GWSP
GLOBAL WATER
SECURITY & SANI
PARTNERSHIP

Drought Risk and Resilience Assessment Methodology

A Proactive Approach to Managing Drought Risk

WORLD BANK GROUP

About the Global Department for Water

The World Bank Group's Global Department for Water brings together financing, knowledge, and implementation in one platform. By combining the Bank's global knowledge with country investments, this model generates more firepower for transformational solutions to help countries grow sustainably.

Please visit us at www.worldbank.org/water or follow us on X: @WorldBankWater.

About GWSP

This publication received the support of the Global Water Security & Sanitation Partnership (GWSP). GWSP is a multidonor trust fund administered by the World Bank's Water Global Practice and supported by Australia's Department of Foreign Affairs and Trade, Austria's Federal Ministry of Finance, the Bill & Melinda Gates Foundation, Denmark's Ministry of Foreign Affairs, the Netherlands' Ministry of Foreign Affairs, Spain's Ministry of Economic Affairs and Digital Transformation, the Swedish International Development Cooperation Agency, Switzerland's State Secretariat for Economic Affairs, the Swiss Agency for Development and Cooperation, U.K. International Development, and the U.S. Agency for International Development.

Please visit us at www.worldbank.org/gwsp or follow us on X: @TheGwsp.

Drought Risk and Resilience Assessment Methodology

A Proactive Approach to Managing Drought Risk

WORLD BANK GROUP

Rights and Permissions

Report design: Clarity Global Strategic Communications

Contents

Boxes

Figures

Tables

Dominic Chavez / World Bank

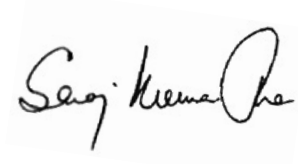
Foreword

Across the globe, droughts are becoming more frequent, severe, and widespread. They put economies, livelihoods, and lives at risk. Their impacts are both explicit and insidious, ranging from lack of potable water to reduced crop yields to lower educational outcomes and economic productivity. Because droughts are typically slow to develop and reveal their full impacts, action tends to be delayed until it's too late. The only option then is disaster relief. And yet, as the drought passes and recovery efforts cease, it's easy for the public to lapse back into a state of complacency. That is, until the next drought episode occurs and the cycle of panic and crisis response begins again.

The best way to avoid this costly cycle is to take steps to manage drought risks *before they manifest*. To do that, we need a robust plan of action.

That's why I'm pleased to present the *Drought Risk and Resilience Assessment Methodology (DRRA)*. It's a framework for action that brings together knowledge and best practices from the world of drought management, with a focus on proactive planning. Paired with other services in the World Bank's drought portfolio, this tool can help governments and communities identify key areas where they can prioritize resources and investments to build resilience to drought. It can be tailored to any country's situation—whether the country is in the grip of drought, susceptible to seasonal dry spells, or anticipating a future where drought becomes widespread in its region.

We cannot prevent drought, but together we can prepare better for it. Preparation empowers us with more choice in times of crisis—and that, in a world of climate impacts where much is uncertain, brings some peace of mind.



Saroj Kumar Jha
Global Water Director
World Bank Group

Acknowledgments

This report was prepared by a World Bank team led by Nathan Engle, Lara Loske-García, and Natalia Limones. The methodology was greatly informed by the drought risk assessment conducted for Romania and led by Chris-Philip Fischer and Natalia Limones.

The authors are grateful for the Water Global Practice's regional Latin America and Caribbean team for their global leadership in applying and testing the Drought Risk and Resilience Assessment (DRRA) methodology as part of the regional Advisory Services and Analytics program Multi-Sectorial Impacts of Droughts in Latin America: Vulnerabilities and Adaptation Strategies. The team thanks David Michaud, Chloe Oliver Viola, Andrea Mariel Juarez Lucas, Ana Cecilia Escalera Rodriguez, and Hye Rean Yoo Kang for championing the DRRA methodology to help strengthen drought risk management in the region.

During the development of this report, the team received invaluable contributions from Christian Borja-Vega, especially regarding prioritization of measures. Hila Cohen Mizrav led the characterization of the Menu of Measures. Under the leadership of Klaas de Groot, Gijs Simons (Future Water) developed factsheets for selected nature-based solutions interventions for drought resilience that have informed this work and were included as excerpts in appendix B.

The report benefitted greatly from the strategic direction provided by World Bank management, including Saroj Kumar Jha (Global Director, Water Global Practice), Benoît Bosquet (Regional Director, Sustainable Development Latin America and Caribbean Region), Yogita Mumssen (Practice Manager, Water Global Practice), and Eileen Burke (Global Lead, Water Resources Management). The team appreciates the valuable comments and feedback provided by colleagues and peer reviewers as part of the safe space review and decision review, including Luc Bonnafous, Markus Enenkel, Peter Goodman, Rashmin Gunasekera, Nagaraja Rao Harshadeep, Stephane Hallegatte, Brenden Jongman, Harun Onder, William Rex, Gabriel Sidman, Shaffiq Somani, Kristina Svensson, Ruth Tiffer-Sotomayor, Pablo Valdivia Zelaya, and Fan Zhang. The team is also grateful for support from and review by Daniel Tsegai (United Nations Convention to Combat Desertification).

Clarity Global Strategic Communications designed and laid out the report and provided conceptual illustrations. Erin Barrett, Sarah Farhat, and Sarah Daggett provided invaluable production and dissemination support. Melissa Edeburn copyedited the report, and Ayelen Becker supported several logistical processes for the publication of the report. The team is pleased to recognize generous funding provided through the Global Water Security and Sanitation Partnership and support from colleagues across the World Bank Group.

Executive Summary

The Drought Risk and Resilience Assessment (DRRA) framework provides guidance for assessing drought risk and identifying interventions for increasing drought resilience. The methodology is built on four blocks, which consist of 10 sub-blocks that describe a comprehensive and structured approach to strengthening drought responses and preparedness. The DRRA considers context by scoping implementing institution capacity and organization, client, donor and partner engagement, and coordination across governments in the given jurisdiction. Overall drought risk is then assessed by characterizing past and future drought hazards, impacts, and vulnerabilities, followed by a gap analysis reviewing current drought response and preparedness measures to comprise the resilience assessment. The last step is identifying and prioritizing possible investments to alleviate drought risk and foster resilience. The DRRA is flexible in that it allows individual applications to be tailored to different country contexts and builds on existing datasets, studies, analyses, and programs while focusing on specific needs and priorities. Instead of replicating existing methodologies and tools, the DRRA brings them together, fills gaps, and points implementers to suitable resources that can inform the assessment in a specific region or country. The objective of the DRRA is to provide a handbook for transitioning from reactive to proactive drought management.

Droughts have been increasing in frequency, duration, and global coverage, impacting approximately 55 million people annually. Since 2000, drought frequency and duration have risen by a third (UNCCD 2022a). Projections indicate that land areas and populations facing extreme droughts could increase 7–8 percent by the late 21st century (Zaveri, Damania, and Engle 2023). In the last five decades, the number of "dry shock" episodes has increased by about 233 percent (Damania et al. 2017). Such dry spells have ramifications for many sectors of the economy, disrupt ecosystems, and have a lasting impact on human well-being. Due to their cascading and wide-ranging impacts, droughts are known to be the most complex and severe weather-related hazard. Studies indicate that droughts are disproportionally detrimental to the Global South and its economic growth. It is estimated that droughts have reduced gross domestic product per capita growth rates in developing countries by 0.39 percent to 0.85 percent (Zaveri, Damania, and Engle 2023).

Droughts manifest as slow-onset disasters, which are typically associated with delayed disaster relief responses. Although their impacts could be lessened with timely and coordinated action, droughts historically have been overlooked until they develop into full-fledged emergencies. More recently, flash droughts, the more rapid-onset counterpart of more "conventional" droughts, have received increasing attention. Importantly, the extent of drought impacts can be best mitigated by implementing drought management plans. Donald Wilhite (2012) coined the term "hydro-illogical cycle" to describe the reactive nature of drought management that entails broad awareness of droughts only once the event has reached a critical stage and that turns into apathy in times of wetter periods. However, planning for droughts in non-drought periods can reduce or even avoid impacts, minimizing physical and emotional suffering in the process (De Nys, Engle, and Magalhães 2017).

The World Bank has developed the DRRA as a cross-sectoral coordinating mechanism for prioritizing drought investments to help countries transition from reactive to proactive drought management. The DRRA builds on previous reports by the World Bank and on internationally recognized concepts, such as the "three pillars approach for drought resilience": (1) monitoring and early warning, (2) risk and impact assessment, and (3) risk mitigation, preparedness, and response. The DRRA consolidates methodologies, such as Assessing Drought Risks and Hazards and the EPIC Response framework, to provide comprehensive and systematic guidance for understanding and managing droughts. In addition, the DRRA is designed to draw from and inform broader climate resilience assessments, such as the World Bank Climate Change and Development Reports (CCDRs) and the Adaptation and Resilience Diagnostics. In that it aims to identify measures to reduce drought risks and impacts before an event occurs, the DRRA is different from the Post-Disaster Needs Assessment (PDNA), which is conducted following a drought crisis to understand relief measures.

The DRRA prioritizes investment options in the context of country-specific or regional capacities, impacts, vulnerabilities, and needs across a range of relevant sectors and systems. The DRRA will help countries assess drought risks and costs or damages (including avoided costs) to justify and prioritize investment options.

This report targets task teams, sector specialists, and their client counterparts to facilitate collaborative programming for drought resilience. Implementation of the methodology requires deep knowledge of drought management, country context, and sector specifics. Deploying an interdisciplinary and intersectoral team is paramount to ensure the methodology's successful application and to identify suitable interventions.

This report permits users to quickly compare available analytical tools. It brings together established and often complementary tools for each DRRA sub-block (figure ES.1) and provides guidance for selecting and combining them. It references case studies illustrating implementation of each building block.

FIGURE ES.1

Building Blocks and Sub-Blocks of the Drought Risk and Resilience Assessment

Block I — **Scope coordination and capacity**

- Scope coordination within the implementing institution
- Scope coordination between government, donors, development partners, and other stakeholders
- Scope coordination across government

Block II — **Assess drought risk**

- Assess current and recent drought hazards
- Assess main trends of future drought hazards
- Assess current and recent drought impacts
- Assess country/region vulnerability to drought

Block III — **Evaluate current resilience**

- Evaluate current drought response
- Evaluate current drought preparedness

Block IV — **Prioritize areas for action**

- Prioritize measures to reduce drought risks and increase drought resilience

Source: Original figure for this publication.

The DRRA is embedded in its regional and institutional context, defining its success. A preliminary participatory scoping exercise determines in which context a DRRA is conducted. First, the scoping must consider the collaboration and interest of local agencies and various sectors' stakeholders in upgrading drought management. It must then judge the readiness and capacity of ongoing government, donor and stakeholder engagement and coordination in the given country. Organizing a workshop that brings relevant external and internal, as well as cross-sectoral, stakeholders to the table can ensure inclusivity and understanding of both challenges and opportunities. The workshop is helpful in identifying existing work and studies that can inform the assessment while avoiding duplication of efforts. The outcome of this scoping exercise (block I) will lay the groundwork for and set the direction of the DRRA and will align priorities for and expectations regarding implementation objectives. Furthermore, as the first building block of the DRRA, this exercise ensures stakeholder involvement, buy-in, and ownership, which are essential for its success.

Comparing hazard characteristics with knowledge of drought impacts and vulnerabilities reveals drought risk hotspots that inform prioritization of efforts and resource allocation. Drought risk results not only from hazards, but also from exposure and vulnerability. Generally, the risk of drought causing damage and socioeconomic/ecological losses reflects the severity and probability of occurrence, exposure, and vulnerability (Vogt et al. 2018; Limones et al. 2020). By conducting a drought risk assessment (block II), teams can identify where the drought hazard is most significant and the areas and sectors that are the most vulnerable to drought. The DRRA emphasizes understanding of drought risk and recommends a thorough assessment of each of the elements of overall risk, as dictated by data and information availability, as well as time and resources. The recommended methods are (1) qualitative risk assessments, (2) empirical semi-quantitative assessments, and (3) data-driven quantitative assessments. The World Bank conducted a machine learning-based, data-driven drought risk assessment in Romania that applied the European Commission's EDORA Framework to show how drought hazards can lead to impacts, to identify thresholds-of-hazard indices that trigger impacts in different sectors, and to determine the likelihood of respective anomalies being experienced due to drought.

Understanding hazard characteristics and trends of future droughts lays the foundation for informed decision-making. A DRRA may start with an analysis of historical or current drought hazard metrics and thus look at precipitation, evapotranspiration, flows, vegetation conditions, soil moisture, and other parameters. The analysis is followed by an assessment of future drought hazards, including climate change projections. Due to the complexity and multifaceted nature of droughts, use of several indices and indicators is recommended to characterize drought hazards. The DRRA framework offers four approaches: (1) using the data and knowledge from an established drought monitoring system in the country/region, (2) relying on drought portals that provide temporal maps of indices, (3) working with preprocessed indices served in web portals, and (4) constructing indices with on-the-ground information from local agencies. The selection of approaches will depend on data availability, resources allocation, and time constraints. Where drought monitoring systems do not exist, their establishment is recommended. For example, Brazil developed a drought monitoring system that measures indicators on a monthly basis, and depending on pre-defined thresholds, helps trigger specific actions.

Drought impacts evolve gradually and are thus often not immediately evident. Droughts affect all economic sectors, individuals, communities, society as a whole, and various ecosystems. Their impacts can range from stunting due to malnutrition, to the death of hundreds of dolphins in the Amazon due to low water flows, to community anxiety associated with water shortages and failing crops. Unless the DRRA has a clear sectoral focus, all potential drought impacts should be assessed. Knowledge of these impacts reveals drought risk hotspots and vulnerabilities that inform the prioritization of efforts and resource allocation. Information on drought impacts can be gained through drought impact chain identification, estimation of drought macroeconomic impacts, human impact assessments, PDNA/Damage and Loss Assessments, or simply a review of an existing impact database or monitoring system in the country. Additional tools and methodologies for drought impact assessments range from established impact database monitoring systems in the country or region to remote sensing-based analyses.

A high level of vulnerability to drought threatens livelihoods and capacity to meet the most basic needs. Although drought impacts are felt across society, impacts manifest to varying degrees, depending on the level of vulnerability. Vulnerability can be understood as a system's susceptibility to and inability to handle the adverse effects of drought. The DRRA should include an assessment of vulnerability, which aims to determine what causes risk and how it is managed. By indicating areas with the highest needs, this assessment will inform prioritization of drought responses and preparedness measures. King-Okumu (2019) categorizes vulnerability assessments as one of three types: (1) people-centered, (2) land-based mapping and models of ecosystem-service production, or (3) hydrometeorological assessments, including water balance accounting. The DRRA provides a comprehensive overview of ways vulnerability can be evaluated.

Investments in drought preparedness and pre-arranged drought responses maximize risk management and resilience. Notably, drought-risk assessment toolkits, approaches, and methodologies rarely account for current drought response and preparedness and how these systems can be best upgraded, thereby missing the resilience dimension. Approaches to resilience assessment (block III) include (1) desk-based stock-taking of drought response and drought preparedness mechanisms, (2) in-depth assessment of drought management plans and climate adaptation actions, and (3) identification of key program areas around which to prioritize investments relevant to drought. The EPIC Response framework provides a template to identify the relevant stakeholders and program areas while gauging their level of development and effectiveness. To identify drought investments, drought risks (block II) must be mapped against the current level of drought resilience and challenges facing the current drought management system (block III).

Systematically assessing the benefits of drought investment options permits the efficient allocation of limited resources to areas where they can make the most significant impact. The DRRA results in a list of evaluated and prioritized investment options to mitigate drought risk and build resilience (block IV). To properly assess investment options, the long-term benefits of a program or project must be weighed against costs. Assessing the benefits entails comparing project outcomes with expected drought impacts in the business-as-usual scenario.

This report is intended to guide collaborative program development. The report will be updated to reflect lessons from DRRA implementation in various country and regional contexts.

World Bank

Abbreviations

AgBMPs	Agricultural Best Management Practices
A&R	Adaptation and Resilience Diagnostic
BACI	Benefits of Action and Costs of Inaction
BCA	Benefit-Cost Analysis
CCDR	Country Climate and Development Report
CMIP6	Coupled Model Intercomparison Project Phase 6
CMU	Country Management Unit
CORDEX	Coordinated Regional Downscaling Experiment
DALA	Damage and Loss Assessment
DEWS	Drought Early Warning Systems
DMDU	Decision-Making Under Deep Uncertainty
DRAMP	Drought Resilience, Adaptation and Management Policy
DRRA	Drought Risk and Resilience Assessment
EC	European Commission
EDORA	European Drought Observatory for Resilience and Adaptation
EM-DAT	Emergency Event Database
ES	Ecosystem Services
EU	European Union
FAO	Food and Agriculture Organization
GEE	Google Earth Engine
GFDRR	Global Facility for Disaster Reduction and Recovery
GWP	Global Water Partnership
HRNA	Human Recovery Needs Assessment
IDMP	Integrated Drought Management Programme
IHSN	International Household Survey Network
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
KNMI	Royal Netherlands Meteorological Institute (Koninklijk Nederlands Meteorologisch Instituut)
MoM	Menu of Measures
NbS	Nature-Based Solutions
NEX-GDDP-CMIP6	Earth Exchange Global Daily Downscaled NASA Projections
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
OECD	Organisation for Economic Co-operation and Development
PDNA	Post-Disaster Needs Assessment
PESTEL	Political, Economic, Social, Technological, Legal, and Environment
SDHI	Standardized Drought Hazard Indices
SPEI	Standard Precipitation Evapotranspiration Index
SPI	Standard Precipitation Index
SROI	Social Return on Investment
SUDS	Sustainable Urban Drainage Systems
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
WBCA	Weighted Benefit-Cost Analysis
WCRP	World Climate Research Programme
WEI	Water Exploitation Index
WHE	Water Harvesting Explorer
WRI	World Resources Institute
WSD	Water Security Diagnostic

1.

Introduction: Understanding Drought Disaster Management and Existing Approaches

1.1 Droughts Are Complex and Often Ignored for Too Long

Although droughts pose significant risks to the economy, society, and ecosystems, their impacts are not easily assessed, and many actual losses are unaccounted for. Against the backdrop of climate change and population growth, droughts exacerbate existing strains on water resources. Smirnov et al. (2016) attribute 60 percent of the projected increase in drought exposure to climate change, 9 percent to population growth, and 31 percent to the interaction of the two.

Dry episodes have been increasing in both frequency and global coverage. Drought frequency and duration have risen by a third since 2000. Globally, an estimated 55 million people a year are affected by droughts (UNCCD 2022a). In 2022, the United Nations (UN) warned that approximately 22 million people in the Horn of Africa were at risk of starvation (Rodella, Zaveri, and Bertone 2023). Empirical estimates show that droughts have a disproportionate impact on developing countries and their economic growth. Zaveri et al. (2023) found that droughts reduce gross domestic product growth per capita between 0.39 percent and 0.85 percent, on average. Projections indicate that land areas and populations facing extreme droughts could increase 7–8 percent by the late 21st century (Zaveri, Damania, and Engle 2023). In the last five decades, the number of dry shock episodes has increased by about 233 percent (Damania et al. 2017). Climate models project an upward trend in the occurrence of heat and drought events, which will cause production losses and tree mortality. Widespread incidents of food insecurity and malnutrition have already increased in Africa and in Central and South America (IPCC 2022).

Although drought events made up 6 percent of all the disasters that occurred between 1970 and 2019, they caused 7 percent of reported economic losses and accounted for 34 percent of all reported deaths (WMO 2021). In the same period, more than 90 percent of climate-related deaths occurred in the global south (UNCCD 2022a). Women who experienced large dry shocks in their infancy are 29 percent more likely to have children suffering from anthropometric failure. In turn, children who witnessed large dry shocks in infancy are more likely to suffer long-term health impacts reaching into adulthood and to have an increased likelihood of being stunted. In Sub-Saharan Africa, it is estimated that more than 35 percent of children under the age of five are stunted (Damania et al. 2017).

Drought impacts are felt across ecosystems, such as freshwater and coastal ecosystems, which suffer from reduced water flows. A drought in the Amazon led to the death of hundreds of dolphins in 2023 (Santos de Lima et al. 2024). Despite their magnitude, the effects of drought are often under-reported and ignored, translating into slowly unfolding disasters that can grow into full-fledged emergencies across sectors and segments of economies (Staupe-Delgado 2019). Drought does not elicit the same immediate response from the public or motivate as much political action as other natural disasters. Given their slow onset and wide-ranging and cascading impacts, droughts are often considered the most complex and severe weather-related hazard.

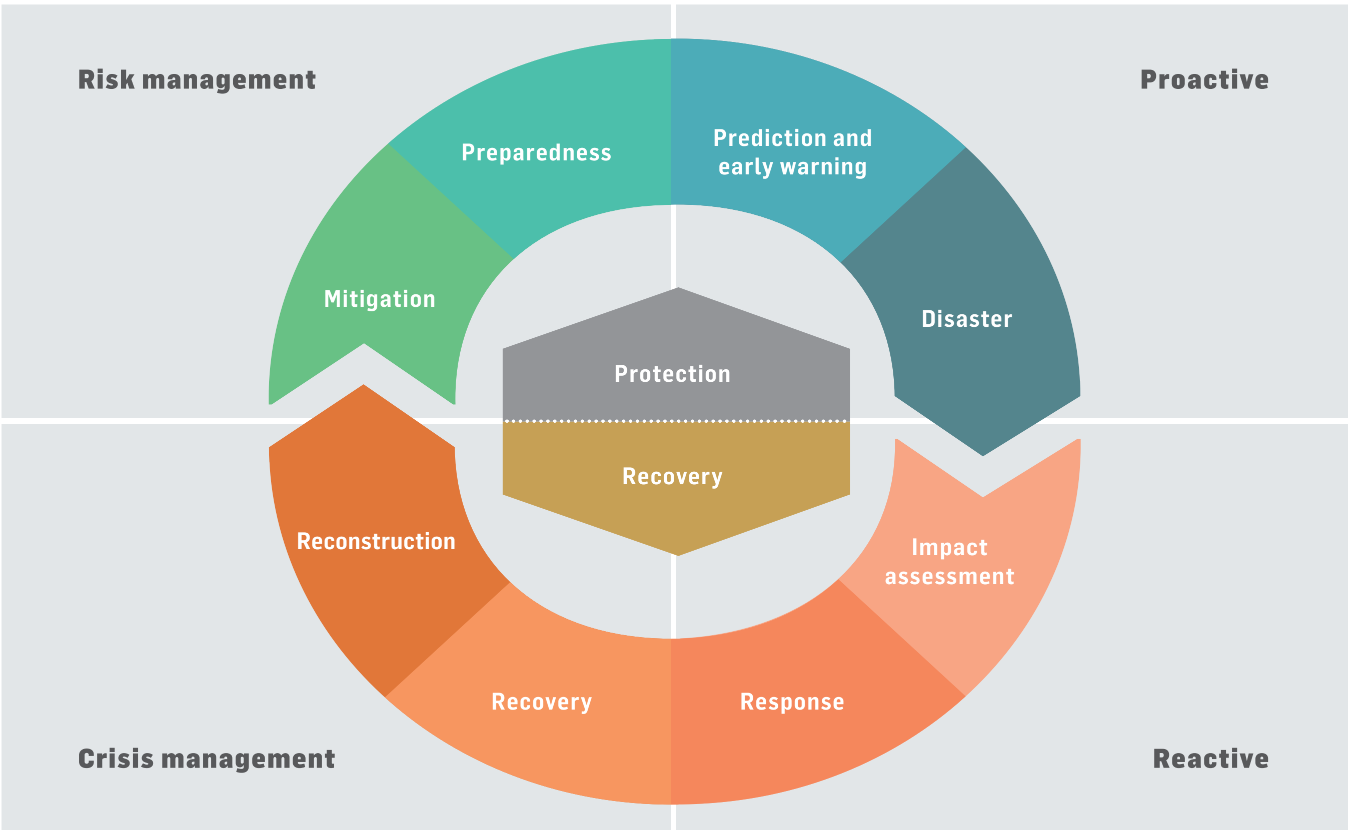
Droughts can be characterized as meteorological, agricultural, hydrological, environmental, or socioeconomic droughts and can have distinct characteristics and implications across sectors.[1] The sectors suffering directly or indirectly during droughts include agricultural production, water supply, energy production, transportation and tourism, human health, biodiversity, and natural ecosystems. Crucially, drought risks and the indices and (geo)statistical analyses used to understand these risks may differ significantly, depending on the primary concern, whether it be public health, agriculture and crop losses, water supply, hydropower, manufacturing and industries, or something else.

Figure 1.1 depicts the full cycle of disaster risk management incorporating both risk and crisis management elements. Box 1.1 describes some of the most relevant terms used throughout this report.

Additional concepts not included in box 1.1 include flash droughts and “precipitation/evaporation sheds.” Although these concepts are not a focus of this report, they can impact water availability and are thus briefly outlined in box 1.2.

FIGURE 1.1

Cycle of Disaster Risk Management



Source: Adapted from De Nys, Engle, and Magalhães 2017.

BOX 1.1

Drought-Related Terms Used in this Report

DROUGHT: Period of abnormally dry weather sufficiently prolonged to cause a serious hydrological imbalance (WMO 1992).

ARIDITY: When precipitation is insufficient for maintaining vegetation, an area is considered arid. Aridity is measured by comparing long-term water supply (precipitation) with long-term average water demand (evapotranspiration) (Cap-Net et al. 2020).

WATER SCARCITY: An imbalance between the supply and demand of freshwater in a specified domain (country, region, catchment, river basin, and so on) as a result of a high rate of demand compared with available supply, under prevailing institutional arrangements and infrastructural conditions (FAO 2012).

WATER SHORTAGE: A shortage of water supply of an acceptable quality; low levels of water supply, at a given place and a given time, relative to design supply levels. The shortage may arise from climatic factors or other causes. For a comparison of definitions related to water shortages see figure B1.1 (FAO 2012).

(box continues next page)

BOX 1.1 *(continued)*

VULNERABILITY: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes (Nakicenovic et al. 2000). Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, the system's sensitivity, and the system's adaptive capacity. Vulnerability is often understood as the opposite of resilience.

REACTIVE DROUGHT MANAGEMENT: A reactive approach to drought management is equivalent to crisis management: it includes relief measures and actions taken after the start of a drought event. This approach is adopted in emergency situations and can lead to inefficient technical and economic solutions caused by time constraints that inhibit a thorough evaluation of options and stakeholder participation. Reactive drought management does little to reduce drought impacts caused by future drought events (Vogt et al. 2018).

PROACTIVE DROUGHT MANAGEMENT: A proactive approach to drought risk management includes the design, with stakeholder participation, of appropriate measures and related planning tools in advance. The proactive approach is based on both short-term and long-term measures and includes monitoring systems for a timely warning of drought conditions, identification of the most vulnerable members 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. Proactive drought management is reflected in the three pillars of integrated drought management (Vogt et al. 2018).

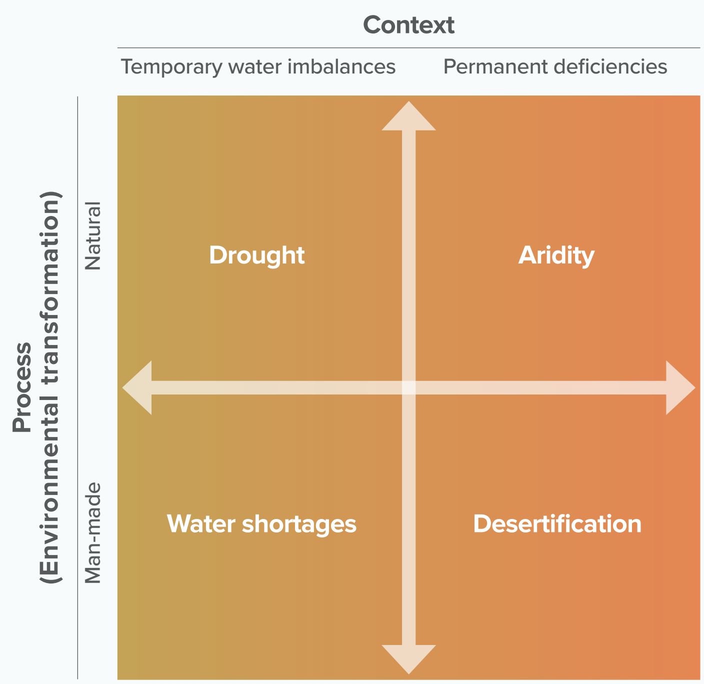
RESILIENCE: IPCC (2023) defines resilience as "The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning and/or transformation."

The Integrated Drought Management Programme provides a glossary of drought-related terms.[a]

[a] Integrated Drought Management Programme, "Glossary," https://www.droughtmanagement.info/find/glossary/.

FIGURE B1.1.1

Types of Water Shortages Based on Context and Driving Forces



Source: Adapted from Karavitis et al. 2014.

BOX 1.2

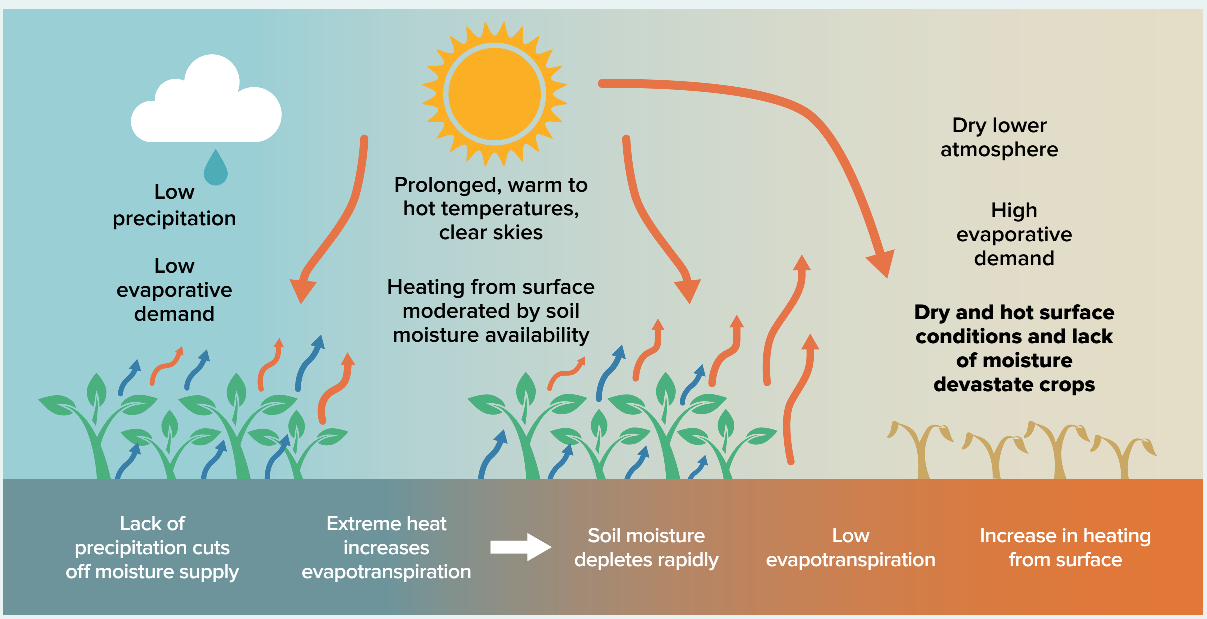
How Flash Droughts and Precipitation/Evaporationsheds Impact Water Availability

CLIMATE CHANGE WILL FUEL THE FREQUENCY OF FLASH DROUGHTS

Droughts are typically characterized as disasters in slow motion, distinguishing them from other types of disasters, specifically rapid-onset events such as floods. Recently, flash droughts, such as one in 2012 in the United States that caused more than US$30 billion in economic losses (Yuan et al. 2023), have garnered attention. Flash droughts are characterized by their rapid onset, challenging drought monitoring and forecasting, as well as the implementation of drought mitigation measures. Otkin et al. (2018) proposed that flash droughts be defined on the basis of the rate of intensification at which they unfold, which can be a matter of weeks. Flash droughts often develop when below-average precipitation is followed by elevated evaporation caused by high temperatures, low humidity, strong winds, sunny skies, and decreased soil moisture (see figure B1.2.1). A combination of these conditions can result in the rapid development of flash droughts, which could develop into other types of droughts, such as hydrological or agricultural droughts, or which could trigger and interact with compound extreme events, such as heat waves or wildfires.

FIGURE B1.2.1

Climatic Conditions Leading to Flash Droughts



Source: Adapted from Parker and Gallant 2021.

Climate change contributes to a rising risk of flash drought occurrences and, thus, to the frequency of impacts felt across society, ecosystems, and the economy. The agriculture sector is especially impacted by flash droughts, and projections show that cropland areas affected by flash droughts will increase across all continents (Christian et al. 2023).

(box continues next page)

BOX 1.2 *(continued)*

Christian et al. (2023) indicate that flash drought frequency will increase on a global level with greater fossil fuel use and higher radiative forcing. In addition, elevated risks of flash droughts over cropland have been reported. Finally, studies indicate that in addition to occurrence, both the duration and severity of flash droughts will increase; precipitation decreases are combined with greater flash drought frequency in the Amazon, Iberian Peninsula, and Anatolia (Christian et al. 2023). Furthermore, a review of drought events between 1951 and 2014 indicates that sub-seasonal droughts, influenced by anthropogenic climate change, have developed faster and transitioned globally to flash droughts (Yuan et al. 2023).

