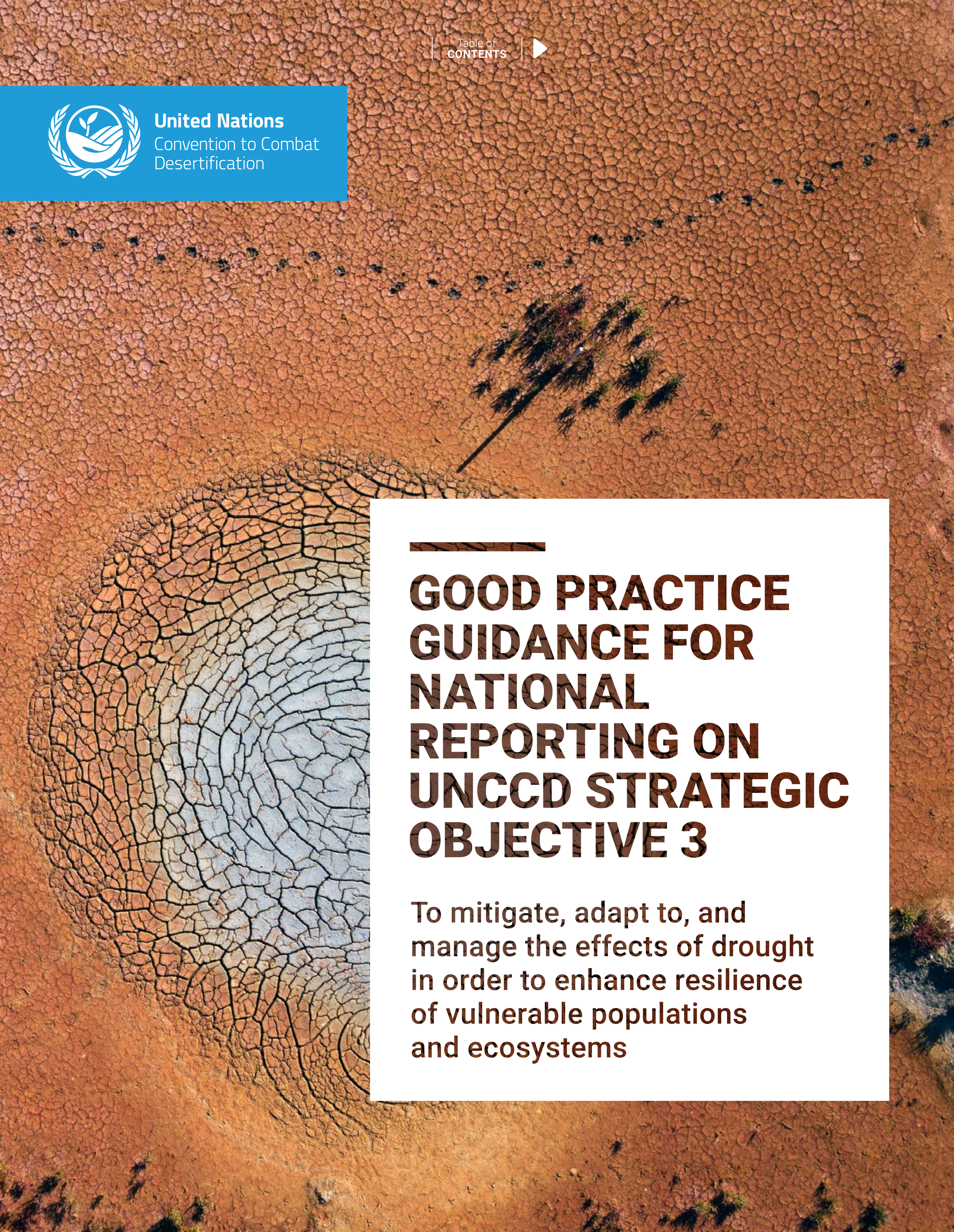


United Nations
Convention to Combat
Desertification

GOOD PRACTICE GUIDANCE FOR NATIONAL REPORTING ON UNCCD STRATEGIC OBJECTIVE 3

To mitigate, adapt to, and manage the effects of drought in order to enhance resilience of vulnerable populations and ecosystems

Citation

Barker, L.J., Rickards, N.J., Sarkar, S., Hannaford, J., King-Okumu, C., Rees, G. 2021. Good Practice Guidance for National Reporting on UNCCD Strategic Objective 3: To mitigate, adapt to, and manage the effects of drought in order to enhance resilience of vulnerable populations and ecosystems. United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany.

Acknowledgments

This Good Practice Guidance for National Reporting on UNCCD Strategic Objective 3 was prepared by the UK Centre for Ecology & Hydrology (UKCEH) for the United Nations Convention to Combat Desertification (UNCCD).

Lead authors

Lucy J. Barker, Nathan J. Rickards, Sunita Sarkar, Jamie Hannaford, Caroline King-Okumu, Gwyn Rees (all UKCEH).

Contributors and reviewers

Valentin Aich, Riccardo Biancalani, Gunilla Björklund, Veit Blauhut, Michael Brüntrup, Victor M. Castillo, Tom Chitson, Sandie Clemas, Neville Crossman, Michael Eastman, Katrin Ehlert, Cathleen Fruehauf, Mariano Gonzalez-Roglich, Adam Griffin, Antje Hecheltjen, Rafael Hernández, Moses Isabirye, Thokozani Kapichi, Habiba Khiari, Nina Köksalan, Janis Kreiselmeier, David Lopez-Carr, Ramona Magno, Fatou Mar, Mustapha Mimouni, Sara Minelli, Gustavo Naumann, Mandakh Nyamtseren, Brian O'Connor, Barron Joseph Orr, Jorge Miguel Leal Pinedo, Narcisa Pricope, Pedro Antonio Núñez Ramos, Ravindranath Nijavalli, Abir Ben Romdhane, Dirk Schattschneider, Sergio Vicente-Serrano, Robert Stefanski, Mark Svoboda, Amjed Hadj Taib, Daniel Tsegei, Micha Werner, Jia Xiaoxia, Evence Louis Zoungrana.

Published in 2021 by United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany

ISBN 978-92-95118-36-2 (hard copy)
ISBN 978-92-95118-37-9 (e-copy)

United Nations
Convention to Combat Desertification

Publication coordinator: Sara Minelli

Design and layout: QUO Bangkok, Co., Ltd.

This publication was made possible with the financial support of the Government of Spain.

Photo credits

Cover: ©Unsplash

GOOD PRACTICE GUIDANCE FOR NATIONAL REPORTING ON UNCCD STRATEGIC OBJECTIVE 3

To mitigate, adapt to, and manage the effects of drought in order to enhance resilience of vulnerable populations and ecosystems

©Unsplash

Foreword

Ibrahim Thiaw
Executive Secretary
UNCCD

Societies, ecosystems and economies all over the world are suffering from the negative impacts of drought. The UN Global Assessment Report on Disaster Risk Reduction *GAR Special Report on Drought 2021* estimates that, from 1998 to 2017, droughts affected at least 1.5 billion people and led to economic losses of USD 124 billion worldwide. While no country is immune, the impacts of drought hit the poorest countries and the most vulnerable people the hardest.

As global average temperatures rise towards 2°C warmer than pre-industrial levels, drought impacts are predicted to worsen in many regions, particularly under business-as-usual scenarios. More than 2 billion people are projected to be exposed to more frequent and severer droughts by 2100, as further highlighted in the *GAR Special Report on Drought 2021*.

A paradigm shift is urgently needed. We must move away from a reactive and crisis-based approach to a proactive and risk-management approach. Dealing with negative drought impacts, such as forced migration or civil unrest, is far costlier than getting ahead of the curve to reduce future risk and increase resilience to the changing drought hazard.

Parties to the United Nations Convention to Combat Desertification (UNCCD) have long recognized the need to address drought as a global problem that can accelerate desertification and land degradation, compromising ecosystem health and people's livelihoods, and catalysing social instability. In 2017, Parties to the UNCCD made the mitigation of drought one their five strategic objectives under the 2018-2030 Strategic Framework, following a drought described as the worst humanitarian crisis since the Second World War. About 20 million people across Africa and the Middle East were on the brink of starvation (UN-OCHA). Two years later, the Parties adopted a global monitoring framework and requested the secretariat, in cooperation with relevant specialized institutions, to develop harmonized methodological guidance for national reporting.

This Good Practice Guidance was prepared to support Parties to report on the progress made towards Strategic Objective 3, which has the aim of mitigating, adapting to, and managing the effects of drought in order to enhance resilience of vulnerable populations and ecosystems. The Guidance informs the work of Parties, particularly for global level reporting of the hazard posed by drought, the population exposed to drought and the vulnerability of those exposed to harm. These are the three fundamental components of drought risk, and each is represented by an indicator identified in the monitoring framework.

This Guidance balances state-of-the-art methodologies and data availability with the need for relative simplicity and global applicability. It is consistent with international standards and relevant resolutions of the World Meteorological Organization. However, no two droughts are the same; as such no unique formula exists to monitor and manage all of them. Through this Guidance, the UNCCD aims to improve collaboration among global drought monitoring efforts within all relevant intergovernmental mechanisms, without replacing the approaches and level of granularity needed to monitor drought at the national and local levels.

Recognizing that national circumstances vary, the monitoring approaches documented in this Guidance can be customized in response to data availability and monitoring capacity. Country Parties can start tracking their progress towards Strategic Objective 3 right away, while emerging scientific developments globally open the doors to further refinement of drought risk monitoring and reporting approaches into the future.

The time is now for the global community to come together and harmoniously address the issue of drought.

Ibrahim Thiaw
Executive Secretary
United Nations Convention
to Combat Desertification

Executive Summary

This Good Practice Guidance (GPG) document provides guidance on how to calculate three indicators used for reporting progress towards the United Nations Convention to Combat Desertification (UNCCD) Strategic Objective 3 (SO3) "To mitigate, adapt to, and manage the effects of drought in order to enhance resilience of vulnerable populations and ecosystems".

The three SO3 indicators describe the three components of drought risk according to the IPCC framework (hazard, exposure and vulnerability) and are as follows:

- **Level 1:** Trends in the proportion of land under drought over the total land area,
- **Level 2:** Trends in the proportion of the total population exposed to drought, and
- **Level 3:** Trends in the degree of drought vulnerability.

Methods to calculate each indicator are presented, including how to calculate the indicators over the baseline period 2000-2015 and when Parties may need to recalculate the indicators as a result of new data and/or methods becoming available. Global default datasets are presented in addition to guidance on the interpretation of the indicator values, the limitations of current recommendations, and opportunities to improve the indicators and their sensitivity for monitoring progress towards SO3 in the future.

The methods and datasets recommended in the GPG for SO3 monitoring are based on Decision 11/COP.14 and its Annex, document ICCD/COP(14)/CST/7, guidelines of the World Meteorological Organization (WMO), and where possible, datasets used for other reporting activities, such as for the Sustainable Development Goals (SDGs) and UNCCD Strategic Objective 2. The supporting datasets and metrics recommended in this GPG have been selected on the basis of having global coverage and being readily available. This GPG recognizes that Parties may have their own datasets and metrics that they may use to derive the indicators needed for SO3 monitoring. Therefore, it provides guidance on when it may be more appropriate to use such datasets instead of the recommended globally available datasets.

The Level 1 Indicator describes the occurrence of drought hazard over time as a percentage of the total land area. It is recommended that the Level 1 Indicator is derived using the Standardized Precipitation Index (SPI) following WMO guidance for meteorological drought monitoring (Hayes et al. 2011). Methods and tools are recommended to calculate the SPI using freely available global datasets – the selection of which depends on data availability, reliability and the location of the reporting Party. The trends in the occurrence of drought is reported according to the proportion of land in four drought intensity classes, mild, moderate, severe and extreme drought, which are based on the SPI values for a 12-month accumulation period. The Level 1 Indicator should be used as a record of the drought hazard during the reporting period, the intensity of which is indicated by the drought intensity classes. It is important to note that drought is a periodic event, and climate variability means it is possible drought may or may not have occurred in either the reporting period, or baseline period.

The Level 2 Indicator describes the exposure of the population to the drought hazard, identified by the Level 1 Indicator, as a percentage of the total population. The Level 2 Indicator establishes who is exposed to drought based on their geographical location and the level of drought intensity experienced as defined by the Level 1 Indicator. The Level 2 indicator can be calculated using either in-country data or freely available global gridded population datasets. The Level 2 Indicator has the potential to be further disaggregated by sex, facilitating the quantification of demographic aspects of drought exposure. The selection of data is dependent on data availability, reliability, and the location of the reporting Party. The outputs produced for the Level 2 Indicator gives a clear indication of where a population is most likely to be subjected to the direct effects of drought, and enables patterns of drought exposure to be identified from a spatial output. In this way, its interpretation should allow for a clear assessment of a population's exposure to drought within a country.

The Level 3 Indicator describes the degree of vulnerability of a country's population to drought, using the Drought Vulnerability Index (DVI) based on methods developed by Naumann et al., (2014) and Carrão et al., (2016). The DVI combines a set of vulnerability factors characterizing the inherent social, economic and infrastructural components of drought vulnerability. In order to address variability and limitations in capacity and data availability, three tiers of vulnerability assessment (VA) are described that require increasing numbers of datasets, higher spatial resolutions and sex-disaggregated data. Globally available datasets are described for the minimum Tier 1 VA up to the Tier 3 VA; in addition, a global DVI dataset is described, which can be used when data for a Tier 1 VA assessment is not available. The DVI is calculated for each country individually, and as such, comparisons between countries should not be made. A high DVI value indicates that a population is more vulnerable to drought, and an increase, a decrease, or no change will provide the Party with an understanding of how the vulnerability of their population is changing across reporting periods.

It is important to note that this first iteration of the GPG for SO3 monitoring focusses on the exposure and vulnerability of populations for the Level 2 and 3 Indicators. In accordance with Decision 11/COP.14, it does not cover ecosystem exposure to drought; the exposure of ecosystems will be included and addressed in future versions of the GPG as appropriate, and in accordance with any future COP decisions. An assessment of ecosystem vulnerability is also not included in this version of the GPG. It is important that methods recommended and used for SO3 monitoring have been applied and validated at the global scale, however, the methodology presented in this GPG has only been expanded to include ecological factors for agricultural systems (Meza et al., 2020).

Appendix A of this GPG outlines how the indicators described in this document could be developed and improved in the future to more effectively monitor progress towards SO3, in particular, the consideration of ecosystem exposure and vulnerability to drought. It also discusses the further scientific advancements required in order to implement such changes.

Contents

Figures

Tables

Boxes

Acronyms

AED	Atmospheric evaporative demand
AMO	Atlantic Multidecadal Oscillation
CCD	Cold cloud duration
CDI	Combined Drought Indicator
CHIRPS	Climate Hazards Group InfraRed Precipitation with Stations
CIESIN	Centre for International Earth Science Information Network
CO2	Carbon dioxide
COP	Conference of the Parties
DHS	Demographic and Health Surveys
DMCSEE	Drought Management Centre for Southeastern Europe
DRAMP	Drought Resilience, Adaptation and Management Policy
DVI	Drought Vulnerability Index
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
EDO	European Drought Observatory
EIA	Environmental Impact Assessment
ENSO	El Niño Southern Oscillation
EO	Earth Observations
EOSDIS	Earth Observing System Data and Information System
ERA	ECMWF Reanalysis
FAO	Food and Agricultural Organization of the United Nations
FEWS NET	Famine Early Warning Systems Network
GDAL	Geospatial Data Abstraction Library
GDCS	Global Drought Classification System
GDP	Gross domestic product
GHM	Global Hydrological Model
GIS	Geographic Information System
GLOFAS	Global Flood Awareness System
GMAS	Global Multi-Hazard Alert System
GPCC	Global Precipitation Climatology Centre
GPG	Good Practice Guidance
GPW	Gridded Population of the World
GRDC	Global Runoff Data Centre
gROADS	Global Roads Open Access Data Set
GRUMP	Global Rural-Urban Mapping Project
GWP	Global Water Partnership
HydroSOS	Hydrological Status and Outlooks System
IDMP	Integrated Drought Management Programme
IPCC	Intergovernmental Panel on Climate Change
ISIC	International Standard Industrial Classifications

JMP	Joint Monitoring Programme for Water Supply, Sanitation and Hygiene
JRC	Joint Research Centre
LSM	Land surface model
MPI	Multi-dimensional Poverty Index
NDMC	National Drought Mitigation Center
NDVI	Normalized Difference Vegetation Index
NetCDF	Network Common Data Form
NMHS	National Meteorological and Hydrological Service
OECD	Organisation for Economic Co-operation and Development
PCA	Principle Components Analysis
PDSI	Palmer Drought Severity Index
PE	Potential Evapotranspiration
SDG	Sustainable Development Goal
SEDAC	Socioeconomic Data and Applications Center
SO3	Strategic Objective 3
SPEI	Standardized Precipitation Evapotranspiration Index
SPI	Standardized Precipitation Index
SSI	Standardized Streamflow Index
UK	United Kingdom
UKCEH	UK Centre for Ecology & Hydrology
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNDRR	United Nations Office for Disaster Risk Reduction
UNESCAP	United National Economic and Social Commission for Asia and the Pacific
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNHCR	United Nations High Commissioner for Refugees
UNICEF	United Nations Children's Fund
UNISDR	United Nations International Strategy for Disaster Reduction
UNPD	United Nations Population Division
UNFPA	United Nations Population Fund
UNWPP	United Nations World Population Prospects
US	United States
USDM	US Drought Monitor
VA	Vulnerability Assessment
VCI	Vegetation Condition Index
VHI	Vegetation Health Index
WAVES	Wealth Accounting and the Valuation of Ecosystem Services
WHO	World Health Organization
WMO	World Meteorological Organization
WRI	World Resources Institute

©Unsplash

DEFINITIONS

This section defines key terms and concepts used in this Good Practice Guidance (GPG). Where it has been possible, intergovernmental-agreed standard definitions have been used throughout, with appropriate references given.

Adaptive capacity

The "ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (IPCC, 2014c).

Agriculture, value added (% of gross domestic product)

Where agriculture corresponds to International Standard Industrial Classifications (ISIC) divisions 1-5 and includes forestry, hunting, and fishing, as well as cultivation of crops and livestock production.[1] This factor refers to the value added for agriculture as a percentage of the gross value added at factor cost. It implies a higher coping capacity of populations (Naumann et al., 2014).

Aridity

Distinguished from **drought** as being an enduring feature of a location/environment. It is a natural permanent imbalance in the water availability consisting of low average annual precipitation, with high spatial and temporal variability, resulting in overall low moisture and low carrying capacity of the ecosystems (Pereira et al., 2002).

