



DROUGHT RESILIENCE, ADAPTATION AND MANAGEMENT POLICY FRAMEWORK

SUPPORTING TECHNICAL GUIDELINES



United Nations
Convention to Combat
Desertification

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FRAMEWORK: SUPPORTING TECHNICAL GUIDELINES**

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Printed in India on FSC paper.

Published by UNCCD, Bonn, Germany

August 2019

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Acknowledgements:

The UNCCD focal points from Egypt, China, Columbia, Brazil, Switzerland, Australia, South Africa, European Union and the USA.

CONTENTS

List of acronyms	v
1. Introduction	1
1.1 The drought resilience, adaptation and management policy framework	1
1.2 The 'three key pillars' of drought risk reduction	3
1.3 Purpose of these technical guidelines	4
2. Implement drought monitoring and early warning systems	5
2.1 Overview	5
2.2 Definitions	5
2.3 Selecting drought indicators and triggers	6
2.4 Which are the 'best' drought monitoring and forecasting indicators?	11
2.4.1 Meteorological drought	11
2.4.2 Hydrological drought	13
2.4.3 Agricultural drought	13
2.4.4 Socio-economic drought	14
2.4.5 Composite	14
2.5 Reliable drought forecasting	16
2.6 A drought risk assessment for monitoring and early warning	18
2.7 Communicate and respond to drought warnings	18
3. Assess drought vulnerability and risk	19
3.1 Overview	19
3.2 Definitions	19
3.3 Drought vulnerability assessments	20
3.3.1 Defining the components of drought vulnerability	20
3.3.2 Selecting variables for vulnerability assessment	21
3.3.3 Preparing variables for the vulnerability assessment	23
3.3.4 Validating the vulnerability assessment model	26
4. Limit impacts of drought and better respond to drought	27
4.1 Overview	27
4.2 Definitions	27
4.3 Reduce exposure and increase resilience to drought	27
4.3.1 Diversifying and modernizing agriculture	27
4.3.2 Sustainable land and water resources management	28
4.3.3 Communication, education and capacity building	29
4.4 Transfer and share drought risks	29
5. Recommendations	31
6. References	33

FIGURES

Figure 1.	Drought Resilience, Adaptation and Management Policy (DRAMP) Framework	2
Figure 2.	Integrated Phase Classification Version 2.0 (area-based) used to classify famine by the Famine Early Warning Systems Network	6
Figure 3.	Six-month global Standardized Precipitation Index for December 2016–May 2017: Comparison of the standard deviation of precipitation from location to location	12
Figure 4.	FAO Agricultural Stress Index for 1 June 2017	13
Figure 5a.	US Drought Monitor for 29 November 2016	14
Figure 5b.	US Drought Monitor for 14 February 2017	14
Figure 6.	Schematic view of the global integrated drought monitoring and prediction system algorithm	16
Figure 7a.	Seasonal drought outlook and observed drought from USDM for summer 2012, providing an example of a very inaccurate forecast	17
Figure 7b.	Seasonal drought outlook and observed drought from USDM for summer 2011, providing an example of an accurate forecast	17
Figure 8.	Example methodological framework for drought vulnerability assessment	20
Figure 9.	Conceptual framework showing the multiple dimensions to be included for assessing vulnerability to drought	21
Figure 10a.	Example drought vulnerability assessments at village scale, Andhra Pradesh, India	22
Figure 10b.	Example drought vulnerability assessments at national scale, administrative districts in Republic of Korea	22
Figure 10c.	Example drought vulnerability assessments at continental scale, Africa	22
Figure 10d.	Example drought vulnerability assessments at global scale	23

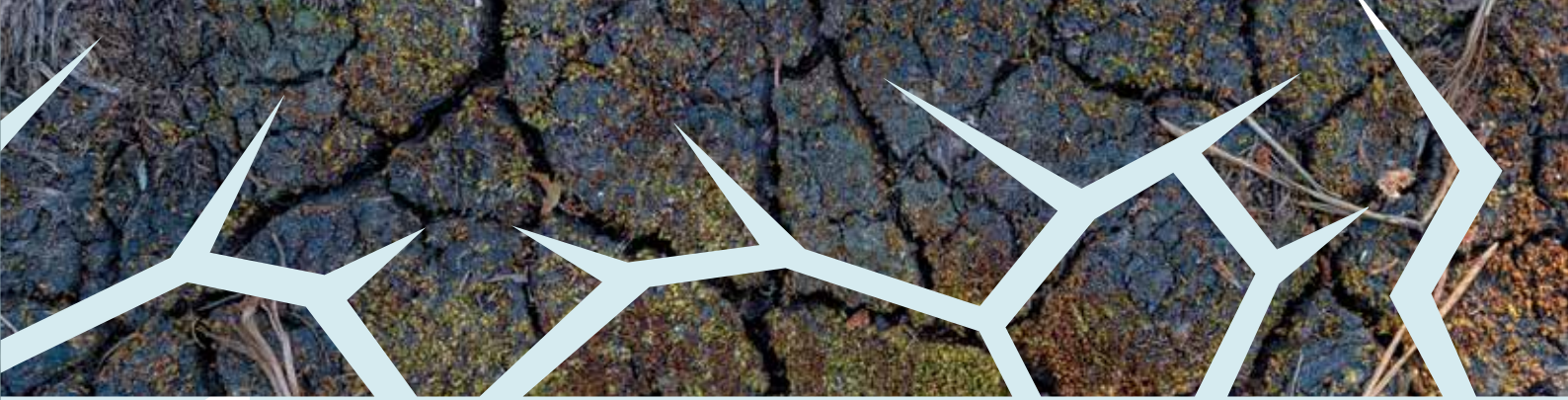
TABLES

Table 1.	Summary of major drought indicators and indices	8
Table 2.	Probability of recurrence of drought event described by the Standardized Precipitation Index	12
Table 3.	USDM drought categories and their association with the six input indices	15
Table 4.	Common global-scale dimensions and indicators/variables used in drought vulnerability assessments	24

LIST OF ACRONYMS

ASI	Agricultural Stress Index
CPC	Climate Prediction Center
DRAMP	Drought Resilience, Adaptation and Management Policy
EDI	Effective Drought Index
FAO	Food and Agriculture Organization of the United Nations
GDIS	Global Drought Information System
GDP	Gross Domestic Product
GIDMaPS	Global Integrated Drought Monitoring and Prediction System
GIEWS	Global Information and Early Warning System
GWP	Global Water Partnership
ICT	Information and Communications Technology
IDRI	Inflow-Demand Reliability Indicator
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute [for Climate and Society]
IWRM	Integrated Water Resource Management
MSDI	Multivariate Standardized Drought Index
MSRRI	Multivariate Standardized Reliability and Resilience Index
NASA	National Aeronautics and Space Administration (USA)
NDVI	Normalized Difference Vegetation Index
OFDA/CRED	Office of Foreign Disaster Assistance/Centre for Research on the Epidemiology of Disasters
PCA	Principal Components Analysis
SDI	Streamflow Drought Index
SPEI	Standardized Precipitation Evapotranspiration Index
SPI	Standardized Precipitation Index
SSFI	Standardized Streamflow Index
SSI	Standardized Soil Moisture Index
UNCCD	United Nations Convention to Combat Desertification
UNISDR	United Nations Office for Disaster Risk Reduction (now UNDRR)
UNW-DPC	UN-Water Decade Programme on Capacity Development
USDM	United States Drought Monitor
USGS	United States Geographical Survey
VHI	Vegetation Health Index
WMO	World Meteorological Organization
WRI	World Resources Institute
WSRI	Water Storage Resilience Indicator





1

INTRODUCTION

These technical guidelines present practical information for supporting the development and implementation of national drought resilience, adaptation and management plans. The accompanying Drought Resilience, Adaptation and Management Policy (DRAMP) Framework¹ documents the recent evolution of drought viewed in the context of disaster risk reduction and proposes a framework that integrates six goals for nations to reduce exposure and vulnerability to drought, increase resilience, transform their economies and political and cultural institutions, develop comprehensive drought management plans, and share drought risks. Progress in implementing the DRAMP Framework can only be made if guidelines to support the development and implementation of systems for drought monitoring, early warning, vulnerability and risk assessment, and risk mitigation and response are available.

These technical guidelines and the DRAMP Framework should underpin a drought management planning process. Drought planning gives decision makers and stakeholders the opportunity to identify communities, sectors and regions vulnerable to drought and devise ways to mitigate impacts before they occur. Drought planning is an effective and economically efficient way to allocate resources to managing drought. Drought planning that is transparent and inclusive empowers people, raises awareness, builds capacity and increases resilience among communities and nations to the escalating threats of land degradation and desertification posed by climate change and drought. The existing 10-step process can guide the development and implementation of drought plans (see Crossman (2017) and World Meteorological Organization (WMO) and Global Water Partnership (GWP) (2014)); these technical guidelines support in particular step 5: writing of the key parts of the drought management plan.

1.1 The challenges in assessing drought impacts and vulnerability

The DRAMP Framework takes an integrated, multi-pronged approach to reducing risks and impacts of drought. Organized around six cross-cutting goals (Figure 1), the DRAMP Framework identifies pragmatic actions for countries to better prepare and respond to drought and guides the design and implementation of drought policies from national to sub-national levels. The six goals of the DRAMP Framework are not mutually exclusive, with many of the actions for managing and adapting to drought applicable for more than one goal. The six goals of the DRAMP Framework are:

- 1. Reduce exposure to drought:** Reduce the potential for loss of people, livelihoods, ecosystem services and resources, infrastructure, and economic, social, or cultural assets in places that could be adversely affected by drought.
Example: The diversification of cropping from a monoculture grain system 30 years ago to a mix of grain crops with drought tolerant potato and corn has reduced potential for agricultural losses from increased drought occurrence in Inner Mongolia, China (Lei et al. 2016).
- 2. Reduce vulnerability to drought:** Reduce the propensity or predisposition to be adversely affected by drought.
Example: Farmers have a higher capacity to adapt to drought when they are more experienced, better educated, have more secure land tenure, have better access to electricity, and are more aware of climate risks (Alam 2015).

¹ See "Draft advocacy policy frameworks: Gender, Drought, and Sand and Dust Storms" at https://www.unccd.int/sites/default/files/sessions/documents/2017-08/ICCD_COP%2813%29_19-1711042E.pdf

3. Increase resilience to drought risk: Strengthen the ability of communities, ecosystems and economies to anticipate, absorb, accommodate or recover from the effects of drought in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of natural capital.

Example: The adoption of conservation agriculture (minimizing soil disturbance, maintaining permanent soil cover and introducing crop rotations) increases soil biodiversity and carbon stocks and regulates oxygen and nutrient cycles, making soil and crops more resilient to heat and drying extremes experienced during drought (Lal 2004, Lipper et al. 2014).

4. Transformation: Alter fundamental attributes of social, economic and ecological systems (including value systems; regulatory, legislative, or bureaucratic regimes; financial institutions; and technological or biological systems).

Example: Put local communities at the centre of drought decision-making processes, policy design and planning since the social impacts of droughts depend on people’s capacity to live with diminished water supply as well as their ability to adapt (Logar and van den Bergh 2013).

Figure 1. Drought Resilience, Adaptation and Management Policy (DRAMP) Framework

The coloured DRAMP Framework goals show the alignment to each of the three key pillars of drought risk reduction. These technical guidelines describe practical measures for implementing the *three key pillars*.



5. Prepare, respond and recover from drought: The backbone of management and planning approaches to reduce drought risks, including development of comprehensive drought monitoring and early warning systems.

Example: Design comprehensive drought monitoring and early warning systems (integrating multi-scale climate, soil, water and socio-economic indicators) (UNISDR 2015, Windhoek Declaration 2016), decision-support tools, and real-time drought assessment products (UNCCD et al. 2013, Tadesse 2016) that provide key and timely information for supporting decisions.

6. Transfer and share drought risks: Distribute risks among wider section of society to include all those benefiting directly and indirectly from robust drought risk management.

Example: Design and implement intelligent, risk-reducing financial strategies that support relief, reconstruction and livelihood recovery, such as micro-insurance, insurance and reinsurance as well as national, regional and global risk pools – for example, weather index insurance and safety nets (Shiferaw et al. 2014).

1.2 The ‘three key pillars’ of drought risk reduction

Following the principles of disaster risk reduction (UNISDR 2015), the *three key pillars of drought* risk reduction are designed to guide practical actions for nations to implement their drought policy and management plans. The *three key pillars* are (Tsegai et al. 2015):

Key pillar #1

Implementing drought monitoring and early warning systems:

- a. Monitor key indicators and indices of precipitation, temperature, soil moisture, vegetation condition, streamflow, snowpack and ground water
- b. Develop reliable seasonal forecasts and develop appropriate decision-support tools for impacted sectors
- c. Monitor the consequences of drought especially the impacts to vulnerable sectors such as agriculture
- d. Communicate reliable warning messages and respond to the risks in a measured and timely fashion

Key pillar #2

Addressing drought vulnerability and risk:

- a. Identify drought impacts on vulnerable economic sectors including food and agriculture (cropping and livestock), biodiversity and ecosystems, and energy, tourism and health sectors
- b. Assess physical, social, economic and environmental pressures on communities to identify who and what is at risk and why – before, during and shortly after drought
- c. Assess conditions or situations that increase the resistance or susceptibility to drought and the coping capacity of communities affected by drought
- d. Assess the extent of potential damage or loss in the event of a drought

Key pillar #3

Implementing measures to limit impacts of drought and respond better to drought:

- a. Implement structural or physical measures, and non-structural measures to limit the adverse impacts of drought, prioritized based on level of vulnerability (Key pillar #2)
- b. Response includes all efforts, such as the provision of assistance or intervention during or immediately after a disaster to meet the life-saving and basic subsistence needs of the vulnerable and affected communities and sectors
- c. Measures need to be relevant to sectors affected by drought based on their vulnerability – particularly agriculture, water and the environment, as well as transport and tourism
- d. Measures can be long-, medium- or short-term, depending on implementation time
- e. Biodiversity, land and ecosystem services play a vital role in reducing vulnerability and mitigating impacts of drought.

