in a mix of policy and institutional types; and frameworks that facilitate experimentation, learning and change (Dietz et al., 2003). DRR, including drought risk reduction, has a much larger impact on the effectiveness and potential success of long-term adaptation than commonly acknowledged.

Coherence across climate change adaptation, mitigation and DRR approaches is essential to achieving sustainable development (IPCC, 2012). For example, the Paris Agreement encourages countries to formulate and implement NAPs that facilitate the integration of climate change adaptation into relevant development planning and strategies, including on DRR. In addition, Target (e) of the Sendai Framework calls for a substantial increase in the number of countries with national and local DRR strategies that promote policy coherence, including on climate change (United Nations, General Assembly, 2015a).

Chapters 1 and 2 recognize the need for systemic innovation where complexity, ambiguity and diversity characterize risk drivers. However, there are numerous and significant challenges in the case of drought. Drought risk is fundamentally embedded in human security. Progress on linking climate and human security has not been sufficient to respond comprehensively to drought risk. Drought risk results from interacting pressures across the water–food–energy nexus. Beyond the theoretical, there is much accumulated experience of the shortcomings of traditional drought risk management, but limited practical experience in addressing systemic risks. Coherence is needed, but it is still unclear how agreement and alignment on coherent approaches are derived and sustained.

The challenges are numerous, complex and significant as drought impacts filter through water, agriculture, food security, energy, ecosystems and livelihoods. Consistent or comprehensive estimates of drought costs are difficult to estimate due to challenges that include the attribution of impacts across the life cycles of events, and the multiple formal and informal economies through which these events flow. Many countries lack systematic quantitative data on environmental and socioeconomic impacts. Nonetheless, there are accounts of large losses to GDP in many countries and a record of large investments to deliver drought plans.

As the case studies in Chapter 2 illustrate, these system components have often been studied and managed individually, without consideration of trade-offs, cultural similarities, and differences and complementarity for jointly ensuring water, energy and food security. Such approaches have underestimated the complexities involved and the opportunities for more meaningful actions to support sustainability goals.

Different ways of generating knowledge and action have been advocated and also tested in some cases. They often involve participatory and collaborative processes to integrate multiple paths for developing actionable knowledge that can contribute to transformation of society. Examples include co-development across sectors, science–policy interfaces, democratization of expertise, and knowledge brokering and facilitation.

The Sendai Framework, with its outcome seeking the substantial reduction of disaster risk and losses and its goal seeking to prevent new and reduce existing risk, is essential to achieving SDGs (UNDRR, 2019). Progress is being made with regard to implementation of SDGs; however, pathways to propel the transformation required to meet SDGs by 2030 are not yet advancing at the speed nor scale required (Independent Group of Scientists, 2019; United Nations, 2019, 2020).

The strong theoretical rationale for coherence in systemic management is not always reflected in practice, suggesting there are mismatches in processes and institutions that hinder potential coherence between DRR and other approaches. In respect of climate change adaptation and mitigation, these include (OECD, 2020b):

- Fragmented responsibilities: Ministries or agencies overseeing climate change adaptation, mitigation and DRR at the national level do not always have a culture or authority for coordinating their respective policy agendas (Seidler et al., 2018).
- Different funding structures: Funding mechanisms for climate change adaptation, mitigation and DRR are often spread across institutions and levels of government. As a result, funding schemes are often constrained by the limited scope of the issuing organization, leading to further silos. Funding structures can also create perverse incentives, for example resulting in the prioritization of short-term disaster financing needs over long-term risk reduction (OECD, 2018).

- Data availability and use: There has been notable progress in recent years in data availability and climate- and disaster risk-related modelling. Examples include recent developments on continental-scale hazard and risk assessments (IPCC, 2014b, 2014c, 2019).
- Perception of a temporal mismatch: Disasters caused by extreme environmental events are usually distinct in time and space and require a rapid response. In contrast, long-term perspectives are a key element of climate change adaptation and mitigation strategies.

As noted in the IPCC Special Report on Extremes and in multiple GARs, approaches to disaster risk management and reduction are not limited to emergency responses nor are they bound by short time frames of event duration (IPCC, 2012; UNISDR, 2011, 2013, 2015; UNDRR, 2019). Such approaches play distinct roles in constraining the development of future risks and vulnerabilities when well designed or well implemented, and can enable or propagate risks and vulnerabilities when design or implementation is poor.

The negative consequences of the failure to integrate drought-related considerations into climate change adaptation and mitigation and DRR should not be underestimated (IPCC, 2012; Gerber and Mirzabaev, 2017). Nevertheless, an inordinate emphasis on the long-term projections of climate change impacts has the potential for reducing the field of drought risk reduction to a hazard-centric viewpoint rather than equal and longer-standing considerations on the causes of disaster and particularly drought-related exposure and vulnerability (e.g. Garcia, 1981; Burton et al., 1978). It is important not to ignore the much longer history of research and practice on addressing root causes of vulnerability in the disaster and drought risk reduction community that is now actively employed by the climate change adaptation and mitigation community (IPCC, 2012, 2014, 2019; Wilhite and Pulwarty, 2017).

# 3.3

# Knowing and doing better

This section characterizes the barriers and outlines the opportunities for countries and communities to respond to the complexity of drought-related risks more effectively.

## 3.3.1

### Transitions to sustainability

For the purposes of this report, “transitions to sustainability” refers to multidimensional and fundamental processes through which established socioecological–technical systems transform or shift to more sustainable modes of production and consumption (Markard et al., 2012; EEA, 2019). Values, intentions, goals, guidance and governance play particular roles in transitions (Smith et al., 2005); what is considered sustainable can be subject to interpretation, and might change over time (Garud et al., 2010). Thus this report emphasizes the continuum from short-term proactive drought preparedness and response through to long-term prospective risk management and risk reduction.

Sustainability transitions involve difficult decisions and trade-offs characterized by high degrees of uncertainty (e.g. price, performance, acceptance, use and environmental outcomes of innovations) and disagreement and conflict among stakeholders about desired futures, pathways and trade-offs (Kern and Rogge, 2016, 2018). While the need for understanding adaptive cycles and broad governance frameworks has long been recognized, implementation is rare outside of a few highly contextual cases (White et al., 2001; Chapter 2).

There is only limited practical experience of steering such processes. Moreover, concerns such as increasing political and private sector resistance and local acceptability may become more pressing as implementation gains momentum. In addressing policy problems of this type, technically rational decision-making approaches may provide partial or misleading guidance because they struggle to integrate many of the fundamental characteristics of transitions (EEA, 2019). Purely risk-based approaches including "predict then act" methods can backfire in deeply uncertain conditions (U.S. Global Change Research Program, 2018), the reasons for which are numerous and may include:

- Uncertainties are underestimated and, in some cases, de-emphasized
- Competing analyses can contribute to gridlock
- Long-term monitoring – physical and social – is undervalued
- Misplaced belief in the fixed nature and assumptions of a priori knowledge can mask awareness of rapidly changing conditions or surprises

Predetermined path dependencies at multiple levels (including sunk costs of infrastructure, organizational conventions on understanding and practice, traditions of land tenure, paradigms of defining innovation systems as the result of markets alone and professional tradition) all thwart adaptive capacity and reduce the range of choice, and hence innovation. Not all proposed or supported sustainability transitions are successful, and not all successful transitions are steps in the right direction (see Box 3.1 for an example).

Barriers to transitions can include the difficulty of overcoming tradition and culture, antiquated laws and institutions, inertia in complex social systems, the long time required for changes in technology, inadequate financial investment and more.

### *Constraints on implementation*

Public acceptance of the significance of problems and of the proposed approaches is key to successful implementation. Case studies of climate-resilient development pathways at state and community scales show participation, social learning and iterative decision-making are governance features of strategies that deliver mitigation, adaptation and sustainable development in a fair and equitable manner (Lempert et al., 2018). Incremental voluntary changes are amplified through community networking, polycentric governance (Dorsch and Flachsland, 2017), partnerships, and long-term change to governance systems at multiple levels (Stevenson and Dryzek, 2014; Lövbrand et al., 2017; Pichler et al., 2017; Termeer et al., 2017).

The ability to identify explanatory factors affecting the progress of drought policy is constrained by a

**Box 3.1. Limits to transitions to sustainability – water privatization**

The replacement of public water systems with private systems illustrates an example of a heavily advocated but failed transition. Large-scale water privatization was proposed as an alternative development model to address the lack of success in providing comprehensive, safe, and affordable water and sanitation. Early supporters of privatization argued that greater financial and management efficiencies reduced risks of corruption and access to new sources of capital could help turn around unsuccessful water systems.

However, the concept ultimately failed because of a combination of factors, including an inability to prove sufficient economic and operational improvements over well-implemented public models, massive public opposition on the grounds of a lack of equity and transparency, and a preference for public over private control of water. A diverse mix of public, private, NGO and civil society systems remains the viable approach and a coordination and implementation challenge today (Gleick, 2018; Garrick et al., 2020).

lack of data on responses and adaptation actions across nations, regions and sectors. More fundamentally, there is an absence of frameworks for assessing progress. Most hypotheses on what drives sustained adaptation have limited testing, and evaluations of whether and why an adaptation initiative has been effective are lacking. Research in developing countries is scarce on effective multilevel governance including sustained participation by civil society, women and minorities (IPCC, 2019).

Throughout the case studies and the broader drought risk management literature, various elements of the 10-step process for developing national drought polices (Chapter 1) are being undertaken. However, all steps are being met only in a few, if any, cases. To illustrate, findings from the South American case studies include:

- The main governmental reaction to a drought is the declaration of an "agricultural emergency". This declaration postpones state and federal taxes, extends loan repayment due dates and provides immunity against bank foreclosures.
- Multiple drought mitigation actions are instituted by governments (e.g. good agronomic practices to add resilience and enabling adoption of insurance instruments) and by individuals or firms (e.g. modifying land allocation or stocking rates, agronomic management and marketing strategies). Farm-level responses are effective under weak to moderate droughts, but strong events overwhelm buffering capacity, particularly for small farms.
- The limited knowledge of interactions among drought characteristics and the types and magnitudes of likely impacts is a major impediment to proactive drought risk management. It is therefore difficult to know when to issue different levels of warnings or initiate mitigation actions. Information on the agricultural impacts of various climate hazards is not systematically collected or recorded, despite its critical importance.
- Responsibilities for drought response are dispersed among many institutions at multiple jurisdictional levels. There is little coordination among institutions to define who does what and when, before, during and after a drought.
- There is a strong need for innovative involvement of a diverse set of actors (NGOs, farmers, agronomic advisers and extension agents) to co-design effective drought information systems.
- Governance failures are prevalent, such as lack of capacity or coordination failures across agencies; the influence of interest groups; and how most of the benefits of adaptation are in the form of avoided impacts that are largely invisible and for which policymakers rarely get rewarded.

Implementing recommendations without attending to the associated risks may be a step backwards in the transformation, as stakeholders may be left confused, marginalized and frustrated by the perceived lack of progress. Thus, many recommendations – for moving from the status quo to a prospective drought management framework – risk underestimating the complexity of mitigation and adaptation in a changing drought environment. These risks include:

- Increasing recognition of adaptation buffers arising from ecosystems including watersheds and landscapes, but relatively little commensurate action to support this awareness.
- Limited coordination on implementation across the scales of governance, resulting from unclear responsibilities of actors and conflicting timescales of interventions.
- Limited community acceptance of needed adaptations. Cognitive and cultural biases and deep uncertainty often lead to strong political opposition to any action.
- Market failures due to limited data availability and in some cases misapplication of data and information that further increase long-term risks and vulnerability. Many co-benefits of addressing multiple threats and opportunities have been identified but not realized in practice.
- Inadequate representation of the precarious nature of everyday life for highly vulnerable people in drought-prone regions.

## 3.3.2

### Doing more with what is already known

Opportunities do exist to apply what is already known in the management of drought-related systemic changes. There are options for land and ecosystem transitions, which include conservation agriculture, efficient irrigation, agroforestry, ecosystem restoration and avoided deforestation. Singh et al. (2020) outline feasibility assessments of 23 adaptation options. While these adaptation options are highly situation dependent in terms of value and may involve significant trade-offs, and thus are not necessarily transferrable elsewhere, they offer options for proactive planning by individuals and organizations (IPCC, 2019). Policies concerning their implementation need to match the state of the system, identify complementary factors and develop processes to resolve potential trade-offs.

#### *Adaptation, scaling and implementation*

**KEY MESSAGE**

- **In many cases, limitations to scaling, replicating or sustaining "successful" project-based approaches are exposed when overwhelmed by severe sustained drought events or cumulative impacts of sequences of smaller events.**

Scaling community-based adaptation may require structural changes. This implies the need for transformational adaptation in some regions. Implementation would involve multilevel governance and institutional capacities by enabling anticipatory and flexible decision-making pathways that access and develop collaborative networks.

Examples of adaptation measures that may be incentivized through financial and economic mechanisms include:

- Improved land and soil management for agriculture, forestry (or agroforestry) and pastoral management and stock scheduling
- Improved water (including soil water) management such as increased economic efficiency of water use (e.g. water pricing, water reuse and water quality protection or enhancement) and interventions such as conjunctive water use and appropriate solar pumping of groundwater
- Crop management, including crop (and variety) selection, irrigation regimes, cultivation practices and crop rotations
- Diversification by communities at risk to alternative or supplementary (part-time and full-time) livelihoods and provision of food relief
- Stabilization of food prices and of prices in markets for key production inputs in times of drought

There are successful schemes that demonstrate the effective use of such measures. These include Ethiopia's Productive Safety Net Programme and the Caribbean experience with index insurance (Bahru et al., 2020; Chapter 2).

The strategic challenge for transitioning governance systems lies in coordinating emerging innovations towards systemic change while simultaneously opening up, or alternatively breaking down, unsustainable regimes and institutions. Overcoming disincentives and inertia to sustaining collaborative action is shaped by culture, trade-offs, values and so forth, and is still where much of the iceberg of knowledge remains submerged.

Coupled with those disincentives is the need to balance efficiency with redundancy (i.e. infrastructure backups and ecosystem buffers), recognize and acknowledge uncertainty and, in some cases, indeterminacy of thresholds, and advance consistent assessment methods.

How learning takes place and how such learning is secured, employed, financed and sustained are questions of enabling capabilities to move beyond "panaceas" (Dietz et al., 2003; Ostrom et al., 2007;

Scoones et al., 2020). Individuals and entrepreneurs play key roles in such learning processes by providing community leadership and/or facilitation, building trust, developing visions, and connecting people and nodes in learning networks.

Knowledge is limited about how to facilitate demand-based innovations that are transformative in rural and urban systems. White et al. (2001), Snowden and Boone (2007), Fischhoff (2020) and others outline several barriers to the effective development and application of usable information that are still salient:

- Knowledge continues to be flawed by areas of ignorance
- Knowledge is available but not used effectively or with results contrary to those planned or expected
- Knowledge is used effectively but takes a long time to have effect
- Knowledge is used effectively in some respects but is overwhelmed by the scale and rate of increases in vulnerability and in population, assets, poverty and lack of empowerment elsewhere

Despite the potential for so-called "leap-frog" technologies (e.g. wireless communication) to be applied to poorer areas or countries, their capacity to use advanced technologies such as precision agriculture remains weak and is still focused on supply-side solutions.

### *Policy support*

Policy approaches are more effective when they address contextual and psychosocial factors influencing climate actions, which differ across contexts and individuals (Steg and Vlek, 2009; Stern, 2011; Fischhoff, 2020). There are significant gaps in factors enabling adaptation. Knowledge is still limited on:

- How cognitive and motivational factors promote adaptive behaviour
- How potential adaptation actions might affect behaviour to influence vulnerability outcomes

Financial and regulatory preconditions are needed to stimulate actors to embrace the necessary investments.