Baseline period

The baseline period is 2000-2015 in line with the reporting requirements for all strategic objectives included in the UNCCD 2018-2030 Strategic Framework.[2] For the Level 1 and Level 2 Indicators in this GPG, indicators calculated for the baseline period are used as context for future reporting process to assess the status of drought hazard and exposure over time. For the Level 3 Indicator, the **Drought Vulnerability Index** (DVI) values calculated for the baseline period should be compared to DVI values from each reporting period to assess trends in drought vulnerability over time. This is assuming that the DVI has been calculated consistently with no changes to the input datasets or methodology between the baseline and reporting periods. In this GPG, the baseline period is split into four year intervals for the purposes of reporting and summarizing the three indicators.

Capacity to cope or coping capacity

The "ability of people, institutions, organizations, and systems, using available skills, values, beliefs, resources, and opportunities, to address, manage, and overcome adverse conditions in the short to medium term" (IPCC, 2014c).

Cultivated area equipped for irrigation (per cent)

The cultivated land that is equipped for irrigation, expressed as a percentage of the total cultivated land. This factor is not valid for the few countries that irrigate pastures. It is calculated by dividing the area equipped for irrigation (which is the area equipped to provide water via irrigation to crops, including full/partial controlled irrigation, equipped lowland areas and areas equipped for spate irrigation[3]) by the cultivated area.[4] This refers to the physical area actually cultivated and does not include land which is temporarily fallow. This factor gives an indication of the short-term coping capacity of the agriculture sector to drought. However, it does not consider if this equipment is in working order, if land is being irrigated or if there is long-term planning on the use of the water resources for irrigation to ensure long-term adaptive capacity.

Degree of drought vulnerability

In this GPG, the assessment of a country's vulnerability to drought as represented by the **Drought Vulnerability Index** (DVI).

[1] http://www.fao.org/faoterm/en/?defaultCollId=7 [Collection: Organic agriculture, Entry: 99393]
[2] https://www.unccd.int/sites/default/files/sessions/documents/2017-11/cop21add1_eng.pdf
[3] http://www.fao.org/faoterm/en/?defaultCollId=7 [Collection: Water, Entry: 100468]
[4] http://www.fao.org/faoterm/en/?defaultCollId=7 [Collection: FAOTERM, Entry: 22510]

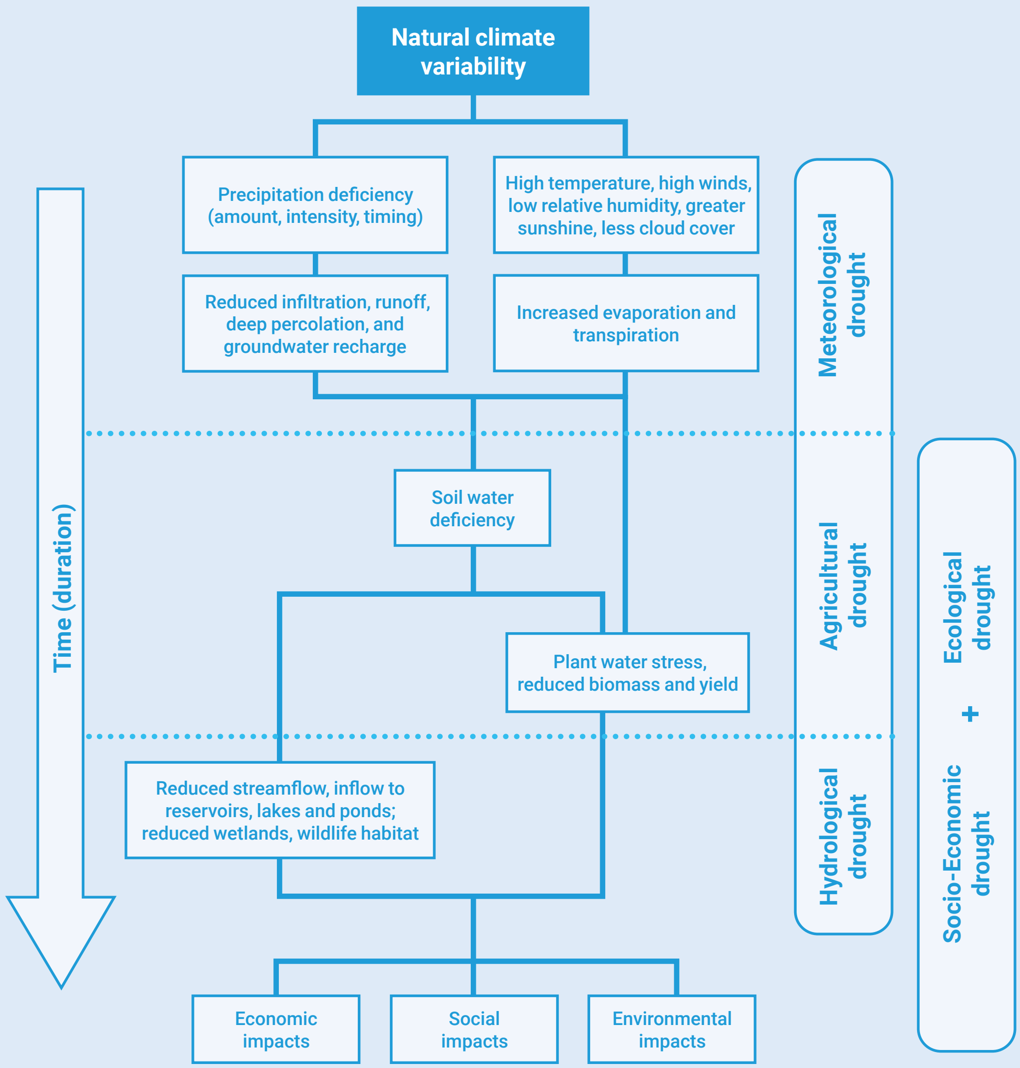
Box 1

Definitions of different 'types' of drought that may occur as a result, or impact, of a meteorological drought

Beyond the simple conceptual definition of drought as a departure from 'normal' conditions, drought definition is a complex and contentious area. A commonly agreed upon 'universal' definition for drought does not exist and, to a large extent, is fundamentally impractical (Lloyd-Hughes, 2014) due to the complexity of deficits propagating through the hydrological cycle, resulting in impacts on soil moisture, groundwater levels, river flows, water supplies, ecosystems, and the society and economy (see figure of Sequence of drought occurrence and impacts for commonly accepted drought types below).

All droughts originate from a deficiency of precipitation or meteorological drought but other types of drought and impacts cascade from this deficiency.[5]

Sequence of drought occurrence and impacts for commonly accepted drought types



Source: Adapted from the National Drought Mitigation Center (NDMC)

5 https://drought.unl.edu/Education/DroughtIn-depth/TypesofDrought.aspx

Box 1 continued

Definitions of different 'types' of drought that may occur as a result, or impact, of a meteorological drought

To this end, various 'types' of drought have been recognized, typically distinguishing between meteorological, hydrological, agricultural and socioeconomic drought (after Wilhite and Glantz, 1985), although further differentiation is often used, for example, with recognition of 'ecological drought'. While widely referred to as 'types' of drought, this word is used for convenience rather than implying these are distinct and mutually exclusive. Fundamentally, the 'types' are manifestations of one and the same thing (a meteorological anomaly), but with different characteristics owing to attenuation or lags as this anomaly propagates through the hydrological cycle. Furthermore, these 'types' are often defined based on the sector of the hydrological cycle in which impacts occur. It follows that it is possible for these different 'types' of drought to occur at the same time in a given location depending on the rate of propagation of the meteorological deficits.

There is no formal, universally agreed taxonomy of these 'types' of drought, but some common definitions from the scientific literature with brief discussions are provided below.

Meteorological drought – the UNCCD definition of drought, given above, is a general one, but this definition primarily describes meteorological drought, that 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).

Hydrological drought – 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" (Tallaksen and Van Lanen, 2004). Given the lag-times in propagation through the hydrological cycle, it typically develops more slowly than meteorological drought – although this depends very much on the responsiveness of hydrological systems, which varies significantly depending on the nature and configuration of surface and groundwater storage. Within this classification, groundwater drought is sometimes recognized separately, such that the term hydrological drought is sometimes used in general but sometimes more specifically for surface water. Van Loon (2015) provides a comprehensive introduction to hydrological drought and highlights how the concept can be subdivided into many further sub-types according to dominant hydrological processes, seasonality (and so on).

Agricultural drought – also known as soil moisture drought, period of reduced soil moisture that results from below-average precipitation, less frequent rain events and/or above-normal evapotranspiration, resulting in impaired growth and reduced yields (King-Okumu, 2019). While the term typically refers to reduced soil moisture, increasing temperatures can directly impact crops through physiological stress. More generally the term can also refer to agricultural impacts from drought due to hydrological deficits (e.g. due to a lack of available water for irrigation).

Socioeconomic drought – when human activities are affected by reduced precipitation and related water availability. Socioeconomic drought associates human activities with elements of meteorological, agricultural and hydrological drought, and "occurs when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply" (King-Okumu, 2019). Within this broad classification, arguably a very broad range of drought types could in theory be identified, based on the economic sectors impacted (e.g. see the discussion of Hannaford et al., 2019).

Ecological drought – prolonged or widespread deficit in soil moisture or biologically available water. The IPCC refers to both agricultural and ecological drought as 'soil moisture drought' but often these two are treated as independent types: agricultural drought is thought of as affecting agroecosystems, while ecological drought is thought of as affecting other natural or managed terrestrial and freshwater ecosystems, such as forests or wetlands, and their flora and fauna. Given this, it makes sense to refer more generally to 'soil moisture drought' as the physical phenomenon and agricultural and ecological drought as based primarily on sectoral impacts. Furthermore, ecological drought goes beyond terrestrial impacts caused by low soil moisture, as increased temperatures and reduced water availability can cause ecosystem degradation and physiological stress leading to, for example, tree mortality (Breshears et al., 2013) or fish kills. Ecological, or environmental, drought has received less treatment in the literature until relatively recently, although a number of recent papers have advanced the concept (e.g. Crausbay et al., 2017; Slette et al., 2019; Vicente-Serrano et al., 2020).

Further complexity is added by the fact that drought rarely occurs as a single event but rather is linked with other hazards, such as heatwaves and wildfires, as well as previous drought events. Drought definition is also hampered by the variation in the spatial and temporal scales over which it occurs. Droughts typically evolve slowly, and typically last many months to several years, although extreme 'megadroughts' can persist for decades (e.g. Cook et al., 2015). In contrast, so-called 'flash droughts' occur over short periods (less three months), are typically characterized by high temperatures and result in a rapid depletion of soil moisture that can lead to major impacts (Otkin et al., 2018; Pendergrass et al., 2020).

Drought

A period of dry weather long enough to cause a serious hydrological imbalance (World Meteorological Organization, 1992; IPCC, 2012). The UNCCD defines drought as "the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems" (UNCCD Article 1 of the Convention).[6]

There are numerous definitions of the term 'drought', but common to all is the fact that drought is a relative concept, and must be seen as a departure in precipitation relative to the 'normal' conditions for the time of year, for the location in question (Tallaksen and Van Lanen, 2004; Mishra and Singh, 2010). Some common definitions from the scientific literature and a brief discussion on drought are provided in Box 1.

It is important not to confuse a drought event, which refers to a given, time-bound event defined relative to the time/place in question, with the fundamentally distinct and more permanent concepts of **water scarcity** and **aridity**.

Drought indicator

A variable or parameter used to describe **drought** conditions, for example: precipitation, streamflow, groundwater levels and soil moisture (World Meteorological Organization and Global Water Partnership, 2016).

Drought index

Typically, a computed numerical representation of **drought** characteristics is assessed using climatic or hydrometeorological inputs (derived from observed measurements, remote sensing or modelled data). Drought indices provide quantitative assessment of various key characteristics (e.g. the intensity, location, timing and duration) of drought events. Thus, drought indices – in combination with additional information on exposed assets and their vulnerability characteristics – are essential for tracking and anticipating drought-related impacts and outcomes (World Meteorological Organization and Global Water Partnership, 2016). It should be noted that drought indices are inherently also **drought indicators** as they describe drought conditions, and in many cases are used interchangeably. Given the challenges of drought definition described above, it is no surprise that there has been a proliferation of different approaches to quantify the drought hazard through the use of various drought indices. Lloyd-Hughes (2014) identified over 100 different drought hazard indices in the literature, but the growth of literature in this area since (e.g. Bachmair et al., 2016a) means the number of indices potentially available for application is likely to be many more. This GPG utilizes the globally accepted drought index, the **Standardized Precipitation Index** (SPI) in order to derive the **Level 1 Indicator.**

[6] https://www.unccd.int/sites/default/files/relevant-links/2017-01/UNCCD_Convention_ENG_0.pdf

Drought intensity class

Class of drought intensity as described by a **drought index**. In this GPG, drought intensity class refers to classes of **Standardized Precipitation Index** (SPI) values by drought intensity: mild drought (-1 to 0), moderate drought (-1.5 to -1), severe drought (-2 to-1.5) and extreme drought (less than -2). As the intensity classes become increasingly extreme, the likelihood of those values occurring (and the time spent in that category) decreases. The SPI and intensity classes are described further in Sections 1.1, 1.2 and 1.4.

Drought Vulnerability Index (DVI)

A composite index of drought **vulnerability**. It is comprised of three components: social, economic and infrastructural, which are each linked to vulnerability. For the purposes of this GPG, each component can also be an arithmetically derived number consisting of **social, economic and infrastructure factors**, which are observable or measured variables available as global and/or national datasets.

Economic vulnerability factors

The observable/measured variables available as global and/or country-level and sub-national datasets, which are being recommended in this GPG for use in constructing the economic component of the **Drought Vulnerability Index** (DVI). These factors have been used in the scientific literature and recommended by experts to define economic vulnerability to drought.

Energy consumption per capita

Use of primary energy on a per capita basis, where primary energy refers to energy before transformation to other end-use fuels. This includes indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport.[7] Though it does reflect climatic, geographic and economic factors, such as the relative price of energy, it is a measure of economic activity, with high-income economies consuming five times as much energy on a per capita basis than low- and middle-income economies. This factor implies that a growing economy would be more able to implement short-term coping and long-term adaptation strategies.

Exposure

Characterizes the presence of people, society, livelihoods, ecosystem, environment, resources, infrastructure, economic or cultural assets that could be adversely affected by hazards (IPCC, 2014b). In the context of a spatially and temporally varying hazard, exposure can be seen as the extent to which a unit of assessment falls within the geographical range of a hazard event (Birkmann et al., 2013). Knowing how many people are exposed to drought is an important first step in identifying those that have the potential to be impacted by the hazard (Pricope et al., 2020). In the GPG, we define exposure (and measured by the **Level 2 Indicator**) in terms of the number of people who are exposed to **drought** using the **Level 1 Indicator** data.

GDP per capita (constant 2010 US dollars)

The gross domestic product (GDP) divided by mid-year population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in constant 2010 US dollars.[8] This is a proxy for the average standard of living of residents in a country or area.

Gender

Refers to the social attributes and opportunities associated with being male and female, and the relationships between women and men, and girls and boys, as well as the relations between women and those between men. These attributes, opportunities and relationships are socially constructed and are learned through socialization processes. They are context/time specific and changeable. Gender is part of the broader sociocultural context. Other important criteria for sociocultural analysis include class, race, poverty level, ethnic group and age.[9]

[7] https://data.worldbank.org/indicator/EG.USE.PCAP.KG.OE

[8] https://data.worldbank.org/indicator/NY.GDP.PCAP.KD

[9] https://trainingcentre.unwomen.org/mod/glossary/view.php?id=36&mode=letter&hook=G

Level 1 Indicator

As set out in Decision 11/COP.14, the Level 1 Indicator is **"Trends in the proportion of land under drought over the total land area"**. For the purposes of reporting on progress towards Strategic Objective 3 (SO3), the proportion of land under drought is expressed as the proportion of land under four **drought intensity classes:** mild drought, moderate drought, severe drought and extreme drought.

The unit of measurement for the Level 1 Indicator is the spatial extent expressed as the proportion (percentage or %) of the total land area of the country that is under each drought intensity class in each reporting year. Values should be given to one decimal place.

Level 2 Indicator

As set out in Decision 11/COP.14, the Level 2 Indicator is **"Trends in the proportion of the population exposed to drought of the total population"**, which is defined by the percentage (%) of the population exposed to a **drought intensity class** defined by the **Level 1 Indicator** for each **reporting year**. Values should be given to one decimal place.

Level 3 Indicator

As set out in Decision 11/COP.14, the Level 3 Indicator is **"Trends in the degree of drought vulnerability"**, which is the general direction in which the assessment of a country's vulnerability (as represented by the **Drought Vulnerability Index**) is changing over time (or remaining stable in the case of no change) against the **baseline period**.

Global Drought Classification System (GDCS)

A drought classification system that is being developed by World Meteorological Organization (WMO) as a way to harmonize national drought indices produced by National Meteorological and Hydrological Services (NMHS). This system will contribute to the WMO Global Multi-hazard Alert System (GMAS) framework, which aims to support the provision and dissemination of official national weather alerts and warnings by countries.

Government effectiveness

Captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies (Worldwide Governance Indicators, 2015). As such, it is one of the proxies to assess a country's ability to cope with drought events (Naumann et al., 2014).

Hazard

A possible, future occurrence of natural or human-induced physical event that may have adverse effects on vulnerable and exposed elements (Cardona et al., 2012; IPCC, 2014c). In this case, hazard refers to a **drought** event caused by a natural hydrometeorological deficit (and measured by the **Level 1 Indicator**) that has potential to impact exposed and vulnerable populations and ecosystems.

Infrastructural vulnerability factors

The observable/measured variables available at global and/or country- and sub-national level datasets, which are being recommended in this GPG for use in constructing the infrastructural component of the **Drought Vulnerability Index** (DVI). These factors have been used in scientific literature and recommended by experts to define infrastructural **vulnerability** to drought.

Life expectancy at birth

The number of years a newborn infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout its life.[10] This is an indication of the health status of a country, where a healthier population would be inherently more resilient to drought impacts.

[10] https://data.worldbank.org/indicator/SP.DYN.LE00.IN

Literacy rate (per cent of people aged 15 years and above)

The percentage of people aged 15 years and above that can both read and write, with understanding, a short simple statement about their everyday life. The literacy rate is described as an outcome indicator to evaluate educational attainment, although does not necessarily measure the quality of education. It can predict the quality of the labour force and can be used as a proxy instrument to measure the effectiveness of education systems. The accumulated achievement of education is fundamental for further intellectual growth and social and economic development. A high rate of female literacy implies that women can seek and use information for the betterment of the health, nutrition and education of their household members and are empowered to play a meaningful role.[11] A populace with a high literacy rate would be better equipped to both cope with drought and implement drought mitigation and adaptation strategies.