These *three key pillars* have been developed to during the UN-Water Decade Programme on Capacity Development (UNW-DPC) series of regional drought management policy capacity-building workshops that took place in Eastern Europe, Latin America and the Caribbean, Asia-Pacific and Africa from 2013–2015. The *three key pillars* are recommended as the basis of national drought policy and management plans, providing a practical way to organize multiple actions and activities that nations need to implement to better prepare and respond to drought.

1.3 Purpose of these technical guidelines

These technical guidelines review and present technical information for implementing the *three key pillars* of drought risk reduction policy and management plans. The guidelines also provide support for the 10-step process of drought management planning and implementation, especially step 5 (World Meteorological Organization (WMO) and Global Water Partnership (GWP) 2014).

The DRAMP Framework outlines many actions for managing and adapting to drought. Some actions proposed by DRAMP cannot be designed and implemented in the short term and/or it is not possible to design technical approaches and guidelines to support their implementation. For example, some of the actions proposed under the Transformation goal of the DRAMP Framework are long-term, high-level actions that challenge long-established cultural and political norms – such as removing perverse incentives,

establishing procedures for whole-of-government coordination and strategic approaches to drought, and recognizing the full value of water, land and ecosystems.

The material in the technical guidelines is derived from assessments of risk and vulnerability methods, and monitoring and forecasting tools including data used to trigger drought management responses such as precipitation, streamflow, groundwater, reservoir levels and soil moisture.

The document also provides an inventory of the key indicators used to monitor and forecast drought onset, duration, end, severity and impacts. A large body of scientific literature and the key drought policy documents (UNCCD et al. 2013, Tsegai et al. 2015, UNISDR 2015, Tadesse 2016, Windhoek Declaration 2016) were consulted to ensure that these technical guidelines contain the latest advances in science and policy.





2 IMPLEMENT DROUGHT MONITORING AND EARLY WARNING SYSTEMS

Drought early warning systems typically aim to track, assess and deliver relevant information concerning climatic, hydrologic and water supply conditions and trends. Ideally, they have both a monitoring (including impacts) component and a forecasting component. The objective is to provide timely information before or during the early onset of drought to prompt action (via threshold triggers) within a drought risk management plan to reduce potential impacts. A diligent, integrated approach is vital for monitoring such a slow onset hazard.

World Meteorological Organization and Global Water Partnership (2016)

2.1 Overview

This chapter provides guidelines for selecting and calculating indicators or indices to monitor and forecast drought onset, end and impacts, and identify triggers for different management responses during drought. Drought is a natural hazard highly suitable to monitoring because the slow onset of droughts makes it possible to observe changes in precipitation, temperature, soil moisture, surface and ground water reserves, and social and economic behaviours. Detecting these changes early is important for triggering effective and efficient actions to prepare for drought and mitigate drought impacts. It is important that indicators and indices accurately describe the impacts of drought. The indicators assessed in this document have already – to some level – passed the test of effectiveness and accuracy because they are commonly used in drought-prone regions around the world.

2.2 Definitions

It is important to clearly define the difference between **indicators** and **indices**.

Indicators are meteorological, hydrological or biophysical variables (such as precipitation, temperature, streamflow, groundwater and water storage levels, and soil moisture) that describe drought conditions (World Meteorological Organization and Global Water Partnership 2016).

Indices are computed numerical representations of drought severity, often calculated using combinations of meteorological, hydrological or biophysical indicators (World Meteorological Organization and Global Water Partnership 2016). Indices provide quantitative information about the severity, timing, duration and extent of a drought. The severity is a departure from the norm and thresholds of drought severity identify drought start, end and location. The timing of a drought's beginning and end are also very important because drought impacts can be highly variable depending on when moisture shortages occur in relation to other factors. For example, a short drought can have a big impact if it occurs during a key phase of the crop growth cycle, or a longer drought can have a smaller impact if it occurs during the fallow stage. Drought indices calculated using historical data can be used to estimate future probability of drought occurrence and severity.

2.3 Selecting drought indicators and triggers

Drought indicators and indices are essential tools for decision makers and the wider public to detect drought, assess its impacts and then take actions to reduce risks (Steinemann et al. 2015). Drought indicators and indices link data with decision making and can be used to answer the following questions:


- How do we know that the current situation can be classified a drought?
- How severe is the drought?
- When should we act?
- How do we know that the drought has ended?

Triggers are specific values of indicators that determine the timing and extent of actions that respond to drought conditions (Steinemann and Cavalcanti 2006). The characterization of drought will typically use the terms “mild, moderate, severe, extreme drought,” or “level 1, level 2, level 3 drought”, based on a single indicator or a combination thereof. The Famine Early Warning Systems Network (FEWS-NET) uses a more nuanced approach, which focuses directly on impacts of extended dry periods

(Figure 2). There are different triggers of response under each category of drought occurrence and impact.

The choice and combination of variables used to develop drought indicators as well as the identification of triggers needs to be done in a transparent and scientifically sound way to ensure validity of drought management plans. There are several studies that evaluate the usefulness of drought indicators to help select the best types and combinations of indicators and triggers (Byun and Wilhite 1999, Heim 2002, Keyantash and Dracup 2002, Zargar et al. 2011, Dogan et al. 2012, Jain et al. 2015, Fluixá-Sanmartín et al. 2018). Work by Steinemann and colleagues over the past 15 years has aimed to improve understanding of end-user needs of drought indicators and indices to help design a robust process for selecting appropriate indicators and indices (Steinemann and Cavalcanti 2006, Steinemann et al. 2015). A valuable output from their work is a 12-step process for drought indicator and trigger selection applied to the development of a drought management plan for the State of Georgia, USA. Box 1 lists the 12 steps, briefly explaining each one. National and sub-national authorities developing drought monitoring and early warning systems as part of a drought management plan are encouraged to follow the 12-step process in Box 1.

Figure 2. Integrated Phase Classification Version 2.0 (area-based) used to classify famine by the Famine Early Warning Systems Network

	Phase 1 Minimal	Phase 2 Stressed	Phase 3 Crisis	Phase 4 Emergency	Phase 5 Famine
Phase Name and Description	More than four in five households (HHs) are able to meet essential food and non-food needs without engaging in atypical, unsustainable strategies to access food and income, including any reliance on humanitarian assistance	Even with any humanitarian assistance at least one in five HHs in the area have the following or worse: Minimally adequate food consumption but are unable to afford some essential non food expenditures without engaging in irreversible coping strategies.	Even with any humanitarian assistance at least one in five HHs in the area have the following or worse: Food consumption gaps with high or above usual acute malnutrition OR Are marginally able to meet minimum food needs only with accelerated depletion of livelihood assets that will lead to food consumption gaps.	Even with any humanitarian assistance at least one in five HHs in the area have the following or worse: Large food consumption gaps resulting in very high acute malnutrition and excess mortality OR Extreme loss of livelihood assets that will lead to food consumption gaps in the short term.	Even with any humanitarian assistance at least one in five HHs in the area have an extreme lack of food and other basic needs where starvation, death, and destitution are evident. (Evidence for all three criteria of food consumption, wasting, and CDR is required to classify Famine.)
Priority Response Objectives	Action required to Build Resilience and for Disaster Risk Reduction	Action required for Disaster Risk Reduction and to Protect Livelihoods	Urgent Action Required to: 		
			Protect livelihoods, reduce food consumption gaps, and reduce acute malnutrition	Save lives and livelihoods	Prevent widespread mortality and total collapse of livelihoods

Source: <http://www.fews.net/IPC>

Other work by Steinemann et al. lists a **set of attributes deemed desirable for indicators** based on a series of expert stakeholder workshops:

- Statistically consistent and comparable terms – for example measured in percentiles
- Relative to historic drought conditions to put current drought severity into perspective
- Individual and separate, rather than pre-aggregated into an index, yet possible to combine with user-defined weights
- Easy to understand and implement as well as related to familiar concepts
- Able to represent a range of conditions – for example, meteorological and hydrological
- Relevant across different time scales and spatial scales

Several researchers have assessed the usability and relevance of drought indicators and indices to help condense over 100 potentially useful measures (Zargar et al. 2011) into a manageable list from which location-appropriate actions can be selected. Recent work by the World Meteorological Organization and the Global Water

Partnership (2016) reviewed the meteorology, hydrology, soil moisture and remote sensing indicators as well as composite indices most often used to monitor drought. They used a traffic-light approach to score 50 indicators and indices for its ease of use based on a set of criteria. The criteria assessed the availability of code to create the indicator, time-scale of input data, treatment of missing data, number and form of input variables required, the complexity of calculations to compute the indicator, level of obscurity of the indicator and the availability of the indicator output (for example, the indicator is already produced and is available online).

Table 1 lists the indicators scored as green by the World Meteorological Organization and Global Water Partnership (2016), meaning that they are relatively easy to obtain and use. However, the authors warn that a green rating does not necessarily mean that an indicator is best suited for a particular location. The most appropriate indicator should be determined by the needs of users and the application. Since there were no soil moisture or hydrology indicators rated as green, a small number of orange-rated indicators popular in the scientific literature on drought have been included.

Box 1: The 12-step process for selecting drought indicators and triggers of response

Steinemann and Cavalcanti (2006) propose this 12-step method for designing and applying drought indicators and triggers for drought monitoring and early warning as part of drought management planning. The steps were developed over a four-year period and involved over 100 stakeholders across the US state of Georgia. Although developed in the USA, the steps are equally applicable in any location globally.

Development of indicator and triggers:

- 1. Define scale and scope of analysis:** select the spatial units and extent of indicators. Options include climate divisions, river basins, political jurisdictions or critical water use areas. Extent could be country-wide or parts of the country more vulnerable to drought, such as rain-fed agricultural areas.
- 2. Develop drought indicators:** starting from an extensive list of indicators, use expert knowledge to select key indicators. Indicator selection criteria should include how well the indicator represents critical drought impacts, primary drought vulnerabilities, water supplies and demands, and types of drought affecting the area. Also important is the availability, historic record, and validity of data for the indicator. Different indicators may be selected to represent different types of drought conditions in different locations, such as groundwater levels where agriculture depend on groundwater, or reservoir levels in urbanised areas. Table 1 summarises more common and easy to use indicators.
- 3. Establish drought plan levels and triggering scale:** identify a consistent, intuitive and easy to implement approach for associating triggers with drought levels, and for comparing and combining multiple indicators and triggers. A simple approach is percentiles and cumulative thresholds of probability such as 0.35, 0.20, 0.10, 0.05, representing mild, moderate, severe and extreme drought, respectively.
- 4. Develop triggering objective:** develop a set of performance measures for indicators and triggers that describe the desired behaviour of indicators and associated triggers. For example, set rules about the indicator's advance warning of drought onset, progression, and end, false alarms, and timing to implement management responses.

Analysis of indicators and triggers:

- 5. Transform indicators to triggering scale and levels:** develop a triggering system that would provide a statistically consistent framework for combining, comparing, and evaluating multiple indicators.
- 6. Calculate multi-period indicators:** convert indicators based on single time periods into indicators for multiple and sequential time periods. The multi-period indicators are important to meet performance objectives (step 4) because they provide more stable drought triggers, minimize possible false alarms and reduce the risk of missing a lagged or persistent drought signal.

Box 1: The 12-step process for selecting drought indicators and triggers of response (continued)

7. Calculate individual and multiple triggering sequences: the triggering sequence is the drought level associated with each indicator (single and multi-period) for each month in the historic data record.

8. Calculate final drought sequences: develop a systematic and scientifically justifiable approach for combining multiple trigger sequences into a single drought sequence on which to make decisions. For example, triggering sequences could be combined in three ways:

- Most severe drought levels
- Majority of drought levels
- Drought start and drought end

Evaluation of indicators and triggers:

9. Elicit expert assessments: determine which indicators and triggers are the most appropriate based on performance of the sequences against historic droughts. Experts could be both national specialists as well as local environmental, agricultural and urban water managers along with local community representatives. Relevant questions include:

- Which indicators, triggers and combinations thereof would have produced a drought level triggering sequence that would best reflect drought conditions in each location?
- Which drought level should be declared and when, based on information available?
- What drought level status (for each month and each location) would have produced the best overall management and impact mitigation response?

10. Compare final drought sequences with expert assessments: compare the expert assessments of retrospective drought impacts, indicators and triggers (step 9) with the final drought sequences (step 8) to identify the most promising indicators and triggers for each location/region.

11. Refine final drought sequences and iterate evaluation process: use an iterative process to arrive at the final drought sequences and indicator triggers. This may involve returning to step 1 to develop new indicators/triggers, or in most cases, returning step 5 to refine triggers.

12. Select final indicators and triggers for drought plan.

Table 1. Summary of major drought indicators and indices

Indicator	Rating	Inputs	Source and/or example	Notes
Meteorology				
Aridity Anomaly Index (AAI)		P, T, PET, ET	Gommes et al. (2010)	Operationally available for India; applicable to agriculture in tropical climates.
Deciles		P	Gibbs and Maher (1967)	Easy to calculate; examples from Australia are useful.
Keetch–Byram Drought Index (KBDI)		P, T	Keetch and Byram (1968) http://www.wfas.net/index.php/keetch-byram-index-moisture--drought-49	Calculations are based upon the climate of the area of interest; currently available for USA.
Per cent of Normal Precipitation		P	Hayes (2005)	Simple mathematical calculations.
Standardized Precipitation Index (SPI)		P	Guttman (1999); World Meteorological Organization (2012) http://drought.unl.edu/monitoringtools/~downloadables/program.aspx	Highlighted by the WMO as a starting point for meteorological drought monitoring. Recommended by WMO in 2009 as main indicator for monitoring drought (Hayes et al. 2010). Easy to calculate and applicable in all climates. Free software available for calculation.

