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Multiscale Approaches for the Assessment and Monitoring of Social and Ecological Resilience to Drought

A report of the Science-Policy Interface

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Multiscale Approaches for the Assessment and Monitoring of Social and Ecological Resilience to Drought

A report of the
Science-Policy Interface

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"Multiscale Approaches for the Assessment and Monitoring of Social and Ecological Resilience to Drought" was prepared under the supervision of the UNCCD Science-Policy Interface (SPI) working group dedicated to Objective 2. In keeping with decision 19/COP.12 as well as with internal SPI procedures, all technical reports have undergone a scientific review by the larger SPI group (including all five Committee on Science and Technology (CST) Bureau members and all five observer organizations), a review by several former SPI members, and an international, independent review process that has included six domain experts covering all regions. The technical report was prepared by an author team of three coordinating lead authors, three lead authors, and eleven contributing authors.

The draft report produced by the authors underwent a two-step peer review process, including an internal review and an independent external scientific review. For the latter, six external reviewers (individual experts) from the different UNCCD regions, and two representatives of international organisations, which are relevant to the UNCCD processes on drought and land degradation were selected. The coordinating lead authors ensured that all peer review comments received appropriate consideration. The report was reviewed by the Bureau of the Conference of the Parties of the UNCCD.

FOREWORD

Drought is a global phenomenon, and it is getting worse. No region or country has been spared, and climate change is increasing the extent, frequency, intensity and duration of droughts in many parts of the world. Already, some countries previously thought to be resilient to drought have seen shrinking water reservoirs affect hydropower generation, agricultural irrigation, drinking water supplies and riparian habitat important to wildlife and people. Others are finding river levels too low for economically viable shipping. The most vulnerable populations are the most at risk. In many nations that depend on land to grow crops and graze livestock, children are dying from treatable diseases, because they lack enough nutritious food. UNICEF projects that by 2040, one in four children will be living in areas with extreme water shortages.

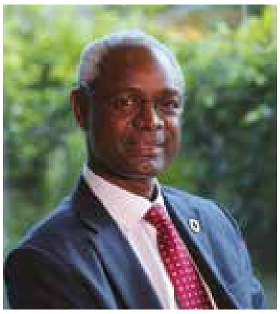
More is coming. Scientists are warning us on how climate change has and will continue to increase the intensity, frequency and duration of droughts events. They are clear that, even as we cut emissions, we must also ensure our land and water use decisions lead to increased water security. Thus, among the most important things we can do is to reduce the impacts of these droughts on communities and ecosystems by building resilience.

Building resilience is not easy. Drought is complex. Its causes are varied, and it has both direct and indirect impacts on food security, human well-being and ecosystem health. Episodes of drought that occur where land has become degraded can spur human migration and even civil unrest. The need to increase water security is vitally important, something achievable by addressing the links and interactions among water scarcity, climate change and land degradation. Research suggests that water scarcity can be mediated, at least in part, with better land- and water-use decisions and by restoring degraded land.

But these solutions require timely information. They need the kind of information that comes from resilience assessment and monitoring.

This technical report has been written to provide the science-based evidence for approaches to assessing and monitoring ecological and social resilience to drought in the face of climate change, especially for vulnerable populations and ecosystems. Its aim is to empower policy makers and practitioners to bring drought into existing efforts to assess and monitor resilience to climate change (something many countries are doing to develop climate change adaptation pathways). The report also provides a comprehensive review and analysis of available indicators and approaches for assessing and monitoring drought resilience, so that monitoring approaches can be established at multiple scales. It offers a roadmap for countries to help in the selection of the most appropriate indicators.

Resilience is notoriously difficult to measure and monitor. In the case of drought resilience, it is arguably even more challenging. These challenges, however, can be overcome with the right information. It is not enough to know about precipitation trends and reservoir levels. We need to know how to increase our ability to bounce back from drought and to withstand and recover from this all too frequent and all too costly natural disaster. This report takes a major step in the right direction.



Ibrahim Thiaw

Executive Secretary
United Nations Convention to Combat Desertification

EXECUTIVE SUMMARY

Human influence has increased the frequency and intensity of droughts on global and local scales. Human-induced climate change and other human activities, such as land cover changes, are already affecting weather extremes in every region across the globe. Between 2000 and 2020, these changes resulted in large losses in terrestrial water storage. The depletion of these terrestrial reserves of water makes the effects of drought particularly severe. These impacts are exacerbated when these stores are not replenished following previous droughts. The resulting water stress - that is, the imbalance between available water and water demand by both natural systems and human societies - affects many parts of Asia, the Middle East, and North Africa, as well as parts of North America.

The Intergovernmental Panel on Climate Change (IPCC) considers drought to be the costliest of natural hazards. Drought is a highly complex natural phenomenon, with multiple direct and indirect, short-term, and long-term impacts across various spatial and temporal dimensions. Nearly 1.3 billion people across the world rely on drought-sensitive agricultural activities as their main source of income. Urban areas are also affected by droughts, with an estimated one in every five cities with more than 1 million residents occurring in areas with a high to very high risks of drought, affecting about 370 million people around the world.

The impacts of droughts are mitigated by the resilience of ecosystems and societies. A society's resilience to drought depends on maintaining and developing its natural, economic, physical, human, and social capital with the help of enabling policies and institutions and through the sustainable governance of natural resources. Human decisions on land use and land management play an important role in both ecological and social resilience to drought.

The objective of this technical report is to provide *science-based evidence on approaches for assessing and monitoring ecological and social resilience to drought, especially for vulnerable populations and ecosystems, while considering the effect of climate change on drought risk and based on a review of existing literature.* This report is the first review and analysis of available indicators and approaches for assessing and monitoring drought resilience conducted for the UNCCD with the purpose of informing national and international processes.

ABBREVIATIONS

ACCRA	Africa Climate Change Resilience Alliance
ASAL	Arid and Semi-Arid Lands
ARC	African Risk Capacity
CDPMN	Caribbean Drought and Precipitation Monitoring Network
CEDRA	Climate Change and Degradation Risk and Adaptation Assessment
CoBRA	Community Based Resilience Analysis
CGIAR	Consortium of International Agricultural Research Centers
COP	Conference of Parties
CRSAP	Climate Resilience Strategy and Action Plan
CSIRO	Commonwealth Scientific and Industrial Research Organization
CWC	Canopy Water Content
DFID	The Department for International Development of the United Kingdom (now replaced by the Foreign, Commonwealth & Development Office (FCDO))
DRAMP	Drought Resilience, Adaptation and Management Policy
DRR	Disaster Risk Reduction
ET	Evapotranspiration
EPA	Kuwaiti Environment Public Authority
FAO	Food and Agriculture Organization
FIP	Forest Investment Program
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GPG	Good Practice Guidance for national reporting
GPP	Gross Primary Productivity
GWP	Global Water Partnership
HEA	Household Economy Approach
IGA	Income generating activities
IPC	Integrated Food Security Phase Classification
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
LAC	Local Adaptive Capacity
LDN	Land Degradation Neutrality

NAP	National Adaption Plan
NbS	Nature-based Solutions
NDMAP	National Drought Mitigation and Adaptation Plan
NDMA	National Drought Management Authority
NDMC	National Drought Mitigation Center, University of Nebraska
NDVI	Normalized Difference Vegetation Index
NPP	Net Primary Productivity
MoU	Memorandum of Understanding
MSME	Micro, Small and Medium Enterprises
M&E	Monitoring and Evaluation
OECD	Organization for Economic Co-operation and Development
RAPTA	Resilience Adaptation Pathways and Transformation Approach
SADC	Southern African Development Community
SDG	Sustainable Development Goals
SDS	Sand and dust storms
SLF	Sustainable Livelihood Framework
SLM	Sustainable Land Management
SNC	Second National Communication
SO	Strategic Objective
SOM	Soil Organic Matter
SPEI	Standardized Precipitation Evapotranspiration Index
SPI	Science-Policy Interface
TAMD	Tracking Adaptation and Measuring Development
TWI	Topographic Wetness Index
UNCCD	United Nations Convention to Combat Desertification
UNESCAP	UN Economic and Social Commission for Asia and the Pacific
UNDRR	The United Nations Office for Disaster Risk Reduction
UNGA	United Nations General Assembly
USAID	United States Agency for International Development
WFP	World Food Programme
WRSI	Water Requirement Satisfaction Index
WMO	World Meteorological Organization
WWF	World Wildlife Fund for Nature
ZVAC	Zambia Vulnerability Assessment Committee

GLOSSARY OF KEY TERMS

Adaptation	In human systems, the process of adjustment to actual or expected climate and its effects to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects. Human intervention may facilitate adjustment of natural systems to expected climate (IPCC, 2012).
Drought	**Drought** is the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems (UNGA, 1994). **Meteorological drought** occurs when the precipitation for a given period is lower by some pre-defined amount from the long-term mean amount of precipitation an area receives (Wilhite, 2002). **Agricultural drought** relates various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, etc. (NDMC, 2021; IPCC, 2021). **Ecological drought** is a prolonged and widespread deficit in naturally available water supplies that creates multiple stresses across ecosystems (NDMC, 2021; Vicente-Serrano *et al.,* 2021; IPCC, 2021). **Hydrological drought** occurs when deficits in surface and sub-surface water supplies (including streams and lakes) are below a defined threshold (Wilhite, 2002). **Socio-economic drought** occurs when there is a shortage of water for society at large, or when the supply of water is smaller than the demand due to a weather-related disruption (Mishra and Singh, 2010). **Flash drought** is the rapid onset or intensification of drought set in motion by lower-than-normal rates of precipitation, accompanied by abnormally high temperatures, winds, and radiation (Ford and Labosier, 2017; Mo and Lettenmaier, 2015; Christian *et al.,* 2021).
Drought impacts	A specific negative effect of drought on the economy, society, and/or environment and is a symptom of vulnerability (GWP CEE, 2015).

Drought resilience indicator	A variable used to measure and describe drought resilience (based on WMO and GWP, 2016).
Drought risk	The likelihood that damages and economic losses will be incurred during and after a drought and that depends on the interactions between three dimensions: 1) the severity and the probability of an occurrence of a certain drought event, 2) the exposed assets and/or people, and 3) their intrinsic vulnerability or capacity to cope with drought (Vogt *et al.*, 2018).
Drought-smart land management	Interventions that improve the capacity of landscapes, catchments, waterbodies, vegetation, and soils to accept, retain, release, and transmit water and improve plant water use efficiency (based on Reichhuber *et al.*, 2019).
Economic capital	An aggregate of available monetary resources, including savings, credit and debt (formal and informal), remittances, pensions, and wages (Serrat, 2017).
Ecosystem	A functional unit consisting of living organisms, their non-living environment, and the interactions within and between them. The components included in a given ecosystem and its spatial boundaries depend on the purpose for which the ecosystem is defined. In some cases, ecosystems are relatively sharply defined, while in others they are diffuse. Ecosystem boundaries can change over time. Ecosystems are nested within other ecosystems, and their scale can range from very small to the entire biosphere. In the current era, most ecosystems either contain human societies or are influenced by the effects of human activities in their environment (IPCC, 2018).
Evidence	The results of a scientific assessment of the observations and experiments that serve to support, refute, or modify a hypothesis, belief, or proposition (edited from OECD, 2021). The degree of evidence reflects the amount, quality, and consistency of scientific/technical information (edited from IPCC, 2021).
Exposure	The presence of people, livelihoods, species or ecosystems, environmental functions, services and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected by an event (IPCC, 2014).

Hazard	The potential occurrence of a natural or human-induced physical event, trend, or impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources (IPCC, 2014).
Human capital	The skills, knowledge, ability to work, and good health that together enable people to pursue different livelihood strategies, to achieve their livelihood objectives, and, in this context, to increase their social resilience to drought (Lax and Krug, 2013).
Land	The terrestrial bio-productive system that comprises soil, vegetation, other biota, and the ecological and hydrological processes that operate within the system (UNGA, 1994).
Nature-based solutions	Actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits. Nature-based solutions and land-based solutions generally include considerations of adaptation, mitigation, and resilience (Cohen-Sacham *et al*., 2016).
Poverty level	A level of income usually defined relative to all incomes within a country or among countries. Generally, a person living in extreme poverty is anyone who lives on less than USD 1.90 a day. However, malnutrition and a lack of accommodation can also be an expression of poverty. According to a different definition, a person is poor if their environment restricts their ability to achieve their potential (OECD, 2001).
Resilience	The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions (IPCC, 2014).
Social capital	Social resources, including informal networks, membership in formalized groups, and relationships of trust, that facilitate cooperation and build individual, community, and national-level resilience (Lax and Krug, 2013; IPCC, 2019).

Scale	The spatial, temporal, quantitative, and analytical dimensions used to measure and study any phenomenon. The spatial scale comprises 1) spatial extent – the size of the total area of interest for a particular study (e.g., a watershed, a country, the entire planet), and (2) spatial grain (or resolution) – the size of the spatial units within this total area for which data are observed or predicted (e.g., fine-grained or coarse-grained grid cells) (IPBES, 2018).
Vulnerability	The propensity or predisposition to be adversely affected by a hazard. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and a lack of capacity to cope and adapt (IPCC, 2014).
Water scarcity	An imbalance between the supply and demand of freshwater in a specified domain (country, region, catchment, river basin, etc.) as a result of a high rate of human demand for water compared with available supply under prevailing institutional arrangements (including price) and infrastructural conditions (FAO, 2012).
Water stress	An imbalance between water availability and water demands and needs in societies and ecosystems (edited from EEA, 2021). **The level of water stress:** freshwater withdrawal as a proportion of available freshwater resources is the ratio between total freshwater withdrawn by major economic sectors and total renewable freshwater resources, after taking into account environmental water requirements (SDG 6.4.2). It is an important indicator to measure drought resilience as water stress can strongly modify the nature and severity of 'natural' droughts (FAO, 2018). **Plant water stress:** the difference between the available water to evaporate and the existing atmospheric demand.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KEY MESSAGES

The monitoring and assessment of social and ecological resilience to drought is critical for understanding the capacity of ecosystems and societies to cope with, adapt to, and recover from drought. Drought resilience assessments can inform decisions to adjust human activities to better manage land and water use ahead of anticipated droughts and/or in response to drought onset. Drought resilience assessments can contribute to moving from reactive to proactive drought response regimes.

The science-based evidence reviewed in this report describes measuring drought resilience as highly context-specific, suggesting 'one-size-fits-all' approaches to drought resilience assessments will not work. At present, no single, definitive, universal metric effectively measures resilience to drought. However, a range of relevant indicators and a substantial body of baseline evidence are available to capture the effects of drought and its impacts on vulnerable populations and ecosystems. A set of globally agreed indicators and associated methodological guidelines have been established, tested, and made available to countries.

KEY MESSAGE 1

The report identifies indicators to measure ecological and social resilience to drought (associated with maintaining or improving natural, economic, social, human, and physical capital) along with corresponding frameworks and methods for conducting drought resilience assessments.

Drought resilience indicators and methodologies identified in this report can be adapted to the needs of individual countries. Drought resilience assessments do not require the use of all indicators all the time and in all settings. There are significant differences in local conditions and priorities, and only those indicators that are best suited for each given case should be selected and used. However, it is essential that assessments include indicators of both social and ecological resilience to provide a comprehensive picture of resilience.

KEY MESSAGE 2

The report identifies a shortlist of common indicators and methods already agreed at the global level and in use by many countries for assessing the effects of droughts and changes attributable to sustainable land management (SLM).

An understanding of the role of SLM in increasing social and ecological resilience to drought can be improved through increased technical exchange amongst stakeholders at national, subnational, and local levels to identify current capacities and the use of indicators. Tracking impacts and successes in mitigating the effects of droughts on vulnerable people and ecosystems is important for better understanding the ability and capacity to cope with, adapt to, and recover from droughts in the future.

KEY MESSAGE 3

The report identifies a wide range of resilience measurement and assessment tools and frameworks already available. Countries or responsible institutions can select and adapt their preferred assessment tools to measure progress toward their particular desired drought assessment goals as well as progress toward other sustainable development priorities, including reducing land degradation, addressing climate change, and protecting biodiversity.

Frameworks can be selected according to the resilience component of interest (e.g., disaster risk reduction, farmer resilience, and urban connectivity and capacity). For each of these existing frameworks, the applicable scale, required data sources, and key outcomes of the process are highlighted in Chapter 3.

KEY MESSAGE 4

The report outlines methods for presenting the findings of drought resilience assessments using a resilience index that scores ecological and social resilience to drought into one of five levels.

The index can score combinations of indicators to provide an overall resilience score, or it can score categories of relevant indicators separately. Combining indicator scores must take into account the multiple interdependencies and threshold relationships between and among indicators. A color-coding scheme can be applied for spatial mapping, enabling location-based prioritization of activities for improving drought resilience.

KEY MESSAGE 5

The report identifies additional actions needed to improve the effectiveness and use of monitoring and assessing ecological and social resilience to drought. Technical exchange amongst stakeholders at national, subnational, and local levels to identify current capacities and gaps is critically important for improving the use of drought resilience assessment indicators.

This exchange should include evidence of the effectiveness of SLM as a means to improve ecological and social resilience to drought. Particular priority for drought resilience assessments should be given to tracking the resilience of vulnerable populations and ecosystems. Society should bear in mind that low resilience to drought in one area can act as a threat-multiplier and may have wide-reaching consequences at larger scales.

POLICY PROPOSALS

Efforts by national agencies and sectors are needed to improve data generation for tracking indicators useful for assessments of ecological and social resilience to drought. This data can also help to build capacity and to establish feedback mechanisms between government departments implementing national social, economic, environmental, land, and drought policies.

The report recommends the following actions for further promoting the assessment and monitoring of drought resilience.

PROPOSAL 1

Establish two science-based operational definitions of drought resilience that (a) focus on resistance to drought impacts and (b) emphasize the generation of benefits from improved resilience.

To improve drought resilience monitoring and assessments, the SPI recommends using two operational definitions of drought resilience: i) a constrained working definition of resilience to drought that focuses on resistance to the impacts and risks of droughts and that is measurable in terms of reductions in these effects on populations and ecosystems; and ii) a positive definition of resilience to drought that focuses on capturing and measuring the benefits achieved by building resilience to drought that extend beyond reducing risks and negative impacts. This definition might refer to the positive effects of drought resilience on natural, economic, human, physical, and social capital.

PROPOSAL 2

Systematically collect, monitor, review, prioritize, and assess information on drought impacts.

Information about past impacts and costs from previous droughts is important for assessing and monitoring drought resilience as it evolves in response to changes in drought-related vulnerabilities, exposures, and hazards. This information is also essential to support integrated drought risk management. Integrated drought risk management includes three pillars: monitoring and early warning, vulnerability and impact assessment, and mitigation and response (IDMP, 2021). Integrated drought risk management guides national drought plans and policies, as well as ongoing discussions of loss, damages, returns on investments, natural capital accounting, and the United Nations System of Environmental and Economic Accounting (UNSEEA) framework. To collect data on past drought impacts and risks at national, subnational, and local levels, countries and institutions may consider using systematic and comparable approaches, such as those of the post-disaster needs assessment guides of the Global Facility for Disaster Reduction and Recovery (GFDRR). These approaches may include the following:

a. identifying, defining, and validating drought impact metrics and establishing scientific, evidence-based practices for understanding the minimum requirements for using core indicators and data for assessing drought resilience at different spatial scales and for different environmental systems and economic sectors;

b. qualitatively describing and, to the extent possible, quantitatively measuring drought impacts wherever appropriate using a systematic approach to collecting information deemed important and valuable at the national and/or sub-national levels;

c. assessing direct and indirect impacts on hydrological systems that affect ecological systems, agriculture, water resource availability, and different water-sensitive socioeconomic sectors, such as energy, food, tourism, and health;

d. examining the mitigation of the complex and cascading effects of drought that occur where preventive or remedial sustainable land management (SLM) actions could be taken;

e. analysing the extent to which SLM can prevent drought impacts from affecting vegetation conditions, water availability, and patterns of production, nutrition, health and well-being; and

f. exploring the impacts of drought and drought resilience on gender minorities and vulnerable populations.

PROPOSAL 3

Monitor and assess drought risk in natural and managed ecosystems.

Drought resilience is the capacity of ecological and socials systems to absorb and/or adapt to current and future droughts impacts. This capacity is measured relative to different levels of drought risk. Thus, drought risk information is critical for assessing and monitoring the drought resilience of natural and managed ecosystems. It is particularly vital for areas under pressure and on the brink of ecological collapse and that are more vulnerable to climate change and the effects of drought. Monitoring drought risk should (a) focus on the effects of drought on ecosystem services and on natural capital that enables ecosystems and populations to sustain themselves during drought, and (b) provide information for the development and promotion of drought impact mitigation initiatives that involve ecosystem conservation and restoration and drought-resilient water and crop management practices.

PROPOSAL 4

Support further research on the relationship between land drought and climate change.