Population

The total population inhabiting the given land unit. For the purposes of the **Level 2 Indicator**, 'population' refers to the absolute count of people per grid cell and the 'total population' refers to the summed count of people for the whole country. For the **Level 3 Indicator**, 'population' refers to the total population of the country, and the total (male or female) population of the sub national spatial unit being used, depending on the proposed **Tier of Vulnerability Assessment** used.

Population aged 15-64 years (per cent of total population)

The total population between the ages 15 to 64 as a percentage of the total population and is an indication of the impacts different age groups have on the environment and on infrastructure, helping in the analysis of resource use and formulation of future policy and planning goals with regard to infrastructure and development.[12]

Population below the international poverty line (per cent)

The percentage of the population living on less than $1.90 a day at 2011 purchasing power.[13] People living in poverty are more likely to live in areas and under conditions that increase their exposure and make them more susceptible to suffering from the impact of natural hazards, while decreasing their coping and adaptation capacities (Hagenlocher et al., 2019; supplementary information 3).

Precipitation

The liquid or solid product of the condensation or sublimation of water vapour falling from clouds or deposited from air on to the ground (World Meteorological Organization and UNESCO, 1998).

Population using safely managed drinking water services (per cent)

Proportion of population that is using an improved drinking water source that is located on the premises, available when needed, and free from faecal and priority chemical contamination. Improved drinking water sources include piped water, boreholes or tubewells, protected dug wells, protected springs, rainwater, and packaged or delivered water.[14] The higher the proportion of the population with access to safe drinking water, the better the living conditions of these populations and hence, the better equipped they are to cope with drought.

Reference period

The standard climate normal period used to standardize precipitation data to derive the **Standardized Precipitation Index** (SPI). Current WMO guidelines define 1981-2010 as the standard climate normal period (World Meteorological Organization, 2017), however, it should be noted, this may change in future reporting processes as more data are made available.

---

11 https://data.worldbank.org/indicator/SE.ADT.LITR.ZS

12 https://data.worldbank.org/indicator/SP.POP.1564.TO.ZS

13 As a result of revisions in purchasing power parity (PPP) exchange rates, poverty rates for individual countries cannot be compared with poverty rates reported in earlier editions.

14 https://www.sdg6monitoring.org/indicator-611/

Refugee population by country or territory of asylum

The population of people recognized as refugees under the following criteria: the 1951 Convention Relating to the Status of Refugees or its 1967 Protocol; the 1969 Organization of African Unity Convention Governing the Specific Aspects of Refugee Problems in Africa; in accordance with the UNHCR statute; and those granted refugee-like humanitarian status or people provided temporary protection.[15] Country of asylum is the country where an asylum claim was filed and granted. Refugee populations are more likely to be exposed to natural **hazards** (living in make-shift dwellings, etc.) and less capable of coping with disasters (Naumann et al., 2014).

Reporting process

As set in Decision 15/COP.13, this is the four-year frequency for UNCCD reporting. The first reporting process for SO3 monitoring is planned to start in 2021, for the **reporting period** 2016-2019. Parties will then report Level 1, Level 2 and/or Level 3 Indicators to UNCCD every four years.

Reporting period

The four-year time period over which the three SO3 Indicators are quantified in each **reporting process**. The **Level 3 Indicator** is calculated for each reporting period, whilst the Level 1 and Level 2 Indicators are calculated for each **reporting year** within the reporting period.

Reporting year

Each **reporting period** is comprised of four reporting years. In the case of the **Level 1 and Level 2 Indicators**, indicators are calculated for each reporting year.

Resilience

The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization and the capacity to adapt to stress and change (Lavell et al., 2012).

Rural population (per cent)

The percentage of the total population that live in rural areas, which is calculated by subtracting the urban population from the total population.[16] Rural populations may have greater income inequities, and livelihoods that are more dependent on natural resources, for example, which may make them disproportionately vulnerable to drought.

Sex

The physical and biological characteristics that distinguish males and females; sex-disaggregated data is data that is cross-classified by sex, presenting information separately for men and women, and boys and girls.[17]

Social vulnerability factors

The observable/measured variables, available as global and/or country and sub-national datasets, which are being proposed in this GPG for use in the construction of the social component of the **Drought Vulnerability Index** (DVI). These factors have been used in scientific literature and recommended by experts to define social **vulnerability** to drought.

Standardized Precipitation Index (SPI)

A **drought index** widely used to monitor meteorological **droughts**. It was developed by McKee et al. (1993) and is based on long-term **precipitation** data which is fitted to a probability distribution function and then transformed to the normal distribution so that an SPI of zero describes the normal precipitation for the given location, month and accumulation period (World Meteorological Organization, 2012). Deviations from this (positive and negative) are then expressed in terms of standard deviations. More extreme values indicate that these deviations are more severe but also less likely to occur. The SPI is recommended by WMO for monitoring meteorological droughts because it is relatively simple to calculate using only one **drought indicator** input, it can be compared over both time and space and can be calculated for different user-defined accumulation periods (Hayes et al., 2011). It is important to note that there are limitations to the application of the SPI, particularly in arid climates (e.g. Wu et al., 2007) – these limitations are discussed in more detail in Section 1.5.

The SPI is calculated by aggregating (i.e. summing) monthly precipitation data over a given accumulation period. This could be 1-24 months, for example, in line with a great majority of applications of the SPI, although the index has been calculated at the daily and weekly time step for operational drought

[15] https://data.worldbank.org/indicator/SM.POP.REFG

[16] http://www.fao.org/faoterm/en/?defaultCollId=7 [Collection: FAOTERM, Entry: 56112]

[17] https://trainingcentre.unwomen.org/mod/glossary/view.php?id=36&mode=letter&hook=S

monitoring purposes, and accumulations longer than 24 months are also used in practice. Here we recommend using 12 months to provide an indication of annual precipitation deficits for each spatial entity individually (e.g. grid cell or a rain gauge), yielding a monthly time series of 12-month precipitation accumulations. This is then transformed to the standard normal distribution so that the SPI has a standard deviation of one and a mean of zero (McKee, Doesken and Kleist, 1993). An SPI value is calculated for each calendar month, for each grid cell and each accumulation period. More information on the SPI and SPI accumulation periods can be found in the WMO SPI User Guide (World Meteorological Organization, 2012). In this GPG, accumulation periods are denoted as SPI-x; for example, SPI-12 corresponds to a 12 month precipitation accumulation period.

Susceptibility

The likelihood of damage in an extreme natural event; it describes the structural conditions of ecosystems and society (Meza et al., 2019).

Tier of Vulnerability Assessment (Tier of VA)

A representation of a level of methodological complexity in calculating the **Drought Vulnerability Index** (DVI). It is being used in a similar way as was defined in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) and approved through Decision 20/CP.7.

Total land area

The total surface area of a country excluding the area covered by permanent inland waters, such as major rivers and lakes.

Total renewable water resources per capita

The total annual actual renewable water resources per inhabitant,[18] including surface and groundwater sources[19] for the whole country. This variable does not take into account whether the water is easily accessible, or safe, but is indicative of how much water each person in a country could have access to at any given time, which may indicate a higher adaptive capacity to drought.

Vulnerability

As defined in ICCD/COP(14)/CST/7 and sourced from the 2016 Report of the Open-ended Intergovernmental Expert Working Group on Indicators and Terminology Related to Disaster Risk Reduction (A/71/644),[20] vulnerability refers to "conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards, such as drought." Hence, vulnerability is an inherent property of a system that exists independently of the external hazard (Vogt et al., 2018), i.e. the same level of hazard may impose different consequences in different systems (communities, individuals, countries, regions) due to the distinct underlying vulnerabilities of the systems. In turn, vulnerability to the hazard and its impacts can be altered by the actions of society, such as land and water management practices, among others (King-Okumu et al., 2020).

Here we consider three components of vulnerability, in line with the framework proposed by the UNISDR (2004):

- **Social vulnerability**, which is linked to the level of well-being of individuals, communities and society;
- **Economic vulnerability**, which is highly dependent upon the economic status of individuals, communities and nations; and
- **Infrastructural vulnerability**, which comprises the basic infrastructures needed to support the production of goods and sustainability of livelihoods.

Water scarcity

A long-term imbalance between the supply and demand of freshwater in a specified domain (country, region, catchment or river basin, etc.) as a result of the high rate of demand compared with available supply, under prevailing institutional arrangements (including price) and infrastructural conditions (FAO, 2012; Reichhuber et al., 2019). A region experiencing water scarcity will be more vulnerable to **drought** than other areas.

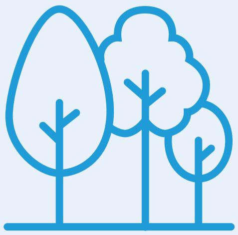
18 http://www.fao.org/faoterm/en/?defaultCollId=7 [Collection: Water, Entry: 100429]
19 http://www.fao.org/faoterm/en/?defaultCollId=7 [Collection: Water, Entry: 100427]
20 https://www.preventionweb.net/files/50683_oiewgreportenglish.pdf

INTRODUCTION

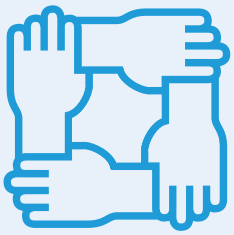
The thirteenth session of the Conference of the Parties (COP13) of the United Nations Convention to Combat Desertification (UNCCD) adopted a Strategic Framework for 2018–2030. This was laid out in Decision 7/COP.13, and includes Strategic Objective 3 (SO3) and two associated expected impacts, 3.1 and 3.2:[21]

STRATEGIC OBJECTIVE 3:

To mitigate, adapt to, and manage the effects of drought in order to enhance resilience of vulnerable populations and ecosystems.



EXPECTED IMPACT 3.1:
Ecosystems' vulnerability to drought is reduced, including through sustainable land and water management practices.



EXPECTED IMPACT 3.2:
Communities' resilience to drought is increased.

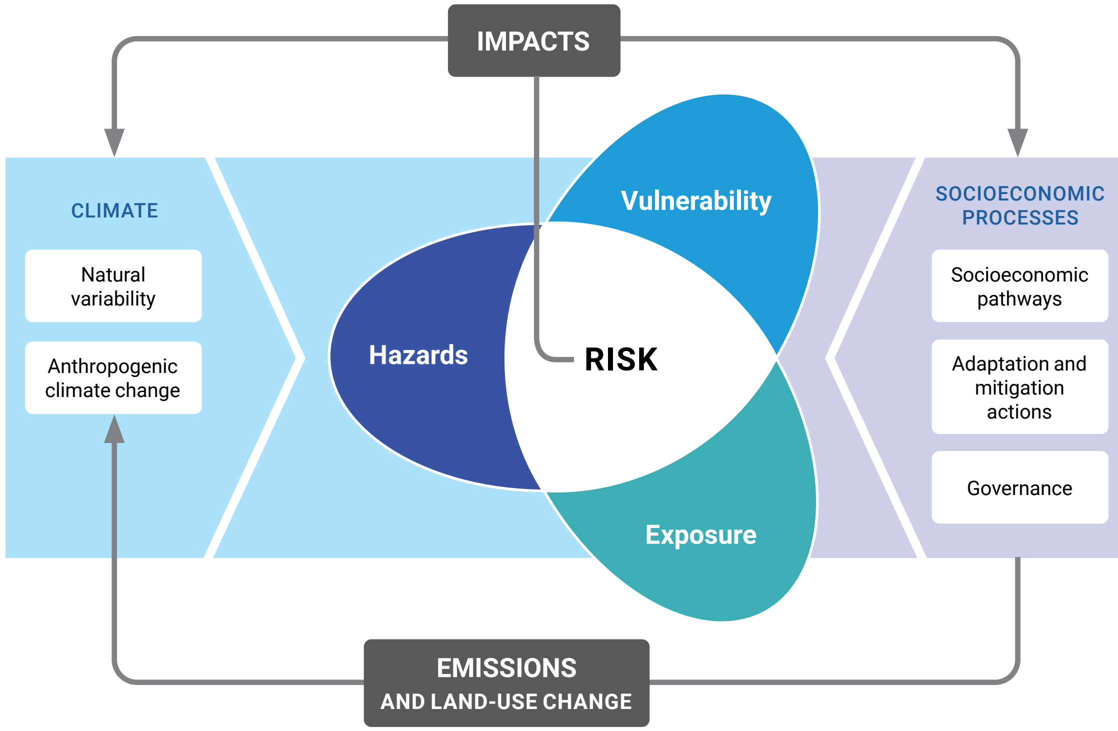
Drought is a ubiquitous natural hazard that occurs in all climate zones, leading to significant economic, societal and environmental impacts. Globally, droughts are one of the most costly hazards (e.g. FAO, 2017; World Meteorological Organization and Global Water Partnership, 2017). They often cover broad areas and have long durations, which can result in a larger proportion of the population being affected than for other hazards (UNISDR, 2009). Moreover, in many areas of the world, droughts are likely to become more severe in the future due to anthropogenic warming (IPCC, 2012). In addition to anthropogenic warming, future water scarcity is likely to be exacerbated by social and demographic changes, leading to growing demands for water and pressures on the environment through land degradation and intensifying resource exploitation (UNESCO, 2019; UNCCD and FAO, 2020).

Drought risk describes how likely a country or region is to be negatively impacted by drought (IPCC, 2014b). This can be assessed by means of the combination of **hazard, exposure and vulnerability**. Decision 11/COP.14 and its associated document ICCD/COP(14)/CST/7 outline the decision to characterize and monitor drought hazard, exposure and vulnerability. Understanding who and what are at risk provides critical information to deploy meaningful mitigation and adaptation strategies (Figure 1).

21 Icons made by Freepik from www.flaticon.com

Figure 1

IPCC risk framework



Source: Adapted from IPCC 2014a

Indicators for SO3 monitoring

By its Decision 11/COP.14,[22] the COP adopted a methodology and a tiered approach for the establishment of an indicator and monitoring framework for SO3. **The adopted framework includes three indicators to report on – drought hazard, drought exposure and drought vulnerability of affected Parties.** This framework is set out in Table 1, as given in the Annex to the Decision. A detailed description of the adopted indicator and monitoring framework, and associated metrics/proxies is contained in ICCD/COP(14)/CST/7.[23]

Country Parties to the Convention, in Decision 11/COP.14, requested the UNCCD Secretariat in cooperation with the United Nations Office for Disaster Risk Reduction (UNDRR) and the World Meteorological Organization (WMO) and its Global Multi-Hazard Alert System (GMAS) framework, and in consultation with additional agencies[24] and other relevant specialized institutions, to:

- Compile and provide affected country Parties with national estimates of candidate metrics/proxies associated with the Level 1 and Level 2 Indicators from global datasets as default data for validation; and
- Prepare methodological good practice guidance, and provide capacity-building and technical assistance to affected country Parties on the compilation/validation and use of such default data, as well as approaches to assess drought vulnerability.

[22] https://www.unccd.int/sites/default/files/sessions/documents/2019-11/11-cop14.pdf

[23] https://www.unccd.int/sites/default/files/sessions/documents/2019-08/ICCD_COP%2814%29_CST_7-1910576E.pdf

[24] Including the Food and Agriculture Organization of the United Nations (FAO), the Global Water Partnership (GWP), the Integrated Drought Management Programme (IDMP), the Intergovernmental Panel on Climate Change (IPCC), and the United Nations Population Fund (UNFPA).

Table 1

Summary of the indicators and the basis for the metrics/proxies relevant to each of the three levels of the proposed drought indicator and monitoring framework as given in the Annex to Decision 11/COP.14

Level	Progress indicator	Basis for candidate metrics/proxies*
Level 1 – Simple drought hazard indicator	Trends in the proportion of land under drought over the total land area	World Meteorological Organization Global Drought Indicator[25] (standardized into classes) monitored and mapped monthly, and aggregated for the United Nations Convention to Combat Desertification reporting period.
Level 2 – Simple drought exposure indicator	Trends in the proportion of the population exposed to drought of the total population	Percentage of the population exposed to each drought class defined in Level 1.
Level 3 – Comprehensive drought vulnerability indicator	Trends in the degree of drought vulnerability	Composite index of relevant economic, social, physical and environmental factors that contribute to drought vulnerability.

* The description provided for the candidate metrics/proxies should be considered preliminary as these will evolve through a multilateral process such as the World Meteorological Organization Global Multi-Hazard Alert System framework. This will help ensure progress towards the collaborative development of standards in methods and data supported by good practice guidance, as well as national ownership of the reporting process.

It is important to note that this Good Practice Guidance is strictly for the intended purpose and does not attempt to provide or replace any guidance or processes used for official declarations of drought that may be used by country Parties (e.g. in drought management plans) and it should not be used as such.

Purpose of this Good Practice Guidance

Starting with the 2022 UNCCD reporting process and every four years thereafter, country Parties will be requested to report on the Level 1, Level 2 and Level 3 Indicators, both individually or in combination, as deemed appropriate according to national and subnational conditions and circumstances.

This Good Practice Guidance (GPG) provides simple guidance on preparing and interpreting the three indicators in Decision 11/COP.14 and its Annex. It balances the current state of-the-art validated and scientifically reviewed methodologies and data availability on the one hand, with the need for relative simplicity and global applicability on the other.

These three indicators: Level 1 Indicator on drought hazard, Level 2 Indicator on drought exposure and Level 3 Indicator on drought vulnerability should be calculated by Parties for the UNCCD baseline period of 2000-2015, and in future reporting processes in line with the reporting requirements for all strategic objectives included in the 2018-2030 Strategic Framework. The baseline period provides context for Parties to understand their drought hazard, exposure and vulnerability over time for SO3 monitoring. The periodic nature of drought and natural climate variability means that it is possible that drought may or may not have occurred in the relatively short baseline period. As such, any observed changes or trends in the proportion of land under drought and the proportion of the total population exposed to drought over this short time-frame should be interpreted with caution for Level 1 and Level 2 Indicators. The baseline for the Level 3 Indicator can be used to directly compare drought vulnerability and assess whether vulnerability is increasing, decreasing or remaining stable over time. The baseline period is summarized using four-year intervals, reflecting the four-year reporting periods used for SO3 monitoring. More information on calculating the baseline period is discussed for each level of indicator in the respective methodology sections.

[25] Now known as the Global Drought Classification System (GDCS; SERCOM-1(II)/Doc. 5.1.1).