Indicator	Rating	Inputs	Source and/or example	Notes
Meteorology (continued)				
Weighted Anomaly Standardized Precipitation (WASP)		P, T	Lyon (2004) http://iridl.ldeo.columbia.edu/maproom/Global/~Precipitation/WASP_Indices.html	Uses gridded data for monitoring drought in tropical regions.
Crop Moisture Index (CMI)		P, T	Palmer (1968)	Expansion of PDSI specifically for agriculture; Weekly values are required.
Effective Drought Index (EDI)		P	Byun and Wilhite (1999) https://www.ru.ac.za/iwr/research/spatsim/	Can be calculated using the SPATSIM software freely available.
Palmer Drought Severity Index (PDSI)		P, T, AWC	Alley (1984)	Not green due to complexity of calculations and the need for serially complete data. Mostly superseded by newer indices such as SPI.
Standardized Precipitation Evapotranspiration Index (SPEI)		P, T	Vicente-Serrano et al. (2009) http://spei.csic.es	Serially complete data required; output similar to SPI but with a temperature component. Code to calculate is freely available.
Soil moisture				
Soil Moisture Anomaly (SMA)		P, T, AWC	N.A.	Intended to improve upon the water balance of PDSI. Data requirements make it challenging to calculate.
Hydrology				
Palmer Hydrological Drought Severity Index (PHDI)		P, T, AWC	Jacobi et al. (2013)	Serially complete data required. Estimates complete water balance but does not include water management decisions and irrigation.
Standardized Streamflow Index (SSFI)		SF	Modarres (2007); Telesca et al. (2012)	Uses the SPI program along with streamflow data.
Streamflow Drought Index (SDI)		SF	Nalbantis and Tsakiris (2009) http://drinc.ewra.net	Similar calculations to SPI, but using streamflow data instead of precipitation. Widely available and easy to use but does not consider flow management interventions.
Remote sensing/agriculture				
Enhanced Vegetation Index (EVI)		Sat	Huete et al. (2002) https://www.star.nesdis.noaa.gov/smcd/emb/~vci/VH/vh_browse.php	Does not separate drought stress from other stress. High resolution and full global coverage.
Evaporative Stress Index (ESI)		Sat, PET	Anderson et al. (2010) https://hrsl.ba.ars.usda.gov/drought/	Does not have a long history as an operational product. Only USA coverage.
Normalized Difference Vegetation Index (NDVI)		Sat	Huete et al. (2002) https://www.star.nesdis.noaa.gov/smcd/emb/~vci/VH/vh_browse.php	Calculated for most locations.

Indicator	Rating	Inputs	Source and/or example	Notes
Remote sensing/agriculture (continued)				
Temperature Condition Index (TCI)		Sat	ogan (1995)	Usually found along with NDVI calculations.
Vegetation Condition Index (VCI)		Sat	Liu and Kogan (1996)	Usually found along with NDVI calculations.
Vegetation Drought Response Index (VegDRI)		Sat, P, T, AWC, LC, ER	Brown et al. (2008)	Takes into account many variables to separate drought stress from other vegetation stress. Applicable to vegetation growing season.
Vegetation Health Index (VHI)		Sat	Kogan (2001) https://www.star.nesdis.noaa.gov/smcd/emb/~vci/VH/vh_browse.php	One of the first attempts to monitor drought using remotely sensed data. High resolution global coverage.
Water Requirement Satisfaction Index (WRSI and Geo-spatial WRSI)		Sat, Mod, CC	Verdin and Klaver (2002) http://chg.geog.ucsb.edu/tools/geowrsi/index.html	Operational for many locations. Developed by FAO to detect famine. Provides robust alternative to field-based observations.
Normalized Difference Water Index (NDWI) and Land Surface Water Index (LSWI)		Sat	Chandrasekar et al. (2010) http://www.eomf.ou.edu/modis/visualization/	Produced operationally using Moderate Resolution Imaging Spectroradiometer data.
Composite or modelled				
Combined Drought Indicator (CDI)		Mod, P, Sat	Sepulcre-Canto et al. (2012) http://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1000	Uses both surface (SPI, soil moisture) and remotely sensed data. Only available for Europe.
Global Integrated Drought Monitoring and Prediction System (GIDMaPS)		Multiple, Mod	Hao et al. (2014) http://drought.eng.uci.edu	An operational product with global output for three drought indices: Standardized Soil Moisture Index, SPI and MSDI.
Global Land Data Assimilation System (GLDAS)		Multiple, Mod, Sat	Rodell et al. (2004) https://disc.sci.gsfc.nasa.gov/services/grads-gds/gldas	Useful in data-poor regions due to global extent. Can be used in real-time monitoring of droughts with multiple impacts.
Multivariate Standardized Drought Index (MSDI)		Multiple, Mod	Hao and AghaKouchak (2013)	Available but interpretation is needed. Only available for USA.
United States Drought Monitor (USDM)		Multiple	Svoboda et al. (2002)	Usually found along with NDVI calculations.

P = precipitation; T= temperature; PET = potential evapotranspiration; ET = evapotranspiration; AWC = available water-holding capacity; SF = streamflow; Sat = satellite data; LC = land cover; ER = eco-region; Mod = modelled; CC = crop coefficient.

Source: Modified from World Meteorological Organization and Global Water Partnership (2016)

2.4 Which are the “best” drought monitoring and forecasting indicators?

The selection of specific indicators or indices for monitoring drought occurrence and impacts and forecasting drought cannot be prescribed in these technical guidelines. Choice of indicators will be determined by specific regional to national circumstances, such as availability of spatio-temporal data, technical capacity and the nuances of the climatic, social, economic and environmental conditions. Selecting indicators is a trial-and-error process and testing indicator suitability can be time-consuming, given the unique characteristics of the location (see Box 1) (World Meteorological Organization and Global Water Partnership 2016). It is essential to align drought monitoring and early warning systems, as well as policy and management planning and decision-making, with quantitative index-based values that robustly identify drought severity, onset and duration. It has been shown by Dogan et al. (2012) that taking into consideration more than one drought index can provide certain advantages, because comparing and combining different indices may help to:

- Better characterize droughts
- Examine the sensitivity and accuracy of drought indicators
- Investigate the correlation between indicators
- Explore how coherent the drought indicators are in the context of a specific objective

Investment in research into the most suitable indicators and indices for a location is unavoidable.

Some indicators listed in Table 1 stand out as preferred choices based on their ease of use and level of uptake by existing drought monitoring and early warning systems. Although it is argued that the integration of precipitation with other drought-related variables, such as soil moisture and streamflow, is essential for efficient drought monitoring and early warning systems (AghaKouchak 2015), precipitation-based indicators can be recommended as a starting point, given that drought is essentially an exceptional lack of water compared to the expected normal (Carrão et al. 2016, Van Loon et al. 2016) and extended precipitation deficits cause agricultural, hydrological and/or socio-economic disasters. Therefore, meteorological drought indicators and indices can be used as proxies for agricultural and hydrological drought (Vicente-Serrano et al. 2012).

2.4.1 Meteorological drought

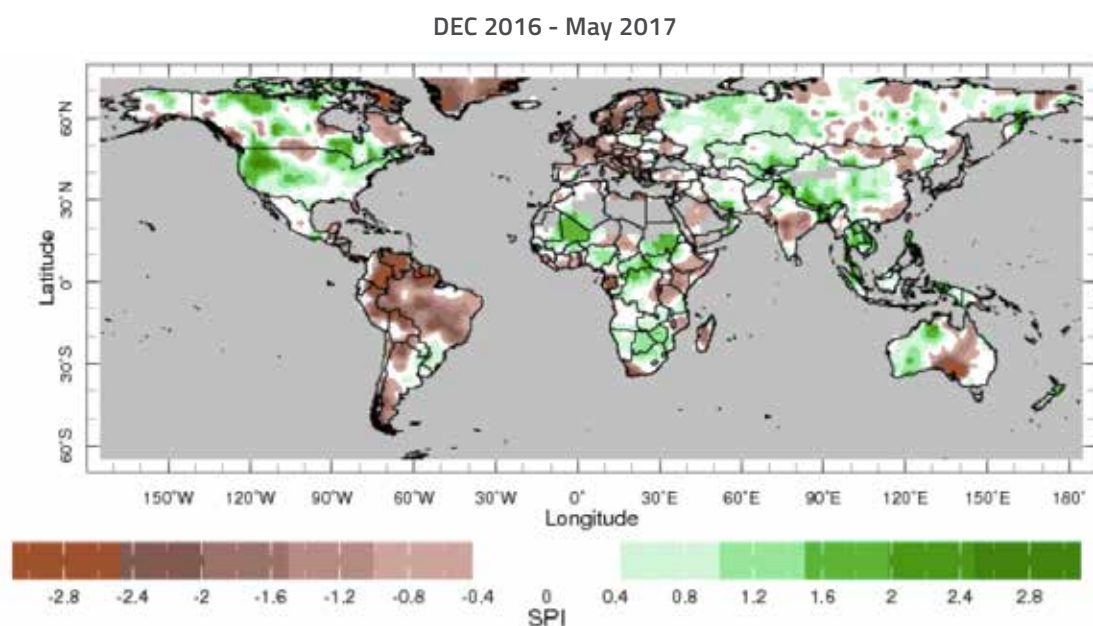
Meteorological drought is a precipitation deficiency, possibly combined with increased potential evapotranspiration, extending over a large area and spanning an extensive period of time (Van Loon 2015). The **Standardized Precipitation Index (SPI)** is often used to monitor meteorological drought because it efficiently summarizes temporal anomalies in precipitation. In a recent survey (2010–2014) of national meteorological and hydrological service agencies, 35 countries out of 43 that responded said they use the SPI to monitor drought (World Meteorological Organization and Global Water Partnership 2016). Bachmair et al. (2016) also found that SPI and other simple precipitation-based indices are most commonly used in operational drought monitoring and early warning systems. The WMO, based on consultation and an expert workshop involving 54 participants from 22 countries, recommend every country use SPI to monitor meteorological drought because it is relatively easy to use and widely available precipitation data is the only required input (World Meteorological Organization 2012).

The SPI quantifies precipitation deficits for different timescales (1, 3, 6, 12, 24 and 48 months) and is normalized, so it is applicable to both wet and dry climates. Figure 3 shows an example of global SPI calculated for the six-month period of December 2016 to May 2017. The SPI can be used to assess the rarity of a current drought and the precipitation required to end it. The drought categories of SPI in Table 2 can be used as triggers for implementing various levels of planning and management actions. Drought starts when the SPI value is equal or below -1.0 and ends when the SPI value becomes positive (World Meteorological Organization 2012). At least 30 years of continuous monthly precipitation data is required, with longer periods preferred. Precipitation means, standard deviations, skewness, gamma functions and cumulative probabilities must be calculated as input into the final SPI, so a free computer program is recommended for calculating SPI² on a Windows PC.

SPI can also be used as a pioneer index to monitor agricultural, hydrological and socio-economic drought. For example, in China, an SPI-categorized drought lasting 1–3 months triggers an agricultural drought, while an SPI-categorized drought lasting 6–12 months can trigger a hydrological drought, and an SPI-categorized drought of 12 months or longer triggers a local socio-economic drought.

² <http://drought.unl.edu/MonitoringTools/DownloadableSPIProgram.aspx>

Figure 3. Six-month global SPI for December 2016 – May 2017: Comparison of the standard deviation of precipitation from location to location



Source: <http://iridl.ldeo.columbia.edu/maproom/Global/Precipitation/SPI>

Table 2. Probability of recurrence of drought event described by the Standardized Precipitation Index

SPI	Category	Number of times in 100 years	Severity of event
0 to -0.99	Mild dryness	33	1 in 3 years
-1.0 to -1.49	Moderate dryness	10	1 in 10 years
-1.5 to -1.99	Severe dryness	5	1 in 20 years
-2.0 or less	Extreme dryness	2.5	1 in 50 years

Source: World Meteorological Organization (2012)

The major shortcoming of SPI is the reliance on a single parameter: precipitation. While precipitation is the main variable determining drought onset, duration, intensity and end (Heim 2002, Carrão et al. 2016), temperature becomes increasingly important in drought monitoring because climate change models predict temperature increases and temperature rises affect the severity of drought (Sheffield and Wood 2008). An expanded SPI has been developed by Vicente-Serrano et al. (2009) to include temperature data for describing potential evapotranspiration. The **Standardized Precipitation Evapotranspiration Index (SPEI)** can be calculated using free R code which requires some technical expertise.³ Testing has shown that SPEI

performs better than SPI at capturing streamflow, soil moisture, forest growth and crop yield impacts during summer droughts (Vicente-Serrano et al. 2012).

Effective Drought Index (EDI) is an alternative and potentially superior index because it is more sensitive than SPI to shorter drought periods and to detecting the onset and end of a drought (Jain et al. 2015). The EDI can be used to assess drought severity with daily precipitation as the major input. EDI was found to be consistent with other drought indices for various time-steps and is preferable for monitoring long-term droughts in arid/semi-arid regions (Dogan et al. 2012).

³ Computer code available at <http://spei.csic.es>

2.4.2 Hydrological drought

Hydrological drought is a lack of water in the hydrological system, manifesting itself in abnormally low streamflow in rivers and abnormally low levels in lakes, reservoirs and groundwater (Van Loon 2015). If streamflow data is available, the **streamflow Drought Index (SDI)** and the **Standardized streamflow Index (SSFI)** are relatively simple to calculate indices of streamflow. These are important when surface water flow, storage and diversions become critical components for agricultural production, urban and industrial water supply and freshwater ecology. Van Loon and Laaha (2015) have measured the severity of hydrological drought using flow duration curves and percentiles, concluding that the spatial variation of hydrological drought severity strongly depends on terrestrial hydrological processes. A robust assessment of hydrological drought depends not just on streamflow data, but also hydro-dynamically correct models of land systems, which require a high level of technical expertise to analyse and may not be widely available.