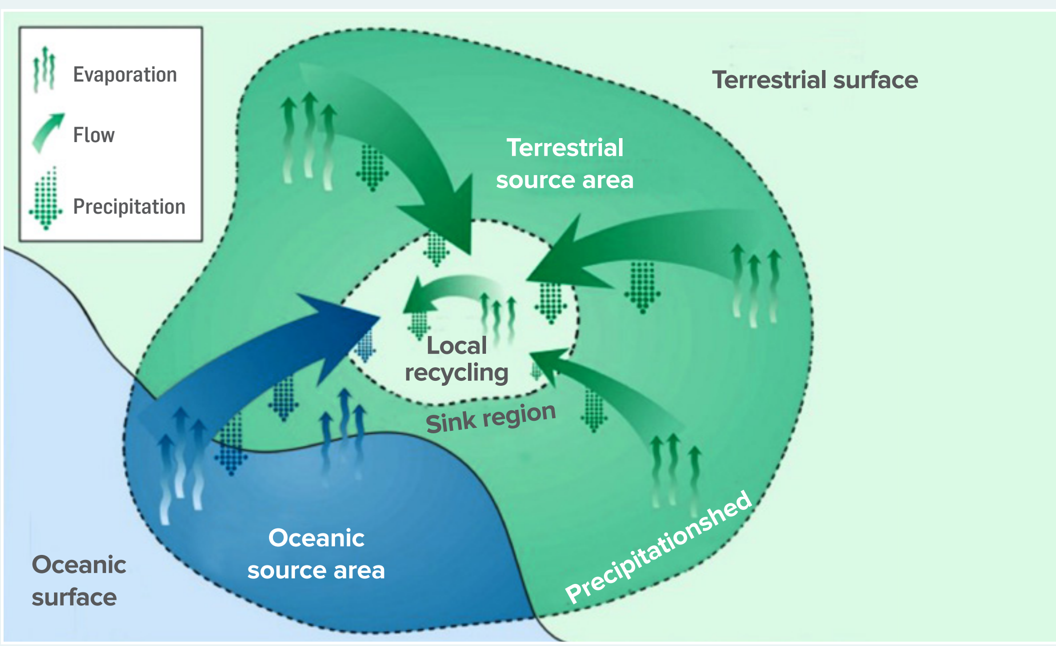
ATMOSPHERIC WATERSHEDS CONNECT REGIONS THROUGH FLOWS OF WATER VAPOR

Understanding and sustainably managing water resources usually involves studying the water cycle and hydrology within a specific country, river basin, or watershed. Key parameters for assessing the status of water resources in a given system include precipitation, evapotranspiration, surface runoff, and changes to water storage. This sometimes involves looking at green and blue water balances. However, moisture and water vapor can move across watersheds, thereby creating water flows that connect different basins and watersheds. To fully capture impacts on water availability in a given location, researchers must consider atmospheric water flows need alongside basin-level water balances.

Researchers call atmospheric watersheds “precipitationsheds” and “evaporationsheds” (see figure B1.2.2). The former refers to regions that are sources of precipitation; the latter describes regions that receive that precipitation. This land-atmosphere feedback across basins needs to be better understood (Rockström et al. 2023; Wang-Erlandsson et al. 2018).

FIGURE B1.2.2

Precipitationsheds and Evaporationsheds



Source: Keys et al. 2012.

Drought impacts depend significantly on systemic vulnerabilities, which are intricate and nonlinear even within one society or ecosystem. For instance, in arid and semi-arid regions, ecosystems and human activities may develop adaptations to limited water availability. Agriculture, lifestyle, and infrastructure in these regions are typically designed to cope with low rainfall, but they usually have a narrower margin than wet areas for maneuvering due to dryness, and deficits can eventually lead to water shortages. Conversely, regions that usually receive adequate rainfall have a larger water margin overall, which can provide a buffer against immediate shortages. However, these regions may lack the adaptive practices necessary to handle prolonged or severe droughts, possibly leading to more economic and social disruptions during exceptional droughts compared with regions where dryness is the norm. Some drought-prone, well-organized societies are currently capable of maintaining functionality and stability and transforming potentially catastrophic droughts into manageable scenarios. In contrast, others lacking preparedness can experience exacerbated drought effects, leading to deepened vulnerability and severe disruptions. In general, the way equally intense droughts may cause different impacts depending on the context highlights the challenge of understanding the phenomenon.

Another challenge is that drought impacts can be direct or indirect and short term or long term (Cap-Net et al. 2020). Additionally, impact assessments often focus on direct effects. Secondary and indirect impacts may be equally important but pose difficulties for quantification (Eckhardt, Leiras, and Thomé 2018).

Historically, droughts have been overlooked empirically and conceptually, and their management has been largely reactive in nature (Staupe-Delgado 2019). Donald Wilhite (2012) refers to this crisis management approach as the "hydro-illogical cycle." One reason for the slow uptake of a more proactive drought management approach is the low political salience and perceived severity of a disaster that builds over time and whose impacts can be protracted, geographically dispersed, or both. Sudden-onset disasters are perceived as representative of all types of disasters, and the majority of disaster-related research focuses on understanding and evaluating them (Staupe-Delgado 2019). Countries often lack clear frameworks for identifying and implementing prevention and response interventions. Nevertheless, there are increasing calls for a paradigm shift from reactive drought management to proactive drought management.

A well-established methodology that supports management of drought impacts is the Post-Disaster Needs Assessment (PDNA), jointly developed by the European Union, the World Bank, and the United Nations Development Programme (UNDP). Crucially, PDNAs provide a comprehensive and standardized methodology for assessing impacts and recovery, avoiding situations in which, historically, several assessments were undertaken in parallel. PDNAs are conducted right after disasters occur and gather information regarding impacts, response measures, and recovery costs (EU, UNDG, and World Bank 2013).

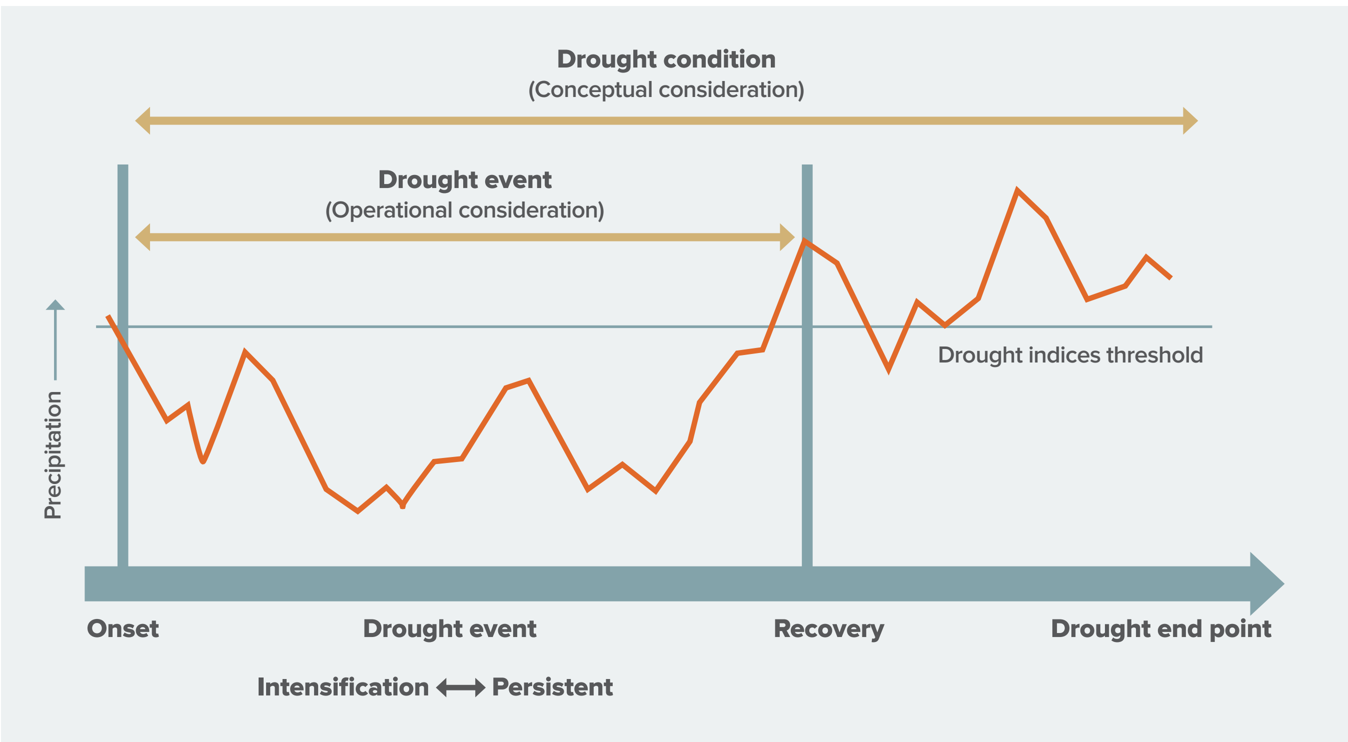
PDNAs are effective in quickly evaluating the impact, vulnerability, and economic aspects of disasters, facilitating immediate relief measures. However, PDNAs conducted shortly after events cannot consider lagged, indirect, compounded, or long-term impacts. Not all stages of a drought event cycle can be considered in a PDNA (see figure 1.2). Because PDNAs focus on immediate action, they are not a tool to build cross-sectoral drought preparedness and resilience. Furthermore, PDNAs embrace a relatively rigid application, and their time constraints hinder tailoring to individual country needs or contexts (EC, GFDRR, and UN 2018).

1.2 Many Solutions Exist for Proactive Drought Management

The most successful approach to managing droughts is by transitioning from crisis management or a reactive response to a risk management or proactive response. Preparedness reduces costs through mitigation of the social, economic, and environmental impacts that drought would otherwise have caused, and it increases resilience to future droughts (Serrat-Capdevila et al. 2022). Proactive drought management also reduces risks while increasing social capacity to address them. Planning for droughts in non-drought periods can reduce and, in some cases, even avoid impacts, minimizing physical and emotional suffering (De Nys, Engle, and Magalhães 2017). Furthermore, integrated approaches for addressing climatic extremes, specifically droughts, support most of the Sustainable Development Goals (Cap-Net et al. 2020). Finally, nature-based solutions (NbS) are an important consideration when planning for and prioritizing drought management interventions. NbS often entail lower initial investments than engineered solutions and can reduce long-term costs by naturally enhancing ecosystem services and mitigating drought impacts (box 1.3).

FIGURE 1.2

Stages of a Drought Event



▪ Abnormally dry (Level 0) ▪ Soil moisture levels are low, crop and pasture growth delayed ▪ Water alerts are issued	▪ Moderate (Level 1–2) ▪ Some crop and pasture damage ▪ Fire risk moderate to high ▪ Water conservation measures activated ▪ Socioeconomic impacts are mild to moderate	▪ Level 2–4 drought ▪ Water shortages, crop damage and fires are widespread ▪ Fire risk high to extreme ▪ Socioeconomic impacts are moderate	▪ Meteorological indices have returned to normal ▪ Soil moisture is restored in cultivated land ▪ Pasture growth re-establishes ▪ Reservoirs and lakes refill	▪ Agricultural and natural ecosystem productivity returns to average pre-drought conditions ▪ Lake and reservoir levels return to average pre-drought conditions ▪ Socioeconomic conditions: Do they return when the drought ends? In some cases we hit a "new normal"

Source: Adapted from Howard et al. 2021.

BOX 1.3

Nature-Based Solutions Are Integral for Integrated Drought Risk Management

Nature-based solutions (NbS) are a crucial element in the pursuit of drought resilience and climate change adaptation (Zaveri, Damania, and Engle 2023). Importantly, these solutions need to be considered as both complementary and possible substitutes for existing management and infrastructure investments. They are ideally positioned within an integrated set of solutions. Although NbS do not generate water, some NbS, such as reforestation, can impact precipitation patterns and atmospheric moisture recycling. NbS can influence natural processes for the redistribution of water over time and space within a watershed. Broadly, NbS for climate risk mitigation are categorized as (1) *protection* of intact landscapes, (2) *management* of working lands, and (3) *restoration* of high-value habitats.[a] More specifically, these solutions can include interventions related to targeted habitat protection, agricultural/ranching/forestry best management practices, artificial wetlands, native revegetation, natural and hybrid surface interventions, sub-surface and groundwater storage interventions, wetland restoration, floodplain and river restoration, and riparian restoration (Vigerstol et al. 2023). Detailed ecological and hydrological assessments are essential, particularly for vegetation or localized storage interventions, which might further reduce streamflow during droughts or create unintended negative consequences downstream.

Assessing and quantifying the benefits of NbS to mitigate droughts is generally challenging but should not lead practitioners to favor grey infrastructure investments over green or green-grey solutions. Integrating NbS in broader programs can drastically increase these investments' overall impacts. DRRA application should avoid building institutional or regulatory barriers to implementation of NbS (Van Zanten et al. 2023). Appendix B presents an overview of some NbS that could increase water security and mitigate drought risk.

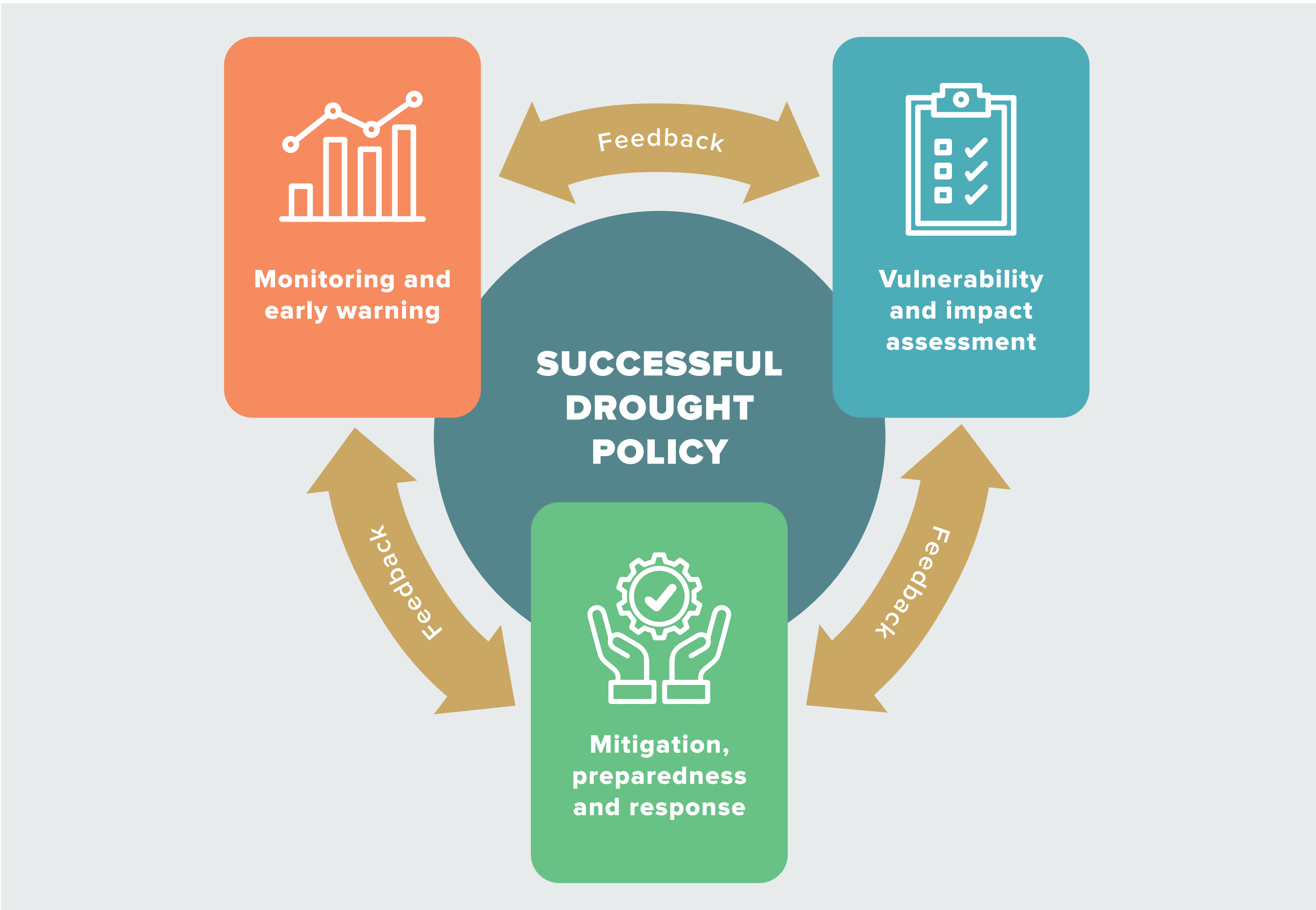
[a] Measuring the impact of drought on wildlife species remains a significant scientific challenge, even in developed countries. This difficulty underscores a substantial gap in current understanding of ecological responses to drought conditions. Wildlife species often exhibit complex and varied responses to drought, influenced by a multitude of factors including habitat type, species-specific water dependencies, and ecosystem interactions. Traditional monitoring techniques frequently fall short in capturing these nuanced dynamics, necessitating the development of more sophisticated methods and technologies. Advancements in remote sensing, coupled with comprehensive field studies, could offer more accurate and granular insights into how droughts affect wildlife populations and their habitats.

The three pillars of integrated drought management are reflected in most proactive drought management frameworks. As depicted in figure 1.3, integrated drought management in accordance with the three pillars includes (1) monitoring and early warning systems, (2) vulnerability and impact assessments, and (3) identification and implementation of drought mitigation and preparedness measures.[2]

In addition to the abovementioned integrated drought management approach, the Global Facility for Disaster Reduction and Recovery (GFDRR) and the World Bank have developed an implementation guide for assessing drought hazards and risks. Although it is not built around the three pillars, the guide promotes four guiding principles for drought risk assessments: (1) a system-scale perspective, (2) assessment of droughts in relation to their impacts, (3) understanding that drought risk changes over time, and (4) the idea that effective drought management increases resilience and enhance preparedness.

FIGURE 1.3

Three Pillars of Effective Drought Management as Developed by the Integrated Drought Management Programme



Source: Adapted from Cap-Net et al. 2020.

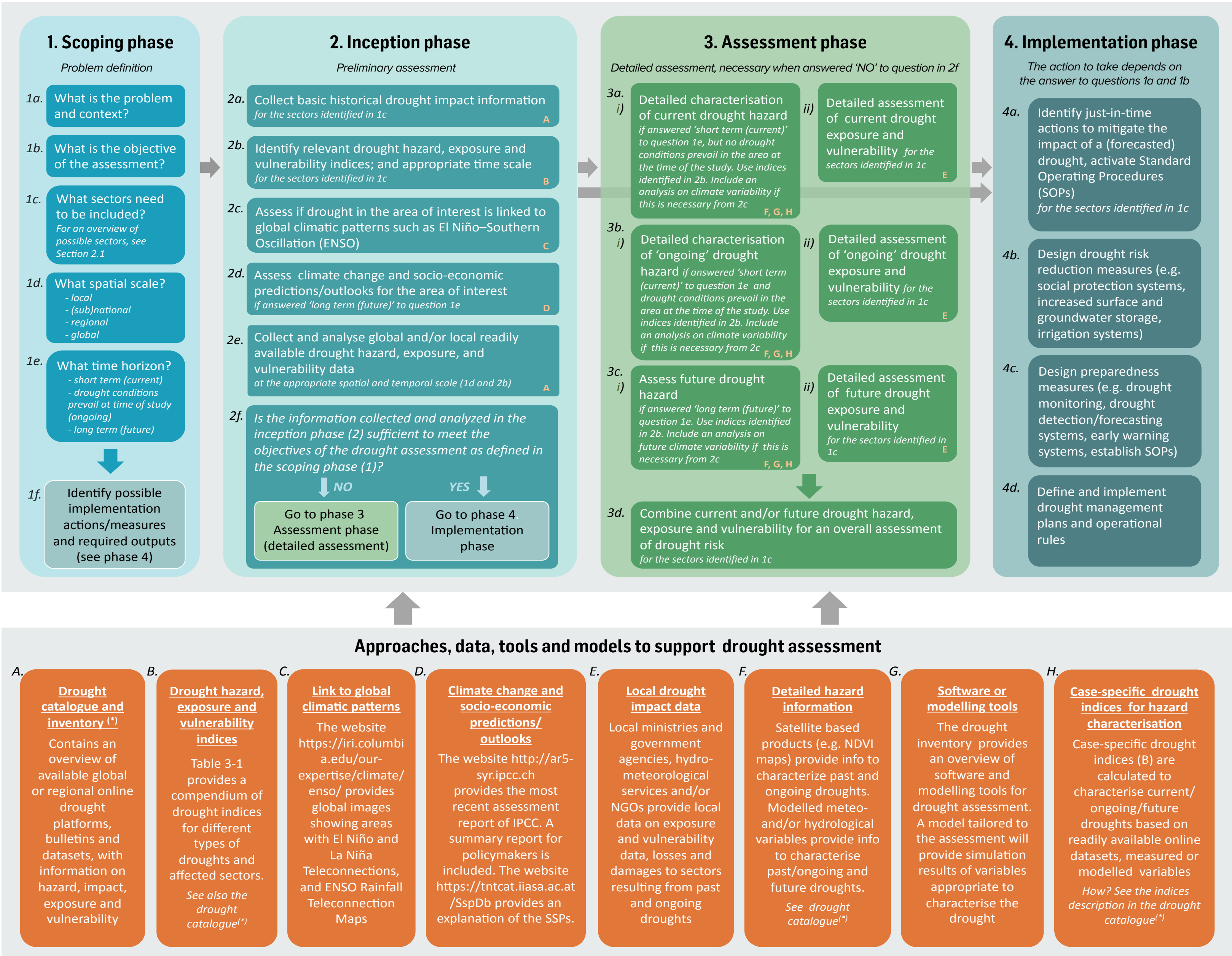
This framework is flexible and is specifically tailored to responding to drought disaster needs (see figure 1.4) with just-in-time to sector-specific or regional solutions (World Bank 2019). It was developed alongside a catalogue of drought hazard and risk tools, a global inventory (Deltares 2017) of these tools, and a comparative assessment report (Deltares 2018). However, this collection of resources focuses narrowly on drought risk assessments while providing limited guidance on drought management and resilience-building practices.

The importance of integrated approaches to drought management is further elaborated in the EPIC Response framework developed by the World Bank and Deltares. This collection of programs supports creation of an effective governance system to manage hydro-climatic risks (droughts and floods). Numerous program areas are organized into five key elements that form the basis of the framework: (1) enabling environment, (2) planning at multiple and nested geographical levels, (3) investing in healthy watersheds and water infrastructure, (4) controlling water use and development, and (5) responding better to hydro-climatic risks (Browder et al. 2021; Crossman 2018).

Appendix A presents a more detailed comparison of complementary tools for the DRRA, elaborating on synergies made possible and gaps filled by the DRRA. These tools comprise the drought risk assessment developed by GFDRR, the EPIC Response framework, the Climate Change and Development Reports (CCDRs), and the Adaptation and Resilience Diagnostic.

FIGURE 1.4

Drought Risk Assessment Implementation Guide Developed by the Global Facility for Disaster Reduction and Recovery



Source: World Bank 2019.
Note: Letters at the bottom right of the phase boxes refer to the orange boxes at the bottom of the figure. ENSO = El Niño Southern Oscillation; IPCC = Intergovernmental Panel on Climate Change; NGO = nongovernmental organization; SSP = Shared Socioeconomic Pathways. * www.droughtcatalogue.com

1.3 Why DRRAs Are Needed and How They Are Organized

This report elaborates on all the building blocks of a proactive, risk-based assessment of drought management needs and opportunities. Instead of developing a completely new approach, it organizes already-established tools, frameworks, and methodologies—including the PDNA methodology, the three pillars, the GFDRR's risk assessment implementation guide, and the EPIC Response framework—into four building blocks that consist of several sub-blocks. The list of tools presented within each block is not exhaustive.

It is important to acknowledge prior drought tool consolidation efforts. The drought toolbox from the United Nations Convention to Combat Desertification is just one exemplary effort, based on the three pillars, to consolidate drought management tools and methods. Other tool compilations include the Flood and Drought Portal (DHI 2023) and Flood and Drought Management Tools.[3] In addition, Deltares developed, in conjunction with GFDRR's drought hazard and risk assessment guide (World Bank 2019), a catalogue of drought-specific hazard and risk tools.[4] The DRRA does not reiterate but instead links the content of these collections and initiatives, referencing relevant toolboxes and databases and explaining how their use can be further complemented (see figure 1.5).

The DRRA's structure permits users to quickly compare available tools and select the most appropriate options for their purpose. The DRRA provides guidance on approaches suitable for different application cases, depending on country capacity, data availability, resources allocated to complete the exercise, and level of engagement and demand for the assessment.

The proposed methodology provides solutions for actors preparing for, experiencing, or in the wake of a drought. Proactive and comprehensive approaches to DRRA are encouraged, but when actors are facing an unfolding drought without plans, a more rapid and less resource-intensive version of the DRRA can be implemented. Furthermore, the presented solutions allow actors to address different types of droughts at different jurisdictional levels and with various sectoral emphases.

DRRAs are of interest to professionals working on initiatives in sectors such as water resources management, agriculture, climate change, and disaster risk management, and they represent an opportunity to link human development with disaster management efforts and to embed drought management within existing World Bank country programs and initiatives. This report is, therefore, written primarily for task teams and sector specialists, as well as their client counterparts, to facilitate collaborative programming for drought resilience.

Generally, DRRAs can be prepared as standalone assessments or can complement a broader ecosystem of evaluation tools, such as Water Security Diagnostic studies and CCDRs, that collectively contribute to informed investments and robust drought resilience strategies.

DRRAs, encompassing current program evaluation, gaps, and upgrade analyses, can be undertaken through a sectoral lens. Even though the significance of the risk is better understood if multiple sectors and systems are integrated into assessments, the presented framework allows for a targeted sectoral focus. The flexible nature of the approach permits a tailored exploration of sector-specific nuances, facilitating a granular understanding of drought risks. Appendix C presents questions to guide DRRA implementation.

The DRRA is supported by and was developed in conjunction with a Menu of Measures (MoM), which is based on the program areas defined in the EPIC Response framework and organizes measures alongside these areas (see figure 4.2 in block III). The MoM does not just list potential measures to improve drought preparedness; it provides additional resources and examples of projects that illustrate these options. Specifically, for blocks III and IV, the MoM creates the context in which programs in the drought management system are identified and then evaluated. This report's MoM reflects the EPIC Response framework for the purpose of ensuring links and consistency with existing frameworks applied within and outside of the World Bank. It is not an exhaustive list of potential drought resilience-building measures but rather a complement to other lists identifying such measures.

In the following chapters of this report, each building block and sub-block of the DRRA is elaborated, illustrated with case studies, and underpinned by a list of available methodologies. Importantly, a DRRA including the activities described in this report is initiated only at the request of a client government and requires the government's ownership/leadership for implementation.

FIGURE 1.5

Building Blocks and Sub-blocks of the Drought Risk and Resilience Assessment

Block	Sub-blocks
Block I	**Scope coordination and capacity**
	Scope coordination within the implementing institution Scope coordination between government, donors, development partners, and other stakeholders Scope coordination across government
Block II	**Assess drought risk**
	Assess current and recent drought hazards Assess main trends of future drought hazards Assess current and recent drought impacts Assess country/region vulnerability to drought
Block III	**Evaluate current resilience**
	Evaluate current drought response Evaluate current drought preparedness
Block IV	**Prioritize areas for action**
	Prioritize measures to reduce drought risks and increase drought resilience

Source: Original figure for this publication.

Notes

1 National Drought Mitigation Center, "Types of Drought," https://drought.unl.edu/Education/DroughtIn-depth/TypesofDrought.aspx.

2 Integrated Drought Management Programme, "The Three Pillars of Drought Management," https://www.droughtmanagement.info/pillars/.

3 United Nations Convention to Combat Desertification, "Drought Toolbox," accessed June 11, 2023, https://www.unccd.int/land-and-life/drought/toolbox.

4 IW:LEARN, "Flood & Drought Management Tools," accessed June 11, 2023, https://fdmt.iwlearn.org/.

2.

Scoping Coordination and Capacity (Block I)

Initiating a DRRA requires understanding of the context in which it will be applied. A quick scoping exercise to determine whether the DRRA will be successful is essential and can include, inter alia, existing internal and external initiatives, capacities, available resources, and commitment. The information gathered will provide important insights into the selection of tools based on time, resources, and capacity. For optimal allocation of resources and efforts, the context scoping allows teams to draw on synergies from related activities while being able to inform others. Generally, this check entails a review of (1) the implementing institution's internal coordination, (2) government, donor, development partner, and other stakeholder coordination, and (3) coordination across government (see figure 2.1).

A readiness assessment will identify both World Bank sectors and entities involved in drought-related efforts in the country or region of interest and relevant initiatives and programs in that country or region that are not led, supported, or coordinated by the World Bank. By highlighting gaps and duplications, this assessment will set the stage for more seamless coordination of donors, government entities, and development partners, and for an integrated and cohesive approach to DRRA implementation. Involving local agencies and stakeholders from various sectors in the assessment can foster a sense of ownership and commitment, which is important for a realistic and ground-based DRRA.

FIGURE 2.1

Block I of the Drought Risk and Resilience Assessment

Block I

Scope coordination and capacity

- **Scope coordination within the implementing institution**
- **Scope coordination between government, donors, development partners, and other stakeholders**
- **Scope coordination across government**

Source: Original figure for this publication.

> This chapter describes application of block I of the DRRA by the World Bank and, therefore, uses World Bank terminology. Importantly, DRRAs are not exclusively developed for World Bank operations. Block I can be adapted to the needs and structures of the respective implementing institution/entity—be it a country or a donor.

2.1 Scoping Coordination within the Implementing Institution

WHY THIS BUILDING BLOCK IS IMPORTANT: Characterization of drought hazard—the severity, frequency, duration, extent, When the World Bank is the implementing entity, the DRRA begins with determination of a Country Management Unit's (CMU) level of interest in evaluating a client's drought needs and opportunities and its readiness to undertake a DRRA. If a government office is the initiating entity, it must itself assess its own internal readiness. It is essential to ascertain whether sufficient technical capacity and funding resources are or could be allocated to address drought-related challenges. In addition, it is crucial to assess whether a multi-sectoral DRRA is feasible.

POSSIBLE RESULTS: For the World Bank, by examining the Country Strategy, the current country portfolio, and the portfolio's performance, this part of the assessment aims to establish whether drought is genuinely regarded as a priority in the CMU's initiatives and projects and whether teams are prepared to support and budget for a DRRA. Additionally, this assessment indicates whether a DRRA could be successfully planned and implemented with the client.

By evaluating the prevailing culture of the interdisciplinary collaboration/multi-sectoral dialogues in the target country, the assessment aims to inform the possibility of integrated multi-sectoral operations for drought resilience. Identifying obstacles and implementation challenges in this context helps set realistic expectations for a comprehensive DRRA. By no means is the assessment meant to critique the structure and function of the CMU writ large. Rather, it aims to provide an initial reality check regarding the operational readiness of the CMU to facilitate a DRRA and the capacity of staff across practices to prioritize time for that exercise. If a government itself is the initiating entity, the same assessments should be made of that entity.

This sub-block should consist of a CMU/country-level reflection on the feasibility of:

- Integrating DRRAs into overall strategies and operations
- Creating incentives for and promoting a culture of collaboration and knowledge sharing to support a DRRA
- Establishing clear coordination mechanisms for collecting (and sharing) DRRA-related information from client agencies and partners
- Creating staff training/learning opportunities to enhance expertise in drought assessment and multi-sectoral approaches

Within a CMU, challenges that could hamper a DRRA include:

- Limited expertise with the complexities of drought and limited awareness of the need for multi-sectoral collaboration for DRRAs and drought management
- Communication and information sharing gaps
- Competing priorities and resource constraints

Within a country, a DRRA could be hampered by a complex stakeholder landscape, that is, by stakeholders of varying capacities and with different levels of World Bank engagement.

HOW THIS BLOCK RELATES TO OTHER BUILDING BLOCKS: This part of the assessment seeks to gauge the feasibility, from the implementer's side, of planning a comprehensive multi-sectoral DRRA to address drought-related challenges. It helps determine whether a DRRA is achievable and to identify which sectors will collaborate on/lead the effort.

2.2 Scoping Coordination between Government, Donors, Development Partners, and Other Stakeholders

WHY THIS BUILDING BLOCK IS IMPORTANT: Seamless coordination of the government, donors, development partners, and other stakeholders sets the stage for an integrated and cohesive approach to a DRRA, avoiding gaps and duplications, creating traction, and ideally, resulting in a collective schedule for implementation/delivery.

POSSIBLE RESULTS: By identifying donors and development partners working on a client country's drought-related matters and determining how the government is coordinating their efforts, this part of the assessment can identify gaps and overlaps, resulting in a better coordinated DRRA. This part of the assessment can be completed through one or more workshops and bilateral meetings that engage all entities working on drought in the country.

The following actions will ensure effective coordination:

- With the approval of the government, establish a dedicated coordination mechanism, such as committee, platform, or working group, to foster partnership, advocacy, and networking. Donors and partners should actively commit to sharing information and expertise.
- Formalize an agreed-on framework for donors and partners to contribute to the DRRA. The framework should encompass sharing of existing resources or relevant deliverables and should specify standardized methodologies, data collection tools, and assessment indicators. Each participant should work with a particular sector(s) in order to contribute datasets or analyses aligned with its current engagement in the country.