This GPG for SO3 is designed to be used by country Parties and all stakeholders alongside version 2.0 of the Good Practice Guidance for monitoring SDG 15.3.1 (i.e. Strategic Objective 1; Sims et al., 2021). The methodology is intended to be universal, allowing Parties to select the most appropriate datasets for the three indicators, whether these are the default globally available open source datasets or their own equivalent national datasets where available. This GPG is based, to the greatest extent possible, on internationally established methodology and standards, and is supported by datasets that are routinely updated, maintained and available over the long term. Recognizing that national circumstances and capacities vary, the GPG has been designed so that the approaches documented can be customized in response to data availability and capacity. To achieve this balance, this GPG provides not only recommended global datasets and indices, but also guidance on when it may be more appropriate to supersede these with alternative in-country datasets and indices.

This GPG provides detailed information on definitions and concepts, methods of calculation, data sources and collection, rationale and interpretation and limitations, and will ultimately provide the basis for the refinement of national reporting tools (e.g. templates, manuals, glossaries[26] and decision-support tools such as Trends.Earth[27]). This GPG will also be instrumental for capacity development efforts to enable countries to monitor and report on SO3.

Overview of approach, processes and data used within the GPG

This GPG supports reporting on achievement towards SO3 of the 2018-2030 Strategic Framework of the UNCCD and the progress made towards ecosystems vulnerability reduction and increased resilience of communities to drought. Improvement is based on The guidance contained in ICCD/COP(14)/CST/7 on hazard, exposure and vulnerability indicators and methods were built upon. As such, methods have been recommended that would enable country Parties to report, with currently-available data and established methodologies, for the 2022 UNCCD reporting process. However, this GPG acknowledges that further scientific and data advancements are likely to be needed to enable all country Parties to routinely monitor and consistently assess drought hazard, exposure and vulnerability for the purpose of achieving SO3 (see Appendix A).

The supporting datasets and metrics recommended in this GPG have been selected on the basis of having global coverage and being readily available. This GPG recognizes that Parties may have their own datasets and metrics that they may use to derive the indicators needed for SO3 monitoring. It provides guidance, therefore, on when it may be more appropriate to use such datasets instead of the recommended globally available datasets.

[26] https://prais.unccd.int/node/7
[27] http://trends.earth/docs/en/

Box 2

Criteria for establishing the indicators and monitoring framework for SO3 as contained in Decision 11/COP.14 and its Annex

(a) **Indicator set hierarchy and logic.** Following the UNCCD indicator set hierarchy, which makes it possible to distinguish what to measure (progress indicators) and how it should be measured (candidate metrics/proxies).

I. Strategic objectives

a. Progress indicators

i. Metrics/proxies;

(b) **Sensitivity of the indicator** to the strategic objective, which, here, focuses on how drought affects the resilience of vulnerable populations and ecosystems to future drought;

(c) **Comparability** of nationally reported data on candidate metrics/proxies for the indicator, with consideration of issues concerning the development and practical implementation of international standards in underlying data, methodologies and guidance;

(d) **Readiness** of candidate metrics/proxies for the indicator for operational use, based on the suitability of the indicator and challenges that may need to be overcome for its effective use, including:

(i) Global coverage of candidate metrics/proxies for the indicator to enable the development of national estimates and provide them to affected country Parties from global datasets, as default data; and

(ii) Capacity to create ownership at the national level, whereby countries can follow standardized guidance to develop indicator data, empowering them to validate, replace or reject the default data;

(e) **Gender disaggregation** potential or the ability for indicator data to be collected, analysed and reported upon with respect to gender in order to ensure assessment of the contributive differences in the distribution of achievements between women and men;

(f) **Adaptability.** It is recommended that both the Drought Monitoring Framework and the indicator set be regularly re-evaluated for (i) suitability as monitoring and evaluation efforts mature; and (ii) usefulness in decision-making given that needs may change and scientific tools may improve.

Six criteria for establishing the tiered drought indicator and monitoring framework for SO3 are set out in the Annex to Decision 11/COP.14 (see Box 2). Table 2, taken from ICCD/COP(14)/CST/7, describes the three SO3 indicators and their ability to meet five of these six criteria. Note that only five of the six criteria are used to assess the three SO3 indicators as the first criteria "Indicator set hierarchy and logic" is set out in Decision 11/COP.14. Methods, data and indicators used in this GPG have been recommended in order to meet these criteria, and the three SO3 indicators have been assessed in this GPG according to the ranks described in Figure 2.

This first iteration of the GPG for SO3 monitoring focuses on the **exposure and vulnerability of populations** for the Level 2 and 3 Indicators. It does not cover ecosystem exposure to drought, in accordance with Decision 11/COP.14; the exposure of ecosystems will be included and addressed in future versions of the GPG as appropriate, and in accordance with any future COP decisions. An assessment of ecosystem vulnerability is also not included in this version of the GPG. The methodology presented in this GPG has only been expanded to include ecological factors for agricultural systems thus far (Meza et al., 2020), and it is important that methods recommended in this GPG have been applied and validated at the global scale. The importance of including an ecosystem component in order to fulfil the requirements of the SO3 monitoring framework agreed in Decision 11/COP.14 is discussed further in Appendix A.

Although the wording of Decision 11/COP.14, its Annex and ICCD/COP(14)/CST/7 describe the need for gender disaggregation in the criteria for SO3 monitoring (as discussed above), given the differentiation between sex (the physical and biological characteristics that distinguish males and females) and gender (which refers to the social attributes and opportunities associated with being male or female), SO3 monitoring in this GPG considers the criteria of 'Disaggregation by sex' instead.

Table 2

Tiered approach taken directly from ICCD/COP(14)/CST/7 for the establishment of an indicator and monitoring framework for UNCCD Strategic Objective 3 on drought.

It is anticipated that countries would pursue the level or combination of levels in this framework most appropriate to national circumstances and capacities

Level	Description
Level 1 – Simple drought hazard indicator	This would be a commonly calculated and easy-to-use global drought indicator[28] for which data are being regularly produced in most countries, which could be aggregated under a common framework consistent with international standards and be supported in terms of data collection, analysis and reporting by an existing multilateral process. Ideally the development of candidate metrics/proxies for this indicator would leverage ongoing collaboration between National Meteorological and Hydrological Services (NMHSs) to ensure that steps towards standardization are taken multilaterally with full consideration of national circumstances. Such an indicator would score high in terms of 'Readiness' and 'Comparability', however it would be much less responsive to the 'Sensitivity' and 'Gender disaggregation' criteria.
Level 2 – Simple drought exposure indicator	This indicator would link the Level 1 simple drought hazard indicator with a commonly calculated and easy-to-use proxy for drought exposure, such as the population exposed to drought. The development of the underlying candidate metrics/proxies could be conducted within the multilateral process identified for Level 1. This would lead to an improvement on the 'Sensitivity' score but with limited or no improvement for the 'Readiness', 'Comparability' and 'Gender disaggregation' criteria.
Level 3 – Comprehensive drought vulnerability indicator	This indicator would build on Level 1 and Level 2 to more directly and more comprehensively address the strategic objective, which is to mitigate, adapt to, and manage the effects of drought in order to enhance resilience of vulnerable populations and ecosystems. Vulnerability in this context refers to the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards, such as drought. The assessment of drought vulnerability is essential for the identification of the underlying causes of drought impacts, which is essential to developing appropriate policy responses. However, there is no single metric or proxy that can adequately represent the complexity of drought vulnerability, which means that this indicator would need to be a composite of the physical, social, economic, and environmental factors contributing to community and ecosystem vulnerability to drought, ideally collected at both the national and subnational levels. Exploration of this level could be pursued in collaboration with the multilateral process identified in Levels 1 and 2. This Level 3 indicator would score highest on 'Sensitivity' and would have the greatest capacity for 'Gender disaggregation'. However, noting the complexity of this approach and the likely demands in terms of data and methods, it would currently score lower in the national ownership aspect of 'Readiness'. In addition, the likely variability in the availability of required data sets would influence 'Comparability' among countries. A harmonization/standardization process focused on candidate metrics/proxies and methodologies could help address these concerns if conducted multilaterally.

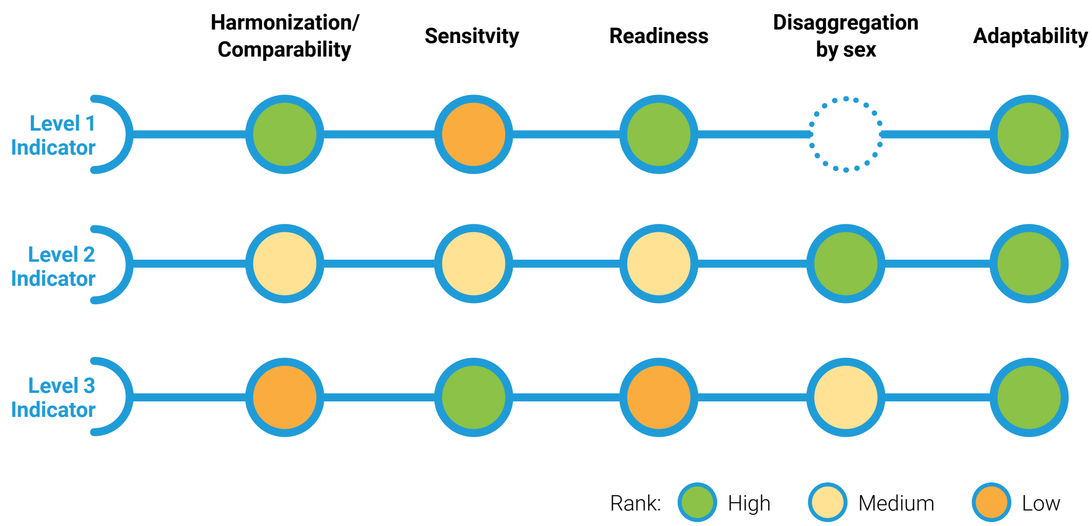
In this GPG, the criteria of 'Comparability', 'Sensitivity', 'Readiness', 'Disaggregation by sex' and 'Adaptability' of each of the three SO3 indicators have been qualitatively assessed and ranked from low to high, as shown in Figure 2. Where the Indicators currently rank low in terms of these criteria, it is hoped that these ranks could be improved, for example through further research, data availability and the inclusion of ecosystem components as discussed in Appendix A.

As outlined in Table 2 (taken from ICCD/COP(14)/CST/7) and shown in Figure 2, the Level 1 Indicator ranks high in terms of 'Comparability', 'Readiness' and 'Adaptability'. However, in the current state, scores low in terms of 'Sensitivity' to SO3 monitoring in isolation. As discussed in Appendix A, the addition of drought indices monitoring hydrological and agricultural drought in the future would improve the 'Sensitivity' of this indicator. ICCD/COP(14)/CST/7 states that Level 1 Indicator ranks low in terms of 'Disaggregation by sex'. It has not been given a rank here as it is concerned with the physical occurrence of drought hazard (and does not include a demographic component); this will not change in the future.

[28] Note that this 'global drought indicator' has now been renamed the Global Drought Classification System (GDCS; SERCOM-1(II)/Doc. 5.1.1) and is discussed further in Section 1.2.4.

Figure 2

Current status of the three SO3 indicators as described in this GPG ranked according to the criteria described in Decision 11/COP.14 and given in Box 2



The Level 2 Indicator provides an improvement of 'Sensitivity' to SO3 monitoring over the Level 1 Indicator, but with limited improvements or no improvement for 'Readiness' or 'Comparability' (Figure 2) when considering a full assessment of exposure, which includes additional elements such as ecosystem exposure. ICCD/COP(14)/CST/7 states that the Level 2 Indicator would have limited improvement for the criteria of 'Disaggregation by sex'. However, the methodology provided in this GPG makes the additional recommendation to address the criteria for disaggregation by sex, therefore facilitating potential improvement on this indicator from the Level 1 Indicator, and as such the Level 2 Indicator is ranked 'high'.

The Level 3 Indicator ranks high in terms of 'Sensitivity' and 'Disaggregation by sex' in ICCD/COP(14)/CST/7. However, here 'Disaggregation by sex' is ranked as medium (Figure 2) given the tiered approach to the vulnerability assessments for the Level 3 Indicator described in Chapter 3. The variability in the availability of datasets needed to calculate the Drought Vulnerability Index (DVI) means the 'Readiness' of the Level 3 Indicator is low. The recommended tiered approach provides a framework whereby vulnerability can be assessed even with limited availability of datasets.

Structure of the GPG

The GPG is split into three main chapters, one for each of the indicators (Level 1, Level 2 and Level 3) used for SO3 monitoring. For each indicator, the methods for deriving the indicator are explained, global datasets recommended and guidelines provided on when in-country datasets may be more appropriate. This is followed by guidance on how to interpret the results and a discussion of the limitations of the approaches used.

The Level 1 Indicator is calculated using gridded Standardized Precipitation Index (SPI) data, and reports the per cent of the total land area under drought intensity classes in each reporting year. Outputs from the calculation of the Level 1 Indicator are used in the derivation of the Level 2 Indicator, which assesses the exposure of the population to each of the drought intensity classes. Finally, the Level 3 Indicator uses the DVI to monitor trends in the degree of drought vulnerability within a tiered framework, providing options for a range of data availability and reporting capacities.

When reporting any of the three indicators to UNCCD for the first time, indicators for the baseline period (along with indicator values for all subsequent reporting periods) should be also reported. Guidance on this is included for each indicator in the relevant chapter.

Appendix A discusses future opportunities for how SO3 monitoring could be progressed in order to improve the comparability, sensitivity, readiness, disaggregation by sex and adaptability of the three SO3 indicators.

1

1.

LEVEL 1 INDICATOR

TRENDS IN THE PROPORTION OF LAND UNDER DROUGHT OVER THE TOTAL LAND AREA

This chapter describes the terminology, concepts, methodology, data sources, interpretations and limitations of the Level 1 Indicator for assessing the trends in the proportion of land under drought as described in Decision 11/COP.14 and its Annex.

1.1 Summary

Drought is a hazard experienced in all climate zones, and is defined as a period of dry weather long enough to cause a serious hydrological imbalance (World Meteorological Organization, 1992). The Level 1 Indicator in this GPG specifically describes the status of meteorological drought hazard that occurred during the reporting period within a country. Further aspects of drought and requirements for global scale monitoring are described in Appendix A.

The methodology recommended here is a globally accepted drought index: the Standardized Precipitation Index (SPI) (Hayes et al., 2011) to characterize the meteorological drought hazard using globally available datasets, although it should be noted that in-country datasets (via NMHSs) may, in some cases, offer greater spatial resolution, longer data records and greater acceptance for Parties.

By identifying the proportion of land under drought (or, affected by drought) using four meteorological drought intensity classes (mild, moderate, severe and extreme drought), Parties can determine what regions are experiencing more extreme droughts in order to prioritize mitigation efforts in conjunction with assessments of drought exposure and vulnerability using the Level 2 and 3 Indicators, respectively. The Level 1 Indicator values reported to the UNCCD summarize the percentage of land area in each of these four drought intensity classes.

> It is important to note that the Level 1 Indicator reports whether land has been affected by drought during the four-year reporting period. It is possible that there may not have been drought conditions, as defined by the Level 1 Indicator, during the reporting period. This means that the proportion of land under drought would be 0%. More on the interpretation of the Level 1 Indicator, and its limitations, can be found in the following sections.

The Level 1 Indicator is a status indicator, highlighting whether mild, moderate, severe or extreme drought occurred during the reporting period. The reported proportion of land under drought is a function of climate variability, and so its status depends on whether drought occurred in the reporting period. Other drought indices characterizing additional drought types that might be considered for Level 1 reporting are discussed in Appendix A.

1.2 Methodology

It is recommended that the SPI is used as the basis for the calculation for the Level 1 Indicator given it has been endorsed by the WMO for its use for meteorological drought monitoring (Hayes et al., 2011). However, as will be discussed in Section 1.5, there are limitations to this approach in arid regions, and it may be more appropriate to use a different drought index such as the Standardized Precipitation Evapotranspiration Index (SPEI) in such regions.

It is also recognized that country Parties and NMHSs may already be using drought indices in order to monitor drought, and that these may differ from the SPI-12 as recommended in this GPG for SO3 monitoring. Where this is the case, and other indices are currently used for drought monitoring, it is possible that these existing activities can and should be exploited and used for Level 1 SO3 monitoring. The use of drought indices other than the SPI is discussed in Section 1.2.4.

There are three steps for the calculation of the Level 1 Indicator:

1. Calculate SPI using an accumulation period of 12 months (SPI-12) and gridded precipitation data;
2. Identify the drought intensity class of each grid cell based on the calculated value of SPI; and
3. Calculate proportion of land in each drought intensity class.

The first time the Level 1 Indicator is reported to the UNCCD, it should also be calculated for the baseline period (2000-2015) and any previous reporting periods. Guidance on producing the Level 1 Indicator for the baseline period is provided in Section 1.2.6.

1.2.1 Step 1: Calculate SPI

Step 1 inputs and outputs	
Input	Gridded precipitation data
Output	Gridded SPI data for full precipitation time series

In this first step, gridded precipitation will be used to calculate monthly time series of the SPI using SPI-12, which provides an annual summary of precipitation deficits. Further discussion of the rationale and limitations of using SPI-12 is provided in Sections 1.4.1 and 1.5, respectively. Recommended precipitation data and data requirements are discussed in Section 1.3.

For the purposes of SO3 Level 1 Indicator reporting, the recommended SPI derivation process is based on WMO guidelines (World Meteorological Organization, 2012), but with the use of a reference period, and is described in Box 3.

The use of a reference period, although not stated in the WMO SPI User Guide (World Meteorological Organization, 2012), is important to ensure that in each four-year reporting period, the precipitation data are standardized against the same 'reference period' or climatological standard normal period. This ensures data are comparable between the reporting periods as well as across both time and space. The current WMO standard climate normal period is 1981-2010 (World Meteorological Organization, 2017). However, if and when the standard climate normal period is updated (e.g. World Meteorological Organization, 2019), it is recommended that the SPI is recalculated for the baseline (see Section 1.2.6) and all historic reporting periods. As such, it is recommended that the reference period used to calculate the SPI be clearly stated in national reports of the Level 1 Indicator to the UNCCD.

The SPI should be derived for all months in the full available time series (which should ideally be of at least 30 years in length; World Meteorological Organization, 2012) using the reference period described above, before data for the reporting period are selected as described in Section 1.2.2.

The process described in Box 3 results in a gridded dataset, with time series of SPI-12 for all months, for all grid cells. This can then be mapped spatially for any calendar month in the time series.