Although drought is a natural phenomenon affecting all regions, the changing climate and human pressures on land and water have exacerbated the severity, frequency, and duration of droughts and their economic impacts. This exacerbation is expected to worsen in the future. The SPI suggests the UNCCD—in collaboration with the Integrated Drought Management Programme (IDMP) and other relevant international organizations—support research on the impacts of climate change on drought resilience, particularly for arid and semi-arid regions of the world under various climate change scenarios. This work should build on existing relevant SPI and the IPCC publications, particularly the UNCCD SPI publication on The Land-Drought Nexus (Reichhuber *et al*., 2019) and the IPCC special report on Climate Change and Land (IPCC, 2019). This research should provide scientific evidence to guide countries in developing and investing in integrated drought risk management and in promoting practices that improve drought resilience.

PROPOSAL 5

Integrate the findings from social and ecological drought resilience assessments into early warning systems that trigger decision-making on drought risk mitigation.

Results from the assessment and monitoring of resilience to drought should be tied to early warning systems and triggers to inform decision makers about responses that proactively strengthen drought resilience. Early warning systems need to integrate not only biophysical factors, such as precipitation changes, but also changes in social factors affecting drought resilience. These early warning systems should be designed to trigger responsive drought-relief actions, proactive drought risk mitigation and drought preparedness, and investments in drought-smart sustainable land and water management (Pulwarty and Sivakumar, 2014).

PROPOSAL 6

Strengthen drought resilience assessment capacities and create widely applicable, novel tools and advanced technology for drought resilience data collecting, monitoring, assessment, learning, and information sharing.

The UNCCD SPI recommends that the UNCCD secretariat—along with the Global Mechanism of the UNCCD (GM), FAO, UNDRR, UNEP, IDMP, UNESCO, and other cooperation partners—support Party Countries, where necessary, in the application of the advanced technologies of artificial intelligence, machine learning, spatial observation, crowdsourcing, citizen science, big data, household surveys, cloud services, and other digital-based, innovative tools to improve drought resilience assessments and drought early warning systems. These systems could be used to collect otherwise-unavailable data on indicators of natural, physical, social, human, and economic capital and to improve analysis on the interactions and connections between ecosystems and social economic sectors, including rural and urban areas. They could also improve accessibility to information for all stakeholders and cooperation partners for land management and business investment.

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Chapter 1: **INTRODUCTION**

1.1 OBJECTIVE AND STRUCTURE OF THE REPORT

The purpose of this technical report is to help achieve Objective 2 of the UNCCD Science-Policy Interface (SPI) Work Program for 2020-2021 by *“providing science-based evidence on the approaches for the assessment and monitoring of the resilience of vulnerable populations and ecosystems to drought, also considering the effect of climate change on drought risk, based on a review of existing synthesis reports and, if necessary, referring to primary literature”* (UNCCD Decision 18/COP.14).

The report is the first review and analysis of available indicators of drought resilience conducted for the UNCCD and its Parties with the purpose of informing national and international processes on the monitoring and assessment of drought resilience. It is meant to inform national focal points of each Country Party to the UNCCD, members of the Committee on Science and Technology of the UNCCD Conference of Parties (COP), and the broader community of stakeholders concerned with drought and drought resilience.

The report has four chapters. This chapter defines resilience to drought for human populations and for ecosystems and highlights the intricate connections between the two. It then lays out the conceptual framework that guides the report. It closes with a broad introduction to drought resilience indicators and their role in building drought resilience. Chapter 2 provides an inventory of existing drought resilience indicators and methodologies suitable for assessing and monitoring drought resilience across scales, from national and sub-national to local. Based on this inventory, Chapter 3 lays out a step-by-step approach for using indicators to measure and assess drought resilience. It further offers some general guiding principles for the development and use of indicators to measure drought resilience and presents some lessons from broader resilience measurement and assessment tools. The concluding Chapter 4 offers some recommendations and needed actions.

1.2 EVIDENCE OF DROUGHT IMPACTS ON ECOSYSTEMS AND HUMAN POPULATIONS

Drought is a highly complex natural hazard with multiple direct and indirect, short-term and long-term impacts (Wilhite and Pulwarty, 2017). Although most of the time drought is slow and gradual, it can also occur rapidly as a flash drought (Svoboda *et al.,* 2002; Otkin *et al.,* 2018; Ford and Labosier, 2017; Mo and Lettenmaier, 2015; Christian *et al.,* 2021). Drought is not only determined by precipitation, but it also depends on atmospheric evaporative demand and evapotranspiration, which are strongly modified by climate change (IPCC, 2021). Thus, drought is affected by current anthropogenic forcing. To most people, droughts are more readily associated with their impacts and significance rather than with the causal processes that drive them. For these reasons, defining droughts has always been challenging (Wilhite and Pulwarty, 2017; Wilhite and Glantz, 1985).

Abnormal hydrological imbalance is at the core of drought. This report follows the UNCCD's definition of drought. In its founding document, the UNCCD defines drought as *"the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems"* (UNGA, 1994). Similarly, the World Meteorological Organization (WMO) defines drought as a *"prolonged absence or marked deficiency of precipitation" and a "period of abnormally dry weather sufficiently prolonged for the lack of precipitation to cause a serious hydrological imbalance"* (WMO, 1992). In most languages and in popular understanding, drought is considered to mean abnormal dryness or a lack of water.

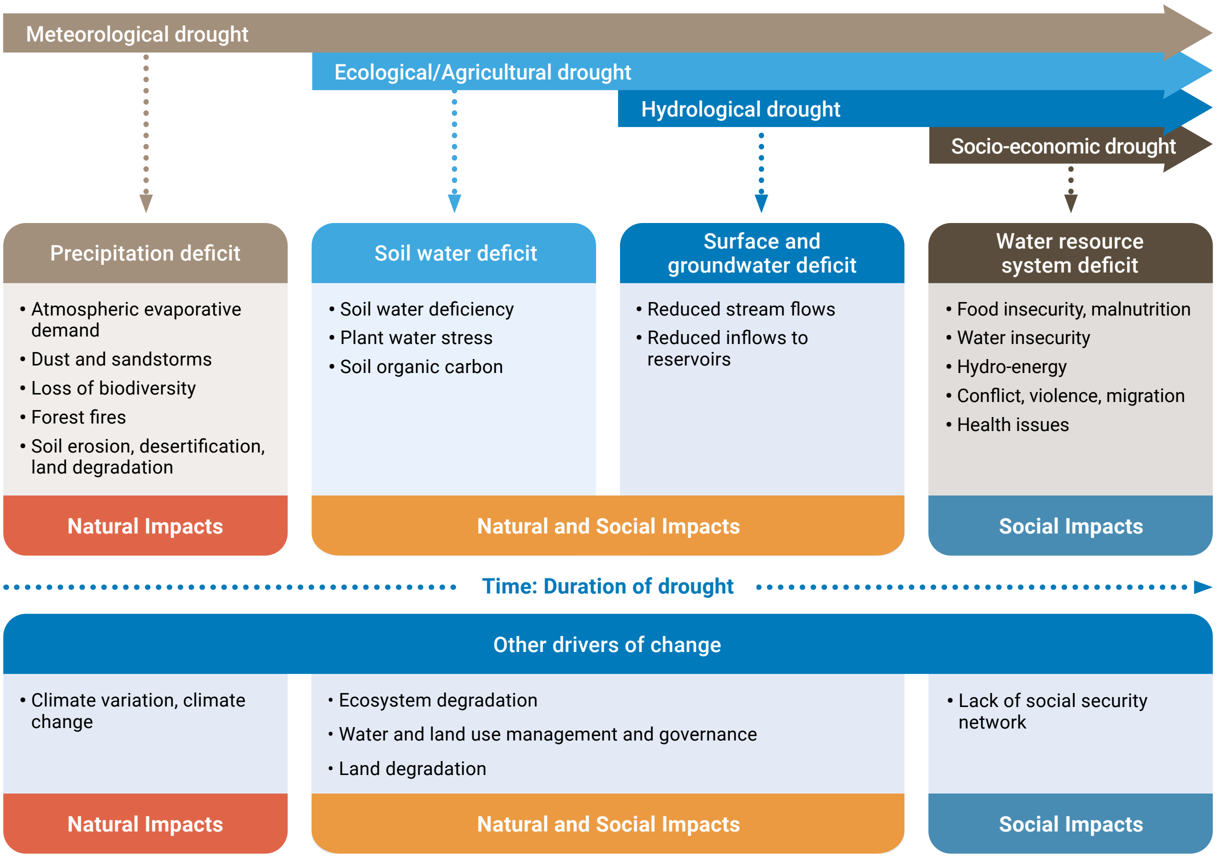
Cascading natural and social impacts from different types of droughts propagate with time. The 2019 UNCCD-SPI technical report, *The Land-Drought Nexus: Enhancing the Role of Land-Based Interventions in Drought Mitigation and Risk Management,* describes multiple definitions of drought developed by different stakeholders, expert groups, and practitioners to suit their focus and the type of interventions required (Reichhuber *et al.,* 2019). These multiple definitions exist simultaneously alongside more popular understandings of the concept of drought. Understanding how drought-affected water imbalances influence everything from atmospheric systems to soil, terrestrial, and freshwater ecosystems to human societies is critical for mitigating drought effects and building drought resilience.

Commonly considered drought types include the following:

- **Meteorological drought** occurs when precipitation falls short of the expected or normal precipitation over an extended period of time (Wilhite, 2002)
- **Agricultural drought** relates various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortfalls, differences between actual and potential evapotranspiration, soil water deficits, reduced groundwater, or diminished reservoir levels (NDMC, 2021; IPCC, 2021). Agricultural drought often results in reductions in crop productivity as a consequence of soil water deficits and increased demands for water.
- **Ecological drought** describes a prolonged and widespread deficit in naturally available water supplies — including changes in natural and managed hydrology — that create multiple stresses across ecosystems (Causbay *et al*., 2017; NDMC, 2021; Vicente-Serrano *et al*., 2020; IPCC, 2021).
- **Hydrological drought** occurs when deficits in surface and sub-surface water supplies (including streams and lakes) are below a defined threshold (Wilhite, 2002).
- **Socio-economic drought** occurs when there is shortage of water for society at large or when the supply of water is smaller than the demand due to a weather-related disruption (Mishra and Singh, 2010).

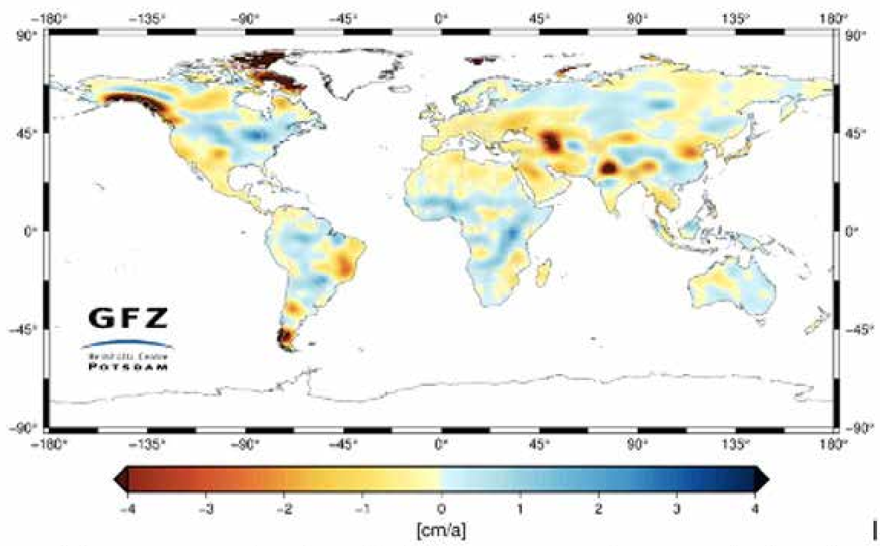
These types of droughts vary in their severity of impacts on natural and social systems over time. They also strongly interact with other drivers of change such as climate change, land degradation, ecosystem degradation, and other social, economic, and technological factors (Figure 1).

FIGURE 1 Drought types and their impacts across time



Source: Adapted from Crocetti *et al.*, 2020.

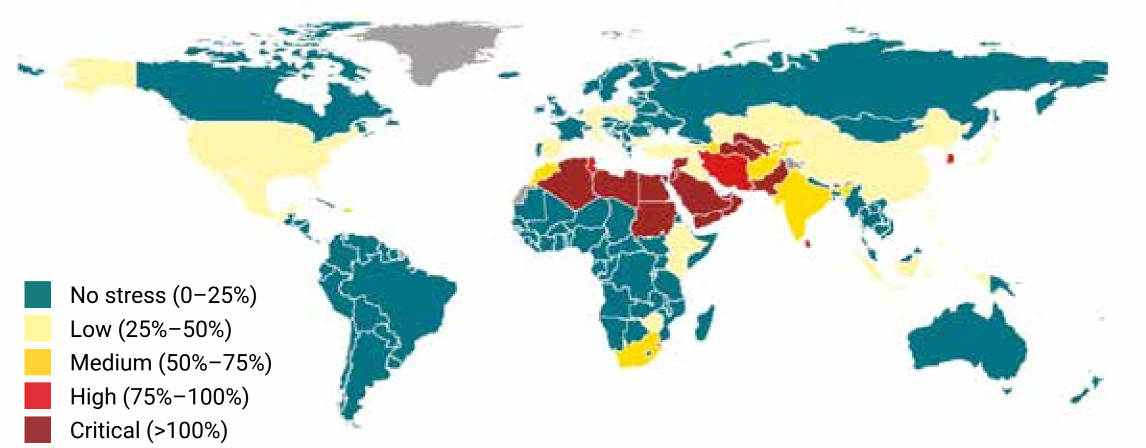
FIGURE 2 Terrestrial water storage (TWS) trends of the past 20 years (2002-2021)



Source: WMO, 2021.

Human influence has increased the chance of concurrent heatwaves and droughts on a global scale (Chiang *et al.,* 2018; Zscheischler and Seneviratne, 2017). Human-induced climate change is already affecting weather and climate extremes in every region across the globe (Seneviratne *et al.,* 2021). Continued global warming is projected to further change the global water cycle, including its decadal and interannual variability (Pendergrass *et al.,* 2017). These changes will affect monsoon precipitation in regions around the world and the severity of wet and dry events. The frequency and intensity of agricultural and ecological droughts in some regions will increase in direct relation to increasing global temperatures (IPCC, 2021), potentially leading to cascading effects across sectors that will result in economic losses. **The effects of drought are becoming particularly severe where terrestrial reserves of water have been depleted and not yet replenished following previous droughts.** Climate change and human activities have already led to large decreases in terrestrial water stores between 2000-2020 (Figure 2). Many parts of Asia, the Middle East, North Africa, and North America are currently experiencing high levels of water stress (Figure 3).

FIGURE 3 Levels of water stress by country



No stress (0–25%)
Low (25%–50%)
Medium (50%–75%)
High (75%–100%)
Critical (>100%)
not applicable

Source: FAO, 2021b.

Around the world, nearly 1.3 billion people rely on drought-sensitive agricultural activities as their main source of income. However, drought is not only a rural phenomenon; by some estimates, one in every five cities with more than 1 million residents is located in an area with a high to very high risk of drought, affecting around 370 million people around the world (FAO, 2019).

The Intergovernmental Panel on Climate Change (IPCC) describes drought as the costliest of natural hazards (Mirzabaev *et al.,* 2019). However, the true scale of the problem is unknown. That is because, while direct impacts of droughts in terms of human mortality and economic losses are well researched (e.g., the International Disaster Database (EM-DAT) provides information about human and economic costs of droughts at https://www.emdat.be; see also Obasi, 1994), indirect and off-site effects of droughts are often not quantified. In particular, the availability of data on the direct and indirect impacts of drought is especially inadequate for many of the low-income countries most affected by drought. This relates, for example, to the indirect effects of drought on food security, poverty, human health, and migration (Mirzabaev *et al.,* 2019).

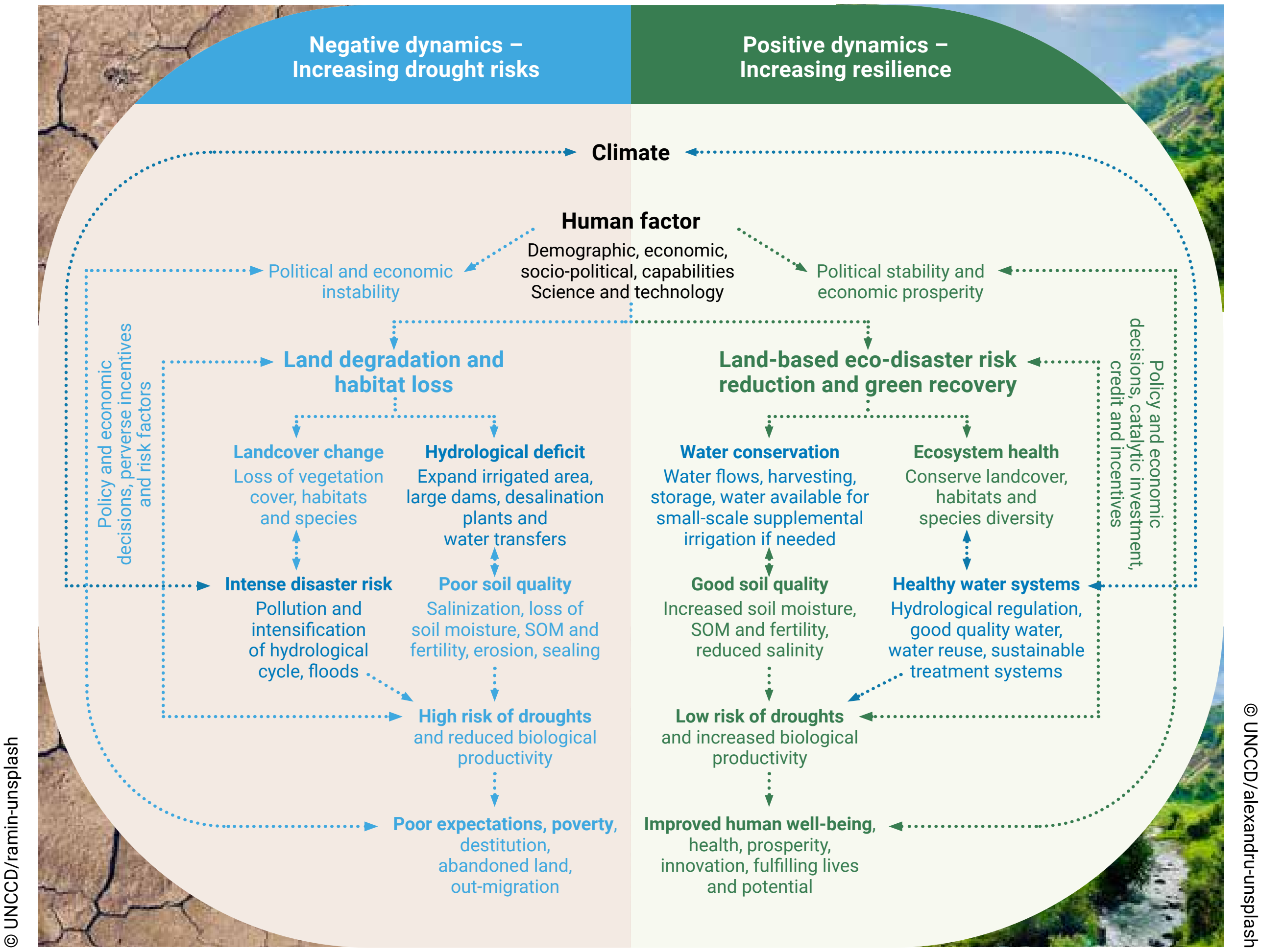
The direct and indirect impacts of droughts are illustrated by the following four selective examples:

1. **Food systems.** Drought reduces crop yields and livestock productivity and, in extreme cases, can result in the complete loss of production or livestock herds (Ciais *et al.,* 2005; Zampieri *et al.,* 2017). Drought also increases interannual variability of food production, leading to food shortages and higher prices. Drought impacts on rural crop production affect not only rural populations and livelihoods, but they can rapidly spread throughout local, regional, and global food systems and labor markets. These impacts affect both rural and urban areas beyond the immediate vicinity of the droughts in places that are not otherwise directly experiencing drought. Higher food prices and food shortages resulting from drought can lead, in some cases, to social instability and forced migration.
2. **Sand and dust storms (SDS).** SDS are directly linked to drought and the impacts of droughts (Middleton and Kang, 2017; Middleton, 2018). Droughts can increase SDS frequency, intensity, and area of impact (Issanova *et al.,* 2015; Mirzabaev *et al.,* 2019), especially when coupled with unsustainable land use (Reichhuber *et al.,* 2019). As an important hazard, SDS can be measured to provide important metrics for assessing drought impacts (Fekete *et al.,* 2020). SDS can also play a teleconnection role, whereby SDS can transport drought impacts (e.g., those affecting human health; Goudie, 2014; Sprigg *et al.,* 2014) to areas far from the location of drought events (Yang *et al.,* 2015; Yaping *et al.,* 2011).
3. **Conflicts.** Droughts can cause or amplify already existing risks of conflict and drive migration (e.g., Somalia; Maxwell and Fitzpatrick, 2012), including across borders. Hence, building drought resilience contributes to the political stability of socio-economic systems at national and regional levels.
4. **Drought-induced ecosystem stress and collapse.** A wide range of ecosystems are currently threatened by climate-change-intensified droughts (IPCC, 2021). Under certain conditions, these droughts can overwhelm the resilience of ecosystems and lead to major shifts in ecosystems or even their collapse (He *et al.,* 2017; Bergstrom *et al.,* 2021). For example, in 2019-2020, a combination of heatwaves and drought led to unprecedented, large-scale forest and savanna fires in Australia, resulting in major structural and functional changes within these ecosystems (Bergstrom *et al.,* 2021).