- Collectively identify funding priorities to enable efficient allocation of resources while avoiding duplication. Harmonizing funding approaches, such as setting up joint funding mechanisms or collaborative agreements, will ensure coherence and minimize additional effort.
- Establish formal or informal monitoring mechanisms to track progress and ensure delivery of various DRRA contributions, ultimately promoting accountability and strengthening drought partnerships in the country.

HOW THIS BLOCK RELATES TO OTHER BUILDING BLOCKS: This part of the assessment seeks to gauge the feasibility of planning a multi-donor or partnership-based comprehensive multi-sectoral DRRA to address drought-related challenges, and it will shape its implementation modality. That is, it will help to determine whether the DRRA should be a joint assessment by the World Bank and the government, a World Bank-led assessment, or a World Bank-supported assessment.

2.3 Scoping of Coordination across Government

WHY THIS BUILDING BLOCK IS IMPORTANT: Involving local agencies/stakeholders from various sectors in the assessment process fosters a sense of ownership and commitment, and it is essential for a realistic and ground-based DRRA. This sub-block enables identification of potential policy and priority conflicts among sectors, helping to streamline policy formulation and implementation. It can reveal a willingness or capacity, or a lack thereof, to share relevant data.

Political commitment and country leadership are vital for the success of the DRRA. The country must demonstrate true high-level demand and willingness to cooperate with the World Bank or any other partner in performing a DRRA. Understanding the country's perspective and capacity is fundamental to deciding whether to go forward with the assessment or to tailor it accordingly.

POSSIBLE RESULTS: An important outcome of this part of the assessment, which can be completed through workshops and meetings that engage the entire group of relevant sectoral agencies and stakeholders, is a map of partners and governmental agencies involved in drought management.

Another important outcome: securing high-level leadership to push for cross-sectoral work and interagency cooperation. An important message to convey to the country is that managing drought is not only a water supply or agricultural issue. Conflicting objectives of relevant ministries can create competition and hinder coordination efforts. It is crucial to work with high-level leadership actors to identify any such objectives.

Ideally, the country already has a data-driven, not purely political, national steering committee or similar body responsible for tracking drought and formulating drought policy and a national drought plan. Such entities often exist but lack functionality and actual assessment capacity. But they can facilitate dialogue and allocate funds to relevant ministries to support DRRA data collection.

On the World Bank side, clear communication of the benefits of a DRRA is essential. In that context, a high-level workshop to explain the challenges, the processes, and the advantages to the country is recommended. It can take place before or after the previous sub-blocks are completed or in parallel with those sub-blocks. Emphasizing the benefits of better risk identification and more effective targeting of resources can help garner support from the country and facilitate its active participation in the DRRA.

HOW THIS BLOCK RELATES TO OTHER BUILDING BLOCKS: This part of the assessment seeks to gauge the country's demand for and capacity to contribute to a comprehensive multi-sectoral DRRA. This block is aligned with the spirit of the EPIC Response framework. If there is no demand and lack of adequate interest to commit adequate resources to the process, the assessment cannot be conducted.

3.
Assessing Drought Risk (Block II)

On completion of the context scoping and readiness assessment (block I), the DRRA team develops a drought risk assessment based on hazard, impact, and vulnerability characterization (see figure 3.1).

> This chapter describes consolidation of the results of each of the block II sub-blocks into a "drought risk model" underpinned by both a case study and a comparison of tools that can support drought risk assessment.

Drought risk is the result of hazard, exposure, and vulnerability. Hazard is the occurrence of a drought event with possible adverse effects. Exposure encompasses population and economic resources in an area where drought occurs. Vulnerability is defined as a system's susceptibility to drought's adverse effects and lack of capacity to handle those effects (Limones et al. 2020; Nakicenovic et al. 2020). Generally, the risk of drought causing damage and socioeconomic/ecological losses reflects the severity and the probability of occurrence, exposure, and vulnerability (Vogt et al. 2018).

FIGURE 3.1

Block II of the Drought Risk and Resilience Assessment

Block II

Assess drought risk

- Assess current and recent drought hazards
- Assess main trends of future drought hazards
- Assess current and recent drought impacts
- Assess country/region vulnerability to drought

Source: Original figure for this publication.

POSSIBLE RESULTS: By conducting a drought risk assessment, teams can identify areas and sectors that are not only vulnerable to drought, but also likely to experience the phenomenon. They also can identify which type(s) of drought (meteorological, hydrological, agricultural, etc.) leads to significant impacts for each sector or system considered. The aim is to produce an assessment of the probability and severity of drought occurrences and to evaluate potential consequences. Thus, the delivery of the drought risk assessment block consists of a numerical/visual representation of the risk, based on graphs and maps, a qualitative description, or both. Once teams select areas of intervention, they can prioritize potential drought risk reduction and drought resilience strengthening measures (through block IV).

IDEAS FOR DEVELOPING DROUGHT RISK ASSESSMENTS AND A SNAPSHOT OF AVAILABLE TOOLS: Antofie, Doherty, and Marin-Ferrer (2018) distinguish between two main risk assessment methods: qualitative or (semi-) quantitative. A qualitative risk assessment depicts risk as a descriptive class/score or a qualitative ranking of risk levels for different areas. The latter can be performed simply by overlaying the areas that are vulnerable with those experiencing significant drought hazards. The result is a map highlighting the areas at higher risk. This qualitative ranking can be sufficient for a DRRA, and it may be the only option in data-scarce environments. Limones et al. (2020) based their ranking of drought risk in Angola on prior impacts. However, a qualitative ranking does not convey costing of the risks, for which a sensitivity analysis or another type of (external) validation of the ranking is needed.

Data-driven semi-quantitative or quantitative assessments allow for assignment of values in terms of risk indices or even levels of probability of losses. They build on the principle that drought must be defined and assessed in relation to its impacts. Thus, they aim to explore the (statistical) links among key climate and hydrological variables, droughts, and consequential effects over time and space. Carrão, Naumann, and Barbosa (2016) and Antofie, Doherty, and Marin-Ferrer (2018) provide an overview of tested approaches and risk index calculations. A good example of a fully data-driven drought risk quantitative assessment is the current effort by the European Commission's European Drought Observatory for Resilience and Adaptation (EDORA) Project. The project's drought impact database compiles and structures information on both drought levels and impacts over the last 40 years across the European Union (EU). Box 3.1 presents Romania's current drought risk baseline based on the model built for the EDORA Project—a baseline at a level of detail achievable only if teams have sufficient longitudinal data on impacts (that is, if linking the impact of events and their occurrence and severity is possible and statistically sound).

BOX 3.1

Machine Learning-Based, Data-Driven Drought Risk Assessment for Romania

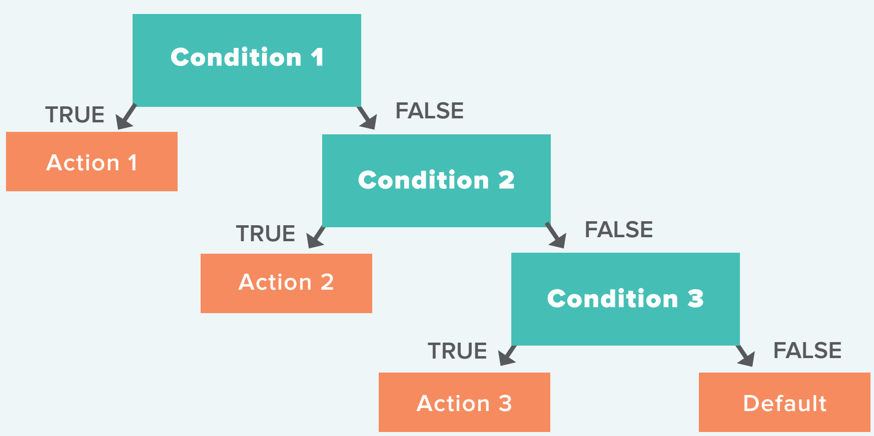
Based on the model built for the European Commission's EDORA Project, the World Bank conducted a deep-dive drought risk assessment for Romania with more granular data. The exercise built on a drought hazard characterization (see box 3.3) and on an impact collection and assessment (see box 3.7). These previous assessments compiled historical values for hazards and impacts for all of Romania's river basin administrations (these are administrative boundaries). Cost estimates of these impacts were assigned where possible.

A set of Standardized Drought Hazard Indices (SDHIs) is calculated on a monthly basis and comprises predictors for the model (that is, the triggers/biophysical drivers of the dependent impacts). The model correlates anomalies of inventory impact variables with anomalies of hydrometeorological hazard indices. For the drought risk assessment for Romania, SDHI thresholds were defined for each impact type and location.

The attribution of drought impacts to different systems is enabled through the application of the so-called fast-and-frugal trees machine-learning technique (see figure B3.1.1). Fast-and-frugal trees are simple decision algorithms for solving binary classification tasks. On the basis of predictor variables, namely the SDHI, they predict the values of a binary criterion variable, for example, transportation losses 20 percent below the average or energy production losses of 5 percent.

FIGURE B3.1.1

Example of a Binary Decision Tree for Recognizing Drought Impacts



Source: Adapted from de Mesentier Silva et al. 2016.

Once the above-described operation is performed, teams can understand (1) the different configurations of a drought hazard that can lead to each impact, (2) the thresholds of the hazard indices that trigger an issue in the different sectors and areas, and (3) the likelihood that these issues will be experienced in each place due solely to drought (that is, distinguished from other potential causes).

(box continues next page)

BOX 3.1 *(continued)*

The accuracy scores used to create machine-learning models describe the models' capacity to predict the occurrence or absence of an impact. The models are constructed with the goal of minimizing false alarms, that is, simulated reductions in production levels that were not actually observed. Consequently, the models are relatively conservative in that they highlight only the proportion of anomalies that are undoubtedly linked to drought. In many cases, the models may thus underestimate the role of drought, yielding relatively optimistic estimates of risk.

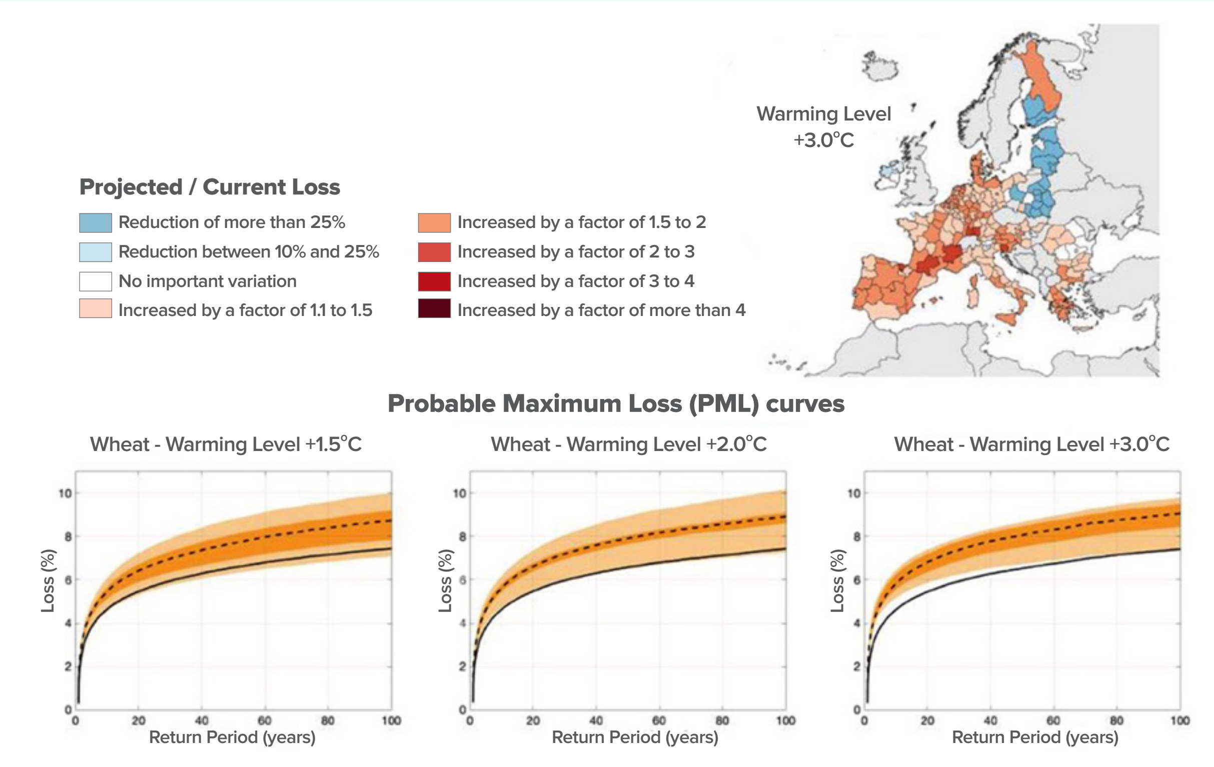
For some sectors and systems, and in some zones, the accuracy and sensitivity of machine-learning models will be very high. In those cases, the connection between the hazard and the respective impact is distinctive, and drought undoubtedly drives the behavior of the anomalies. In other cases, the anomalies and drought may not have a strong correlation, so the expected losses caused by drought appear less significant compared with losses derived from other drivers.

The created models allow teams to predict impacts depending on when and how often the selected drought hazard indices' thresholds are surpassed. In the final step, predictions from the decision trees are composed and added up. The objective of the Romania exercise is to map the grouped likelihoods that areas will experience a certain decrease in the system's performance due to drought.

Probable maximum loss curves are being created for different types and levels of impacts in all the systems at risk (an example of development of probable maximum loss curves and drought risk maps is presented in figure B3.1.2).

FIGURE B3.1.2

Drought Risk Maps and Probable Maximum Loss Curves Developed by the EDORA Project



Source: Rossi et al. 2023.

TABLE 3.1

Strengths and Weaknesses of Three Types of Drought Risk Assessment

Type of assessment	Budget	Time	Effort	Strengths	Weaknesses	Reference
Qualitative risk assessment	$	🕓	💡	Useful approach for data-scarce environments. Rapid, inexpensive. Can be utilized even without specialized expertise or resources for more in-depth analyses.	Neither quantifies the risk nor defines what risk component (H, V, or E) is most relevant in each case. Does not link vulnerability components with types of impacts. Set of indicators is not exhaustive and does not provide a complete definition of vulnerability. Ground-truthing is qualitative. Normally not capable of including future drought risk.	Limones et al. (2020)
Empirical semi-quantitative assessment	$ $	🕓 🕓	💡 💡	Provides a map of areas at high drought risk in numerical terms and links risk to the most important component (H, V, or E) in each case.	Does not establish a linkage with actual impacts.	Carrão, Naumann, and Barbosa (2016)
Data-driven quantitative assessment (for example, EDORA)	$ $	🕓 🕓	💡 💡 💡	Provides a map of areas at high drought risk and a proxy or a magnitude of the potential risk. Includes ground-truthing because it incorporates impacts in the assessment.	Requires machine-learning/ modeling expertise. Depends on a comprehensive impact compilation and assessment with longitudinal data.	See application example in box 3.1.

Source: World Bank Group.
Note: H = hazard; V = vulnerability; E = exposure.

Table 3.1 presents three types of risk assessments. Teams are encouraged to consult the *Global Inventory of Drought Hazard and Risk Modeling Tools and Resources* (Deltares 2018) for a more comprehensive overview of approaches.

The subsequent sub-blocks are each dedicated to assessing a variable of the overall risk equation, thus forming the basis for the above-mentioned risk modeling.

3.1 Assessing Current and Recent Drought Hazards

WHY THIS BUILDING BLOCK IS IMPORTANT: Characterization of drought hazard—the severity, frequency, duration, extent, and propagation patterns (from precipitation deficits to soil and hydrological stress issues) of drought in a given country or region—can help teams assess the likelihood of drought occurrence and identify trends and hotspots. Fully linked to this characterization is monitoring, which consists of tracking the evolution of drought. In many cases, monitoring can serve as an early warning system, allowing authorities and communities to detect drought in its initial stages and to act accordingly.

Monitoring and characterization of the hazard are preferably performed through the calculation and posterior analysis of Standardized Drought Hazard Indices (SDHIs). These indices are used to quantify and assess the severity, duration, and spatial extent of drought conditions on the basis of meteorological, vegetation, and hydrological data, particularly precipitation, evapotranspiration, temperature, soil moisture, and vegetation health.

POSSIBLE RESULTS: Hazard characterization will help teams identify the severity, frequencies, and durations of droughts over time and space. It is useful to understand how a current drought manifests in the context of average conditions and how past drought events evolved. More broadly, hazard characterization can also help teams identify areas with higher drought hazard trends and characteristics.

Analyses for evaluating and tracking drought hazards can consider precipitation, evapotranspiration, flows, vegetation conditions, soil moisture, and other parameters. Drought is a complex and multifaceted phenomenon, so ideally teams use several drought indices (SDHI mainly) and indicators to provide complementary information about the various dimensions of drought conditions. Some standardization of drought classification categories is encouraged for consistency in communicating the extent of the drought within and between these sectors (see box 3.2).

HOW THIS BLOCK RELATES TO OTHER BUILDING BLOCKS: Drought hazard characterization is the foundation of any DRRA; it provides the context for improving drought risk management. The results of this analysis frame all subsequent steps of the DRRA and significantly inform the types and scopes of block II vulnerability, impact, and overall risk assessments.

Furthermore, indices and indicators selected for drought characterization and monitoring can feed into the development and delivery of information and decision-making/decision-support tools. Once a proactive drought preparedness plan is developed and in place, monitoring of defined drought-characterization indices and indicators can be used to trigger specific measures.

IDEAS FOR DEVELOPING THIS BUILDING BLOCK AND A SNAPSHOT OF AVAILABLE TOOLS: If the target country or region relies on a monitoring system (see box 3.2) that offers SDHI or indices derived from them, teams could complete block II just by developing a narrative or an overview of drought patterns based on the monitoring system's information.

Jacques Gaimard / Pixabay

BOX 3.2

Drought Monitoring System in Brazil

As an element of a drought preparedness plan, Brazil developed a drought monitoring system. Different stages of drought are defined on the basis of drought indicators and associated with possible impacts (see figure B3.2.1). To build the map, numerous institutions monitor rainfall (the amount of precipitation in each location), reservoir levels, soil moisture, and other critical information in each of the country's states. These indicators are measured and combined monthly and visualized with a map. Depending on the stage or intensity of a drought, predefined measures or types of actions are triggered. As important as the map is the organizational arrangement of people, institutions, and processes that contribute the information depicted on it (De Nys, Engle, and Magalhães 2017).

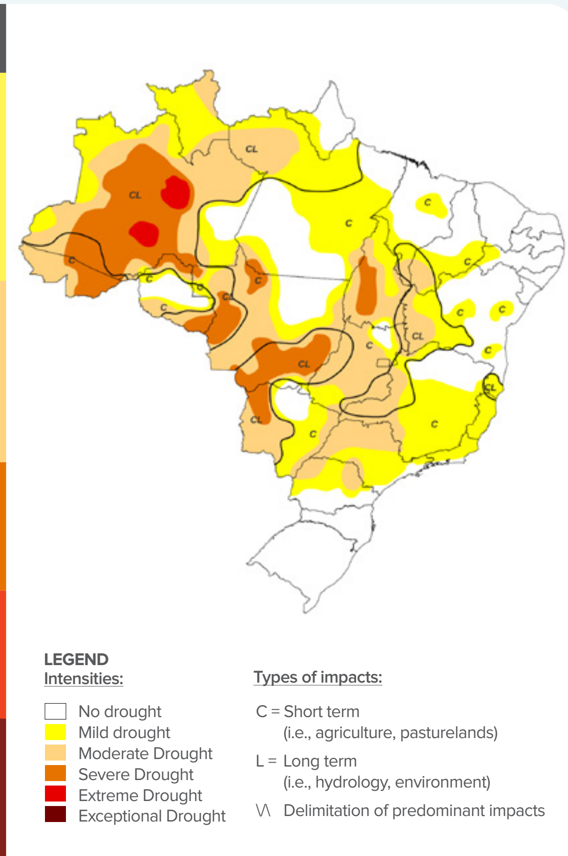
FIGURE B3.2.1

Stages of Drought and Their Potential Impacts in Brazil

a. Drought stages

Category	Percentile	Description	Possible Impacts
D0	30	Abnormally dry	Going into drought: short-term dryness slowing planting and growth of crops or pastures. Coming out of drought: some lingering water deficits; pastures or crops not fully recovered
D1	20	Moderate drought	Some damage to crops, pastures; streams, reservoirs, or wells low; some water shortages developing or imminent; voluntary water-use restrictions requested
D2	10	Severe drought	Crop or pasture losses likely; water shortages common; water restrictions imposed
D3	5	Extreme drought	Major crop/pasture losses; widespread water shortages or restrictions
D4	2	Exceptional drought	Exceptional and widespread crop/pasture losses; shortages of water in reservoirs, streams, and wells creating water emergencies

b. Drought monitoring map



Sources: Adapted from De Nys, Engle, and Magalhães 2017; Adapted from Monitor de Secas 2024.

Khasar Sandag / World Bank

In the absence of a drought monitoring system, teams can turn to several global and regional drought portals that provide temporal maps of drought indices that could support a rough spatiotemporal characterization of the hazard. If the scope of the assessment is focused on a particular recent or ongoing event, this approach could suffice, but it should acknowledge the limitations of not using granular or ground-based data.

A collection of most of these geo-visualization tools for the monitoring and early warning of drought events was developed and is updated by the UNCCD, and the Integrated Drought Management Programme's (IDMP) "Drought and Early Warning" portal also keeps track of these tools.[1] Additionally, the Global Facility for Disaster Reduction and Recovery (GFDRR) and Deltares have developed a global inventory, at the global and regional level, of drought hazard and risk modeling tools, resources, and drought datasets and platforms (Deltares 2017) as well as a catalogue of drought hazard and risk tools (Deltares 2018). These resources provide links to mapping portals and describe what to use them for and how to apply them.

A more in-depth but still relatively rapid option that relies on medium-resolution open-source global datasets is to download and use preprocessed indices provided in web portals like the Standardized Precipitation-Evapotranspiration Index (SPEI) global drought monitor and the related SPEI global dataset, which offer near real-time information about drought conditions at the global scale, with a 1-degree spatial resolution and a monthly time resolution.[2] SPEI time scales between 1 and 48 months are provided and can be downloaded in a user-friendly way as a time series for a point or a bounding box.

For the Standardized Precipitation Index (SPI), which solely describes precipitation deficits, similar series can be downloaded from several portals, such as "ClimatView—A Tool for Viewing Monthly Climate Data" or the International Research Institute's "Global Drought Analysis Tool."[3] Agricultural drought indices can be downloaded from the Food and Agriculture Organization's "Agricultural Stress Index System."[4]

Drought hazard characterization, in this case, may consist simply of plotting the time series and comparing patterns among indices (see box 3.3), but the time series can be further analyzed depending on the resources available for and the scope of the assessment. To guide such a characterization, Vogt et al. (2018) developed a comprehensive list of parameters to calculate, including frequency of droughts, severities, intensities, durations, onsets, end points, peaks, and areas affected.

BOX 3.3

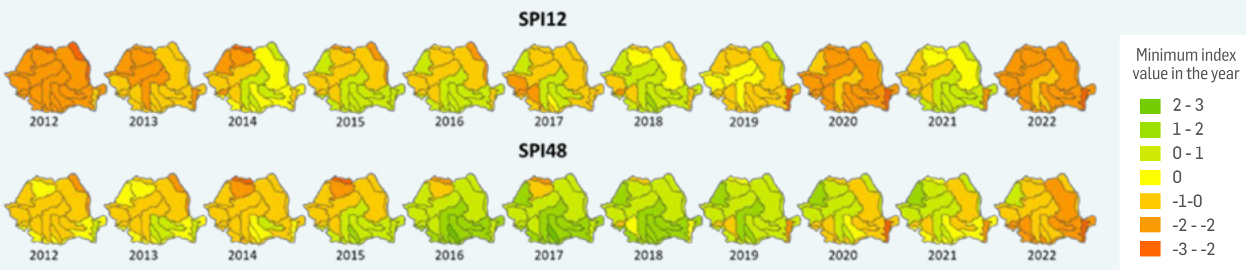
Hydrometeorological Drought Hazard Characterization in Romania

In this case study, Standardized Drought Hazard Indices (SDHIs) were used to depict the severity and spatial extent of drought in the historic context in Romania. Two broadly recognized and complementary SDHI were applied at the level of river basin districts, the Standardized Precipitation Index (SPI), and the Standardized Precipitation-Evapotranspiration Index (SPEI). The key difference between SPI and SPEI is that SPEI accounts for both precipitation and evapotranspiration; SPI considers only the former.

Once the SDHI were calculated, some statistics were extracted and mapped to perform an interpretation of the spatiotemporal evolution of the drought during the last decade of study (see figures B3.3.1 and B3.3.2).

FIGURE B3.3.1

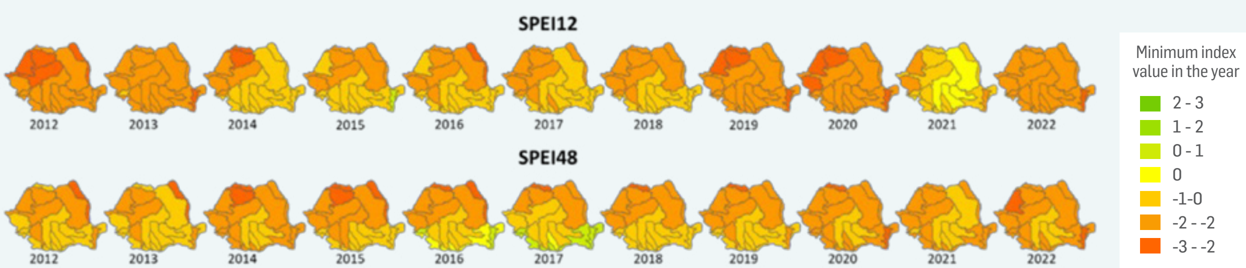
Minimum Value of the SPI 12 and SPI 48 Drought Indices Every Year from 2012 to 2022 in Romania's River Basin Administrations (Administrative Boundaries)



Source: World Bank 2024.

FIGURE B3.3.2

Minimum Value of the SPEI 12 and SPEI 48 Drought Indices Every Year from 2012 to 2022 in Romania's River Basin Administrations (Administrative Boundaries)



Source: World Bank 2024.

Additionally, SPEI and SPI results were complemented with other parameters to obtain a more holistic drought hazard characterization. Such additional parameters included, for example, the evolution of the total actual runoff in Romania to represent national-level water statistics, flows, Water Exploitation Index (WEI), and WEI+ indices in the river basin administrations.

Importantly, monitoring different aspects of drought along the full hydrologic cycle may require a collection of indicators and indices beyond those recommended above for their broad application and ease of use. The selection of drought indicators/indices depends on available resources and the scope of the exercise. It should be determined by the distinctive traits of droughts that are closely linked to the country stakeholders' primary areas of concern. To support selection, the *Handbook of Drought Indicators and Indices* (WMO and GWP 2016) describes the purpose of the most used indicators and indices as well as the level of difficulty of their application and interpretation. Importantly, a summary table compares all the analyzed tools. Steinemann, Iacobellis, and Cayan (2015) provide a useful framework for the application of indices and indicators.

Constructing indices and indicators on the basis of ground information received from local agencies or with high accuracy/resolution open-source datasets is another possible approach. The same array of indices mentioned above can be built with user-friendly calculators, such as the SPI Generator by the National Drought Mitigation Center (2018) or the SPEI Calculator by the Spanish Higher Council for Scientific Research.[5] Constructing indices and indicators requires extensive collection of hydrometeorological data—including in situ or estimated longitudinal data on moisture, flows, and groundwater parameters—in coordination with local agencies and data processing by a local expert. Thus, this approach is recommended only if the required information is readily available and shared and would provide far more accurate results than off-the-shelf tools to analyze drought hazard (see box 3.4). Table 3.2 compares methodologies for characterizing drought hazard, some of which can be utilized even without specialized expertise or resources for more in-depth analyses.

DATA NEEDS: Meteorological, hydrological, hydrogeological, biophysical, agricultural data (time series/statistical datasets, remote sensing datasets, surveys, and so on), or a combination thereof are needed to characterize drought hazard.

UNDP (2020) presents a non-exhaustive list of open datasets that provide information on precipitation and soil moisture. Google Earth Engine (GEE) provides satellite-based and model-based climatic, hydrological, and hydrogeological estimates.

The World Bank (2019) provides extensive practical guidance on how to set up drought hazard assessments.

Watershed and Development Initiative / USAID

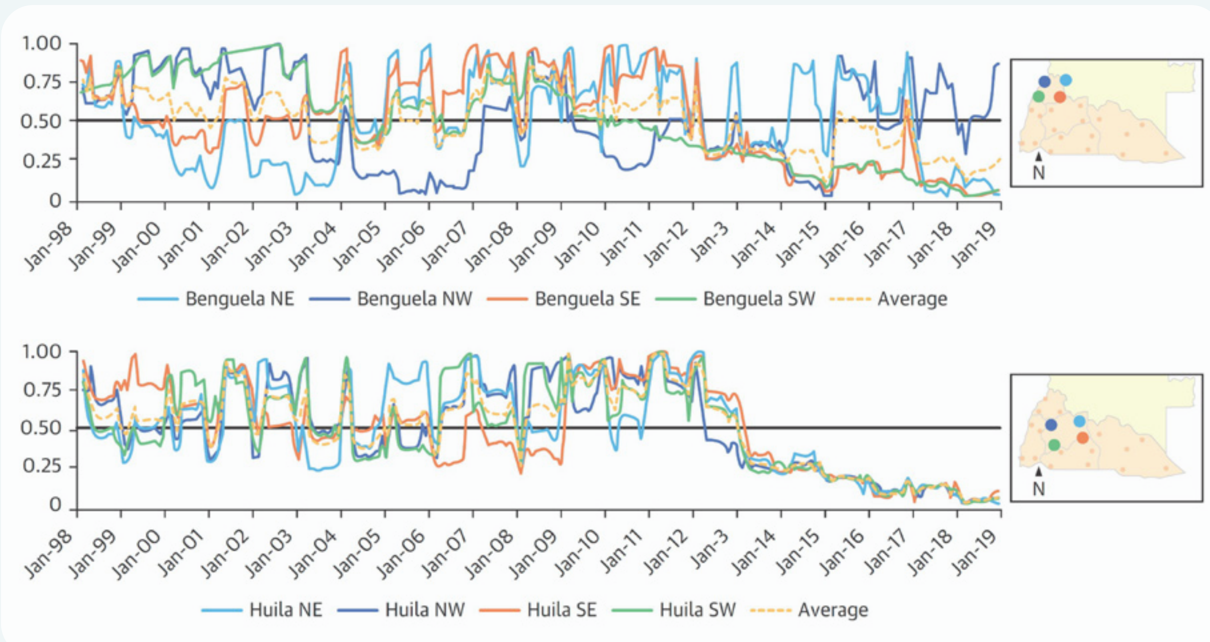
BOX 3.4

Preparing a Drought Hazard Overview for Southern Angola with Indices Calculation and Ground Data

The Drought Exceedance Probability Index was selected to analyze recent drought hazard in Angola because precipitation time series were available for parts of the region. These series were used to calibrate the Tropical Rainfall Measuring Mission Multi-satellite Precipitation Analysis, or Tropical Multi-satellite Precipitation Analysis (TMPA) product (see figure B3.4.1). The Drought Exceedance Probability Index does not work with pre-established timescales, which makes it very useful in defining actual precipitation drought onsets and durations and in identifying deficit peaks.

FIGURE B3.4.1

Drought Evolution in Provinces of Angola, Based on Corrected TMPA Series



Source: Serrat-Capdevila, Limones et al. 2022.

However, it was necessary to go beyond the rainfall phenomenon. To understand the evolution of water availability during the identified drought period, the monthly precipitation minus the actual evapotranspiration (P-Eta) was computed at a medium spatial resolution (0.25°, ~25 kilometers) across the entire region as a hydrological drought indicator. On-the-ground evapotranspiration data were not available, so in this case the indicator was based entirely on satellite estimates from the Global Land Evaporation Amsterdam Model.

TABLE 3.2

Methodologies for Characterizing Current/Recent Drought Hazards

Methodology	Budget	Time	Effort	Strengths	Weaknesses	Reference
Preparation of an overview based on information from an established monitoring system in the country/region*	💲	🕒	💡	Fast. Can be performed without expert input. The country is already aware of the hazard levels, this block is well covered before the DRRA exercise.	Accuracy and comprehensiveness of the overview depends on the characteristics of the already-existing monitor.	Example of drought monitors: • Brazil : Monitor de Secas • Spain: AEMET • USA: Drought Monitor • Mexico: Monitor de Sequia • Europe: Drought Observatory
Preparation of an overview based on global and regional drought portals that provide temporal maps of drought indices*	💲	🕒	💡	Fast. Can be performed without expert input.	The description of the hazard will include no data analysis, only maps and graphs obtained from the portals. Resolution or accuracy issues.	Examples of portals for resources and tools: • UNCCD Inventory of Portals, Resources and Tools • IDMP Inventory of Portals, Resources and Tools • GFDRR and Deltares Inventory of Portals, Resources and Tools (Deltares 2017) • Global Integrated Drought Monitoring and Prediction System (GIDMaPS)
Hazard characterization based on downloaded preprocessed indices served in web portals*	💲💲	🕒🕒	💡💡	Data-driven assessment. Flexible.	Resolution or accuracy issues. Some of the globally available SPEI series are built with simplified evapotranspiration estimates. Requires some low- to medium-difficulty data analysis.	Examples of preprocessed drought indices: • For downloading series: ClimatView • For downloading series: IRI Global Drought Analysis Tool • For downloading series: SPEI Global Drought Monitor • Pan-African high-resolution • drought index dataset • FAO's Agricultural Stress Index System See application example in box 3.3.
Hazard characterization based on construction of indices and indicators with ground information received from local agencies or with relatively high-accuracy/resolution open-source datasets	💲💲	🕒🕒🕒	💡💡💡	Data-driven assessment. Flexible. Maximum accuracy potential.	Requires local data availability and local agency cooperation. Accuracy issues if data quality is not validated. Long processing time. Requires a drought expert to build the indices, conduct the analysis, and facilitate the interpretation.	Tools for selecting indices and guidelines for their application: • Handbook of Drought Indicators and Indices (WMO and GWP 2016) • Steinemann, Iacobellis, and Cayan (2015) • Tsakiris et al. (2007) See application example in box 3.4.