An example area of the United Kingdom is introduced in Box 4 and is used throughout Chapters 1 and 2 to illustrate the recommended methods for deriving Level 1 and Level 2 Indicators for SO3 monitoring. Figure 3 is an illustration of December SPI-12 grids using data from the United Kingdom for a four-year period to emulate a reporting period.

Box 3

SPI derivation process for the SO3 Level 1 Indicator

Recommended SPI derivation process	
1.	Using the selected monthly precipitation data series (which should meet the requirements listed in Section 1.3.1) for each grid cell in the full territorial area of the country, aggregate precipitation using a 12-month accumulation period. For example, this means that the 12 month precipitation accumulation for December 2019 is the total monthly precipitation for January 2019 to December 2019, and the 12 month precipitation accumulation for April 2019 is the total monthly precipitation for May 2018 to April 2019; i.e. for each month a new value is determined from the previous 12 months. It is important to note that a missing value in one or more of the constituent months of the aggregation leads to a missing value for the total aggregation – see Section 1.3.1.2 for more information on missing data.
2.	Use the WMO climatological standard normal period of 1981-2010 (i.e. 1 January 1981–31 December 2010; World Meteorological Organization, 2017, 2019) as a reference period to fit the Gamma probability distribution function to all 12-month precipitation accumulations within the 1981-2010 period for each grid cell.
3.	The probability distribution parameters derived for the reference period (1981-2010) should then be applied to the full time series of monthly 12-month precipitation accumulations for each grid cell.
4.	Finally, the time series should be converted to the standard normal to produce the necessary monthly SPI-12 time series for each grid cell for the entire period of record.

Box 4

Background for area used to produce the worked example outputs for the Level 1 and Level 2 Indicators in this GPG

In Section 1.2 and Section 2.2, SPI data from the UK (Tanguy et al., 2017) is used to illustrate the steps described to calculate the Level 1 and Level 2 Indicators in Figures 3-7 (for Level 1) and Figures 10-12 (for Level 2).

The area is intended to illustrate the process of calculating the Level 1 and Level 2 Indicators for a country Party. To provide some spatial context the area used is shown in this box.

The SPI data has a resolution of 5 km and each grid cell has an area of 25 km^2. This information is used in the example calculation of the Level 1 Indicator.

The example has a total land area of 36,000 km^2 and contains 1,440 5-km grid cells

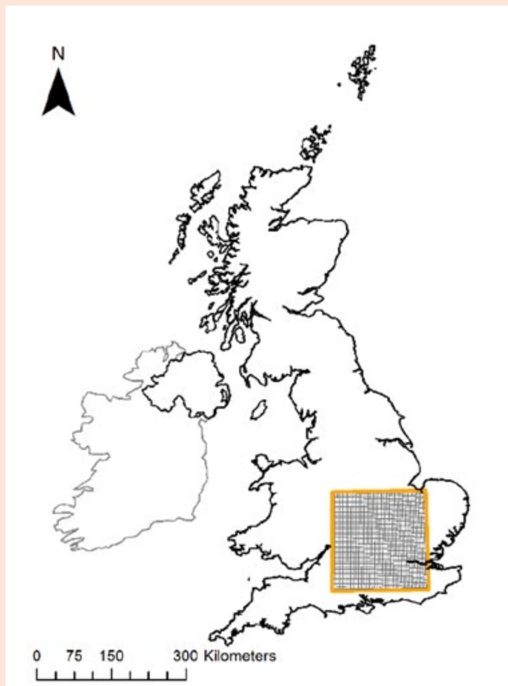
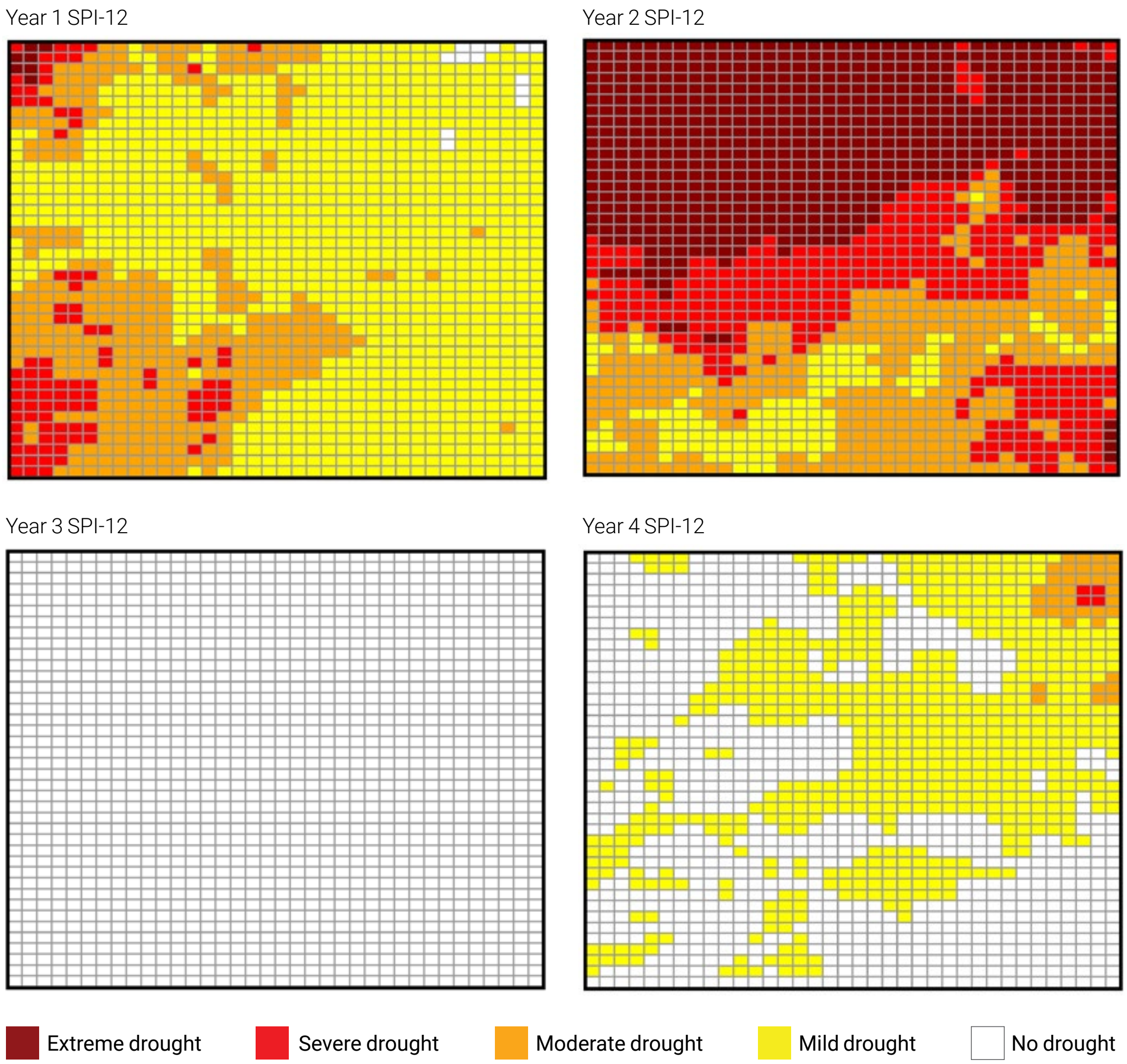


Figure 3

SPI-12 grids for each of the four years using the worked example from the United Kingdom introduced in Box 4



Note: No cells were classed as being affected by drought in Year 3 of the worked example

1.2.1.1 Tools to calculate SPI

Default SPI data will be available via Trends.Earth for the purposes of SO3 monitoring. However, there are various open access tools that can be used to derive the SPI, a selection of which is listed in Table 3.

Table 3

Selected list of available SPI calculation tools

Please note this list is not exhaustive and other tools are available

Application	Notes	Reference
SPI Program	Windows GUI, designed to drive SPI for gauge station data (i.e. point data for a limited number of sites)	https://drought.unl.edu/droughtmonitoring/SPI/SPIProgram.aspx
SCI package in R	Programmatic access via R on Windows/ Linux for gridded or point (gauge) data	Gudmundsson and Stagge (2016)
SPEI package in R	Programmatic access via R on Windows/ Linux for gridded or point (gauge) data	Beguería and Vicente-Serrano (2017)
Climate and Drought Indices in Python (SPI, SPEI, PET)	Python code to calculate SPI programmatically for gridded data in NetCDF format	https://www.drought.gov/data-maps-tools/climate-and-drought-indices-python-spi-spei-pet

1.2.2 Step 2: Identify the drought intensity class of each grid cell based on the calculated value of SPI

Once the SPI has been calculated for each grid cell and month in the time series, the time series for the reporting period (i.e. previous four years) should be assessed. In this step, spatial data of the drought intensity classes will be produced as well as summary counts of the number of cells in each drought intensity class.

Step 2 inputs and outputs	
Input	Gridded SPI data derived in Step 1
Output	a) December SPI-12 grids for each of the four reporting years (used as input for Level 2 Indicator)
	b) Counts of the number of grid cells in each drought intensity class for each reporting year

Using the gridded SPI data output from Step 1, the December SPI-12 values for each year of the four-year reporting period (i.e. four SPI-12 grids) should be extracted. The December SPI-12 values represent the precipitation deficits (or excesses) over the Gregorian (January-December) calendar year.

For each of the four SPI-12 grids, the number of cells in each of the SPI drought intensity classes should be counted. The SPI intensity classes are listed in Table 4. Note that this classification will be reviewed for future versions of the GPG and will be aligned with the Global Drought Classification System (GDCS). The four SPI-12 grids should be saved to calculate the Level 2 Indicator – see Chapter 2.

Table 4

SPI drought intensity classes

SPI values	Drought intensity class
0 to -0.99	Mild drought
-1.0 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
-2 and less	Extreme drought

Note: SPI values greater than 0 indicate that it was wetter than normal for the given period and that there was no drought.
Source: Adapted from World Meteorological Organization (2012)

For each December SPI-12, the cells where SPI values are in the 'mild drought' class should be selected (e. g. as shown in Figure 4) and the number of cells selected recorded. This step should be repeated for the remaining three drought intensity classes, as shown in the example in Table 5. Positive SPI values should be discarded for the purposes of the Level 1 drought indicator, as these indicate that it was wetter than normal for the given cell and time step (i.e. there were no drought conditions as defined by the SPI-12).

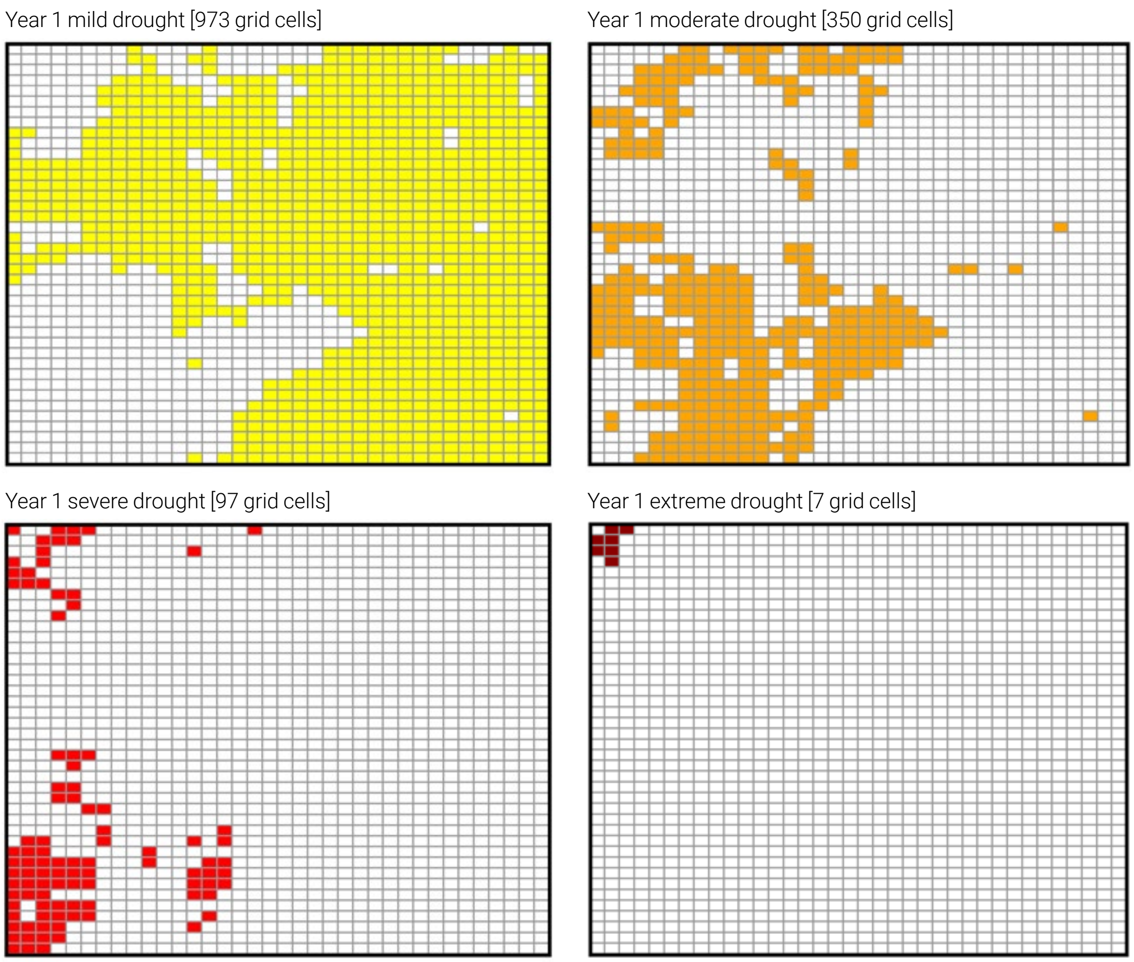
Table 5

Counts of cells in each SPI drought intensity class for each year of the worked example

Number of cells in each drought intensity class					
Reporting Year	**Mild drought**	**Moderate drought**	**Severe drought**	**Extreme drought**	**Total number of cells under drought**
1	973	350	97	7	1,427
2	122	355	338	625	1,440
3	0	0	0	0	0
4	612	37	4	0	653

Figure 4

Individual drought intensity classes and counts of the number of cells in each class (in brackets) for Year 1 of the worked example shown in Table 5



1.2.3 Step 3: Calculate proportion of land under drought

In this final step, the proportion of land under each drought intensity class is calculated, i.e. the Level 1 Indicator.

Step 3 Data inputs and outputs	
Input	a) Counts of the number of grid cells in each drought intensity class for each reporting year
	b) Total number of grid cells classified as land (for total land area) within the border of the land area
Output	Level 1 Indicator: Proportion of land under each drought intensity class

For each reporting year calculate the percentage of the total land area in each drought intensity class. Take the total number of cells in each drought intensity class derived in the previous step, divide by the total number of grid cells in the country Party land area (i.e. grid cells classified as land within the boarder of the land area), and multiply by 100 to get the percentage of land in the given drought intensity class, as shown in Equation 1 with example outputs shown in Table 6.

$$\%\ cellCount_{ij} = \left(\frac{cellCount_{ij}}{Total\ number\ of\ cells} \right) \times 100$$

Equation 1 to calculate the proportion of land (% cellCount) in each drought intensity class (i) and reporting year (j), where cellCount is the number of cells affected by drought and Total number of cells is the number of grid cells classified as land within the boarder of the land area.

Table 6

Example conversion of number of cells to proportion of land area under drought for Year 1 of the worked example shown in Table 5

There are a total of 1,440 grid cells in the area used for the worked example introduced in Box 4. This process should be repeated for the remaining three years of the reporting period

	Mild drought	Moderate drought	Severe drought	Extreme drought	Total
Total number of cells affected by drought	973	350	97	7	1,427
% of land area under drought	67.6	24.3	6.7	0.5	99.1

1.2.4 Using other drought indices

Where country Parties and NMHSs may already be using drought indices to monitor drought which differ from the SPI-12 recommended in the GPG, it is possible that these existing activities can and should be exploited and used for Level 1 SO3 reporting.

In order to utilize other indices and monitoring tools, they should be based on gridded precipitation products (derived either from gauges, remote sensing or blended products) so that the proportion of land under drought during the reporting period can be derived in a comparable way. Alternatively, Parties may use other indices to quantify meteorological drought that include other variables as well as precipitation. Exact methods on how this would be done in practice will depend on the index in use. Some indices are readily comparable – for example, Parties using the Standardized Precipitation Evapotranspiration Index (SPEI) can apply the same methods recommended in this GPG to report their SO3 Level 1 Indicator. For other indices currently in use (for example the Palmer Drought Severity Index (PDSI), the Normalized Difference Water Index (NDVI), or the Drought Reconnaissance Index[29]), it is also preferable that the index used can be split into statistically derived severity categories that are in some way equivalent to the SPI drought intensity classes described in Table 4.

The development of the Global Drought Classification System (GDCS, formerly the Global Drought Indicator or GDI) by WMO through the GMAS framework will provide methods on how a multitude of drought indices can be translated onto a harmonized legend of drought classes (labelled from D0 to D4; SERCOM-1(II)/Doc. 5.1.1). WMO advises that drought indicators should be statistically based to make it easier to integrate them into the GDCS; for more detail on the GDCS see Section 1.4.1. More information, references and source codes for over 50 drought indices and indicators are provided in the Integrated Drought Management Programme (IDMP) Handbook of Drought Indicators and Indices (World Meteorological Organization and Global Water Partnership, 2016).

1.2.5 Creating a gridded spatial summary for the reporting period

In addition to the tabular reports of the Level 1 Indicator described above, the Level 1 Indicator should also be summarized spatially to map the most extreme conditions that occurred in the reporting period.

To summarize the reporting period spatially for the Level 1 Indicator, the most extreme drought intensity class should be identified for each grid cell for each reporting year within the reporting period. In the event of a grid cell having a positive SPI, hence never being in drought in the reporting period, it will be labelled as "No drought". An example of SPI-12 data for an individual grid cell and the resulting drought intensity class assignment is shown in Table 7, and an example reporting period grid is shown in Figure 5. The Level 1 Indicator gridded spatial summary for the reporting period is also used as an input for the gridded spatial summary of the Level 2 Indicator, as described in Section 2.2.3.