Most non-governmental actors are in favour of governments setting a framework with rules and norms. However, research shows government action is not usually sufficient (Molenveld et al., 2021). Government is needed to facilitate and secure networks and create the financial and regulatory preconditions to remove barriers to effective adaptation measures including local innovation. Political and financial stakeholders may find actions more cost-effective and socially acceptable if multiple factors affecting behaviour are considered, including aligning these actions with core values.

While policy processes are typically driven by national governments, the bulk of implementation occurs at the sector or local levels. National-level actors must therefore be cognisant of the burden that planning, implementing and monitoring such processes can place on them. Hence, there is a drive to stimulate and support self-organization of local-level partners. There is also a persistent and strong need to acknowledge differing social values and strengthen institutional collaboration, including data collection on drought impact to reduce vulnerability and enhance resilience.

Practical experiences and research literature demonstrate that the outcomes of participatory interventions can be co-opted, or even reinforce the problems they were intended to solve (Ascher, 2017; Turnhout et al., 2019). Caution is required, as it has been observed that partnerships can be formed as a result of a powerful actor mobilizing relationships, largely for their own benefit in terms of enhanced legitimacy, recognition or control (Contu and Girei, 2014).

Many studies show stakeholders failing to address the key issues of representation and power asymmetries: who participates; what values, perspectives and interests do these participants represent; and how can all voices be engaged in a procedurally legitimate way? Thus the importance within learning approaches of leadership, trust, co-design in problem framing and developing visions, and facilitating connection and collaboration. Drought research and management experience in transboundary watersheds (Chapter 2) show that several paradoxes in multi-State water management and governance across borders can militate against the accurate assessment of socioeconomic impacts and the effective use of scientific information for meeting short-term needs and reducing longer-term vulnerabilities.

In developing countries, the need for coherence is not limited to national policies and activities, but also includes coherence of international development and cooperation in support of DRR and climate change adaptation and mitigation. In many developing countries, development partners cooperate with national and subnational authorities and are aligned with country objectives. The issue of drought, and its complex and cascading impacts, offers multiple opportunities for aligning efforts supporting the achievement of the outcomes and goals of the 2030 Agenda, the Convention on Biological Diversity, the Paris Agreement, the Sendai Framework and UNCCD, without the counterproductive recommendation that integration should first occur across all mechanisms and activities.

Increased coherence brings gains in efficiency and effectiveness, as discussed below, but it is not without costs. It can result in trade-offs between investing in climate change adaptation and DRR and making progress on individual policy processes (Daze et al., 2018). The integration of DRR, climate change adaptation and mitigation can occur in a continuum, from strategic to technical to operational (OECD, 2020b), where policy coherence should be a process of systematic alignment coordination (UNFCCC, 2017).

## 3.3.3

### Advancing system transitions for drought-related resilience

The transition from risk to resilience implies incremental adjustments and rapid, sometimes disruptive, transformative changes. Such transitions could have consequences for livelihoods that depend on agriculture and natural resources (IPCC, 2019). Much of the complexity in drought risk arises from the degree of exposure of vulnerable people, industries and ecosystems. This exposure and vulnerability can be reduced by transitioning systems at multiple scales – as part of reducing drought risk.

Diverse adaptation options exist that can be seen as pathways for such a transition. For example, in Israel, technological adaptations to a given water endowment include drip irrigation, reverse osmosis desalination and wastewater treatment (Kramer, 2016). The Greater Tel Aviv Wastewater Treatment Plant (Shafdan) treats approximately 400,000 $m^3$ of wastewater per day for 11 cities and towns with more than 2.5 million people. The plant also uses the surrounding sand dunes to perform the final, tertiary phase of treatment.

Additional approaches include mixed crop–livestock production systems, especially if achieved via farmers adopting new behaviours, and reinforcing long-standing water-efficient practices rather than through large-scale infrastructural interventions. An example of the latter strategy is the *johads* of northern India, which are community-owned, traditional rainwater storage wetlands. *Johads* collect and store water throughout the year for direct use by humans and livestock, and recharge groundwater that supplies nearby water wells. *Johads* also provide refuge to wildlife such as resident and migrant birds.

Countries also employ a range of approaches and tools for spatial planning. Some, including Germany and South Africa, have developed comprehensive national planning frameworks that integrate biodiversity. Many countries have biodiversity offsets and “no net loss” policies and programmes in place;

these include Brazil, Cameroon, Guinea, Madagascar, Mexico and Mongolia.

Maintaining vegetation cover can promote ecosystem resilience and protect against drought impacts. More than half of the land-derived atmospheric moisture comes from transpiration by plants and particularly forests, although the precise fraction remains contested (Jasechko et al., 2013; Wei et al., 2017). Research has shown local climate and water cycles can be non-linear. On the positive side, rainfall in some landscapes can be stabilized and regained by land-use management and restoration of tree cover. A recent study by the World Resources Institute determined that restoring 3,000 ha of native forest around targeted locations in Rio de Janeiro would avoid costs of $79 million over 30 years, as well as avoid an estimated 3.6 million tonnes of chemical products and 260 thousand MWh of energy in water treatment over the next 30 years (Feltran-Barbieri et al., 2018).

A better understanding of the increased risk of climate instability and drought on deforestation and land degradation, and the benefits of an integrated and inclusive approach to prospective risk reduction, may help improve the case for a change of direction.

### *Integrated landscape transitions*

The idea of managing resources in an integrated fashion is not new (White, 1977; Lackey, 1998; Sayer and Campbell, 2001; Gleick, 2018b). Calls to consider water holistically go back decades, as do recommendations to manage drought with interdisciplinary tools and organizations, and include a wide range of voices in decision-making. Holistic water management has been codified in many settings – including at the 1977 United Nations Water Conference and the 1992 International Conference on Water and the Environment (Gleick, 2018b). While there have been difficulties with defining and implementing IWRM, the approach has been described as “a holistic, ecosystem-based approach which, at both strategic and local levels, is the best management approach to address growing water management challenges” (Gleick, 2018b).

Integrated watershed and land-use planning, including in the transboundary cases cited in Chapter 2, are coordinated through multiple government levels. Effective planning can balance property rights, wildlife and forest conservation, and encroachment of settlements and agricultural areas, and it can reduce conflict (Metternicht, 2018). In successful cases, actions are spatially integrated by exploiting natural variations in climate while incorporating local and regional economies (Harvey et al., 2014), rather than physically separating activities (e.g. agriculture, forestry, grazing).

In an assessment of 166 initiatives in 16 countries, integrated landscape initiatives were found to address the drivers of agriculture, ecosystem conservation, livelihood preservation and institutional coordination. However, such initiatives struggled to move from planning to implementation due to lack of government and financial support and the sidelining of the agenda by powerful stakeholders (IPCC, 2014b, 2014c; Zanzanaini et al., 2017).

Land-use management, land restoration and modification of cropping patterns to retain soil moisture are frequently cited as ways to build resilience against droughts (as discussed in Chapter 2). Land-use planning can also enhance management of areas prone to natural hazards, such as droughts and floods, and help resolve issues of competing land use and conflict (Metternicht, 2018). Gerber and Mirzabaev (2017) summarize several recommended requirements and approaches for improving land use in the context of drought as follows:

- More-secure land tenure and better access to electricity and agricultural extension facilitate drought risk mitigation. This is observed in agricultural households in Bangladesh, with access to land tenure, markets and credit significantly increasing farmers’ drought resilience in Morocco.
- Improved access to credit helps households to cope better with drought impacts and manage financial shocks incurred. For example, farming households in Ethiopia need not sell their

productive assets, which in many rural households tend to be livestock, and which may be wiped out during droughts. Developing access to financial services and alternative savings mechanisms can therefore mitigate drought-related vulnerability.

- Diversification of livelihoods and divesting of livestock assets – neither of which are trivial actions – are frequently employed to reduce vulnerability and risk to drought. Households in China and Zimbabwe have adopted off-farm activities, and farmers in Burkina Faso elected to divest rather than lose livestock assets.
- A strong asset base and diversified risk management options are key characteristics for facilitating flexibility. For example, in drought-resilient households in Kenya and Uganda, flexibility arises from households having better education and greater knowledge of coping actions against various hazards. This allows them to diversify their income sources.

On one hand, a State-centred model poorly captures local agile responses to emerging complexities. On the other hand, a market approach can fail to incorporate institutions that foster intersectoral cooperation and communication, impose infrastructure costs on future generations, or capture what are in fact public goods through supply, price and access (Blatter and Ingram, 2000; Ascher, 2007). Effective governance of fluid resources is increasingly and necessarily founded on the cooperative interrelationships of diverse institutions (Blatter and Ingram, 2000). Thus, successful public–private efforts must engage NGOs and civil society partners at equal levels. Box 3.2 presents an example of an emerging public–private–NGO collaboration.

Similar public–private–civil society collaborative efforts are being developed and are displaying the ability to learn as new problems and contexts arise. For instance, the Sustainable Modernization of Traditional Agriculture (MasAgro) project of Mexico's Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food, in close collaboration with the International Maize and Wheat Improvement Center, was recognized by the Monterrey Institute of Technology and Higher Education as being one of 10 projects that are transforming Mexico.

The MasAgro programme began with a relatively narrow technology focus, and evolved towards an innovation system approach. The adaptive management of such a process was in response to context-specific challenges and opportunities. In the heterogeneous context of Mexico, this results in diverse ways of operationalization at the hub level, leading to different collaborating partners and technology portfolios (Camacho-Villa et al., 2016). In MasAgro, a hub is seen as a network of value chain actors from a particular agroecological region who work together on sustainable solutions in maize- and wheat-based farming systems.

### *Barriers to transitions*

Society-wide transformation involves socio-technical transitions and socioecological resilience (Gillard et al., 2016), including acknowledging, agreeing on and removing barriers within social and institutional processes (Pant et al., 2015; Geels et al., 2017; Ickowitz et al., 2017). Adopting integrated approaches to land-use planning for reducing drought-related risks entails coherence in policies on: agriculture; forestry; rural, urban and infrastructure development; and alignment for comprehensive spatial planning. These approaches include energy system transitions, land and ecosystem transitions, urban and infrastructure system transitions, industrial systems transitions and overarching adaptation options to support these transitions.

Barriers to land-based mitigation for DRR and climate change adaptation include opposition due to real and perceived trade-offs between land for mitigation and for food security. Approaches require higher land-use intensity compared to other mitigation options, which, in turn, place greater demands on governance. Imbalances can arise due to uncertain land and water rights, and the absence of trusted partnerships and sharing mechanisms, among other factors. A key governance mechanism that has emerged in the past decade in response to such concerns is the use of standards

**Box 3.2. Turning degraded pastures into productive land in Brazil: the Syngenta / The Nature Conservancy / Brazilian Agricultural Research Corporation case**

Several regions of Brazil have experienced droughts in recent years, which have affected water, food and energy security. They have also influenced crop yield productivity, for instance, by reducing soybean and corn output. The Brazilian Panel on Climate Change projects that climate change will have an even greater impact on the country's agriculture in the future. Rainfall patterns could change drastically, increasing by up to 30% in the south and south-east of the country, while decreasing by as much as 40% in the north and north-east. However, the south is also expected to experience more droughts, and irrigation will become necessary to maintain productive yields. Temperature increase is also expected to lead to an increase in fungal diseases and pests.

Launched in 2020, the Reverte programme aims to regenerate 1 million ha of degraded pastureland into productive agricultural land by 2025 in the Cerrado biome in the highlands of central Brazil. The Cerrado biome covers around 200 million ha or approximately 25% of the Brazilian territory, representing the second-largest biome in South America after the Amazon. Comprising forests, savannahs and grasslands, the biome is rich in water resources and is an important natural carbon sink, thus making its conservation critical.

The programme allows farmers and cattle growers to sustainably expand agriculture into lands that are already open without tree cover, but uncultivated due to soil degradation. To ensure agricultural expansion into recovered pastures generates environmental benefits, The Nature Conservancy and Syngenta – supported by the Brazilian Agricultural Research Corporation – are taking a holistic approach, working on four fronts:

- Agronomic systems: The programme seeks to encourage the adoption of best agricultural and agronomic practices to recover degraded land in an environmental and science-based way. An important element is thus training farmers on production protocols (e.g. crop rotation, inputs, technology, management practices and crop–livestock–forest integration systems, including soybean, corn and associated crops) to restore degraded pastures, allowing farmers to produce food, fibre and energy sustainably.
- Financial solutions: The lack of financial means is the most significant barrier for farmers to convert degraded land. Substantial investments are needed in the first year (for fertilizers, machinery, insurance and digital agriculture tools), yet it takes about 3–8 years to recoup the investment. Therefore, it is essential to identify financial partners that can provide long-term competitive credits to support farmers in adopting the programme, with conditions suited to their economic realities.
- Public and private sector engagement: All partners in the value chain need to agree on shared objectives and actions to support the conversion of degraded pastures into productive areas that foster economic, social and environmental development.
- Business models: The programme aims to demonstrate the economic viability – in terms of increasing land value and improving land productivity – of reclaiming land rather than opening new areas for cultivation. These positive and lasting results should help shift towards innovative agriculture business models that favour regenerative and sustainable agricultural practices, improve livelihoods and mitigate environmental impacts.

and certification systems that include food security, and land and water rights, in addition to the use of indicators related to sustainable use of land and biomass, with an emphasis on participatory approaches. Other governance responses include linking land-based mitigation (e.g. forestry) to secure tenure and support for local livelihoods.

Barriers to land-based mitigation include development pathways that can quickly close windows of opportunity. Other barriers can arise when adaptation in the short term to a climate stress (e.g. increased dependence on groundwater during droughts) ultimately proves unsustainable in the longer term, and becomes a maladaptation, despite the near-term benefits derived for some individuals. Each of these transitions relies on advances made in addressing other complementary transition areas such as biodiversity, water, food and energy.

In many countries and most (agricultural) productive systems, the managers of systems responding to drought are numerous, widely variable in capacity and resources, and somewhat disconnected from the risk management systems. Their interaction with policy / systems / frameworks will be through their bankers or other forms of agribusiness, public or private advisers, NGOs and so on. Systems and behaviour change will be complex and unpredictable – and that needs to be part of the systems analysis.

### *Removing barriers*

Combinations of policies that target multiple barriers and enabling factors simultaneously have long been shown to be effective (Campbell, 1969; Nissinen et al., 2015). At least five factors appear necessary, if not sufficient, for success:

- Developing a shared vision of risks, drivers and opportunities.
- Broadening actor networks and collaborative partnerships and actions at different scales. Encouraging distributed decision-making and participation in governance at all scales including policy and social entrepreneurs and shadow networks of change agents to navigate transformation and take advantage of windows of opportunity.
- Fostering behaviour change and demand-side management, which can significantly reduce pressures on resources and adaptive buffers, substantially limiting the reliance on externally driven interventions.
- Acknowledging that some actors may legitimately have preferences, concerns or outlooks that value dimensions other than least cost or technical efficiency.
- Expanded collaborative use of cultural, economic and environmental incentives for improving partnerships, water-use efficiency and demand management, and for the development of climate services to inform water-related management as new threats arise.

Sufficiency would include a stronger focus on enabling governance and decision-making across all five factors at different levels in a given context.

Crafting, implementing and evolving enabling capabilities for innovation for systemic risk governance involve formal, strategic and systematic coordination across actors (public and private sectors and civil society) and levels of governance beyond ad hoc projects. To do this, the benefits of participation – including co-benefits for other public goods, and the costs of action and inaction must be assessed and articulate, accompanied by a compelling narrative/vision for a better future which put people first. Hall et al. (2003) note economic assessments need to be complemented by an analytical framework that recognizes systems of reflexive, learning interactions and their location in, and relationship with, their institutional context.