2.4.3 Agricultural drought

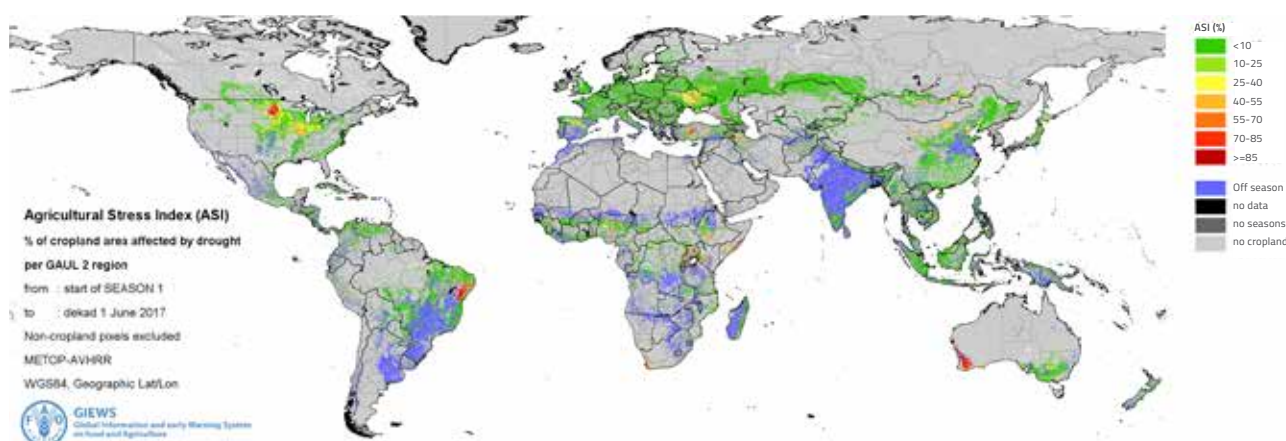
Agricultural drought is a deficit of soil moisture (mostly in the root zone) that reduces the supply of moisture to vegetation and often leads to crop failure (Van Loon 2015). Using widely available and high temporal and spatial resolution remotely sensed imagery, the **Vegetation Health Index (VHI)** and the **Water Requirement Satisfaction Index (WRSI)** are robust measures of drought-induced crop stress. The VHI combines measure of vegetation moisture stress

(NDVI) and temperature stress (BT) with timing of different stages of plant phenology over the growing season. The WRSI combines remotely sensed precipitation and potential evapotranspiration data with soil water holding capacity and crop coefficients to provide early warning estimates of crop yields and potential failures. The WRSI is the percentage of total crop water requirement satisfied by rainfall or available soil moisture. The FAO has developed a spatial implementation of WRSI to estimate real-time crop yields and famine risks. The FAO has also developed high spatial and temporal resolution time-series interpretations of VHI to calculate the **Agricultural Stress Index (ASI)** within the world's cropping land. The ASI is a key part of the FAO's Global Information and Early Warning System (GIEWS) which is used to monitor real-time threats to global food security.⁴ The ASI for 1 June 2017 is shown in Figure 4.

The remotely sensed NDVI-based indicators of vegetation stress are very useful and practical methods for identifying early drought impacts to agriculture, and can be extended to monitor impacts to natural ecosystems and forests. Areas of high vegetation stress in native forests and ecosystems indicate locations where biodiversity could be under considerable pressure from drought.

In the absence of remote sensing technical capacity, researchers have shown that SPEI correlates well with soil moisture in several locations around the world (Vicente-Serrano et al. 2012, Scaini et al. 2015, Wang et al. 2015), suggesting that SPEI can be used as a valid surrogate for indicators of agricultural drought.

Figure 4. FAO's Agricultural Stress Index for 1 June 2017



Source: <http://www.fao.org/giews/en/>

⁴ <http://www.fao.org/giews/en/>

2.4.4 Socio-economic drought

Socio-economic drought occurs when the demand for economic goods exceeds supply because of a weather-related shortages in water supply (Wilhite and Glantz 1985). Indicators and indices for monitoring and early warning of socio-economic drought are relatively uncommon. The **Multivariate Standardized Reliability and Resilience Index (MSRRI)**, developed by (Mehran et al. 2015), integrates two indicators, the inflow-demand reliability indicator (IDRI) and the water storage resilience indicator (WSRI). The IDRI assesses whether the available water (inflow to the system) is sufficient to satisfy water demand for the selected period, regardless of the storage in reservoirs. The WSRI assesses the sufficiency of a reservoir for satisfying water demand during the selected time period. The MSRRI therefore evaluates the supply and storage of water in relation to demand, with negative values indicating a shortage of water. Data on water demand, water storage capacity and levels and water inflows are required, making MSRRI and its components relatively complex to calculate and dependant on detailed data.

2.4.5 Composite

The recent generational advances in spatial data processing and remote sensing put several composite indicators in relatively easy reach for drought monitoring and early warning. The state of the art system is the **US Drought Monitor (USDM)** (Svoboda et al. 2002). The USDM combines six indicators of drought (PDSI, soil

moisture, daily streamflow, rainfall deciles, SPI and VHI) that describe the major types of drought (meteorological, agricultural and hydrological). The USDM uses weighted averages of the inputs to produce a weekly assessment of current drought conditions in the USA. The USDM for 29 November 2016 and 14 February 2017 are compared in Figure 5, demonstrating a substantial change in drought conditions in California and the south-east following the 2016–2017 heavy winter rainfall. The drought categories used by the USDM (Table 3) are potential triggers for different levels of planning and drought management response. The thresholds of each indicator are useful for identifying triggers under each indicator in the USDM. Drought monitoring systems using individual or a subset of indicators used by the USDM can refer to the indicator value ranges and associated drought categories in Table 3 to define potential triggers.

A new platform developed at Princeton in the USA produces several common individual and composite drought indices for monitoring and forecasting drought in sub-Saharan Africa (Sheffield et al. 2013). The **African Flood and Drought Monitor (ADFM)** uses numerous remotely sensed datasets and streamflow data to calculate high resolution spatially continuous indicators describing meteorological, agricultural, ecological and hydrological drought for use in real-time monitoring and seasonal forecasting. The ADFM is a comprehensive system and both the web portal⁵ and Sheffield et al. (2013) should be consulted for full details. The website also includes a tutorial for correct production of the ADFM indicators and indices.

Figure 5a. US Drought Monitor for 29 November 2016

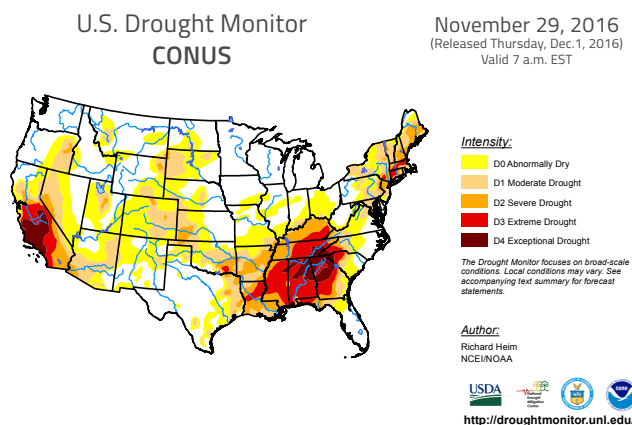
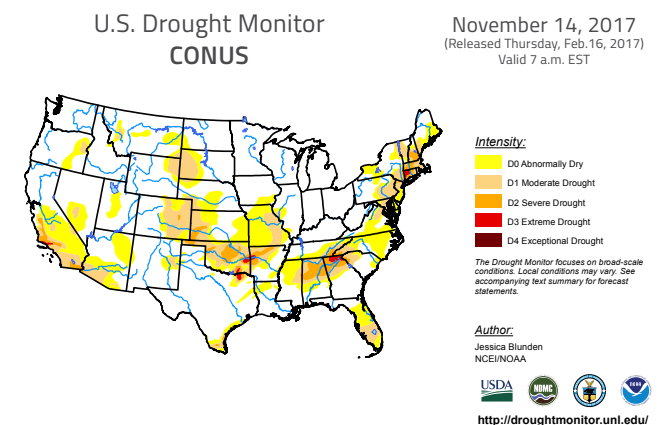


Figure 5b. US Drought Monitor for 14 February 2017



Source: <http://droughtmonitor.unl.edu/MapsAndData/MapArchive.aspx>

⁵ <http://stream.princeton.edu/AWCM/WEBPAGE/index.php>

Table 3. USDM drought categories and their association to the six input indices

US Drought Monitor classification							
Drought type		Associated ranges of indicators					
Category	Description	Palmer drought	CPC soil moisture	USGS weekly	Percent of normal	Standardized precipitation	Satellite vegetation
D0	Abnormally dry	-1.0 to -1.9	21-30	21-30	< 75% for 3 months	-0.5 to -0.7	36-45
D1	Moderate drought	-2.0 to -2.9	11-20	11-20	<70% for 3 months	-0.8 to -1.2	26-35
D2	Severe drought	-3.0 to -3.9	6-10	6-10	< 65% for 6 months	-1.3 to -1.5	16-25
D3	Extreme drought	-4.0 to -4.9	3-5	3-5	< 60% for 6 months	-1.6 to -1.9	6-15
D4	Exceptional drought	-5.0 or less	0-2	0-2	< 65% for 12 months	-2.0 or less	1-5

Source: Svoboda et al. (2002)

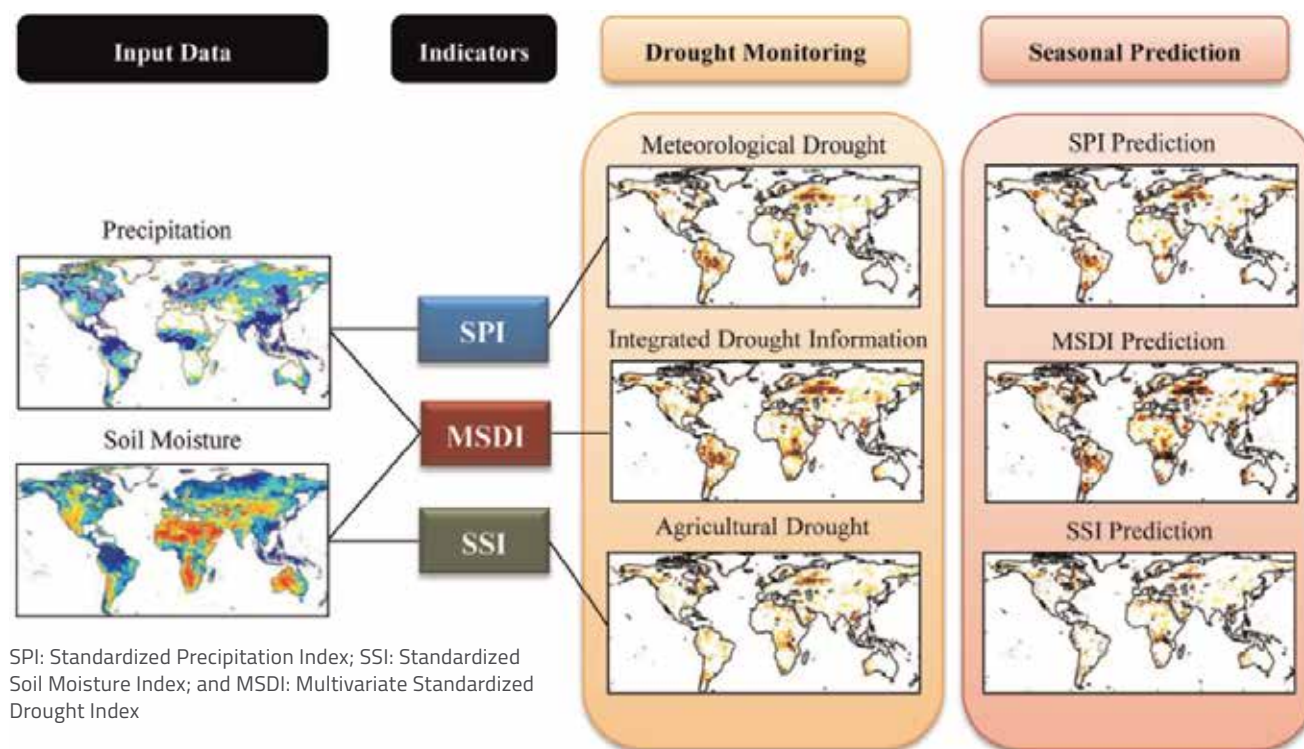
At a global scale, the **Global Integrated Drought Monitoring and Prediction System (GIDMaPS)** (Figure 6) combines precipitation (SPI), soil moisture (SSI) and multivariate (MSDI) indicators (Hao and AghaKouchak 2013, Hao et al. 2014) to monitor near real-time drought events. However, at the time of writing (February 2017), the GIDMaPS data portal and website do not have the most up-to-date data and it is not clear whether the system is currently operational. Another global-scale composite indicator of drought is the **Global Drought**

Information System (GDIS) (Nijssen et al. 2014). The GDIS uses satellite-based precipitation, modelled air temperatures and multiple land surface models to simulate surface moisture storage capacity, combined to produce multi-model near real time estimates of drought conditions, defined as percentiles of soil moisture deficiencies. The GDIS can identify drought events and track to progression of drought in near real time. The GDIS is active and is currently hosted by the US National Integrated Drought Information System (NIDIS).⁶