Source: World Bank Group.
* These instruments can be utilized even without specialized expertise or resources for more in-depth analyses.

3.2 Assessing Main Trends of Future Drought Hazards

WHY THIS BUILDING BLOCK IS IMPORTANT: Drought assessment and management needs to be conceptualized in the context of climate change. Although the local variability and magnitude of changes in drought patterns are difficult to determine using projections and scenarios, drought risks will increase for several regions and sectors unless climate change adaptation measures are adopted. Hence, it is crucial to consider climate scenarios and what they could mean for droughts in a given region (Vogt et al. 2018).

POSSIBLE RESULTS: This step will offer an overview of the potential future development of drought hazards and water scarcity in specified regions.

HOW THIS BLOCK RELATES TO OTHER BUILDING BLOCKS: Some or all of the variables that were chosen to characterize past droughts will be subject to drought projections. The results will directly impact the following steps, for example, by forming a baseline for the drought preparedness gap analysis and a baseline against which possible investments are assessed. If historical droughts proven to cause significant impacts in the target area are projected to increase or intensify, this block suggests how the overall risk might also evolve.

IDEAS FOR DEVELOPING THIS BUILDING BLOCK AND A SNAPSHOT OF AVAILABLE TOOLS: Existing data and analytics can be leveraged to provide a history of droughts. They can also be used with other climate change scenarios and hydrologic models to gain insight into future drought hazards, although uncertainty needs to be carefully considered. A quick overview can be prepared on the basis of information from portals offering regional and country projections and information from interactive maps and graphs. The Intergovernmental Panel on Climate Change (IPCC) offers Coupled Model Intercomparison Project Phase 6 (CMIP6) information and computation of different regional scenarios of the SPI index in the IPCC WGI Interactive Atlas.[6] The National Oceanic and Atmospheric Administration's climate change web portal and the Climate Data Factory's interactive map allow users to develop maps and charts on projections of temperature and precipitation.[7] The Aqueduct Water Risk Atlas maps and analyzes future water risks across locations.[8] The Koninklijk Nederlands Meteorologisch Instituut (KNMI) Climate Change Atlas allows for country-specific data series visualization of a broad array of meteorological variables and hydrological features like net water flux.[9] Very useful rapid overviews can be produced easily with the World Bank Group's Climate Change Knowledge Portal, which offers projected climatology of the Annual SPEI Drought Index for all countries (see box 3.5).[10]

Caution is needed when working with climate projections; uncertainty must be carefully presented. Importantly, some impacts of droughts—on selected crops, for example—will depend on the temporal distribution of hydrometeorological variables and their anomalies as much as on total accumulated values, which are more commonly provided through climate change scenarios. Hydrologic modeling in the global climate models is rudimentary. Model outputs are often used in additional hydrologic analytics and are sometimes hydrodynamic analytics to obtain additional insights related to surface and water resources (including additional scenarios of water infrastructure and use). However, these model outputs are often subject to data and modeling constraints associated with complex systems and future climate scenario uncertainty.

Drought hazard overviews can be complemented by SDHI and trends computed on the basis of CMIP6 for all locations around the globe. Zeng et al. (2022) and Vicente-Serrano et al. (2022) present assessments of global meteorological, hydrological, and agricultural drought under future warming. Christian et al. (2023) provides a similar assessment focused on flash droughts. The NEX-GDDP-CMIP6 dataset by the NASA Climate Analytics Group, available in GEE, can produce a more detailed description. This dataset is made up of global downscaled climate scenarios for variables like near-surface air temperature or precipitation. It is computed across several Shared Socioeconomic Pathways (SSPs). An analysis based on this dataset can be performed in approximately one day or less of work by a specialist. Examples of applications appear in Ghazi, Dutt, and Haghighi (2023) and Xu et al. (2023).

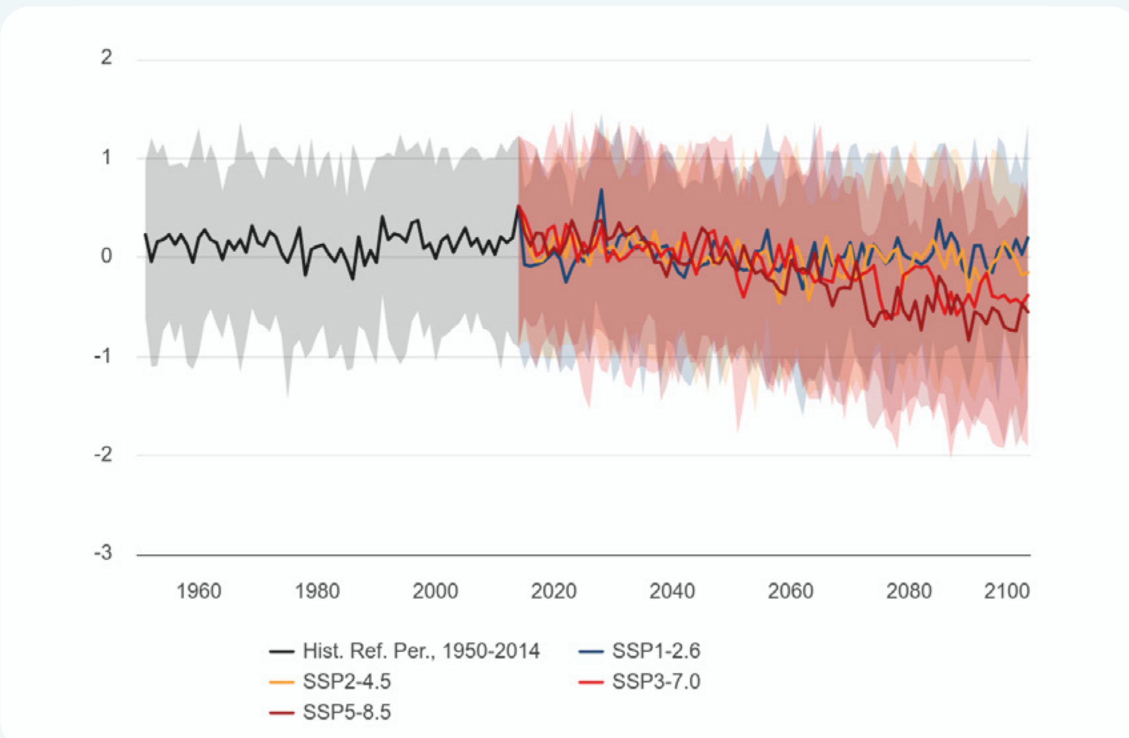
BOX 3.5

Hydrometeorological Projections for Romania

Assessment of Romania's drought risk included a description of the graphs available at the country scale in the World Bank Climate Change Knowledge Portal. It involved an estimation of the evolution of the Standardized Precipitation-Evapotranspiration Index (SPEI) indices for different Shared Socioeconomic Pathways based on Coupled Model Intercomparison Project Phase 6 (CMIP6) data. The historic analyses performed in other blocks of the Romania study revealed that SPEI indices show drought intensification in the last decade for most of the country and that the phenomenon is connected to increasing multi-sectoral impacts on the ground. The simple forward-looking exercise of plotting future SPEI scenarios from the Climate Change Knowledge Portal created a powerful narrative because it revealed that hydrometeorological drought could intensify throughout the century.

FIGURE B3.5.1

Projected Annual SPEI Drought Index in Romania (Reference Period 1995–2014), Multi-Model Ensemble



Source: Based on World Bank Group using data from the CMIP6, World Climate Research Program.

An in-depth analysis can be performed using simulations from available models from the CMIP experiments and from the Coordinated Regional Downscaling Experiment (CORDEX) and applying SDHI (see box 3.6). These projections can be downloaded (expertise required) from several repositories and portals, for example, the World Climate Research Programme's (WCRP) CMIP6 Search Interface, the WCRP's Cordex Search Interface, or the Climate Data Store.[11] The model intercomparison projects also provide simulations from global water models and global hydrological models, which can aid in developing projections for different SDHI.

BOX 3.6

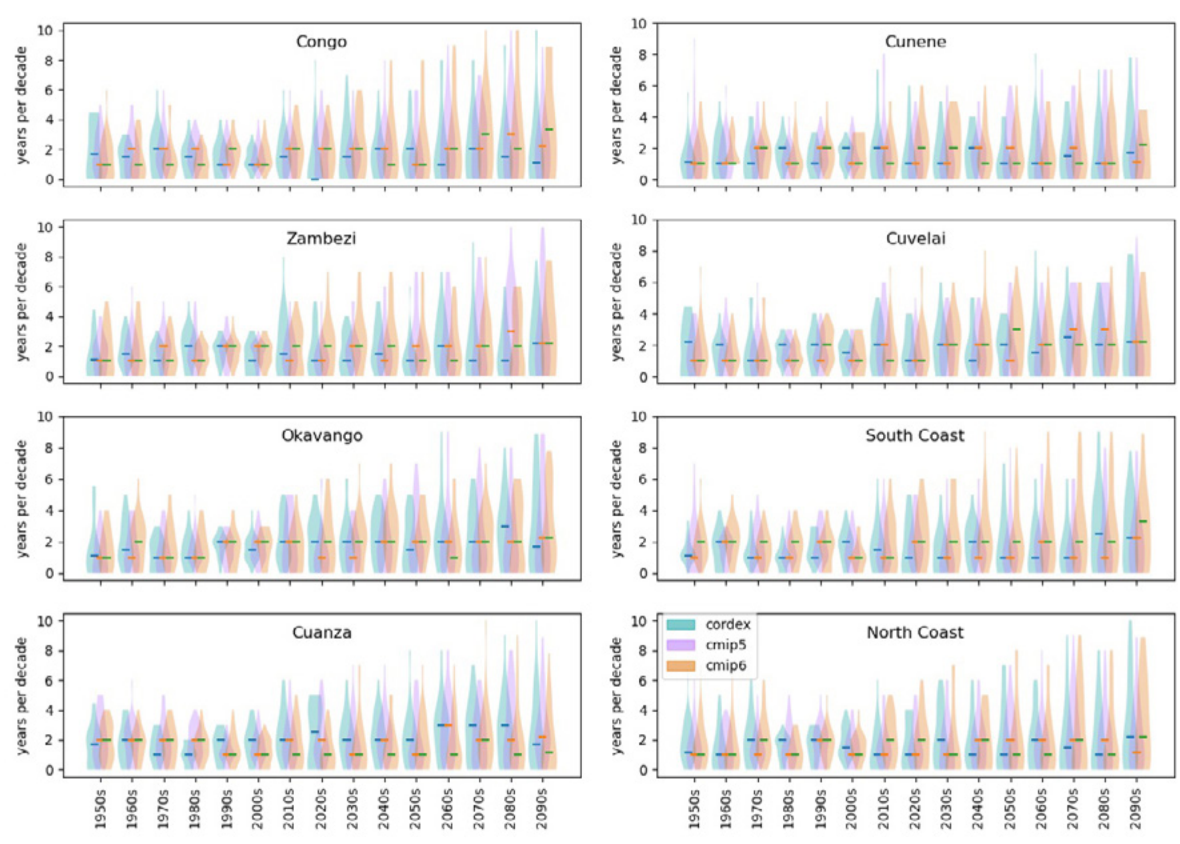
Hydrometeorological Drought Future Scenario Development for the Angola Climate Change and Development Report

As part of the Angola Climate Change and Development Report, researchers used outputs of the Coordinated Regional Downscaling Experiment (CORDEX) and the Coupled Model Intercomparison Project Phase 5 and Phase 6 (CMIP5 and CMIP6), as depicted in figure B3.6.1 and figure B3.6.2, to study projected changes in the frequency of droughts (in 10-year intervals) with a 12-month Standard Precipitation Index (SPI-12) or Standard Precipitation Evapotranspiration Index (SPEI-12) less than -1.0 (a condition of moderate drought).

Overall, droughts characterized by rainfall (SPI) show no uniformly strong change in the future, as the trends in the different modelling approaches differ. However, projections of individual models indicate possible increases in the frequency of drought years. The SPEI shows a more significant change in the future for some of Angola's basins. The CORDEX projections point to a more significant increase in drought, particularly in southern Angola (World Bank Group 2022).

FIGURE B3.6.1

Frequency of Drought Years with SPI-12 Values Less Than -1 (per Decade) in Historical Simulations and Projections Under the RCP85/SSP585 Scenario



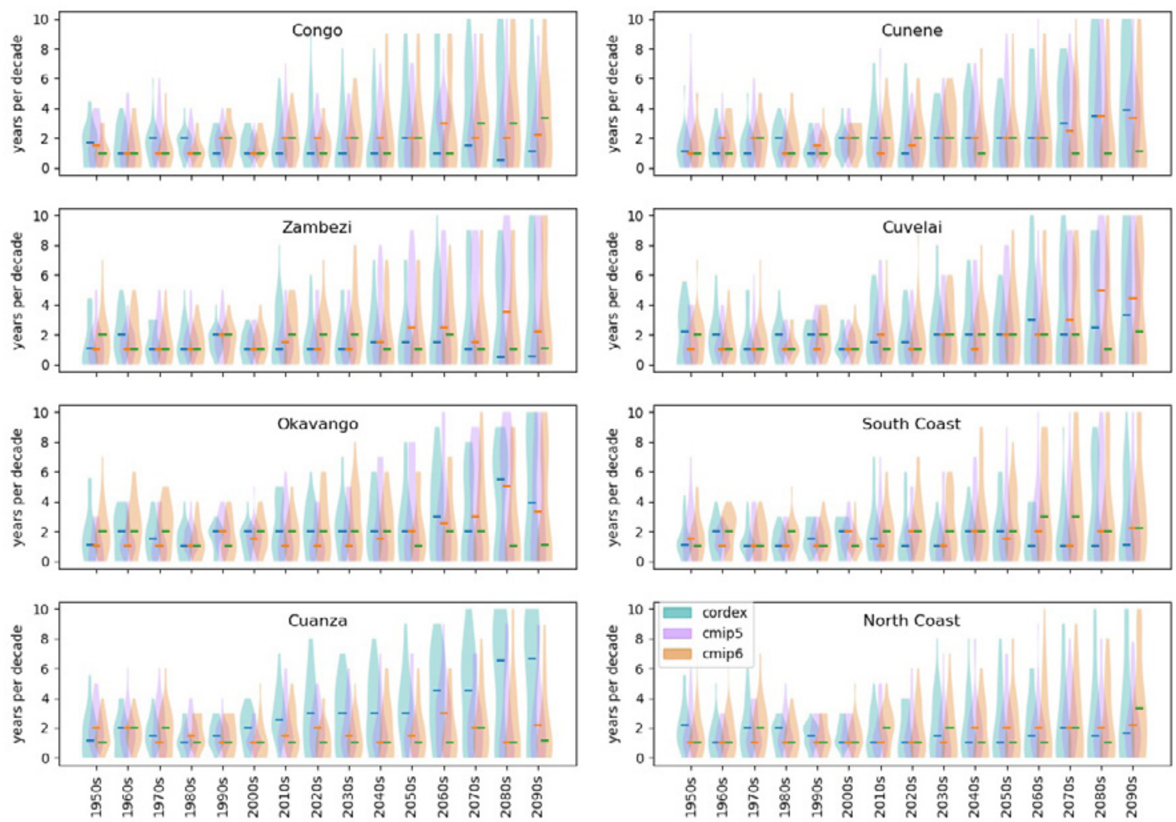
Source: World Bank Group 2022.

(box continues next page)

BOX 3.6 *(continued)*

FIGURE B3.6.2

Frequency of Drought Years with SPEI-12 Values Less Than -1 (per Decade) in Historical Simulations and Projections Under the RCP85/SSP585 Scenario



Source: World Bank Group 2022.

These data can further be explored through additional models (including hydrologic models) to get additional insights recognizing the inherent uncertainty. The World Bank is piloting a hydro-climatic stress test tool to perform drought-related sensitivity analyses using climate scenarios. This approach aligns with the Decision Making Under Deep Uncertainty (DMDU) approach and is recommended for block II of the DRRA. Working with sensitivity analyses, scenarios, or both requires several weeks or months of consultancy work by an expert proficient in handling climate projections data, analysis, and interpretation.

Another advanced option involves basin-level hydrological simulations under future climate change conditions, with the previously mentioned climate scenarios as model inputs. Setting up a model from scratch exceeds the typical scope of a DRRA. Therefore, a prerequisite for adopting this approach is having an existing, well-validated, and calibrated model that accurately represents local hydrological dynamics. If feasible, this method can provide relatively precise and context-specific predictions, enhancing teams' understanding of future runoff conditions for a range of scenarios.

World Bank CCDRs aimed at proposing measures for diversified and climate-resilient development often include analysis of climate change scenarios to highlight the potential impacts of climate change on drought occurrence and severity (see box 3.6). Block II can pull from the outputs of a CCDR for the target country or region. Table 3.3 presents methodologies for characterizing trends in future drought hazards.

DATA NEEDS: Future drought hazard characterization requires considering general circulation models, such as CORDEX and CMIP outputs, as well as CCDRs developed by the World Bank. Prior hydrological models built for the target area can support a more advanced assessment.

3.3 Assessing Current and Recent Drought Impacts

WHY THIS BUILDING BLOCK IS IMPORTANT: Disaster impacts can include economic, human, and environmental impacts. Given the general slow onset of droughts, impacts gradually evolve; they are geographically and temporarily dispersed and both direct and indirect. Thus, drought impacts are often less visible and more difficult to assess or attribute to drought.

Drought impact assessments often prioritize agriculture due to its immediate and more easily measurable economic losses. However, drought can affect multiple sectors, including the environment, forestry, biodiversity, water supply, power generation, and tourism sectors (see figure 3.2).

Capturing less immediate and visible aspects of drought impacts, particularly in areas such as public health and ecosystems, is recommended. Droughts can significantly affect public health by increasing dust and can heighten risk of diseases due to water reductions or pollution. The stress and anxiety associated with water shortages and failing crops can contribute to mental health issues, particularly in rural communities that rely heavily on agriculture for their livelihoods. Droughts can have a tremendous effect on impoverished communities and local economies in many other ways.

Addressing drought impacts on biodiversity and ecosystem services (ecological drought) is also crucial. IDMP developed a comprehensive list of potential drought impacts, which is presented in an annex of *National Drought Management Policy Guidelines: A Template for Action* (Wilhite, WMO, GWP, and National Drought Mitigation Center 2014). Unless the DRRA has a clear sectoral focus, an impact assessment should address all the categories of impacts that are relevant in the given country or region.

Moreover, the economic consequences of drought extend from macroeconomic levels to individual households. Currently, there is a need to expand evaluations to include impacts on other systems beyond agriculture to improve drought risk characterization (Venton et al. 2019; Akyapi, Bellon, and Massetti 2022). By characterizing the impacts of past or ongoing drought events, decision-makers can estimate potential economic losses and social disruptions, aiding in the development of appropriate policies and preparedness measures.

POSSIBLE RESULTS: A range of impacts—ideally, those that are direct/indirect, structural/nonstructural, and monetarily/non-monetarily quantifiable—are assessed for all relevant sectors and levels of drought severity.

Modeling indirect and less evident impacts and risks linked to drought across sectors is challenging due to the dynamic and diverse variables involved. The complexity arises from the temporal lag between drought events and observable effects, coupled with the intricate interactions among various factors within each sector or system. The feasibility of constructing accurate models is constrained by this inherent complexity, so only an extensive compilation of information related to the different variables involved would allow teams to expand the characterization to impacts on systems not so obvious, such as the manufacturing sector and ecosystem services.

HOW THIS BLOCK RELATES TO OTHER BUILDING BLOCKS: Knowledge of drought impacts reveals drought risk hotspots and vulnerabilities that inform prioritization of efforts and resource allocation. Previous building blocks are also linked to drought impact definition: drought hazard characterization is essential to mark pre- and post-disaster baselines, or drought versus normal conditions baselines. Success in implementing block II can be particularly subject

TABLE 3.3

Methodologies for Characterizing Main Trends in Future Drought Hazards

Methodology	Budget	Time	Effort	Strengths	Weaknesses	Reference
Quick overview based on interactive maps and graphs of regional and country climatic projections*	$	🕒	💡	Immediate. No expertise required.	The description of the hazard will consist mainly of visual material obtained from portals and will include no extensive data analysis. Resolution or accuracy issues.	Interactive maps: · World Bank Climate Change Knowledge Portal · World Bank Geospatial Platform · World Bank HydroInformatics Catalog · FAO Earthmap · WGI Interactive Atlas · NOAA Climate Change Web Portal · Climate Data Factory Interactive Map · WRI Aqueduct Water Risk Atlas · KNMI Climate Change Atlas Publications: · Zeng et al. (2022) · Vicente-Serrano et al. (2022) · Christian et al. (2023) See application example in box 3.7.
Detailed overview using the NEX-GDDP-CMIP6 dataset (e.g., in Google Earth Engine) or World Bank Climate Change Knowledge Portal CMIP6 data	$ $	🕒 🕒	💡	Fast. Data-driven assessment. Flexible. Based on downscaled information, which should be interpreted with caution due to uncertainties associated with such information.	Limited variables included. It requires some expertise (less for World Bank Climate Change Knowledge Portal data). Challenges in accurately reproducing fine-scale details and nuances and complex spatial interactions.	Application examples: · Ghazi, Dutt, and Haghighi (2023) · Xu et al. (2023) · World Bank Climate Change Knowledge Portal · NASA Earth Exchange Global Daily Downscaled Projections NEX-GDDP-CMIP6
In-depth analysis applying SDHI to simulated scenarios (CMIP, CORDEX, etc.) or sensitivity analysis applied to SDHI	$ $	🕒 🕒 🕒	💡 💡 💡	Data-driven assessment. Most flexible (models, variables, scales) assessment. Based on downscaled information, which should be interpreted with caution due to uncertainties associated with such information.	Requires an expert. Challenges in accurately reproducing fine-scale details and nuances and complex spatial interactions.	Application examples: · See Angola CCDR in box 3.6 · See other CCDRs Simulations from available models: · WCRP CMIP6 Search Interface · WCRP CORDEX Search Interface · Copernicus Climate Data Store

(table continues next page)

TABLE 3.3 *(continued)*

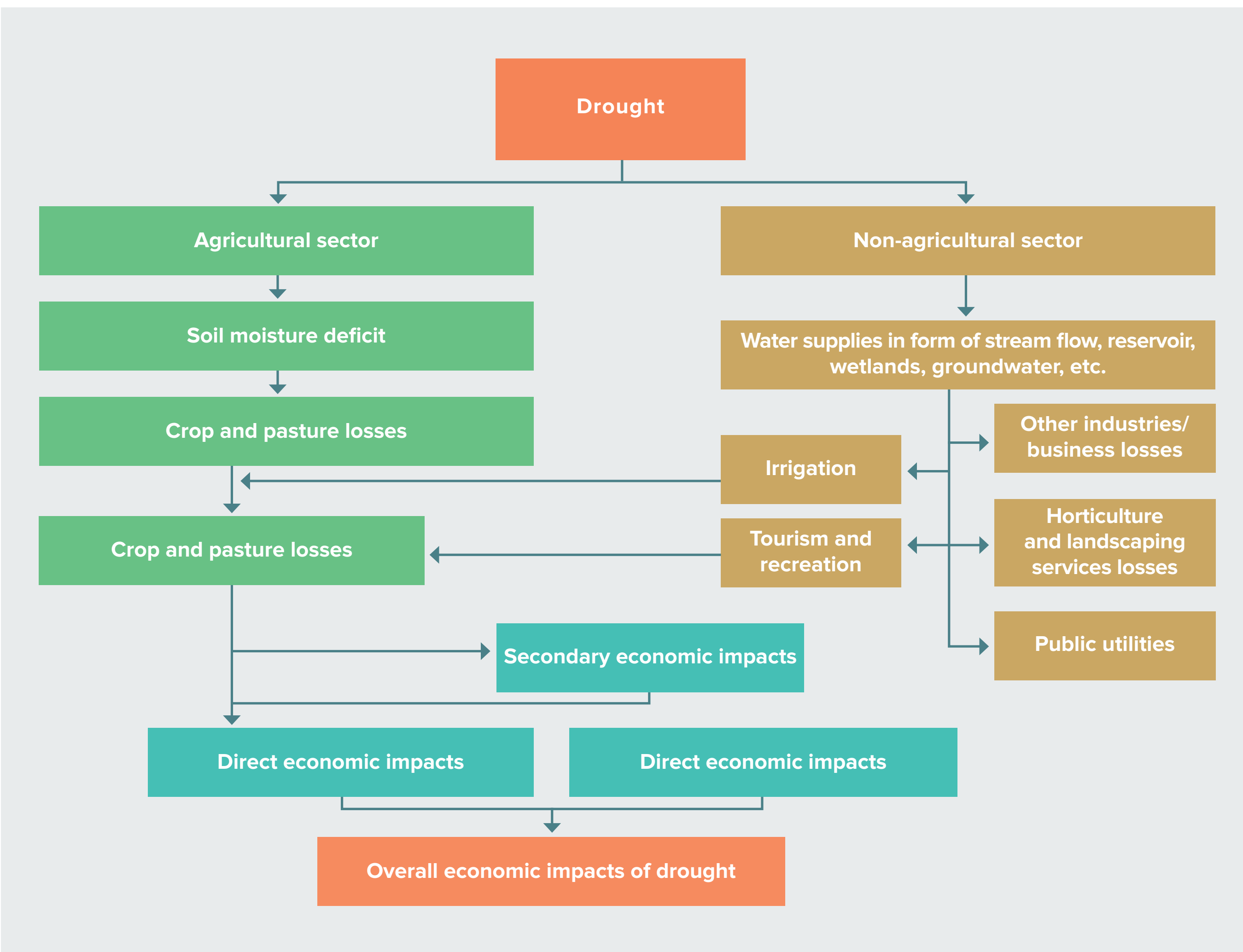
Methodology	Budget	Time	Effort	Strengths	Weaknesses	Reference
Hydrological simulation under future climate change conditions and application of SDHI to the simulated variables				Same as above. Can take into account local hydrological dynamics better and potentially yield the most accurate results.	Same as above. Feasible for a DRRA only if the target area has validated and calibrated models.	Application examples: • Wu et al. (2022) • Tenagashaw (2022) • Khoi et al. (2021)

Source: World Bank Group.

* This methodology can be utilized even without specialized expertise or resources for more in-depth analyses.

FIGURE 3.2

Overview of Sectors Impacted by Drought



Source: Adapted from Ding, Hayes, and Widham 2011.

to the readiness of the country and the demand for a DRRA because significant local engagement and effort are required to collect data on drought impacts.

IDEAS FOR DEVELOPING THIS BUILDING BLOCK AND A SNAPSHOT OF AVAILABLE TOOLS: Important insights about how to perform the analyses for this sub-block appear in King-Okumu (2019) and Ding, Hayes, and Widhalm (2011).

To understand impacts, experts often start with impact chain identification. In a study of drought impact chains, normally based on conceptual maps and narratives, they analyze the cause-and-effect relationships of drought on various aspects of society and the environment. Conceptual maps visually represent the complex linkages and interactions between drought-related factors and their consequences. Narratives provide detailed descriptions of how these factors unfold and affect different sectors, communities, and ecosystems.

By combining conceptual maps and narratives, practitioners gain a deeper understanding of the interconnections and the cascading effects of drought. This approach is based on interviews, surveys, and workshops with stakeholders to identify how changes can lead to effects across multiple areas and to understand the context-specific complexity of a drought's impacts. If made available for the study area, social accounting matrices can reveal how different sectors of the economy are interconnected and how shocks in one sector propagate throughout the entire economy. A qualitative recognition of the impact chains is a helpful starting point for this sub-block; in many areas, the lack of data will prevent a more in-depth analysis and quantification.

The World Bank's *Water for Shared Prosperity* (Zhang and Borja-Vega 2024) could provide valuable insights and references to understand how droughts might affect the target area over time, particularly in relation to the four pillars of prosperity: human capital (health and education), financial capital (jobs and income), social capital (peace and social cohesion), and natural capital (environment). Another relevant World Bank reference that can support identification of drought impacts is *Droughts and Deficits: The Impact of Water Scarcity on Economic Growth* (Zaveri, Damania, and Engle 2023).

Some approaches aim to value impacts. Various initiatives tackle database compilation and monitoring of drought impacts, including the U.S. Drought Impact Reporter, the Caribbean Climate Impacts Database, and the JRC European Drought Observatory, and, at the global level, DesInventar and EM-DAT.[12] A forthcoming publication of the National Drought Mitigation Center (housed at the University of Nebraska–Lincoln) reviews these databases. In general, the databases include minimal information for developing countries due to data collection challenges. It is important to check whether the target area has relevant registers in these databases.

The analytical framework of a Post-Disaster Needs Assessment (PDNA) attempts to study disaster impacts but often focuses on immediate effects, leading to underestimation. Moreover, comprehensive valuations are challenging due to reliance on local feedback, which may not systematically track damages and losses. PDNAs rely on Damage and Loss Assessment (DALA). The Global Facility for Disaster Reduction and Recovery developed a detailed guide for DALAs (GFDRR 2010a, b, c). They define pre- and post-disaster baselines or situations and estimate damage and losses on, typically, each of the most directly and immediately affected sectors.

PDNAs often estimate macro-economic impacts. They collect data, typically from government agencies and national statistics offices, on economic indicators such as gross domestic product, industrial production, trade, investment, and government revenues and expenditures. They then compare baseline scenarios with the drought event. Guidance for establishing connections is available in Freire-González, Decker, and Hall (2017) and Zaveri, Damania, and Engle (2023), among others. Assessment of macro-economic impacts is recommended to complement other analyses in this sub-block.

A tool related to a PDNA but focused on communities is the Human Recovery Needs Assessment (HRNA) or Human Impact Assessment, which focuses on social, economic, and environmental impacts on affected populations. It involves a systematic and structured process of interviews, surveys (to identify vulnerable groups and areas), and data gathering to prioritize recovery interventions and effectively allocate resources. HRNAs also can support long-term preparedness actions.

Like DALAs, HRNAs require government endorsement and the participation of affected communities. The EU, UNDP, and the World Bank developed guidelines to perform HRNAs (EU, UNDP, and WBG 2019). Alternatively, a version of the assessment, Social Impact Assessment, can be carried out. The World Bank and GFDRR prepared a manual for analyzing the social impacts of disasters (World Bank and GFDRR 2015). A DALA/PDNA-like impact collection exercise may be the only option in data-scarce environments.

PDNAs and the connected assessments mentioned above, along with drought impact databases, often focus solely on recording the impacts of a specific/current drought event. The advantage of event-driven data collection and analysis is that it directly attributes impacts to droughts, based on local and expert knowledge. However, by definition, it does not include previous droughts. To quantify drought impacts more extensively, continuous quantitative longitudinal data collection, from country official statistics or agency reports, is crucial. This effort establishes baseline conditions and allows comparison of conditions during droughts and during non-drought periods, indicating the relative severity of drought impacts historically. Some quantitative longitudinal datasets may exist for purposes other than drought but show a “drought signal” (see box 3.7).

Importantly, using such a bottom-up approach often poses aggregation and double-counting issues driven by socioeconomic and environmental interlinkages. A potential remedy could be to adopt a model-based approach, at the expense of additional simplification and the need to make assumptions about several parameters, for which stakeholders and expert judgment can be helpful. The references to PDNA and DALA assessments in table 3.4 offer guidance on how to minimize these potential problems.

When displacement is a consequence of drought, measuring its extent can avoid any implicit place-based bias in socio-economic estimates. For instance, baseline impact numbers often rely on pre-disaster statistics, which fail to account for displacement as well as the likelihood of return. The needs of a population in a given area are influenced by migration because a decline in population can reduce the needs at the disaster location. In any case, it is beneficial to support impact assessments with a “following the people” approach, rather than relying solely on a place-based analysis.

Even if reported damages and losses are the preferred indicators of actual drought impacts, remote sensing is becoming increasingly valuable as a proxy for tracking those impacts in data-scarce environments because it offers large spatial coverage and frequent measurements. Use of remote sensing enhances the efficiency of data collection and provides a sustainable and scalable solution. Assessments should incorporate an evaluation of impacts in those sectors/systems that can be tracked with earth observation, such as agriculture and, importantly, the environment. Remote sensing can allow teams to count on indicators of dust accumulation, wildfires linked to drought, wetland degradation, forest damages, and so on. Box 3.7 mentions how remote sensing analyses were used to assess drought impacts in Romania.

Analysis of drought impact data may involve descriptive statistics in drought and normality scenarios, trend analysis, correlation analysis, or more sophisticated approaches, such as regression or machine learning algorithms. Table 3.4 presents methodologies for drought impact assessment.