Table 7

Example of SPI-12 values for an individual grid cell for the reporting period

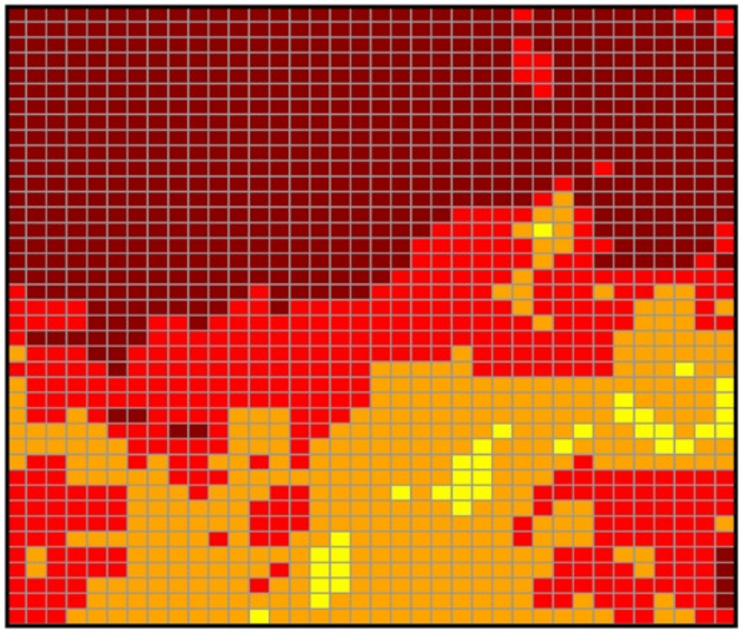
The most extreme drought intensity class is highlighted which is used to summarize the reporting period

Reporting Year	SPI-12 Value	Drought Intensity Class for each reporting year	Drought Intensity Class for the reporting period
1	1.872	No drought	Moderate drought
2	-0.345	Mild drought	
3	1.700	No drought	
4	-1.506	**Moderate drought**	

[29] It is acknowledged that there are many drought indices in operational use (e.g. Lloyd-Hughes, 2014) and others may be in use that are not listed here. The Handbook of Drought Indicators and Indices (World Meteorological Organization and Global Water Partnership, 2016) lists and describes over 50 commonly used drought indices.

Figure 5

Summary map for the Level 1 Indicator for the worked example reporting period showing the most extreme drought intensity class for each grid cell across the four reporting years, based on the SPI data shown Figure 4



Extreme drought | Severe drought | Moderate drought | Mild drought | No drought

1.2.6 Calculating the Level 1 Indicator for the baseline period

This section describes how the Level 1 Indicator should be calculated for the UNCCD baseline period (2000-2015), in line with the reporting requirements for all strategic objectives included in the 2018-2030 Strategic Framework. Calculating the Level 1 Indicator for this period provides context for Parties to understand their drought hazard over time for SO3 monitoring, as well as for the other Strategic Objectives.

The baseline period for the Level 1 Indicator should be used as a record of the drought hazard status over this period. Drought is a periodic event, and climate variability means it is possible drought may or may not have occurred in either the baseline period or the reporting period. In order to truly understand trends in drought hazard, SPI data over a much longer period should be used. Any observed changes or trends in the proportion of land under drought over this short timeframe should therefore be interpreted with caution, as it is likely to underestimate the drought hazard.

The Level 1 Indicator baseline period should be calculated the first time it is included in national reporting to the UNCCD.

There are some instances when the baseline period (and any previous reporting periods) may need to be recalculated. These are as follows:

- If WMO guidance on standard climate normal period is updated, the SPI should be recalculated using this new standard as the reference period and the Level 1 Indicator re-derived for the baseline in addition to any subsequent reporting periods.
- If new and/or improved precipitation datasets used to calculate the SPI become available, the baseline period and any subsequent reporting periods should be recalculated using the new dataset.
- If the methodology for deriving or reporting the Level 1 Indicator for SO3 monitoring changes in the future, for example, as a result of the introduction of the GDCS, which is described in Sections 1.2.4 and 1.4.1.

In order to calculate the Level 1 Indicator for the baseline period, the SPI-12 should be calculated as described in Section 1.2.1, and the December SPI-12 grids selected for each year of the baseline (i.e. 2000 to 2015). The SPI-12 grids for the baseline period for the worked example are shown in Figure 6.

For each year in the baseline period, the number of grid cells in each drought intensity class should be calculated as described in Section 1.2.2. The proportion of land under each drought intensity class should be reported as described in Section 1.2.3 and as shown in the example in Table 6, and should include all years in the baseline period. In the event of a grid cell having a positive SPI, hence never being in drought in the four-year period, it will be labelled as "No drought".

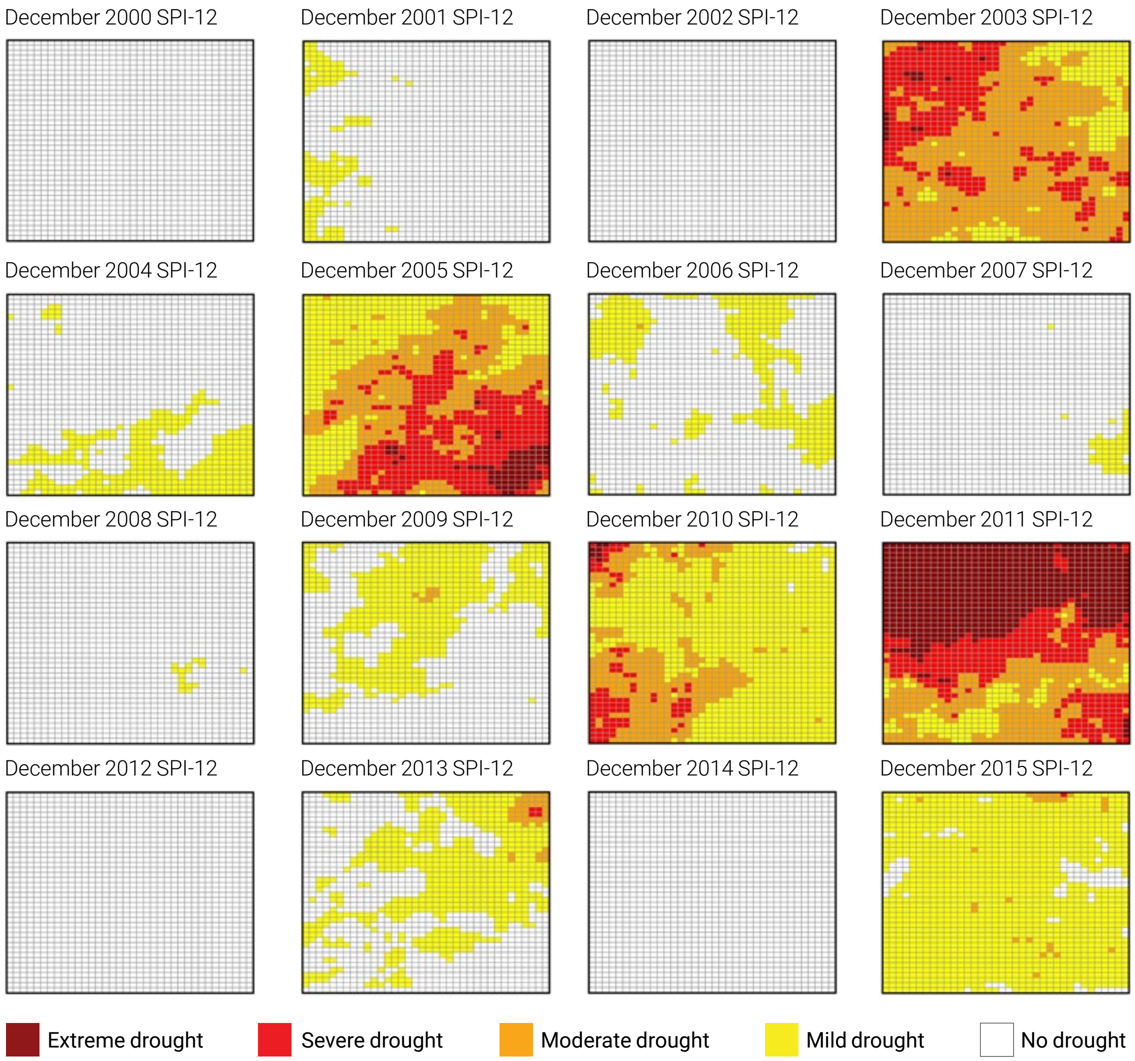


Figure 6

December SPI-12 grids for the baseline period using the example area introduced in Box 3

In addition to the tabular reports of the Level 1 Indicator, the baseline period should be summarized spatially using the gridded SPI-12 data in four-year intervals (i.e. 2000-2003, 2004-2007, 2008-2011 and 2012-2015), reflecting the reporting periods used for SO3 monitoring. To summarize the baseline period spatially for the Level 1 Indicator, the most extreme drought intensity class should be reported for each grid cell for each four-year period within the baseline.

An example of SPI 12 data for an individual grid cell and the resulting drought intensity class assignment is shown in Table 8, and the summary maps for the example area (based on the SPI grids in Figure 6) are shown in Figure 7. The Level 1 Indicator baseline period gridded spatial summary maps are also used for the gridded spatial summary of the Level 2 Indicator baseline period, as described in Section 2.2.4.

Table 8

Example of SPI-12 values for an individual grid cell for the baseline period 2000-2015

The most extreme drought intensity class is highlighted and is used to summarize each four-year period of the baseline

Four-year baseline period	Date	SPI-12 value	Drought Intensity Class	Most Extreme Drought Intensity Class
1	2000-12	1.872	No drought	Extreme drought
	2001-12	0.345	No drought	
	2002-12	1.700	No drought	
	2003-12	-2.006	**Extreme drought**	
2	2004-12	-0.333	Mild drought	Severe drought
	2005-12	-1.526	**Severe drought**	
	2006-12	0.045	No drought	
	2007-12	1.470	No drought	
3	2008-12	1.158	No drought	Moderate drought
	2009-12	-0.080	Mild drought	
	2010-12	-1.251	**Moderate drought**	
	2011-12	-1.313	**Moderate drought**	
4	2012-12	2.035	No drought	No drought
	2013-12	0.069	No drought	
	2014-12	1.763	No drought	
	2015-12	0.638	No drought	

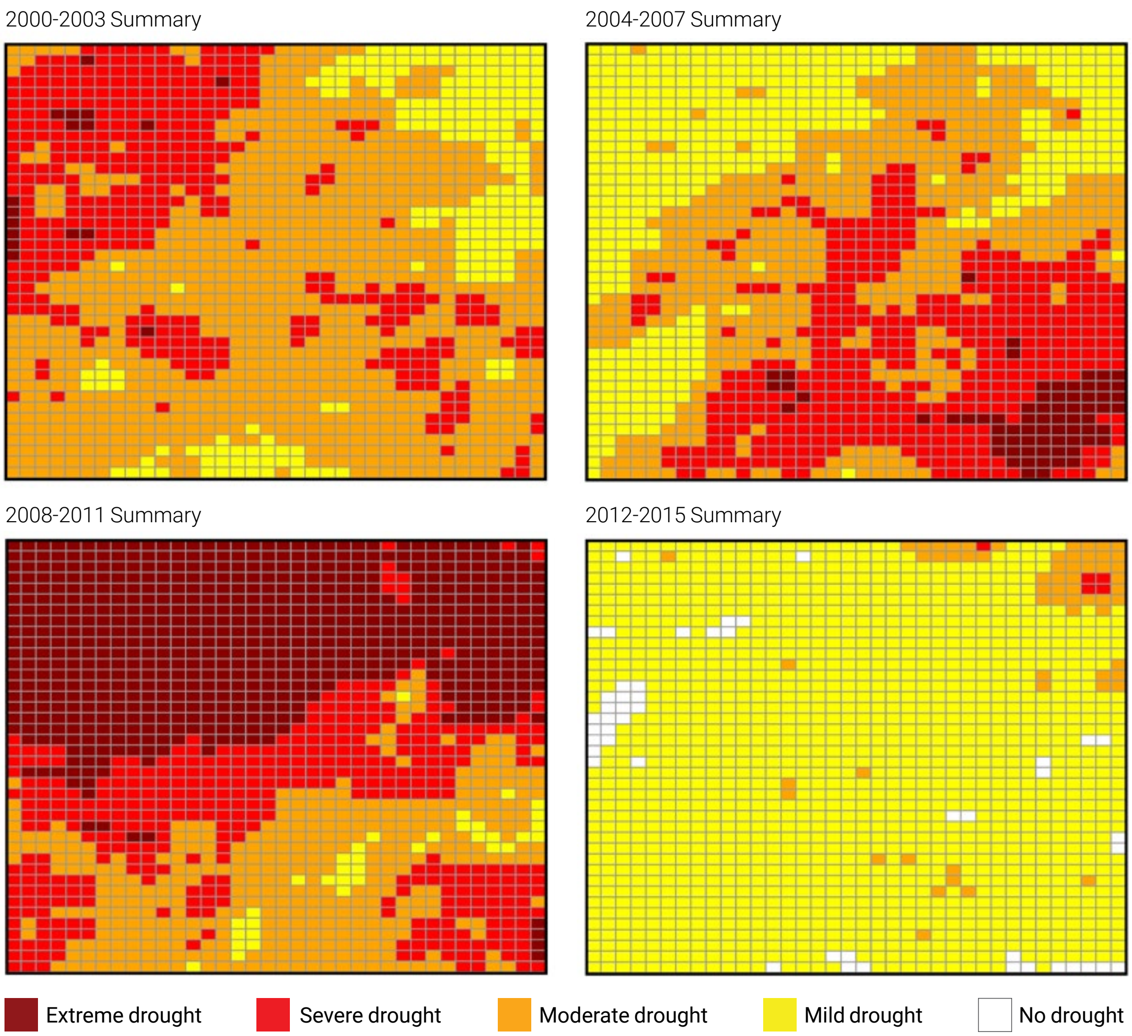


Figure 7

Summary maps for the Level 1 Indicator for the four-year baseline periods, showing the most extreme drought intensity class for each grid cell in the given four-year period; based on the SPI data shown in Figure 6

1.3 Data sources

This section describes the data required to calculate the Level 1 Indicator, including the data requirements for deriving the SPI (Section 1.3.1), globally available precipitation data products (Section 1.3.2) and when it may be appropriate to use in-country precipitation data over the globally available data (Section 1.3.3).

1.3.1 Precipitation data requirements

The precipitation data used to derive the SPI, and so the Level 1 Indicator, has some requirements in terms of the period of record and data completeness. These requirements are described below.

1.3.1.1 Period of record

In order to calculate the SPI, a monthly precipitation dataset is required and should ideally have a continuous record of at least 30 years (World Meteorological Organization, 2012). The data should cover the period used to derive the climatological standard normal (i.e. 1981-2010) as described in the WMO Guidelines on the Calculation of Climate Normals (WMO-No. 1203; World Meteorological Organization, 2017) in order to sample as much of the range of climate variability as possible.

1.3.1.2 Data completeness

Data should be continuous where possible, as missing values affect the confidence of the output index. However, it is accepted that many datasets may have record completeness of less than 90% and when considering national datasets, Parties may have to work with datasets with 75-85% completeness (World Meteorological Organization, 2012). Where data completeness are less than 85%, Parties may consider infilling gaps in data and are recommended to follow guidance provided by the WMO (e.g. World Meteorological Organization, 2018).

1.3.2 Recommended global precipitation datasets

There are a number of global gridded precipitation datasets (e.g. Sun et al., 2018) that are based on gauged data, on remotely sensed data from satellites, or a combination of these sources. The choice of precipitation data has been found to affect operational drought monitoring as drought indices can vary due to the retrieval technique, merging method, period of record and spatial resolution of the precipitation product (Golian et al., 2019). As such, not all precipitation datasets can be considered suitable for the Level 1 Indicator for SO3 monitoring; a detailed review of global precipitation products and their appropriateness for SO3 Level 1 monitoring can be found in Pricope et al. (2020).

Two global gridded precipitation datasets based on observations are discussed here, one based on gauged data and the other from blended gauged and remote sensing data – more detail on each is given below. Table 9 summarizes the two recommended data sources: the GPCC Monitoring Product v6 and Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS) 2.0. Section 1.3.2.3 discusses precipitation from reanalysis systems, which could be considered for use where GPCC or CHIRPS 2.0 may not be appropriate (e.g. see Figure 9).

The higher spatial resolution of CHIRPS 2.0 and slightly longer period of record are advantageous, particularly given the use of the 1981–2010 climatological normal period used when deriving the SPI. CHIRPS 2.0 may also be preferable in areas with low rain gauge density. However, it should be noted that CHIRPS 2.0 is 'quasi-global' and spans 50°S to 50°N. It is recommended that Parties outside of this range use GPCC precipitation data, or in-country or regional products as discussed in Section 1.3.3. Where the size of the country is smaller than the resolution of the global datasets listed in Table 9, it is recommended that the Parties consider the use of national precipitation products as discussed in Section 1.3.3.

Table 9

Global precipitation datasets based on observations recommended to derive the SPI for the Level 1 Indicator

Precipitation dataset	Publisher	Source	Spatial resolution°	Temporal coverage	Temporal resolution
GPCC Monitoring Product v6 [30]	GPCC	Gauged	1.0˚ x 1.0˚ (~111 km) 2.5˚ x 2.5˚ (~277.5 km)	1982 – present*	Monthly
CHIRPS 2.0 [31]	CHG UCSB	Blended gauged and remotely sensed data	0.05˚ x 0.05˚ (~5.55 km)	1981 – present**	Daily, monthly, annual

* i.e. two months prior to present

** i.e. updated in the third week of the following month

1.3.2.1 Gauge-based data: GPCC v6

The WMO endorse the use of a gridded product derived from gauge data from the Global Precipitation Climatology Centre (GPCC): 'GPCC Monitoring Product: Near Real-Time Monthly Land-Surface Precipitation from Rain-Gauges based on SYNOP and CLIMAT data' (Schneider et al., 2018a). GPCC is a WMO approved Global Producing Centre and its products are used world-wide by a range of organizations for water and climate related monitoring and research, including WMO, FAO and UNESCO (Schneider et al., 2018b). GPCC is used operationally as a core input dataset for the regional drought monitoring product produced by the Drought Management Centre for Central and Southeastern Europe (DMCSEE),[32] which was established by UNCCD and WMO in 2007.

However, gauge density is known to affect the accuracy of derived gridded data (e.g. Keller et al., 2015; Legg, 2015). Figure 8 shows the density of gauges per 1.0 degree grid in May 2012 for the GPCC monitoring product. Statistical analysis using data from dense rain gauge networks showed that the sampling error of monthly precipitation is up to twice as high when five gauges are used instead of 10 gauges (Schneider et al., 2014). GPCC provides the number of stations used per grid, meaning the gauge density can be considered by country Parties when selecting an appropriate precipitation data product. It is recommended that Parties located in regions with limited gauge density resulting in unrepresentative precipitation estimates consider the use of CHIRPS 2.0 data for deriving the Level 1 Indicator.