⁶ <https://www.drought.gov/gdm/content/welcome>

Figure 6. Schematic view of the Global Integrated Drought Monitoring and Prediction System (GIDMaPS) algorithm



Source: Hao et al. 2014

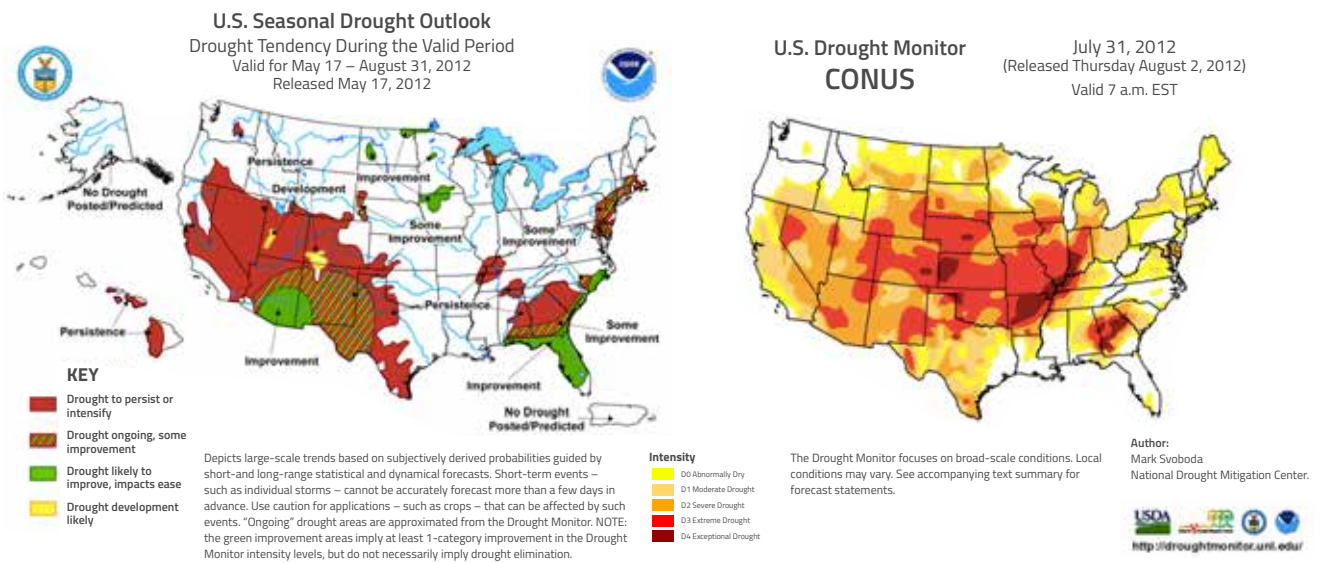
2.5 Reliable drought forecasting

Despite some recent progress, there are still significant limitations in the ability to forecast drought onset, duration, severity, and recovery (Wood et al. 2015). Successful drought prediction requires forecasts of both temperature and precipitation, knowledge of the current state of drought, and the ability to accurately model related changes in drought-relevant moisture stores such as soil moisture, groundwater and snowpack (Wood et al. 2015). Forecasts depend on the availability of highly skilled expertise and judgement to combine temperature and precipitation seasonal outlooks, short-term weather outlooks and information on initial drought-related hydrological, water resource and soil moisture conditions. The US Drought Monitor produces seasonal (90 day) drought outlooks, which can be inaccurate or accurate (Figure 7). Forecasting future droughts beyond short time frames of a month is generally unreliable and forecasts should be treated with care.

Long-term predictions of drought occurrence and frequency over several years to a decade using global climate models are emerging as a tool to support drought management planning.⁷ The climate models estimate future climate trends by considering current climate, natural variability and human influences on climate, such as emissions of greenhouse gases and aerosols. The climate models are the same or similar to those used in IPCC climate change assessments. A significant complication in long-term forecasting of drought using climate models is the identification of the relationships between atmospheric processes and oceanic processes, such as the El Niño–Southern Oscillation and the Indian Ocean dipole, and the contribution of each process to precipitation deficits (Taschetto et al. 2016). Recent work by Taschetto et al. (2016) suggests that oceanic processes contribute less to extended dry periods than previously thought, meaning that atmospheric processes that have a very high degree of randomness are an equal or greater contributor to droughts. The high level of stochasticity makes multi-year drought predictions primarily the domain of researchers. These predictions require expert interpretation to assess their reliability and usefulness of application.

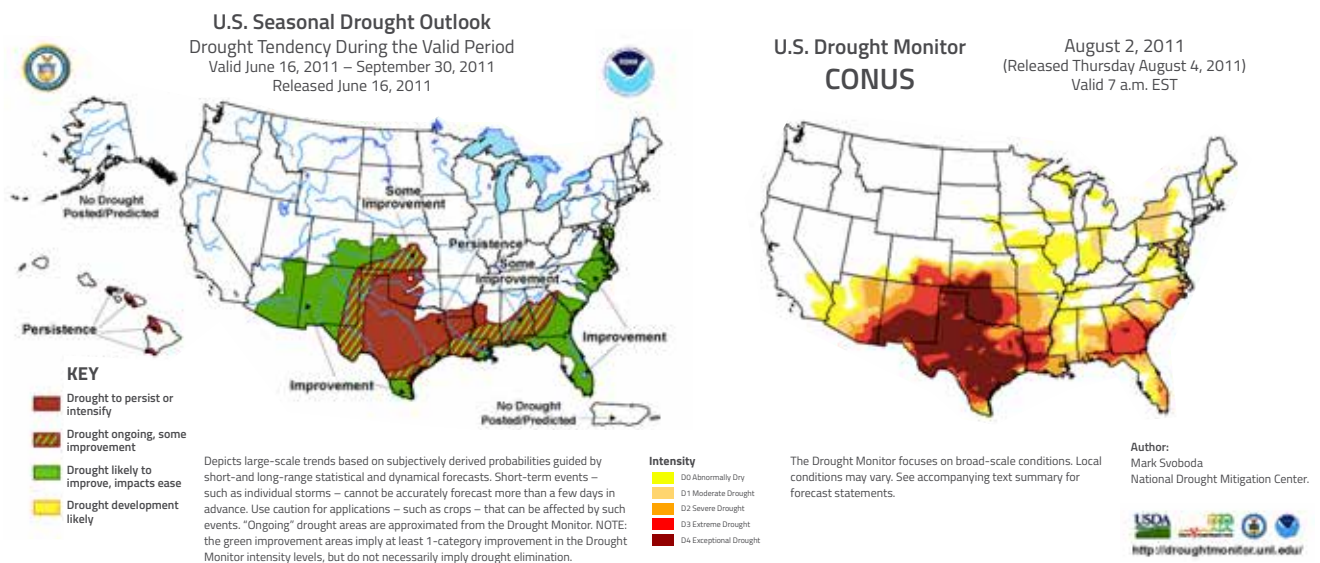
⁷ http://library.wmo.int/opac/doc_num.php?explnum_id=3310

Figure 7a. Seasonal drought outlook observed drought from USDM for summer 2012, providing an example of a very *inaccurate* forecast



Source: Wood et al. (2015)

Figure 7b. Seasonal drought outlook observed drought from USDM for summer 2011, providing an example of an *accurate* forecast



Source: Wood et al. (2015)

2.6 A drought risk assessment for monitoring and early warning

A drought risk assessment is one of the core activities of establishing an effective drought monitoring and early warning system. A risk assessment provides important information for setting priorities and developing actions that prevent drought and mitigate drought impacts (Grasso n.d.). A drought risk assessment extends the vulnerability assessment by including information about the drought hazard independent of the sectors and communities potentially impacted by drought.

Drought risk can be calculated as:

Drought risk = Vulnerability (V) x Hazard (H)

Where vulnerability (V) is calculated as described below (Section 3.3), and Hazard (H) is the likelihood of drought occurrence calculated using the indicators and indices developed for the drought monitoring and early warning system as described in this chapter (Sections 2.3 to 2.5).

The drought risk assessment provides important information to help authorities target drought risk prevention, mitigation and crises response actions to those communities and sectors that are most vulnerable to drought, and in locations where drought characteristics are or expected to be most severe. It is strongly recommended that the drought risk assessment and associated management planning are incorporated into land use and rural development planning, health care systems, environmental and natural resource management approaches, supply chains and business models, and non-agricultural sectors (UNISDR 2015).

The actions to limit impacts of drought and better prepare communities and economic sectors for future droughts are encapsulated in the third key pillar of drought risk reduction, described in more detail in Chapter 4.

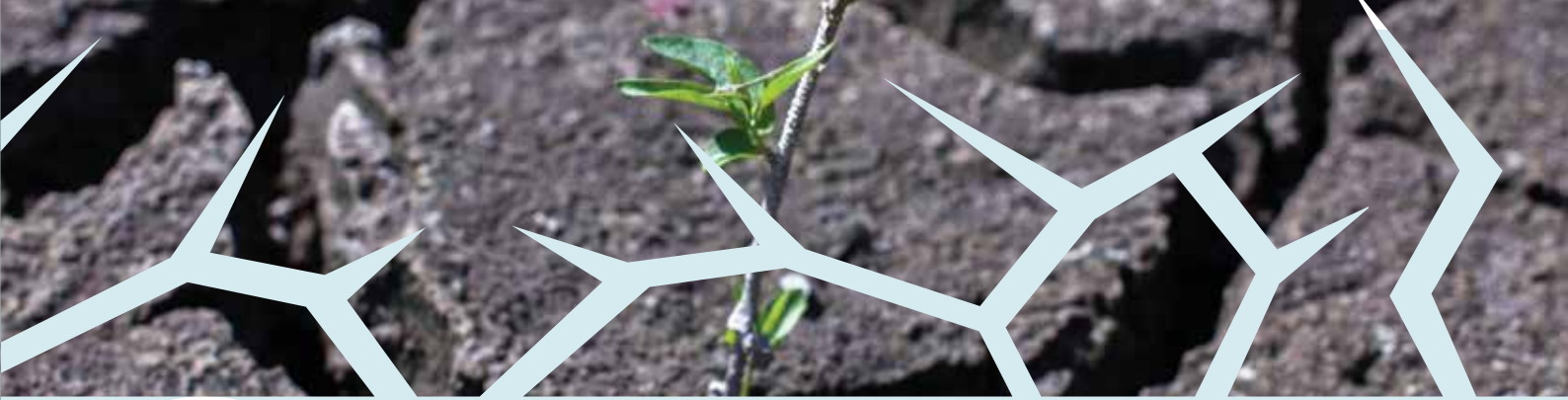
2.7 Communicate and respond to drought warnings

Effective drought monitoring and early warning systems require timely, reliable and simple communication of drought risks. The main aim of an early warning system is to identify when to take action that reduces the chance of losing human lives and mitigates social, environmental and economic impacts of drought. Communication of risk needs to be timely so that authorities and communities can adequately respond to the risk. The communication

needs to be simple so that the risks are well understood by all. The information needs to be scientifically sound and reliable, so that authorities and communities can react to the risks with confidence.

Several innovative information and communications technologies (ICT) can be used for rapid, widespread and simple communication of drought risk (IPCC 2012). Mobile phone and internet communication technology can be used to spread drought risk alerts to all decision-making authorities and all impacted. For example, the rapid uptake and widespread usage of mobile phones in Africa has allowed many countries to forego traditional landline phone communications. Mobile phone ownership has grown from less than 10 per cent in the early 2000s to over 65 per cent in several sub-Saharan countries (Tanzania, Kenya, Ghana, South Africa and Uganda), surveyed in 2014, with SMS communication the most common usage (Pew Research Center 2015). A drought monitoring and early warning system based on a digital platform, automatically triggered by the emergence of specific drought categories such as those described in Table 3, could rapidly send alerts to all mobile phones. Another alert could go out if the drought monitoring and early warning system identifies an area moving or expected to move into a more severe drought category. Social media platforms such as Twitter and Facebook offer a timely and cost-effective venue for spreading drought risk information (IPCC 2012).

Another novel application of ICT for drought monitoring and early warning systems is the use of citizen science smart phone apps as a rapid and low-cost way to collect information about drought impacts as they arise. Citizen science is the collection and submission of scientific data by amateur scientists and the wider public (Bonney et al. 2014). Although considered a recent phenomenon, citizen science has been practised by amateurs for much of recorded history. Thanks to mobile technology, over the past few years citizen science became an accepted and important research tool on large-scale patterns in nature, and holds much promise for inter-disciplinary approach to studying coupled human-ecological systems (Crain et al. 2014). Enhancing drought monitoring and early warning systems with real-time information on drought impacts has been identified as an urgent priority (Bachmair et al. 2016), and citizen science use of smart phone apps allow the public to identify and submit to online databases examples of drought impacts as they occur. While the often-applied criticism of the quality of citizen science data is also applicable to drought impact monitoring, protocols and statistical tools to remove errors and bias are widely available (Bird et al. 2014).



3

ASSESS DROUGHT VULNERABILITY AND RISK

3.1 Overview

This chapter provides guidelines to complete vulnerability and risk assessments for locations, people and economies vulnerable to drought. Vulnerability assessments attempt to understand who is vulnerable to what, when and why, and what can be done to reduce vulnerability. Drought risk assessments involve expanding drought vulnerability by considering the likelihood of occurrence of the drought hazard. Drought vulnerability and risk assessments can be used to identify ways to mitigate drought, design drought management plans and support monitoring and early warning systems. Identifying regions and communities vulnerable to drought is essential for selecting monitoring and early warning indicators and triggers that are applicable in the most vulnerable locations. The drought management and response plans should also be tailored to suit the needs of vulnerable sectors and communities.