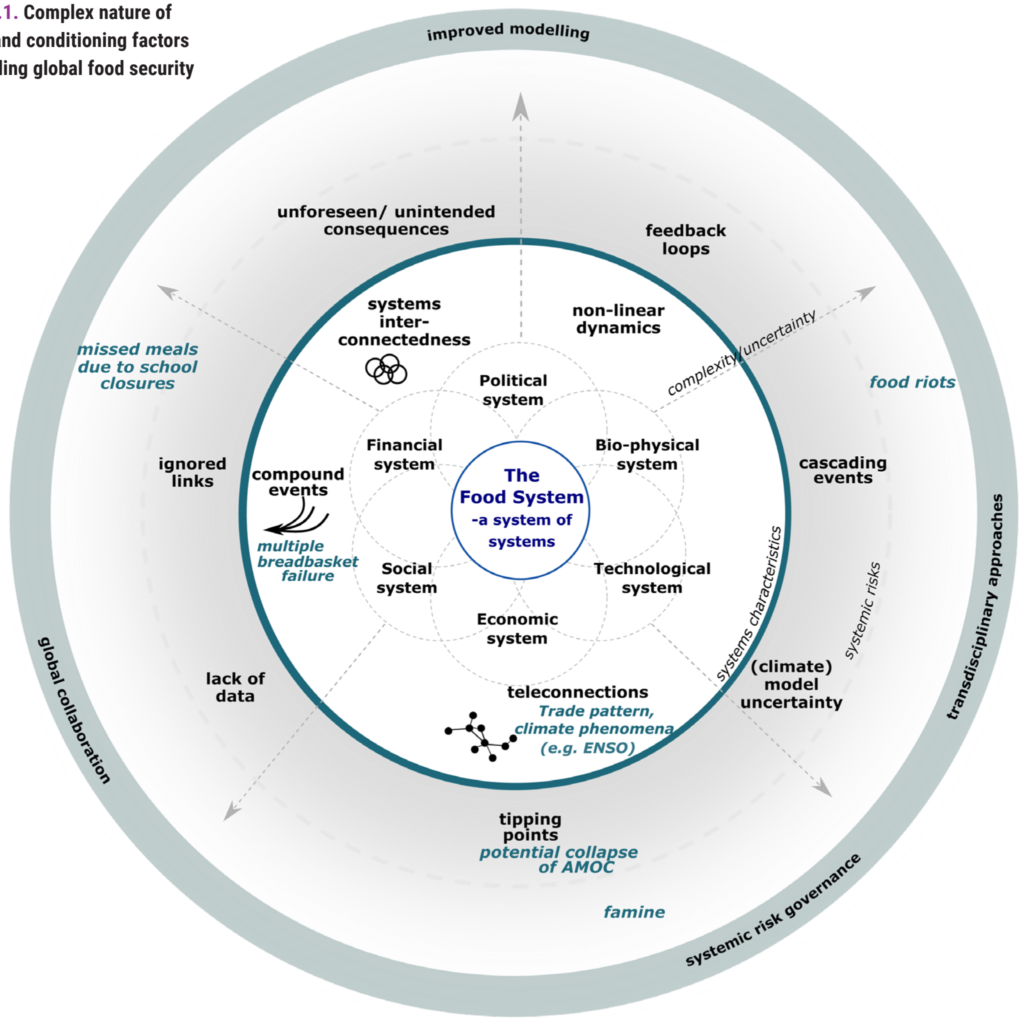
## 3.3.4

### Developing a shared vision: visualizing systemic risks

This section describes advances in conceptualizing, understanding and identifying paths and entry points for navigating a complex, changing system with multiple drivers and scales. Much research has shown that such navigation requires forms of visualization and joint articulation (e.g. Essential Two of the Ten Essentials of the UNDRR Making Cities Resilient campaign). A broad competency commonly used in action-oriented domains is that of visioning: using scenarios, foresight exercises and back-casting to identify potential routes from the present to a desired future, and to inspire and motivate action (EEA, 2018).

Emergent risks are typically obvious in retrospect – a result of a series of events that cross human-imposed boundaries, whether institutional, geographical, disciplinary, conceptual or administrative (UNDRR, 2019). There are emerging examples

**Figure 3.1. Complex nature of drivers and conditioning factors surrounding global food security**




*Note*: AMOC: Atlantic meridional overturning circulation.

*Source*: Gaupp (2020). This figure was published in *One Earth*, vol. 2, no. 6, Gaupp, F., Extreme events in a globalized food system, pp. 518–521, Copyright Elsevier (2020) of visualizing complex drivers, characterizing historical experience in current context, and improving the use of scenarios and gaming strategies for drought and wider climate change contexts.

The process of visualizing dependencies and key nodes requires representing critical trends such as population growth, migration and projected economic development, and highlighting their impacts under varying trajectories (WWF, 2019). For example, Figure 3.1 illustrates the complex nature of drivers and conditioning factors surrounding global food security. Factors highlighted include globally networked risks, shared surface water and groundwater resources, external land ownership, rural depopulation and loss of off-farm food production facilities.

Characterizing potential future influence of environmental, economic and social drought-sensitive drivers – such as land use and sustainability – is critical for guiding strategic decisions that can help nations adapt to change, anticipate opportunities and cope with surprises. The main benefits of a scenario approach are exploration of the nature of trade-offs that can arise and including them in system management. This provides a useful lens through which to view tracking / monitoring of actual trajectories.

In a globally interconnected world, shocks in one or several parts of the system can lead to ripple effects around the world through trade networks (IPCC, 2012; WEF, 2015; Sovacool, 2016; UNDRR, 2019; WEF, 2020). As illustrated in Chapter 1,

**Figure 3.2. Emerging risks experienced in the Caribbean as result of interactions of extreme events, Covid-19, and social, economic and political transformations**

**Current context**

- 90% of Caribbean economies and cities are costal areas
- Poor (coastal) infrastructure
- Low agricultural production and high imports (G)
- Dependence on foreign tourism and remittances
- Vulnerability to weather-climate extremes
- High debt to GDP ratio

**Multiple stressors**

- Inter-regional displacement
- Strong dependence on external markets
- Reduced remittance flows
- Potable water access
- Food insecurity
- Low demand on tourism services
- Sargassum development
- Impact, relief & recovery cycle/limited proactive investments
- Low level of insurance
- Adequacy of medical facilities
- High mental stress levels

**Potential multiple systemic failures**

- Pandemics
- Unavailability of services and good for basic needs
- Inaccessibility of disaster sheltering (social distancing measures)
- Overwhelmed disaster response capabilities
- Reduction of financial capabilities to meet basic needs
- Continuous disruption of basic services

**Tipping points/transitions**

- Unusually active hurricane season (potential for multiple hurricane impacts)
- Supply chain disruption
- Potable water supply for tourism services during the dry season
- Post disaster migration
- Inter-regional displacement
- Further dependence on remittance flows

*Source*: Adapted from ECLAC/UNDRR (2021)

interrelated hazards such as droughts and heatwaves, or droughts and subsequent wildfires, so-called "compound events", might have disproportionally severe impacts on food production or health (Zscheischler et al., 2018; Gaupp, 2020).

A key recent lesson learned is that unanticipated global factors, in some cases unrelated to the hazard being addressed, can intervene to undermine regional, national and local resources and capacity for disaster risk planning and management. The Covid-19 pandemic is a good example of this, demonstrating the interdependence, complexity and inequality created by the global systems linked in driving the catastrophe (Alcantara-Ayala et al., 2021).

The Caribbean region is one among many that demonstrates how the Covid-19 pandemic has exposed the vulnerability of health, economic, social and financial systems in the region. The economies of the Caribbean islands share a common set of environmental, economic and social vulnerabilities – explained notably by their small size and geographic location – and were already at risk from numerous hazards, notably hurricanes and droughts (see Box 3.3). Coupled with historical and inherent drivers of risk – such as fragile informal networks, inequality, poverty and lack of political representation –the most vulnerable have been disproportionately affected (ECLAC/UNDRR, 2021). Location, age, gender, income group, disability, and access to or benefit from social protection schemes and safety nets greatly affect the choices people have to anticipate, prevent and mitigate risks.

Estimated and observed losses from Covid-19 represent a high proportion of annual capital formation and contribute to sluggish longer-term growth (ECLAC/UNDRR, 2021). Figure 3.2 shows that the drivers of impacts from Covid-19 and cascading effects – including on the capacity to respond to disasters related to the Caribbean – stem from outside the region and through external transmission channels. These include the decline in the economic activity of the region's main trading partners and cascading effects such as the lowering of demands for tourism services due to the synchronized downturn of economies around the world, the decline in remittances, and the interruption of global value and supply chains.

**Box 3.3. Compounding hazards and risks in the Caribbean**

The 2013–2016 Caribbean multi-year drought was the most-severe and most-extensive period of dry conditions in the Caribbean/central America region since at least before 1950. Food and water shortages were widespread throughout the region. The multi-year drought appears to be related to precipitation deficits driven by El Niño events and also to temperature-driven increases in potential evapotranspiration. Global warming of 2.0°C above pre-industrial levels is estimated to result in further significant changes in regional climate, which moves the region closer to climates it has not experienced to date (IPCC, 2018). The 2013–2016 drought was then followed by one of the most devasting hurricane seasons on record, with 22 Caribbean States affected, 13 by two storms and 5 by three storms, resulting in significant internal displacement. In addition, the region has had to contend with significant increases in migration into the Caribbean islands from Venezuela as result of political upheaval and a major drought that have affected food and financial security.

## 3.3.5

### The role and use of scenarios

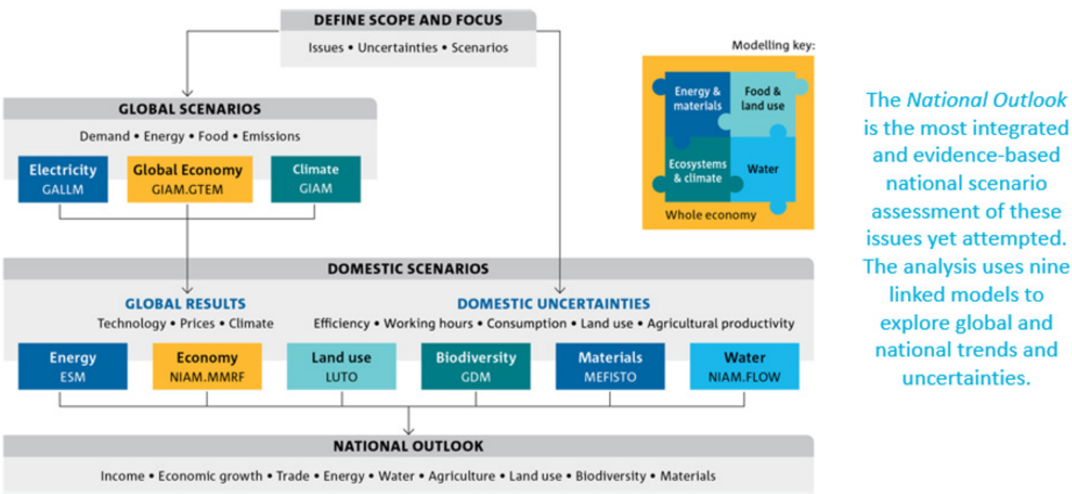
While not suggesting a single "ideal" approach for achieving maximum shared gains, scenarios may help to demonstrate the considerations that can inform decisions based on global, regional, national and local priorities. Their main purpose is to generate perspectives regarding future developments through consideration of relevant critical driving forces (Hickman et al., 2012). This is particularly challenging in capacity-constrained, data-sparse and disaster-prone settings, but can allow for identifying and addressing governance deficits by pointing to pathways of investment in institutions, information and infrastructure. Scenarios of plausible futures can be a valuable part of managing complex systems, depending on how the scenarios are constructed and how they are used.

Useful scenarios for this purpose have the following characteristics. They:

- Start from an adequate model of the current and historical situation
- Are constructed to envelope the range of potential drivers of system change
- Describe the essential features of a comprehensive range of plausible futures
- Allow exploration of the drivers of change, the nature of trade-offs and the options for intervention

Importantly, such scenarios are not and should not be interpreted as predictions of the future. Done well, they allow exploration of a set of plausible futures.

**Figure 3.3. Overview of the Australian National Outlook Analytical Framework, and project flow**




*Note*: ESM: energy sector model; GALLM: global and local learning model; GDM: generalized dissimilarity model; GIAM: global integrated assessment model; GIAM.GTEM: global trade and environment model; LUTO: land-use trade-offs; MEFISTO: material and energy flows integrated with stocks; NIAM.FLOW: national integrated assessment model – surface flows; NIAM.MMRF: national integrated assessment model – Monash multi-regional forecasting model.

*Source*: CSIRO (2015); reproduced with permission

As an example, in 2015, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia released the Australian National Outlook (CSIRO, 2015; Figure 3.3). The outlook presented a set of plausible scenarios based on a loosely coupled model of the Australian economy and environment in a global setting and a range of policy and society options for improving outcomes for Australia over the next few decades. At that initial stage, the outlook essentially presented scenarios and identified the trade-offs associated with a range of possible trajectories (Hatfield-Dodds et al., 2015; Grundy et al., 2016).

The next stage was published in the second Australian National Outlook (CSIRO, 2019). Here, the scenarios, with some relatively minor improvements in modelling, were used by a group of Australian decision makers to agree on likely and preferred outcomes for the Australian economy, society and environment, and to identify choices to move along preferred trajectories. The group comprised leading Australian and multinational financial, manufacturing and agricultural industries, government representatives, community groups and NGOs. It was led by the National Australia Bank and CSIRO. The characteristics of a desirable and plausible future were agreed, the nature of the choices (or levers) available to decision makers in Australia defined, and a series of necessary "shifts" in industries, cities, energy, land and Australian culture described. Scenarios informed what shifts were needed and the degree of change required. A set of immediate actions was then agreed among the group members.

The nature of the system addressed by the Australian outlooks is complex, and none of the decisionmaking group expected the future to closely reflect the scenario trajectories. The value has been in providing a lens to identify critical entry points for guiding the decisions needed, to understand and test assumptions, and to provide the impetus to follow the impact and iteratively adjust the settings.

## 3.3.6

### Storytelling, serious gaming and scenathons

Due to a lack of historical data and to the potential for surprises, traditional risk assessment methods cannot account for unprecedented events such as projected extreme temperatures under certain climate scenarios. Gaming has been used for decades in military planning and in intelligence services to explore decision-making possibilities in environments with incomplete or imperfect information (Herman et al., 2009). More recently, it has been tested in the drought risk planning arena (Hill et al., 2014).

A value unique to all such games has been the occurrence of previously unknown issues, insights or decisions that arise during a game. Games have qualities that separate them qualitatively from straightforward analysis and permit them to generate insights that could not be acquired through analysis, reflection and discussion alone (Schelling, 1987).

Recent applications of approaches such as storytelling techniques (Hazeleger et al., 2015), "serious games" (Solinska-Nowak et al., 2018) and extended "scenathons" (Thomson, 2018) can help to explore plausible future scenarios.

#### *Storytelling*

Storytelling in topics related to climate change refers to the visualization of synthetic climate simulations and their plausible impacts on nature, technology and the society (Lloyd and Shepherd, 2020). Instead of assigning probabilities, storytelling explores plausible future scenarios based on expert knowledge. Understanding the development and evolution of single significant or landmark past drought events, and the conditioning factors that drive extreme impacts, is also needed to avoid relying solely on generalized models that can produce a false sense of security in uncertain and, in some cases, unpredictable situations. Storytelling also offers the opportunity to map and articulate local views and possibilities for helping with cultural continuity and practices associated with landscapes and key species (Hiza-Redsteer et al., 2013; Pulwarty and Verdin, 2013).