Historically, both human societies and biological systems have developed various adaptations to drought. For example, many plants have developed morphological, physiological, and phenological adaptations to drought (Belhassen, 1997; Zandalinas *et al.,* 2018). In human societies, examples of adaptations for building drought resilience include transhumant pastoralism, supplemental groundwater irrigation, water reservoirs and dams, etc. (Dominguez, 2014; Turner *et al.,* 2016; Mirzabaev *et al.,* 2019). These historical adaptations, however, are increasingly strained by ongoing rapid climatic changes, exponential growth in human water use (especially for irrigation), and unsustainable land use and management.

Human decisions on land use and land management play an important role in ecosystem and human resilience to drought (Reichhuber *et al.,* 2019). While healthy soils can store water that functions as a buffer in times of drought, human-induced land degradation reduces soil water storage capacity, amplifies water scarcity, and increases drought risks (Figure 3). Drought-smart land management (D-SLM) practices (i.e., sustainable land management practices that improve soil capacity to accept, retain, release, and transmit water and to increase plant water-use efficiency) help to alleviate the negative impacts of drought on ecosystems, including those affected by climate change impacts (Reichhuber *et al.,* 2019; Gies *et al.,* 2014). The application of sustainable land management practices improves soil and ecosystem health, contributes to carbon sequestration, and improves water use efficiency (Figure 4).

FIGURE 4 Land management affects social and ecological resilience to droughts



Source: King-Okumu *et al.* (2021).

Containing approximately 2047 gigatonnes of organic carbon (Plaza *et al.*, 2018), global soils are an essential carbon sink. This organic carbon is contained within the Soil Organic Matter (SOM). SOM is made up of living and dead biotic elements and contains approximately 58% carbon (C) (Edwards, 2021). SOM is important for soil health, structure, and water retention capacity. Therefore, increasing SOM content is a widely used method to improve soil quality. Due to its impacts on water retention, SOM is an invaluable tool for increasing the resilience of soil against climatic changes. In particular, increasing SOM has been found to improve soil resilience to drought. Research has identified several methods for increasing SOM content. Although the best method depends on the soil-conservation agricultural practices in use, such as the reduction or elimination of tillage, the implementation of continuous cover crops, mulching, and agroforestry have potential to enhance SOM (USDA-NRCS, 2018).

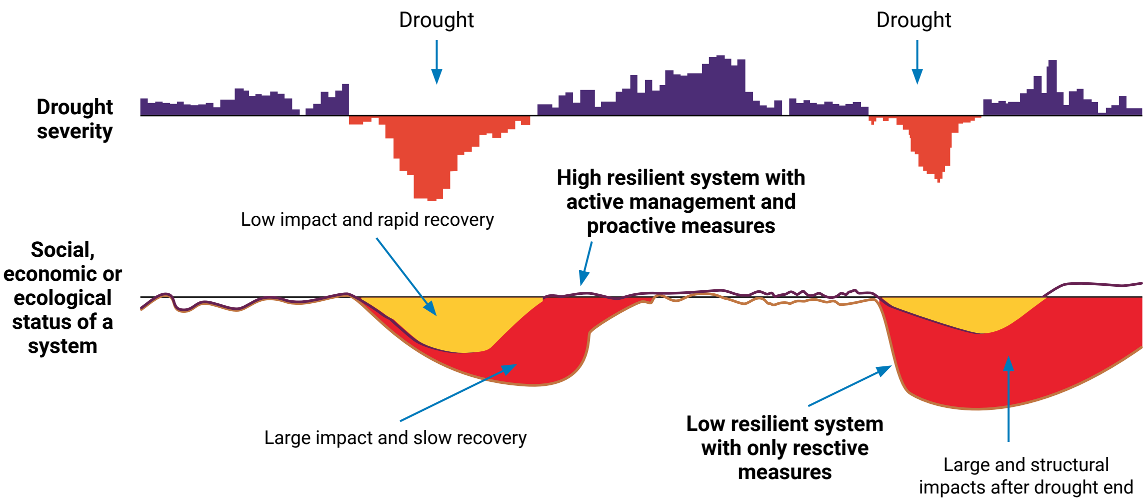
Thus, sustainable land management can serve as a major entry point for building resilience to drought (Reichhuber *et al.*, 2019). Building resilience is a key element of transitioning from "reactive" to "proactive" drought-risk mitigation. Proactive drought-risk mitigation is much less costly than reactive management to drought impacts (Gerber and Mirzabaev, 2017). The cases of Kenya, Ethiopia, and Somalia illustrate this fact. For these countries, USAID (2018a) suggests that USD 4.2 billion could be saved through proactive rather than reactive responses to drought. Estimates indicate that every USD 1 invested in building drought resilience will result in up to USD 3 in savings (USAID, 2018b). Yet, while sustainable land management is a proactive approach for drought-risk mitigation, building resilience against drought also requires

a consideration of the many social, economic, and institutional drivers of vulnerability that cannot be addressed by land management alone (Wilkinson and King-Okumu, 2019).

Climate change together with increasing water demands and accelerating land transformation increase the frequency and intensity of droughts and their direct and indirect costs (Figure 5).

Strengthening the drought resilience of ecosystems and societies requires improving their capacity to absorb drought impacts and to adapt to stress and change through sustainable land and water management while retaining societal and ecosystem functioning. An important aspect of building drought resilience is assessing and monitoring it.

FIGURE 5 **A conceptual illustration of the severity of drought impacts and recovery**

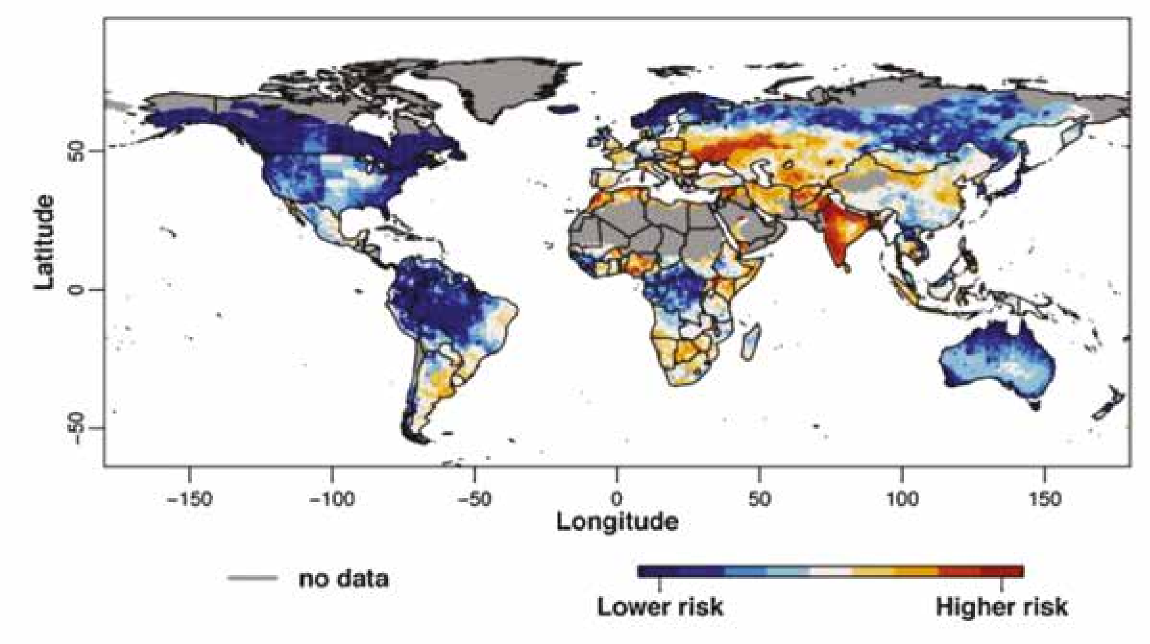


1.3 ASSESSING RESILIENCE TO DROUGHT

Assessing resilience to drought is critical for monitoring the capacity of ecosystems and societies to recover from drought to their pre-disturbance states. Resilience assessments, however, are complex and multidimensional. This section defines the concept of drought resilience and highlights factors to consider and different indicators useful for assessing drought resilience. These are further elaborated in the later chapters.

In this report, resilience to drought is defined using the well-accepted definition outlined by the IPCC as *"the capacity of coupled socio-ecological systems to cope with drought, responding or reorganizing over time in ways that maintain their essential functions, identity and structure while also maintaining the capacity for long-term adaptation, learning and transformation"* (IPCC, 2014). The concept of resilience to drought directly relates to the concept of drought risk. Drought risk is a forward-looking notion, representing a potential for adverse consequences that may result from droughts. Drought risk should not be confused with drought impacts, which are those consequences that have already occurred. Drought risk is the probability of harm or losses resulting from the combined effect of "drought hazard (i.e., the possible future occurrence of drought events), drought exposure (i.e., the total population, its livelihoods and assets in an area in which drought events may occur), and drought vulnerability (i.e., the propensity of exposed elements to suffer adverse effects when impacted by a drought event)" (Carrão *et al.*, 2016, p. 109). Figure 6 highlights the heterogeneity of drought risk contexts across the world.

FIGURE 6 A global map of drought risk



Source: Carrão et al. (2016).

Increasing drought resilience means reducing drought risk. Like drought risk, drought resilience is a function of drought hazard, exposure to drought, and vulnerability to drought. Increasing drought resilience refers to actions that strengthen the capacity for post-drought recovery by reducing the exposure of ecosystems and human societies to drought, addressing their drought vulnerabilities, and, whenever possible, reducing future drought risk. These actions to build resilience could reduce the vulnerability and exposure to drought while providing additional benefits to vegetation, soils, land and water. As populations and ecosystems become more resilient with stronger adaptive capacities, the severity and length of drought impacts become less (GIZ, 2014).

In assessing and monitoring drought resilience, particular attention should be paid to vulnerable populations. Poor and marginalized people tend to be the most vulnerable to drought impacts. Measuring a society's average drought resilience may overlook the resilience levels of the most vulnerable social groups. Vulnerability to drought can be different for rural vs. urban populations, smallholder, rainfed farmers vs. large-scale, commercial, irrigated farms, and pastoralist farms with access to mobile livestock grazing vs. those pastoralists without such access (Beauchamp *et al.,* 2019; Young and Ismail, 2019).

Women and young people are frequently identified as more vulnerable to drought than men. Often, socially constructed gender roles result in inequities that burden women and young people (i.e., those with less decision-making power) more than men (McOmber *et al.,* 2019). The findings of the Building Resilience and Adaptation to Climate Extremes and Disasters (BRACED) program show that everyday violence against girls and women undermines their resilience to future risks (Le Masson *et al.,* 2019). However, in certain circumstances, men may be the most vulnerable (e.g., male farmers using rainfed crop cultivation vs. female farmers using small-scale irrigation). It is important, therefore, to select social indicators of drought resilience that account for socioeconomic differences and that address particular drought impacts affecting vulnerable populations.

Indicators for measuring drought resilience

Progress in society is often assessed via indicators, such as those that measure headway toward the UN Sustainable Development Goals. In general, indicators simplify highly complex and dynamic information, and as a result, they are often contentious and hotly debated (Hinkel, 2011; Carter and Mäkinen, 2011). For example, numerous indicators and indices are available for drought monitoring and early warning (WMO and GWP, 2016). Drought monitoring approaches are often classified according to their indicator use into three types: i) approaches that use a single indicator or index; ii) approaches that use multiple separate indicators and indices; and iii) approaches that use composite or hybrid indicators (WMO and GWP, 2016).

Quantitative and qualitative indicators can provide useful guidance to policy makers seeking to increase resilience. Indicators are used to depict the results of resilience assessments. They also provide a yardstick against which to measure how changes in policies or other factors impact the overall resilience of ecosystems and people. Increased interest in the concept of resilience by many international, non-governmental, and aid organizations has led to a corresponding increase in literature about resilience indicators (Bahadur *et al*., 2013; Winderl, 2014; Schipper and Langstone, 2015).

Quantitative and qualitative indicators are both useful for assessing and monitoring resilience. Quantitative indicators include measures such as income, monetary losses, etc. (Box 1). Qualitative indicators include levels of social self-organization and empowerment.

1.4 METHODOLOGY

This report explores an inventory of resilience indicators and methodological approaches based on a systematic literature review complemented by literature recommendations by UNCCD Science Policy Interface (SPI) members. The systematic literature review provides a rigorous method for identifying and analysing resilience indicators. This approach is used to avoid the problems that are common in literature reviews related to environmental problems, such as a lack of representativeness and bias in the selection of sources (Haddaway *et al.*, 2020). This review is guided by the PRISMA protocol for systematic literature reviews (www.prisma-statement.org) and draws on both peer-reviewed academic literature (indexed in Scopus) and materials and research produced by organizations outside of traditional academic research (located via the Google search engine).

The team screened an initial list of 565 publications identified by a search of key words and terms selected to capture publications on drought resilience indicators, as well as any additional literature terms as suggested by UNCCD SPI members on drought and resilience themes. The time period for the review was 2005-2021. The language of the publications reviewed was English. Key words and terms included “drought resilience indicator”, “resilience indicator”, “resilience index”, and “resilience indices”. These were combined with “dryland”, “forest”, “grassland”, “rangeland”, “mountain”, “wetland”, “coastal zone”, “indigenous knowledge”, “local knowledge”, “traditional knowledge”, “gender”, “women”, “climate change”, “soil”, “scale”, “land”, “urban”, “rural”, “vulnerability”, “human”, “social” and “drought”.

While the search revealed a substantial body of literature on resilience, on droughts, on indicators per se, and on indicators of resilience to climate change, the selection of literature for the purposes of this report focused on drought resilience indicators, while integrating ideas from this broader literature whenever appropriate. For example, a consideration of the importance of climate change impacts on the frequency and intensity of droughts informed a decision to include literature on climate resilience measurement and assessment (especially in drylands) as complementary inputs to this report.

Following a review of the 565 publications, 367 were determined to be broadly relevant to the topics related to drought and resilience. A secondary review of these publications revealed 49 that could be considered specifically relevant to the identification and analysis of drought resilience indicators. Studies were included for consideration if they specifically applied or evaluated drought resilience indicators to cope with different socio-economic and ecosystems characteristics. Furthermore, studies were selected if the indicators they address are in use by many countries and have supporting datasets available. The drought resilience indicators identified from these 49 studies are inventoried in this report (Table 1).

It should be noted that studies were excluded from the review if they concerned indicators (primarily from the ecological literature) that have a complex experimental character and involved advanced modelling and research (e.g., studies of non-structural carbohydrate levels in trees). These were determined to be unsuitable for application at regional or country-level scales due to their high cost and low data availability.

TABLE 1 Number of publications reviewed and those selected for inclusion

Resilience categories	Total list of publications returned by key word search	Additional literature sources suggested by UNCCD SPI-members on drought and resilience themes	Total number of publications reviewed	Number of publications selected with information specifically on drought resilience indicators
Social drought resilience indicators	231	170	223	35
Ecosystem drought resilience indicators	34	130	144	14
Total	265	300	367	49

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Chapter 2:
INVENTORY AND ANALYSIS OF EXISTING INDICATORS AND METHODOLOGICAL APPROACHES

2.1 A TYPOLOGY OF DROUGHT RESILIENCE INDICATORS

This report uses the well-known concept of ‘the five capitals’—natural, social, human, physical, and economic capital—to characterize different dimensions of drought resilience and related indicators. This ’five capitals’ framework is now used as an important analytical framework by many researchers in the sustainability sciences (e.g., Hendriks *et al.,* 2021 for food systems; Dasgupta, 2021 for biodiversity). It is also consistent with the UNCCD’s drought resilience, adaptation, and management policy framework (UNCCD, 2019a).

The capacity of landscapes to withstand and recover from drought impacts (while maintaining their capacity for long-term adaptation and transformation) involves maintaining and developing natural capital. Natural capital can be defined as the world's stocks of natural assets which include soil, air, water, and all living things. It is from this natural capital that humans derive a wide range of services, often called ecosystem services, that make human life possible. In this report, we describe the capacity of a landscape to maintain and/or replenish its natural capital as “ecological resilience” to drought.

Meanwhile, the ability of human societies to cope with and recover from drought impacts (also while maintaining their capacity for long-term adaptation, learning, and transformation) involves maintaining and developing social capital (e.g., collective action, social protection), human capital (e.g., education, skills), physical capital (e.g., water infrastructure), and economic capital. We describe this capacity as "social resilience" to drought.

Indicators identified and presented in this report are scalable and suitable for monitoring and assessing drought resilience across multiple scales from land-plot levels to landscape/watershed levels to sub-national and national levels.

Table 2 presents an overview of drought resilience indicators identified in the literature that address ecological resilience to drought (i.e., resilience supporting natural capital) and social resilience to drought (i.e., resilience supporting social, human, physical, and economic capital). These indicators can be both quantitative and qualitative.

For each indicator type, details about its characteristics, indicator metrics, and references are further discussed in the sections that follow and in the report's annexes. For example, information about the indicators and methodological approaches used for assessing ecological resilience to drought are provided in Annex 2 of this report. Indicators and methodological approaches used for assessing social resilience to drought are provided in Tables 4-7 in this chapter.

While conducting drought resilience assessments, it is not required that all indicators are used all the time and in all settings. Local conditions and priorities vary widely, and only indicators that are suited to these circumstances are needed. However, assessments should include indicators of both social and ecological resilience to provide a comprehensive picture of overall drought resilience.

TABLE 2 An overview of indicators of drought resilience using the capitals approach

Capital	Indicators	Data sources	Data complexity
Ecological resilience			
Natural capital	Terrestrial water storage capacity over time	National ministries and institutions; the FAO Global Information System on Water and Agriculture	Simple to moderate
	Ecosystem water use efficiency in natural ecosystems (e.g., forest, grassland, wetland), managed ecosystems (e.g., agricultural) and semi-managed ecosystems (e.g., rangeland), including rural and urban ecosystems		
	Ecosystem recovery time, including time for recovery of vegetation "health" following a drought disturbance	Remotely sensed satellite data (e.g., Landsat/MODIS/ Sentinel satellites) and localized studies based on field data; Global-level default data relevant to SDG 15.3.1 (e.g., the proportion of land that is degraded over total land area as determined by three sub-indicators, including land cover, soil organic carbon (SOC), and land productivity (NPP))	Moderate to advanced
	Seasonal soil moisture levels and characteristics influencing soil moisture holding capacity (such as soil organic carbon (a sub-indicator of SDG15.3.1), soil texture, and others)		
	Biodiversity, species richness (i.e., number of species), and crop diversity		
Social resilience			
Economic capital	Extent of exposure of household due to dependence on availability of water; Share of population below poverty line, insurance coverage, etc.	Statistical agencies; household surveys, expert and non-expert interviews, desk research, data portals by FAO and World Bank, etc.	Simple to moderate. Where spatial data is combined, an advanced capacity for data collection and processing may be needed.

2.1.1 INDICATORS OF ECOLOGICAL RESILIENCE TO DROUGHT

Choosing appropriate indicators of ecological resilience to drought represents a major challenge, and to a large extent reflects a critical gap in the drought resilience literature. Information relevant to ecological drought resilience should include drought resilience indicators that are meaningful at different spatial and temporal scales. Most literature about drought resilience in an ecological context concerns particular species (e.g., a tree species or other plant species) with little attention to ecosystems overall. Existing literature that addresses drought resilience across different biomes—such as forests and shrublands, grasslands, wetlands, croplands, urban land, mixed-land-use areas (e.g., agro-forestry zones), and others—is limited. Forests, grasslands, and croplands are the most studied.

Usually, indicators of ecological resilience to drought are measured using quantitative analyses. In some cases, quantitative metrics are combined with qualitative measures. This assessment proposes the following four categories of indicators for assessing and monitoring ecological resilience to drought (i.e., indicators addressing natural capital):

1. Water-related indicators;
2. Ecosystem recovery time following droughts (i.e., the change in vegetation "health" or "stress" and the corresponding recovery time to the pre-disturbance conditions);
3. Soil characteristics; and
4. Biodiversity.