DATA NEEDS: Statistical data, censuses, stakeholder/household surveys, interviews, and remote sensing data are needed for drought impact assessments. King-Okumu (2019) reviews the data sources for such assessments.

Flore de Preneuf / World Bank

BOX 3.7

Drought Impact Assessment for Romania

For the characterization of drought impacts in Romania, spatial-temporal data series at different scales and timeframes were assessed for the following sectors and systems: (1) agriculture, livestock, and fisheries, (2) energy production, (3) inland fluvial transportation, (4) industrial productivity, (5) natural ecosystems, and (6) water supply.

The National Database Romanian Tempo Online statistics and EUROSTAT statistics for Romania facilitated the data compilation task. Romanian authorities provided some of the time series data, particularly 2022 data.

The data on sectors and systems encompasses different temporal intervals, occasionally focused on the most recent drought (2022), while in other instances extending further back in time. In some cases, the analyses relied only on historical data that, regrettably, does not include 2022 data.

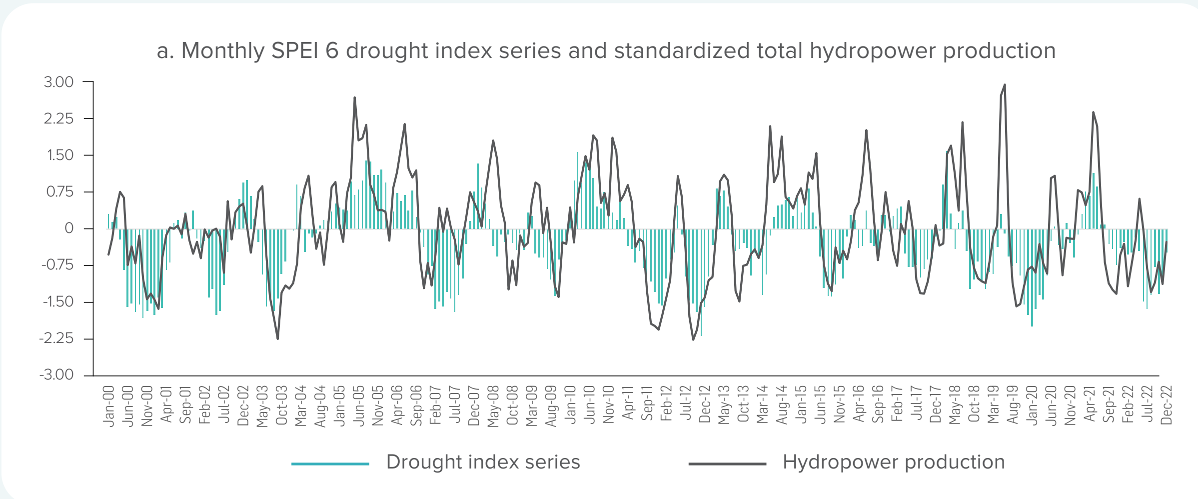
The research team compared these variables to the Standardized Precipitation-Evapotranspiration Index (SPEI) and Standardized Precipitation Index (SPI) results obtained in previous steps and described in boxes 3.1, 3.3, and 3.5. The specific methodology used to link hazard and impact often is based on the correlation of the SPEI (or SPI) series in a specific river basin administration (calculated for the previous section) with the variables relative to each impact. To measure how much the impact variables change in drought periods, the study team applied statistical techniques and graphical representations to compare two samples, the first taken in periods of normality and the second, during a drought. For example, for national hydropower production, the team found a correlation close to R 0.7 with an average SPEI6. Researchers were able to attribute and measure the mean reductions expected under different drought thresholds (see figure B3.7.1).

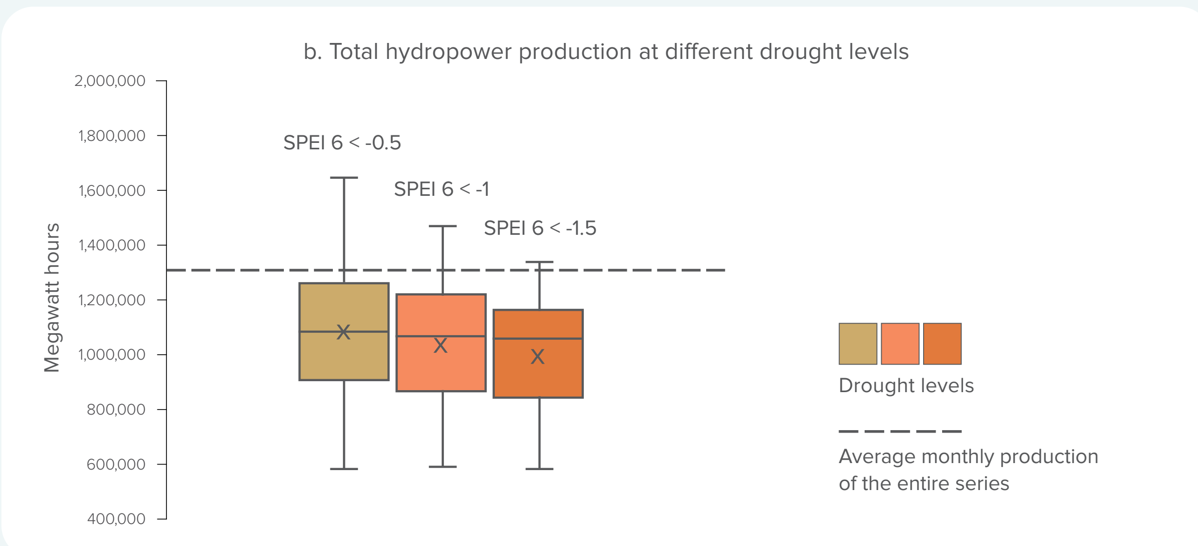
(box continues next page)

BOX 3.7 *(continued)*

FIGURE B3.7.1

Hydropower Generation in Romania, 2000–2022





Source: Adapted from World Bank 2024.

As a complement to the ground data analyses, the team prepared a remote sensing-based overview of the changes in vegetation health, dry matter production, and yields of some key crops with data from Copernicus to assess the losses experienced during the most severe droughts.[a] The team validated the losses using local statistics.

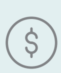
The heterogeneity of the gathered datasets conditioned the level of detail of the assessment performed for each sector/system, but using a variety of approaches allowed researchers to provide a holistic overview of impacts attributable to drought.

[a] Copernicus Global Land Service, "Vegetation," https://land.copernicus.eu/global/products/dmp.

Romwell "Ouie" Sanchez / USAID

TABLE 3.4

Methodologies for Drought Impact Assessment

Methodology	Budget	Time	Effort	Strengths	Weaknesses	Reference
Preparation of an overview based on the information from an established impact database/ monitoring system in the country/region*				Compatible with all the methods. Rapid, easy, inexpensive.	Event-based assessment. Heavily reliant on pre-existing database on a drought in the country/ region/impact monitoring system.	Established databases: • DesInventar • EM-DAT • Caribbean Climate Impacts Database • EU JRC European Drought Observatory • Famine Early Warning Systems Network
Remote sensing analysis, with earth observation variables used as proxy of impacts*				Compatible with and complementary to all the methods. Allows for expansion to some environmental impacts. Rapid, inexpensive.	Connection to the ground non-existent because the approach is desk-based. Social effects of drought cannot be directly captured. Unlikely to consider the needs of the most vulnerable. Heavily reliant on pre-existing data accessible outside the target country.	References: • Global RApid post-disaster Damage Estimation (GRADE) approach Gunasekera et al. (2018) • Copernicus • GEE for easy-to-access data on water presence, vegetation health and productivity, dust, fires, groundwater dynamics, etc. See application example in box 3.7.

(table continues next page)

TABLE 3.4 ***(continued)***

Methodology	Budget	Time	Effort	Strengths	Weaknesses	Reference
HRNA or Human Impact Assessment	$ $	🕒🕒	💡	Compatible with the other approaches. People-centered: assesses impacts on the ground and needs of the most vulnerable.	Requires local interaction and feedback (time-consuming). Sample might not be fully representative.	Reference: EU, UNDP, and WBG (2019)
Impact chains identification	$ $	🕒🕒	💡💡	Compatible with all the other approaches. Can be developed with different levels of complexity/detail. Identifies main issues linked to drought based on input from local stakeholders.	Qualitative. Requires local interaction and feedback (time-consuming).	Application examples and references: · Lückerath, Rome, and Milde (2023) · EDORA Project impact chains definition · Zhang and Borja-Vega (2024)
Estimation of the drought macro-economic impact	$ $	🕒🕒	💡💡	Compatible with all the other approaches. Rapid, easy, inexpensive, unless a more advanced option that looks into the future impacts is also used. Captures effects through supply chains. Some tools allow for ex-ante modeling of impacts.	Connection to the ground is minimal. Rapid and desk-based. Lacks inclusion of the needs of the most vulnerable. Heavily reliant on pre-existing data.	References: · Freire-González, Decker and Hall (2017) · Zaveri, Damania, and Engle (2023) · Damania et al. (2017) · Global Change Assessment Model (GCAM), an integrated assessment tool for exploring sectoral consequences and responses to global change. Can be narrowed down to drought effects. Can provide a sense of future impacts. Datasets: · World Bank Open Data · OECD Stats · OCHA humanitarian data by development partners worldwide
PDNA/DALA (or adaptations)	$ $ $	🕒🕒	💡💡	Economic case is presented. Methods are comprehensive: cross-sectoral, long-term view. Intended to be multi-scale and include fieldwork. Relatively fast if pre-existing statistics exist.	Event-based assessment, so it misses indirect and lagged effects. Time constraints may compromise application. Connection to the local level and affected communities is acknowledged to be weak, especially where timeframes are constrained. Heavily reliant on pre-existing data accessible in the target country.	References: · DALA methodology parts 1–3 GFDRR (2010a, b, c) · PDNA methodology · EC, GFDRR, and UNDG (2013)
Expansion/ adaptation of the PDNA/DALA-like approach with longitudinal quantitative data	$ $ $	🕒🕒🕒	💡💡	Same strengths as PDNA/DALA but also incorporates risk evolution.	Same weaknesses as PDNA/DALA, although not event-based. Not possible in data-scarce environments. Likely to take more time.	Reference: OCHA humanitarian data by development partners worldwide See application example in box 3.7.

Source: World Bank Group.
* This methodology can be utilized even without specialized expertise or resources for more in-depth analyses.

3.4 Assessing Country/Region Vulnerability to Drought

WHY THIS BUILDING BLOCK IS IMPORTANT: A high level of vulnerability to drought threatens livelihoods and fulfillment of the most basic needs. Although one hazard can affect multiple communities simultaneously, the impacts manifest to varying degrees in those communities, depending on their level of vulnerability or resilience. Vulnerability is generally understood as a function of sensitivity and coping (or adaptive) capacity (Serrat-Capdevila et al. 2022; Nakicenovic et al. 2000). Because droughts often involve complex interactions among many hydrometeorological, environmental, and socioeconomic factors at different scales and over time, the vulnerability element becomes crucial in understanding those interactions.

POSSIBLE RESULTS: This step will lead to a vulnerability assessment (see figure 3.3), which can help decision-makers prioritize adoption of drought preparedness measures. The vulnerability assessment aims to identify what causes risk and how it is managed in the analyzed areas.

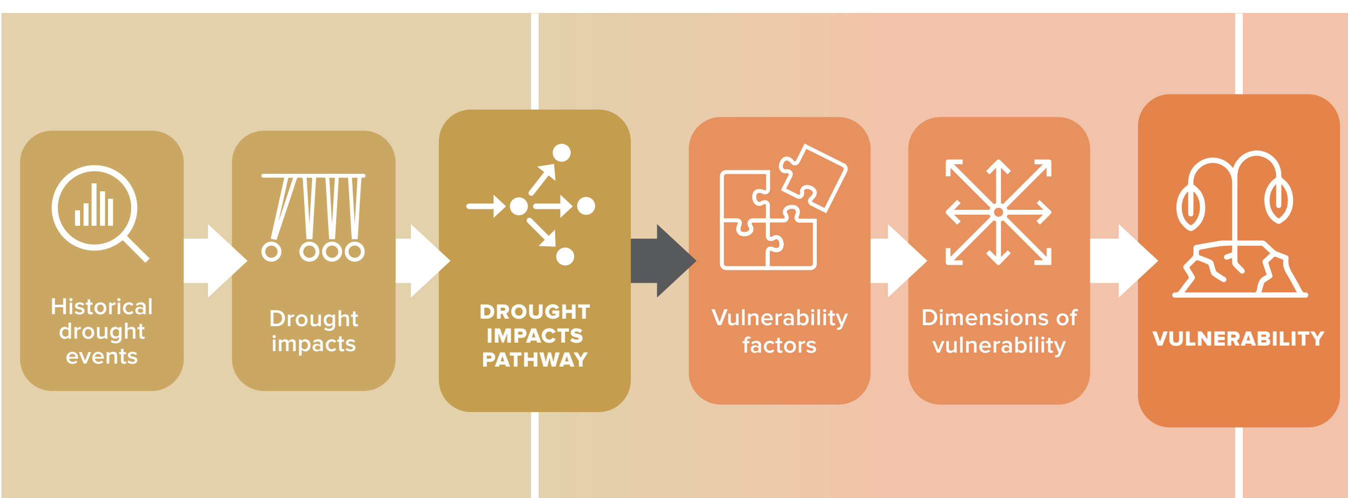
Vulnerability assessments offer a strong entry point for stakeholder identification and engagement, which can create awareness of the approach, its objectives, and its opportunities while minimizing the likelihood of plan failure, as well as foster political ownership (De Nys, Engle, and Magalhães 2017).

King-Okumu (2019) categorizes vulnerability approaches as (1) people-centered, (2) land-based mapping and models of ecosystem service production, and (3) hydrometeorological assessments including water balance accounting. Some approaches focus on a single criterion, whereas others use multi-criteria.

Most vulnerability assessments are based on indication (that is, they rely on producing indicators of vulnerability), but they do not explicitly provide a value for the potential losses that they identify and, therefore, are not based on those losses and hence are distinguished from impact assessment. If an impact assessment has been successfully completed, teams are encouraged to include empirical approaches based on attribution/contribution in vulnerability assessments. By characterizing past drought events' intensities, duration, and associated impacts, teams can link the drought hazard to its consequences in different systems/sectors or areas, identifying the most vulnerable ones. These attribution/contribution assessments help establish linkages and relationships between vulnerability factors and observed impacts (see box 3.8). In any case, empirical approaches to vulnerability assessment can be complemented with modeling of relevant sensitivity and coping/adaptive capacity factors.

FIGURE 3.3

Exploring Vulnerability in Impact and Vulnerability Assessments



Source: Adapted from FAO 2024.

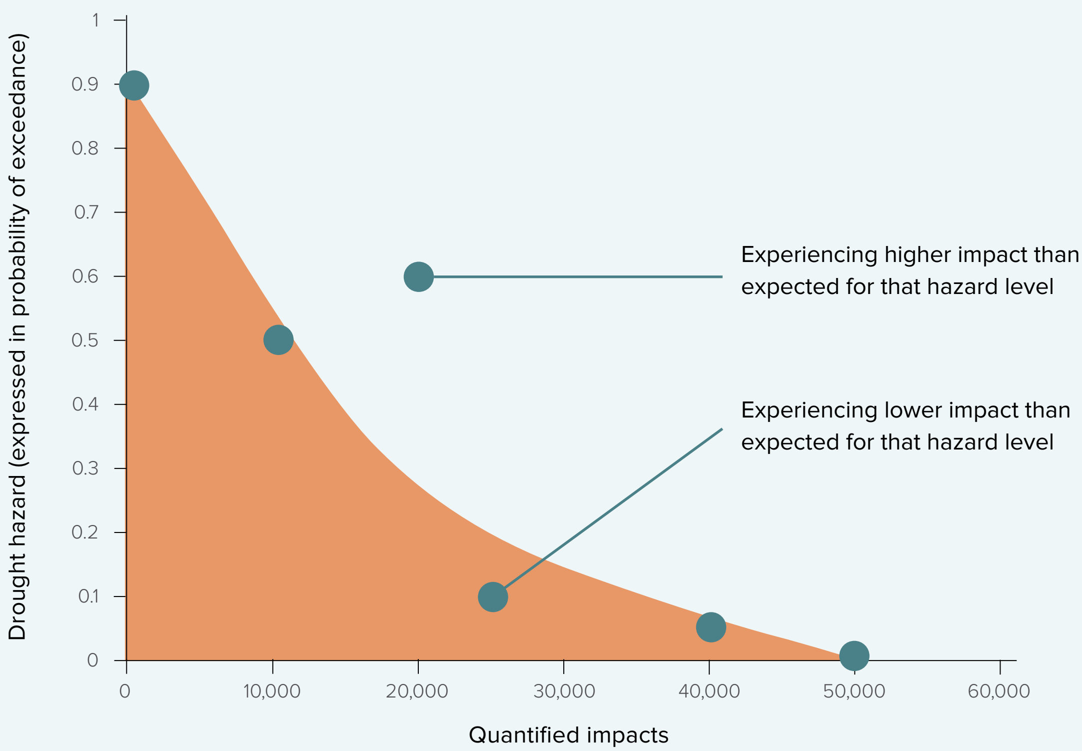
BOX 3.8

Multidimensional Vulnerability Assessment for Romania

Researchers performed a straightforward vulnerability assessment of all the sectors for which sufficient historical data on impacts were compiled. They ranked highly impacted systems and areas at equivalent drought hazard scores, following the logic of figure B3.8.1.

FIGURE B3.8.1

Empirical Estimation of Vulnerability Levels Based on the Impact Experienced at Various Drought Hazard Levels



Source: Example based on World Bank 2024.

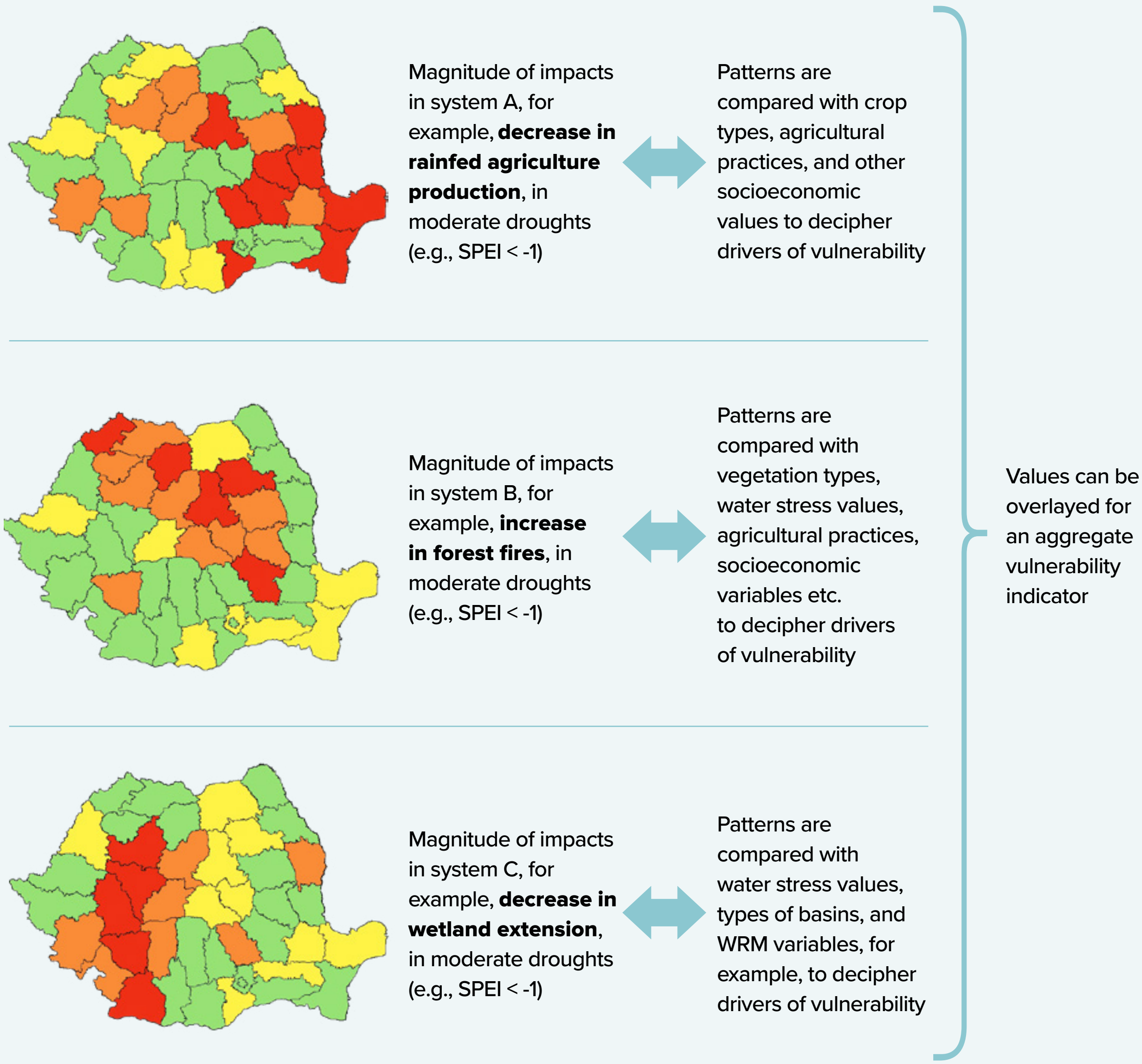
Once vulnerability patterns are recognized, they can be compared to socioeconomic indicators, water access, water scarcity levels, types of vegetation and crops, and so on (see figure B3.8.2). Consequently, the drivers of vulnerability are recognized, which in some cases will provide a sense of coping capacities and in other cases will point to sensitivity issues.

(box continues next page)

BOX 3.8 ***(continued)***

FIGURE B3.8.2

Creation of Empirical Vulnerability Scores and Maps Based on Attribution of Impacts



Source: Example based on World Bank 2024.

It is helpful to overlap and combine frameworks to balance out possible strengths and weaknesses, as indicated in table 3.5. Integrating several approaches (King-Okumu 2019), both indication and attribution-based and empirical and modeling approaches, ensures a more data-driven, informed, and holistic understanding of drought vulnerability. However, the complexity of the exercise will be conditioned by available resources and local engagement.

TABLE 3.5

Methodologies for Vulnerability Assessment

Methodology	Budget	Time	Effort	Strengths	Weaknesses	Reference
Vulnerability assessment based on ranking highly impacted systems and areas at equivalent drought hazard scores. Attribution exercise.*	$	🕓	💡	Once impacts are assessed, it takes little effort to pinpoint the main vulnerable sectors/ systems, crops, areas, etc. Data-driven: drought impact data and hazard data comparison helps identify areas, crops, and sectors that suffer most. Can support distributional impacts identification. Can focus on affected critical facilities.	Requires a quantitative impact assessment. Might not allow for linking vulnerability levels to characteristics of sectors/systems, crops, etc.	Inspiration for addressing different sectors/systems: · Pedro-Monzonís et al. (2016) · Simelton et al. (2009) · Bottero et al. (2017) · Kern, Su, and Hill (2020) See application example in box 3.8.
Global drought vulnerability maps*	$	🕓	💡	Visually comparative, within or among countries. Provides a contextualized initial picture.	Usually focus on national level. Does not always target the most drought-prone areas within countries. Vulnerability map does not stand alone without exposure map.	References: · Carrão, Naumann, and Barbosa (2016) · IWMI geovisualization portal Mapping Drought Patterns and Impacts: A Global Perspective · Gridded Livestock of the World (not exclusively for drought vulnerability, more for exposure) · Gridded Population of the World (not exclusively for drought vulnerability, more for exposure) · EU JRC Drought vulnerability indicators for global-scale drought risk assessments · Richts and Vrba (2016) · Zhang and Borja-Vega (2024)
Tracking of SDGs*	$	🕓	💡	All countries have committed, and the international community is positioned to provide support.	Focus on national-level datasets. Does not always target the most drought-prone areas within countries.	Reference: Sustainable Development Report Portal
Macroeconomic assessment approach and attribution exercise*	$ $	🕓 🕓	💡	Can explore how much the economy relies on water-intensive sectors. Can explore long-term economic effects of drought on the economy. Relatively fast and straightforward.	Often overlooks informal economies. Economic assessments are controversial and often contested/ rejected. Attribution not easy.	Reference: Most PDNAs of droughts include subnational description of vulnerabilities based on the macro-economic shocks experienced in the target drought event. More advanced application examples: · World Bank (2005) · USAID (2018)

(table continues next page)

TABLE 3.5 ***(continued)***

Methodology	Budget	Time	Effort	Strengths	Weaknesses	Reference
Institutional analysis and capacity assessment	$ $	◷ ◷	💡	Situates assessment in governance context. Provides roadmap for design of assessment process. Connects well with block I and with subsequent building blocks.	Subjective, political, dynamic. Identifying and including all relevant stakeholders can be challenging. Requires local interaction and feedback (time-consuming).	Application examples: · Green Nylen et al. (2018) · Khan, Gao, and Abid (2020)
People-centered: Community-based resilience and livelihoods assessment approach and other inclusive approaches	$ $ $	◷ ◷ ◷	💡 💡	Analysis broader than income only. Includes economic case at the household level. Can accommodate long-term time horizon. Considers capacities and different types of sensitivities relevant to drought, linked to basic population metrics. Supports distributional impacts identification, pinpoints groups at risk. Familiar to practitioners. Connects to agroecosystems.	Data-intensive and time-consuming. Focuses on household scale; may not be multi-scale. May not capture effects on the national and regional economy. May be logistically challenging. Representativity issues. In pre-existing conflict situations, can be sensitive. Often misses identification of strategic water management solutions.	Application examples: · Limones et al. (2020) · Farahani and Jahansoozi (2002) · Ayantunde, Turner, and Kalilou (2015) · Ghimire, Shivakoti, and Perret (2010) · Mdemu (2021) · Scognamillo, Mastrorillo, and Ignaciuk (2022) · Buurman, Bui, and Du (2020) · Naumann et al. (2014) Frameworks for performing the assessment: · UNDP and EC (2016) · National Drought Mitigation Center et al. (2011) · FAO: Guidelines I&V assessments · FAO: Climate Vulnerability and Capacity Analysis Handbook (not focused exclusively on drought; includes case studies using methodology) · PROVIA (2013) · Compilation of useful indicators for this type of approach available within EU JRC drought vulnerability indicators for global-scale drought risk assessments Meza et al. (2018) Some open datasets: · Global Data Lab · IHSN Past household surveys by development partners worldwide · OCHA humanitarian data by development partners worldwide · E-agriculture assessments by FAO

(table continues next page)

TABLE 3.5 *(continued)*

Methodology	Budget	Time	Effort	Strengths	Weaknesses	Reference
Ecosystem-based agroecological approach	💲💲	🕓🕓	💡💡💡	Examines the susceptibility and health of vegetation, changes in biodiversity and impacts on wildlife and natural habitats. Supports distributional impacts identification. Ensures coverage of resource-dependent production systems. Can connect to climate models and to economic models. Can be mapped and monitored at low cost using satellite-derived data. Many agricultural adaptation options likely to be identified.	Minimal inclusion of poor and marginal groups. Not always systematic and more oriented to agriculture than other sectors. May not capture vulnerabilities in urban areas. Focuses on field scale—may not be multi-scale. Relatively short time horizons. Does not consider water needs in other sectors of the economy.	Application examples: · Sultana et al. (2023) · Bahta, Jordaan, and Phatudi-Mphahlele (2019) · Zhang et al. (2021) · Tsesmelis et al. (2019) Frameworks for performing the assessment: Only for sophisticated versions, often beyond the scope ofDRRAs: · Biodiversity, Ecosystems, and Landscape Assessment · Economics of Land Degradation · System of Environmental-Economic Accounting · Integrated Valuation of Ecosystem Services and Tradeoffs · FAO (2017) Open datasets: · The Economics of Ecosystems and Biodiversity (TEEB) database with country-wide accounting of main ecosystem services · Ecosystem Services Valuation Database Portal · European Drought Observatory (EU JRC Risk of Drought Impacts for Agriculture indicator) · MAES: Mapping and Assessment of Ecosystems and their Services (shapefile and attributes with down scaled ecosystem services in Europe)
Water balance accounting and basin management approach	💲💲	🕓🕓	💡💡💡	Can be performed easily with water access statistics in the country. Can capture vulnerability of water resources, hydrological systems, and aquifers to drought. Considers water availability and demand across the economy. Can connect to climate models and scenarios and early warning systems. Can enable identification of capacity needs. Can include factors such as WASH, access to irrigation, or storage availability. Supports distributional impacts identification.	Difficult to apply in data-scarce regions. Institutional challenges in coordinating data collection, management, and analysis. Data on water extractions often incomplete in drought-affected areas. May require information on groundwater management.	Application examples: · Serrat-Capdevila et al. (2022, 2023) · Karimi, Pareeth, and Michailovsky (2019) · Hoque et al. (2021) Note: there are many examples in the literature; these represent easy applications, sufficient for a DRRA. Some open datasets: · AQUASTAT & AQUAMAPS Portal · Aqueduct Water Risk Atlas Data · TerraClimate: Monthly Climate and Climatic Water Balance (available in GEE) · Compilation of useful indicators for this type of approach available within EU JRC drought vulnerability indicators for global-scale drought risk assessments

Source: World Bank Group.
* This methodology can be utilized even without specialized expertise or resources for more in-depth analyses.

Research conducted at broad scales may overlook local context and legitimacy, while research conducted at narrow scales can be excessively demanding. Vulnerability assessment approaches must balance these scales to effectively uncover the underlying causes of distributional impacts, namely, how drought affects diverse groups, systems, or sectors differently depending on their varying degrees of sensitivity and coping/adaptive capacity.

HOW THIS BLOCK RELATES TO OTHER BUILDING BLOCKS: Vulnerability is a key element in defining risk and is necessary for drought risk mapping. It is fully connected to drought impact assessment, in particular, as depicted in figure 3.3. Drought vulnerability assessments will allow the transition to a risk management approach that targets drought resilience measures to the most vulnerable. Furthermore, vulnerability assessments can be linked to early warning systems, which can support both rapid actions and long-term investments.

Data needs: Statistical data, censuses, stakeholder/household surveys, interviews, and remote sensing data are needed for vulnerability assessments. King-Okumu (2019) reviews the data sources for assessment of vulnerabilities to droughts. Useful indicators are available in the Global Data Lab portal, in household surveys by development partners worldwide, and in UN humanitarian data.[13]

Notes

1 United Nations Convention to Combat Desertification, "Drought Toolbox," accessed June 11, 2023, https://www.unccd.int/land-and-life/drought/toolbox and Integrated Drought Management Programme, "Monitoring & Early Warning," https://www.droughtmanagement.info/pillars/monitoring-early-warning/.

2 SPEI (Standardized Precipitation-Evapotranspiration Index), "SPEI Global Drought Monitor." https://spei.csic.es/map/maps.html#months=1#month=6#year=2024.

3 Tokyo Climate Center and World Meterological Organization Regional Climate Center in RA II (Asia), "ClimatView--A Tool for Viewing Monthly Climate Data, https://ds.data.jma.go.jp/tcc/tcc/products/climate/climatview/frame.php?&s=1&r=0&d=0&y=2019&m=2&e=8&t=0&l=0&k=0&s=1, and International Research Institute, "Global Drought Analysis Tool," https://iridl.ldeo.columbia.edu/maproom/Global/Drought/Global/CPC_GOB/Analysis.html.

4 Food and Agriculture Organization of the United Nations, "Earth Observation--Agricultural Stress Index System," https://www.fao.org/giews/earthobservation/asis/index_1.jsp?lang=en.

5 SPEI, "Tools," https://spei.csic.es/tools.html.

6 Intergovernmental Panel on Climate Change, "IPCC WGI Interactive Atlas," https://interactive-atlas.ipcc.ch/.

7 National Oceanic and Atmospheric Administration, "NOAA's Climate Change Web Portal: CMIP6," https://psl.noaa.gov/ipcc/cmip6/ and Climate Data Factory, "Climate Data Factory," https://climate.theclimatedatafactory.com/.

8 World Resources Institute, "Aqueduct Water Risk Atlas," https://www.wri.org/data/aqueduct-water-risk-atlas.

9 Koninklijk Nederlands Meteorologisch Instituut, "KNMI Climate Change Atlas," https://climexp.knmi.nl/plot_atlas_form.py.

10 World Bank Group, "Climate Change Knowledge Portal," https://climateknowledgeportal.worldbank.org/.

11 Earth System Grid Federation, "CMIP6," https://esgf-data.dkrz.de/search/cmip6-dkrz/, and Climate Data Store, "CMIP6 Climate Projections," https://cds.climate.copernicus.eu/cdsapp#!/dataset/projections-cmip6?tab=overview.

12 United Nations Office for Disaster Risk Reduction, "Desinventar Sendai," https://www.desinventar.net/ and Centre for Research on the Epidemiology of Disaster, "Public EM-DAT," https://public.emdat.be/.

13 Global Data Lab, https://globaldatalab.org/; International Household Survey Network, https://catalog.ihsn.org/catalog/?page=1&ps=15; and Office for the Coordination of Humanitarian Affairs, https://data.humdata.org/dataset.

4.

Evaluation of Current Resilience (Block III)

Having assessed the drought risk, the DRRA next characterizes current drought response and preparedness, which comprise the main resilience assessment. Block III calls for two evaluations: one of drought response and the other of drought preparedness (see figure 4.1). These evaluations can use the same methodologies and tools. Nevertheless, their approaches vary in that they focus on different program areas.