Input to these approaches requires fine-grained reliable descriptions, in space and time, of the social–ecological–technological moving parts of a system, together with fine-grained descriptions, also in space and time, of extreme weather events. The "storyline" approach to extreme event attribution and the probabilistic "risk-based" approach have uses in such descriptions. However, co-developed stories or narratives are more readily aligned with the forensic approach to evidence that is prevalent in the ecological literature, cultivating heuristics (expert-based rules of thumb) and detailed methods for analysing causes, mechanisms and potential surprises (Allen et al., 2010; Lloyd and Shepherd, 2020; Pulwarty et al., forthcoming).

#### *Serious gaming*

Serious gaming include a wide range of methods, practices and theories such as simulations, virtual reality, experimental learning, case studies or modelling. The adjective "serious" is used to distinguish such games from entertainment vehicles. By combining game elements with systems analysis and simulation techniques, serious games are a useful tool in drought risk management as they provide players with rich social experiences of hypothetical events and make them collectively solve problems (Hill et al., 2014). They help policymakers, local action groups or other stakeholders in drought-related topics to raise awareness, understand hazards, assume different perspectives and explore preventative actions. Serious gaming brings together science-based assessments, local and traditional knowledge, practice and implementation.

#### *Scenathons*

A promising advance in these approaches is the use of "scenathons". Scenathons are "scenario marathons" and social learning experiments that help facilitate negotiations among differentially empowered and unequally resourced stakeholder groups. They are designed to simulate negotiations among different parties using model-informed plausible projections of future climate or land-use systems. In one illustration, the Food, Agriculture, Biodiversity, Land-Use, and Energy (FABLE) Consortium was convened as part of the Food and Land-Use Coalition, which aims to understand how countries can transition towards sustainable land-use and food systems. The FABLE consortium applied the scenathon process to allow country teams to align national pathways iteratively and collaboratively with global FABLE targets and to balance trade flows (FABLE, 2019).

Given the above discussion on the challenges to traditional approaches of risk management and of governance, the following section defines and advances the concept of adaptive governance in the context of drought-related systemic risks.

# 3.4

# Adaptive drought risk management and governance

Decision-making that takes account of multiple values, uncertainty and sequencing of implementation is maturing. Further innovation and experience are needed to ensure these approaches are inclusive and applicable to a wide range of contexts. This is particularly challenging in capacity-constrained, data-sparse and disaster-prone settings. Institutional reforms are needed to create rules and incentives for fair and efficient allocation across multiple sectors and scales. The balance and sequence of reforms in this iterative process will vary by context. Above all, more inclusive, transparent and flexible governance architectures are needed to spur collective action and to reconcile knowledge, expectation and values, commensurate with the challenge of sustainably managing resources, ecosystems and human well-being.

Given increasing rates of change and the potential for surprises, including the rapid transition from severe sustained drought to desertification, it has become necessary to orient drought-resilient pathways towards enabling faster transitions to sustainability (Kern and Rogge, 2016; Ehnert et al., 2018).

To promote coherence of actions, transitions require coordinated, mutually reinforcing policy action across supra-regional, national, regional and local governance levels, underpinned by enhanced multilevel dialogue and improved flow of information and resources in both directions.

Addressing globally networked risks that can drive issues of equity and environmental degradation requires multilateralism and cooperation. Evolved international cooperation and empowered global institutions are key to effectively dealing with systemic risks.

On national and subnational scales, governance should enable coordinated and evidence-based drought response, such as through the national drought policy 10-step programme described in Chapter 1. However as discussed in this report, focusing on the national level alone is inadequate for addressing multidimensional, drought-related systemic risks.

## 3.4.1

### Characterizing adaptive risk management and governance

**KEY MESSAGE**

- **An adaptive approach to risk management and governance that bridges structural and systemic changes and enables capacity, prototyping, learning and action at multiple scales is needed.**

#### *Structural and systemic approaches*

A key challenge to developing approaches capable of managing the systemic nature of risk is to distinguish between the differing needs for characterizing and governing structural versus systemic risks and their associated assumptions. Scoones et al. (2020) frame structural approaches to reinforce the prevalent economic and political processes and associated interests that serve to perpetuate current conditions. The lack of emphasis on environmental triggers and processes, individual agency and possibilities for incremental change that can address critical nodes in the system may downplay the roles of complexity and serendipity.

Systemic approaches focus on intentional change targeted at the interdependencies of specific institutions, technologies and constellations of actors, to steer complex systems towards normative goals. Approaching risk management from a systemic perspective exposes interdependencies, connectivity across scale and geography, and the potential for non-linear shifts in system dynamics across scales.

These approaches emphasize the role of ecological dynamics in social change and vice versa, and seek fundamental changes in the way production and consumption is governed, organized and practised by societies. Large-scale systemic approaches by themselves have been criticized for an overly managerial approach, and a de-emphasis on individual agency and the possibilities for anticipating windows for incremental change and emergent opportunities. Adaptive risk management and governance of systemic risks require an awareness and understanding of the dynamic and co-evolving nature of drought and society such that when aligned, they help to transition to and increase resilience of structural and systemic factors.

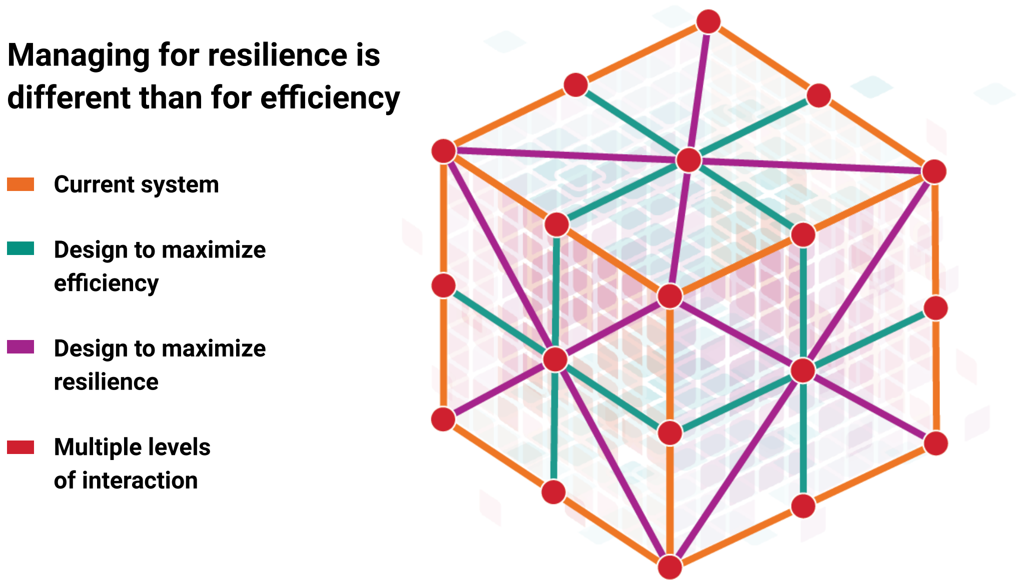
### *Governance*

**KEY MESSAGE**

- **Adaptive governance aims to deal with uncertainties and surprises inherent in transforming complex social, technological and ecological systems. It relies on iterative learning, planning, policymaking implementation and evaluation over time (U.S. Global Change Research Program, 2018; EEA, 2019).**

Governance has many connotations. In its broadest and most common form, it denotes the structures and processes for collective decision-making (Nye and Donahue, 2000). It is also described as a different way of governing in which the State is not the only actor (Stoker, 1998). However, as Giddens (1999) noted, strengthening the role of mediation, levelling the playing field and guiding equitable resolutions to conflict remains in the purview of the political – including governmental or parliamentary – processes. Improving governance can

**Figure 3.4. Simplified illustration of the differences between designing for efficiency as opposed to resilience at multiple scales of interaction**




*Source*: Adapted from ECLAC/UNDRR (2021)

lead to new and better forms of regulation that go beyond traditional hierarchical state activity, implying "some form of self-regulation by societal actors, private-public cooperation in solving societal problems and engendering new forms of multilevel policy" (Biermann et al., 2009).

While profound changes in capacities and structures are increasingly recommended and required, these are not always readily achieved in practice. The attendant complexities of adaptation are usually underestimated.

Such changes involve paying attention to capacities, learning, evidence-based policymaking, innovation, leadership and behavioural change.

### *Risk governance*

Risk governance has been defined as "the totality of actors, rules, conventions, processes and mechanisms concerned with how relevant risk information is collected, analysed and communicated, and management decisions are taken" (IRGC, 2018). It is usually associated with how to enable societies to benefit from change – so-called "upside risk" or opportunity – while minimizing downside risk or losses (UNDRR, 2019). In contrast, systemic risk is usually seen as downside risk. The realization of systemic risk leads to a breakdown, or at least a major dysfunction, of global systems (e.g. the food system). Assessing, communicating and managing – in short, governing – systemic risk is compounded by the potential for losses to cascade across interconnected socioeconomic systems, to cross political borders, to irreversibly breach system boundaries and to impose intolerable burdens on entire countries. Risk governance is also confounded by almost intractable difficulties in identifying causal agents and assigning liability.

Sustainability in the context of systemic risks involves better understanding of the factors that can leverage fundamental changes in institutions, governance, values and behaviour. This is essential to bringing about positive and equitable transitions while allowing for seemingly redundant or overlapping structures. In this characterization, the redundancy provided by having multiple nodes of support (vertically and horizontally) offers backup, partial rather than complete failure when overwhelmed, and key nodes for interventions to maintain system integrity or to meet new and emergent values.

The Global Risk Assessment Framework (GRAF), initiated by UNDRR, offers a platform for exchange between users of risk knowledge and insight, between producers of risk knowledge and insight, and between users and producers. It was established to support governments, the private sector and financial institutions to achieve the outcomes, goals and targets of the 2030 Agenda, Paris Agreement and the Sendai Framework. GRAF aims to improve the understanding and management of current and future risks. This includes further understanding the need for cross-layering and latticing at all spatial and temporal scales (Figure 3.4).

Transitions require policy action at all levels of governance. Ensuring they reinforce each other requires vertical coordination and mapping of responsibilities, inconsistencies and barriers. Promoting top-down and bottom-up processes of governance requires new mechanisms to promote dialogue among different levels and increased flows of information and resources.

## 3.4.2

### Enabling capabilities for developing and sustaining multi-scalar drought-related resilience and governance

A range of approaches to sustainability transitions have been proposed (Markard et al., 2012; Kern and Rogge, 2018; EEA, 2019; GCA, 2019). Although some have been tried, several key questions remain. As transitions are major shifts with landscape implications critical in the case of drought, they are opposed by existing dominant interests, institutions and organizations that seemingly benefit in the short run from the status quo.

Path dependence at multiple levels is affected by sunk infrastructure costs and entrenched practices such as through professional societies and their conventions, traditions of land tenure, paradigms of systems categorization and economic growth. Hence, path dependence stifles adaptive capacity and innovation. Thus, the strategic challenge for transition governance is to orient emerging innovations towards systemic change while simultaneously opening up (or breaking down) unsustainable regimes and institutions. When capacity is increased in diverse communities, increased learning capability can lower the need to precisely predict thresholds and improve understanding of system dynamics such that tipping points might be better prepared for (even if not predicted).

#### *A new view of data*

Reliable and accessible data is needed to inform decision-making and provide windows for investments and actions. Additionally, credible and accessible knowledge and decision-making tools such as DEWSs need to be people centred. Often considered only as technical and scientific instruments, these tools can empower vulnerable sectors and social groups to mitigate loss and damage through the introduction of their own local knowledge and experience (IPCC, 2007, 2019; UNDRR, 2019).

#### *Enabling transformative partnerships*

Innovation requires transformative coalitions and partnerships. Research and the private sector are crucial, but "open innovation" policies will, of necessity, target users, civil society, communities and other actors. More support for social and grassroots innovation can enable deeper and more transformative transition pathways.

The broad dimensions of effective governance frameworks include:

- Accountable multilevel governance that includes non-State actors, such as industry, civil society and scientific institutions
- Coordinated sectoral and cross-sectoral policies that enable collaborative multi-stakeholder partnerships
- Strengthened global-to-local financial architecture that enables greater access to finance and technology
- Climate-related trade barriers
- Improved climate education and greater public awareness
- Accelerated behaviour change, including towards recycling and reducing the water footprint
- Strengthened drought monitoring and evaluation systems
- Reciprocal international agreements sensitive to equity and SDGs

The importance of broadening community participation is well established (Bryan et al., 2014, 2016; Graham et al., 2015; Wangui and Smucker, 2017). Different modes of cross-stakeholder interaction and actor networks strengthen institutional capacity for governing systemic risks. These include the role played by large multinational corporations, small enterprises, civil society and non-State actors. Horizontal collaboration (e.g. transnational city networks) and vertical collaboration within nations can play an enabling role (Ingold and Fischer, 2014; Hsu et al., 2017; Ringel, 2017; EEA, 2019).

### *Partnerships and governance*

Effective governance of complex threats does not occur without effective partnerships – across communities, watersheds and landscapes in the case of drought. Scoones et al. (2020) note that an enabling approach by itself (i.e. without a broader governance framework) may neglect significant structural or political obstacles to social transformation and burden those facing greatest vulnerability with the tasks of transformation. Where they have occurred, enabling initiatives need to be collaboratively mapped and analysed thoroughly in relation to the barriers to and opportunities for how collaborative networks and partnerships have been developed or dissolved.

Active scanning for opportunities and entry points to effective governance is needed for leveraging justice and respect for human rights, and inclusion of indigenous peoples and local communities in problem framing and decision-making vital to all the transitions, particularly those taking place in diverse landscapes.

Numerous and diverse countries, subunits of governments and non-governmental actors, including civil society and private firms, all play independent or quasi-independent roles in governance arrangements (Keohane and Nye, 2000). These agents may create or exacerbate concerns of equity, transparency and power, which affect the opportunities, barriers and choices (e.g. land use, water demand, and energy sources and use) in transition policy. Integrative approaches to land use and climate interactions take different forms and operate with different institutions and governance mechanisms.

Applying levers for transformative change requires a process of systematic coordination at global to national, and national to local scales and back up the chain. Levers can be pursued and operationalized vertically at local, subnational, national, regional and global levels of government, and horizontally across sectors through collaboration across governments and intergovernmental organizations, the private sector, civil society organizations and citizens.

Different types of integration with special relevance for the land–climate interface can be characterized as follows:

- Cross-level integration: Local-, national- and international-level efforts must be coordinated with national and regional policies and be capable of drawing direction and financing from global regimes, thus requiring multilevel governance (see Table 3.1).
- Cross-sectoral integration: Rather than approach each application or sector (e.g. energy, agriculture or forestry) separately, there is a conscious effort at co-management and coordination in policies and institutions that rely on the products, services and sustainability of supply chains, such as at the energy–water–food nexus (Biggs et al., 2015).
- End-use/market integration: Often involves exploiting economies of scale across products, supply chains and infrastructure (Nuhoff-Isakhanyan et al., 2016; Ashkenazy et al., 2018). Examples include: integrated territorial planning addressing specific land-use decisions or local landscape participatory planning with farmer associations, microenterprises and local institutions identifying hotspot areas, identifying land-use pressures and scaling out sustainable land management response options (Liniger et al., 2019).

Major challenges to crafting and implementing effective adaptive governance include identifying and addressing governance gaps, and how governance emerges to deepen the understanding of public–private–civil society partnerships, standards and accountability for the flow of authoritative information, resources and financing (Koliba et al., 2011). Effective adaptative governance requires collaborative coordination of global efforts addressing systemic drought risk drivers and impacts. Such an approach requires a mechanism capable of working across the scales and features in Table 3.1, to layer the complementary benefits of addressing drought and underwrite common goals across currently unaligned components of the targets of the Sendai Framework, the Paris Agreement, the Aichi Biodiversity targets and indeed across all SDGs.