These four categories of ecological drought resilience indicators were identified from the literature as representing ecological drought resilience characteristics relevant across all ecosystems. However, some of these categories and/or specific indicators may be more relevant for some ecosystems and less relevant for others. For example, soil-related indicators may be most relevant for assessing drought resilience in agriculture. On the other hand, vegetation-specific indicators—such as the Normalized Difference Vegetation Index (NDVI)—may be more useful across naturally occurring ecosystems. NDVI quantifies vegetation activity by measuring the difference between near-infrared light (reflected by healthy vegetation) and red light (absorbed by healthy vegetation). In some cases, different vegetation communities may share the same soils and the same climate but demonstrate different levels of drought resilience because of differences in species richness. Therefore, measuring indicators is situation specific. Table 3 provides an overview of indicators of ecological resilience to drought by type, indicating their applicability to specific ecosystems.

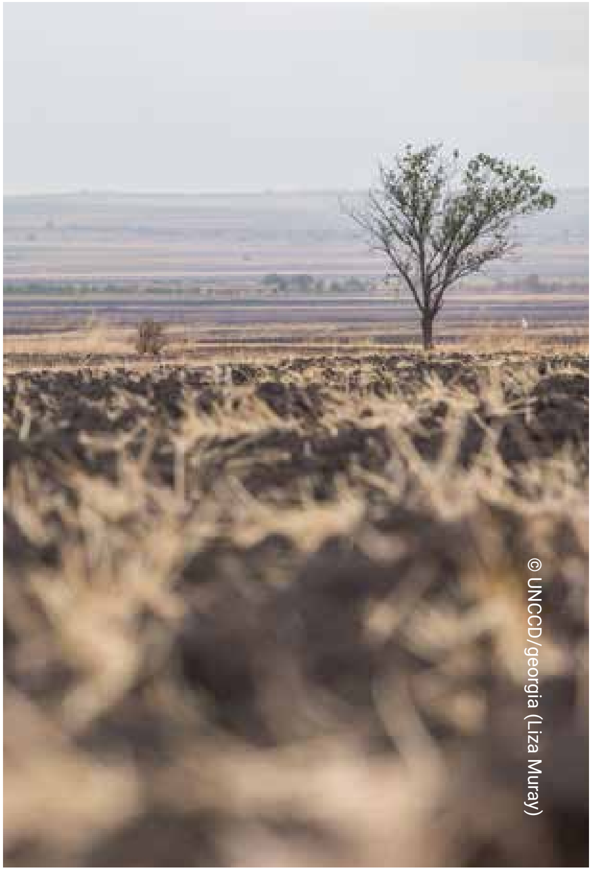

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TABLE 3 Indicators of ecological resilience to drought as applied to specific ecosystems and focusing on natural capital

Category of indicators	Ecosystem	Indicator measurement	References	Data Complexity	Notes
Water Imbalance	All ecosystems	Ecosystem water use efficiency (WUE) and change in water use efficiency over time (SDG indicator 6.4.1); change in terrestrial water storage over time	Sharma and Goyal, 2018; FAO, 2018 (Guidance on SDG indicator 6.4.1 reporting)	Simple to moderate (quantitative)	This is useful for detailed spatial information about a terrestrial ecosystem's response to hydro-climatic disturbances. Care is required when interpreting the findings across different biomes.
		Level of water stress (i.e., freshwater withdrawal as a proportion of available freshwater resources)	UN Water, 2016; FAO, 2018 (Guidance on SDG indicator 6,4,2 reporting)	Simple to moderate (quantitative)	Hydrological imbalances are central to the UNCCD definition of droughts and their effects on ecosystems.
Ecosystem recovery time	Agricultural Land	Change in gross primary productivity (GPP)	Yu *et al.*, 2017	Moderate to advanced (quantitative)	Vegetation indices from remote sensing data (e.g., the NDVI) are available worldwide and relatively easy to analyse across space and time. Greenness saturation can make NDVI less applicable to dense forests, but alternative remote sensing indices exist for these forest ecosystems (Gustau *et al.*, 2021). Being *ex-post* indicators, vegetation indices should take into account the characteristics of past droughts and their effect on observed NDVI changes. Global datasets of vegetation indices also need to be verified by data collected on the ground.
	Grassland	Change in NDVI and time of NDVI recovery after the disturbance.	Lu *et al.*, 2019		
	Forest	Change in NDVI and corresponding time to NDVI recovery	Dorman *et al.*, 2015; Miranda *et al.*, 2020		
	Shrubland	Change in NDVI and corresponding time to NDVI recovery	–		
	All ecosystems	Change in NDVI and corresponding time to NDVI recovery	Na-U-Dom *et al.*, 2017		

TABLE 3 Indicators of ecological resilience to drought as applied to specific ecosystems and focusing on natural capital (continued)

Category of indicators	Ecosystem	Indicator measurement	References	Data Complexity	Notes
Soil characteristics	Agricultural land	Soil carbon; soil texture	Jacobi *et al.*, 2013; UNCCD 2021	Simple to moderate (quantitative)	Soil moisture holding capacity and soil organic matter (SOM) play key roles in the recovery of agricultural lands. Soil organic carbon (SOC) earth observation default data is provided by the UNCCD for national reporting.
	Grassland	Soil carbon			
	Forest	Soil carbon			
	Shrubland	Soil carbon			
Biodiversity	Agricultural land	Crop diversity	Lin, 2011	Simple to complex (quantitative)	Ecosystems containing higher numbers of species are more resilient and change less during climate extremes, such as droughts. They also recover more quickly afterward. Here, care needs to be taken to compare similar ecosystems (e.g., comparing temperate forests that have higher vs. lower biodiversity rather than comparing temperate forests with tropical rainforests).
	Grassland	Number of grass species	Vogel *et al.*, 2012 Isbell *et al.*, 2015		
	Forest	Number of tree species	Anderegg *et al.*, 2018		
	Shrubland	Number of shrub species	–		
	Urban areas	Green spaces within a city	Blue *et al.*, 2017		
	All ecosystems	Change in plant species diversity or the ecological condition of undeveloped land	Blue *et al.*, 2017		

The first category of ecological resilience indicators focuses on water-related measures. Ecosystem water use efficiency (WUE) is defined as the ratio of net primary productivity (NPP) to evapotranspiration (ET) and is used as an indicator of ecosystem functioning or its response to hydroclimatic disturbances (Sharma and Goyal, 2018). Indicators in this category are particularly relevant to water-limited ecosystems in which runoff generation is very low and not necessarily as important across all other ecosystems. Thus, care needs to be taken when interpreting the findings across different biomes. Freshwater withdrawal as a proportion of available freshwater resources can be used to characterize the level of water stress and can serve as a good measure of societal vulnerability to drought.

The second category of ecological resilience indicators includes measures of ecosystem recovery time following droughts. These indicators capture past drought resilience *(ex post)* and mainly use spatial and temporal analyses of vegetation indices from remote sensing imagery. The third indicator category includes indicators of soil characteristics. These include soil moisture holding capacity (which plays a key role in the ecosystem recovery; Redmond *et al.*, 2017; Yu *et al.*, 2017) and measures of soil organic carbon (SOC) (Lal, 2020; Speranza *et al.*, 2010; Jacobi *et al.*, 2013; Muller *et al.*, 2013). Increased soil organic matter (SOM) improves soil moisture retention, reducing ecosystem vulnerability to water stress and increasing resilience to droughts (Jacobi *et al.*, 2013; Dorman *et al.*, 2015).

The fourth category of ecological resilience indicators focuses on biodiversity. Ecosystems containing higher numbers of species are more resilient, change less during droughts, and recover more quickly afterward. For example, natural forests with high tree diversity are more resilient than managed forests with one or two tree species, and mono-cropping agriculture is less resilient than diversified cropping systems) (Isbell *et al.,* 2015; Pfisterer and Schmid, 2002; Pretzsch *et al.,* 2013).

Some indicators of ecological resilience to drought—e.g., soil moisture holding capacity, biodiversity and species richness, and ecosystem water use efficiency—are indicators of future drought resilience (*ex-ante* indicators). Others, such as measures of drought-related changes to NDVI, assess resilience based on indicators of past responses to drought (ex-*post* indicators). Use of the latter needs to include a consideration of the severity of the past droughts when interpreting assessment results, since it is expected that ecosystems are more resilient to mild and moderate droughts than they are to severe or extreme drought events.

All the indicators for assessing and monitoring ecological resilience to drought can be applied at and across different scales, from plot levels to landscape/watershed levels to sub-national and national levels. A large number of methodologies can be used to measure these indicators. Annex 2 in this report provides a table of practical examples and methodologies of indicators used to measure ecological resilience to drought.

Key sources of data for ecosystem drought resilience studies come from satellites (such as Landsat and MODIS) and local ecological research on soils, tree, and grass species, and their characteristics. Depending on the scale of the analysis, data on climate variables can be either from individual weather stations, from weather/climate models, or from other generated gridded datasets that provide such information.

2.1.2 **INDICATORS OF SOCIAL RESILIENCE TO DROUGHT**

Indicators of social resilience to drought are context specific. In some circumstances, a small number of these indicators may be sufficient to assess drought resilience, while in other circumstances more indicators may be required. The choice of which indicators to use is often influenced by the context and by the nuanced differences in what is understood to be social resilience to drought.

Indicators of social drought resilience were identified from the literature if they met certain criteria: they are globally available; they are in use by many countries already; they have readily available supporting datasets; and they are frequently cited in the drought resilience assessment literature. Quantitative and qualitative indicators are both used to meaningfully characterize levels of social resilience, and the difficulty of the data complexity ranges from simple to moderate (although easily available data in one country may be difficult to access or generate in another).

While indicators of ecological resilience to drought assess characteristics and responses of natural capital that affect drought resilience, indicators of social resilience to drought anticipate or measure drought responses of economic capital, physical capital, social capital, and human capital. Indicators affecting these four types of capital are summarized in separate tables: Table 4 addresses indicators of economic capital; Table 5 addresses indicators of physical capital; Table 6 addresses indicators of social capital; and Table 7 addresses indicators of human capital.

TABLE 4 Indicators to measure social resilience to drought, focusing on economic capital

Indicator	Scale	Dimensions of social system considered	Data types and sources	Reference	Data Complexity
Percentage of population living below the national poverty level; Percentage of target population (from those x% are women) who restore their livelihood activity/income to pre-drought levels	Communities, districts, regions, nations	Vulnerable populations (e.g., women); urban and rural systems; food security; employment and income security	Secondary data analysis; household surveys; records from micro, small and medium enterprises or productive organizations; focus group discussions; key informant interviews and surveys	Luh *et al.*, 2015	Simple to moderate (quantitative)
Percentage and extent of crop/livestock insurance coverage within target area/ population	Communities, districts, regions, nations	Agricultural systems within rural contexts	Reports from insurance providers; local authorities; farmer groups and associations; focus group discussions; surveys.	Bahadur *et al.*, 2015	Simple (quantitative)
Economic losses (e.g., number of farmers/pastoralists who lost >50% of their crops/livestock in the past 10 years due to drought; percentage of crop/ livestock yield/productivity lost every 5 years due to drought; national direct economic losses attributed to drought relative to GDP)	Communities, districts, regions, nations	Agricultural systems within rural contexts; economic loss and damage; food security; employment and income security	District agricultural reports; local and national statistics; self-assessment questionnaires; disaster loss and damage databases; disaster loss databases and reports from Sendai Framework National Focal Point, hydro-meteorological agencies, etc.	FAO, 2015 (SHARP framework); UNDRR 2018 (SDG indicator 1.5.2 and metadata at UN SDGs Web, 2021)	Simple (quantitative)

TABLE 5 Indicators to measure social resilience to drought, focusing on physical capital

Indicator	Scale	Dimensions of social system considered	Data types and sources	Reference	Data Complexity
Total number of facilities and infrastructures (e.g., percentage coverage of population/area by a particular facility or asset). Access to markets measured through remoteness or physical distance indicators.	District, state (sub-national), nation	Urban and rural systems	Land use plans; key informant interviews with relevant authorities; interviews with Small and medium-size enterprises and actors along the value chain	Mafi-Gholami *et al.*, 2020; FAO, 2015	Simple to moderate (quantitative)
Availability of adaptation technologies and innovations (e.g., number/ percentage of target population able to protect / replace / increase / improve their productive assets above pre-drought or baseline levels)	Community, district, region, nation	Urban and rural systems	Reliable/relevant sources from clusters or government (e.g., baseline assessment information); expert interviews and focus groups, reference to a 'normal' situation)	Columbia Basin Trust (2014); Livelihoods Center	Simple to moderate (quantitative)
Connection/access to dry season irrigation, groundwater use, drought resistant acequia landscape, water reservoirs and other water infrastructure (linked to ecological resilience / natural capital indicators, e.g., SDG 6.4.2: amount of freshwater withdrawn by all economic activities in an area compared to the total renewable freshwater resources available).	Household, community, district, region, nation	Vulnerable populations; rural systems; water security	Land use land cover maps (existing or developed); government records; focus group discussions. (for SDG 6.4.2, national statistic offices, ministries of water resources, agriculture or environment, national water resources and irrigation master plans and other reports, etc.)	Fernald *et al.*, 2015; UNESCAP, 2020	Simple to advanced (quantitative)

TABLE 6 Indicators to measure social resilience to drought, focusing on social capital

Indicator	Scale	Dimensions of social system considered	Data types and sources	Reference	Data Complexity
Number of deaths, missing persons, and persons affected by drought	Community, district, region, nation	Vulnerable populations (e.g., women); need to control for drought severity and other relevant factors	Relevant statistical agency (linked to SDG target 1.5 and indicator 15.1)	CHRR, CIESIN, and World Bank, 2005; Alam et al., 2021	Simple to moderate (quantitative)
Population / women / men / Indigenous peoples and local communities with secure rights to land, property, and natural resources (e.g., measured by the percentage with legally documented or recognized evidence of tenure and/or the percentage who perceive their rights are recognized and protected)	Community, district, region, nation	Vulnerable populations (e.g., women); rural systems; water and land rights/security	Relevant statistical agency; census data; land registries or cadasters; household survey questionnaires; metadata on types and coverage of various tenure systems (optional)	Fernald *et al.*, 2015; Columbia Basin Trust, 2014	Simple to moderate (quantitative)
Governance structures (e.g., presence of decentralized climate change/natural resource or land use commissions and plans/strategies, such as national/local disaster and adaptation plans, drought hazard mitigation and recovery plans or strategies, drought early warning systems, complementing central government drought response structures)	Community, district, region, nation	Climate change disaster risk reduction institutional capacity	Desk review of policies, annual plans and project reports; expert or community interviews. (For SDG 1.5.3 and 1.5.4, National Sendai Monitor Report; For SDG indicator 1.5.3, Adoption and implementation of national disaster risk reduction strategies in line with the Sendai Framework for DRR 2015–2030; and for SDG 1.5.4, Local governments' adoption and implementation of local DRR strategies in line with national DRR strategies)	Luh *et al.*, 2015; Columbia Basin Trust, 2014; Ewbank *et al.*, 2019	Simple (qualitative or quantitative)

TABLE 6 Indicators to measure social resilience to drought, focusing on social capital (continued)

Indicator	Scale	Dimensions of social system considered	Data types and sources	Reference	Data Complexity
Stakeholder power and the degree of inclusion/autonomy in decision-making processes (e.g., measures of gender inclusion and consensus, number of consultation meetings and workshops, attendance of multiple stakeholders)	Community, district, region, nation	Urban and rural systems	Household survey questionnaire; interviews with community leaders	Fernald *et al.*, 2015; Arup ACCCRN, 2014; IIED, 2014; DFID, 2014	Simple to moderate (qualitative or quantitative)
Ability to self-organize (e.g., measured by the number of grassroots networks, community or self-help groups, community gardens, cooperatives etc.)	Community, district, region, nation	Rural systems	Interviews with community leaders; local administrative registries/ authorities	FAO, 2015 (SHARP framework)	Simple (qualitative or quantitative)
Percentage of farmers with access to extension and advisory services; degree of collaboration with technical support institutions; access to social protection programs and alternative employment opportunities	Community, district, region, nation	Rural systems	Interviews with local authorities or community leaders; reviews of local budgets and plans	FAO, 2015 (SHARP framework); Ewbank *et al.*, 2019, Ulrichs *et al.*, 2019	Simple (quantitative)

TABLE 7 Indicators to measure social resilience to drought, focusing on human capital

Indicator	Scale	Dimensions of social system considered	Data types and sources	Reference	Data Complexity
Local knowledge (e.g., presence of customary institutions, and Indigenous, traditional and local forms of drought mitigation, as well as knowledge of adaptation mechanisms and practices)	Household, community, district, region, nation	Rural systems	Taking stock of local perceptions and accounts through surveys/interviews with households/ communities or local leaders	Fernald *et al.*, 2015; Twigg, 2007; Speranza *et al*, 2010	Simple to moderate (qualitative or quantitative)
Ability to diversify crops and income generation (e.g., percentage of target households (from those Y% are women) in z area that have enough cash to meet their needs; number/percentage of target population able to stabilize/ improve their net income)	Household, community, district, region, nation	Vulnerable populations Food security Economic resilience	Household surveys; focus group discussions; reliable information from clusters or local government; secondary data analysis; income records	Fernald *et al.*, 2015; Columbia Basin Trust, 2014; Save the Children, 2008 (Household Economy Approach)	Simple to moderate (quantitative)

Social resilience to drought is understood in many ways, from the resilience to cope with and recover from economic losses (Box 1) to the resilience to maintain or recuperate psychological well-being. Indicators of social resilience also vary widely, from indicators such as access to irrigation and reliability of water supplies to 'poverty' indicators, such as income, literacy, or malnutrition. Governance—specifically the presence of one or more strong institutions that are responsible for knowledge management (i.e., through enhancing information-sharing and coordination among relevant actors across multiple scales to improve drought preparedness and response)—can be another indicator of social resilience (Brüntrup and Tsegai, 2017). Ultimately, social resilience to drought is strongly impacted by the following factors: by shared values, attitudes, and beliefs within a community; by peer group support and community engagement; by social protection and social networks (Ulrichs *et al.,* 2019); by opportunities for empowerment; and by the complex interplay between individual, family, organizational, and community-level factors.

More specific indicators offer more accurate information about drought resilience. Thus, local-level drought resilience indicators can serve as the best sources of information. Almost all indicator frameworks and publications use household or farm-level scales for the scale of analysis, although other local-level scales, such as watershed or other administrative zones, are also used. Frequently, therefore, contextual details about people's livelihoods, socio-cultural characteristics, and household composition are considered to influence resilience. Information gathered at these local levels can be aggregated up to sub-national and national levels to guide further resilience planning.

The selection of indicators is important. Selecting the wrong indicators based on inaccurate assumptions about a given context can lead to challenges, such as the creation of harmful incentives and unintended consequences for disaster management (Hallegatte and Engle, 2019). For example, access to irrigation and water-supply dams is often used as a key indicator of drought resilience (because irrigation improves crop production and alleviates water scarcity), but this sort of infrastructure may sometimes increase a population's vulnerability during drought periods by creating a dependence on reservoir storage. Thus, indicators adopted in the field may actually have perverse impacts on a society (UNDRR, 2019). Assessments must make room for such nuances and be adjusted to fit the context rather than applied across all contexts in a one-size-fits-all approach.

BOX 1. Measuring economic resilience to drought

Economic resilience to drought is often understood through the lens of direct and indirect economic losses. Direct economic loss is the monetary value of the total or partial destruction of physical assets existing in an affected area (i.e., the approximate value of the physical damage incurred relative to GDP). Indirect economic loss is a decline in economic value added *as a consequence of* direct economic loss and/or human and environmental impacts.

This aspect of resilience is globally measured and reported on as part efforts to achieve the UN SDG Target 1.5 by 2030, building the resilience of impoverished populations and those in vulnerable situations and reducing their exposure and vulnerability to climate-related extreme events and other economic, social, and environmental shocks and disasters.

The SDG target 1.5.2, in particular, focuses on vulnerable populations' direct economic losses (relative to global GDP) attributed to disasters, including drought. The greater the capacity of communities or countries to mitigate and respond to drought and associated losses—including the planning and implementation of sustainable land management practices—the higher their economic and overall resilience. Methods for tracking economic losses within the SDG framework focus on the total economic impact including both direct economic and indirect economic losses.

To summarize the most relevant indicators, we have considered those most widely used in the international context given data availability and their applicability to improve sustainable land management and increase drought resilience in natural and social systems. Table 8 provides a short list of common indicators and methodologies already agreed upon at the global level (and in use by many countries) for assessing the effects of droughts and changes attributable to sustainable land management. Further technical exchange amongst stakeholders at national, subnational, and local levels to identify current capacities and facilitate the local use of available indicators could improve our understanding of the impact of sustainable land management as means to improve the resilience to drought of ecosystems and populations. Tracking the success of efforts to mitigate drought impacts on vulnerable people and ecosystems will improve the ability and capacity of people everywhere to cope with, adapt to, and recover from drought.