Program areas represent drought management interventions grounded in the categories of the EPIC Response framework. They provide a comprehensive systematic structure for organizing drought programs, interventions, and potential measures, collectively forming what the World Bank designates as a drought-related Menu of Measures (MoM). Teams conducting DRRAs can use the classification of program areas and specific programs that shape the MoM as a reference to analyze the current status of each of the areas.

FIGURE 4.1

Block III of the Drought Risk and Resilience Assessment

Block III

Evaluate current resilience

- **Evaluate current drought response**
- **Evaluate current drought preparedness**

Source: Original figure for this publication.

Characterization of current drought response and preparedness can take any one of three approaches:

- **Desk-based stock-taking of drought response and drought preparedness mechanisms from existing reports.** This approach would be possible only if sufficient material is online or if deliverables on similar assessments have been recently developed. For countries lacking this information, *A Multi-Criteria Assessment Framework for National Drought Planning* (Alkadir, Pek, and Salman 2022) is a valuable reference. This publication establishes a standardized method for reviewing national drought plans and applies this gap analysis in more than 30 countries. Additionally, it provides a suite of recommendations for enhancing these plans.

- **In-depth assessment of drought management plans and climate adaptation actions to address droughts.** The European Drought Observatory for Resilience and Adaptation (EDORA) Project has created a methodology and questionnaire for assessing drought management plans and has applied it to EU member states (EU 2023; UNCCD 2022c), as illustrated in box 4.1. These tools can also be applied to other countries, using focus group discussions and interviews to complete the survey. In its current form, the survey mainly focuses on identifying existing program areas. It should be augmented with questions regarding their performance and expanded to include an analysis of capacity gaps for implementation. Table 4.1 presents additional assessment frameworks with characteristics and implementation processes similar to those of the EDORA framework.

- **Identification of the relevant stakeholders and program areas and assessment of their level of development and effectiveness.** The EPIC Response Assessment Methodology evaluates a country's hydro-climatic risk management system by assessing the maturity level of flood and drought risk management by government counterparts, key experts, and other stakeholders (Deltares 2023). The effort required to conduct interviews and workshops with focus group discussions can be significant, but a rapid desk review can also be conducted, as is the case with the other two approaches.

BOX 4.1

European Union-Wide In-Depth Assessment of Drought Management Plans and Climate Adaptation Actions for Drought

The European Drought Observatory for Resilience and Adaptation (EDORA) Project developed a questionnaire for EU members aimed at assessing (1) drought policy frameworks, (2) governance, (3) drought indicators and monitoring, (4) drought management approaches, (5) management of exemptions for the Water Framework Directive, (6) drought measures, (7) cost-benefit analysis, and (8) maturity of the drought management system.

The 30-plus questions are often open-ended and allow for clarifications and comments. In some cases, the survey offers pre-determined answers to avoid ambiguity and to facilitate provision of sufficient detail (see figure B4.1.1). Questions on performance and capacity gaps are included.

FIGURE B4.1.1

Part of a Questionnaire on the Status of the Drought Policy Framework

2. Drought policy framework

2.1 How is drought management regulated in the EU MS?

2.1.1 Is drought management regulated at national level by ...:

☐ a law adopted as primary regulation by parliament?

☐ in place ☐ under review ☐ under development

2.1.2 Does the drought management legislation ...

Please select one or several of the response options and specify further details (in English):

☐ ... define a drought (event)? If YES, please specify: ...

☐ ... establish a relationship between droughts and climate change? If YES, please specify: ...

☐ ... establish a relationship or distinction between droughts and water scarcity? If YES, please specify: ...

☐ ... define drought risk? If YES, please specify: ...

☐ ... define a/several competent drought management authority/ies (e.g. river basin administration, regional, district or local administration)? If YES, please specify: ...

☐ ... define drought management actions? If YES, please specify: ...

☐ ... clearly assign the drought management actions to (specific) competent authorities (so in case a drought event shows up, it is clear who does what)? If YES, please specify: ...

☐ ... not address any of the above.

2.2 What is the status of drought management plans?

2.2.1 Are there any specific drought management plans or strategies?

2.2.2 Are there any other strategies or plans that address drought management explicitly?

2.2.3 Is there any national guidance document for drought management?

Source: EDORA Project.

(box continues next page)

BOX 4.1 ***(continued)***

To ensure consistency in completion of the questionnaire, the EDORA Project team conducted interviews and workshops with relevant agencies and stakeholders in each country. The published survey results identify gaps and areas of intervention across the European Union.

TABLE 4.1

Methodologies for Drought Resilience Assessment

Methodology	Budget	Time	Effort	Strengths	Weaknesses	Reference
Desk-based stock-taking of drought response and drought preparedness mechanisms from existing reports*	💲	🕓	💡	Rapid, inexpensive. Easier if target is a country with a national drought plan already evaluated through the UNCCD and FAO multi-criteria assessment framework for national drought planning.	Heavily reliant on pre-existing data accessible outside of the country. Difficult to assess program area performance or capacity without feedback from local stakeholders.	Set of program areas to examine can be extracted from: · Menu of Measures (MoM) · EPIC response framework Browder et al. (2021) · Overviews already available for some countries Alkadir, Pek, and Salman (2022)
In-depth assessment of drought management plans and climate adaptation actions to address droughts; EDORA-like assessment	💲💲	🕓🕓	💡	Reflects local views and actual circumstances.	Requires roughly 20 days for an experienced consultant to run workshops, focus group discussions, interviews, and reporting. Accounting of implemented program areas needs to be complemented with a discussion on performance and capacity gaps.	Application examples: · UN-ISDR and SIDA (2008) · Green Nylen et al. (2018) Evaluation frameworks, checklists, and questionnaires: · EDORA Project methodology for the "In-depth assessment of drought management plans and a report on climate adaptation actions against drought in different sectors" (UNCCD 2022c) · Catalogue of IWRM assessment tools to help assess (1) enabling environment, (2) institutions and participation, (3) management instruments, (4) financing · Urquijo-Reguera et al. (2020) See application example in box 4.1.
EPIC response assessment of Program Areas relevant to drought	💲💲💲	🕓🕓🕓	💡	Can reflect local views and actual circumstances. Fully comprehensive in addressing program areas and their interconnections. Links to flood response/ preparedness.	Can take months to be developed and often requires extensive work by a team (although more desk-based reviews are possible): workshops, focus group discussions, interviews, and reporting. Needs to be complemented with a discussion of program area performance.	Browder et al. (2021)

Source: World Bank Group.
* This methodology can be utilized even without specialized expertise or resources for more in-depth analyses.

These qualitative and generally straightforward approaches do not require profound expertise. However, providing a comprehensive picture of existing and enforced programs at different scales can be resource-demanding and time-consuming. Government endorsement and engagement of local stakeholders are essential.

Importantly, the lending toolkit used by the International Monetary Fund to assess a country's preparedness to become eligible for its climate resilience funding programs can be insightful for evaluating a country's standing regarding drought response and preparedness.[1]

All approaches can involve mapping of relevant institutions and stakeholders in the drought management system, if not performed thoroughly in the first block, and an assessment of different capacity dimensions: institutional; knowledge, data, and technology innovation; human and communities;

Thomas Nyarugwe / GOAL Global / USAID

and financial. Some previous capacity gap assessments can inform the surveys to be performed and the questionnaires to be developed. Such assessments include the USAID report for the Caribbean region (USAID 2022) and a report by the Government of Nepal (MoFE 2020). A toolkit to assess capacity gaps and needs to implement the Paris Agreement can also guide the exercise.[2] Any relevant results of the Capacity Gaps Assessment program of the UN-Water SDG 6 Capacity Development Initiative can be indicative. Finally, an assessment application developed by Khan, Gao, and Abid (2020) can serve as an example.

The analyses undertaken for block III must include an evaluation of the performance of the different program areas. Figure 4.2 depicts the structure of the MoM, offering a detailed, though not exhaustive, overview of the programs that should be in place in a comprehensive drought management system.[3] Importantly, this MoM is merely an illustrative example of how a drought management system is organized; other similar compendiums and classifications of drought-related interventions and programs—for example, the EDORA classification and the Integrated Drought Management Programme's three pillars—can be equally relevant as a reference for DRRAs.

FIGURE 4.2

Illustrative Example of the Menu of Measures

ENABLING MEASURES

Sectoral frameworks

- Drought management laws and policies
- Water resources management laws and policies
- Water supply and sanitation laws and policies
- Agriculture and irrigation laws and policies
- Disaster risk management and disaster finance laws and policies (incl. drought risk financing mechanisms and instruments)

Hydrometeorological services

- National framework for meteorological and hydrological services
- Drought monitoring and early warning systems
- Drought vulnerability and impact assessment
- National water data
- Forecasting and modeling for water services
- Agrometeorological advisory services
- National climate assessment

PLANNING MEASURES

Drought risk mitigation and contingency planning

- National planning
- Integrated Water Resources Management plans and integrated basin plans, including storage planning
- Cities and urban water supply planning
- Irrigation water supply planning
- Coastal planning

(figure continues next page)

FIGURE 4.2 ***(continued)***

INFRASTRUCTURE MEASURES

Nature-based solutions

- Watershed management and restoration
- Groundwater recharge
- Forest management and restoration
- Wetlands/floodplain management and restoration

Water infrastructure

- Water resources, including storage and conveyance infrastructure, rehabilitation, and retrofits
- Agricultural water-use efficiency programs
- Water supply and sanitation network expansion and efficiency
- "New Water," including desalination, water treatment, and water reuse
- Alternative sanitation technologies, such as dry toilets, waterless urinals, and container-based solutions

CONTROL MEASURES

Water allocation and groundwater management

- Flexible water allocation
- Water pricing
- Integrated water resources management
- Conjunctive groundwater management

RESPONSE MEASURES

Drought response and recovery

- National drought response
- Urban drought response
- Water resources management drought response
- Agriculture drought response
- Drought response for pastoral communities
- Social protection drought response

WHOLE-OF-SOCIETY MEASURES

- Local government and utilities
- Public participation and stakeholder engagement
- Social inclusion
- Public awareness and risk communication
- Scientific collaboration with universities, local governments, research centers, and nongovernmental organizations

Source: Original figure for this publication.

4.1 Evaluating Current Drought Response

WHY THIS BUILDING BLOCK IS IMPORTANT: A strengths and weaknesses assessment will quickly identify the existence of any disaster response strategies that are effective in mitigating impacts. Understanding the strengths of these strategies allows for their reinforcement and replication in other areas of vulnerability. Identifying weaknesses in the current drought response provides insights into the potential allocation of resources for improving that response. The assessment may reveal strengths and weaknesses in existing policies and governance structures that can inform adjustments.

POSSIBLE RESULTS: This assessment will identify the strengths and weaknesses of the current drought response through a gap analysis and will develop a preliminary list of possible investment areas. These areas may include essential policy or institutional actions suitable for development policy financing, as well as critical investments needed to build the physical and social infrastructure required for effective drought response.

SWOT (strengths, weaknesses, opportunities, and threats) analysis or PESTEL (political, economic, social, technological, environmental, and legal) analysis—a tool used to identify the macro (external) forces facing an organization—could both be produced to identify barriers to and areas for improvement in drought response.

This sub-block should ideally focus on the following program areas (as listed in the MoM):

- Hydrometeorological services that pertain to drought monitoring and response
- Drought risk mitigation and contingency planning as droughts unfold
- Drought response and recovery programs

DATA NEEDS: A strengths and weaknesses assessment of drought response requires policies, sector-specific plans, drought risk management policies and plans, previous reports, and PDNAs.

HOW THIS BLOCK RELATES TO OTHER BUILDING BLOCKS: Comparing the effectiveness of existing response strategies (block III) to the drought risk characterization (block II) provides a full account of systems and areas requiring improvement and indicates where more response resource allocation is needed. By integrating the findings from both assessments, decision-makers can prioritize and develop a well-informed and targeted drought risk response strategy.

4.2 Evaluating Current Drought Preparedness

WHY THIS BUILDING BLOCK IS IMPORTANT: Evaluating the current functionality of drought preparedness provides insights into necessary actions. Successful drought preparedness requires cross-sectoral coordination, which national drought policies can support. National-level drought preparedness can be further categorized into efforts for river basins and for sectors.

POSSIBLE RESULTS: This assessment will identify the strengths and weaknesses of the current drought preparedness through a gap analysis and will develop a preliminary list of possible investment areas. These areas may include essential policy or institutional actions suitable for development policy financing, as well as critical investments needed to build the physical and social infrastructure required for effective drought preparedness.

SWOT analysis, PESTEL analysis, and similar displays could be produced to identify barriers to and areas for improvement in drought preparedness.

The DRRA team should be able to point to specific areas where technical, financial, and human resources for preparedness can be optimized and where capacity-building efforts, such as training for local officials or the development of new management protocols, are needed. It also should be able to point to necessary improvements in communication channels or in utilization of available data to inform decisions and resource allocation.

This sub-block should focus on analyzing the performance of the following program areas (as listed in the MoM):

- Sectoral frameworks
- Hydrometeorological services that pertain to risk characterization, drought early warning systems, drought communication, and so on
- Drought risk mitigation and contingency planning
- Nature-based solutions
- Water infrastructure
- Water allocation and groundwater management
- Other aspects of the whole-of-society approach: census and statistics availability, participation, education, and drought risk communication, and so on

DATA NEEDS: A strengths and weaknesses assessment of drought preparedness requires policies, sector-specific plans, previous reports, and PDNAs.

HOW THIS BLOCK RELATES TO OTHER BUILDING BLOCKS: Comparing the effectiveness of existing preparedness strategies (block III) to the drought risk characterization (block II) provides a full account of systems and areas requiring improvement and indicates where increased resource allocation for drought preparedness is needed. By integrating the findings from both assessments, decision-makers can prioritize and develop a well-informed and targeted drought preparedness strategy.

Notes

1 International Monetary Fund, “Resilience and Sustainability Trust,” https://www.imf.org/en/Topics/Resilience-and-Sustainability-Trust.

2 Paris Committee on Capacity Building, “PCCB Toolkit to Assess Capacity Building Gaps and Needs to Implement the Paris Agreement,” https://unfccc.int/process-and-meetings/bodies/constituted-bodies/paris-committee-on-capacity-building-pccb/areas-of-work/capacity-building-portal/pccb-toolkit-to-assess-capacity-gaps-and-needs-to-implement-the-paris-agreement.

3 For World Bank staff, a more expansive and continuously updated internal tool links program areas and programs to specific World Bank methodologies and projects as these methodologies and projects are being developed and implemented.

5.

Prioritizing Areas for Action (Block IV)

The final phase of the DRRA draws from the results of all the preceding building blocks to inform the prioritization of potential measures (block IV [see figure 5.1]).

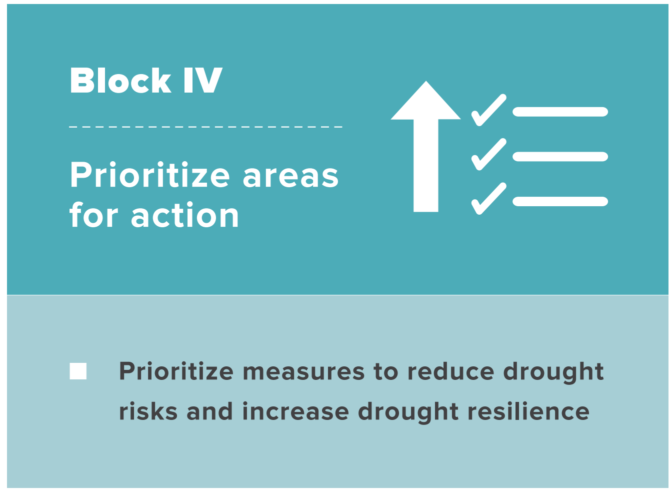
WHY THIS BUILDING BLOCK IS IMPORTANT: Building block IV strengthens efficient allocation of limited resources by focusing efforts and investments on measures where they can have the most significant impact in reducing drought risk and enhancing resilience, thereby realizing long-term cost savings. It is aimed at identifying areas where opportunities for drought risk reduction exist, presenting the benefits these opportunities could provide, and justifying potential investments. Analyses of these investments must reflect social and environmental, not just economic, benefits, as well as indirect benefits and co-benefits. Regarding this point, finance ministries, particularly in regions susceptible to various risks, may find it challenging to concentrate exclusively on a single hazard, so it is important to identify where preparing for drought can yield benefits that extend beyond mitigating the impact of drought. Doing so is consistent with the messages of the EPIC Response framework.

POSSIBLE RESULTS: Block IV ideally yields a list of potential priority measures and interventions, and a quantification or a narrative about their costs and benefits. This block can be pivotal in shaping financing decisions for World Bank member countries. It can support World Bank development policy financing and the design of related prior actions, which together underpin the policy and institutional reforms necessary to enhance drought management. It can support World Bank investment project financing and Program-for-Results financing by identifying adequate investments in physical and social infrastructure, as well as management improvements, that enhance drought resilience.

At this point, the team engaged in the DRRA will have successfully pinpointed the specific regions, systems, and sectors susceptible to risk and impacts. In addition, the team will have identified areas with a pressing need to contemplate potential drought preparedness and response measures. Narrowing the application of the time-intensive assessment tools in this building block to these areas is essential. After the team, guided by the categories included in the MoM, assesses the performance of the program areas and programs related

FIGURE 5.1

Block IV of the Drought Risk and Resilience Assessment



Source: Original figure for this publication.

to drought response and preparedness in building block III, it must engage stakeholders and relevant agencies at different levels in portfolio discussions to ascertain their perspectives on the desirability, feasibility, and adequacy of investing in the identified options.

Some benefits of interventions identified in the MoM might not be immediately apparent to stakeholders, so identifying, quantifying, and demonstrating them could prove illuminating. The team may propose additional or more specific interventions, which should also undergo assessment. Furthermore, the team could apply straightforward decision support tools to identify a set of feasible options to present to the client. Multi-Criteria Decision Analysis (MCDA) is one such valuable approach, which incorporates nuanced understanding of factors influencing infrastructure choices and often involves GIS overlaying. World Bank Advisory Services and Analytics, or ASA, work in Angola has applied MCDA to determine suitable types of water supply infrastructure and to evaluate the potential of a set of nature-based solutions at the scale of four provinces (Limones et al. 2024).

In general terms, it is essential to evaluate the long-term benefits of a program or project to contrast them with its costs. Recognizing the benefits entails comparing project outcomes with expected drought impacts in a scenario in which no action is implemented—the “inaction scenario,” making the expected impacts the “costs of inaction.” Evaluation of expected impacts is performed in sub-block 6 of the DRRA. When applicable, the benefits of the intervention should be compared with expected drought impacts in a scenario in which an alternative project is selected.

Ideally, multiple methodological approaches are used to assess the benefits of drought resilience projects. A combination of assessments can be guided by table 5.1, wherein the enumerated strengths and weaknesses offer insights into how specific tools may complement one another.

Importantly, drought’s gradual onset and prolonged duration require assessment methodologies that can capture the evolution and accumulation of impacts and the benefits of the proposed intervention over time. Furthermore, drought exhibits nuanced, indirect ramifications that present greater challenges in terms of quantification when compared with other hazards. These ramifications tend to diffuse temporally and spatially, spreading across sectors and systems, necessitating a meticulous delineation of the causal chain of effects as a base to evaluate the indirect benefits of programs. The reduction in vulnerability to future droughts in these sectors and systems should be measured as an indirect benefit. In particular, it is important to look at potentially positive externalities that might occur when the benefits of an action spill over to third parties who are not directly responsible for that action. In the case of mitigating drought impacts, positive externalities might manifest as a stable food supply, health benefits, climate change mitigation, and so on.

Economic analysis allows policymakers to prioritize investments by pinpointing cost-effective strategies, ensuring optimal resource allocation. It assesses trade-offs among various options amid resource competition, quantifies both direct and indirect impacts, evaluates policy effectiveness, and fosters collaborative decision-making among diverse stakeholders. The World Bank and California’s Water Authority (2023) have developed *Guidelines for Drought Risk Management–Economic Methods, Models and Tools*, which comprehensively gathers methodologies and explains application modalities for evaluating drought programs. The guidelines present the need to incorporate different dimensions (Vermeulen et al. 2023) in benefit-cost analysis (BCA) or cost-effectiveness analysis). All the approaches compiled in these guidelines, and some additional approaches, are included in the table 5.1.

Apart from their economic gains, drought risk interventions could offer a range of direct and indirect social benefits that need to be identified and valued to the extent possible, even if predominantly through qualitative means. These benefits include enhancing community resilience by fostering cooperation and self-reliance, improving public health through better access to clean and reliable water and increased food security and nutrition, promoting social equity and empowerment by addressing the needs of vulnerable populations and groups, increasing (or maintaining) educational opportunities, diversifying livelihoods to enhance economic security, and preserving cultural practices and traditions. Social return on investment (SROI) can help quantify the social value generated by drought management projects, measuring social outcomes in monetary terms. SROI approaches should rely on participatory methods to involve local communities in identifying and evaluating the social benefits of the interventions.

In addition to social advantages, drought risk interventions could yield significant environmental benefits. These measures encompass ecosystem restoration and biodiversity enhancement, surface and groundwater resource management that enhances water quality and availability, contributions to climate change mitigation and adaptation, soil conservation to reduce erosion and degradation, efficient water use leading to conservation, reduced habitat destruction and land degradation, and the enhancement of ecosystem services such as water regulation, carbon sequestration, and pollination reduction. However, relying solely on environmental benefits as the primary motivation for an intervention may be difficult to justify to clients, so ecosystem service (ES) assessments, especially for infrastructure-related investments, are useful for block IV. Experts can use ES assessments to model the process through which an action results in a specific outcome and can subsequently assess the benefits provided by such an outcome by looking at physical and social indicators that are of significance.

The World Bank developed guidelines for assessing costs and benefits, offering methods, a specific decision framework, and practical case studies to help developers of nature-

TABLE 5.1

Methodologies for Prioritizing Potential Investments

Methodology	Budget	Time	Effort	Strengths	Weaknesses	Reference
Drought Resilience, Adaptation and Management Policy (DRAMP) Framework (or similar framework) **Discussion with stakeholders, with Delphi+ assessment or other assessments (participatory decision-making)***	💲	🕒🕒	💡💡	Analyzes stakeholders acceptability. Valuable for the initial screening of options. Inclusive. Contextualized understanding. Incorporates qualitative insights and evolving priorities.	Lack of specificity in actual solutions for certain regions or sectors. Susceptible to dominant voices bias. Often not based on quantitative data or rigor. Meaningful stakeholder discussions can be resource-intensive.	Crossman (2018)
Menu of Measasures discussion with stakeholders, with Delphi or other assessments (participatory decision-making)*	💲	🕒🕒	💡💡	Same benefits as DRAMP.	Same weaknesses as DRAMP, but it is more specific.	See figure 4.2.
Multi-Criteria Analysis (MCA)	💲💲	🕒🕒	💡💡	Data-driven. Normally does not involve complex modeling. Comprehensive. Can incorporate qualitative and quantitative data. Flexible in scales and approaches. When applied at the initial stage, can help narrow down options for the client. When applied to analyze a concrete program, it considers multiple benefits and trade-offs.	Data-intensive. Can reflect incomplete or subjective criteria/ feedback. Assumes independency among criteria and is less valid in complex decision contexts. Does not capture the long-term and cascading effects of interventions. Robustness of the results can be sensitive to changes in criteria weightings and data inputs. Often purely technical and data-driven.	Top-down approaches for narrowing down programs to debate with the client/ stakeholders: · FAO Decision Support for Mainstreaming and Scaling Out Sustainable Land Management · Serrat-Capdevila et al. (2023) · Alkadir, Pek, and Salman (2022) Approaches for evaluating specific programs with stakeholders' feedback: · Ruangpan et al. (2021) · Appendix G of California Department of Water Resources (2014)
Cost-effectiveness analysis	💲💲	🕒🕒	💡💡	Analyzes economic efficiency. Alternative method to benefit-cost analysis (BCA) when data for benefits are not available or benefits are hard to quantify or monetize. Simple. Focuses on costs and identifies budget-efficient options.	Does not provide a comprehensive comparison of all costs and benefits. Weaknesses similar to those of BCA.	References: · Guimarães Nobre et al. (2019) · Kumar et al. (2021) · Zou et al. (2013)

(table continues next page)

TABLE 5.1 ***(continued)***

Methodology	Budget	Time	Effort	Strengths	Weaknesses	Reference
Ecosystem services (ES) valuation	💲💲	🕒🕒	💡💡	Focused on environmental benefits, but indirectly on society, through services. Co-benefits can be analyzed. Scenario evaluation is possible. Can be customized. Incorporates quantitative and qualitative aspects.	Data-intensive. Medium complexity. Assigning monetary values to ecosystem services often involves subjective judgments. Monetary valuation does not capture all benefits and costs associated with ES.	InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs)
Regional economic analyses	💲💲	🕒🕒	💡💡💡	Some applications are easy to use, especially those for input-output analysis. Cross-sectoral analyses of benefits. Captures intersectoral relationships within the regional economy.	Data-intensive. Purely economic. Assigning monetary values to non-market values like environmental aspects is challenging. May not fully capture the long-term benefits of certain drought management strategies, such as those related to climate resilience.	Input-output analysis: · Impact Planning (IMPLAN) model · Kang et al. (2019) · Regional Input-Output Modeling System (RIMS II) Computable general equilibrium models: Regional Economic Modeling Incorporated (REMI) system
Equity and distributional effects analyses	💲💲	🕒🕒	💡💡💡	Analyzes social effects of interventions. Flexible in scales and approaches. Can capture systemic interconnections.	Data-intensive. Complex. Does not include environmental considerations. May not fully capture the long-term benefits of certain drought management strategies.	Distributional impact analysis application examples: · Williams et al. (2020) · El-Khattabi et al. (2021) Social welfare function: · Adler (2019) Sustainability impact assessment: OECD (2010)
BCA and weighted benefit-cost analysis (WBCA)	💲💲	🕒🕒🕒	💡💡💡	Analyzes economic efficiency. Data-driven. Comprehensive. Structured quantitative comparison (monetized). Long-term planning scenarios and uncertainty and risk analysis is possible. Transparent. Considers multiple benefits and trade-offs. Applying social equity weights in WBCA captures distributional concerns. Incorporating SROI enriches the analysis.	Data-intensive. Focuses on quantitative inputs/outputs. Incorporating the scales of the drought and its impacts requires many assumptions. BCA may oversimplify the complex nature of drought management. Assigning monetary values to non-market values is challenging. May not fully capture the long-term benefits of certain strategies, such as those related to climate resilience.	References: · World Bank (2010) · Fennell et al. (2023) · Arena et al. (2014)

(table continues next page)

TABLE 5.1 *(continued)*

Methodology	Budget	Time	Effort	Strengths	Weaknesses	Reference
Climate adaptation assessments/ DMDU	💲💲	🕒🕒🕒	💡💡💡	Analyzes climate resilience. Promotes robust decision making under uncertainty. Guides strategic and operational choices, highlighting potential conflicts and opportunities.	Data-intensive. In some cases, focuses more on assessing performance of a program than on exposing specific drought resilience benefits.	References: • Noleppa and Agripol–Network for Policy Advice GbR (2013) • Rouillard et al. (2016) • Tröltzsch et al. (2016) • Kalra et al. (2015) • Ward et al. (2022)
Water Evaluation and Planning	💲💲💲	🕒🕒🕒	💡💡💡	Analyzes climate resilience and water security. Comprehensive analysis of complex water systems. Scenario evaluation. Can be customized. Includes drought hazard characteristics. Includes quantitative and qualitative aspects. Transparent. Considers multiple benefits and trade-offs.	Data-intensive, especially to fully include the scales of the drought, its impacts, and management. Complex. May not fully capture the long-term benefits of certain drought management strategies. Assumption of rational decision-making. Spontaneous factors not included. Not the only water systems software tool available.	Water Evaluation and Planning: Selected Publications
System Dynamics Modeling	💲💲	🕒🕒🕒	💡💡💡	Focused on complex systems understanding. Informs adaptive management. Cross-sectoral analyses of benefits and co-benefits captures intersectoral relationships, delays, accumulations, nonlinear linkages, and feedback loops. Can be customized. Incorporates quantitative and qualitative aspects. Can accommodate long-term planning scenarios and uncertainty and risk.	Data-intensive. Medium complexity. Difficult to communicate; not as transparent as other approaches. Calibration and validation is necessary but is difficult and resource-intensive.	Tools: • Vensim • Isee systems Application examples: • Sušnik et al. (2012) • Li et al. (2022)
NbS intervention identification and evaluation	💲💲	🕒🕒🕒	💡💡💡	Data-driven. Identifies and evaluates NbS interventions. Mixed approaches: Some tools focus on identifying suitable interventions, mainly based on MCA. Others already provide cost-benefit analysis or support the design of specific types of NbS.	Focused only on a type of investment (NbS). Data-intensive. Medium complexity. Weaknesses described for MCA apply here as well.	Tools range from databases built on peer-reviewed literature to interactive web-based tools, calculator tools, and spatial simulation models. Tools: • NbS Evidence Platform • NbS Benefits Explorer • Water-Proof • Natural water retention measures • CUBHIC • FIESTA-FOGINT • InVEST • Soil Water Assessment Tool • Spatial Process in Hydrology • Water Harvesting Explorer • Sustainable Asset Valuation • Limones et al. (2024)

Source: World Bank Group.
+ A Delphi assessment is a structured forecasting or consensus-building technique that utilizes expert opinions through iterative surveys (Crisp et al. 1997).
* These methodologies can be utilized even without specialized expertise or resources for more in-depth analyses.

based solutions projects (Van Zanten et al. 2023). Importantly, the World Bank outlined a methodological framework for assessing the benefits of action and costs of inaction (BACI) analysis in drought preparedness and mitigation (Venton et al. 2019). The framework points to some tools and explains how BACI analysis—encompassing economic, social, and environmental dimensions—can be embedded in the overall development of a drought risk management strategy. It aims to guide authorities and stakeholders in formulating the right questions at various stages. The approaches compiled in these guidelines are included in table 5.1.

In an advanced approach to building block IV, practitioners must also assess how measures designed for drought resilience could unintentionally increase or decrease the risk from another hazard as well as identify co-benefits that could be obtained. For these purposes, system dynamics models are very useful because they can effectively represent the complex interactions and feedback loops within a project's system, which operate at different spatial and temporal scales. These models allow for a holistic understanding of how various natural and human factors interact to produce outcomes, including potentially positive impacts. The models enable scenario planning, helping teams examine the impact of policy and management interventions within a system. System dynamics models can help to understand how droughts propagate through economic mechanisms and can help them identify and simulate complex interactions among drought conditions, potential interventions and measures, labor, productivity, and economic resilience. The effectiveness of drought programs and policy instruments will be affected by broader ecological, socioeconomic, and institutional mechanisms, which should be taken into account.

Climate adaptation assessments and Decision Making Under Deep Uncertainty (DMDU) methodologies help practitioners consider multiple uncertainties, including future climate change, and how to identify the most robust set of solutions for managing them. The World Bank has published several guidelines on this topic (World Bank 2020; Bonzanigo et al. 2018); DMDU-related approaches in Vallejo and Mullan (2017) and the Climate Risk Informed Decision Analysis are also beneficial for realizing these objectives. However, while complementary, these DMDU tools frequently exceed the temporal constraints and resource allocations typically designated for DRRAs.

World Bank

DATA NEEDS: Prioritizing potential investments requires:

- Information on potential resilience-building interventions
- Input, feedback, and opinions from agencies and stakeholders through surveys or interviews
- Cost estimates and resource requirements for each investment option, including initial investments and operational costs
- Cost estimates for the impacts identified in previous building blocks
- Historical economic accounts, disaggregated
- Water demand data for various sectors
- Historical environmental monitoring data, such as water quantity and quality measurements, biodiversity assessments, and habitat data to measure outcomes/ effectiveness of similar projects/investment options in times of drought
- Market prices and cost data for goods and services related to the ecosystem services.
- Data collected through surveys, interviews, or other methods to assess the non-market value of ecosystem services
- Historical socioeconomic indicators on different population groups or communities, such as employment rates, income levels and distribution, and poverty rates to measure outcomes in similar projects/investment options

HOW THIS BLOCK RELATES TO OTHER BUILDING BLOCKS: Building block IV closes the DRRA and requires data and results from all the other building blocks. It allows identified solutions to be analyzed in-depth and discussed with clients for prioritization and implementation.

Adventist Drought and Relief Agency / USAID

Jorge E. Martínez Santamaría / USAID

Closing Remarks

The DRRA framework summarized in this report represents a comprehensive approach to understanding and proactively addressing drought risk. Its primary focus is to provide guidance on identifying drought management needs and opportunities while supporting enhancement of existing drought management systems.

Importantly, the DRRA framework encourages the collaboration of partners, governmental institutions, and any stakeholders involved in drought risk management and benefiting from drought resilience measures. Tailoring the DRRA to the application context allows teams to maximize its benefits.

The DRRA methodology recommends and directs teams to existing methodologies, tools, and resources that can complement and form the basis for the DRRA implementation in the given country or region. Ideally, the DRRA is conducted in conjunction and close collaboration with other ongoing initiatives and complements these initiatives as needed to comprehensively identify and prioritize drought resilience measures.

It is anticipated that both the DRRA framework and this report will undergo further refinement and enhancement, informed by feedback and practical experience. Ongoing and forthcoming applications of the DRRA in diverse national and regional contexts are essential for iteratively adjusting the approach, thereby improving its utility as a guide for users in selecting and applying the appropriate tools and methodologies in each of the DRRA building blocks.