The central goals of the mechanism would be to build literacy about systemic risks, and strengthen dialogue, coherence and synergies among relevant partners and stakeholders engaged in managing globally networked and transboundary risks to reduce their influences as drivers of local imbalances (Wilder et al., 2020). The dimensions of such a global mechanism are outlined further in section 3.4.4.

### *Leadership, partnerships and trust*

Achieving ambitious targets requires leadership, enhanced multilevel governance, vision, widespread participation in transformative change and, most critically, processes for sustaining partnerships.

Different ways of developing knowledge based on co-production, transdisciplinarity, science–policy

**Table 3.1. Promoting vertical coordination of actions across global, regional, national, and local governance levels**

| Scale | Opportunities for sustainability transitions |
|---|---|
| **Global level** | • Enabling a coordinated response to global collective problems, for instance those arising from distributed impacts on the environmental commons (e.g. multiple and synchronous breadbasket failures) or globalization (of trade, financial flows, food systems, etc.)<br>• Addressing equity and redistribution issues (e.g. food production and food systems, drought and food relief, capacity-building)<br>• Making impact and efficiency gains by aligning and converging global and regional efforts to reduce systemic drivers of drought risk and corollary cascading impacts |
| **Regional level** | • Setting visions and targets for leveraging regional strengths and advantages to reinforce national capabilities<br>• Developing binding regulations and directives directly applicable to surface water and groundwater in transboundary States<br>• Coordinating reporting responsibilities in Member States to map and follow progress with transitions<br>• Investing in knowledge, infrastructure, skills, innovation deployment, etc., to guide transitions<br>• Leveraging data, information and knowledge networks |
| **National level** | • Coordinating funding for sustainability activities – especially ecosystem, groundwater and forested land protection – as buffers for major events<br>• Developing a large toolbox of potential knowledge and communication instruments such as drought early warning across timescales to foster transitions available<br>• Coordinating among sectors and across local–national disconnects through influence over local decision-making, for example, getting subnational regions on board (depending on national governance structures) and minimizing those slow to engage or opting out<br>• Setting regulatory and market rules for many transition-relevant sectors (e.g. water and agriculture), in line with regional or transnational agreements<br>• Shaping energy transitions and ensuring equity through targeted national infrastructure investments |
| **Local level** | • Providing space for experimentation and close collaboration with a broader network of local stakeholders, private sector and citizens<br>• Building an appetite for novel inclusive partnerships allowing contextual information to inform problem framing and learning approaches to solution exploration<br>• Building local political momentum and acceptance of needed actions<br>• Providing governance of key local systems and issues<br>• Implementing at local levels, for example, spatial planning (affecting habitats, industrial symbiosis, travel), buildings, public spaces, transport and waste |

*Source*: Adapted from EEA (2019)

interfaces, democratization of expertise and knowledge brokering can facilitate participatory and collaborative processes that integrate actionable insights and contribute to effective and legitimate solutions over time. The imperative for adaptive learning in cultivating such novel processes cannot be overstated, not least so as to be able to identify and mitigate the possibility of outcomes being co-opted or amplifying the problems they were intended to solve.

The 2030 Agenda has made explicit the need for engaging and working with all relevant societal sectors in bottom-up and top-down approaches and experience. The United Nations has adopted the following definition of sustainability partnerships:

> Multi-stakeholder initiatives voluntarily undertaken by Governments, intergovernmental organizations, major groups and other stakeholders, which efforts are contributing to the implementation of inter-governmentally, agreed development goals and commitments.
>
> (Stibbe et al., 2018)

A multi-stakeholder partnership is defined as:

> An ongoing collaborative relationship among organisations from different stakeholder types aligning their interests around a common vision, combining their complementary resources and competencies and sharing risk, to maximise value creation towards the Sustainable Development Goals and deliver benefit to each of the partners.
>
> (Stibbe et al., 2020)

Partnerships require different sectors and actors working together vertically and horizontally in an integrated manner by pooling financial resources, knowledge and expertise (Table 3.2). Cross-sectoral and innovative multi-stakeholder partnerships represent a critical means of implementation for achieving drought risk management and adaptive governance.

The key issues of representation and power asymmetries are often overlooked or poorly addressed, including who participates and with what values, which perspectives and interests do these participants represent, and how can all voices be heard and included in a procedurally legitimate way. Thus, the breadth of the actor network extends beyond those affected to the context in which they operate, including financial institutions and issue influencers.

The sustainability of partnerships is fundamentally determined by trust and shaped by the continuation of relationships being trusted among people. Rather than solely relying on external motivators for individual compliance (e.g. retribution and incentives), it is preferable to focus on internal motivators, including trust in others (Ostrom, 1990; Hamm et al., 2013; Stern and Coleman, 2015; Song et al., 2019). Stern and Coleman (2015) characterize four types of trust in collaborative frameworks:

- Rational trust, based on calculation of expected benefits and risks
- Procedural trust, in fairness and integrity of the procedures involved
- Affinitive trust, shaped by emotions, charisma, shared identities or feelings, but not always longer-term interactions
- Dispositional trust, signalling one's predisposition to trust another entity

These four types highlight the need for a multi-dimensional approach when trying to understand and form trust in collaborative arrangements. Song et al. (2019) conclude that rational trust, which pertains to calculated risks and expectations utility, strongly predicted goal consensus. Procedural trust based on process-based notions – such as integrity, fairness and perception of equity, justice and dignity – can partially compensate for a lack of informal interactions. Song et al. (2019) also found affinitive trust – informal and characteristic-based aspects of longer-term relationships, such as familiarity, respect and shared experiences – was least visible in analyses, but was most significant for influencing decision-making in binational resource management. This result follows from much earlier work on the role of trust and respect in preserving human dignity as keys for effective public policy (Lasswell, 1971; Ascher, 2017). Acknowledging the diversity of trust processes, and the central role of affinitive trust as defined by Stern and Coleman (2015) and Coleman and Stern (2018), is critical to successfully seeking inclusive participation and employing collaborative processes to pursue common goals.

**Table 3.2. Processes for sustaining horizontal partnerships and enabling capabilities**

| Processes | Enabling capabilities |
| --- | --- |
| **Collaborative vision building around local and globally driven drought-related risks, and developed through scenarios of potential pathways** | Provide a common vision that attracts a diversity of supporters upon which all can agree |
| **Facilitating knowledge building and utilization through collaborative problem framing, risk assessments and capabilities development** | Build / enhance knowledge of the people and resources, including ideas, viewpoints and solutions |
| **Developing and sustaining networks and collaborative learning across the drought-related actor networks and their influencers** | Bridge different and similar actors and stakeholders across and within organizational hierarchies and types; this could be divided into three subcategories:<br>• Bonding (link with similar others)<br>• Bridging (bring together similar and/or different groups to create momentum, gain support and react to various challenges)<br>• Linking (communicate and engage with key individuals in different sectors, and link across scales) |
| **Pursuing flexibility, openness and humility as a matter of respectful discourse** | Numerous studies and implementation experience conclude that flexibility, transparency and respect should be built into the collaborative process<br>Flexibility is important in the process to accommodate changing timetables, issues, data needs, interests and knowledge; building respect and openness involves accepting the diverse values, interests and knowledge – including local knowledge – of the parties involved |
| **Facilitating / developing (social) innovations through an architecture of participation arising from multiple origins and venues – public, private and civil society institutions** | Foster knowledge building and innovations by bringing together different kinds of thinking, processes, products and options, and new ways to conduct business |
| **Systematically aligning financing targeted at key nodes can limit, slow or prevent system collapse, and allow opportunities presented by system change to be explored** | Ensure sufficient (public and private) resources are available, costs are recovered from the users by public and private financial instruments (charges, prices, insurance, etc.) and decision-making and financing are under the same control |

*Sources*: Adapted from Westley et al. (2013), Pulwarty and Maia (2015) and others including GAO (2008); Varady et al. (2013); IPCC (2012); Broto and Bulkeley (2013); Brouwer et al. (2016); Pattberg and Widerberg (2016); Garrick et al. (2018); NASEM (2021)

Ecological adaptive management and DRR collaborative learning networks all require partnerships that are multidimensional, contextual and problem oriented. To adopt a contextual orientation to systematically developing and sustaining partnerships is to identify ways that decisions affect and are affected by elements of social processes – participants, perspectives, situations, values, strategies, outcomes and effects (Lasswell, 1971).

In rapidly changing areas with increasing drought severity and persistence, three key areas that sustain ongoing partnerships between events have emerged (Folke et al., 2005; Brunner, 2010; Westley et al., 2013):

- Preparing and mobilizing for change: Preparing the collaborative network to take advantage of opportunities for change, for example, raising awareness of new challenges.
- Recognizing or creating and engaging windows of opportunity: Understanding the importance of timing when it pertains to connecting with and mobilizing others. Identifying and supporting champions, leaders, and social and policy entrepreneurs at any level who are willing to take risks and convince others to take risks.
- Identifying and communicating opportunities for "small wins": The ability and capacity to identify (often small) projects on which actors involved can agree take a "whole system" perspective and find mutually beneficial leverage points.

Targeting small wins at critical nodes may prevent cascading system collapse or at least allow for "graceful failure" (i.e. with as little negative impact as possible) and serve to build trust in addressing more complicated threats.

Collaborative relationships among the public sector, the private sector and civil society are more productive and sustainable if they provide incentives and value to all stakeholders, rather than the reification of one group or one scale as "the" source of knowledge or innovation over others (Contu and Girei, 2014). Knowledge for drought-resilient solutions is as important as information about risks, vulnerabilities and impacts, and exists in the formal and informal sectors, at local levels and in traditional societies (GCA, 2019).

### *Scales, decentralization and incentives*

**KEY MESSAGE**

- **Centralized and decentralized approaches can complement each other, especially when the actor network is broadened beyond a sender–receiver model of information communication or a provider–client consultancy approach (Figure 3.5).**

While practical experience suggests strong coordination is often needed to tackle multidimensional challenges, decentralization (including participatory deliberation techniques) can help to deliver effective policy in complex systems. Standards, evaluation and level playing fields can be coordinated or facilitated at higher levels of governance. However, decentralization without resources and authority strongly limits its effectiveness. Furthermore, ongoing vigilance will always be needed to balance centralized and decentralized authority and functions (UNISDR, 2011; IRGC, 2021). Decentralization by itself is not a panacea.

Mapping and clarifying accountability within the complexity that emerges in cross-sector, cross-jurisdictional decision-making arrangements requires consideration of how the accountability and autonomy of one network actor might comingle, compete or complement the accountability structures of other network actors (Koliba et al., 2011). One aspect for knowledge development and practice involves analytical tools to identify and assess how and where failures of accountability and mission specificity lead to failures in performance.

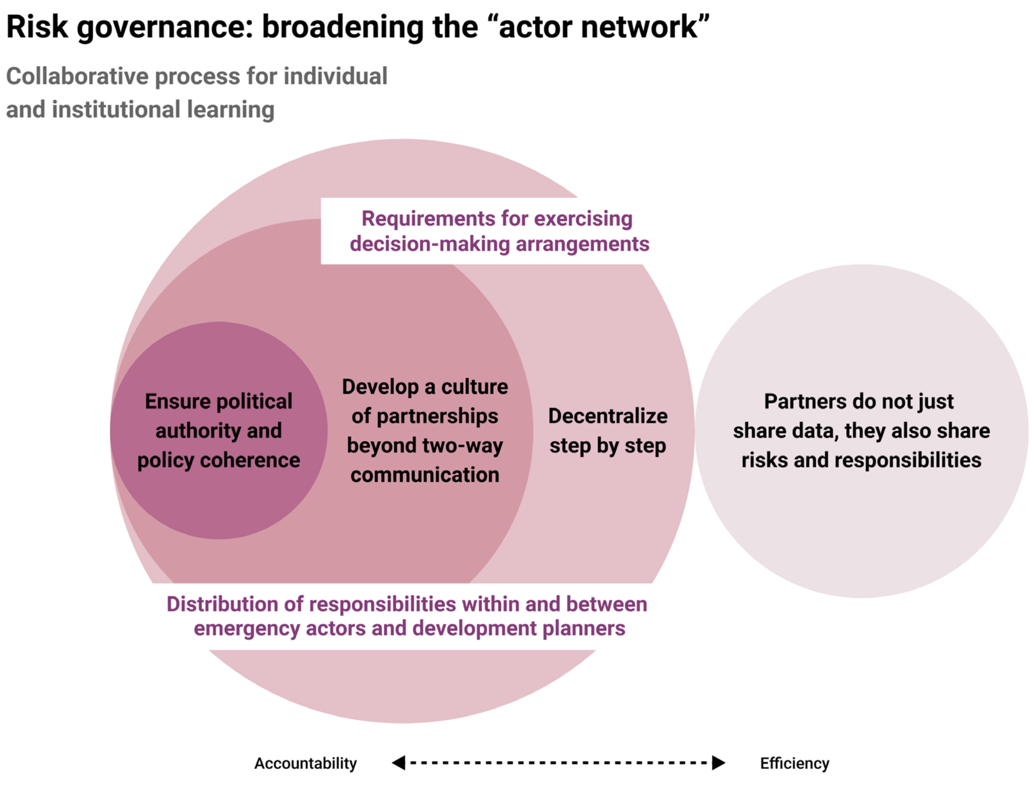
Partnerships crafted using the above guidelines improve the chance that central resources meet local needs, and that other vulnerabilities are reduced over time. In this framing, early warning systems are embedded in an ongoing technical, social and political process of risk communication as a prospective activity – vertically and horizontally. The science–decision-maker interface shapes the anticipation of, the treatment of and the outcomes produced by these converging forces. This complexity impels a move beyond the traditional expert-to-decision-maker framing, or even two-way communication, to incorporate indigenous and traditional knowledge, different forms of risk assessment, relational information, systems analyses and systems-based approaches (e.g. portfolio management).

Scaling up such experiences calls for innovative financing arrangements that merge public planning and investment with local priority setting and decision-making, such as, for example, in post-disaster reconstruction (UNISDR, 2011).

Integration of individuals' framing and local initiatives with top-down adaptation policy is critical (Butler et al., 2015), as failing to do so may lead actors to mistrust authority and can discourage them from taking necessary adaptive actions (Wamsler and Brink, 2014).

Alignment of such levers needs to be supported through: a shared vision across policy planning and goals; systematic coordination across actors, sectors and levels of government; participatory implementation mechanisms; and metrics for monitoring and evaluation.

**Figure 3.5. Simplified illustration of the differences between designing for efficiency as opposed to resilience at multiple scales of interaction**




*Source*: Adapted from ECLAC/UNDRR (2021)

Polycentricity – a proposed approach to governance in which multiple governing bodies interact to make and enforce rules within a specific policy arena or location – is often advocated for pursuing the common good, and to achieve collective action in the face of disturbance and change (Ostrom, 2010). However, as also recognized by Ostrom (2007, 2012), such seemingly comprehensive framings are also vulnerable to tensions among actors, power asymmetries, coordination breakdowns and negative institutional interactions. Individual agency plays a role at each stage of the process in ensuring procedures are followed and long-term goals are kept in view.

One of the challenges of sustaining engagement among diverse communities is the rate of staff turnover (rotating positions) and dwindling programme resources within agencies, and the increased use of contractual personnel, who may not have the background nor the social capital to strengthen these processes (Song et al., 2019).