3.2 Definitions

The diversity within drought vulnerability studies is extremely high, and there is a lack of common conceptual understanding of vulnerability, standardized methodology and common vulnerability metrics. The lack of agreement on definitions makes it difficult to compare results obtained by different drought vulnerability assessments within a country or region. Therefore, a **consistent definition and conceptual framework** of vulnerability is the first step in a vulnerability assessment. There are two dominant definitions or frameworks:

1. From the disaster risk reduction community: the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards (UNISDR 2015).
2. From the climate change adaptation community: the degree to which a system is susceptible to, or unable to cope with, adverse effects of drought. Vulnerability is a

function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity (IPCC 2014).

The first definition that comes from the disaster risk reduction community is people-centred and focuses on the ability of people and communities to cope with and respond to a drought hazard. While the interdependencies between people and their natural environment are implied through ways in which environmental conditions can influence a community's susceptibility to drought, the definition does not provide a holistic perspective that envelopes social, environment and economic systems. The holistic approach is very important in considering drought because land and natural capital play an integral role in reducing vulnerability.

The second definition, which comes from the climate change adaptation community, takes a holistic view by identifying drought as having an impact on the whole system, not just people and communities. The core elements of the second definition are exposure, sensitivity and adaptive capacity, defined as follows:

- **Exposure:** the nature and degree to which a system experiences environmental or socio-political stress (Adger 2006). The characteristics of these stresses include their magnitude, frequency, duration and areal extent of the hazard.
- **Sensitivity:** the degree to which a system is modified or affected by disturbances (Adger 2006), such as a change in climatic conditions caused by the onset of drought.
- **Adaptive capacity:** the ability of a system to evolve and accommodate environmental hazards or policy changes and to expand the range of variability with which it can cope (Adger 2006). Can also include the ability of a system to take advantage of opportunities, or to cope with the consequences (Füssel and Klein 2006).

3.3 Drought vulnerability assessments

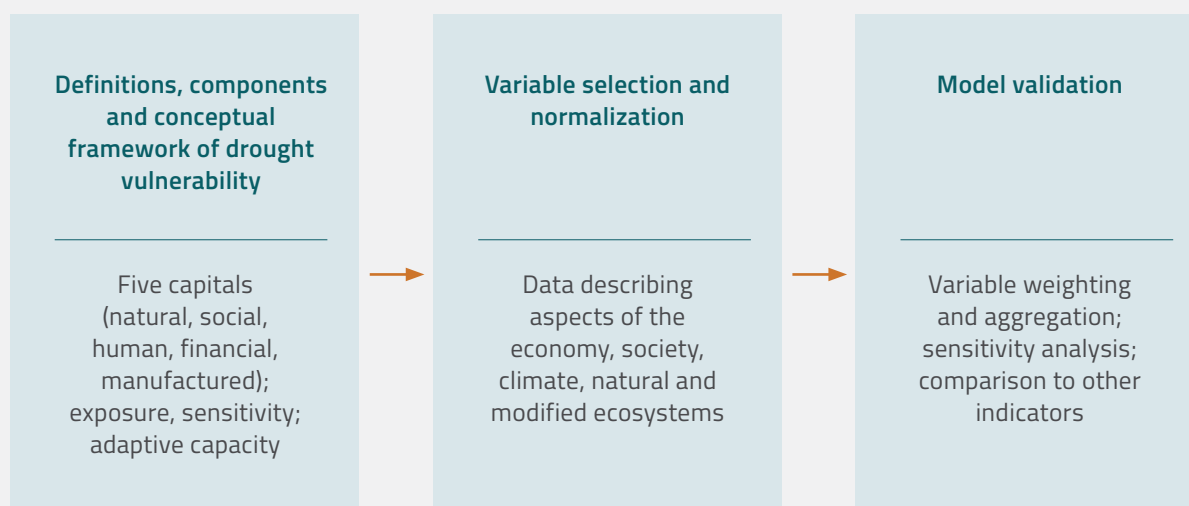
Completing a drought vulnerability assessment is important for several reasons. First, it identifies the communities and sectors that are most likely to be affected by drought. This allows for designing and tailoring effective drought management plans, policies and risk mitigation measures that prioritize actions toward communities and groups where the risk is the greatest. Also, identifying vulnerable communities and sectors is a necessary condition for developing drought preparedness, monitoring and early warning response systems. In addition, a vulnerability assessment is an important learning and knowledge gathering exercise for improving the understanding of human and natural processes that

contribute to drought vulnerability as well as community resilience. Finally, a vulnerability assessment can provide important insights on the typically marginalized groups of society – such as women, children, the elderly and sick, the landless, farmers, pastoralists and indigenous communities.

A drought vulnerability assessment should be framed using the following steps (Naumann et al. 2014) (see Figure 8):

1. Define the components of drought vulnerability: build a conceptual framework and clarify definitions
2. Select variables and normalize
3. Model validation through a weighting and sensitivity analysis, and comparison with other indicators

Figure 8. Example methodological framework for drought vulnerability assessment



Source: Modified from Naumann et al. (2014)

3.3.1 Defining the components of drought vulnerability

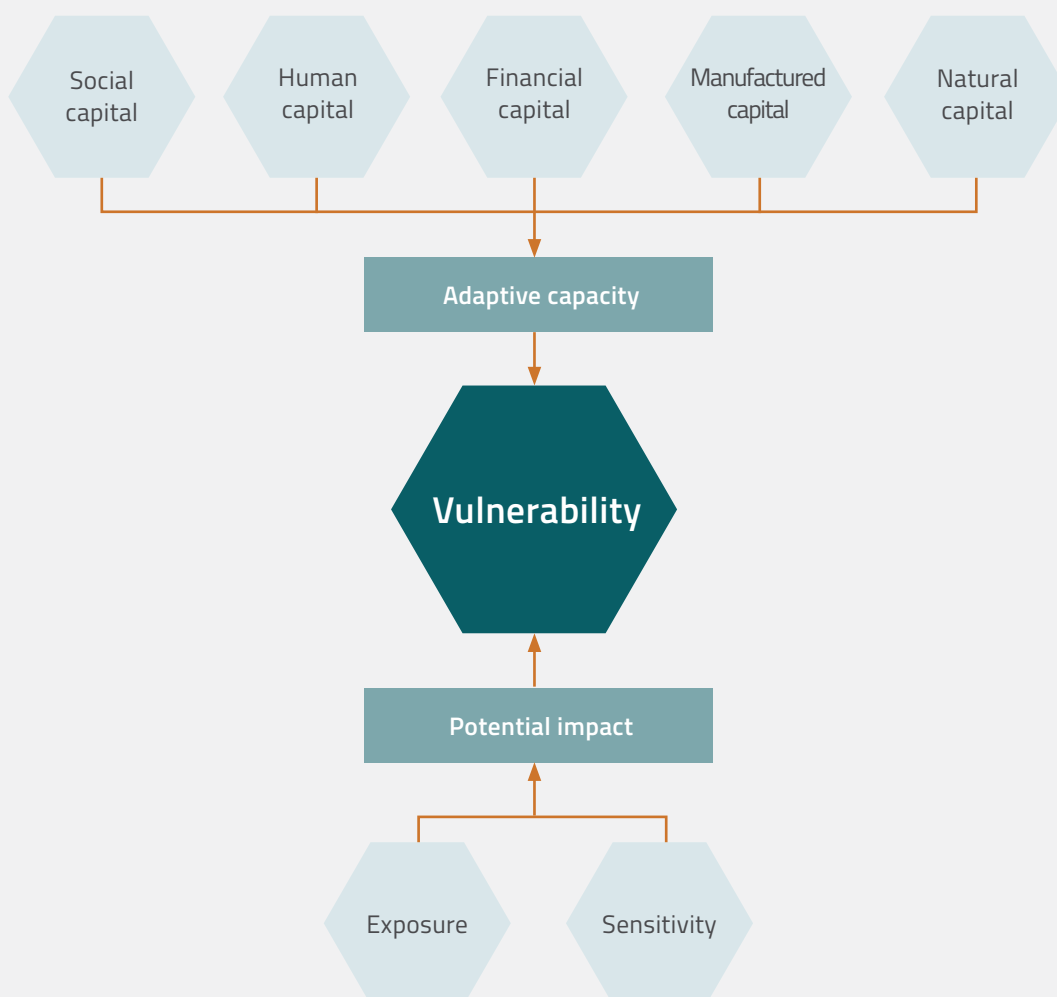
Defining a conceptual framework is the first step in a vulnerability assessment, to ensure that there is clarity of definitions and the assessed aspects of drought vulnerability. The conceptual framework can guide the selection of indicators and variables (Eriksen and Kelly 2007). The climate change adaptation and mitigation scientific literature abounds with vulnerability frameworks. A popular formula for calculating vulnerability is:

$$\text{Vulnerability (V)} = \text{Exposure (E)} + \text{Sensitivity (S)} - \text{Adaptive Capacity (AC)}$$

Vulnerability assessments should be consistent and comprehensive, incorporating multiple dimensions –

social, economic, physical, environmental and institutional. An efficient framework for calculating vulnerability of a system – which includes people, communities and sectors to drought – is presented in Figure 9. Variables describing drought – such as spatial extent, probability of occurrence (based on historic drought records), projected frequencies under climate change and intensity – are often used to estimate exposure. For estimating sensitivity, variables describing the system of interest (for example, agriculture) are needed, such as dependency on water resources, extent of land degradation, population densities, and diversification of income sources. For estimating adaptive capacity, variables describing the five type of capital (natural, social, human, financial and manufactured) are needed. The next section presents variables frequently used in vulnerability assessments. Potential data sources are also provided as an initial source for acquiring relevant data.

Figure 9. Conceptual framework showing the multiple dimensions to be included for assessing vulnerability to drought



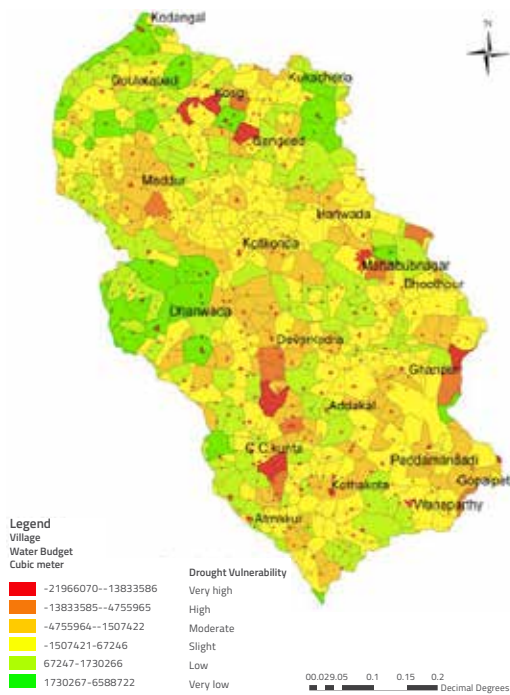
Source: Modified from Gbetibouo et al. (2010)

3.3.2 Selecting variables for vulnerability assessment

Selecting variables for a vulnerability assessment at the national level is hampered by the geographically uneven distribution of drought induced pressures and responses in time and space (Eriksen and Kelly 2007). Drought impacts vary between communities, social groups within a community, between households and between people within a household. There is also spatial heterogeneity of socio-economic characteristics and levels of technology adoption that influence adaptation responses (Stringer et al. 2009, Corbeels et al. 2014, UNISDR 2015, McNeeley et al. 2016).

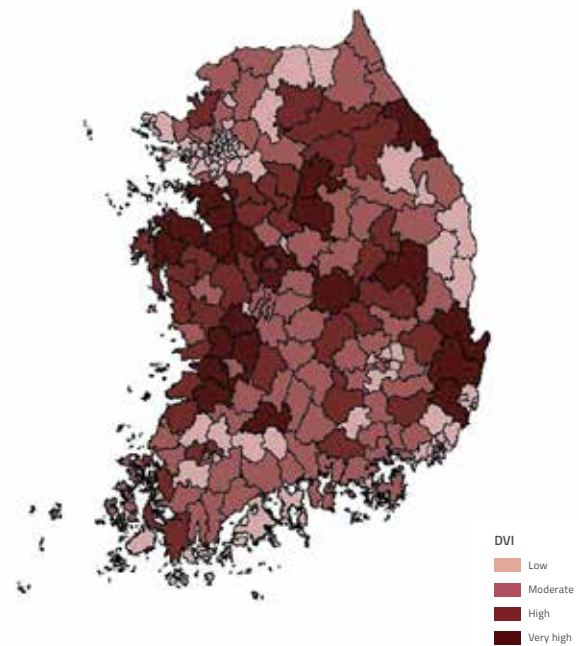
Eriksen and Kelly (2007) advise that **indicators should be sufficiently sensitive in scale and time to capture local patterns of variability**, so that ‘pockets of vulnerability’ – for example geographical areas or sectors of a community where factors and processes conspire to destroy response capacity – can be assessed by the assessment. Vulnerability assessments completed at sub-national scale may be more sensible, since they can include more detailed data at higher resolution, as well as participatory and qualitative approaches. But these assessments are unable to provide comparison on the country scale, which are often needed to allocate the drought-management resources. Figure 10 shows examples of vulnerability assessments at different scales, demonstrating the varying detail of information in relation to the scale of decision making.