World Bank teams and all relevant entities are encouraged to familiarize themselves with the framework and to explore opportunities for its implementation with the objective of strengthening global drought resilience.

For further information or clarifications, please contact the Global Department for Water at the World Bank.

Appendix A

Embedding the DRRA within Existing Frameworks

The DRRA methodology was developed to provide guidance for a systematic analysis of drought risk and the identification and prioritization of drought resilience measures. The methodology is built on the existing wealth of resources, serving to organize and complement them in providing an approach to operationalize a shift to more proactive drought management. Table A.1 provides an overview of existing resources and the ways the DRRA complements them.

TABLE A.1

World Bank Resources and Methodologies Complemented and Supported by the DRRA

Assessment	Complementarities and synergies
Assessing Drought Hazard and Risk: Principles and Implementation Guidance (World Bank 2019)	This report was developed by the World Bank, GFDRR, Deltares, the University of California at Santa Barbara, the Institute for Environmental Studies at Vrije Universiteit Amsterdam, the National Drought Mitigation Center, and IHE-Delft. It informs the DRRA, especially block II, highlighting many synergies in terms of hazard identification, future trends, vulnerabilities, and exposure/impacts. In addition, the report emphasizes the need for a scoping phase, which block I of the DRAA elaborates on and strengthens by encouraging assessment of the implementing agency's readiness and by promoting partnerships with other organizations and donors active in the space. Moreover, the DRRA advances consideration of drought management practices, specifically by reviewing current drought responses and preparedness (block III) and prioritizing investment options (block IV).
EPIC Response framework *An EPIC Response: Innovative Governance for Flood and Drought Risk Management* (Browder et al. 2021)	This report was jointly developed by the World Bank and Deltares. It focuses on assessing and developing programs that support management of hydro-climatic risks, namely floods and droughts. The EPIC Response framework advocates for managing both floods and droughts in conjunction because they are both hydro-climatic risks at the opposite ends of the extremes. Thereby, it analyses a collection of programs focusing on either floods, droughts, or both of them in tandem, ultimately supporting the creation of a more effective governance system through suggested institutional upgrades. The report is an important reference for the DRRA. It significantly informs the accompanying Menu of Measures (MoM). The programs related to drought management are particularly relevant to the DRRA and are initial reference points for comprehensively assessing current drought responses and preparedness. Coupled with the risk assessment, drought response and preparedness assessment allow for a gap analysis that consequently informs the identification of drought risk and resilience measures. The MoM developed by the World Bank and provided in block III borrowed and adapted the EPIC Response framework program areas to the specific scope of drought management.
Country Climate and Development Reports (CCDRs) *The Development, Climate, and Nature Crisis: Solutions to End Poverty on a Livable Planet—Insights from World Bank Country Climate and Development Reports Covering 42 Economies* (World Bank Group 2023)	The World Bank launched the Country Climate and Development Reports (CCDRs) in 2022 to support alignment of sustainable development priorities and climate change risks. The objective is to identify and prioritize actions to strengthen adaptation and reduce greenhouse gas emissions, ultimately contributing to climate-resilient development. The World Bank plans to provide CCDR assessments to all client countries. When developing a DRRA, practitioners should consider outputs from CCDRs that were conducted in the respective country or region and vice versa. Results of the CCDRs and DRRAs can inform one another and support the identification of priorities, climate change hotspots, and trends. CCDRs represent an opportunity to incorporate drought modeling and analysis of future trends to inform drought risk management. CCDRs are based on the analysis of a range of climate change scenarios to highlight the potential impacts of climate change across society, ecosystems, and the economy, potentially including impacts on drought occurrence and severity. Like the CCDRs, DRRAs aim to provide a multi-sectoral lens on drought risk and resilience, thereby focusing on collaboration across disciplines and sectors. However, the DRRA is different from a CCDR in that it provides a deep dive on drought-specific risks to sustainable development priorities and on ways to strengthen drought resilience through the identification and prioritization of investments. CCDRs pursue a similar objective but focus more broadly on climate change risks in addition to climate change mitigation opportunities.

(table continues next page)

TABLE A.1 *(continued)*

Assessment	Complementarities and synergies
Adaptation and Resilience Diagnostic	The Adaptation and Resilience (A&R) Diagnostic is a framework and indicator-based scoring tool developed and applied by the World Bank's Climate Change Group. The diagnostic evaluates progress and identifies gaps and priorities for climate adaptation and resilience. Additionally, it is a guide for designing adaptation and resilience-building strategies. The diagnostic aims to support and track adaptation policy development and implementation. It has been applied in conjunction with CCDR reports. Like the DRRA, the A&R Diagnostic aims to facilitate broader client and country dialogue and bring together multi-sectoral stakeholders. However, the DRRA is more targeted in that it focuses specifically on identifying measures to strengthen drought risk and resilience, whereas the diagnostic's whole-of-society approach aims to capture a plethora of measures needed to adapt to climate change. The diagnostic is underpinned by 190 indicators that capture universal principles for effective climate change adaptation. The diagnostic includes a traffic-light rating system that evaluates each indicator qualitatively and quantitatively. Like the CCDR, DRRA results can inform A&R diagnostics and vice versa.
Water Security Diagnostic (World Bank 2021b)	The Water Security Diagnostic (WSD) methodology provides a framework for understanding the key cause-and-effect relationships among water endowment, sector architecture, sector performance, and water security outcomes. Additionally, a complete WSD looks beyond the present situation and considers the key stresses on changing water security years and even decades into the future, the country's aspirations for water security improvement, and ways these aspirations can be fulfilled in the face of the key stresses. A WSD is a time-intensive undertaking that delivers significant and long-lasting impact. It usually involves modeling and analysis of scenarios or options for reform, investment, or both to improve future water security, considering demographic, economic, and climate change projections. A DRRA and WSD are complementary: the former provides a deep dive on drought risk, and the latter positions that risk within the broader water security context.
Sectoral Deep Dives	The DRRA complements and is compatible with sector-specific frameworks. More specifically, studies that focus on the selected economic sectors and types of interventions that can mitigate drought impacts and foster resilience are relevant links with a DRRA and can inform one another. The World Bank's *What the Future Has in Store: A New Paradigm for Water Storage* focuses on addressing the global water storage gap. Water storage, in general, be it green, grey, or hybrid, is a crucial measure that allows water banking for dry periods and thus ensures water availability for different types of uses (Burke et al. 2023). Other sector-specific drought risk studies that provide suggestions for measures to increase resilience include the review of Salvador et al. (2023) on the health implications of droughts.

Appendix B

Examples of NbS Interventions for Drought Resilience in Latin America and the Caribbean

Building drought resilience is only possible when assessments and analytics inform measures to strengthen and develop institutional structures, which in turn form the basis for infrastructure investments. Importantly, grey, green, and hybrid interventions must all be considered.

Numerous case studies and publications attest to the potential of nature-based solutions (NbS) to contribute to water security, thus addressing drought risk (Vigerstol et al. 2023). However, grey infrastructure typically receives more attention. Even within the realm of NbS for water security, application of grey infrastructure for flood management is prominent. To facilitate and support the implementation of NbS for drought management, six fact sheets (forthcoming) for distinct interventions were developed as part of the regional application of the DRRA in the Latin America and Caribbean region. Following is an excerpt of the NbS for each intervention, provided to highlight its potential role and contributions to attaining water security and drought resilience. Although these fact sheets were developed with a focus on the Latin America and Caribbean region, they are relevant to other regions, and they can be complemented by other types of NbS interventions.

Selected NbS for managing drought risk follow.

REFORESTATION

Reforestation involves the restoration of native forest habitat in areas where this habitat has been degraded or lost. In general, two different reforestation approaches can be distinguished: (1) active reforestation, which introduces native tree species using seedlings or seeds, and (2) passive measures, which aim to create a suitable enabling environment for natural regeneration. Afforestation, not included in the description below, is considered when growing trees in an area that was not previously covered by trees.

New trees generally enhance local infiltration through changes in above- and below-ground vegetation. However, reforestation's impacts on water availability depend strongly on temporal and spatial scales. In many geographical locations, forest types, and climate conditions, reforestation reduces annual water yields due to vegetation's increased soil water access and transpiration (Filoso et al. 2017). Notably, increased landscape transpiration after revegetation also enhances atmospheric moisture recycling, leading to increased precipitation either locally or elsewhere in the "precipitationshed" (Keys et al. 2014). Even if annual water yield somewhat decreases, reforestation's regulation of flow often benefits downstream water uses by steadying availability.

The relation between reforestation and drought resilience is complex. At present, a comprehensive understanding is limited by the prevailing research focus on exotic species and by insufficient local evidence (Filoso et al. 2017). Reforestation's impacts on drought risk depend, in part, on the type of forest restored and the density of tree cover (Ilstedt et al. 2016). Restoration of cloud forests is considered highly beneficial to drought resilience (The Nature Conservancy 2023; Liu et al. 2021).

WETLAND PROTECTION AND RESTORATION

Wetlands provide important natural regulatory functions, storing floodwaters and maintaining surface water flow during dry periods. Wetland restoration involves the re-establishment of the hydrology, plants, and soils of former or degraded wetlands that have been drained, farmed, or otherwise modified (The Nature Conservancy and Agence Francaise de Developpement, n.d.). Wetland restoration can involve removal of artificial structures or blocking of drainage systems to re-establish natural hydrology, construction of check dams or other erosion control structures, revegetation with native species, excavation of upland soils, and other efforts. Wetland protection focuses on ensuring the integrity of wetlands through measures that inhibit wetland degradation and allow for the continuous provision of ecosystem services.

Healthy wetlands capture and store water, thus carrying water from wet periods over to dry periods and allowing more water to infiltrate the soil. Depending on the surface or subsurface waters to which they connect, wetlands can increase baseflows and groundwater levels, thus enhancing water users' drought resilience (Deltares 2022). Wetlands' water retention and supply differs widely among ecological and climatological systems. If the local context is sufficiently considered in its design and implementation, wetland restoration can successfully reduce hydrological drought risk (Vigerstol et al. 2023).

NATURAL AND HYBRID SURFACE AND SUBSURFACE WATER STORAGE

This category of NbS includes water storage and harvesting options that utilize spaces in the water and soil system for temporary storage of surface water, rainwater, and groundwater. These options include rainwater harvesting systems, managed aquifer recharge, sand dams and subsurface dams, ponds, and infiltration ditches. These options are not considered purely built/grey infrastructure, but rather include a natural component. The World Bank Group report *What the Future Has in Store: A New Paradigm for Water Storage* (Burke et al. 2023) contains detailed definitions of natural and hybrid water storage options.

Water storage solutions can effectively mitigate water shortages by carrying over water from wet periods, in some cases helping reduce evaporation, both in climates with strong wet and dry seasonal patterns and during multi-month (or even multi-year) cyclical droughts (Burke et al. 2023). With increased frequency and intensity of meteorological droughts expected as climate change progresses (Reyer et al. 2015), natural and hybrid water storage solutions are potentially effective climate adaptation measures that could reduce risks associated with hydrological and agricultural droughts (for example, in irrigated systems). Although technical, financial, social, and environmental factors differ from one to another storage option, they all "bank" water and build a buffer for drier periods.

Storage solutions that combine the strengths of green infrastructure and grey infrastructure are desirable when aiming for solutions with relatively long residence times.

AGRICULTURAL BEST MANAGEMENT PRACTICES

Agricultural best management practices (AgBMPs) are strategic interventions in agricultural systems that are designed to reduce environmental impacts. AgBMPs can play a crucial role in preventing land degradation while, if properly applied, avoiding production losses. Although often applied at the farm level, AgBMPs can yield important benefits across a watershed. In the context of drought risk reduction, AgBMPs that conserve water by enhancing infiltration and reducing runoff are particularly relevant. These AgBMPs include cover cropping, strip cropping, contour farming, terracing, grassed waterways, contour buffer strips, mulching, and agroforestry (Pan et al. 2018).

The World Resources Institute report *Nature-Based Solutions in Latin America and The Caribbean: Regional Status and Priorities for Growth* makes mention of agroforestry and farmland best practices as two of the most applied NbS in the Latin America and Caribbean region to enhance water availability (Ozment et al. 2021). Factors such as location, climate, crop type, type and amount of fertilizer applied, local cropping practices, presence of irrigation infrastructure, and institutional constraints can affect the overall impact of AgBMPs on drought risk (The Nature Conservancy 2022).

Most AgBMPs affect the hydrological cycle by enhancing infiltration and percolation, thereby influencing the partitioning between surface runoff and groundwater recharge. Depending on hydrogeological conditions, AgBMPs can promote replenishment of aquifers, positively affecting baseflows and thus enhancing the availability of water in aquifers and rivers under dry conditions. In some cases, a counterbalancing effect of increased annual evapotranspiration from cover crops can lead to an overall negative annual water yield (Qi, Helmers, and Kaleita 2011), which should be taken into consideration when planning AgBMPs for drought risk management benefits.

VEGETATIVE WATER USE

In the context of drought risk reduction, managing vegetative water use means addressing vegetation density, composition, or productivity, typically through management and maintenance efforts, to enhance water availability. Examples:

- **Silvicultural operations (such as thinning) in forested environments.** Thinning practices in forests involve the selective removal of trees and shrubs to reduce stand density. Improving water availability is one of the main thinning objectives, along with enhancing forest health, promoting biodiversity, and reducing fire risk (Archer et al. 2017).

- **Removal of invasive species.** This removal reduces the water consumption of invasive species, which often consume more water than native plants (Fuentes-Lillo et al. 2023), thereby increasing water availability.

Other objectives include restoring biodiversity, enhancing soil stability and nutrient cycling, and containing the spread of invasive species to protect surrounding natural areas.

A careful balance between mechanical and manual methods needs to be considered to achieve primary objectives while minimizing disruption of soil and undergrowth. Prescribed burning is sometimes applied in forest thinning or invasive species removal to eliminate undesired species and promote the regeneration of native plants.

All techniques in this NbS category rest on one principle: the removal of vegetation with a relatively high water uptake, thus reducing water consumption of the overall ecosystem (Brill et al. 2023). Thinning reduces the number of trees and consequently decreases overall evapotranspiration. It allows more rainfall to infiltrate the soil, potentially recharging aquifers and enhancing water availability during dry periods. Thinning practices help maintain higher soil moisture levels, benefiting understory vegetation and making the forest ecosystem more resilient to drought. Removal of woody vegetation in grasslands leads to fewer woody plants competing for water, thus increasing soil moisture levels and benefiting native grasses and other herbaceous plants. Trees and woody vegetation have access to water stored deep under the surface, as demonstrated, for example, by pines in Patagonian grasslands (Gyenge, Fernández, and Schlichter 2003).

With a lower water consumption, more precipitation reaches streams and rivers, increasing their flow and providing more consistent water sources for ecosystems and human use. By improving the health and diversity of the forest, thinning increases the forest's capacity to withstand and recover from drought conditions. However, it is important to recognize that trees and woody plants contribute to biodiversity, provide habitat, and influence local climate conditions. Effective brush management focuses on ensuring that brush and woody vegetation are managed in a way that supports overall ecosystem health and resilience. Healthier trees and more robust ecosystems are better equipped to manage water stress.

Native plants are often better adapted to local climate conditions, including drought. By restoring native species, forests and grasslands can more efficiently use available water and withstand periods of low water availability.

SUSTAINABLE URBAN DRAINAGE SYSTEMS

Sustainable urban drainage systems (SUDS) aim to mimic natural drainage in a developed area, where rainfall soaks into the ground and saturates soil and vegetation before significant runoff occurs. The systems thereby regulate the water cycle and, to a certain extent, enhance water availability in dry periods, at least locally. In addition, SUDS reduce heat stress and overall vulnerability to drought. SUDS include green roofs, permeable pavements, urban water harvesting, bioswales, green spaces (parks). They improve the quality of the water before it reaches the receiving water body.

The World Bank flagship report *A Catalogue of Nature-based Solutions for Urban Resilience* (World Bank 2021a) explores the benefits of different SUDS. The SUDS with the strongest linkages to drought regulation functions are "building solutions" (green roofs/facades), "open green spaces," and "retention ponds," which, unlike other urban water storage solutions, are permanently filled. The World Bank report *What the Future Has in Store* (Burke et al. 2023) refers to these options.

Most SUDS are implemented to reduce urban flooding by managing and retaining stormwater (Browder et al. 2019; Ozment et al. 2021). However, storage of excess water in green roofs or retention ponds can reduce drought impacts by promoting reuse of water in dry periods (Eisenberg and Polcher 2020). Infiltration-enhancing measures, such as bioswales and permeable pavements, might augment groundwater recharge. Water storage, water reuse, and groundwater recharge, as well as the capture and slowing of runoff by constructed wetlands, are integrated in the "sponge city" concept. This concept emerged from China and is increasingly applied in urban development strategies (Nguyen et al. 2019). Along with urban flood mitigation and water purification, the recycling of stormwater for urban water supply during times of drought is considered one of the main purposes of a sponge city.

In addition to potentially mitigating the hazard component of drought risk, some urban NbS can enhance drought resilience by reducing vulnerability through their cooling effect. Converting to green roofs can reduce the surface temperatures of the roofs by 30°C to 60°C and ambient temperatures by up to 5°C. In general, evaporation from stored water (for example, in ponds and basins) contributes to a cooling effect for most SUDS (Morales-Torres et al. 2016).

Appendix C

Key Questions Guiding DRRA Implementation

The following collection of questions can guide DRRA implementation. The questions are not exhaustive but do cover the most important considerations. They can help implementers tailor the DRRA to the specific country or regional context and to any specific needs and priorities.

BLOCK I: SCOPING COORDINATION AND CAPACITY

Block I focuses on the enabling environment and context in which the DRRA will be conducted. In this phase, opportunities, challenges, existing initiatives, and possible synergies are assessed.

1 Scoping coordination within the implementing institution	▶ How **aware of drought** and its cross-cutting nature is the country team? ▶ How strong is the **culture of collaboration and knowledge sharing** within the country team? ▶ Do any **cross-sectoral assessments** integrate cross-cutting issues? ▶ What drought-relevant **tools, studies, and projects** have been or will be developed, implemented, or both?
2 Scoping coordination between government, donors, development partners, and other stakeholders	▶ Is the World Bank or are other partners best positioned to **lead the DRRA**? ▶ What is the **relationship of the World Bank Group (WBG)** to other donors and development actors active in drought management in the given country? ▶ Is it feasible and beneficial to **engage in a platform** for a multi-donor, partnership-based comprehensive DRRA? ▶ Is **funding from non-WBG initiatives** available to additionally support the DRRA? ▶ Have other **partners developed** drought risk assessments or drought resilience evaluation that can be built on? ▶ Are there any ongoing or completed **drought risk and resilience-relevant initiatives** under the leadership of partners?
3 Scoping coordination across government	▶ Is the country **open to being informed about drought-related policy changes, strategic planning, or investment priorities**? ▶ What **institutions and governmental entities are responsible** for and involved in managing drought risk and developing drought resilience? How do they collaborate? ▶ How **aware of drought** and its cross-cutting nature and impacts is the client government? Is drought management a priority? ▶ What is the **data-sharing practice** of country stakeholders? ▶ Would the **creation of a data-driven, local, inter-sectoral coordination entity** (e.g., national steering committee) for implementing the DRRA be desirable, feasible, and straightforward? ▶ What is the general **level of actors' willingness and capacity** to share relevant data?

BLOCK II: ASSESSING DROUGHT RISK

Block II comprises the drought risk assessment. The objective is to gather information on drought hazards, impacts, and vulnerabilities to develop a more comprehensive understanding of drought risk.

4 **Assessing current and recent drought hazards**	▶ What **institutions** are in charge of monitoring drought? ▶ Are there established mechanisms for **knowledge sharing** among **hydrometeorological. agencies, different sectors**, and stakeholders? ▶ Regarding **drought monitoring**, are there specific **sectoral focuses**, such as agricultural and water resources management? ▶ How available are the **measured raw data** on precipitation, evapotranspiration, soil moisture, groundwater conditions, flows, and other parameters? At what scale are the data available? ▶ What, if any, types of **drought indices** are compiled and at what spatial and temporal scales? ▶ How well are **historical drought events** documented? ▶ What, if any, additional expertise or collaboration is needed regarding drought monitoring and characterization?
5 **Assessing main trends of future drought hazards**	▶ Have recent studies or assessments focused on **future drought** and its connection to climate change? ▶ What is the current state of **knowledge regarding future drought trends** and uncertainties in the given country or region? ▶ To what extent are **climate scenarios** incorporated into existing (sectoral or spatial) drought risk assessments and planning processes?
6 **Assessing current and recent drought impacts**	▶ Will this **DRRA focus on a specific sector**, or does it aim to be comprehensive? ▶ What specific drought-related risks and **impacts are of most concern**? ▶ Does the country or region have a systematic **impact database**/monitoring system? If not, have any **post-drought assessments** examined impacts? ▶ How far back do **historical statistics** go regarding agricultural and livestock production, forestry, river navigation, water supply, power generation, employment, industry outputs, and other parameters potentially impacted by drought? ▶ Do **water resources authorities monitor** volumes abstracted, those serviced, and their economic performance? Are these data easily accessible? ▶ Do **water utilities monitor** volumes abstracted, those serviced, and their economic performance? Are these data easily accessible? ▶ How advanced are **biodiversity accounting and ecosystem services accounting** in the country or region?
7 **Assessing country/ region vulnerability to drought**	▶ Is there good-quality information on **ecosystem characterization and land use characteristics**? ▶ Are **SDGs tracked** beyond the national level (i.e., on a more granular level)? ▶ How far back do **historical statistics** go regarding population demographics, including age distribution, gender indicators, income levels, education, and employment patterns? ▶ Are **data on access to basic services** like water, sanitation, or health facilities easily accessible? At what scale? ▶ Is the country/region monitoring water exploitation indices or similar indicators related to water balances? At what scale? ▶ Are studies **on institutional capacity** at local administrative levels available? ▶ Is information on poverty, vulnerabilities, and disaster impacts available at the **household level**? How often is it updated?

BLOCK III: EVALUATING CURRENT RESILIENCE

Block III focuses on the existing level of drought resilience. Current response and preparedness for droughts are assessed by reviewing the Menu of Measures (MoM) and the respective program areas, as informed by the EPIC Response framework.

8 **Evaluating current drought response**	▶ Do any reports, studies, or projects address specific program areas **outlined in the MoM**? ▶ For which program areas are there clear **gaps or opportunities** for improvement? ▶ Have any country/region priorities and needs in relation to specific program areas been identified?
9 **Evaluating current drought preparedness**	▶ Do any **reports**/exercises analyze the **drought management status** of the country/region? ▶ Do any reports, studies, or projects address specific program areas **outlined in the MoM**? ▶ For which program areas are there clear **gaps or opportunities** for improvement? ▶ Have any country/region priorities and needs in relation to specific program areas been identified?

BLOCK IV: PRIORITIZING AREAS FOR ACTION

Block IV is the consolidation of all assessments to identify and prioritize potential measures to reduce drought risk and enhance drought resilience. The outcome is a list of prioritized potential measures, so it is crucial to first determine whether the country has already identified promising drought-related interventions and to determine the extent to which these measures have been assessed and discussed.

10 **Prioritizing measures to reduce drought risks and increase drought resilience**	▶ Has the country previously identified any **promising drought-related interventions**? If so, what are they? ▶ What is the **current status of these identified measures**? Have they been formally recognized as a priority or approved for implementation? ▶ To what extent have these measures been assessed? Are there existing evaluations or reports comparing or detailing their effectiveness, feasibility, or impacts? **How comprehensive are the assessments** of these interventions? Do they cover cost, benefits, risks, and implementation challenges? ▶ What **stakeholder perspectives** have been considered in the assessment of these measures? ▶ Are there preferred methodologies or tools based on previous experience or expertise that stakeholders would recommend for analyzing the potential options (e.g., cost-effectiveness, cost-benefit)? ▶ What are the primary **criteria the government uses for evaluating potential measures** (e.g., social impact, environmental benefits, long-term sustainability)? Should any criteria be weighted more heavily due to their importance or urgency? ▶ What **specific trade-offs** should be considered in the evaluation of measures (e.g., are there potential conflicts between economic efficiency and social equity that need to be addressed)? ▶ Are there particular **benefits or drawbacks that are frequently overlooked** but should be included in the analysis? ▶ **What level of detail is required for the DRRA findings to be actionable?** At this stage, do stakeholders need a high-level overview to make preliminary decisions, or is a detailed quantitative analysis necessary for in-depth evaluation?

References

Adler, M. D. 2019. *Measuring Social Welfare: An Introduction*. USA: Oxford Univeristy Press.

Akyapi, Berkay, Matthieu Bellon, and Emanuele Massetti. 2022. *Estimating Macro-Fiscal Effects of Climate Shocks from Billions of Geospatial Weather Observations*. International Monetary Fund.

Alkadir, M. A., E. Pek, and M. Salman. 2022. *A Multi-Criteria Assessment Framework for National Drought Planning*. Rome: Food and Agriculture Organization.

Antofie, T. E., B. Doherty, and M. Marin-Ferrer. 2018. *Mapping of Risk Web-Platforms and Risk Data: Collection of Good Practices*. Luxembourg: Publications Office of the European Union.

Arena, C., M. Cannarozzo, A. Fortunato, I. Scolaro, and M. R. Mazzola. 2014. "Evaluating Infrastructure Alternatives for Regional Water Supply Systems by Model-assisted Cost-benefit Analysis–A Case Study from Apulia, Italy." *Procedia Engineering* 89: 1460–1469.

Ayantunde, A. A., M. D. Turner, and A. Kalilou. 2015. "Participatory Analysis of Vulnerability to Drought in Three Agro-pastoral Communities in the West African Sahel." *Pastoralism* 5 (3). https://doi.org/10.1186/s13570-015-0033-x.

Bahta, Yonas T., Andries Jordaan, and Boitumelo Phatudi-Mphahlele. 2019. "Ecological Vulnerability Indicators to Drought: Case of Communal Farmers in Eastern Cape, South Africa." *Jamba: Journal of Disaster Risk Studies* 11 (1): 591.

Bonzanigo, Laura, Julie Rozenberg, Gregory Felter, Robert Lempert, and Patrick Michael Reed. 2018. *Building the Resilience of WSS Utilities to Climate Change and Other Threats: A Road Map*. Washington, DC: World Bank Group.

Bottero, Alessandra, Anthony W. D'Amato, Brian J. Palik, John B. Bradford, Shawn Fraver, Mike A. Battaglia, and Lance A. Asherin. 2017. "Density-Dependent Vulnerability of Forest Ecosystems to Drought." *Journal of Applied Ecology* 54 (6): 1605–1614.

Brill, Gregg, Deborah Carlin, Cora Snyder, Hannah Baleta, Kari Vigerstol, Naabia Ofosu-Amaah, Michael Matosisch et al. 2023. *Benefit Accounting of Nature-Based Solutions for Watersheds: Guide V2*. Oakland, California: United Nations CEO Water Mandate and Pacific Institute.

Browder, Greg, Ana Nunez Sanchez, Brendan Jongman, Nathan Engle, Eelco Van Beek, Melissa Castera Errera, and Stephen Hodgson. 2021. *An EPIC Response: Innovative Governance for Flood and Drought Risk Management*. Washington, DC: World Bank.

Browder, Greg, Suzanne Ozment, Irene Rehberger Bescos, Todd Gartner, and Glenn-Marie Lange. 2019. *Integrating Green and Gray: Creating Next Generation Infrastructure*. Washington, DC: World Bank and World Resources Institute.

Burke, Eileen, Jacqueline Marie Tront, Kimberly Nicole Lyon, William Rex, Melissa Ivy Castera Errea, Mili Chachyamma Varughese, Joshua Taylor Newton, Ayelen Nadia Becker, and Allison Louise Vale. 2023. *What the Future Has in Store: A New Paradigm for Water Storage*. Washington, DC: World Bank Group.

Buurman, J., D. D. Bui, and L. T. T. Du. 2020. "Drought Risk Assessment in Vietnamese Communities Using Household Survey Information." *International Journal of Water Resources Development* 36 (1): 88–105.

California Department of Water Resources. 2014. *Handbook for Assessing Value of State Flood Management Investments*. https://cawaterlibrary.net/document/handbook-for-assessing-value-of-state-flood-management-investments/.

Cap-Net, GWP (Global Water Partnership), IDMP Integrated Drought Management Programme), and WMO (world Meterorological Organization). 2020. *Drought Risk Reduction in Integrated Water Resources Management*. Cap-Net United Nations Development Program.

Carrão, Hugo, Gustavo Naumann, and Paulo Barbosa. 2016. "Mapping Global Patterns of Drought Risk: An Empirical Framework Based on Sub-national Estimates of Hazard, Exposure and Vulnerability." *Global Environmental Change–Human and Policy Dimensions* 39: 108–124.

Christian, Jordan I., Elinor R. Martin, Jeffrey B. Basara, Jason C. Furtado, Jason A. Otkin, Lauren E. L. Lowman, Eric D. Hunt, Vimal Mishra, and Xiangming Xiao. 2023. "Global Projections of Flash Drought Show Increased Risk in a Warming Climate." *Communications Earth & Environment* 4: 1–10. https://doi.org/10.1038/s43247-023-00826-1.

Crossman, Neville D. 2018. *Drought Resilience, Adaptation and Management Policy (DRAMP) Framework*. United Nations Convention to Combat Desertification.

Damania, Richard, Sébastien Desbureaux, Marie Hyland, Asif Islam, Scott Moore, Aude-Sophie Rodella, Jason Russ, and Esha Zaveri. 2017. *Uncharted Waters: The New Economics of Water Scarcity and Variability*. Washington, DC: World Bank Group.

De Mesentier Silva, F., A. Isaksen, J. Togelius, and A. Nealen. 2016. "Generating Heuristics for Novice Players." In *2016 IEEE Conference on Computational Intelligence and Games (CIG)*. Institute of Electrical and Electronics Engineer. https://doi.org/10.1109/CIG.2016.7860407.

De Nys, Erwin, Nathan L. Engle, and Antônio Rocha Magalhães. 2017. *Drought in Brazil: Proactive Management and Policy. Drought and Water Crises*. Boca Raton: CRC Press.

Deltares. 2017. *Global Inventory of Drought Hazard and Risk Modeling Tools and Resources*. Deltares. https://publications.deltares.nl/11200758_002_0001.pdf.

Deltares. 2018. *Comparative Assessment of Drought Hazard and Risk Modeling Tools*. Deltares. https://www.deltares.nl/en/expertise/publicaties/comparative-assessment-of-drought-hazard-and-risk-modeling-tools.

Deltares. 2022. "Policy Brief: Nature-based Solutions to Mitigate Impacts of Droughts." Deltares. https://atuk.com.ec/documentos/deltares-2022-policy-brief-based-solutions-and-droughts.pdf.

Deltares. 2023. "EPIC Response framework.mov." https://vimeo.com/820423508/9637b9ca5e?share=copy.

DHI (Drought Hazard Index). 2023. "Flood and Drought Portal." Accessed June 11, 2023. https://www.flooddroughtmonitor.com/home?u=DEMO&p=DEMO.

Ding, Y., M. J. Hayes, and M. Widhalm. 2011. "Measuring Economic Impacts of Drought: A Review and Discussion." *Disaster Prevention and Management: An International Journal* 20 (4): 434–446.

EC (European Commission). 2023. *Stock-taking Analysis and Outlook of Drought Policies, Planning and Management in EU Member States*. Luxembourg: Publications Office of the European Union.

EC, GFDRR (Global Facility for Disaster Reduction and Recovery), and UN (United Nations). 2018. *Post Disaster Needs Assessment (PDNA): Lessons from a Decade of Experience*. https://www.gfdrr.org/sites/default/files/publication/Final_PDNA_Evaluation_Report.pdf.

EC, UNDG (United Nations Development Group), and World Bank. 2013. *Post-Disaster Needs Assessments: Volume A Guidlines*. https://www.gfdrr.org/en/publication/post-disaster-needs-assessments-guidelines-volume-2013.

Eckhardt, Daniel, Adriana Leiras, and Antônio Márcio Tavares Thomé. 2018. "Systematic Literature Review of Methodologies for Assessing the Costs of Disasters." *International Journal of Disaster Risk Reduction* 33: 398–416.

Eisenberg, B., and V. Polcher. 2020. "Nature Based Solutions–Technical Handbook." https://unalab.eu/system/files/2020-02/unalab-technical-handbook-nature-based-solutions2020-02-17.pdf.

El-Khattabi, Ahmed Rachid, Shadi Eskaf, Julien P. Isnard, Laurence Lin, Brian McManus, and Andrew J. Yates. 2021. "Heterogeneous Responses to Price: Evidence from Residential Water Consumers." *Journal of Environmental Economics and Management* 107: 102430. https://doi.org/10.1016/j.jeem.2021.102430.

EU (European Union), UNDP (United Nations Development Programme), and WBG (World Bank Group). 2013. *Guidelines for Assessing the Human Impact of Disasters*. https://www.undp.org/publications/guidelines-assessing-human-impact-disasters.

FAO. 2012. *Coping with Water Scarcity: An Action Framework for Agriculture and Food Security*. Rome: Food and Agriculture Organization of the United Nations.

FAO. 2017. *Tracking Adaptation in Agricultural Sectors: Climate Change Adaptation Indicators*. Rome: Food and Agriculture Organization of the United Nations. https://www.fao.org/3/I8145EN/i8145en.pdf.

FAO. 2024. "Drought Portal--Knowledge Resources on Integrated Drought Management." Accessed July 21, 2024. https://www.fao.org/in-action/drought-portal/preparedness/vulnerability-and-impact-assessment/vulnerability-impact-assessment-compendium-chapter-1/en.