### *Knowledge and agency for facilitating governance transitions*

The traditional focus on physical systems has resulted in existing knowledge tending to focus inordinately on technical solutions (White et al., 1977; IPCC, 2012, 2019). Much less is understood in the context of implementation about non-technological forms of innovation, such as social initiatives and urban experimentation that develop networks and sustain partnerships beyond the cycle of specific events such as single droughts. In the context of structural and systemic risks, Scoones et al. (2020) outline necessary enabling capabilities as follows:

- Fostering human agency, values and capacities necessary to manage uncertainty, act collectively, and identify and enact pathways to desired futures
- Recognizing potential of human agents for collective action
- Explicitly addressing asymmetries in power and circumstances of social injustice
- Enabling community-led environmental action, hackathon spaces for grass-roots innovation and common approaches to sustainable local economies

A growing number of studies identify core mechanisms, challenges and possible governance interventions to manage system disruption and reconfiguration. Think tanks, academic researchers and centres of excellence have critical roles in delivering the above needs in advocating for and engaging the private sector, youth, entrepreneurs, investors and even the general public to become active agents of change.

The accumulation of knowledge about complex and changing systems does not automatically mean an increase in explanatory power and the ability to predict. To minimize such failures of association, continuous decision engagements, joint seminars and one-on-one exchanges that link social and decision processes may guide practical actions if they are joined in a common function or purpose (Lasswell, 1971; Pulwarty et al., 2009).

Keeping a common purpose in sight requires more than policy entrepreneurs; it requires innovators who keep the norms of the process and system complexity in frame at each step. As Hoppe (1999) observes, “norm entrepreneurs” are actors skilled at promoting and structuring the normative foundations for partnerships, building systemic risk literacy and persuading others to join in their efforts – they can play instrumental roles in partnerships in which social learning and shared values are developed. However, there is limited systematic data or comparative studies, and there is a particular need for new knowledge for:

- Anticipating and governing negative consequences of transitions, particularly in terms of sectors and regions that are deeply committed to non-sustainable industrial and land-use practices
- Addressing sources of locked-in practices, perspectives and resistance to change at the system level likely to slow down transition efforts

- Addressing the deeper and longer-term drivers of landscape changes
- Facilitating public–private–civil society partnerships, contributions and equitable solutions

Key individuals play central roles in such learning processes including providing leadership, building trust, developing visions and sense-making (Westley, 2002; Olsson et al., 2004; Huitema and Meijerink, 2009; Gutierrez et al., 2011). As used here sense-making refers to the processes involved in giving meaning to existing and new contexts, experiences and developments. Individuals act as important brokers for connecting people and networks and encourage distributed decision-making and participation in governance at all scales (Bebbington, 1997; Crona, 2006; Ernstson et al., 2010). They serve as critical nodes in learning networks (Manring, 2007; Pulwarty et al., forthcoming).

Empowering marginalized groups in technical and leadership positions is key to applying insights from global to local adaptation, including drought risk planning and management. Two critical levers for equity and effectiveness are (Nakashima et al., 2012; IPCC, 2019):

- Gender-inclusive approaches to land, water and sustainable development. Gender is a leverage point in decisions relating to desertification, land degradation, food security, and enabling land and climate response options (Kaijser and Kronsell, 2014; Moosa and Tuana, 2014; Djoudi et al., 2016; Thompson-Hall et al., 2016; Fletcher, 2018).
- Indigenous knowledge and local knowledge in land-based, risk mitigation and adaptation options. Indigenous knowledge refers to the understandings, skills and philosophies developed by societies with long histories of interaction with their natural surroundings (IPCC, 2012, 2019).

## 3.4.3

### Financing, coherence and information services

**KEY MESSAGE**

- **Resilience should not be considered as a drought- or climate-finance add-on after other financing decisions have been made, but as an investment in the present and in future economic, social and environmental sustainability.**

The case studies in Chapter 2 demonstrate the need for improved coherence in financial strategies for managing drought-related systemic risks at the global and national levels. Recognizing the drought risk management issue as part of a complex system opens roles for financing and related services and clears new directions for the way in which they are employed.

In the move to sustainable finance systems, adaptation and drought resilience need to be built into investment and financing planning from the beginning (GCA, 2019).

In addition, the public sector needs to recognize its role as an essential provider and enabler of finance for adaptation actions for the foreseeable future. While some investments in resilience will generate bankable financial cash flows, many will not. Greater public resources will be required, whether for resilient economic systems such as agriculture and infrastructure, or for social safety nets and risk-pooling mechanisms. In parallel, governments must take many other kinds of actions, such as:

- Introducing and layering policy incentives to improve planning and land use
- Strengthening climate services
- Building public sector capacity
- Strengthening the functioning of the financial

sector to better disclose, price and manage risk, to align financing approaches to make drought-resilient investment (including in pursuing development outcomes) and to expand into new risk-pooling markets

The private sector also has a critical role to play, on its own account and also to complement the public sector. Firms in the agriculture, industry and commerce sectors can make their own operations and supply chains more resilient and profitable by investing in adaptation and mitigation. Data and finance companies can provide services to respond to market needs, including but not restricted to supporting enhanced risk assessment and informed decision-making that avoids the creation of new risk, or developing and scaling up insurance products that will provide contingent financing and create incentives for greater resilience. Members of the private sector can step up as active advocates to help shape and amplify the pressure for change. More-ambitious actions by the private sector will require a higher level of collaboration between the public and private sectors than seen today.

The development and enhancement of microfinance institutions to ensure social resilience and smooth transitions in the adaptation to climate change impacts are an important local institutional innovation (Hammill et al., 2008). Financing needs for land and water security investments remain high in many countries, and should be seen as investments rather than expenditures. Much remains to be done in strategic investment planning and pathways, including feasibility studies required for investments, blended finance for land- and water-related investments, and improving environmental performance of development finance.

The Addis Ababa Action Agenda encourages mobilization of financial resources from diverse sources and at relevant levels to promote environmentally sustainable development (United Nations, General Assembly, 2015c). Some capital is usefully flowing to the so-called "new economy", emphasizing level playing fields, equity and environmental sustainability, but far more is continuing to support the old economy (Schaer and Kuruppu, 2018). There is a growing amount of attention on the combination of policy instruments that address three domains of action: behavioural changes, economic optimization and long-term strategies (Grubb et al., 2015).

UNCCD has identified key priorities and policy mixes for targeting finance and aligning economic incentives for drought risk reduction in the context of increasing aridity and desertification. These include:

- Encouraging changes in behaviour of individuals, corporations, government or society with, for example, financial incentives to switch to crops that are drought tolerant
- Compensating losses of affected populations so as to avoid a spiralling poverty trap
- Providing a flow of financial capital that can either enable beneficial investments to be made or promote the smooth functioning of commodity markets, especially in economies where financial and credit markets are already constrained without the added stress of droughts

Piloting of different financial instruments, in some cases with support from development partners, can also help governments develop risk financing strategies to respond to the impacts of climate-related disasters. However, for such pilots to succeed, they must include clear exit, replication or scale-up plans to allow relevant stakeholders to build on examples of good practice.

Monitoring and evaluating sustainability and resilience in investments also remain key gaps in learning for implementation. Adaptation measurement is challenged by limited understanding of what indicators to measure and how to attribute altered vulnerability to adaptation actions. Improved guidance on what constitutes sustainable financing will drive investment towards adaptation and away from maladaptive investments. For example, the European Union is working towards this goal through its Action Plan for Financing Sustainable Growth presented in 2018. The role of domestic policy and regulation should not be underestimated in increasing investments in resilience.

National reporting systems provide an important basis for the monitoring and evaluation of climate change adaptation and DRR. The level of detail that can be captured by separate or joint reporting systems for climate change adaptation and DRR varies. In all cases, a persistent challenge is to ensure that the information generated informs subsequent policymaking processes. There are still knowledge gaps about the form, structure and potential of these arrangements.

### *Drought risk transfer mechanisms*

Insurance is a valuable mechanism for those who can afford to pay policy premiums to transfer risks to the financial markets. Through accurate pricing of risk, insurance has the potential to facilitate ex ante risk-reducing behaviour, policy, investment and action. It can also help build resilience through a more-efficient allocation of resources by targeting high-impact, probabilistic events (realized intensive risk) – although it is less well suited to high-frequency, low-impact events (realized extensive risk) – as well as supporting more rapid recovery after climate-related extreme events. However, the development of formal drought insurance mechanisms is hindered in many developing countries by high transaction costs, asymmetric information and adverse selection (OECD, 2016). Public finance can be used to support the establishment of new insurance schemes, help existing initiatives scale up or contribute to an enabling regulatory environment. This can include local initiatives (e.g. index-based insurance) as well as national and regional schemes (e.g. regional risk pooling such as the African Risk Capacity and the Caribbean Catastrophic Risk Insurance Facility). Understanding of the role of public finance (domestic or international) in subsidizing premiums as a form of adaptation is limited. However, public–private partnerships, such as the Insurance Development Forum and the InsuResilience Global Partnership, are improving understanding and collaboration.

It should be stressed that insurance is a complementary tool for prevention, mitigation, preparedness, response and adaptation, spreading the financial risks of probabilistic extreme events. However, it does not address slow-onset change wherein premiums may become unaffordable as risks increase. It is highly likely that increasing risks due to climate change will be factored into premiums by insurance companies, which will lead to pressure to start differential pricing and make it harder to obtain low-cost insurance for more vulnerable individuals, assets and locations. Initiatives must be carefully designed to incentivize upfront adaptation and avoid maladaptation.

### *Catastrophe and resilience bonds*

As the frequency and intensity of drought and other extreme events increase due to climate change, local and national governments are increasingly expected to step up to cover the damage and pay for reconstruction. Often considered as “insurers of last resort”, public authorities are increasingly being called upon as the “first resort”, and they need to find sustainable business models to fund resilience.

It remains difficult for a public authority to leverage public and private support to pay upfront when the cost is high, the benefits are diffuse and the probability of extreme losses is low. Catastrophe bonds are similar to life insurance policies, which pay out only when the worst disasters strike. The priority has been large public infrastructure projects. For example, in North America, the New York Subway System and Amtrak issued catastrophe bonds after Hurricane Sandy in 2013 (Vaijhala and Rhodes, 2018).

Resilience bonds are similar to progressive health insurance programmes that provide incentives to make healthy choices (e.g. exercising regularly), which reduce long-term risks and the cost of care. These can be used to expand investment in resilience building in communities vulnerable to catastrophic events, for example to leverage new project finance for resilient infrastructure that offers a measurable reduction in risk. Resilience bonds can therefore be designed to fund prospective and corrective risk reduction projects, in addition to reactive disaster recovery actions.

While these financial mechanisms are critical, it should not be concluded that these will cover the extent of financing needed for addressing the full spectrum of drought-related systemic risks. Hence, there is a need for improving on-the-ground prospective risk reduction and coordination across vertical and horizontal scales, for implementing equity-based approaches that offer practical prospective approaches for addressing drought risks.

### *Aligning climate change adaptation, mitigation and drought risk management*

In developing countries, the need for coherence is not limited to national policies and activities, but also includes coherence of development cooperation in support of climate change adaptation and mitigation, sustainable and resilient urban development and DRR. A number of United Nations agreements and frameworks were thus adopted in 2015 and 2016, including the 2030 Agenda, the New Urban Agenda, the Paris Agreement and the Sendai Framework, each with their own objectives and mandates. However, it is only in combination that they cover the range of potential benefits of sustainable development in the face of systemic drought-related risks.

SDG16 and SDG17 of the 2030 Agenda are noteworthy in that they provide credible and underused pathways to support coherent and effective addressing of drought risk. SDG16 ("Peace, justice and strong institutions") aims to promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable and inclusive institutions at all levels. SDG17 ("Partnerships for the goals") seeks to strengthen the means of implementation and revitalize the global partnership for sustainable development. Pertaining as they do to strengthening and resourcing governance capable of pursuing risk-informed sustainable development, SDG16 and SDG17 resonate strongly with the elements highlighted under governance of the Ten Essentials of the UNDRR Making Cities Resilient campaign (Figure 3.6). Used judiciously, they can contribute to realization of the commitments of the New Urban Agenda.

In respect of the Paris Agreement, the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts identifies eight slow-onset events (sea-level rise, increasing temperatures, ocean acidification, glacial retreat and related impacts, salinization, land and forest degradation,

**Figure 3.6. Ten Essentials of the UNDRR Making Cities Resilient campaign**

| | | | | |
|---|---|---|---|---|
| **Essential 1**<br>Organize for resilience | **Essential 2**<br>Identify, understand and use current and future risk scenarios | **Essential 3**<br>Strengthen financial capacity for resilience | **Essential 4**<br>Pursue resilient urban development and design | **Essential 5**<br>Safeguard national buffers |
| **Essential 6**<br>Strengthen institutional capacity for resilience | **Essential 7**<br>Increase social and cultural resilience | **Essential 8**<br>Increase infrastructural resilience | **Essential 9**<br>Ensure effective preparedness and disaster response | **Essential 10**<br>Expedite recovery and build back better |

Governance    Integrated planning and preparation    Response/recovery

*Source*: Adapted from ECLAC/UNDRR (2021)

loss of biodiversity and desertification) and includes drought as an extreme event (UNFCCC, 2013). IPCC assessments (IPCC, 2012, 2019) and numerous other assessments (e.g. Lempert et al., 2018) further note drought is closely linked to slow-onset, incremental climatic change. This definition of drought, as an extreme event but inextricably linked to and amplified by slow-onset drivers, acknowledges that changes in temperature, precipitation, land degradation and desertification affect the intensity and impacts of droughts and undermine capabilities for effectively adapting to climate change.

As outlined in the section 3.4.2, coherence can be pursued and operationalized horizontally across sectors, vertically at different levels of government (local, subnational, national, regional and global) and through collaboration across stakeholder groups (e.g. governments and intergovernmental organizations, the private sector, civil society organizations and citizens). Such coherence can be grouped into three types:

- Strategic coherence (visions and policy goals): Systematic alignment of visions, goals and priorities on resilience across drought risk reduction and climate change mitigation and adaptation in national development plans and strategies, providing a framework for pursuing operational coherence. With aligned goals and objectives at the strategic level, the basis for coherence in implementation is strong.
- Operational coherence (institutions and services): Policy frameworks and institutional arrangements supportive of the implementation of aligned objectives on drought risk reduction and adaptation, limiting the burden on often-stretched human, technical and financial resources. Linking adaptation and drought risks at the operational level through the development of effective policies and institutional arrangements can also prevent duplication of efforts or conflicting activities.
- Technical coherence (knowledge development and applications): Strengthened technical capacities to assess risks and opportunities, to identify, prioritize and finance resilience measures. For example, climate change adaptation planning can benefit from tools and information already well established in the DRR community, such as DEWSs and risk assessments, whereas emerging evidence of good practice approaches to climate change adaptation can inform disaster risk management measures, reducing the potential for maladaptation (World Bank, 2013).

### *Information services in a changing environment*

**KEY MESSAGE**

- **Scientific capabilities are often developed to address research questions, but not tailored to an operational setting, and much less for improving knowledge, developing application prototypes and building resilient infrastructure as changes are occurring. Developing science and services of value for societal issues often needs to be multidisciplinary and transdisciplinary, and performed in conjunction with a range of partners.**

There is growing awareness among governments, businesses and the general public of risks arising from drought and climate change on timescales from months through to decades. Several cases illustrate changes in the management of drought-related risks may be most readily accomplished when:

1. There is an occurrence of a focusing event (climatic, legal or social), creating widespread public awareness and opportunities for action.
2. There is engagement of leadership and the public, including “policy entrepreneurs”.
3. There is a basis for integrating research and management (Wilhite and Pulwarty, 2017).

Point 3 emphasizes the need for developing the capacity to apply knowledge and to evaluate the consequences of actions among partners, to ensure the reliability and credibility of the projections of changes in the system outputs and to enable acceptable revisions of management practices in light of new information.