Figure 10a. Example drought vulnerability assessment at village scale/Andhra Pradesh, India



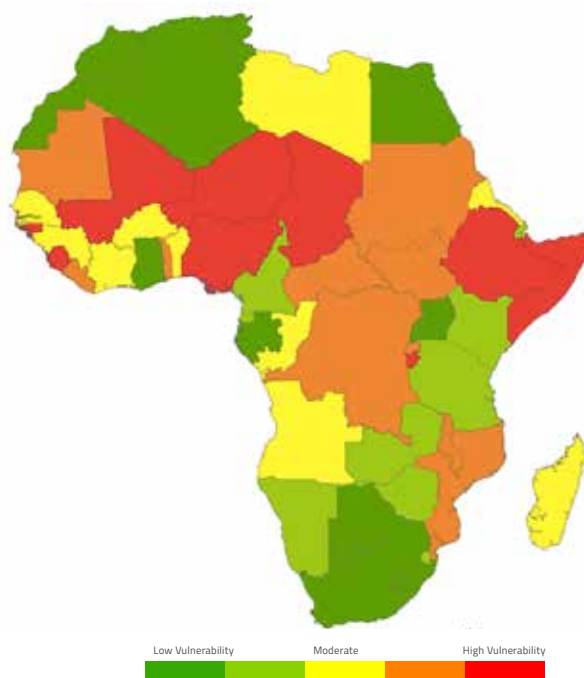
Source: Ganapuram et al. 2013

Figure 10b. Example drought vulnerability assessment at national scale/administrative districts in Republic of Korea



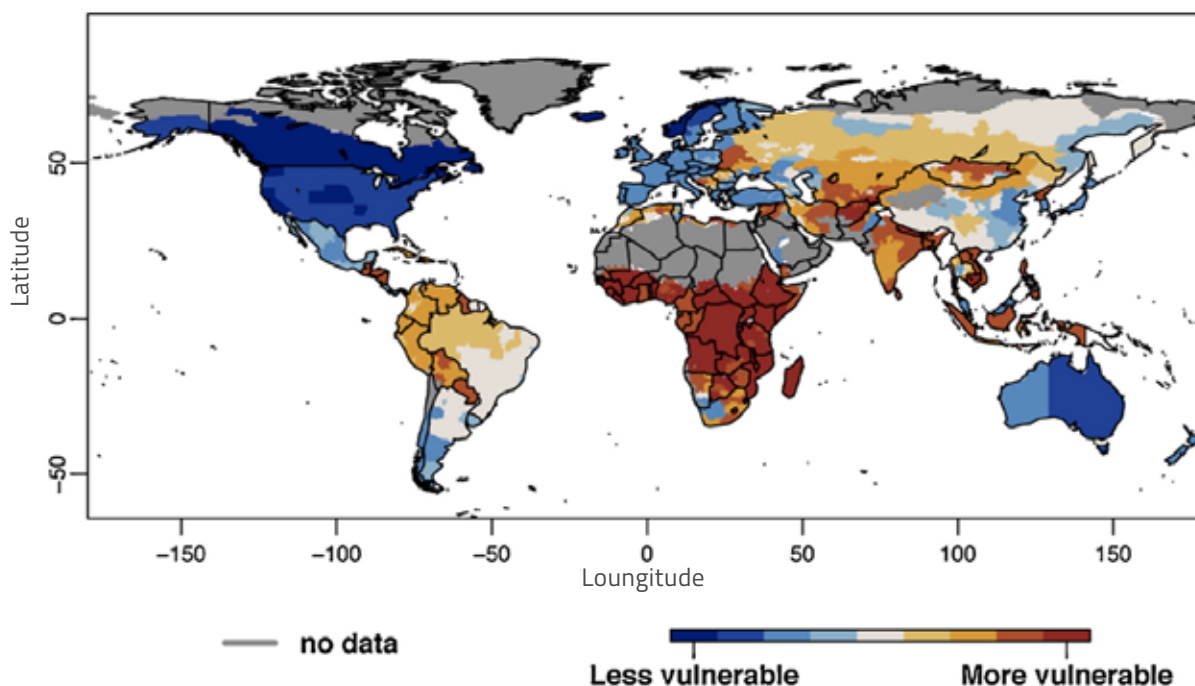
Source: Kim et al. 2015

Figure 10c. Example drought vulnerability assessment continental scale/countries in Africa



Source: Naumann et al. 2014

Figure 10d. Example drought vulnerability assessment global scale



Source: Carrão et al. 2016

The job of selecting variables is aided by a recent review by González Tánago et al. (2016) who assessed 41 drought vulnerability assessments and tabulated the most commonly used factors and variables. Two recent studies of drought vulnerability assessments for Africa (Naumann et al. 2014) and globally (Carrão et al. 2016) provide useful guidance on selecting variables. Table 4 summarizes common variables those used in the recent African and global vulnerability assessments. While many of the variables and indicators listed in Table 4 are global-scale data at a country resolution, many of the indicators and variables could be available at finer scale through national statistical agencies or research institutes. For national or sub-national scale vulnerability assessment, the table can be used as a starting point for selecting variables and the statistical agencies could be consulted for availability at country level.

The biophysical variables most often used in vulnerability assessments to characterize the onset, duration, extent and intensity of drought – such as SPI, NDVI, precipitation, soil moisture and water resource availability – are also indicators often used in drought monitoring and early warning systems. **It is important to have consistency of indicators across drought monitoring and early warning systems and vulnerability assessments**, so that the onset of drought and its impact on vulnerable systems is explicit and recognized early. Selection of variables for an assessment needs to be guided by indicators used in monitoring. Furthermore, variables that are used to

assess vulnerability, and monitor drought can also be used to quantify the drought hazard component of a risk assessment (see Section 2.6).

3.3.3 Preparing variables for the vulnerability assessment

All selected variables should be normalized using minimum-maximum transformation to a common scale. For example, Wiréhn et al. (2015) use the following formula to normalize the variable values in the range 0 to 100:

$$\text{Normalized Indicator Value} = \frac{(\text{Actual Value} - \text{Minimum Value})}{(\text{Maximum Value} - \text{Minimum Value})} \times 100$$

Normalization is very important, since it ensures all variables should have the same range and distribution for valid combination in a vulnerability assessment. Before the vulnerability assessment is completed, all variables should be tested for co-linearity and independence with an exploratory analysis of initial vulnerability indicators. Highly correlated indices should not be used. Examples on testing and removing correlated variables are available (O'Brien 2007, Kim et al. 2015), but using them requires a high level of technical expertise, so a statistician should be consulted for advice.

Table 4. Common global-scale dimensions and indicators/variables used in drought vulnerability assessments

National data and statistics agencies should be consulted for finer resolution national-scale data.

Dimension	Example indicators/variables	Resolution	Source for global-scale data
Exposure			
Drought characteristics	Standard Precipitation Index (SPI)	Various	IRI http://iridl.ldeo.columbia.edu/maproom/Global/
	Normalised Difference Vegetation Index (NDV)	~10km	NASA https://neo.sci.gsfc.nasa.gov
Climatic (current, future)	Precipitation (mm/year)	Various	FAO Aquastat http://www.fao.org/nr/water/aquastat/main/index.stm
	Temperature	Various	http://www.ntsug.umd.edu/project/mod16
	Evapotranspiration	Various	http://www.ntsug.umd.edu/project/mod16
Soil and topography	Soil properties	250m – 1km	ISRIC https://www.soilgrids.org/
Water resource availability	Total renewable water resources per capita (m ³ /person/year)	Country	FAO Aquastat http://www.fao.org/nr/water/aquastat/main/index.stm
Sensitivity			
Water resource use	Proportion of cultivated land irrigated (%)	Country	FAO Aquastat http://www.fao.org/nr/water/aquastat/main/index.stm
	Ratio of total annual water withdrawals to total available annual supply	Country or river basin	WRI Aqueduct http://www.wri.org/applications/maps/aqueduct-country-river-basin-rankings/
	Access to safe drinking water (% of total population)	Country	FAO Aquastat http://www.fao.org/nr/water/aquastat/main/index.stm
Land use	Cultivated area (% of total land area)	Country	FAO Aquastat http://www.fao.org/nr/water/aquastat/main/index.stm
Land degradation	Global map of soil degradation (GLASOD)	Various	ISIRC http://www.isric.org/projects/global-assessment-human-induced-soil-degradation-glasod
Economic diversification	Agriculture as proportion of GDP (% of total GDP)	Country	FAO Aquastat http://www.fao.org/nr/water/aquastat/main/index.stm
Population density	People / km ²	Country	FAO Aquastat http://www.fao.org/nr/water/aquastat/main/index.stm
Social capital			
Disaster preparedness	Disaster risk reduction score	Country	World Bank Open Access Data http://data.worldbank.org
Governance and corruption	Worldwide Governance Indicators	Country	World Bank http://info.worldbank.org/governance/wgi/index.aspx#home

Dimension	Example indicators/variables	Resolution	Source for global-scale data
Income distribution	Gini coefficients	Country	World Bank http://www.worldbank.org/en/research/brief/all-the-ginis
Employment	Unemployment (% of total labour force)	Country	Word Bank Open Access Data http://data.worldbank.org
Access to services	Potable water supply (% of rural population with access)	Country	Word Bank Open Access Data http://data.worldbank.org
Rural-urban population	Rural population (% of total population)	Country	Word Bank Open Access Data http://data.worldbank.org
Refugee intake	Refugee population by country of asylum	Country	Word Bank Open Access Data http://data.worldbank.org
Gender equality	Gender inequality index	Country	FAO Aquastat http://www.fao.org/nr/water/aquastat/main/index.stm
Natural capital			
Land cover	Global tree cover (% per pixel)	30m	USGS https://landcover.usgs.gov/glc/
	Global bare ground (% per pixel)	30m	USGS https://landcover.usgs.gov/glc/
Biodiversity	Monthly net primary productivity	10km	NASA https://neo.sci.gsfc.nasa.gov
Human capital			
Literacy and education	Literacy rates (% of people aged 15+)	Country	Word Bank Open Access Data http://data.worldbank.org
Health and disease prevalence	Life expectancy at birth (years)	Country	Word Bank Open Access Data http://data.worldbank.org
	Prevalence of undernourishment (% of total population)	Country	FAO Aquastat http://www.fao.org/nr/water/aquastat/main/index.stm
Population distribution	Population aged 15–64 (% of total population)	Country	Word Bank Open Access Data http://data.worldbank.org
Financial capital			
Income (individual, national)	GDP per capita	Country	Word Bank Open Access Data http://data.worldbank.org
Poverty rates	Poverty at \$1.90 per day, 2011 PPP (% of total population)	Country	Word Bank Open Access Data http://data.worldbank.org
Public debt	Central government debt (% of GDP)	Country	Word Bank Open Access Data http://data.worldbank.org
Manufactured capital			
Infrastructure development	Water storage capacity (as % of total water resource available)	Country	FAO Aquastat http://www.fao.org/nr/water/aquastat/main/index.stm
Energy consumption	Energy use per capita (M BTU per person)	Country	USA Energy Information Administration http://www.eia.gov/beta/international/

Source: Modified from Carrão et al. (2016) and Naumann et al. (2014)

The next activity is to **apply a weighting scheme** to the variables to represent the level of importance of the inputs to the vulnerability assessment appropriately. Weighting schemes can be divided into three groups:

1. Arbitrary choice of equal weights
2. Statistical methods
3. Expert judgment

Equal weights are invalid, since indicators of vulnerability are not equal contributors and expert judgement is constrained by the availability of experts (Gbetibouo et al. 2010). Statistical methods are preferred and could use **principal components analysis (PCA)** or factor analysis techniques. A PCA is a technique for extracting – from a set of variables – a few orthogonal linear combinations that most successfully capture the common information. This also involves a high level of technical expertise; thus, a statistician should be consulted. The review of vulnerability assessments by González Tánago et al. (2016) concluded that just under two thirds of researchers mention and describe the applied weighting scheme. Almost half of these use statistical methods, such as principal component analysis, while eight consulted experts and/or stakeholders for weighing the variables (González Tánago et al. 2016).

3.3.4 Validating the vulnerability assessment model

The methods used to build and test the validity of a vulnerability assessment model will have a substantial impact on the results. The methods and underlying variables must be visible. A robust vulnerability assessment comparable across time and locations must be transparent (Eriksen and Kelly 2007). Transparency is increased by an uncertainty (or sensitivity) analysis that systematically adds or deletes a variable and systematically adjusts weights and weighting schemes. The impact of adding or deleting a variable and modifying the weighting scheme on the results of the vulnerability assessment should be the main concern when building the composite vulnerability indicator, although this is often not addressed in published drought vulnerability assessments (González Tánago et al. 2016)

An **uncertainty (or sensitivity) analysis** investigates how uncertainty in the input factors – such as the variables, weighting scheme, and method of aggregation – permeates the structure of the drought vulnerability assessment and its results. For example, a sensitivity analysis could involve multiple evaluations of the

vulnerability model using three different weighting schemes, two different variable aggregation schemes and systematic removal and addition of each variable to generate many different model outputs. The main decisions tested for this analysis are:

1. Inclusion or exclusion of variables for the different weighting schemes
2. Variable aggregations in the dimensions of vulnerability according to the theoretical framework (Figure 9)

Experts in environmental modelling and statistical analysis should be consulted for uncertainty and sensitivity analyses.

A common approach for **testing the validity of the vulnerability** assessment is to correlate results to past drought impact data. Many countries and regions do not have comprehensive databases of drought impacts, which creates limitations for testing validity by using the described method. Validation has also been done through field surveys, community meetings and interviews, gathering expert opinions and consulting specialized literature. For example, Naumann et al. (2014) correlated drought vulnerability with the number of people retrieved from the OFDA/CRED International Disaster Database, who were reported to be affected by drought disasters.⁸ This global database on natural and technological disasters contains data on the occurrence and effects of natural disasters worldwide from 1900 to present.

Another important aspect of drought vulnerability assessment is **end-user engagement**. Engaging the final users in parts of the vulnerability model development and the assessment process adds credibility to the model and validates the outputs, since the results will be more relevant if end-users are involved in the assessment process. It is important to present results to end-users in a way that is easy to understand – in previous assessments, this has been done with the maps (González Tánago et al. 2016). Spider diagrams and simple presentation of scores are effective in communicating results of drought vulnerability assessments to end-users. Simple presentation of vulnerability assessment results makes it easier for decision-makers to visualize the hazards and communicate it to potentially affected stakeholders, such as agricultural producers (Wilhelmi and Wilhite 2002). It is important to invest in making the assessment results approachable – for example, by selecting an intuitive range of colours for mapping to reach illiterate audiences (Ganapuram et al. 2013).