TABLE 8 **Globally agreed indicators that can contribute to drought resilience monitoring at national and global levels, indicating their sensitivity to the influence of sustainable land management (SLM)**

Focus	Indicator definition (methodological guidance)	Custodian (SDG Tier classification[a])	Sensitivity to SLM[b]
People exposed to drought and their degree of vulnerability to drought	Trends in the proportion of total population exposed to drought Trends in the degree of drought vulnerability (Good Practice Guidance for National Reporting on UNCCD Strategic Objective 3)	UNCCD (not an SDG indicator)	Exposure indicator: No Vulnerability indicator: Yes
Peoples' livelihoods and economies	SDG indicator 1.5.2: Direct disaster economic loss in relation to global gross domestic product (United Nations Statistics on SDG indicator 1.5.2 and SDG indicators metadata repository for target 1.5)	UNDRR (Tier II)	Yes
Hydrological imbalances and their relation to land and water management for economic development and ecological sustainability	SDG indicator 6.4.2: Level of water stress: freshwater withdrawal as a proportion of available freshwater resources (FAO on SDG indicator 6.4.2 and Step-by-step methodology for monitoring water stress 6.4.2)	FAO (Tier I)	Yes

TABLE 8 Globally agreed indicators that can contribute to drought resilience monitoring at national and global levels, indicating their sensitivity to the influence of sustainable land management (SLM) (continued)

Focus	Indicator definition (methodological guidance)	Custodian (SDG Tier classification[a])	Sensitivity to SLM[b]
Land degradation and national systems for target-setting and monitoring to manage land sustainably and increase resilience to drought	SDG indicator 15.3.1: Proportion of land that is degraded over total land area (UNCCD Good Practice Guidance for Sustainable Development Goal Indicator 15.3.1)	UNCCD (Tier I)	Yes
Social capability to plan, govern, and cooperate effectively to reduce disaster risk	SDG indicator 1.5 3: Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030; SDG indicator 1.5.4: Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies (SDG indicators metadata repository for target 1.5)	UNDRR (Tier II)	Yes, if SLM makes up part of the national disaster risk reduction strategy and local plans

Abbreviations: FAO = Food and Agriculture Organization of the United Nations; SDG = Sustainable Development Goal; SLM = sustainable land management; UNCCD = United Nations Convention to Combat Desertification; UNDRR: United Nations Office for Disaster Risk Reduction.

Notes:

[a] Tier classification for global SDG indicators <https://unstats.un.org/sdgs/iaeg-sdgs/tier-classification/>.

Tier 1: Indicator is conceptually clear, has an internationally established methodology and standards are available, and data are regularly produced by countries for at least 50 per cent of countries and of the population in every region where the indicator is relevant.

Tier 2: Indicator is conceptually clear, has an internationally established methodology and standards are available, but data are not regularly produced by countries.

Tier 3: No internationally established methodology or standards are yet available for the indicator, but methodology/standards are being (or will be) developed or tested.

[b] In this table, SLM practices introduced are assumed to be drought-smart, as stated in document ICCD/COP(14)/CST/3.

Chapter 3: TECHNICAL GUIDANCE

This technical guidance chapter is structured in four parts. First, it lays out a step-by-step approach to using indicators to measure and assess drought resilience. Second, it offers some general guiding principles for the development and use of indicators to measure drought resilience. Third, lessons from broader resilience measurement and assessment tools (that do not necessarily focus on drought) are presented. Finally, an example of how to represent the results of drought resilience assessments is described.

3.1 A STEP-BY-STEP APPROACH TO USING DROUGHT RESILIENCE INDICATORS

This section provides an overview of a stepwise approach to drought resilience assessments, with each step described in detail. While the steps are described chronologically for the sake of simplicity, in reality, the steps in the process are iterative and informed by insights from across scales and sectors. Resilience assessments reflect current contexts and conditions, but these are likely to continually change. Therefore, while insights gained from past experience can be used as a starting point, these do not necessarily reflect future conditions. This calls for a flexible approach.

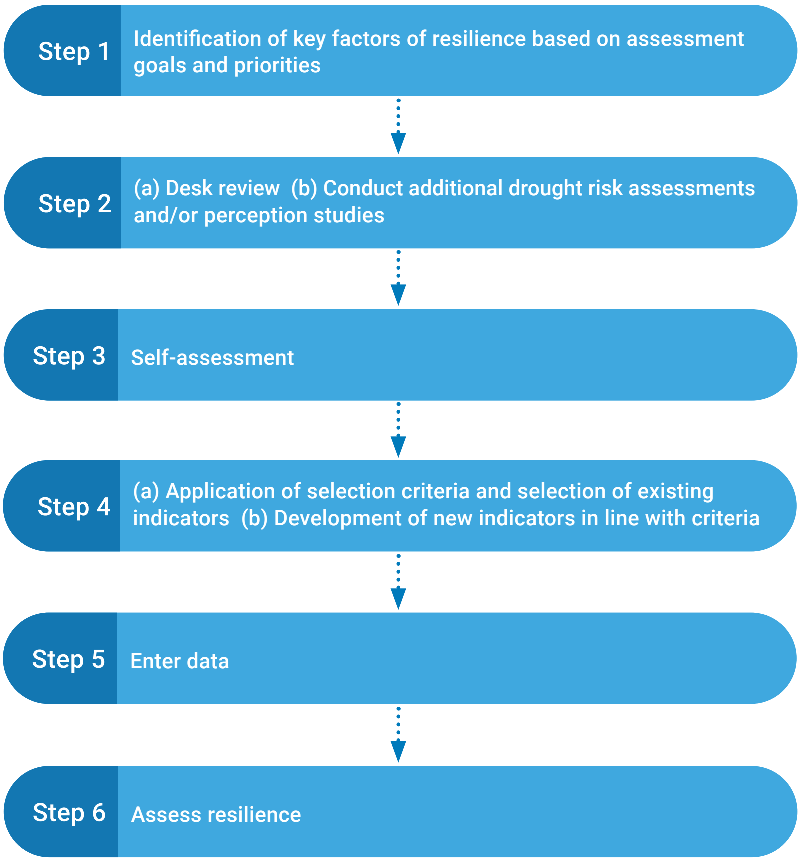
Combinations of different indicators and metrics offer important insights for assessing drought resilience. A review of scientific literature, a selection of national drought plans and strategies, and various international reporting documents (Annex 4) reveals typical processes used for climate change reporting (including reporting on LDN, NAP, SDG, NCs, etc.) already underway in several countries. Lessons learned from these reports are also useful for drought resilience assessments.

Entry points and processes for measuring and assessing resilience vary by country. In most cases, however, the institutions responsible for assessments must start with a clear understanding of the primary goals and priorities for measuring drought resilience. While some may prioritize the need to produce highly technical and granular assessments based on specific data for a particular environmental system, others may choose to focus on developing less technical scoping products that address drought resilience through participatory processes.

Next, the assessment should build on a thorough desk review of relevant policies, literature, and an inventory of data and indicators already in use. Countries reporting on their land degradation neutrality (LDN) and sustainable development goal (SDG) targets may find drought resilience assessments are not onerous, because they are already collecting relevant indicators and data. (Annex 1 of this report maps drought resilience indicators to relevant SDG targets and indicators.) A self-assessment of national, regional, or local capacities (i.e., technical, financial, and institutional capacities) to assess drought resilience will further highlight gaps that need to be addressed before undertaking assessments and can serve as a basis for securing the necessary financing and resources. When these preliminary assessments are complete, countries are ready to collect data and to decide on an appropriate framework for assessing resilience to drought. A resilience assessment framework is an analytical tool that can be applied to organize and synthesize the interrelated components, variables, methods, steps, or pathways employed in a structured approach to evaluate, assess, and/or monitor resilience (see Section 3.3).

The main steps for assessing drought resilience are illustrated in Figure 7 and described below. Practical examples helpful for understanding these steps can be found in Annex 4 of this report.

FIGURE 7 The key steps in an assessment of drought resilience



STEP 1: Identifying ecological and social resilience based on assessment goals

Stakeholder consensus concerning the main goals and priorities for undertaking a drought resilience assessment directly affects the selection of indicators. Understanding what key factors of resilience are of interest—ideally decided on jointly by multi-sector stakeholders—a will determine what existing resilience assessment framework should apply, what data is needed, and what institutions should be involved in the process. At the same time, the resilience of a system cannot be understood simply as the sum of the resilience of its components. Direct, indirect, and longer-term effects on ecosystems and national economies should be taken into account, including climate change processes.

This step is intended to allow countries to focus or guide their assessments of drought resilience.

STEP 2: Conducting a desk review

The second step in an assessment of drought resilience involves a desk review of the following: existing literature (including climate risk and disaster studies); drought vulnerability and impact assessments (where available); existing drought policies and strategies; and of other key documents. This review is needed to understand the different dimensions of drought resilience, as well as drought-related risks, vulnerabilities, and exposure within relevant socioeconomic sectors and environmental systems.

This step provides a good overview of what knowledge and resources already exist, what policy framework to operate within, what institutions should be involved in the process, and what sources of financing can potentially be used. Sometimes when drought-specific studies and reports are not available at the relevant scale or do not provide robust evidence, an intermediate step (i.e., 2(b) in Figure 7) of conducting additional drought risk assessments coupled with perception studies can provide a better understanding of the context.

STEP 3: Conducting a self-assessment of capacities and priorities

A self-assessment of capacities and priorities informs decisions about what drought resilience indicators to use. The self-assessment also achieves several other things: it ensures the setting of realistic objectives; it flags any gaps or barriers that may hinder the assessment and, where possible, points to resources to overcome them; and it starts the process of obtaining the necessary data.

The results of the desk review can be used by decision makers to formulate, in an informed and deliberate way, their primary objective in measuring and assessing resilience. Countries may be interested in generating information with a high level of accuracy and specificity or in capturing the multi-dimensionality of drought through participatory policy processes. On the other hand, they may be interested in undertaking a basic, indicative assessment that fulfils multiple reporting obligations in both the domestic and international contexts. Each option represents a trade-off between accuracy, multi-dimensionality, and technical effort.

Many countries may prefer to use a technically less demanding resilience assessment framework with easily available or existing indicators, even if these indicators may not be definitive and are not necessarily applicable across multiple scales. This kind of 'basic' assessment may also make use of data that is already routinely collected by countries and that can be accessed through their respective statistical agencies or remote sensing platforms.

When using resilience assessment frameworks that rely on national-level datasets, it is important to consider that these data do not generally effectively target the most drought-prone regions within countries (King-Okumu *et al*., 2020). However, the use of data from spatially explicit studies and an enhancement of national-level datasets through capacity building can help overcome this.

STEP 4: Applying selection criteria and selecting/developing indicators

National governments, in fulfilment of their international reporting obligations and their own domestic targets, can "direct and coordinate assessments, including sub-national and regional processes," particularly involving water governance bodies (UNCCD, 2019c). After selecting the appropriate indicators for the context of the assessment (based on Steps 1-3), governments may choose a relevant set of indicators for measuring and assessing resilience (see Section 3.2).

Sometimes, using fewer indicators that provide approximate measures of important dimensions of resilience are considered preferable to a large number of detailed indicators on several potentially relevant but less informative aspects of drought resilience. This may be particularly true if the costs involved in data collection and monitoring of these resilience indicators are high.

Countries need to make efforts to reduce data gaps to obtain more robust indicators. These gaps may cause nations to overlook and underestimate the effects of drought on the most vulnerable populations. Involving the most vulnerable groups in the assessment ensures their priorities and well-being are taken into account.

Where possible, countries can assess vulnerability using a bottom-up approach. This should (i) focus on people and their livelihoods; (ii) capture changes in the provision of ecosystem services, including from agriculture and across other sectors; and (iii) account for the effects on the water balance at basin and sub-basin levels that further exacerbate vulnerability to drought. This assessment may be a community-driven process, potentially conducted at the level of self-help groups, cooperatives, or basin/resource-use councils, as has been done in Mexico (see UNCCD, 2019c, p. 14). Tools that can be employed in a participatory manner include Tree Diagrams, Seasonal Calendars, Scenario Development, Rivers of Life, and Resource/Hazard Mapping, among others.

Countries may draw on processes that are already ongoing at local levels and connect or aggregate them where possible to national- and global-level actions. Countries may also choose to undertake a top-down assessment using global indicators (such as SDG indicators) and combine them with a GIS-based approach (see Section 2.2). Such a spatial approach can be used to identify systemic changes over time, whether they are positive or negative, ultimately linking this with the bottom-up approach described above (Mansuri and Rao, 2013).

STEPS 5 and 6: Entering data and assessing resilience

The final steps of the process involve entering the collected data and assessing resilience. These steps may be guided by any one of the available resilience assessment frameworks described in Section 3.3. Again, as this is an iterative process, countries may need to review and validate the resilience assessment and to revisit previous steps in light of changing conditions and lessons learned to continually improve the quality of results and the process itself.

3.2 GUIDING PRINCIPLES

This section provides guiding principles for the selection of indicators for assessing drought resilience.

A. Indicators need to be understood to assess resilience

While indicators are critical to assessing resilience, they should not be understood as a simple tool that provides a comprehensive measure of social and ecological resilience to droughts. Instead, indicators are a way of quantifying and monitoring resilience information while considering the time horizons to possible recovery (i.e., whether short- or long-term). As such, resilience indicators cannot be used on their own and require analysis prior to their selection. Indicators also provide a yardstick for measuring how changes in policies or other factors impact the overall resilience of societies and ecosystems.

B. Key criteria guide the selection of indicators for social and ecological resilience to drought

The selection of indicators for assessing social and ecological resilience should be guided by key criteria. Key criteria identified by Spearman and McGray (2011) in the context of climate change adaptation are useful, especially for policy formation and implementation. These have been adapted for drought resilience and are listed as questions below. More positive answers ("yes") to the questions mean an indicator is more effective as a measure of drought resilience.

1. Validity: Does the indicator measure a change in drought resilience?
2. Precise Meaning: Do stakeholders agree on exactly what the indicator measures in this context?
3. Practical, Affordable, and Simple: Are drought resilience-relevant data available at a reasonable cost and effort? Will it be easy to collect and analyse the information?
4. Reliability: Can the indicator be consistently measured against the drought resilience baseline over the short, medium, and long term?
5. Sensitivity: To what degree is the indicator affected, either adversely or beneficially, by climate variability or change? To what degree is the indicator affected by changes in the system's capacity to respond to these effects (also known as adaptive capacity)?

6. Clear Direction: Are we sure whether an increase in value is good or bad and in what dimensions?

7. Utility: Will the information collected be useful for management, accountability, and learning?

8. Owned: Do stakeholders agree that this indicator makes sense for describing resilience?

The best drought resilience indicators are those for which responses are positive to all the questions. However, users must balance trade-offs between criteria. Indicators that are reliable over a long time-horizon may not always be the simplest to use. Ultimately, users may choose to prioritize indicators that are the most accessible and practical for use.

While data collection and processing capacities may vary between regions, some meaningful data—in some shape or form—are usually available (UNDRR, 2019). Greater international attention and more focused funding to obtain useful indicator data across different socioeconomic sectors and environmental systems are improving resilience assessment results. The availability of open-source global datasets is improving for several variables that provide information on drought severity, drought vulnerability, and risk (UNDRR, 2019).

Detailed, site-specific data, such as agricultural losses by crop type and locality, are also increasingly available. In addition, more countries have established national disaster-loss databases as part of a "low-cost, high-impact strategy" to assess drought risk and resilience to inform future actions (UNDRR, 2016). As more countries commit to measuring and reporting on indicators that help them understand their resilience to drought and climate change, calls grow for more investment in monitoring infrastructure and assessments.

It is important to note that accessing and generating meaningful data does not necessarily require a large amount of funding and technology. Many national governments—even in the most vulnerable countries—have the means to collect, analyse, and use data of different types, and in many cases, development actors and the private sector are able to fill data gaps. Globally, countries are investing in statistical capacity-building, mainstreaming cross-sectoral collaboration, and exploiting synergies between complex data systems. It is critical to keep building on this strong momentum and to ensure that coordinated, integrated global and national efforts continue to strengthen data generation, capacities, and reporting (UNDRR, 2019).

3.3 AN OVERVIEW OF RESILIENCE ASSESSMENT FRAMEWORKS

This section explores some of the existing theoretical frameworks available for guiding drought resilience assessments. A resilience assessment framework is an analytical tool that can be applied to organize and synthesize the interrelated components, variables, methods, steps, or pathways employed in a structured approach to evaluate, assess, and/or monitor resilience.

Many tools exist for measuring and assessing resilience, generally. These are not specific to drought, but the lessons learned from them, as presented in this report, are pertinent for drought resilience assessments. In general, institutions responsible for improving social and ecological resilience embed resilience assessment tools within their own frameworks, using their own definitions, methodologies, and data requirements. This has led to variation in the application of the resilience concept.

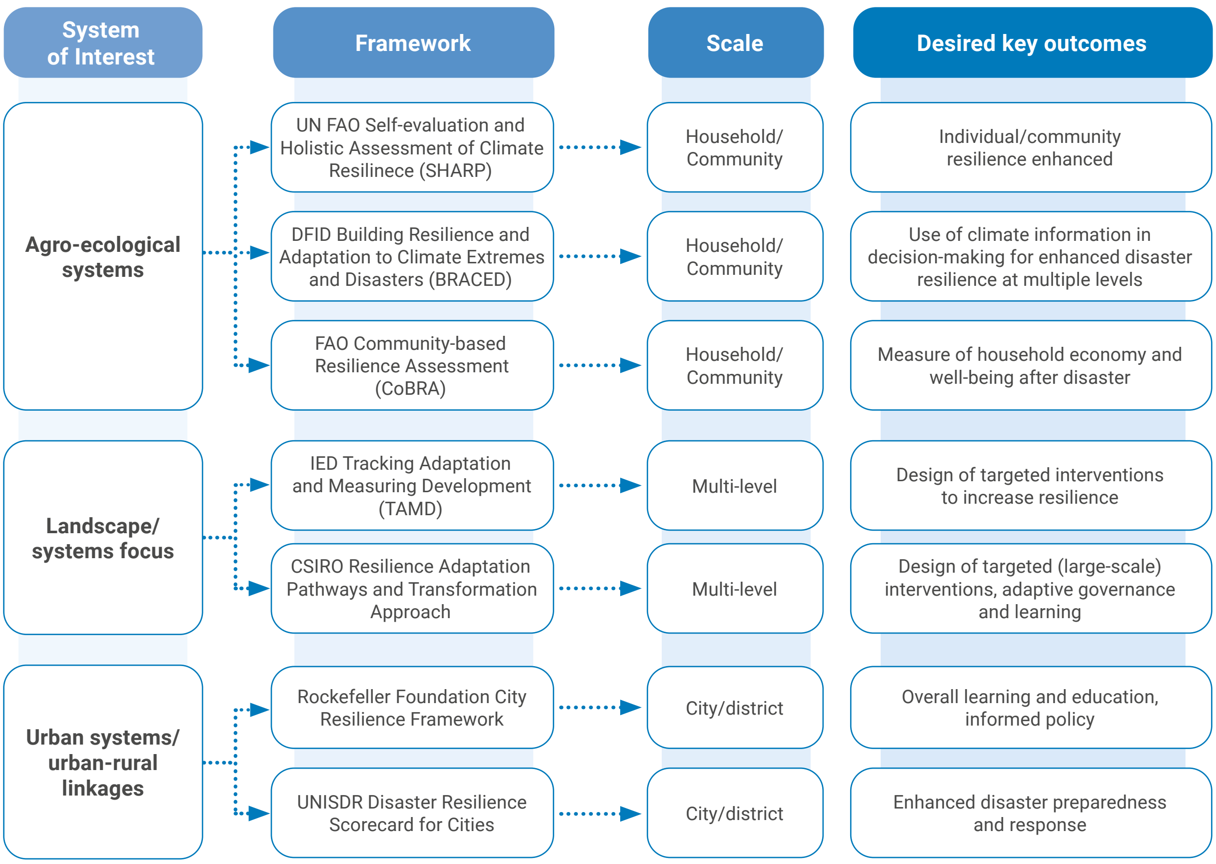
While some frameworks focus explicitly on agro-ecological systems, for example, others take a wider systems or landscape perspective. Some frameworks are applied in rural settings, while others are applied in urban contexts. Still other frameworks include explicit disaster risk reduction proactive measures as drought plans, monitoring systems, etc.

From a policy perspective, applying a landscape-level framework will yield the best results, because it considers the complex interlinkages between socio-ecological systems (Browder *et al.*, 2021). However, countries must try to identify frameworks that they find to be "simple and operational" to address complexity and assess resilience in their particular contexts (Douxchamps *et al.*, 2017).

Examples of resilience assessment frameworks are provided in Figure 8. These examples can guide the selection of an appropriate framework based on a user's national sustainable development and climate change priorities and desired assessment outcomes. Each framework is further described with reference to its methodological guidance in Box 2. The list is not exhaustive but, it provides multiple examples.

Once countries have used this guidance to select a suitable framework, they can visit the respective guidance report or webpage to select specific tools to apply in their area of interest. Frameworks can be selected depending on the key resilience component of interest (i.e., ecological, socioeconomic, or both). For frameworks focused on key components, the applicable scale, required data sources, and key outcomes of the process are highlighted.