1.3.2.2 Blended gauge and remote-sensing based: CHIRPS 2.0

The Climate Hazards group Infrared Precipitation with Stations (CHIRPS)[33] 2.0 dataset is a blended product, combining 0.05o climatology for sparsely gauged locations, producing high resolution estimates based on infrared Cold Cloud Duration (CCD) observations (i.e. remotely sensed data) and gauged station data (Funk et al., 2015). CHIRPS 2.0 has been found to compare well to other gridded precipitation products, has been used to monitor droughts, and was developed to support the United States Agency for International Development Famine Early Warning Systems Network (FEWS NET; Funk et al., 2015).

If CHIRPS 2.0 is selected for calculating the Level 1 Indicator, it is recommended that country Parties ensure the estimates provided are representative and may want to validate the data using observed precipitation data from rain gauges. CHIRPS and CHIRPS 2.0 data have been validated against station data in the scientific literature in many countries and regions across the world, including Pakistan (Nawaz et al., 2021), eastern Africa (Dinku et al., 2018), the central Andes (Rivera et al., 2018) and China (Bai et al., 2018), and has shown good sensitivity to local precipitation estimates although with some limitations (e.g. in detecting snowfall and at higher altitudes).

[30] https://opendata.dwd.de/climate_environment/GPCC/html/gpcc_monitoring_v6_doi_download.html

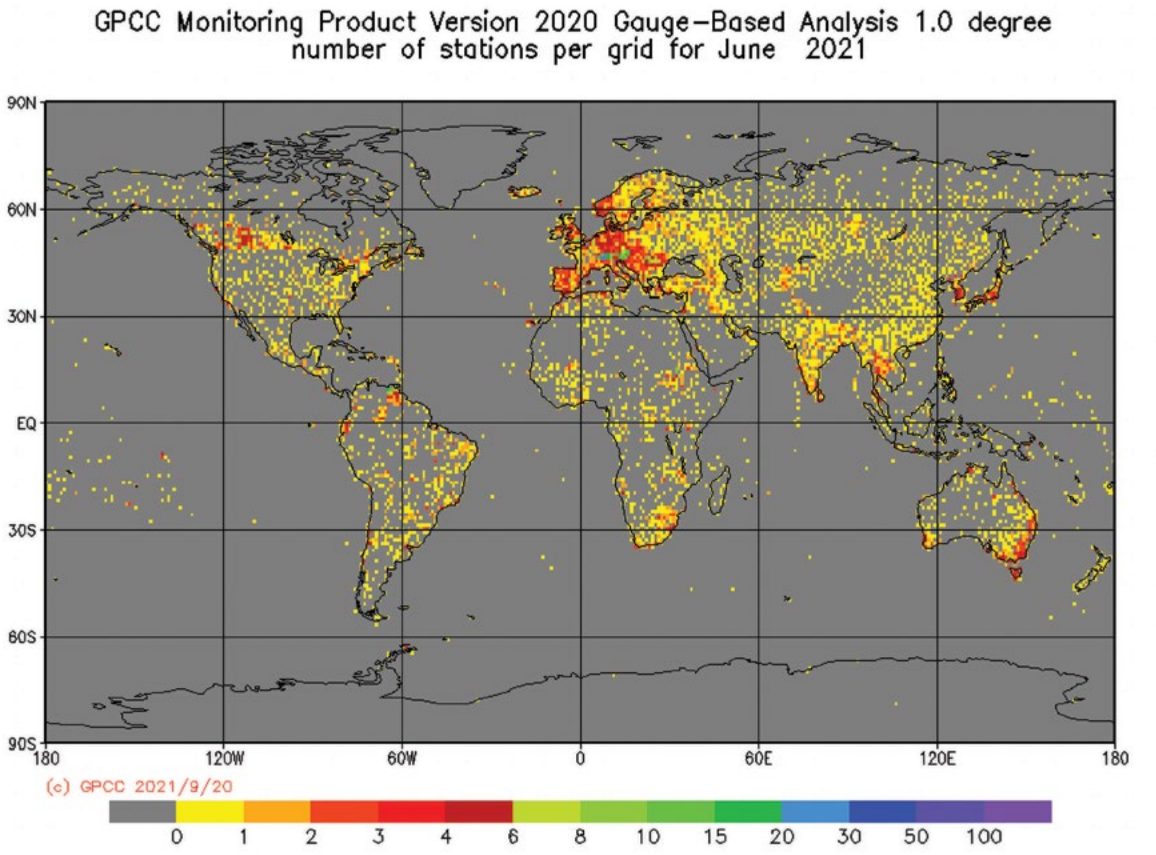
[31] https://www.chc.ucsb.edu/data/chirps

[32] http://www.dmcsee.org/en/drought_monitor/

[33] https://www.chc.ucsb.edu/data/chirps

Figure 8

Number of stations per grid in the GPCC Monitoring Product Version 2020 Gauge-Based Analysis 1.0 degree in June 2021



Source: GPCC Visualizer. Available at: https://kunden.dwd.de/GPCC/Visualizer (Accessed: 20 September 2021).

1.3.2.3 Data from reanalysis systems

A further potential source of data is precipitation from reanalysis systems such as ERA5[34] (Hersbach et al., 2020). Reanalyses combine sophisticated weather forecasting models and historical observations, via data assimilation systems and therefore, have the advantage of providing continuous spatial and temporal coverage at the global scale, and availability in near-real time. Another advantage of such reanalysis data is the availability of other metrics, such as evapotranspiration, as discussed in Appendix A. However, while some assessments of ERA5 precipitation have been undertaken (e.g. Nogueira, 2020), before such products can be recommended with confidence, there remains a need for detailed global-scale evaluation for drought applications. Such reanalysis data could be of use in areas of low gauge density (meaning GPCC estimates are more uncertain) or outside the geographic range of CHIRPS 2.0 (see Figure 9).

[34] https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5

1.3.3 Use of national/regional precipitation data products

In some cases, Parties may prefer to use in-country data provided by the NMHSs or regional precipitation products instead of the global precipitation products recommended in Table 9. This may be for a number of individual or a combination of reasons, including:

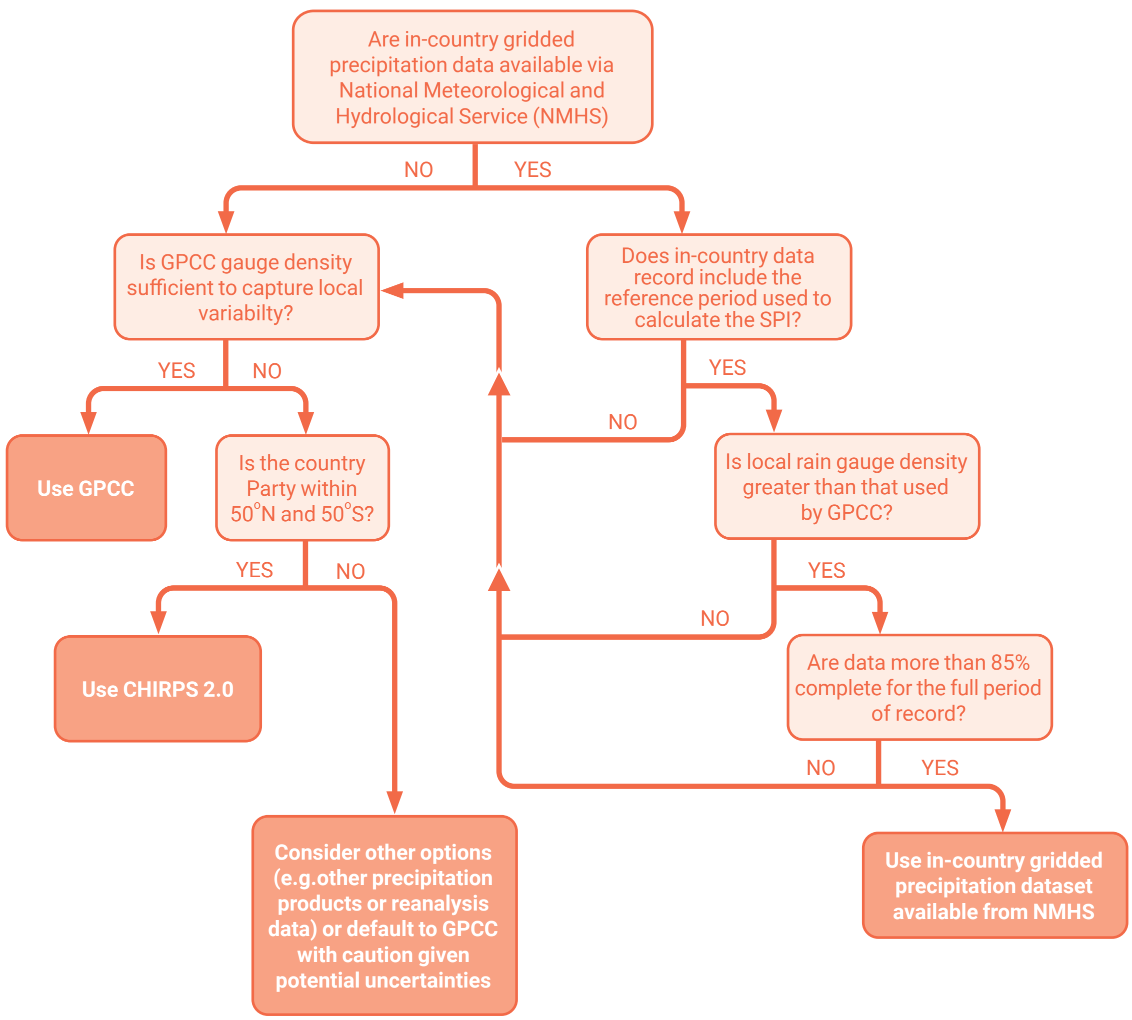
- In-country/regional products may have a higher spatial resolution and/or a longer period of record which would provide greater historical context for assessments of drought hazard;
- In-country/regional products may already be in use to produce the SPI (or other drought indices being used to derive the Level 1 Indicator); and
- In-country/regional products may be based on gauged data with a higher density than GPCC and, therefore, have less uncertainty where gauge data within GPCC is low.

Figure 9 sets out the recommended decision-making process for assessing when in-country (or regional) precipitation data products may be more appropriate to derive the Level 1 Indicator over the globally available products listed in Table 9.

If an in-country gridded precipitation product is not available, Parties may wish to derive precipitation grids using data from in-situ rain gauges. It is beyond the scope of this GPG to provide instruction on how to derive such gridded datasets, however Parties are directed to WMO guidance on this topic e.g. Collier (2000), and papers in scientific literature (e.g. Keller et al., 2015; Vicente-Serrano et al., 2017).

Figure 9

Decision tree to help Parties chose the best precipitation data source to derive the Level 1 Indicator



1.4 Rationale and interpretation

1.4.1 Rationale for using SPI as the Level 1 Indicator

The SPI was used as the basis of the SO3 Level 1 Indicator due to the recommendation by WMO for monitoring meteorological drought, as set out in the Lincoln Declaration on Drought Indices (Hayes et al., 2011). Furthermore, in Resolution 21 (Cg-XVI), the Sixteenth World Meteorological Congress requested all WMO Members to ensure that all NMHSs around the world use the SPI to characterize meteorological droughts, in addition to other drought indices that are already in use in their service,[35] making it a good starting point for most Parties. However, the SPI has limitations in dry climates and should be applied with caution in regions with arid conditions (Wu et al., 2007), as discussed in Section1.5.

The Lincoln Declaration on Drought Indices (Hayes et al., 2011) states that SPI is simple to calculate, only needs one input, and can be compared across both time and space. The Lincoln Declaration has helped cement the status of SPI as a drought monitoring index in the last decade. It has been widely used globally and has been seen as the de facto standard for a much longer time, both in academic studies (e.g. 210,000 results for 'Standardized Precipitation Index' in Google Scholar) and in practice (e.g. used by US Drought Monitor,[36] European Drought Observatory[37] and a range of other monitoring and early warning platforms, including the DMCSEE[38] and UK Water Resources Portal[39]). The SPI is widely used at all scales, from catchment through to national- and global-scale assessments. While developed for drought situation monitoring, it is widely used for a range of applications, including forecasting, risk assessments and long-term climate change impact assessments (e.g. see the reviews of Dai, 2011b; Bachmair et al., 2016a; Mukherjee et al., 2018; Blauhut, 2020).

The SPI-12 was selected in order to summarize the annual precipitation deficits for each reporting year. This 12-month accumulation captures long-term precipitation deficits and is more likely to highlight extreme conditions, which are linked to impacts on hydrology (including groundwater) and water resources (World Meteorological Organization, 2012).

A key advantage of the SPI is its flexibility, allowing computation over a range of timescales that have relevance to different types of drought impacts (e.g. hydrological, agricultural, environmental – see Box 1). Another benefit of the standardization process is that variants of the index can be used to compare across the hydrological cycle. Standardized indices have been proposed for many different hydrometeorological variables, for example the SPEI (Vicente-Serrano et al., 2010), the Standardized Runoff Index (Shukla and Wood, 2008), Standardized Streamflow Index (SSI) (Vicente-Serrano et al., 2012; Barker et al., 2016) and Standardized Groundwater Index (Bloomfield and Marchant, 2013). In this manner the propagation of droughts through the hydrological cycle can be quantified consistently. While not in a suitable state of readiness for inclusion at present, these other indices are considered further in Appendix A.

Another key advantage to using the SPI (or other standardized indices, such as the SPEI) is that it will easily translate into the GDCS under development by WMO and GMAS. The GDCS will provide a methodology to align indices used for national drought monitoring and reporting using a harmonized classification scheme to create an easy-to-understand global system of drought reporting. The GDCS was formerly known as the GDI (as outlined in SERCOM-1(II)/Doc. 5.1.1); the name was changed to avoid the implication that there was only one index that could be used for drought monitoring. In the Annex to Decision 11/COP.14 the GDCS (then, GDI) was recommended as the basis for Level 1 Indicator monitoring, and as such, methods for calculating and reporting will be revised in future versions of the GPG.

[35] https://library.wmo.int/doc_num.php?explnum_id=3429
[36] https://droughtmonitor.unl.edu/
[37] https://edo.jrc.ec.europa.eu/
[38] http://www.dmcsee.org/en/drought_monitor/
[39] https://eip.ceh.ac.uk/hydrology/water-resources/

1.4.2 Interpretation of the Level 1 Indicator

Based on the SPI, the resulting values for the Level 1 Indicator reporting provide the proportion of land in each of the drought intensity classes (mild, moderate, severe and extreme drought) in each of the four reporting years (see Table 6). The drought intensity classes not only provide an indication of the severity of precipitation deficits, but also the likelihood of such deficits occurring, as shown in Table 10 and based on findings from the World Meteorological Organization (2012).

The proportion of land under drought is dependent on whether there has been any dry periods with below normal precipitation as defined by the SPI-12 in each year of the reporting period. This means that the Level 1 Indicator should be used as a status indicator to show whether there were drought conditions or not. The use of a 12-month accumulation period provides an overview of long-term precipitation deficits over the reporting period, however, it should be noted that shorter SPI accumulations would produce different results. This is discussed in more detail in Section 1.5 and Appendix A.

A larger proportion of land affected by drought indicates that there were widespread precipitation deficits across the country in that year. By comparing the relative proportions of land affected by drought in each drought intensity class, the intensity of the precipitation deficits across the country can be assessed.

The baseline summary assessment of the Level 1 Indicator provides an initial drought status, which will be added to with every subsequent reporting period. As discussed in Section 1.2.6, caution should be exercised in the interpretation of any changes or trends in the Level 1 Indicator due to the effect of natural climate variability on the occurrence of droughts.

Table 10

SPI drought intensity classes and likelihood of occurrence in a 100-year period

SPI values	Drought intensity class	Number of times in 100 years	Indicative severity (or frequency) of event[40]
0 to -0.99	Mild drought	33	1 in 3 years
-1.0 to -1.49	Moderate drought	10	1 in 10 years
-1.5 to -1.99	Severe drought	5	1 in 20 years
-2 and less	Extreme drought	2.5	1 in 50 years

Source: Adapted from World Meteorological Organization (2012)

[40] The frequencies shown here (as presented in the SPI User Guide; World Meteorological Organization, 2012) reflect the frequencies of a normal distribution. However, it should be noted that the reference period used and the fit of the frequency distribution (as discussed in Section 1.5) may influence the frequencies associated with the drought intensity classes.

1.5 Comments and limitations

The SPI is recommended here as a well-established, flexible and robust drought index suitable for quantifying drought hazard on a global scale. However, we must emphasize that, like any single indicator or index used to assess drought, the SPI has a number of limitations that constrain its applicability. Chiefly, it only quantifies one aspect (meteorological deficits) of what is a complex, multifaceted hazard. There are also several important technical considerations that must be addressed when interpreting results emerging from any application of the SPI. We address these briefly here, but cannot cover these topics exhaustively – the reader is referred to further sources where necessary.

First, we highlight the following considerations related to the use of SPI as a single drought indicator to be used as the Level 1 Indicator of choice, relative to other drought indicators.

'Types of drought': most crucially, the SPI is a meteorological drought indicator solely based on precipitation, and as previously noted, other 'types' of drought (e.g. hydrological, agricultural) which may follow meteorological drought may be inferred by aggregating over multiple timescales, but these may not be well captured by the single timescale (SPI-12) chosen here, as discussed below. As SPI is an only precipitation-based indicator, it has an inherent limitation in any meteorological drought indicator. We return to this in Appendix A. Note that this same issue applies where other precipitation-based drought indices may be being used by Parties for Level 1 reporting.

Application in arid climates: the calculation of the SPI is based on mathematical rainfall distribution. In regions with very low, and/or a high proportion of months of zero precipitation, it is very challenging to fit a distribution to this highly skewed data. SPI values in such regions should be used and interpreted with caution (Wu et al., 2007; Pietzsch and Bissoli, 2011; Ziese et al., 2014). The SPEI (Vicente-Serrano et al., 2010) is often applied in such regions. The role of evapotranspiration is discussed in more detail in the paragraph below.