The National Integrated Drought Information System in the United States of America, the European GDO and FEWS NET are examples of end-to-end information systems in which monitoring and forecasting, risk assessment, and engagement of communities and sectors are aligned across the weather–climate continuum. These provide coordination of diverse regional, national and local data and information for supporting alerts, planning and preparedness (Pulwarty and Verdin, 2013; Vogt et al., 2018).

There have been carefully documented successful cases of drought risk interventions to prevent humanitarian crises, including during the severe drought in Ethiopia in 2015–2016, as a result of FEWS NET and efforts on the ground.

Some climatic changes could be unprecedented in their harmful socioeconomic impacts, while others with adequate forewarning and planning could offer benefits (Hewitt et al., 2020; Chapter 1). There is a commensurate and pressing need for decision makers to have access to, and to use, high-quality, available, relevant and credible climate information about the past, present and future to help make better-informed decisions and policies.

WMO refers to the provision and use of such information as climate services (WMO, 2019). Many regions and countries have insufficient capability and capacity to develop and deliver climate services, which undermines confidence in national service providers and sends users in search of alternative and sometimes less-credible services. The ability to build service capacity is often compounded by competition among national bodies for funding. There are also major imbalances regarding access to essential services, and there is no relationship between the level of climate risks that a country faces and the level of per capita spending on developing climate information in that country (Georgeson et al., 2017). The lack of resources, capability and capacity is at odds with the growing demand for climate services, and severely hampers proper co-development and delivery of sustainable climate services that can help society make effective decisions.

Decision makers seek inter alia an understanding of the variability of droughts in the context of climate change, or observational data sets, or modelling capability for predictions and projections, or downstream applications. Chapters 1 and 2 have illustrated the limited ability of scientific entities to address the needs of decision makers, including providing scientific output that is operationally useful.

## 3.4.4

### Towards a drought-resilient world: pathways for action

Human institutions and actions determine the resilience of the environment and of people. Locally evolved institutional arrangements governed by stable communities and buffered from outside forces have managed drought and other environmental hazards for centuries (Dietz et al., 2003). However, these arrangements can often be overwhelmed when rapid change occurs and when external pressures beyond local control are applied.

Climate change is exacerbating existing weather and climate variability. It is likely to increase the number and impact of climate shocks absorbed by rural and urban communities. Systemic drought-related risk epitomizes this complexity. The resilience of food systems is integrally determined by the decisions and actions of people at many levels and by complex interactions of society, the environment and the economy. Business as usual will see continuing land and water degradation and vulnerability, combined with heightened risks from climate change, contributing to greater social problems of poverty and migration, and possibly conflict.

Given the increasingly systemic nature of risks, ideal conditions for governance are increasingly rare (Ostrom et al., 2007). Despite advances in hydroclimatology, predicting variability of water demand and supply precisely for specific locations will remain a major challenge, particularly given global climate change. Scientific knowledge of the impacts of systemic risks remains limited and in need of increased attention. This limitation is compounded by inadequate data on drylands, as well as in some newly water-scarce environments and economies in which conditions are uncertain.

Furthermore, eliminating drought risk entirely is neither physically possible nor economically feasible because rapid social and economic transitions are taking place. For example, as presented in Chapters 1 and 2, groundwater is increasingly being used formally and informally to offset meteorological drought, while some drylands are increasingly being used for energy, including wind, solar and geothermal sources. Such changes ultimately alter the risk equation.

Economic growth in developing countries has brought development benefits, but is often coupled with degradation of natural resources and negative environmental impacts.

As shareholders of multilateral and bilateral development banks and development finance institutions, donor governments hold specific roles in improving the environmental performance of development finance in water-related investments. They need to coordinate efforts across ministries and institutions to promote the integration of environmental considerations into financing at the project and policy levels.

The enabling environments created from informational bases, engagement strategies, policy frameworks and institutional arrangements need improvement, even when increased funds are available. This observation is an expression of contextual orientation and the pragmatist maxim, which together link decision processes and social processes (Lasswell, 1971; Dunn, 2018).

UNDRR can help bring together systemic perspectives and expertise to improve analysis and prospective drought risk management across social, ecological, cultural and economic impacts under threat from drought and related risks. In addition, UNDRR can work across SDGs, the goals of the Paris Agreement, the Convention on Biological Diversity and UNCCD to support the enabling conditions for the transition to drought/systemic risk governance, overcoming traditional barriers to acquiring learning, innovations and effective action during extended or intensifying drought events. Components across the frameworks include:

- Improving social protection at local levels (FAO, 2021b)
- Nature-based solutions that sustain ecosystem services
- Financial services to support risk reduction and risk-informed investment
- Early warning information systems across multiple timescales
- Collaborative framing networks that engage public, private and civil society networks

Addressing the above issues confirms several principles for public administrators to craft effective multi-stakeholder partnerships and governance where iterative learning is central (e.g. Brouwer et al., 2016). These include:

- Embracing systemic change
- Engaging in participatory learning such that multi-stakeholder partnerships enable actors, influencers and local communities to learn together by sharing knowledge and collective experience

With these in mind, the following section offers a series of recommendations for advancing governance across the continuum from drought risk to resilience.

### *Improving adaptive risk management and governance of systemic drought risks*

**KEY MESSAGES**

Two critical recommendations are made to achieve a shared vision and acceptable action-oriented drought-resilient development:

- Develop a national drought resilience partnership that works to ensure a seamless link between national and local levels with public, private and civil society partners.
- Support the establishment of a global mechanism for drought management focused on systemic risks.

Coordination and implementation of prospective risk management and adaptive governance approaches that address systemic drought risks require aligning responsibility and finance mechanisms layered across the global to national and national to local scales, and back up the chain.

The Addis Ababa Action Agenda calls for reforms to the international sustainable development architecture, including that international mechanisms and institutions need to keep pace with the increased complexity of the world and respond to the imperatives of sustainable development (United Nations, General Assembly, 2016). The Addis Ababa Action Agenda builds on the Monterrey Consensus of the International Conference on Financing for Development. The conference marked the first exchange of perspectives from four key groups: governments, civil society, the business community and institutional stakeholders on global economic issues. It highlighted the urgent need to enhance coherence and consistency, including implementation of governance mechanisms at different scales to ensure a more inclusive and representative international architecture.

The coherence of and consistency in governance mechanisms across scales called for by the Addis Ababa Action Agenda, the 2030 Agenda and the Sendai Framework are yet to be realized, in part due to inaction or an absence of political will. Actions often fall short because of genuine differences among the national interests of different States, difficulties in States systematically aligning common interests and approaches acknowledging that national policy decisions can have systemic, far-ranging effects beyond national borders (United Nations, General Assembly, 2016).

However, States construct international regimes on the basis of their interests, which in turn reflect the interests of the major constituencies that exert influence over State leaders (Keohane, 1989). As illustrated in this chapter, alignment is needed from a global mechanism to national scales and between national and local scales and back up the chain.

**Facilitating pathways to drought-related systemic risk governance**

The following constitutes a basic set of key actions to develop the necessary evidence base and actions to inform and support improved adaptive management and governance of drought-related systemic risks among international agencies, regional entities, national resource managers and communities:

- Invest in drought risk identification and mapping:
    - Develop a national drought risk inventory to systematically monitor losses and assess risks across scales
    - Map vertical and horizontal decision-making arrangements and key stakeholders, including the public and private sectors, civil society and the science and technology community, as a step towards their taking part in drought risk management, design, planning and implementation
    - Map financial instruments and financial leveraging opportunities and their relevance to key national and local drought risks
    - Use costs of action and of inaction estimates to the extent possible on drought-related

risks, so as to target those elements of risk that can be most efficiently reduced before compounded impacts occur and where management can produce positive economic and social co-benefits

- Employ horizontal partnership development to co-develop shared visions for a participation architecture and mainstreaming of resilience-based approaches in drought risk management and reduction including:
    - Systematic coordination across actors, sectors and levels of governance going beyond ad hoc projects, for example into portfolio management approaches
    - Harmonized implementation strategies, including blended finance
    - Adoption of a suite of success metrics
- Offer social protection, considering the social protection floors and poverty line including:
    - Conducting impacts-based drought risk assessments focused on vulnerable communities in national and sector development planning and investment
    - Smoothing consumption across drought cycles by promoting resilient livelihoods and protection of financial and non-financial assets
    - Enhancing access to credit and financial protection, for example, conditional cash transfer and temporary employment schemes, catastrophe and resilience bonds, microinsurance and loans
- Ensure social accountability through increased public information and transparency by:
    - Placing policy responsibility for drought risk reduction, including for emergent risks driven by climate change, in a single unit with political and investment authority
    - Developing decentralized, layered functions, and including local initiatives based on partnerships among government, private sector and civil society (use the principle of subsidiarity and appropriate levels of devolution, including budgets and to civil society)
- Align goals and investment for financing drought-related systemic risk reduction to promote coherence in financing through the implementation of international mechanisms such as the 2030 Agenda, the Paris Agreement and the Sendai Framework by:
    - Developing a culture of public administration supportive of systemic risk management of complex risks
    - Piloting and incorporating innovative financial strategies to upgrade settlements, and promote benefits of technology and efficiency of water, energy and land use
    - Working with international partners, development agencies and relevant international mechanisms to develop a global mechanism for drought management

Table 3.3 provides a preliminary list of actions and actors supporting the implementation of the recommendations presented above.

Increasingly globally networked risks, local imbalances, the resulting contagion of cascading risks and ensuing actions are overwhelming traditional approaches to drought risk management. Systemic innovation strategies for equitably addressing such multi-scaled risks are fundamentally different from regular innovation strategies, in that they are founded on notions of complexity, ambiguity and diversity to manage present risks and adapt and thrive as new risks emerge.

Instead of targeting only one outcome (e.g. a high crop yield), systems-based management aims at the capacity of systems and people to be able to imagine, adapt and co-produce a sustainable and equitable future.

Transitions to systems-based management are themselves an important component of the resilience of socioecological and increasingly technological systems (Berkes et al., 2003). System transitions can be enabled by enhancing the capabilities of public, private and financial institutions to accelerate national and local policy planning and implementation, along with accelerated and appropriate technological innovations.

However, decisions are often not based on weighing costs and benefits alone, but on heuristics, culture and values (Aarts and Dijksterhuis, 2000; Kloeckner et al., 2003; Ascher, 2007) within organizations, institutions (Hall et al., 2003; Munck et al., 2014; Dooley, 2017), and communities.

An immediate and critical need is to craft new narratives of measures of human well-being and interaction with natural systems, within and among countries in increasingly drought-prone, drought-emergent and water-scarce seasons and regions.

Droughts provide a useful analogue and practical experience for a much wider suite of complex and growing risks – including those posed by climate change – even with their mix of slow and fast onsets, fluctuating intensities and duration, and even within the same event. The uncertain nature of projected impacts and the need for a flexible approach highlight the importance of: continuous learning; leadership and engagement of key government bodies; broad private and civil society stakeholder participation and coordination; clear allocation of roles, responsibilities and resources; and monitoring, evaluation and continuous learning.

A significant challenge in the development of pathways for living sustainably with nature and with increasingly complex drought-related risks will be in guiding evolution of financial and economic systems towards a globally sustainable economy. This will involve steering away from the current limited paradigm of economic growth and drawing upon diverse value bases and sources, including indigenous and local knowledge (Nakashima et al., 2012; Smith and Sharp, 2012; Stiglitz et al., 2019).

Such narratives would show the limits of current systems and business-as-usual actions in reducing risks into the future, and articulate shared values and opportunities for realizing the benefits and dividends of adaptive governance of systemic risks for global, national and local communities.

**Table 3.3. Building enabling conditions for the shift to drought-related systemic risk governance**

| Drought resilience partnership: national and local | Global mechanism for drought management: international and national |
|---|---|
| • Ensure ministries and agencies at the national level have information and incentives to integrate DRR and climate change adaptation and mitigation across their portfolios, and report back on progress nationally<br>• Use ministries and agencies with a presence at the local level and responsible for implementation to ensure national directives on DRR and climate change adaptation and mitigation are integrated with local development plans<br>• Reinforce the mandate of relevant ministries and agencies to enforce existing regulatory measures and provide incentives in support of climate change adaptation and DRR, such as land-use management and environmental protection<br>• Bring domestic attention and resources to the reduction of drought risks, take risk-prevention measures and take advantage of windows of opportunity<br>• Create centres of excellence at regional levels so drought-related technical resources and capacities can be used to assist in decision support, and maintain interest between events<br>• Develop processes for sustaining early warning across timescales and develop collaborative partnerships that put people first | • Understand and engage countries and communities through shared capabilities, levers for transformation and technical support; monitor, assess and forecast drought-related systemic risks<br>• Develop international collaboration and dialogue on drivers of globally networked risks and vertical coordination across regions, nations and communities<br>• Develop thematic working groups, including industry and civil society actors, for facilitating coordination focused on feasibility, capacity and accountability (Figure 3.5)<br>• Create centres of excellence at intermediate levels so drought-related technical resources and capacities can be pooled<br>• Use the opportunity of external systemic risk drivers such as Covid-19 to prioritize resilience building and build back smarter and greener across global mechanisms; such efforts can include increased investment in climate-smart technologies that are scale appropriate<br>• Develop processes for sustaining early warning across timescales and geographies, and develop collaborative partnerships that put people first |

# 4. Conclusions

## 4.1 The state of current knowledge

The Sendai Framework makes clear that disaster risk cannot be substantially reduced unless the dynamic and systemic nature of risk is better understood, and governance systems evolve to better incorporate systems-based and adaptive approaches. New tools for risk-informed decision-making are essential to allow human societies to live and thrive in uncertainty (UNDRR, 2019). Much can be learned from these tools.

The dynamics of drought shed light on the characteristics and interactions of socioecological and technological systems that allow hazards to become disasters, and how society's values, demands and attendant resource management affect ecosystems, human health and sustainable development. Developing capabilities to successfully meet the challenge of drought can therefore also help societies build skills to better manage and even prevent other complex risks and shocks.

Drought is a recurrent feature of almost every region due to natural climate variability. It is characterized by substantial deficits in multiple indicators of hydroclimatic variables, and is neither aridity nor water scarcity. Droughts have been characterized as slow-onset events compared with other natural hazards. Their pervasive socioeconomic and environmental impacts can last from weeks to decades, and cover areas ranging from watersheds to hundreds of thousands of square kilometres. They have widespread, multifaceted and long-lived impacts determined by hazard severity, human and ecosystem exposure and vulnerability, and coping capacity. Given the complex nature of their distribution through time, space and sector, such impacts are challenging to reliably attribute and accurately quantify.

There may be far-reaching consequences when droughts are not adequately managed or when they are especially severe. Such consequences affect entire economies and environments, including societies far from where the original drought events occurred. Drought impacts can be multiple, and include food and water insecurity, reduction in energy supply, ecosystem degradation, potentially worsening or provoking civil unrest, conflict and migration.

Droughts can be exacerbated by compounding effects such as co-occurrence with heatwaves and antecedent soil moisture deficits, or the feedback and connections among droughts, wildfires and subsequent floods. Risk increases in a non-linear fashion in such situations. In the worst cases, droughts can lead to long-term land degradation and desertification, reduction in livelihood options, undermining of existing management practices and disruption of entire societies.

Human actions resulting in water scarcity and feedback loops in the climate system play key roles in drought intensification and propagation. For example, the construction of reservoirs and other structures intended to mitigate impacts in the short term may exacerbate them in severe conditions by increasing demand or dependence on reservoir storage as events intensify or persist. Vulnerabilities are even more starkly revealed, and often amplified, when a drought is particularly intense or of long duration.

Perhaps more than other hazard, droughts raise fundamental questions about the capacity to measure, evaluate and respond to risk. For example, even the onset and the end of a drought are challenging to characterize; its duration is unpredictable, potentially lasting for many years, and all the while, impacts accumulate and cascade.