FIGURE 8 **A selection of resilience assessment frameworks based on systems of interest**



BOX 2. Examples of resilience assessment frameworks at multiple scales

UN FAO Self-evaluation and Holistic Assessment of Climate Resilience (SHARP)
The added value of the SHARP framework is its focus on farmers and pastoralist resilience. It takes into account relevant dimensions such as access to markets, group membership, and sustainable land management practices. The assessment is structured around 13 themes, each with multiple sub-questions. It also prioritizes assessments for women and vulnerable peoples, and guides the user to undertake gender disaggregated data collection and analysis. Data sources for this approach include community engagement (e.g., interviews, mapping, surveys, transect walks) and records from statistical agencies.

Guidance: www.fao.org/3/a-i4495e.pdf

DFID Building Resilience & Adaptation to Climate Extremes & Disasters (BRACED)
The BRACED framework focuses on disaster risk reduction using climate information and involves an analysis of this risk reduction for vulnerable populations. It is structured around four main objects with 20 sub-questions. It also guides users to undertake gender disaggregated data analysis. Data sources for this approach include community engagement (e.g., interviews, mapping, surveys, and transect walks) and records from statistical agencies.

Guidance: BRACED

FAO Community-based Resilience Assessment (CoBRA)
The CoBRA framework focuses a resilience assessment on farmers and their livelihoods and on emergency responses. It uses a household-economy analysis and structures this analysis on the five capitals approach. It requires localized field work and community engagement (e.g., interviews and focus group discussions)

Guidance: CoBRA

IIED Tracking Adaptation and Measuring Development (TAMD)
The TAMD framework focuses on climate risk management and its associated adaptation outcomes. Its methodology is set across two ‘tracks’, comprising of 12 indicators aggregated at local, regional, and national levels (i.e., it can be used at multiple scales). The methodology calls for climate risk modelling, climate risk and vulnerability assessments, interviews, and surveys.

Guidance: TAMD

CSIRO Resilience Adaptation Pathways and Transformation Approach (RAPTA)
CSIRO examines the connection between vulnerable people and systems and advocates for transformative pathways towards resilience. Its step-by-step approach is set out across three major interlinked modules, each with three sub-themes for assessment. Data collection is done through stakeholder engagement mechanisms.

Guidance: RAPTA

Rockefeller Foundation City Resilience Framework (CRF)
CRF puts the focus of the resilience assessment on health and well-being, economy and society, infrastructure and environment, and leadership and strategy. These are measured by 12 indicators, comprising four dimensions and three sub-indicators. Data may be collected through multiple sources, including interviews, vulnerability studies, statistical records, mapping and city plans.

Guidance: City Resilience Framework

UNISDR Disaster Resilience Scorecard for Cities
This framework looks at urban disasters from the lens of policy, research, coordination, financing, communications, and disaster recovery. The methodology is organized around multiple themes and sub-questions that cities can apply themselves. Eighty-five evaluation criteria are used. Data may be collected from the climate change plans and strategies of cities/regions, from Hydromet agencies, and from satellite imagery.

Guidance: UNISDR Scorecard

Further considerations relevant to the selection and use of resilience assessment frameworks are highlighted below. These pertain to scale, temporal focus, ability to capture 'transformational' elements, and undertaking resilience cost assessments.

1. Scale

Resilience assessments should assess social and ecological resilience at multiple scales. The factors affecting resilience at different scales—from land units to watersheds, from communities to nations—interact across these scales. Understanding this interaction is crucial to understanding the state of the overall system and the resilience pathways potentially created through these interactions.

Most resilience assessment frameworks, however, focus on only one scale (e.g., national, local, or the scale of specific ecosystems). This is a reflection of the fact that the most comprehensive, multiscale resilience assessments are often too time consuming for many countries. While similar resilience assessment frameworks may be applied at different scales, indicators used in these assessments, as well as the weighting prescribed to them, may vary significantly.

Among the resilience assessment frameworks reviewed here, the Tracking Adaptation and Measuring Development (TAMD) framework from The International Institute for Environment and Development (IIED) and the Resilience Adaptation Pathways and Transformation Approach (RAPTA) framework created by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) are the closest to true multiscale assessments (Douxchamps *et al.,* 2017). When using either of these two frameworks, the appropriate scale for each indicator must be chosen at the time of assessment preparation, or vice versa, depending on the process and priorities of the responsible agency.

In some cases, the scale of the resilience assessment may be chosen first, and indicators appropriate for that scale are subsequently identified. Information can first be gathered at community or localized scales. For example, both TAMD and RAPTA suggest the use of indicators of social cohesion and the presence of social safety nets at local scales followed by the aggregation and compilation of datasets at national or higher scales.

In addition, TAMD and the UNDP Community-Based Resilience Analysis (CoBRA) tools are in fact both multiscale and multi-method frameworks, and therefore can be widely and flexibly applied. For reference, both these tools require several weeks for full implementation.

2. Temporal focus

Some resilience assessment frameworks recommend that indicators of resilience should be measured at two points in time, including measures ex-ante and ex-post to a drought event. This is the case for the Building Resilience & Adaptation to Climate Extremes & Disasters (BRACED) framework of the former Department for International Development (DFID; now the Foreign, Commonwealth and Development Office) of the United Kingdom. Other resilience assessment frameworks not discussed in detail here—such as the framework developed by the World Food Programme (WFP)—measure resilience using indicators for pre-disaster and post-disaster scenarios.

Other frameworks pay more attention to processes and global pictures of capacities rather than snapshots at different points in time (e.g., CARE's Africa Climate Change Resilience Alliance (ACCRA) Local Adaptive Capacity (LAC) framework, Tearfund's Climate Change and Degradation Risk and Adaptation Assessment (CEDRA), and the Characteristics of a Disaster-Resilient Community framework of DFID). Frameworks of this kind follow the "characteristics" method for assessing resilience that argues for describing a system's changing characteristics rather than measuring indicators (Douxchamps *et al.,* 2017).

3. Ability to capture societal and ecological changes affecting resilience

Users may have a clear idea of what they consider to be ‘desirable’ characteristics of a drought resilient system and may compare this to the results of their drought resilience assessment. An alternative approach is to define a set of undesirable system characteristics and to discuss these hypothetical undesirable characteristics with relevant stakeholders. This method is proposed, in part, by the RAPTA framework introduced above (Douxchamps *et al.,* 2017).

The idea is relevant for countries that wish to measure their capacities for ‘transformation’, which is a key concept in resilience thinking but is very difficult to measure in practice. In fact, the literature review did not reveal any tools that explicitly include indicators of transformation in their methodology. Thus, transformation can only be characterized or deduced through proxies—e.g., the presence of alternative of livelihood options or a system’s capacity to adapt and absorb shocks—or the desirable and undesirable characteristics of a system.

4. Undertaking drought resilience cost assessments

Assessing the economics of drought resilience can shed light on whether and how pre-emptive action and disaster risk reduction investments can result in both cost savings and avoided losses. This is highly relevant for policy makers, who must allocate scarce financial and technical resources across multiple sectors of their national economies.

In Kenya, USAID has used existing data (especially from the National Drought Management Authority) and empirical evidence to conduct economic drought resilience assessments. These data sources were combined with the CoBRA resilience assessment framework to dynamically model the potential impact of different response scenarios over 15 years for a population of 3 million across 11 livelihood zones in Turkana and Northeast Counties.

Nutrition outcomes significantly increased in 2013, coinciding with the start of large drought resilience investments for Kenya’s arid and semi-arid (ASAL) counties. Investing in early response and resilience measures were shown to provide benefits of USD 2.8 for every USD 1 invested. Across the study area, the models revealed early humanitarian responses would save an estimated USD 381 million in humanitarian relief over a 15-year period. When lost income and livestock losses were included in the models, the savings increased to an average of USD 52 million/year.

It is therefore recommended that users select a resilience assessment framework that enables such calculations to be made so that informed decisions can be made about drought mitigation and land management investments.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3.4 PRESENTING RESULTS OF A DROUGHT RESILIENCE ASSESSMENT

Assessing drought resilience involves several preparatory steps as described in Figure 7. This section describes how to undertake the final step of this process using an example. The example can be replicated with country/location-specific data when conducting drought resilience assessments.

Presenting the results of a drought resilience assessment involves compiling and evaluating the quantitative/qualitative characteristics of each indicator and presenting these in an easily understood fashion. One method is to combine the values of these indicators into aggregate resilience scores that correspond with categories of drought resilience characterized in a drought resilience index. An example of a five-category drought resilience index is presented in Table 9.

The main purpose of summarizing very complex and multi-faceted information about ecological or social drought resilience in a single index is to readily inform and improve policy and programs directed at building resilience to drought. Drought resilience indices also provide the means for monitoring dynamic changes in drought resilience across time and for measuring the success of development interventions for increasing drought resilience. These indices, however, should be used in combination with more detailed information about drought resilience that is most useful for prioritizing investments and development projects in areas with lower or the least drought resilience. This non-aggregated and granular data is critical for strengthening resilience to drought in particular localities and tailoring policy interventions to specific local needs.

TABLE 9 Five levels of resilience with their corresponding color codes and descriptions

Resilience levels	Resilience designation	Colour code	Description
1	Very low resilience		Unable to cope with droughts, i.e., drought will lead to permanent ecological/social impacts
2	Low resilience		Able to cope with droughts and avoid ecological/social collapse, but will experience significant disruptions, and will lose the capacity for long-term adaptation, learning, and transformation
3	Medium resilience		Able to cope with droughts, but will experience significant disruptions, will maintain the capacity for long-term adaptation, learning, and transformation
4	High resilience		Able to cope with droughts with minor disruptions, will fully maintain the capacity for long-term adaptation, learning, and transformation
5	Very high resilience		Fully capable to cope with droughts without any disruptions, and will fully maintain the capacity for long-term adaptation, learning, and transformation


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An important consideration when developing a drought resilience index is drought duration. An ecological or social system may be resilient to short and mild drought, but not resilient to a long and severe drought. Similarly, a system may be resilient to drought in present conditions, but its resilience declines with the increasing frequency/severity of droughts into the future as consequence of climate change. Thus, choosing a reference point in time against which resilience can be discerned is important. The choice of this drought reference point (i.e., is it the worst or an average drought? in which period?) can be made by the assessment team based on local characteristics and priorities.

A color-coding scheme can be an easy and effective way to visually communicate the results of a drought resilience index (e.g., Table 9). An assessment team can choose their own color scheme. A color code for the resilience index is also useful for spatial mapping that shows areas with low or high resilience and that enables location-based priority setting in efforts to strengthen resilience. There are already numerous examples of such visual applications of color-coded maps in drought-related resilience assessments (e.g., for ecosystem water use efficiency in India; Sharma and Goyal, 2018; see the map in Annex 3) and in assessments of ecosystems and societies to drought (e.g., Mexico; Ortega-Gaucin *et al.*, 2018; Annex 3).

The categories used for drought resilience indices (and their corresponding colors) are based on ranges of values for each indicator. These ranges of values are determined by the assessment team. There is no correct way of deciding on the ranges of values. Each team determines these values by considering local characteristics identified by experts and community focus groups.

Drought resilience indices can characterize drought resilience at multiple scales. However, drought resilience index scores at lower scales may not be the same at higher scales (e.g., at a district level compared to a country level), because the aggregated data may average out relevant local-level drought resilience information. For example, if most districts in any given country have high resilience and only a few districts have low resilience, the average country-level resilience can be skewed towards high resilience. The choice of which scale of drought resilience to represent depends on the users' purpose.

The methodology for scaling-up may also play a significant role in the quality of information captured by drought resilience indices (e.g., giving different weights to areas with higher population/food production, etc.). In general, more granular data are preferred to aggregate data in resilience assessments, because they provide better quality results.

Similarly, combining ecological and social resilience indicators to create a single drought resilience index is possible, but this broad index presents only general information that is often of limited scientific value. To combine ecological and social resilience indicator values (or scores), an assessment team may weigh them equally or give them different weighting depending on local conditions. Often, however, drought resilience indices present ecological and social resilience separately with different scores and resilience categories for each (e.g., Table 10). Another approach is to score each of the eight types of resilience indicators separately to provide a more detailed picture of the drought resilience of an area (e.g., Table 11).

TABLE 10 An example of a drought resilience index with separate resilience index categories for ecological and social drought resilience

Indicator typologies	Indicators	Resilience categories
Ecological drought resilience	Recovery of vegetation activity, soil carbon, number of grass and tree species, crop diversification	Medium (3)
Social drought resilience	Number of community self-help groups in the area, share of land users utilizing extension and advisory services, distance to markets, availability of water reservoirs, share of people living below the poverty line	Medium (3)

TABLE 11 An example of a drought resilience index with separate resilience index categories for eight resilience indicator types (Chapter 2)

Indicator typologies		Indicators	Resilience level
Natural capital	Water imbalance	ecosystem water use efficiency	medium (3)
	Ecosystem's recovery time after droughts	recovery of vegetation activity	medium (3)
	Soil characteristic	soil carbon	medium (3)
	Biodiversity and species richness	number of grass and tree species, crop diversification	low (2)
Social capital		number of community self-help groups in the area	high (4)
Human capital		share of land users utilizing extension and advisory services	medium (3)
Physical capital		distance to markets, availability of water reservoirs	low (2)
Economic capital		share of people living below the poverty line	low (2)

Chapter 4: **FURTHER ACTIONS NEEDED**

Drought resilience—the ability of societies to anticipate, absorb, accommodate, or recover from the effects of droughts in a timely and efficient manner--ensures the preservation, restoration, and improvement of a society's structures and functions in the face of drought impacts. This resilience to drought depends on maintaining and developing natural, economic, physical, human, and social capital with the help of enabling policies and institutions and the sustainable governance of natural resources.

The monitoring and assessment of the resilience of ecosystems and vulnerable populations to drought contributes to moving from reactive to proactive drought-response regimes and to improving the effectiveness and efficiency of proactive drought risk mitigation measures. The rising costs of droughts due to climate change impacts makes the assessment and monitoring of drought resilience more urgent and critical.

Information from drought resilience monitoring and assessments is essential for developing and promoting drought impact mitigation initiatives, such as *inter alia* ecosystem conservation and restoration, the adoption of drought resilient water and crop management practices, regenerative agriculture and agroecological practices, and socio-economic measures, such as drought risk mitigation planning, social protection schemes, and drought insurance models.

Drought resilience monitoring and assessments are particularly important in the context of vulnerable populations and ecosystems. These populations and ecosystems with low drought resilience may be small and localized, but their vulnerabilities can act as threat-multipliers with far-reaching consequences across larger scales. Building resilience at local or sub-national levels can therefore contribute to increased stability of wider socio-economic and ecological systems at regional and global levels.

Many countries currently collect data that can be readily used as indicators drought resilience. This data is often collected on a regular basis for other purposes or reporting obligations. In many cases, periodic assessments of drought resilience can therefore be conducted using this available information. In other cases, however, efforts are needed across national agencies and sectors to improve data generation for drought resilience assessments and to build assessment capacity in government departments. This improved capacity should establish feedback mechanisms for sharing data and findings between government departments implementing national social, economic, environmental, land, and drought policies.

The following proposals are intended for policymakers, practitioners, and the scientific community to improve capacities for drought resilience assessments and monitoring at multiple scales and to make these efforts an integral part of national drought preparedness and drought risk mitigation plans.

PROPOSAL 1. Establish two science-based operational definitions of drought resilience that (a) focus on resistance to drought impacts and (b) emphasize the generation of benefits from improved resilience.

To improve drought resilience monitoring and assessments, the SPI recommends using two operational definitions of drought resilience: i) a constrained working definition of resilience to drought that focuses on resistance to the impacts and risks of droughts and that is measurable in terms of reductions in these effects on populations and ecosystems; and ii) a positive definition of resilience to drought that focuses on capturing and measuring the benefits achieved by building resilience to drought that extend beyond reducing risks and negative impacts. This definition might refer to the positive effects of drought resilience on natural, economic, human, physical, and social capital.

PROPOSAL 2. Systematically collect, monitor, review, prioritize, and assess information on drought impacts.

Information about past impacts and costs from previous droughts is important for assessing and monitoring drought resilience as it evolves in response to changes in drought-related vulnerabilities, exposures, and hazards. This information is also essential to support integrated drought risk management. Integrated drought risk management includes three pillars: monitoring and early warning, vulnerability and impact assessment, and mitigation and response (IDMP, 2021). Integrated drought risk management guides national drought plans and policies, as well as ongoing discussions of loss, damages, returns on investments, natural capital accounting, and the United Nations System of Environmental and Economic Accounting (UNSEEA) framework. To collect data on past drought impacts and risks at national, subnational, and local levels, countries and institutions may consider using systematic and comparable approaches, such as those of the post-disaster needs assessment guides of the Global Facility for Disaster Reduction and Recovery (GFDRR). These approaches may include the following:

a. identifying, defining, and validating drought impact metrics and establishing scientific, evidence-based practices for understanding the minimum requirements for using core indicators and data for assessing drought resilience at different spatial scales and for different environmental systems and economic sectors;

b. qualitatively describing and, to the extent possible, quantitatively measuring drought impacts wherever appropriate using a systematic approach to collecting information deemed important and valuable at the national and/or sub-national levels;

c. assessing direct and indirect impacts on hydrological systems that affect ecological systems, agriculture, water resource availability, and different water-sensitive socioeconomic sectors, such as energy, food, tourism, and health;

d. examining the mitigation of the complex and cascading effects of drought that occur where preventive or remedial sustainable land management (SLM) actions could be taken;

e. analysing the extent to which SLM can prevent drought impacts from affecting vegetation conditions, water availability, and patterns of production, nutrition, health and well-being; and

f. exploring the impacts of drought and drought resilience on gender minorities and vulnerable populations.

PROPOSAL 3. Monitor and assess drought risk in natural and managed ecosystems.

Drought resilience is the capacity of ecological and socials systems to absorb and/or adapt to current and future droughts impacts. This capacity is measured relative to different levels of drought risk. Thus, drought risk information is critical for assessing and monitoring the drought resilience of natural and managed ecosystems. It is particularly vital for areas under pressure and on the brink of ecological collapse and that are more vulnerable to climate change and the effects of drought. Monitoring drought risk should (a) focus on the effects of drought on ecosystem services and on natural capital that enables ecosystems and populations to sustain themselves during drought, and (b) provide information for the development and promotion of drought impact mitigation initiatives that involve ecosystem conservation and restoration and drought-resilient water and crop management practices.

PROPOSAL 4. Support further research on the relationship between land drought and climate change

Although drought is a natural phenomenon affecting all regions, the changing climate and human pressures on land and water have exacerbated the severity, frequency, and duration of droughts and their economic impacts. This exacerbation is expected to worsen in the future. The SPI suggests the UNCCD—in collaboration with the Integrated Drought Management Programme (IDMP) and other relevant international organizations—support research on the impacts of climate change on drought resilience, particularly for arid and semi-arid regions of the world under various climate change scenarios. This work should build on existing relevant SPI and the IPCC publications, particularly the UNCCD SPI publication on *The Land-Drought Nexus* (Reichhuber *et al.*, 2019) and the IPCC special report on *Climate Change and Land* (IPCC, 2019). This research should provide scientific evidence to guide countries in developing and investing in integrated drought risk management and in promoting practices that improve drought resilience.

PROPOSAL 5. Integrate the findings from social and ecological drought resilience assessments into early warning systems that trigger decision-making on drought risk mitigation

Results from the assessment and monitoring of resilience to drought should be tied to early warning systems and triggers to inform decision makers about responses that proactively strengthen drought resilience. Early warning systems need to integrate not only biophysical factors, such as precipitation changes, but also changes in social factors affecting drought resilience. These early warning systems should be designed to trigger responsive drought-relief actions, proactive drought risk mitigation and drought preparedness, and investments in drought-smart sustainable land and water management (Pulwarty and Sivakumar, 2014).

PROPOSAL 6. Strengthen drought resilience assessment capacities and create widely applicable, novel tools and advanced technology for drought resilience data collecting, monitoring, assessment, learning, and information sharing

The UNCCD SPI recommends that the UNCCD secretariat—along with the Global Mechanism of the UNCCD (GM), FAO, UNDRR, UNEP, IDMP, UNESCO, and other cooperation partners—support Party Countries, where necessary, in the application of the advanced technologies of artificial intelligence, machine learning, spatial observation, crowdsourcing, citizen science, big data, household surveys, cloud services, and other digital-based, innovative tools to improve drought resilience assessments and drought early warning systems. These systems could be used to collect otherwise-unavailable data on indicators of natural, physical, social, human, and economic capital and to improve analysis on the interactions and connections between ecosystems and social economic sectors, including rural and urban areas. They could also improve accessibility to information for all stakeholders and cooperation partners for land management and business investment.