⁸ www.emdat.be, Université Catholique de Louvain, Belgium

4

LIMIT IMPACTS OF DROUGHT AND BETTER RESPOND TO DROUGHT

4.1 Overview

This chapter provides information on structural (physical) and non-structural measures that can be implemented to reduce the impacts of drought for nations, economic sectors and communities. This chapter also provides information on short- and long-term intervention and assistance strategies during or immediately after drought. In line with the DRAMP Framework, This chapter covers actions that reduce exposure to drought (mitigation and response), increase resilience to drought risk (mitigation and response), and presents novel approaches for sharing drought risks more equally (mitigation), rather than having the risk disproportionately affect communities and sectors that are most vulnerable to drought. Some of the measures discussed here may require transformational change in social, political and cultural structures.

4.2 Definitions

The disaster risk reduction community defines disaster **mitigation** as structural (e.g. engineered and constructed infrastructure, technologies) and non-structural (e.g. policies and awareness raising) measures undertaken to limit the adverse impact of natural hazards.⁹ For example, planting drought tolerant crops or raising awareness of drought risk through school-based education projects are actions that can mitigate the impact of drought. Disaster **response** is defined as the efforts to preserve life and meet the basic subsistence needs of those people affected by the disaster, such as the provision of assistance or intervention during or immediately after a disaster.⁹

4.3 Reduce exposure and increase resilience to drought

Reducing exposure to drought aims to reduce the potential of loss for people, livelihoods, ecosystem services and resources, and infrastructure as well as economic, social or cultural assets. Increasing resilience to drought aims to strengthen the ability of communities, ecosystems and economies to anticipate, absorb, accommodate or recover from the effects of drought in a timely and efficient manner. Exposure and resilience are inextricably linked because options that often reduce exposure in turn increase resilience. For example, agricultural system diversification and the adoption of sustainable land management practices such as climate-smart agriculture and natural infrastructure both reduce the potential losses from drought and help better absorb the effects of extended periods of abnormally low rainfall (Coates and Smith 2012). Structural measures such as new water storage and irrigation delivery infrastructure can reduce the areas of agriculture exposed to drought risks by reducing potential for economic losses as well as increase resilience by improving water security during times of stress.

4.3.1 Diversifying and modernizing agriculture

Reducing number of people, livelihoods and sectors adversely affected by drought involves de-populating and/or reducing the dependence on subsistence and monoculture modes of agriculture in the most impacted and vulnerable areas. Policies that encourage diversification of land and agricultural production systems to reduce

⁹ <https://www.unisdr.org/we/inform/terminology>

reliance on single crops and single land-use types will also reduce the exposure of communities to drought (Collier and Dercon 2014, Lei et al. 2014). Resilience to drought in agricultural systems can be enhanced by diversifying livestock composition and movement as well as crop types and sowing times, managing carrying capacities of pastures and rangelands in line with climate fluctuations, increasing availability and access to water, and – particularly in Africa – supporting agricultural systems that accommodate both smallholders and large-scale farms (Goldman and Riosmena 2013, Collier and Dercon 2014, Opiyo et al. 2015).

Mass migration out of drought-prone areas is not a legitimate alternative unless it is a part of developing country's socio-economic and structural transition process of agricultural commercialization and modernization (Pingali 1997, Collier and Dercon 2014). Policies that support commercialization, mechanization and the resulting increased labour productivity of agriculture that follow the adoption of new technologies and crop diversification will generally lead to increased yields and reduced demand for labour. For example, the mass out-migration of labour from rural areas in China since the 1970s was driven by central government agricultural policy and trade reform along with land tenure reform, food market liberalization and general investment in agricultural infrastructure and agricultural research (Carter et al. 2012, Deininger et al. 2014). The proportion of citizens working in agriculture declined from around 70 per cent in 1978 to 38 per cent in 2009, and over the same period the agriculture sector grew by over 300 per cent in real terms (Carter et al. 2012). It is important to note that increase in agricultural productivity seen in China has been partly achieved by opening of new land to agriculture in the drier north of the country, which has only been possible through development of groundwater irrigation. The consequent rapid depletion groundwater resources is unsustainable, posing a major concern to the central and regional governments (Carter et al. 2012).

4.3.2 Sustainable land and water resources management

Modernization and sustainable intensification of agriculture that promote a shift from subsistence agriculture to the market-oriented one could lead to the abandonment of marginal land and drought prone areas if opportunities to exploit groundwater are limited (Pingali 1997) and/or land degradation and desertification make farming economically unprofitable. Dile et al. (2013) argue that **modernization, sustainable intensification and the adoption of water harvesting technologies** could close the yield gap in sub-Saharan agriculture, limiting the expansion of agriculture

and encouraging restoration of degraded land. The in-situ water harvesting practices include ridging in fields to slow runoff, mulching to reduce evaporation of soil moisture and reduced or no tilling. Ex-situ options include small water harvesting dams and agroforestry measures that stabilize soils and improve microclimates to reduce evaporation. In addition to the positive effect of water harvesting on agricultural yields, many biodiversity, water quality, land restoration and soil erosion reduction benefits can be obtained through techniques primarily designed to reduce exposure and increase resilience to drought (Dile et al. 2013).

Implementing principles of integrated water resource management (IWRM) to reduce pressure on water resources and development of policies to encourage rain-water harvesting to increase availability of water can reduce the exposure of vulnerable agricultural communities to drought risks in sub-Saharan Africa and elsewhere (Mwenge Kahinda et al. 2010, Lebel et al. 2015). Many IWRM options are available to enhance supply and reduce demand on water resources to limit exposure.¹⁰ Some of the options are long-term measures that are implemented in preparation for future drought, while others are short-term and can be implemented during drought to reduce exposure. Supply enhancements are mostly long-term options, outside the rain-water harvesting and nature-based approaches already discussed, and involve large infrastructure projects, such as new or expanded storages, aqueducts and canals, desalinization, wastewater treatment and reuse, groundwater recharge and cloud seeding. Demand reduction options are substantially more cost effective and can be implemented short term, making them suitable for implementation during drought in response to specific triggers of severity. Demand measures include water saving education programmes, regulation of water allocation and use, water monitoring, metering and forecasting systems, water markets and pricing, and water efficient technologies. The implementation of supply augmentation and demand management options must be fair, equitable and targeted at reducing vulnerability.

For each sector vulnerable to drought, there are many specific options available to augment supply and reduce demand – these are too numerous to list here. **Developing sector-specific guidelines for IWRM, drought triggers level and exposure reduction is recommended.**

The nature-based or green infrastructure approaches to sustainable land use and land management that involve wise use of natural resources to improve soil conditions (for example, adding soil organic carbon), increase biodiversity

¹⁰ See http://www.ais.unwater.org/ais/pluginfile.php/571/mod_page/content/85/FAO.pdf

and vegetated land cover, and enhance the supply of ecosystem services will reduce or halt land degradation and desertification and increase the resilience of communities vulnerable and exposed to drought risks (Tsegai et al. 2015, Lei et al. 2016, Tadesse 2016). Soil is particularly important for reducing vulnerability. For example, characteristics of soil porosity, texture, exposure, relief, amount of organic matter and bulk density will all influence soil water retention. A mix of a hard infrastructure (such as water supply augmentations) and soft solutions (such as capacity building, green infrastructure and nature-based solutions) is best for absorbing and recovering from the effects of drought (Coates and Smith 2012).

4.3.3 Communication, education and capacity building

Non-structural measures to reduce exposure and increase resilience to drought risks are centred on methods to communicate and educate communities about drought risk (UNISDR 2015, Tadesse 2016) and build adaptive capacities. For example, identifying and demonstrating clear links between drought risk reduction interventions in agricultural systems and livelihood improvements will motivate farmers to invest scarce resources in interventions (Global Water Partnership Eastern Africa 2016). The relatively high levels of on-farm investment in technology, and/or change in land management practices to reduce drought risks may require farmers to take on debt, and they will be reluctant to take this step unless the benefits to their livelihoods are clearly demonstrated.

Successful communication of the drought risk reduction strategies to farmers and how they can benefit is achieved through group and social network approaches to disseminating information (Global Water Partnership Eastern Africa 2016). The wide spread use of mobile phones and ICT in less developed economies, not only provides a platform for distributing drought warnings (see Chapter 2), but it can also be used to disseminate information about sustainable land management practices that enhance resilience. Community-led, bottom up initiatives can develop sense of ownership of drought resilience and risk reduction strategies (Global Water Partnership Eastern Africa 2016, Tadesse 2016), which engage and empower typically marginalized groups, such as poor, migrants, indigenous people, women, youth, elderly and people with disabilities (UNISDR 2015, Tadesse 2016, Windhoek Declaration 2016).

4.4 Transfer and share drought risks

Sharing the risks of drought means transferring risks from those most vulnerable to the broader community, which

traditionally may not directly be impacted by drought, but which benefit from drought impacts mitigation or elimination. The goal is to design and implement intelligent, risk reducing financial strategies that support relief, reconstruction and livelihoods' recovery in affected areas. These tools need to mobilize financial resources, involving the private sector (Tadesse 2016). Examples of intelligent approaches include insurance products (micro-insurance, reinsurance) and expansion of the risk pools to national, regional and global scales.

A novel approach presented by Shiferaw et al. (2014) is the development of weather index insurance. Index insurance is a type of insurance linked to an index such as rainfall, temperature or crop yields, as opposed to the actual losses that might be difficult to assess. Index insurance has lower transaction costs and wide applicability in rural areas through weather stations, making it more suitable for poor farmers (Alderman and Haque 2007). The weather index is regressed to changes in agricultural productivity and the payment of indemnities is triggered when the index goes below a certain level. For example, an extended period of low rainfall may trigger an insurance payment if there is a previously established correlation between the recorded levels of low rainfall and the crop failure. Drought indices (see Chapter 2) such as the simple SPI or the more complex composite indicators would be ideal for use in weather index insurance for drought. Any index insurance should include a monitoring programme to mitigate the likelihood of adverse outcomes whereby indemnity payments are grossly insufficient to cover the losses. The ability to access global insurance markets and transfer the risks associated with low-probability, high-consequence events makes weather index insurance potentially useful for managing drought risk (Shiferaw et al. 2014).

Weather index insurance can also be used to inform payments delivered under social safety net schemes (Shiferaw et al. 2014). Social safety nets provide livelihood support and ensure food security during times of stress. They are often community-driven and distribute resources among groups that are most vulnerable and most impacted by extreme weather events. The World Bank has established several risk-sharing and safety net programmes and initiatives that provide insurance to farmers impacted by drought.¹¹ Their *Agriculture Insurance Development Program* and the *Global Index Insurance Facility* scale up agriculture insurance for farmers who are vulnerable to catastrophic weather events. In India, the World Bank has developed an innovative crop insurance program that has benefited one million farmers. There is considerable technical detail behind these programmes, so the Bank should be contacted for a consultation.

¹¹ <http://www.worldbank.org/en/topic/agriculture/brief/reduce-risk-vulnerability-and-gender-inequality-in-agriculture>



5

RECOMMENDATIONS

1. Drought monitoring and early warning systems

Many indices and indicators are available for drought monitoring and forecasting, and each needs to be associated with appropriate triggers of response as drought conditions worsen. The indicators and relevant triggers need to be carefully selected. Work by Steinemann and others (Steinemann and Cavalcanti 2006, Steinemann et al. 2015) lists useful guidelines for choosing indicators and trigger points. Table 1 and the Handbook of Drought Indicators and Indices (World Meteorological Organization and Global Water Partnership 2016) should be consulted when selecting appropriate indices and indicators. The US National Drought Monitoring Centre has developed a state-of-the-art drought monitoring and forecasting system, which should be used as a template for developing new drought monitoring systems.

2. Drought risk assessments

The drought risk assessment provides important information to help authorities tailor drought risk prevention, mitigation and crises response actions to those communities and sectors that are vulnerable to drought, and in locations where drought characteristics are or expected to be severe. Assessing vulnerability is a core component of assessing risk. A vulnerability assessment must rely on a conceptual framework and should be populated with data and indicators describing biophysical and socio-economic components of vulnerability. The indicators across drought monitoring and early warning systems and vulnerability assessments need to be consistent, so that appearance of drought and the impact on vulnerable systems is clear and recognized early. The appropriate selection of indicators, especially for adaptive capacity, can illustrate the ability of vulnerable communities to respond and adapt to current and emergent risks. Table 4 should be used as a starting point for selecting indicators to be

used in drought risk assessment. The global indicators in Table 4 should be complemented or interchanged with nationally and locally relevant data if available.

3. Identify, test and implement actions that mitigate drought risk

Many structural (physical) and non-structural measures can be used by nations, sectors and communities to reduce the impacts of drought. Priority needs to be given to policies and actions that diversify and modernize agriculture and broader economies, encourage wise stewardship of land and water resources, educate communities on drought risk and build adaptive capacities. Many specific options are available for each economic sector vulnerable to drought to augment supply and reduce demand of water resources (based on different trigger levels), and better manage the land and biodiversity to enhance resilience to drought. These options are too numerous to list here. Sector-specific guidelines for IWRM, drought trigger levels, land and biodiversity management, exposure reduction and enhanced resilience are recommended for sectors most at risk.

4. Risk sharing

There are several innovative tools that protect communities against severe drought – these include intelligent insurance products (micro-insurance, reinsurance) and the expansion of risk pools to national, regional and global scales. Although design and implementation of these tools are complex, weather index insurance that uses drought indices is an intuitive approach that can also support the intelligent distribution of social safety net payments for insuring livelihoods and food security during times of drought. The World Bank, which has a lot of information and case studies of insurance and risk sharing programs, can be consulted for more information.





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