Farahani, H., and Mehri Jahansoozi. 2022. "Analysis of Rural Households' Resilience to Drought in Iran, Case Study: Bajestan County." *International Journal of Disaster Risk Reduction* 82: 103331.

Fennell, Jessica, Chris Soulsby, Mark E. Wilkinson, Ronald Daalmans, and Josie Geris. 2023. "Time Variable Effectiveness and Cost-Benefits of Different Nature-based Solution Types and Design for Drought and Flood Management." *Nature-Based Solutions* 3: 100050.

Filoso, Solange, Maíra Ometto Bezerra, Katherine C. B. Weiss, and Margaret A. Palmer. 2017. "Impacts of Forest Restoration on Water Yield: A Systematic Review." *PLOS ONE*. https://doi.org/10.1371/journal.pone.0183210.

Freire-González, Jaume, Christopher Decker, and Jim W. Hall. 2017. "The Economic Impacts of Droughts: A Framework for Analysis." *Ecological Economics* 132: 196–204.

Fuentes-Lillo, Eduardo, Jonas J. Lembrechts, Agustina Barros, Valeria Aschero, Ramiro O. Bustamante, Lohengrin A. Cavieres, Jan Clavel, et al. 2023. "Going Up the Andes: Patterns and Drivers of Non-native Plant Invasions Across Latitudinal and Elevational Gradients." *Biodiversity and Conservation* 32: 4199–4219. https://doi.org/10.1007/s10531-023-02697-6.

GFDRR (Global Facility for Disaster Reduction and Recovery). 2010a. *Damage, Loss and Needs Assessment. Guidance Notes: Volume 1. Design and Execution of a Damage, Loss and Needs Assessment*. Washington, DC: The World Bank.

GFDRR. 2010b. *Damage, Loss and Needs Assessment. Guidance Notes: Volume 2. Conducting Damage and Loss Assessments After Disasters*. Washington, DC: The World Bank.

GFDRR. 2010c. *Damage, Loss and Needs Assessment Guidance Notes: Volume 3. Estimation of Post-Disaster Needs for Recovery and Reconstruction*. Washington, DC: The World Bank.

Ghazi, Babak, Sanjana Dutt, and Ali Torabi Haghighi. 2023. "Projection of Future Meteorological Droughts in Lake Urmia Basin, Iran." *Water* 15 (8): 1–16.

Ghimire, Yuga Nath, Ganesh Prasad Shivakoti, and Sylvain Roger Perret. 2010. "Household-level Vulnerability to Drought in Hill Agriculture of Nepal: Implications for Adaptation Planning." *International Journal of Sustainable Development & World Ecology* 17 (3): 225–230.

Green Nylen, Nell, Michael Kiparsky, Dave Owen, Holly Doremus, and Michael Hanemann. 2018. *Addressing Institutional Vulnerabilities in California's Drought Water Allocation. Part 1: Water Rights Administration and Oversight During Major Statewide Droughts, 1976–2016. California's Fourth Climate Change Assessment*. California Natural Resources Agency.

Guimarães Nobre, Gabriela, Frank Davenport, Konstantinos Bischiniotis, Ted Veldkamp, Brenden Jongman, Christopher C. Funk, Gregory Husak, Philip J. Ward, and Jeroen Aerts. 2019. "Financing Agricultural Drought Risk Through Ex-ante Cash Transfers." *Science of The Total Environment* 653: 523–535.

Gunasekera, Rashmin, James Daniell, Antonios Pomonis, Rodrigo Andres Donoso Arias, Oscar Ishizawa, and Harriette Stone. 2018. *Methodology Note on the Global RApid Post-disaster Damage Estimation (GRADE) Approach*. Washington, DC: World Bank Group.

Gyenge, Javier E. , M. Elena Fernández, and Tomás M. Schlichter. 2003. "Water Relations of Ponderosa Pines in Patagonia Argentina: Implications for Local Water Resources and Individual Growth." *Trees* 17: 417–423. https://doi.org/10.1007/s00468-003-0254-2.

Hoque, Muhammad Al-Amin, Biswajeet Pradhan, Naser Ahmed, and Abdullah Alamri. 2021. "Drought Vulnerability Assessment Using Geospatial Techniques in Southern Queensland, Australia." *Sensors* 21 (20): 6896.

Howard, A., L. Biettio, M. Hayes, A. Kleschenko, K. Quevedo, and A. Susnik. 2021. "Commission for Agricultural Meteorology (CAgM): Expert Team 3.1—Report on Drought (2014–2018)." World Meteorological Organization, Geneva, Switzerland.

Ilstedt, U., A. Bargués Tobella, H. R. Bazié, J. Bayala, E. Verbeeten, G. Nyberg, J. Sanou, et al. 2016. "Intermediate Tree Cover Can Maximize Groundwater Recharge in the Seasonally Dry Tropics." *Scientific Reports* 6: 21930. https://doi.org/10.1038/srep21930.

IPCC. 2021. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. doi:10.1017/9781009157896.

IPCC. 2022. *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Cambridge, UK, and New York, NY, USA: Cambridge University Press. https://www.ipcc.ch/report/ar6/wg2/.

IPCC. 2023. "Annex I: Glossary" [Reisinger, A., D. Cammarano, A. Fischlin, J.S. Fuglestvedt, G. Hansen, Y. Jung, C. Ludden, V. Masson-Delmotte, R. Matthews, J.B.K Mintenbeck, D.J. Orendain, A. Pirani, E. Poloczanska, and J. Romero (eds.)]. In *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 119–130. https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_AnnexesIndex.pdf.

Kalra, Nidhi, David G. Groves, Laura Bonzanigo, Edmundo Molina Perez, Cayo Ramos, Carter Brandon, and Iván Rodriguez Cabanillas. 2015. *Robust Decision-Making in the Water Sector: A Strategy for Implementing Lima's Long-Term Water Resources Master Plan*. Policy Research Working Paper, Washington, DC: The World Bank. https://doi.org/10.1596/1813-9450-7439.

Kang, Hyunwoo, Venkataramana Sridhar, Bradford F. Mills, W. Cully Hession, and Jactone A. Ogejo. 2019. "Economy-wide Climate Change Impacts on Green Water Droughts Based on the Hydrologic Simulations." *Agricultural Systems* 171: 76–88. https://doi.org/10.1596/1813-9450-7439.

Karavitis, C. A., D. E. Tsesmelis, N. A. Skondras, D. Stamatakos, S. Alexandris, V. Fassouli, C. G. Vasilakou, P. D. Oikonomou, G. Gregorič, N. S. Grigg, and E. C. Vlachos. 2014. "Linking Drought Characteristics to Impacts on a Spatial and Temporal Scale." *Water Policy* 16 (6): 1172–97. https://doi.org/10.2166/wp.2014.205.

Karimi, P., S. Pareeth, and C. Michailovsky. 2019. *Rapid Assessment of the Water Accounts in Urmia Lake Basin*. Project report. IHE Delft, The Netherlands..

Kern, Jordan D., Yufei Su, and Joy Hill. 2020. "A Retrospective Study of the 2012–2016 California Drought and Its Impacts on the Power Sector." *Environmental Research Letters* 15 094008.

Keys, P. W., R. J. van der Ent, L. J. Gordon, H. Hoff, R. Nikoli, and H. H. G. Savenije. 2012. "Analyzing Precipitationsheds to Understand the Vulnerability of Rainfall Depedent Regions." *Biogeosciences* 9: 733–746. https://doi.org/10.5194/hess-18-3937-2014.

Keys, P. W., E. A. Barnes, R. J. van der Ent, and L. J. Gordon. 2014. "Variability of Moisture Recycling Using a Precipitationshed Framework." *Hydrology and Earth System Sciences* 18 (10): 3937–3950. https://doi.org/10.5194/hess-18-3937-2014.

Khan, Nasir Abbas, Qijie Gao, and Muhammad Abid. 2020. "Public Institutions' Capacities Regarding Climate Change Adaptation and Risk Management Support in Agriculture: The Case of Punjab Province, Pakistan." *Scientific Reports* 10 (1): 14111.

Khoi, Dao Nguyen, Truong Thao Sam, Pham Thi Loi, Bui Viet Hung, and Van Thinh Nguyen. 2021. "Impact of Climate Change on Hydro-meteorological Drought Over the Be River Basin, Vietnam." *Journal of Water and Climate*

Change 12 (7): 3159–3169.

King-Okumu, Caroline. 2019. *Drought Impact and Vulnerability Assessment: A Rapid Review of Practices and Policy Recommendations*. Bonn: UNCCD.

Kumar, Prashant, Sisay E. Debele, Jeetendra Sahani, Nidhi Rawat, Belen Marti-Cardona, Silvia Maria Alfieri, Bidroha Basu, et al. 2021. "Nature-based Solutions Efficiency Evaluation Against Natural Hazards: Modelling Methods, Advantages and Limitations." *Science of The Total Environment* 784: 147058.

Li, Xinqing, Lixiao Zhang, Yan Hao, Pengpeng Zhang, Xin Xiong, and Zhimin Shi. 2022. "System Dynamics Modeling of Food-Energy-Water Resource Security in a Megacity of China: Insights from the Case of Beijing." *Journal of Cleaner Production* 355: 131773. https://doi.org/10.1016/j.jclepro.2022.131773.

Limones, Natalia, Javier Marzo-Artigas, Marcus Wijnen, and Aleix Serrat-Capdevila. 2020. "Evaluating Drought Risk in Data-Scarce Contexts: The Case of Southern Angola." *Journal of Water and Climate Change* 11 (S1): 44–67.

Limones, N., M. Wijnen, and A. Serrat-Capdevila. 2024. "Siting Sand Dams for Enhancing Water Security and Drought Resilience in Rural Areas: A Stepwise Approach." Manuscript in preparation. Washington, DC: World Bank.

Liu, Tiedong, Kai Jiang, Zhaoyuan Tan, Qifang He, Hui Zhang, and Chen Wang. 2021. "A Method for Performing Reforestation to Effectively Recover Soil Water Content in Extremely Degraded Tropical Rain Forests." *Frontiers in Ecology and Evolution* 9: 643994.

Lückerath, Daniel, Erich Rome, and Katharina Milde. 2023. "Using Impact Chains for Assessing Local Climate Risk—A Case Study on Impacts of Extended Periods of Fluvial Low Waters and Drought on a Metropolitan Region." *Frontiers in Climate* 5: 1–20.

Mdemu, M.V. 2021. "Community's Vulnerability to Drought-Driven Water Scarcity and Food Insecurity in Central and Northern Semi-arid Areas of Tanzania." *Frontiers in Climate* 3. https://www.frontiersin.org/journals/climate/articles/10.3389/fclim.2021.737655/full.

Meza, Isabel, Michael Hagenlocher, Gustavo Naumann, Juergen Vogt, and Janna Frischen. 2018. *Drought Vulnerability Indicators for Global-scale Drought Risk Assessments.* EUR 29824 EN. Luxembourg: Publications Office of the European Union.

MoFE (Ministry of Forestry and Environment). 2020. Capacity Gap Assessment Report of the Thematic/Cross-cutting Working Groups. *Building Capacity to Advance Adaptation Plan Process in Nepal.* NAP Nepal Technical Paper 16/2020. Kathmandu: Government of Nepal.

Monitor de Secas. 2024. "Monitor de Secas." Accessed August 5, 2024. https://monitordesecas.ana.gov.br/mapa?mes=6&ano=2024.

Morales-Torres, Adrián, Ignacio Escuder-Bueno, Ignacio Andrés-Doménech, and Sara Perales-Momparler. 2016. "Decision Support Tool for Energy-efficient, Sustainable and Integrated Urban Stormwater Management." *Environmental Modelling & Software* 84: 518–528. https://doi.org/10.1016/j.envsoft.2016.07.019.

Nakicenovic, Nebojsa, Joseph Alcamo, Gerald Davis, Bert de Vries, Joergen Fenhann, Stuart Gaffin, Kenneth Gregory et al. 2000. *Special Report on Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*. Intergovernmental Panel on Climate Change.

National Drought Mitigation Center. 2018. SPI Generator [software]. University of Nebraska–Lincoln. https://drought.unl.edu/Monitoring/SPI/SPIProgram.aspx.

National Drought Mitigation Center, Oklahoma Climatology Survey, Lower Platte River Coridor Alliance, Univeristy of Oklahoma, NIDIS, and NOAA. 2011. *Drought-Ready Communities. A Guide to Community Drought Preparedness*. Lincoln: National Drought Mitigation Center. https://drought.unl.edu/Planning/PlanningProcesses/Drought-ReadyCommunities.aspx.

Naumann, G., P. Barbosa, L. Garrote, A. Iglesias, and J. Vogt. 2014. "Exploring Drought Vulnerability in Africa: An Indicator Based Analysis to Be Used in Early Warning Systems." *Hydrology and Earth System Science* 18 (5): 1591–1604. https://doi.org/10.5194/hess-18-1591-2014.

Nguyen, Thu Thuy, Huu Hao Ngo, Wenshan Guo, Xiaochang C. Wang, Nanqi Ren, Guibai Li, Jie Ding, and Heng Liang. 2019. "Implementation of a Specific Urban Water Management: Sponge City." *Science of The Total Environment* 652: 147–162. https://doi.org/10.1016/j.scitotenv.2018.10.168.

Noleppa, Steffen, and Agripol – Network for Policy Advice GbR. 2013. *Economic Approaches for Assessing Climate Change Adaptation Options Under Uncertainty: Excel Tools for Cost-Benefit and Multi-Criteria Analysis*. Eschborn: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. https://www.adaptationcommunity.net/download/ms/mainstreaming-guides-manuals-reports/Economic_assessment_of_CC_adaptation_options_-_GIZ_2013.pdf.

OECD (Organisation for Economic Co-operation and Development). 2010. *Guidance on Sustainability Impact Assessment*. OECD.

Otkin, Jason A., Mark Svoboda, Eric D. Hunt, Trent W. Ford, Martha C. Anderson, Christopher Hain, and Jeffrey B. Basara. 2018. "Flash Droughts: A Review and Assessment of the Challenges Imposed by Rapid-Onset Droughts in the United States." *Bulletin of the American Meteorological Society* 99 (5): 911–919. https://doi.org/10.1175/BAMS-D-17-0149.1.

Ozment, Suzanne, Maggie Gonzalez, Anelise Schumacher, Emmie Oliver, Ana Gabriela Morales, Todd Gartner, Mariana Silva Zuniga, Gregory Watson, and Alfred Grünwaldt. 2021. *Nature-Based Solutions in Latin America and The Caribbean: Regional Status and Priorities for Growth*. Washington, DC: World Resources Institute.

Pan, Renan, Alexandra da Silva Martinez, Tauane Santos Brito, and Edleusa Pereira Seidel. 2018. "Processes of Soil Infiltration and Water Retention and Strategies to Increase Their Capacity." *Journal of Experimental Agriculture International* 20 (2): 1–14. https://journaljeai.com/index.php/JEAI/article/view/197.

Parker, Tess, and Ailie Gallant. 2021. "'Flash Droughts' Can Dry Out Soil in Weeks. New Research Shows What They Look Like in Australia." *The Conversation*. June 3, 2021. https://theconversation.com/flash-droughts-can-dry-out-soil-in-weeks-new-research-shows-what-they-look-like-in-australia-161286.

Pedro-Monzonís, María, Abel Solera, Javier Ferrer, Joaquín Andreu, and Teodoro Estrela. 2016. "Water Accounting for Stressed River Basins Based on Water Resources Management Models." *Science of The Total Environment* 565: 181–190.

PROVIA. 2013. *PROVIA Guidance on Assessing Vulnerability, Impacts and Adaptation to Climate Change. Consultation document*. Nairobi: United Nations Environment Programme.

Qi, Zhiming, Matthew J. Helmers, and Amy L. Kaleita. 2011. "Soil Water Dynamics Under Various Agricultural Land Covers on a Subsurface Drained Field in North-Central Iowa, USA." *Agricultural Water Management* 98 (4): 665–674. https://doi.org/10.1016/j.agwat.2010.11.004.

Reyer, Christopher P.O., Sophie Adams, Torsten Albrecht, Florent Baarsch, Alice Boit, Nella Canales Trujillo, Matti Cartsburg, et al. 2015. "Climate Change Impacts in Latin America and the Caribbean and Their Implications for Development." *Regional Environmental Change* 17: 1601–1621. https://doi.org/10.1007/s10113-015-0854-6.

Richts, Andrea, and Jaroslav Vrba. 2016. "Groundwater Resources and Hydroclimatic Extremes: Mapping Global Groundwater Vulnerability to Floods and Droughts." *Environmental Earth Sciences* 75 (926).

Rockström, Johan, Mariana Mazzucato, Lauren Seaby Andersen, Simon Felix Fahrländer, and Dieter Gerten. 2023. "Why We Need a New Economics of Water as a Common Good." *Nature* 615 (7954): 794–797.

Rodella, Aude-Sophie, Esha Zaveri, and Francois Bertone. 2023. T*he Hidden Wealth of Nations: The Economics of Groundwater in Times of Climate Change*. Washington, DC: World Bank.

Rossi, L., M. Wens, H. De Moel, D. Cotti, A.-S. Sabino Siemons, A. Toreti, W. Maetens, D. Masante, A. Van Loon, M. Hagenlocher, R. Rudari, M. Meroni, M. Isabellon, F. Avanzi, G. Naumann, and P. Barbosa. 2023. *European Drought Risk Atlas*. Publications Office of the European Union, Luxembourg. https://publications.jrc.ec.europa.eu/repository/handle/JRC135215.

Rouillard, J., J. Tröltzsch, J. Tarpey, M. Lago, P. Watkiss, A. Hunt, F. Bosello, et al. 2016. *The Economic Analysis of Climate Adaptation: Insights for Policy-makers*. Deliverable 10.3, ECONADAPT. https://climate-adapt.eea.europa.eu/en/metadata/publications/the-economic-analysis-of-climate-adaptation-insights-for-policy-makers.

Ruangpan, Laddaporn, Zoran Vojinovic, Jasna Plavšić, Dong-Jiing Doong, Tobias Bahlmann, Alida Alves, Leng-Hsuan Tseng, et al. 2021. "Incorporating Stakeholders' Preferences into a Multi-criteria Framework for Planning Large-scale Nature-Based Solutions." *Ambio* 50 (8): 1514–1531. https://link.springer.com/article/10.1007/s13280-020-01419-4.

Salvador, Coral, Raquel Nieto, Sergio M. Vicente-Serrano, Ricardo García-Herrera, Luis Gimeno, and Ana M. Vicedo-Cabrera. 2023. "Public Health Implications of Drought in a Climate Change Context: A Critical Review." *Annual Review of Public Health* 44: 213–232. https://doi.org/10.1146/annurev-publhealth-071421-051636.

Santos de Lima, Letícia, Francisco Eustáquio Oliveira e Silva, Paula Rosana Dorio Anastácio, Marina Marcela de Paula Kolanski, Ana Carolina Pires Pereira, Marianne Stéfany Resende Menezes, Evandro Landulfo Teixeira Paradela Cunha, and Marcia Nunes Macedo. 2024. "Severe Droughts Reduce River Navigability and Isolate Communities in the Brazilian Amazon." *Communications Earth & Environment* 5: 1–12. https://doi.org/10.1038/s43247-024-01530-4.

Scognamillo, A., M. Mastrorillo, and A. Ignaciuk. 2022. *Reducing Vulnerability to Weather Shocks Through Social Protection–Evidence from the Implementation of Productive Safety Net Programme (PSNP) in Ethiopia.* FAO Agricultural Development Economics Working Paper 22–02, Rome: FAO. https://doi.org/10.4060/cc0824en.

Serrat-Capdevila, Aleix, Natalia Limones, Javier Marzo-Artigas, Marcus Wijnen, and Bruno Petrucci. 2022. *Water Security and Drought Resilience in the South of Angola.* Washington, DC: World Bank.

Serrat-Capdevila, A., N. Limones, and M. Wijnen. 2023. *Making Drought Resilience and Water Security in the South of Angola Happen: Synthesis Report*. Washington, DC: World Bank.

Simelton, Elisabeth, Evan D.G. Fraser, Mette Termansen, Piers M. Forster, and Andrew J. Dougill. 2009. "Typologies of Crop-Drought Vulnerability: An Empirical Analysis of the Socio-economic Factors That Influence the Sensitivity and Resilience to Drought of Three Major Food Crops in China (1961–2001)." *Environmental Science & Policy* 12 (4): 438–452.

Smirnov, Oleg, Minghua Zhang, Tingyin Xiao, John Orbell, Amy Lobben, and Josef Gordon. 2016. "The Relative Importance of Climate Change and Population Growth for Exposure to Future Extreme Droughts." *Climatic Change* 138: 41–53.

Staupe-Delgado, Reidar. 2019. *Overcoming Barriers to Proactive Response in Slow-Onset Disasters.* Contributing Paper to GAR 2019, United Nations Office for Disaster Risk Reduction.

Steinemann, Anne, Sam F. Iacobellis, and Daniel R. Cayan. 2015. "Developing and Evaluating Drought Indicators for Decision-Making." *Journal of Hydrometeorology* 16 (4): 1793–1803.

Sultana, Rumana, Haseeb Md. Irfanullah, Samiya A. Selim, and Mohammad Budrudzaman. 2023. "Vulnerability and Ecosystem-based Adaption in the Farming Communities of Drought-Prone Northwest Bangladesh." *Environmental Challenges* 11: 100707.

Sušnik, Janez, Lydia S. Vamvakeridou-Lyroudia, Dragan A. Savić, and Zoran Kapelan. 2012. "Integrated System Dynamics Modelling for Water Scarcity Assessment: Case Study of the Kairouan Region." *Science of The Total Environment* 440: 290–306. https://doi.org/10.1016/j.scitotenv.2012.05.085.

Tenagashaw, Diress Yigezu. 2022. "Analysis and Characterization of Hydrological Drought Under Future Climate Change Using the SWAT Model in Tana Sub-basin, Ethiopia." *Water Conservation Science and Engineering* 7: 131–142.

The Nature Conservancy. 2022. "Financing Nature for Water Security: A How-To Guide to Develop Watershed Investment Programs--Annex B: Factsheets."

The Nature Conservancy. 2023. "The Invisible Reservoir Biophysical and Economic Study on Investments in Nature-Based Solutions for Water Security and Climate Adaptation in the Cantareira System, São Paulo, Brazil."

The Nature Conservancy and Agence Francaise de Developpement. N.D. "Wetland Restoration: Intervention Category: Restoration." TNC. https://resilientwatershedstoolbox.org/sites/default/files/documents/library/NbS%20Factsheet%20Wetland%20Restoration.pdf.

Tröltzsch, J., J. Rouillard, J. Tarpey, Lago M., P. Watkiss, and A. Hunt. 2016. T*he Economics of Climate Change Adaptation: Insights into Economic Assessment Methods*. Deliverable 10.2, ECONADAPT. https://econadapt.eu/sites/default/files/docs/Deliverable%2010-2.pdf.

Tsakiris, G., A. Loukas, D. Pangalou, H. Vangelis, D. Tigkas, G. Rossi, and A. Cancelliere. 2007. "Drought Characterization [Part 1. Components of Drought Planning. 1.3. Methodological Component]." *CIHEAM / EC MEDA Water* (58): 85–102. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=3ef541cc18cec3e3492f82f96d9e76ea4674ab43.

Tsesmelis, D.E., C.A. Karavitis, P.D. Oikonomou, S. Alexandris, and C. Kosmas. 2019. "Assessment of the Vulnerability to Drought and Desertification Characteristics Using the Standardized Drought Vulnerability Index (SDVI) and the Environmentally Sensitive Areas Index (ESAI)." *Resources* 8 (1): 6. https://doi.org/10.3390/resources8010006.

UNDP (United Nations Development Programme) and EC (European Commission). 2016. *Community Based Resilience Analysis (CoBRA). Conceptual Framework and Methodology*. UNDP Drylands Development Centre. https://www.undp.org/publications/cobra-conceptual-framework.

UNCCD. 2022a. *Droughts in Numbers 2022: Restoration for Readiness and Resilience*. Côte d'Ivoire: UNCCD.

UNCCD. 2022b. *FACTSHEET: Drought and Its Socio-economic Impacts*. Bonn: UNCCD.

UNCCD. 2022c. *Stocktaking of Existing Drought and Related Policies*. Bonn: UNCCD. https://www.unccd.int/sites/default/files/2022-02/stocktaking%20policies%20final-final.pdf.

UN-ISDR (United Nations International Strategy for Disaster Reduction) and SIDA (Swedish International Development Cooperation Agency). 2008. *Review and Analysis of Existing Drought Risk Reduction Policies and Programs in Uganda.* National Report on Drought Risk Reduction Policies and Programmes, The Republic of Uganda. https://www.preventionweb.net/files/8160_UgandaDroughtRiskReductionPolicyAnalyticalReport.pdf.

Urquijo-Reguera, Julia, Maria Teresa Gomez-Villarino, David Pereira, and Lucia De Stefano. 2020. "An Assessment Framework to Analyze Drought Management Plans: The Case of Spain." *Agronomy* 12 (4): 70. https://doi.org/10.3390/agronomy12040970.

USAID. 2018. *Economics of Resilience to Drought: Executive Summary*. USAID. https://2017-2020.usaid.gov/documents/1867/economics-resilience-drought-executive-summary.

USAID. 2022. *USAID Climate Resilience and Disaster Recovery Capacity Assessment for the Caribbean Region*. Gaps and Opportunities Assessment Report, Washington, DC: USAID. https://pdf.usaid.gov/pdf_docs/PA00Z9P8.pdf.

Vallejo, Lola, and Michael Mullan. 2017. *Climate-Resilient Infrastructure: Getting the Policies Right*. Environment Working Paper 121. Organisation for Economic Co-operation and Development. https://www.oecd-ilibrary.org/docserver/02f74d61-en.pdf?expires=1724199972&id=id&accname=guest&checksum=BD8EE24222482105F6F12834EAFA7EE6.

Van Zanten, Boris Ton, Gonzalo Gutierrez Giozueta, Luke Mckinnon Brander, Borja Gonzalez Reguero, Robert Griffin, Kavita Kapur Macleod, Alida Ivana Alves Beloqui, Amelia Midgley, Luis Diego Herrera Garcia, and Brenden Jongman. 2023. *Assessing the Benefits and Costs of Nature-Based Solutions for Climate Resilience: A Guideline for Project Developers.* Washington, DC: World Bank.

Venton, Paul Adrian, Courtenay Cabot Venton, Natalia Limones, Christopher Ward, Frederik Pischke, Nathan Engle, Marcus Wijnen, and Amal Talbi. 2019. *Framework for the Assessment of Benefits of Action or Cost of Inaction (BACI) for Drought Preparedness (English).* Washington, DC: World Bank Group.

Vermeulen, Sam, Jan Cools, Jan Staes, and Steven Van Passel. 2023. "A Review of Economic Assessments of Drought Risk Reduction Approaches in Agriculture." *Journal of Environmental Management* 345: 118909.

Vicente-Serrano, Sergio M., Dhais Peña-Angulo, Santiago Beguería, Fernando Domínguez-Castro, Miquel Tomás-Burguera, Iván Noguera, Luis Gimeno-Sotelo, and Ahmed El Kenawy. 2022. "Global Drought Trends and Future Projections." *Philosophical Transactions of the Royal Society* A. 380 (2238): 20210285.

Vigerstol, Kari, Nathan Karres, Shiteng Kang, Nancy Lilly, and Marika Massey-Bierman. 2023. *Accelerating Adaptation: The Promise and Limitations of Nature-based Solutions in the Race to Adapt to Increasing Floods and Droughts.* Arlington, Virginia, USA: The Nature Conservancy.

Vogt, Juergen V., Gustavo Naumann, Dario Masante, Jonathan Spinoni, Carmelo Cammalleri, Wadid Erian, Frederik Pischke, Roger Pulwarty, and Paulo Barbosa. 2018. *Drought Risk Assessment and Management. A Conceptual Framework.* JRC Technical Reports, Luxembourg: Publications Office of the European Union.

Wang-Erlandsson, Lan, Ingo Fetzer, Patrick W. Keys, Ruud J. van der Ent, Hubert H. G. Savenije, and Line J. Gordon. 2018. "Remote Land Use Impacts on River Flows Through Atmospheric Teleconnections." *Hydrology and Earth System Sciences* 22 (8): 4311–4328. https://doi.org/10.5194/hess-22-4311-2018.

Ward, Frank A., Saud A. Amer, Dina A. Salman, Wayne R. Belcher, Ahmed Abdulhamza Khamees, Hatem Salloom Saleh, Aysar Abdul Azeez Saeed, and Hamdiea Skheel Jazaa. 2022. "Economic Optimization to Guide Climate Water Stress Adaptation." *Journal of Environmental Management* 301: 113884.

Wilhite, Donald A. 2012. "Breaking the Hydro-Illogical Cycle: Changing the Paradigm for Drought Management." *EARTH Magazine 57 (7): 71–72.*

Williams, T.G., S.D. Guikema, D.G. Brown, and A. Agrawal. 2020. "Resilience and Equity: Quantifying the Distributional Effects of Resilience-enhancing Strategies in a Smallholder Agricultural System." *Agricultural Systems* 182: 102832. https://doi.org/10.1016/j.agsy.2020.102832.

WMO (World Meteorological Organization). 1992. "International Meteorological Vocabulary." WMO No. 182. Geneva, WMO.

WMO. 2021. *WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2019).* Geneva: World Meteorological Organization.

WMO and GWP (Global Water Partnership). 2016. *Handbook of Drought Indicators and Indices.* Geneva: Integrated Drought Management Programme.

Wilhite, Donald A., WMO, GWP, and National Drought Mitigation Center. 2014. *National Drought Management Policy Guidelines: A Template for Action.* Integrated Drought Management Programme (IDMP) Tools and Guidelines Series 1, Geneva, Switzerland, and Stockholm, Sweden: WMO and GWP.

World Bank. 2005. *Ethiopia: Risk and Vulnerability Assessment.* Report No. 26275-ET, Washington, DC: World Bank.

World Bank. 2010. *Economics of Adaptation to Climate Change: Synthesis Report.* Washington, DC: World Bank.

World Bank. 2019. *Assessing Drought Hazard and Risk: Principles and Implementation Guidance.* Washington, DC: World Bank.

World Bank. 2020. *Resilient Water Infrastructure Design Brief.* Washington, DC: World Bank.

World Bank. 2021a. *A Catalogue of Nature-based Solutions for Urban Resilience.* Washington, DC: World Bank Group.

World Bank. 2021b. "Water Security Diagnostic Initiative." Accessed July, 18, 2024. https://www.worldbank.org/en/topic/water/publication/water-security-diagnostic-initiative#2.

World Bank Group. 2022. *Angola Country Climate and Development Report.* CCDR Series, Washington, DC: World Bank.

World Bank Group. 2023. *The Development, Climate, and Nature Crisis: Solutions to End Poverty on a Livable Planet--Insights from World Bank Country Climate and Development Reports Covering 42 Economies.* Washington, D.C.: World Bank.

World Bank and California Water Authority. 2023. "Guidelines for Drought Risk Management - Economic Methods, Models and Tools." Manuscript in preparation. World Bank, Washington, DC.

World Bank. 2024. "Romania Drought Risk Assessment." Manuscript in preparation. World Bank, Washington, DC.

World Bank and GFDRR. 2015. *Analyzing the Social Impacts of Disaster. Volume I: Methodology.* Washington, DC: World Bank.

Wu, Guiyang, Jie Chen, Xinyan Shi, Jong-Suk Kim, Jun Xia, and Liping Zhang. 2022. "Impacts of Global Climate Warming on Meteorological and Hydrological Droughts andTheir Propagations." *Earth's Future* 10 (3).

Xu, Lianlian, Tuantuan Zhang, Wei Yu, and Song Yang. 2023. "Changes in Concurrent Precipitation and Temperature Extremes Over the Asian Monsoon Region: Observation and Projection." *Environmental Research Letters* 18: 044021.

Yuan, Xing, Yumiao Wang, Peng Ji, Peili Wu, Justin Sheffield, and Jason A. Otkin. 2023. "A Global Transition to Flash Droughts Under Climate Change." *Science* 380: 187–191.

Zaveri, Esha, Richard Damania, and Nathan Engle. 2023. *Droughts and Deficits: The Impact of Water Scarcity on Economic Growth.* Policy Research Working Paper, Washington, DC: World Bank Group.

Zeng, Jianxing, Jiaxian Li, Xingjie Lu, Zhongwang Wei, Wei Shangguan, Shupeng Zhang, Yongjiu Dai, and Shulei Zhang. 2022. "Assessment of Global Meteorological, Hydrological and Agricultural Drought Under Future Warming Based on CMIP6." *Atmospheric and Oceanic Science Letters* 15 (1): 100143.

Zhang, Fan, and Christian Borja-Vega. 2024. *Water for Shared Prosperity.* Washington, D.C.: World Bank Group.

Zhang, Linlin, Jiangbo Gao, Ze Tang, and Kewei Jiao. 2021. "Quantifying the Ecosystem Vulnerability to Drought Based on Data Integration and Processes Coupling." *Agricultural and Forest Meteorology* 301–302: 108354. https://www.sciencedirect.com/science/article/abs/pii/S016819232100037X.

Zou, Xiaoxia, Yu'e Li, Roger Cremades, Qingzhu Gao, Yunfan Wan, and Qin Xiaobo. 2013. "Cost-Effectiveness Analysis of Water-Saving Irrigation Technologies Based on Climate Change Response: A Case Study of China." *Agricultural Water Management* 129: 9–20.

W24034