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ANNEXES

ANNEX 1. Aligning the drought resilience indicators inventoried in this report to relevant SDG targets and indicators

TABLE A1.1 Indicators of drought resilience focused on natural capital and relevant SDG targets and indicators

Drought resilience indicator	Related SDG targets and indicators
Water-related indicators	**SDG 6.4.** By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity. Indicators: • 6.4.1. Change in water-use efficiency over time • 6.4.2. Level of water stress: freshwater withdrawal as a proportion of available freshwater resources
Ecosystem recovery time after droughts	
Seasonal soil moisture levels and characteristics influencing soil moisture holding capacity	**SDG 15.3.** Combat desertification, restore degraded land and soil, including land affected desertification, drought (…) Indicators: • 15.3.1. Proportion of land that is degraded over total land area • Three sub-indicators: trends in land cover change, trends in land productivity, trends in soil organic carbon (SOC) change
	SDG 2.3. By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists, and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment (linked to the Table below on social capital indicators). **SDG 2.4.** By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality. Indicator: • 2.4.1. Proportion of agricultural area under productive and sustainable agriculture

TABLE A1.1 Indicators of drought resilience focused on natural capital and relevant SDG targets and indicators (continued)

Drought resilience indicator	Related SDG targets and indicators
Biodiversity and species richness	**SDG 15.3.** Take action to reduce the degradation of natural habitats, (…) protect and prevent the extinction of threatened species. Indicator: • Red List Index
	SDG 15.4. Ensure conservation of mountain ecosystems (…). Indicator: • Coverage by protected areas of important sites for mountain biodiversity
	SDG 15.1. Ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services. Indicator: • Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type

TABLE A1.2 Indicators of drought resilience focused on social capital and relevant SDG targets and indicators

Drought resilience indicator	Related SDG targets and indicators
Population / women / men / Indigenous peoples and local communities with secure rights to land, property, and natural resources, measured by (a) % with legally documented or recognized evidence of tenure, and/ or (b) % who perceive their rights are recognized and protected	**SDG 1.4.** Ensure access to basics, services, ownership, land property, appropriate new technology, and financial services Indicator: • 1.4.2. Proportion of total adult population with secure tenure rights to land (a) with legally recognized documentation, and (b) who perceive their rights to land as secure, by sex and type of tenure **SDG 5.a.** Undertake reforms to give women equal rights (…) to ownership and control over land other forms of property (…) Indicators: • Proportion of total agricultural population with ownership or secure rights over agricultural land, by sex • Share of women among owners or rights-bearers of agricultural land, by type of tenure
Health	**SDG 3.9.** Substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination Indicators: • Mortality rate attributed to household and ambient air pollution • Mortality rate attributed to unsafe water, unsafe sanitation, and lack of hygiene (exposure to unsafe Water, Sanitation and Hygiene for All (WASH) services) • Mortality rate attributed to unintentional poisoning

TABLE A1.2 Indicators of drought resilience focused on social capital and relevant SDG targets and indicators (continued)

Drought resilience indicator	Related SDG targets and indicators
Presence of decentralized climate change/natural resource or land use commissions and disaster and adaptation plans	**SDG 1.5.** Build resilience of the poor to climate-related disasters Indicators: • Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population • Direct economic loss attributed to disasters in relation to global gross domestic product (GDP) • Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030 • Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies **SDG 11.3.** Enhance inclusive, sustainable urbanization and capacity for participatory, sustainable human settlement planning and management Indicators: • Ratio of land consumption rate to population growth rate • Proportion of cities with a direct participation structure of civil society in urban planning and management that operate regularly and democratically **SDG 11.a.** Support positive economic, social, and environmental links between urban, peri-urban, and rural areas by strengthening national and regional development planning Indicator: • Number of countries that have national urban policies or regional development plans that (a) respond to population dynamics; (b) ensure balanced territorial development; and (c) increase local fiscal space **SDG 11.b.** Increase the number of cities adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disaster, in line with the Sendai Framework for Disaster Risk Reduction 2015–2030 and holistic disaster risk management at all levels Indicators: • Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030 • Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies

TABLE A1.2 Indicators of drought resilience focused on social capital and relevant SDG targets and indicators (continued)

Drought resilience indicator	Related SDG targets and indicators
Stakeholder empowerment and degree of inclusion/ autonomy in decision-making processes: Indicators to measure inclusion (gender) and consensus, such as number of consultation meetings and workshops, and attendance by multiple stakeholders	**SDG 16.7.** Ensure responsive, inclusive, participatory and representative decision-making at all levels Indicators: • Proportion of positions in national and local institutions, including (a) the legislatures; (b) the public service; and (c) the judiciary, compared to national distributions, by sex, age, persons with disabilities and population groups • Proportion of population who believe decision making is inclusive and responsive, by sex, age, disability and population group **SDG 17.16.** Enhance global partnership for sustainable development Indicator: • Number of countries reporting progress in multi-stakeholder development effectiveness monitoring frameworks that support the achievement of the SDGs **SDG 17.6.** Enhance North-South, South-South, and triangular regional and international cooperation on and access to science, technology and innovation and enhance knowledge sharing on mutually agreed terms Indicator: • Fixed Internet broadband subscriptions per 100 inhabitants, by speed

TABLE A1.3 Indicators of drought resilience focused on human capital and relevant SDG targets and indicators

Drought resilience indicator	Related SDG targets and indicators
Local knowledge: The presence of traditional and local forms of drought mitigation and adaptation mechanisms and practices	**SDG 2.5.** Maintain genetic diversity of seeds (…), managed and diversified seed and plant banks and promote access to and fair, equitable sharing of benefits of genetic and resources and associated traditional knowledge Indicators: • Proportion of local breeds classified as being at risk of extinction • Number of plant and animal genetic resources for food and agriculture secured in either medium- or long-term conservation facilities
Ability to diversify income generation: % of target households (from those Y% are women) in Z area have enough cash to meet their survival threshold or livelihood protection threshold; #/% of target able to stabilize/improve their net income by a specified improvement/ alternative livelihood	**SDG 2.3.** Double agricultural incomes of small-scale farmers including through secure access to financial services and markets Indicators: • 2.3.1. Volume of production per labor unit by classes of farming/ pastoral/forestry enterprise size • 2.3.2. Average income of small-scale food producers, by sex and indigenous status

TABLE A1.4 Indicators of drought resilience focused on physical capital and relevant SDG targets and indicators

Drought resilience indicator	Related SDG targets and indicators
Total number of facilities and infrastructures: e.g., % coverage of population/ area by a particular facility or asset; access to markets measured through remoteness or physical distance indicators.	**SDG 1.4.** Ensure access to basic services, ownership, land property, appropriate new technology, and financial services Indicator: • Proportion of population living in households with access to basic services **SDG 4.a.** Build and upgrade education facilities Indicator: • Proportion of schools offering basic services, by type of service **SDG 9.1.** Develop resilient infrastructure to support economic development Indicators: • Proportion of the rural population who live within 2 km of an all-season road • Passenger and freight volumes, by mode of Transport **SDG 9.a.** Facilitate sustainable and resilient infrastructure in developing countries Indicator: • Total official international support (official development assistance plus other official flows) to infrastructure **SDG 11.2.** Access to transport systems, improving road safety, expanding public transport Indicator: • Proportion of population that has convenient access to public transport, by sex, age and persons with disabilities
Availability of adaptation technologies and innovations: #/% of target population able to protect / replace / increase / improve their productive assets above pre disaster or baseline levels safely	**SDG 17.7.** Promote development, transfer, dissemination and diffusion of environmentally sound technologies to developing countries Indicator: • Total amount of funding for developing countries to promote the development, transfer, dissemination and diffusion of environmentally sound technologies

TABLE A1.4 Indicators of drought resilience focused on physical capital and relevant SDG targets and indicators (continued)

Drought resilience indicator	Related SDG targets and indicators
Connection/access to drought resistant landscapes, water reservoirs, and irrigation mechanisms	**SDG 6.4.** Increase water-use efficiency across all sectors and address water scarcity Indicators: • Change in water-use efficiency over time • Level of water stress: freshwater withdrawal as a proportion of available freshwater resources **SDG 6.3.** Improve water quality, increase recycling and safe reuse globally Indicators: • Proportion of domestic and industrial wastewater flows safely treated • Proportion of bodies of water with good ambient water quality **SDG 6.5.** Implement water resources management at all levels Indicators: • Degree of integrated water resources management • Proportion of transboundary basin area with an operational arrangement for water cooperation **SDG 11.1.** ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums Indicator: • Proportion of urban population living in slums, informal settlements or inadequate housing

TABLE A1.5 Indicators of drought resilience focused on economic capital and relevant SDG targets and indicators

Drought resilience indicator	Related SDG targets and indicators
Percentage of population living below the national poverty level: % of target population (from those X % are women) to restore their livelihood activity/income to pre -disaster level	**SDG 1.1.** Eradicate extreme poverty everywhere Indicator: • Proportion of the population living below the international poverty line by sex, age, employment status and geographic location (urban/rural) **SDG 1.2.** Reduce half of proportion of all living in poverty Indicator: • Proportion of population living below the national poverty line, by sex and age **SDG 8.10.** Strengthen the capacity of domestic financial institutions to encourage and expand access to banking, insurance and financial services Indicators: • Number of commercial bank branches per 100,000 adults and number of automated teller machines (ATMs) per 100,000 adults • Proportion of adults (15 years and older) with an account at a bank or other financial institution or with a mobile-money-service provider

TABLE A1.5 Indicators of drought resilience focused on economic capital and relevant SDG targets and indicators (continued)

Drought resilience indicator	Related SDG targets and indicators
Financial investments	**SDG 2.a.** Increase investment in international cooperation, rural infrastructure, agricultural research, technology development, plant and gene banks to enhance agricultural productivity Indicators: • The agriculture orientation index for government expenditures • Total official flows (official development assistance plus other official flows) to the agriculture sector **SDG 15.a.** Mobilize and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems Indicator: • Official development assistance on conservation and sustainable use of biodiversity • Revenue generated and finance mobilized from biodiversity-relevant economic instruments **SDG 15.b.** Mobilize significant resources from all sources to finance sustainable forest management and provide adequate incentives to developing countries to advance such management, including for conservation and reforestation Indicator: • Official development assistance on conservation and sustainable use of biodiversity • Revenue generated and finance mobilized from biodiversity-relevant economic instruments **SDG 9.3.** Increase the access of small-scale industrial and other enterprises to financial services, including affordable credit and their integration into value chains and markets Indicators: • Proportion of small-scale industries in total industry value added • Proportion of small-scale industries with a loan or line of credit

ANNEX 2. Practical examples and methodologies for using indicators to measure ecological resilience to drought

TABLE A2.1 Practical examples of the application of indicators on ecosystems recovery time after droughts

Case studies	Complexity	Methodology, data and sources
Dorman *et al.*, 2015	Advanced (quantitative, qualitative, spatial)	➔ **Statistical methods used:** linear models, simulations, binomial Generalized Linear Model, visual comparison, correlation, cluster analysis, using the algorithm of Hartigan and Wong (1979) to analyse the spatial pattern of Normalized Difference Vegetation Index (NDVI) change through time, liner regression • Dendrochronological sampling was collected for tree growth measurement • Forest mortality and trees density were measured using a high-resolution (0.25 m) orthophoto • Living and dead trees were identified within subsets that consisted of a randomly selected 10% of the 6070 grid cells • Forest age was calculated based on planting dates GIS layer • Historical aerial photographs were used to delineate previously cultivated fields • Landsat satellite images (from Landsat-5 TM, Landsat-7 ETM) were used to calculate NDVI time-series • precipitation (P), minimum temperature (Tmin), and maximum temperature (Tmax) daily data were obtained from the standard meteorological station

TABLE A2.1 Practical examples of the application of indicators on ecosystems recovery time after droughts (continued)

Case studies	Complexity	Methodology, data and sources
Miranda *et al.*, 2020	Advanced (quantitative, spatial)	➔ **Statistical methods used:** simple linear regression, correlation, several equations • Data were selected from the MODIS sensor, mounted in the TERRA and AQUA satellites • The Normalized Difference Vegetation Index (NDVI) was used for the estimation of several vegetation parameters • Two principal metrics were used to quantify the resilience of the forest as a drought response variable: i) the proportional change in the NDVI (Cp) between the pre-drought period (PreDr) and drought period (Dr) and ii) the magnitude of the NDVI trend over time • For climate data, each pixel was assigned the value of the slope in the temporal series for monthly precipitation. and mean monthly temperature. This was done by fitting a simple linear regression for each temporal series • The elevation and aspect were obtained from the digital elevation model (DEM) • Field work was carried out with two aims: i) relate the satellite information with the field information, discarding a different effect than drought on the NDVI as logging and fires and ii) validate the official cartographic information about tree species composition

TABLE A2.1 Practical examples of the application of indicators on ecosystems recovery time after droughts (continued)

Case studies	Complexity	Methodology, data and sources
Yu *et al.*, 2017	Advanced (quantitative, spatial)	➔ **Statistical methods used:** ET algorithm, which is based on the Penman-Monteith equation; to evaluate the recovery level of ecosystems, several equations were applied. • Land cover type information is derived from MODIS land cover products • DSI (Drought Severity Index) products were used in analyses of droughts and ecosystem responses • Water use efficiency (WUE) derived from the GPP and ET products was evaluated to detect the drought induced changes involved in trade-offs between C gain and water loss in different ecosystems. • Climatic datasets, such as air temperature and precipitation, were obtained from the Climate Research Unit at half-degree resolution. • Global coverage daily soil moisture (SM) data were derived from the ESA Global Monitoring of Essential Climate Variables. The soil moisture data were then summarized, resampled, and gap-filled to 8-day time series at a half-degree spatial resolution • Ecosystem GPP, a metric of photosynthetic activity, was used to evaluate the recovery level of ecosystem vitality after drought impacts
Na-U-Dom *et al.*, 2017	Moderate (quantitative, spatial)	➔ **Statistical methods used:** Savitzky Golay method, auto-regressive model based on De Keersmaecker *et al.*, 2016 • The Normalized Difference Vegetation Index (NDVI) time series were downloaded from the Global Inventory Modeling and Mapping Studies (GIMMS) for qualifying the response of ecosystem • Monthly temperature data were downloaded from the Climate Research Unit Time Series Version 3.23 (CRU-TS 3.23) • The drought effect was evaluated using the Standardized Precipitation – Evapotranspiration index (SPEI). It was calculated from the average water balance, with the same temporal frame as NDVI time series data. In this study, 3-month SPEI was used

TABLE A2.1 Practical examples of the application of indicators on ecosystems recovery time after droughts (continued)

Case studies	Complexity	Methodology, data and sources
Brodrick *et al.*, 2019	Advanced (quantitative, spatial)	➔ **Statistical methods used:** a trained deep learning model was used to determine dry season canopy water content (CWC) for the entire state at a 30m ground level spatial resolution • High-fidelity imaging spectroscopy were used to estimate CWC, the amount of liquid water in forest canopies above 2 m in height • Precipitation, temperature, vapor pressure deficit, climate water deficit and Palmer Drought Severity Index data was collected • Time period; aggregated these data over the period preceding the CWC maps • Drought resistance was investigated by examining the relationship between meteorological deviations and physiological drought response
Blue *et al.*, 2017	Moderate (quantitative, qualitative, spatial)	➔ **Statistical methods used:** tool for urban resilience case studies based on the approaches taken by a) Hajkowicz (2008) (a multi-criteria analysis method that included a priority matrix in which study participants ranked the issues presented according to the issue's importance to the participants) and b) by the Global Environment Facility (a more general mixed-methods approach in which each indicator in the assessment was assigned a set of choices that provided a quantitative rating (0 to 3) for that indicator). • The project team and sector subcommittees selected the quantitative and qualitative indicators for the tool based on expert knowledge and the literature on climate change and urban resilience. For each qualitative indicator (question), the project team developed four scores (answers) ranging from least resilient to most resilient. • For both the qualitative and quantitative indicators, the project team asked participants to assign an importance weight of 1 through 4. A weight of 1 indicated low importance, and a weight of 4 indicated high importance. For the qualitative indicators, the project team developed four possible ratings, with each indicator corresponding to a resilience score of 1 through 4 (again with 1 representing low resilience and 4 representing high resilience). • Resilience scores for indicators, sectors, or the city as a whole were used for the best comparison over time within the same city. Qualitative and quantitative indicators with high importance weights and high resilience scores demonstrate where cities are most resilient overall. • Each of the 54 indicators required specific sources indicated in example study.

TABLE A2.2 Practical examples of the application of indicators on soil characteristics

Case studies	Complexity	Methodology, data and sources
Jacobi *et al.*, 2013	Moderate (quantitative)	➔ **Statistical methods used:** ANOVAs, Kruskal–Wallis rank sum tests, Wilcoxon rank sum tests, Pearson's correlation • A transdisciplinary process included focus-group discussions, a participatory workshop and a combination of scientific predictions on the most probable climate change effects and local experiences of climate change impacts. This process led to the definition of eight key variables to be used as agroecosystem resilience indicators: oil organic matter, depth of Ah horizon, soil bulk density, tree species diversity, crop varieties diversity, ant species diversity, cocoa yields and infestation of cocoa trees • Farms were selected according to their cocoa cultivation system (monoculture, simple agroforestry or successional agroforestry) and their socio-economic characteristics • A sampling plot of 48 × 48 m was installed in the main cocoa plantation • Soil and biodiversity data were sampled in each sub-plot. From these sub-plot data, means for the entire sampling plot were calculated for further analysis • In order to determine yields and management practices, semi-structured interviews were conducted • In terms of soil indicators, soil organic matter (SOM), depth of Ah horizon, and bulk density were assessed by sampling • Tree species diversity in the cocoa sampling plots were determined with the help of local experts • Cocoa yield was measured in the field and through interviews with farmers • The response variables (one mean per farm calculated from the four sub-plots)—depth of Ah horizon, SOM, soil bulk density, tree species diversity, diversity of crop varieties, ant species diversity, cocoa yield and infestation of cocoa trees with M. perniciosa — were tested for significant differences between the explanatory variables simple agroforestry, successional agroforestry, and monoculture

TABLE A2.3 Practical examples of the application of indicators on biodiversity and species richness

Case studies	Complexity	Methodology, data and sources
Isbell *et al*, 2015	Moderate (quantitative)	→ **Statistical methods used:** linear mixed effects models; several equations were applied to define resilience and resistance • A standardized Precipitation-Evapotranspiration Index (SPEI) was used to consistently identify and quantify wet and dry climate events • Each experiment year was re-classified as extremely dry, moderately dry, normal, moderately wet, and extremely wet years based on other versions of SPEI that aggregate water balances over shorter or longer periods of time preceding peak biomass harvests, and then re-fit mixed effects models • Species richness treatments were randomly assigned to experimental units • Sample sizes were chosen within individual experiments to ensure adequate power to detect an effect of richness on productivity

TABLE A2.4 Practical examples of the application of water-related drought resilience indicators

Case studies	Complexity	Methodology, data and sources
Sharma and Goyal (2018)	Moderate (quantitative)	→ **Statistical methods used:** several equations were applied to define ecosystem drought resilience • Global annual MOD17A3 (NPP) and MOD16A3 (ET) products from the NASA Earth Observation System (EOS) program were used • Annual WUEe rasters were prepared using MODIS NPP and ET rasters. Average NPP and ET were computed for every district by taking the average of all pixel values in the district. The district-scale WUEe was calculated as the ratio of NPP and ET. Mean annual WUEe was computed as the average of 15 years (2000–2014) annual WUEe for every district

ANNEX 3. Practical cases of drought resilience assessment and mapping

INDIA: A district-level assessment of the ecohydrological resilience to hydroclimatic disturbances and its controlling factors

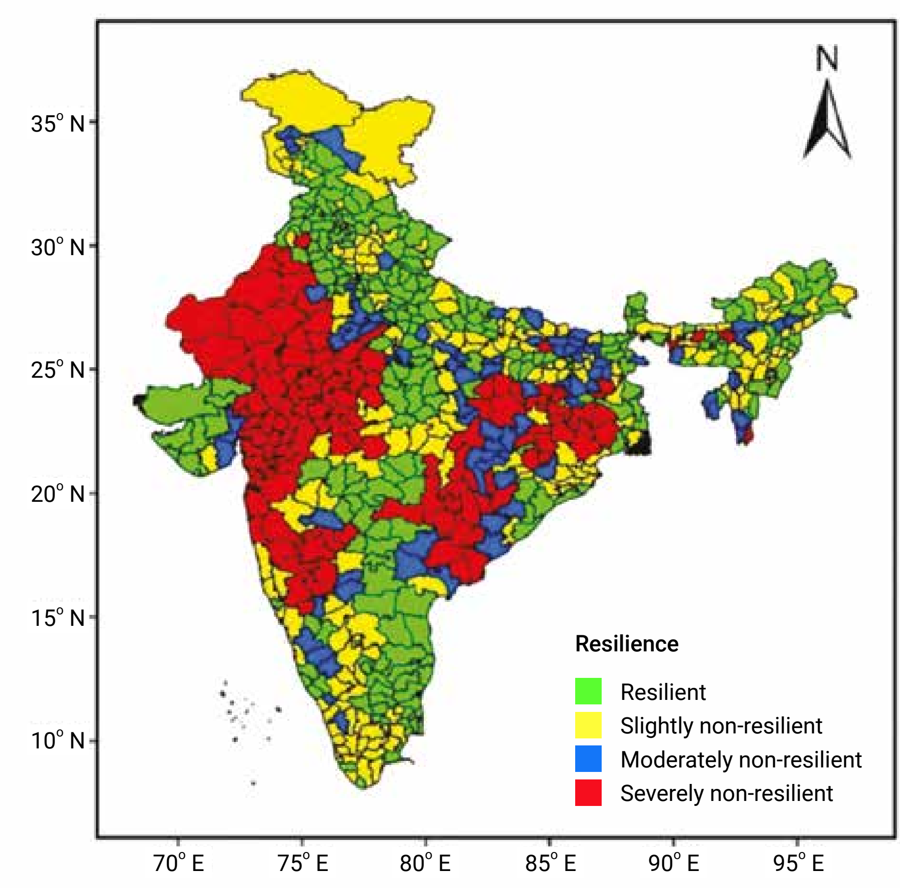
Source: Sharma and Goyal, 2018

In this case study, ecosystem water-use efficiency (WUEe) was defined as the ratio of net primary productivity (NPP) to evapotranspiration and used as an indicator of ecosystem functioning and its response to hydroclimatic disturbances.