Hence, estimates of economic, social or environmental damage should be interpreted with care, as there is usually a significant gap between reported and real impacts. Estimates of costs arising from drought impacts from 1998 to 2017 show droughts have affected at least 1.5 billion people and led to economic losses of at least $124 billion across the world. But these are only partial accounts and most likely gross underestimates. Case studies suggest numerous and multiplying impacts many times these costs.

With human-induced climate change, drought frequency and severity have already increased in some – often already water-scarce – regions of the globe. As the world moves seemingly inexorably towards global average temperatures 2°C warmer than pre-industrial levels, drought impacts are intensifying and are predicted to worsen in many regions, particularly within business-as-usual scenarios.

# 4.2

## The lived experience

The case studies assembled for this report examine key questions, including why society is not doing better at managing drought, given how devastating it can be, and the state of knowledge of drought creation, propagation and impact. The case studies describe factors such as the impact of cycles of drought, the uncertainty of drought initiation and conclusion, and the importance of drought length and severity to impacts.

Droughts have had widely variable effects across regions, countries and continents (e.g. Africa and Australia), with sharp shocks within growth seasons (e.g. in Canada and the United States of America) or cascading down transboundary river systems (e.g. in India, across the Mediterranean region and in southern South America). Although impacts may vary across scales, the effects are initially felt mostly at the landholder, farmer or livestock manager level. However, with time, the impacts are broader, and extend and cascade across communities, the economy and even beyond national borders through for example water, energy and commodities trade.

The case studies demonstrate the increased insecurity of irrigation systems and the increased tendency for many urban centres to be affected by water scarcity and water quality decline. Cascading impacts have included forest loss, soil erosion and degradation, occurrence of SDSs, increasing flood vulnerability, more-frequent wildfires and a greater susceptibility to pests and diseases.

As energy generation requires water, the energy sector shares vulnerability to drought with competing users of water such as agriculture, instream environmental flow needs and urban populations. The interdependencies among water, food and energy are made abundantly clear during drought.

The level of drought vulnerability is unequal, as it has a disproportionate impact on poor and marginalized people where the cost of drought is measured in terms of lives, livelihoods and impoverishment. Thus, the case studies reinforce the message of the drought risk equation – Risk = $f$ (Hazard, Exposure, Vulnerability) – the risk is greatest where the exposed populations are vulnerable and have the least capacity to cope with a drought and to adapt to changing conditions.

Current risk management and governance mechanisms and approaches addressing drought are being overwhelmed by the increasingly systemic nature of drought risk. The case studies describe action in policy development, review and restructure when droughts are severe, and inaction when droughts are no longer evident. Policy disconnects abound across sectors, wherein drought risk management is often treated independently of policies for agriculture, water resource allocation, conservation, energy generation and climate change adaptation and mitigation. Such disconnects can also constrain risk prevention, mitigation or response. Policies and plans across international boundaries are rarely binding.

The case studies identify the need for empowering farmers and communities, and demonstrate the benefits of early warning and monitoring, and the imperative of an enabling policy environment. Farmers, livestock managers and other communities have shown an abundance of local adaptation strategies ranging from adapting crop variety or species choice, introducing a mix of enterprises, planting dates, planting densities, irrigation strategies, water storage, agropastoralism, livestock species and adjusting supply chains. These are supported by extension programmes in many cases. Connections to traditional knowledge are increasingly being sought.

Looking to the future, the case studies reinforce the need for effective drought monitoring, assessment of vulnerability across scales and the availability of mitigation measures to limit impacts during drought. The 10-step drought planning approach and the three-pillar approach to drought risk management developed through IDMP have been identified as important good practices, but the studies show that, in reality, they have rarely been applied. Furthermore, while proactive in nature, such approaches do not yet pursue prospective risk management wherein action seeks to avoid the development of new or increased risks.

Instead, most case studies describe a reactive approach to alleviate crisis situations. This is often the result of an inadequate level of preparedness, a lack of understanding of the costs of inaction, a lack of awareness of and access to data and information about the current and likely state of drought, and inadequate resources to assist decision makers to select and apply this information.

Institutional changes are required to connect across agency silos and to improve the flow of information between meteorological services and science agencies and the means by which information can be shared across civil society.

# 4.3

# From drought risk to resilience

## 4.3.1

### Systemic risk management

This report demonstrates how systemic risk management is fundamental to move from drought risk to resilience. Increasingly globally networked risks, local imbalances, the resulting contagion of cascading risks and ensuing actions are overwhelming existing approaches to drought risk management and governance, which are in most cases inadequate for understanding, planning and decision-making.

A robust evidence base and strong social and institutional capabilities are required for learning and innovation for adaptive drought risk management and governance. Knowledge of the nature of complex, systemic risks needs to be developed and shared across sectors, disciplines and institutional hierarchies, and should include analysis of the deep and long-term drivers of landscape changes and the nature and consequences of transitions from risk to resilience.

Strengthened evidence and action are needed in key areas including: risk identification; mapping of vertical and horizontal decision-making arrangements, key stakeholders and entry points; financial instruments; and financial leveraging opportunities. Promising financial measures include social protection through alignment of existing global mechanisms that have drought as a major thread, employment schemes, resilience bonds, microinsurance, conditional cash transfers and loans.

Further examination of vertical and horizontal partnership development for systematic coordination across actors, sectors and levels of governance going beyond ad hoc projects, and promoting trust and social accountability through increased public information, transparency and engagement are also required. In addition, aligning goals and investment for financing drought-related systemic risk reduction, and taking actions to overcome resistance from entrenched interest groups will be required.

To reduce existing systemic risks and avoid new ones, there must be a shift from dealing reactively with drought impacts to getting ahead of the curve and addressing underlying risk drivers. Socioeconomic and environmental vulnerability of exposed systems must be reduced, and climate change impacts mitigated as part of a transition from reactive to prospective and proactive risk management. Resilience should not be considered as a drought- or climate-finance add-on that comes after other financing decisions have been made, but an investment in near- and long-term economic, social and environmental sustainability.

Systemic risk management requires new capabilities and approaches, drawing on scientific expertise and other forms of knowledge. Greater investment in research of the systemic nature of drought risk is needed, but just as important is developing science and services that are multidisciplinary and transdisciplinary, and contextual in addressing societal challenges, and are undertaken in conjunction with a range of partners. The science to policy dialogue can be empowered through the effective use of scenarios and “serious” games. These do not predict future outcomes, but guide choices among options by making transparent likely trade-offs and synergies including opportunities for partnerships, collaborative vision building and equity.

However, drought confounds its management over the long term. This is due to the increasing complexities and interactions of drought exposure, vulnerability and attendant decision-making. Nevertheless, risk reduction must begin with embedding drought risk assessment, monitoring, forecasting and early warning in measures to increase societal and environmental resilience.

Shifting to integrated, multi-hazard and systemic risk management approaches is essential for prospective and proactive risk reduction, and will assist communities ultimately to better adapt to and through a changing climate.

# 4.3.2

## Adaptive governance

Governance mechanisms that facilitate rapid response to crises are different from those aimed at monitoring slower changes and responding with longer-term measures. As the case of drought illustrates, both are needed. Thus, effective governance of systemic risks must be adaptive and multi-scale in the context of anticipated risks and opportunities, and for managing through a rapidly changing environment. Efforts to work across the risk to resilience continuum are required, to ensure short-term decisions do not create long-term risks, nor that a long-term view does not become undermined by immediate crises and surprises.

Adaptive governance mechanisms need to prioritize iterative learning, planning, policymaking implementation, monitoring and evaluation, and collective decision-making wherein neither the State nor the private sector are the only actors. Adaptive governance can lead to new and improved forms of regulation that go beyond traditional hierarchies and promote private–public–civil society cooperation in problem solving backed by new forms of flexible, multilevel policy and accountability.

Given that there are globally networked and local drivers of drought risk, with consequences that can cascade through time and space, adaptive governance must balance centralized and decentralized authority and functions. Decentralization by itself is not sufficient to deliver solutions to target communities. Centralized and decentralized authorities should complement one another, especially when the actor network is broadened beyond a sender–receiver model of communication.

Effective adaptive governance requires a process of systematic coordination at global to national scales, national to local scales and back up the chain: (a) vertically at local, subnational, national, regional and global levels of government and (b) horizontally across sectors, disciplines and domains through collaboration across governments and intergovernmental organizations, the private sector, civil society organizations and citizens.

At the national level, adaptive governance is nurtured within a policy environment supported by high levels of public awareness, trust in the partnership process especially at local scales, and the acceptability and effectiveness of proposed approaches. Such an environment should:

- Promote policies and directives for drought risk reduction and climate change adaptation and mitigation that are integrated with local development plans
- Create incentives and training in drought-related complexity for government agencies to share responsibility for sustainability across portfolios
- Reinforce existing measures such as the promotion of water-saving practices, the enforcement of sustainable land and water management, and protection of the environment
- Leverage international policy to bring domestic attention and resources to the reduction of climate-related drought risks, such as the creation of centres of excellence where technical resources and capacities can be pooled

Such increased coherence across policies brings gains in efficiency and effectiveness, but it is not without costs. It can result in trade-offs between investing in a coherent approach to drought risk reduction on the one hand, and making progress on individual policy processes on the other hand – whereas both are needed. Therefore, the integration of policy agendas should occur on a continuum, from strategic to operational and technical, where policy coherence is not viewed as an outcome, but rather a process of systematic coordination.

Principles required to craft effective multi-stakeholder partnerships and adaptive governance where iterative learning is central include:

- Increasing systemic risk literacy and embracing systems-based approaches
- Promoting collaborative leadership to enable stakeholders to work together, to share responsibility and to develop confidence to tackle difficult issues
- Adopting horizontal integrative leadership
- Engaging in participatory learning such that multi-stakeholder partnerships enable actors, influencers and local communities to learn together by sharing knowledge and collective experience, and by fostering trust and respect

# 4.4

## The call to action

Risk preventative action has far lower human, ecological and financial costs than waiting for the risk to manifest and then reacting and responding to the shock. The global community must not be overwhelmed by the systemic impacts of drought in the face of climate change, not least given the threat drought poses to sustainable development, peace and security. Droughts are so pervasive, and their impacts so significant, that failure to move to systemic drought management and adaptive governance may trigger ever more serious social, economic and environmental consequences.

Analysis of long-term climate change impacts should not detract from action to be undertaken now to better understand the causes of vulnerability; vulnerabilities that reveal how disasters are a function of human agency. The long history of research and practices within the DRR community, together with knowledge enshrined in traditional and indigenous wisdom, offers critical insights when addressing the root causes of vulnerability and exposure, and must not be ignored. These lessons are starting to be actively employed and further developed as the world adapts to climate change impacts. With what we know, we must do better, and with what we learn, we must improve.

The way forward must build enabling conditions for the transition to drought-related, systemic risk governance. Enabling conditions must engender drought resilience partnerships at the national and local levels, building on approaches such as the 10-step drought planning approach or the three-pillar approach developed through IDMP. However, use of these frameworks should avoid overly prescriptive planning that does not prioritize iterative learning and innovation. For prospective drought risk management, plans will need to be designed to be flexible and to better build in the capacity to learn to change.

A new global mechanism is required to effectively manage drought in the future at and among the international, national and local levels. This should address the complex systemic nature of drought, linking approaches from local to national scales, to the global and back to the local scale. Such a mechanism could facilitate vertical and horizontal governance and associated partnerships to address drought risk. It could also accelerate transitions towards systems-based and prospective approaches to drought risk management and reduction. It should be based on shared values and responsibilities of stakeholders to mobilize and coordinate the needed financial resources and direct them to build systemic drought resilience.

Enhanced efforts are also required to build systemic risk literacy. The development of international dialogue and collaboration in addressing drivers of globally networked risks are also required. These could include public sector organizations working with private sector and civil society actors to focus on feasibility, capacity and accountability, and developing processes for reducing systemic drought risk through adaptive governance that puts people first.

A deeper challenge lies in developing pathways to address drought-related risks that are underpinned by financial systems supportive of a global economic model that prioritizes optimization and efficiency above human and ecosystem health and well-being, to a shift beyond the current limited paradigm of economic growth measured solely in GDP.

These pathways must draw upon diverse value bases and sources, particularly indigenous and local knowledge. Such narratives would show the limits of business as usual in reducing risks into the future, and articulate shared values and opportunities for realizing the global benefits and dividends of adaptive governance of systemic risks for global, national and local communities.

Systemic action to reduce and prevent drought risks provides an effective pathway for reducing a much wider suite of complex and proliferating risks, including the growing and real threat of climate change. Immediate action is required. With a better understanding of the complex nature of drought together with enabled nimble and adaptive governance, it is possible to reduce the risk of drought to people and ecosystems in the near term.

### Role of the United Nations Office for Disaster Risk Reduction in supporting systemic risk reduction for drought

The role of UNDRR is to bring together perspectives and expertise to improve prospective risk management across social, ecological, cultural and economic sectors under threat from droughts and other disasters. UNDRR works across agreements, conventions and frameworks to support the realization of the outcomes and goals of inter alia the 2030 Agenda, the Convention on Biological Diversity, the Paris Agreement, the Sendai Framework and UNCCD, to support the transition to systemic risk governance founded in acquired knowledge, learning and innovation.

With strong support from the scientific community, UNDRR highlights the evidence and the business case for financing systemic risk management, adaptive governance and action for preventative drought risk management. This will provide the basis for prospective efforts avoiding the creation of new drought risk, more-effective management of existing drought risks, and appropriate and equitable action during extended or intense drought events.

UNDRR advocates collaborative partnership and action at different scales and makes the case for distributed decision-making and participation in governance at all levels. It also promotes the fundamental tenet that preventative action now has far lower human, environmental and financial costs than purely reactive responses. This can help communities avoid being overwhelmed by the systemic impacts of drought and learn to manage present risks and adapt and thrive in the face of a changing climate, and as new risks emerge.

# Abbreviations and acronyms

| | |
|---|---|
| ASAL | arid and semi-arid land |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |
| DEWS | drought early warning system |
| DRB | Danube River Basin |
| DRR | disaster risk reduction |
| EDII | European Drought Impact Inventory |
| EM-DAT | Emergency Events Database |
| ENSO | El Niño Southern Oscillation |
| FABLE | Food, Agriculture, Biodiversity, Land-Use, and Energy (Consortium) |
| FAO | Food and Agriculture Organization of the United Nations |
| FEWS NET | Famine Early Warning Systems Network |
| G20 | Group of Twenty |
| GAR | Global Assessment Report on Disaster Risk Reduction |
| GDO | Global Drought Observatory |
| GDP | gross domestic product |
| GHG | greenhouse gas |
| GRAF | Global Risk Assessment Framework |
| GWL | global warming level |
| GWP | Global Water Partnership |
| HMNDP | High-level Meeting on National Drought Policy |
| IDMP | Integrated Drought Management Programme |
| IGAD | Intergovernmental Authority on Development |
| IPCC | Intergovernmental Panel on Climate Change |
| IWRM | integrated water resources management |
| JRC | Joint Research Centre |
| MasAgro | Sustainable Modernization of Traditional Agriculture project |
| NAP | national adaptation plan |
| NGO | non-governmental organization |
| RCP | representative concentration pathway |
| RDrI | risk of drought impact |
| SDG | Sustainable Development Goal |
| SDS | sandstorm and dust-storm |
| SPEI | standardized precipitation evapotranspiration index |
| SPI | standardized precipitation index |
| SSP | shared socioeconomic pathway |
| UNCCD | United Nations Convention to Combat Desertification |
| UNDRR | United Nations Office for Disaster Risk Reduction |
| UNFCCC | United Nations Framework Convention on Climate Change |
| WMO | World Meteorological Organization |

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