The resilience was measured in terms of the ratio of the WUEe under the dry conditions and the mean WUEe, which indicates the ability to absorb hydroclimatic disturbance. In general, the forest-dominated districts had higher resilience compared to districts dominated by other biome types. Also, districts with a temperate climate were found to have higher resilience. The results of this study highlight the need for better ecosystem management policies in the country.

The study revealed a large spatial variation in WUEe in India at district scales, which was significantly higher in the lower Himalayan regions compared to rest of the country. An increasing trend in WUEe was found for central parts of the country.

FIGURE A3.1 A map showing the drought resilience of different districts in India



MEXICO: Drought Vulnerability Indices and mapping

Source : Ortega-Gaucin *et al.*, 2018

This study in Mexico was conducted using the nine steps indicated in Figure A3.2.

FIGURE A3.2 Nine steps in calculating Drought Vulnerability Indices

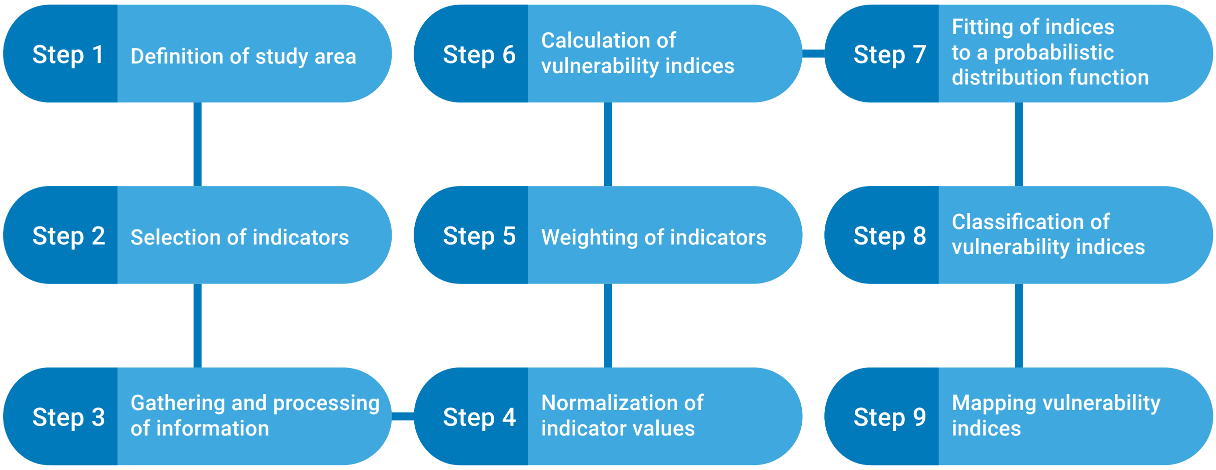
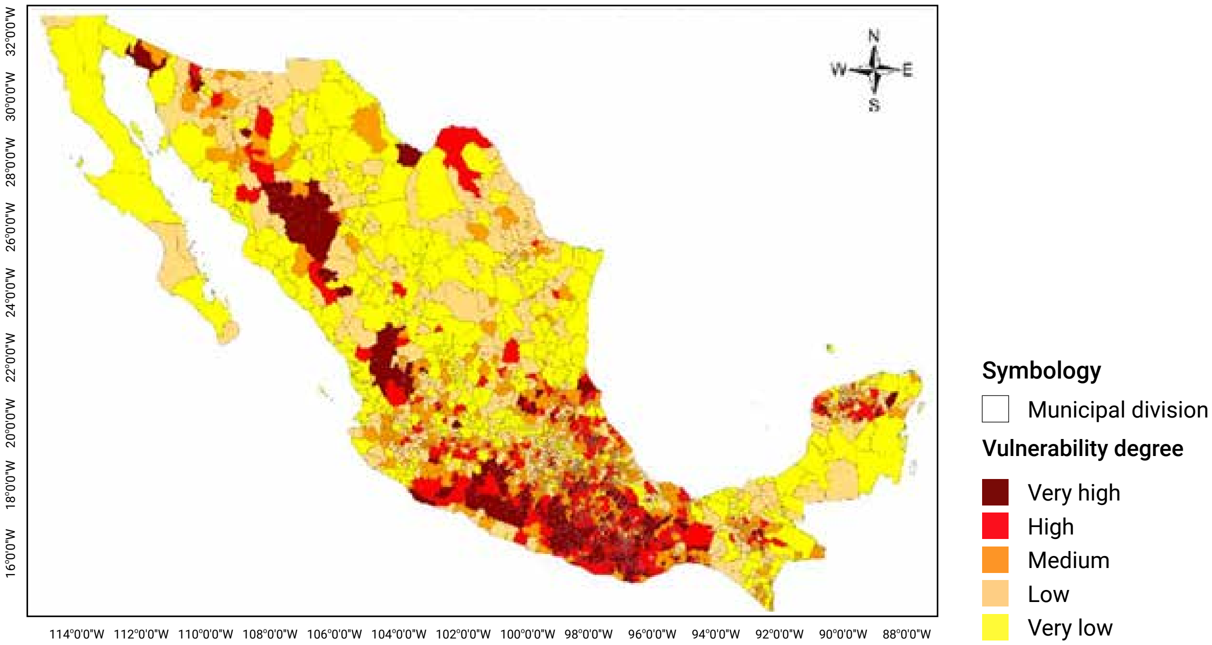


TABLE A3.1 Matrix showing the selected indicators, grouped by type and by the component of vulnerability to drought

Types of Vulnerability		Components of Vulnerability		
		Degree of Exposure (ED)	Sensitivity (S)	Adaptive Capacity (AC)
		Indicators		
Overall	Social	✓ Population density (persons/km^2) ✓ Population in poverty (%) ✓ Population without health care insurance (%)	✓ Households without running water (%) ✓ Households without drainage and flush toilet (%) ✓ Households with dirt floor (%)	✓ Beneficiaries of social programs (%) ✓ Average schooling years (dimensionless) ✓ Medical doctors per thousand inhabitants (dimensionless)
	Econmic	✓ Agriculture and livestock production units (dimensionless) ✓ Value of irrigated and rainfed agriculture production (thousands of MXN) ✓ Value of livestock production (thousands of MXN)	✓ Insufficient production infrastructure (%) ✓ Lack of technical assistance (%) ✓ Commercialization problems (%)	✓ Organization for production (%) ✓ Availability of credit and insurance (%) ✓ Technified agriculture surface (%)
	Environmental	✓ Aridity index (dimensionless) ✓ Degree of watershed exploitation (dimensionless) ✓ Degree of aquifer exploitation (dimensionless)	✓ Surface eroded or impregnated with saltpeter (ha) ✓ Deforested surface (%) ✓ Surface affected by forest fires (ha)	✓ Natural vegetation cover (km^2) ✓ Re-forested surface (ha) ✓ Protected natural areas (ha)

FIGURE A3.3 A map of social vulnerability to drought in Mexico



ANNEX 4. Practical examples and case studies illustrating the application of the six key steps for conducting a drought resilience assessment

Chapter 3 presents a step-by-step process to guide countries in undertaking drought resilience assessments. This section provides case studies and illustrative examples meant to inform the design of each step.

An example for Step 1: Identifying ecological and social resilience based on assessment goals

The identification of key factors of resilience ultimately depends on the assessment objectives and adaptation targets of the planner. For example, the UN Economic and Social Commission for Asia and the Pacific (UNESCAP) has developed a guidebook for practitioners based on lessons from Southeast Asia. It advocates for an approach focused on three key processes of resilience, namely, reducing or preventing drought (Track 1), preparing for and responding to drought (Track 2), and finally, restoring and recovering from drought (Track 3). Within this framework, the CGIAR initiated a five-year (2011-2015) project in Cambodia to help address rural vulnerabilities and ecosystem stability to increase social resilience. Based on scientific recommendations and alignment with national targets, the five key factors for strengthening resilience were (i) increasing incomes of rural households, (ii) developing income-generating activities for the 'extremely poor' households, (iii) diversifying the cropping system, (iv) increasing agricultural sales through promotions, and (v) strengthening the rice value chain and aquaculture systems. Under Track 2, countries are encouraged to build preparedness for drought by undertaking participatory or scientific vulnerability and risk monitoring and assessments. Governments in Southeast Asia are increasingly conducting these assessments and using them to develop robust plans to identify critical assets and initiate targeted resilience-building investments (UNESCAP, 2020).

An example for Step 2: Conducting a desk review

The City Council of Logan, Australia, developed its Climate Change Resilience Strategy for 2021-2031. As a starting point, the working group assessed the 'strategic fit' of their blueprint by taking stock of the various plans, policies, and strategies in place that were relevant to climate change and drought resilience across multiple scales and sectors. Next, the Council took stock of the major climate risks predicted for the region and the key assets at risk, based on a comprehensive literature review (Logan City Council, 2020). At the national level, Australia produced a resilience and adaptation strategy in 2015, which followed a similar process and relied strongly on inputs from scientific institutions such as the Bureau of Meteorology and the Commonwealth Scientific and Industrial Research Organization (CSIRO) (Commonwealth of Australia, 2015). This exercise served three purposes: it ensured that the new strategy would be aligned with the state, regional, national and international level goals mentioned in these documents; it allowed for the Council to include provisions in the strategy to address the previously identified barriers and gaps for resilience building and monitoring; and, finally, it eliminated the need to duplicate studies by building of existing knowledge.

An example for Step 3: Conducting a self-assessment of capacities and priorities

Kuwait has identified drought as a major hazard requiring targeted resilience-building action. The Kuwaiti Environment Public Authority (EPA) undertook an initial self-assessment of capacity, which allowed the relevant institutions to develop a clear mechanism for institutional coordination to achieve the objectives listed in the country's national adaptation plan (NAP). A working group led by the EPA first analysed the major climatic projections, physical impacts, vulnerabilities, and risks for major sectors of the country. Following this, it took stock of the relevant stakeholders and overall adaptation needs and capacities for planning and monitoring resilience to climate change. This included institutional capacities, potential support from the private sector, and informational and resource gaps and availabilities. It was recognized at this stage that geo-spatial data and modelling capacity would be required to meet their monitoring and evaluation objectives. The data were gathered through a comprehensive review of peer-reviewed articles and studies and national reports and built on the analyses already undertaken as part of the country's Second National Communications. GIS data were collated from the national electronic environmental Monitoring Information System of Kuwait (eMISK; Environmental Public Authority of Kuwait, 2019).

An example for Step 4: Applying selection criteria and selecting/developing indicators

As part of its climate resilience monitoring and reporting efforts, Mexico developed an exemplary list of national-level indicators. The process was not based on a participatory approach. Instead, it was the result of an expert rapid stock-taking exercise to evaluate key climate risks and institutional capacities to assess resilience. These served as criteria for the selection of indicators. The list of indicators covered the five capital dimensions (i.e., social, institutional, economic, physical, and natural capital) and ensured that between them, they covered considerations of not only adaptive capacity but also absorptive and transformational capacities. Indicators included the gender inequality index, agriculture index, GINI-index, poverty headcount ratio, and biodiversity and habitat index, among others. In this step, countries must decide if they wish to develop aggregated index values, and whether and how to weight the different indicators under each capital. In the case of Mexico, equal weights were chosen based on simplicity. In other cases, countries may choose to ascribe greater value to certain indicators to reflect the local or national adaptation and development priorities (GIZ, 2014).

Another example from East Africa is provided here to highlight how indicators for measuring resilience can also be developed by adopting a community-centric approach. A participatory approach can give policy and decision-makers insight into what criteria and indicators are important to people on the ground. In 2012-13, four Community Based Resilience Analysis (CoBRA) assessments were undertaken across Kenya, Uganda, and Ethiopia. Focus group discussions were held across the target communities, and participants were asked to list and rank what they consider to be key characteristics of a resilient community using the Sustainable Livelihood Framework (SLF). In this case, the major characteristics that emerged were the following:

- Access to credit, productive farms, employment, diversified income generating activities (IGAs), livestock herds, pasture and fodder, health care for livestock (financial capital)
- Education, food security, health care for humans (human capital)
- Natural resource management (natural capital)
- Access to markets, irrigation, roads, sanitation, shelter, telecommunications, water for humans, water for livestock (physical capital)
- Peace and security (social capital).

Most of the characteristics listed above can be used to produce direct indicators for measuring drought resilience. Others can function as indirect or proxy indicators that measure a community's general level of resilience. Important to note here is the gender dimension of resilience. For example, this assessment found that women consistently mentioned education and water for human consumption as priority resilience characteristics, whereas men tended to focus on peace and security, education, and water for human consumption (Fitzgibbon *et al*. 2014).

CASE STUDIES

Two illustrative case studies are presented here to serve as further examples of possible ways to organize the work to assess drought resilience. These examples come from climate and disaster resilience planning but could also provide useful lessons for drought resilience planning.

BOX A4.1. Climate resilience planning, monitoring, and evaluation in Guyana

The process of developing a Climate Resilience Strategy and Action Plan in Guyana

As part of its adaptation strategy and vision for a green economy, Guyana developed a Climate Resilience Strategy and Action Plan (CRSAP) in 2016. The steps involved in the process are presented below and serve as reference points for the step-by-step approach presented in Chapter 3.

STEP 1: Identifying key factors of resilience based on assessment goals

The Guyana CRSAP stressed measuring and enhancing the country's adaptive capacity to improve climate change adaptation and resilience. This focus meant the approach required a study of social rather than ecosystem resilience metrics. Different measures and indicators were selected according to the context and circumstances of the assessment. The strategy used the five categories of adaptive capacity proposed by the IPCC as a basis, namely informational, human, institutional, financial and the policy/regulatory environments.

STEP 2: Desk review

A review of policies and plans showed strong alignment within the existing climate resilience framework. The CRSAP aligned with Guyana's Low Carbon Development Strategy (2009), the National Climate Change Policy and Action Plan (NCCPAP, 2020-2030), and the National Integrated Disaster Risk Management Plan (2013) and built on existing data collected as part of its Second National Communication (SNC) to the UNFCCC (2012). In 2020, Guyana also developed a National Drought Mitigation and Adaptation Plan (NDMAP) with UNCCD support.

STEP 3: Self-assessment

Key data and information sources were assessed. Key stakeholders consulted during the process included the Dept. of Natural Resources and the Environment, Ministry of Communities, Ministry of Finance, Guyana Lands and Surveys Commission, Ministry of Indigenous Peoples' Affairs, University of Guyana and the Office of Climate Change. Data for measuring indicators was sought from sources such as the World Bank Data Portal, national Hydrometeorological Services, and the Caribbean Drought and Precipitation Monitoring Network (CDPMN). Modelling was undertaken wherever required and GIS mapping capacities were also mobilized.

STEP 4: Indicators selected for the M&E Plan

Based on national and sectoral resilience targets and priorities, four projects for resilience building were planned, with two pertinent to drought. Each project's concept note (i) compiled a climate risk register at project, sectoral, ecosystem or commodity levels, (ii) assessed its relevant climate risks, vulnerabilities and impacts, and (iii) provided a targeted list of activities for building adaptive capacity and resilience. Output-, outcome-, performance- and results-based indicators were selected to measure the success of these activities as part of the M&E plan.

The Climate Resilience Agricultural Systems project was built by selecting between 5 and 10 indicators per project component, resulting in approximately 30 indicators. These ranged from simple (e.g., number of drought resilience trainings implemented in an area) to complex (e.g., geo-spatial mapping to categorize level of agricultural vulnerability in different areas, building a subset of indicators). For the Strengthening Drainage and Irrigation Systems project, between one and five indicators were selected per component, resulting in a total of 13 (e.g., assessing the construction of new canals (area coverage) and measuring technical capacity of agencies to undertake calibration of hydrological computer models).

BOX A4.2. Disaster resilience planning and monitoring in Zambia, an African Risk Capacity (ARC) member state

Pan-African disaster response mechanism

The African Risk Capacity (ARC) is a Specialized Agency of the African Union, established to help governments improve their capacities to better plan, prepare, and respond to extreme weather events and natural disasters such as droughts. It provides an avenue for collaboration, for accessing innovative finance (e.g., a risk pool for disaster insurance), and for developing resilience building solutions. Of the 34 member states under this umbrella, 11 have developed Country Operational Plans, elaborating their disaster response (mainly to drought) and their contingency plans. These are in line with the respective country's national climate change and development priorities and strategies and are developed through some form of multi-stakeholder consultation and knowledge-exchange process. One example from Zambia is presented below.

Zambian Drought Response Operations Plan

Zambia published its Drought Response Operations Plan in 2019, summarizing key national and sectoral climate risks, hazards and drought response capacities. Their approach to resilience measurement or characterization relies strongly on an assessment of vulnerability (particularly, food and livelihood security), and using this as a proxy to determine the level of resilience. While characterizing resilience as the 'opposite' of the state of vulnerability is not the most widely accepted scientific practice, it is certainly an effective and valid approach, particularly in this case, where indicators, processes, and capacities for conducting vulnerability assessment are already in place.

Process, indicators and data sources

A Vulnerability and Needs Assessment is conducted annually (i.e., at the end of cropping season) by the Zambia Vulnerability Assessment Committee (ZVAC) and is paid for by the Government of Zambia, cooperating humanitarian partners, and the Southern African Development Community (SADC). A targeted subset of indicators is selected and assessed through various sources, such as existing rapid assessments of Crop Forecast Survey reports, questionnaires administered to District Disaster Management Committee members, household surveys, annual market assessments, food distribution lists, post-harvest assessments, secondary data review from district disaster/ward management committee reports, as well as field observations and expert judgment of data collectors.

Indicators are mainly aimed at measuring food security/nutrition, livelihoods (agriculture), water security and sanitation and health, to determine the number of people affected by drought, their geographic locations, what their food and non-food needs are, and whether these needs are being met. Examples include

- Water requirement satisfaction index (WRSI);
- Number of households receiving mixed interventions (cash and relief);
- Change in commodity prices (compared to baseline);
- Agriculture performance indicators taken from the national adaptation plan;
- Diversity of income sources within communities;
- Presence of labor opportunities;
- Food consumption score for targeted households;
- Number of key stakeholders participating in all critical processes such as the development of their drought responsive Forest Investment Program (FIP); and
- Existence and functionality of satellite disaster management platforms.

For more complex indicator assessments, the agency uses statistical packages combined with the Integrated Food Security Phase Classification (IPC) protocol.

Source: ARC, 2019

Finally, Table A4.1 presents a list of domestic plans and strategies that served as a basis for the Technical Guidance in Chapter 3.

TABLE A4.1 **National drought resilience relevant plans and strategies used for Technical Guidance**

Country	Document	Link
Australia	Australian Govt. Drought Response, Resilience and Preparedness Plan	https://www.agriculture.gov.au/sites/default/files/documents/aust-govt-drought-response-plan_0.pdf
Gambia	National Drought Plan	https://knowledge.unccd.int/sites/default/files/country_profile_documents/1%2520FINAL_NDP_Gambia.pdf
Kuwait	National Adaptation Plan 2019-2030	https://www4.unfccc.int/sites/NAPC/Documents/Parties/Kuwait%20National%20Adaptation%20Plan%202019-2030.pdf
Moldova	National Drought Plan	https://knowledge.unccd.int/sites/default/files/country_profile_documents/Drought%20Plan%20ENG%2020%20June%20%2C%202019.pdf
USA	Long-Term Drought Resilience Federal Action Plan	https://obamawhitehouse.archives.gov/sites/default/files/docs/drought_resilience_action_plan_2016_final.pdf
Zambia	National Drought Plan	https://knowledge.unccd.int/sites/default/files/country_profile_documents/1%2520FINAL_NDP_Zambia.pdf

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