Absence of evapotranspiration: even as a meteorological indicator, the SPI only partially addresses the drought hazard. It quantifies precipitation deficits, but not the other side of the climatic water balance – that is, it does not account for evapotranspiration losses. This is very important because in many areas of the world, evaporation losses can be as significant, or more significant, as a driving mechanism of drought impacts than precipitation deficits. Globally, around 60 per cent of terrestrial precipitation is evaporated (Rodell et al., 2015), meaning evaporation dominates the water balance over much of the world. Even in humid environments, evapotranspiration losses can be a significant driver of drought events in some seasons, particularly given the role of complex land-surface feedbacks (e.g. Teuling et al., 2013). While SPI provides a robust way to compare precipitation deficits in time and space, assessments of drought severity solely based on the SPI (i.e. precipitation deficits) can potentially be misleading if comparing between regions, and if examining trends over time, given the observed spatial and temporal variations in evaporation. Numerous other meteorological indices have been developed to quantify drought from a water balance perspective by explicitly taking account of evapotranspiration, for example, the very well established PDSI and more recent but widely adopted SPEI. However, it remains the case that accurate quantification of evapotranspiration is a challenging and contentious area, even at small scales, let alone globally. Given the lack of a consistent and accepted approach, it is reasonable to not incorporate this at present. This should be a key priority for the future, and is discussed further in Appendix A.

Link to impacts: ultimately, as there is no single definition of drought (Lloyd-Hughes, 2014), there can be no single index nor aggregation period that can be used to quantify drought severity across contrasting geographical domains, for different sectors or 'types' of drought (e.g. agricultural, hydrological etc.; see Box 1 for more information on the different types of drought). It has been argued that the choice of a suitable indicator, and the time period over which it is aggregated, should be informed through 'ground truth' against observed drought impacts (Bachmair et al., 2016b). To that end, numerous studies have used various statistical methods to link drought indices (including the SPI) to databases of observed drought impacts (e.g. Blauhut et al., 2015; Stagge et al., 2015a; Bachmair et al., 2016b; Blauhut et al., 2016; Noel et al., 2020). The main message emerging from this literature is that the most appropriate indicator for identifying drought impacts is highly context specific, varying with place, season, aggregation period and the type of impacts (or type of drought). The complex relationship between a drought index and the impacts it corresponds to is not only affected by natural factors (e.g. presence or absence of significant land surface storages such as aquifers) but also the exposure and vulnerability of ecosystems and society, which vary over time as well as between countries and regions. Because of this, the SPI-12 recommended here can only be seen as a broad-brush indicator of drought severity, and a given SPI threshold will lead to different types of impact and different degrees of impact in different places.

Second, having adopted the SPI there are a number technical considerations with SPI application, most of which are shared with any drought indicator when applied to the chosen datasets.

Spatial scale: the global datasets recommended to derive the SPI in Section 1.3.2 have been assessed as 'fit-for-purpose' as the default precipitation datasets. However, if national-, supra-national or finer scale gridded datasets exist, many of which may be via NMHSs, these may be more suitable for SPI application given their higher spatial resolution. Where this is the case, guidance in Section 1.3.3 should be followed to assess whether these national datasets are suitable for Level 1 Indicator reporting.

Timescale: the SPI-12 is selected here as a single aggregation period corresponding to annual precipitation deficits. Given the complexity of indicator-impact relationships, other aggregation periods may be more suitable for characterizing drought impacts in some environments. In some places vulnerable to rapid-onset 'flash droughts' (Otkin et al., 2018; Pendergrass et al., 2020), short duration SPI (SPI-1 – SPI-3 for example) may be most significant, whereas in other areas vulnerable to multiannual deficits, SPI-24 (or even SPI-36 or longer) may correspond to most impacts. This differential sensitivity of the SPI has been demonstrated in Europe (Bachmair et al., 2016b), China (Wang et al., 2020) and elsewhere. The SPI-12 is an appropriate compromise. However, when interpreting the outputs, it is important to bear in mind that it is only one accumulation period, and in the future, other timescales may be considered, but guidance would need to be developed on how the most appropriate accumulation period should be selected for the given country Party (itself dependent on a wide range of climatic, physiographic and economic considerations). Finally, the choice of the calendar year for aggregation is itself a further decision influencing comparability between regions. The 12-month accumulation period over the calendar year was selected for practical reasons in order to simplify reporting for the GPG. However, a single 'wet season' can be split across reporting years in regions where it occurs around the turn of the calendar year. Many nations and regions adopt a 'hydrological year' or 'water year' concept (e.g. 1 October – 30 September in the US and parts of northern Europe) to mitigate this. However, climate regimes vary substantially globally and it is not possible to adopt a fixed 12-month period suitable for all environments. In practice, fixing the 12-month period is an inherent sampling issue that is likely to have little bearing on the outcomes (as the same 12 months are always compared and used for standardization) compared to other caveats discussed in this section.

Reference period: the SPI should be parameterized using a reference period, and for practical purposes, the use of the WMO standard climate period (currently 1981-2010) is recommended. However, any 30-year standard period is not likely to fully represent long-term climatic variability in a location – ideally longer periods would be chosen (Wu et al., 2005) although this is often not possible given the constraints of available datasets. The constraint of a relatively short 30-year period is a particular issue in the context of the multi-decadal variability commonly seen in hydrometeorological time series, largely arising from large-scale, low-frequency ocean-atmosphere circulation patterns, such as El Niño Southern Oscillation (ENSO), the Atlantic Multidecadal Oscillation (AMO) and a host of other patterns in different parts of the world. Studies have shown the sensitivity of SPI thresholds to such multi-decadal oscillations and potential impacts on policy/decision outcomes (Núñez et al., 2014). While there is a clear benefit of adopting a single, consistent standard period globally, at the same time, the representativeness of that 30-year period to current and future conditions will vary between regions, depending on the relative influence of drivers such as ENSO, as well as underlying trends emerging from anthropogenic warming, the magnitude of which are spatially variable. It should be noted that in future versions of the GPG, this reference period might change in line with any updated recommendations from WMO. In this case, the baseline (as described in Section 1.2.6) and any existing reporting periods should be recalculated to ensure comparability.

Distribution fitting: the SPI requires the selection of an appropriate statistical distribution to conduct the normalization process, and the Gamma distribution is recommended as a sensible default given its performance in continental-to-global-scale applications of the SPI. However, there is much literature on this subject (e.g. Lloyd-Hughes and Saunders, 2002; Stagge et al., 2015b; Svensson et al., 2017; Tijdeman et al., 2020) that demonstrates that in some locations, the Gamma distribution is outperformed by other distributions. Generally, the choice of distribution (and the fitting methodology) can have a significant influence on the derived SPI values, with the extreme values being particularly sensitive to the choice of distribution. Nevertheless, based on the available literature, the Gamma distribution remains a good choice of default distribution as it balances good general acceptability in most environments with ease of computation and interpretation relative to distributions with a higher number of parameters. If Parties are not using existing SPI data and are instead computing the SPI using national/regional precipitation data products and the methods provided in Section 1.2, the Gamma distribution can be appraised alongside other probability distributions if resources and capacity allow. 'Goodness-of-fit' tests, such as the Kolmogorov-Smirnov, Anderson-Darling and Shapiro-Wilk tests, as described in Stagge et al. (2015b) and Svensson et al. (2017), for example, can be used to assess the fit of distributions. Further recommendations on methodologies for fitting and evaluating probability distributions can be found in standard statistical guides for hydrology and meteorology (e.g. Tallaksen and Van Lanen, 2004; Wilks, 2011). It should also be noted that non-parametric approaches to SPI computation have been proposed (e.g. Hao and AghaKouchak, 2014), that remove the need for statistical distribution fitting. These methods are less favourable for extrapolation outside of the historical range of observations, which is a particularly important limitation given relatively short records.

2

©Unsplash

2.

LEVEL 2 INDICATOR

TRENDS IN THE PROPORTION OF THE TOTAL POPULATION EXPOSED TO DROUGHT

This chapter describes the terminology, concepts, methodology, data sources, interpretations and limitations of the Level 2 Indicator: Trends in the proportion of the total population exposed to drought, to assess exposure to drought hazard. It builds upon Level 1 to more directly address SO3 as outlined in the UNCCD 2018-2030 Strategic Framework.

For this GPG, we consider the number of people who are exposed to drought using spatially distributed population data compared to (overlaid with) the previously described Level 1 Indicator data that characterizes the drought hazard dynamically. We use the IPCC definition of exposure, which refers to the presence of people or ecosystems in locations that may be adversely affected by a hazard (IPCC, 2014c).

2.1 Summary

Exposure to drought is one of the key drivers of drought risk (Carrão et al., 2016). The methodology used here for the calculation of the Level 2 Indicator is intended to be universal, allowing Parties to select the most suitable dataset for the indicator and where appropriate, determine national methods for estimating the drought exposure.

The Level 2 Indicator is simply derived by calculating the percentage of the total population in a given country who are exposed to, and potentially impacted by, drought. Population is just one of several factors that could be considered when assessing exposure to drought (see Carrão et al., 2016; Laurent-Lucchetti et al., 2019; Pricope et al., 2020). Although not currently included in this methodology, such additional factors (e.g. crops, livestock and ecosystems) are discussed in more detail in Section 2.5 and Appendix A.

By analysing the percentage of a population exposed to drought hazard, country Parties can determine the proportion of the total population that are exposed to different levels of drought intensity. This, wherever possible, will be based primarily on comparable and standardized official data sources from the country Party that provide information on the distribution of the population. However, earth observation and geospatial information from regional and global data sources may also be utilized, as highlighted in Section 2.3.

2.2 Methodology

In the UNCCD indicator and monitoring framework for SO3, the Level 2 Indicator links to the Level 1 Indicator to provide a simple proxy for exposure. In this case, this is the percentage of the population exposed to drought for each Level 1 drought intensity class for each of the four years within the reporting period. The Level 2 Indicator is calculated as the percentage of a Party's total population exposed to drought. This has potential to be further disaggregated by sex to explore and analyse demographic aspects of exposure.

The method of computation for the Level 2 Indicator accounts for the spatial distribution of a population or sub-population group (i.e., by sex) in establishing its exposure to drought in a given location. The method considers a population to be exposed where it lies within a drought intensity class as determined by the Level 1 Indicator. The intensity class of drought to which a population is exposed is, therefore, directly taken from the underlying Level 1 Indicator. From this, the percentage of the total population located within each drought intensity class can be calculated, recorded and reported as part of the Level 2 Indicator.

> The first time the Level 2 Indicator is reported to UNCCD, it should also be calculated for the baseline period (i.e., 2000-2015) and any previous reporting periods. Guidance on producing the Level 2 Indicator for the baseline period is provided in Section 2.2.4.

2.2.1 Calculating the percentage of the total population exposed to drought

The approach outlined here involves overlaying population on to the spatial output of the Level 1 Indicator (see Section 2.3 for details of the data required).

There are four basic steps in calculating the percentage of the total population exposed to drought:

1. Overlay population data onto Level 1 spatial output (as derived in Section 1.2);
2. Calculate the total population for the country;
3. Calculate the number of people within each drought intensity class; and
4. Convert the output from Step 3 in to the percentage of people within each drought intensity class.

These steps are described in more detail below.

2.2.1.1 Step 1: Overlay population data on to Level 1 Indicator spatial output

Spatial outputs of hazard intensity are generated as part of the calculation of the Level 1 Indicator for each of the four reporting years (see Section 1.2). Population data for the corresponding years should then be overlaid onto each of these outputs (see example in Figure 10). Where population data are not available for a year, data for the following year within the reporting period should be used. For example, for the 2016-2019 reporting period, if data are not available for 2018 but are available for 2019, then 2019 data would be used for both 2018 and 2019. If data for neither of these years are available, then the most recent data within the reporting period should be used, for example 2017. At least one suitable population dataset within the reporting period must be acquired to enable the reporting of the Level 2 Indicator. This may result in the same population dataset being used for each of the four years if only one dataset is available for any four year reporting period. The data selected should fit the requirements listed in Section 2.3.1.

Note that the Level 2 population data and the Level 1 SPI data should have the same coordinate reference system and origin, or projection. The choice of datum and projection is a national decision, but must be an established spatial or coordinate reference system. It is therefore recommended that each country use its official coordinate system. For this purpose, data can be re-projected where necessary. The chosen projection system should be consistent across reporting periods.

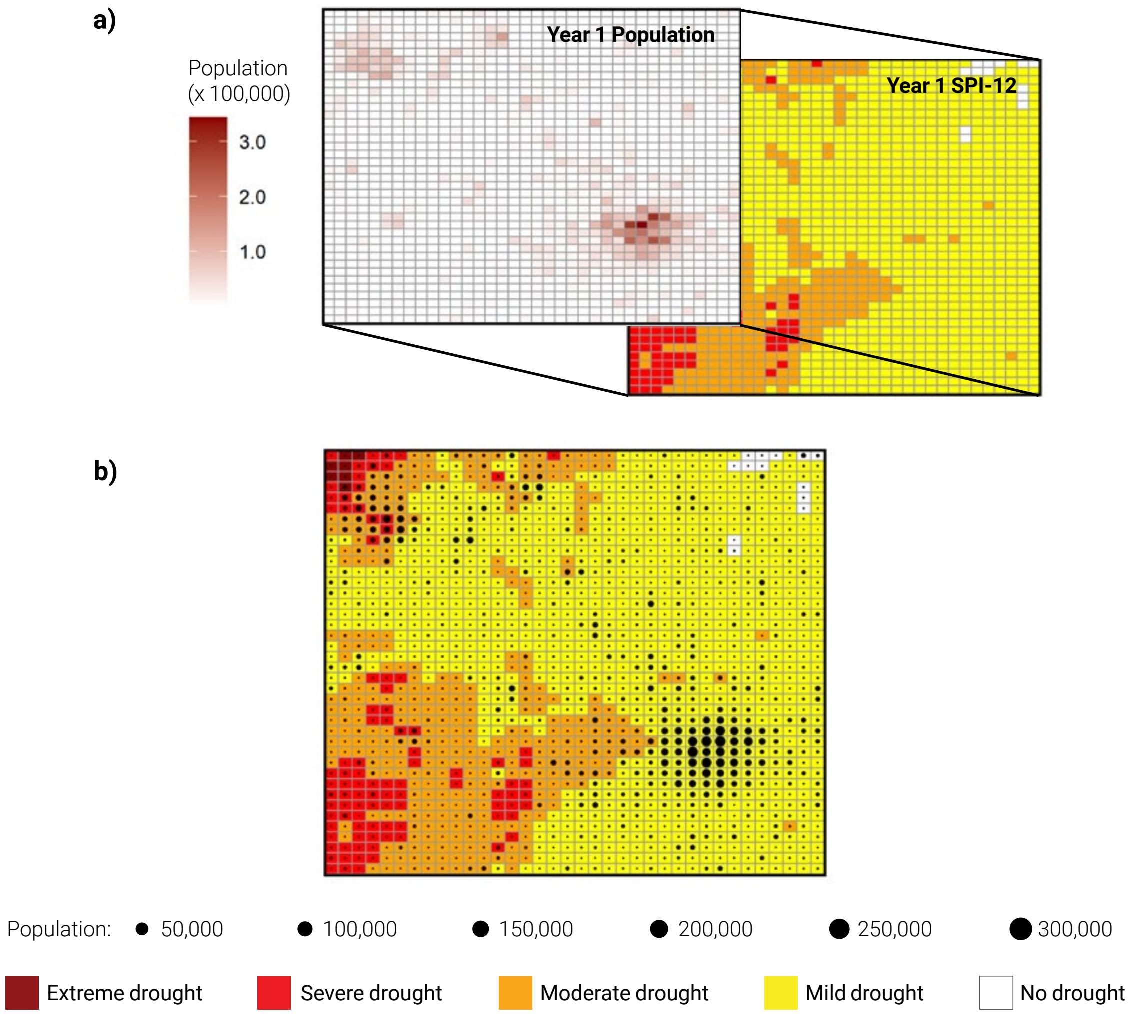
2.2.1.2 Step 2: Calculate the total population for the country

Sum the population for the full territorial area of the country; this will give the total population for the country. This should be done for each reporting year. Record these data, as shown in Table 11 in the row 'Total Population'.

Figure 10

a) Population overlaid with the SPI data for Year 1 of the worked example;

b) Example of population overlay highlighting population counts in cells in each drought intensity class



Note: Here the population raster has been converted to circles in order to more clearly show the data.

2.2.1.3 Step 3: Calculate the number of people within each drought intensity class

Using the output generated in Step 1, calculate the number of people that overlay each of the four drought intensity classes separately for each year, and record as in Table 11 in the columns labelled 'Count'. Note that there may be some of the population that are not exposed to any class of drought intensity, and these should be recorded in the row labelled 'No drought'.

Statistical tools in Geographic Information System (GIS) software such as 'Zonal Statistics' in QGIS or ArcGIS can be used to conduct population counts based on the drought intensity classes defined by the Level 1 Indicator. If such tools are not used or available, the SPI and population data should be at the same spatial resolution and on the same grid to enable a per pixel calculation of exposed population. Where data are not at the same resolution, either the SPI or population data should be re-gridded.[41] It is recommended that re-gridding be based on the data with the finer spatial resolution.

GDAL is an open source library of tools that can be used for raster data analysis, including re-gridding data using 'gdalwarp'.[42] GDAL can be used directly through command line tools, programming languages such as Python, or in open source software such as QGIS.

[41] See for example: https://climatedataguide.ucar.edu/climate-data-tools-and-analysis/regridding-overview

[42] https://gdal.org/programs/gdalwarp.html

2.2.1.4 Step 4: Calculate the percentage of people within each drought intensity class

Use the sum of the total population (Step 2) to calculate the percentage of people that lie within each of the drought intensity classes for each year (see Equation 2). Record these data, as in Table 11 in the '%' columns; this should be done for each year in the reporting period.

$$\%\,ePop_{ij} = \left(\frac{\%\,ePop_{ij}}{Total\ population_j}\right) \times 100$$

Equation 2 Equation to calculate the percentage of the total population exposed (% ePop) to drought intensity class (i) for each year (j), where ePop is the sum of the population exposed to drought intensity class i and Total population is the total number of people in the Party's land area for year j.

Both the tabular data and the mapped spatial outputs should be produced for Level 2 reporting. The extent of the population exposed should be clearly visible on the output maps for each reporting year, for example using the circles shown in Figure 10.

2.2.2 Exposure to drought by sex

Where sex-disaggregated data are available, it is recommended that country Parties derive the Level 2 Indicator for both sexes, alongside that for the whole population. This is a simple calculation, producing the percentage split between males and females within each drought intensity class for each reporting year.

There are three basic steps required for the calculation of this output:

1. Overlay sex-disaggregated population data onto Level 1 spatial output (as derived in Section 1.2.2);
2. Calculate the number of people for each sex within each of the four drought intensity classes; and
3. Convert the output from Step 2 into the percentage share between males and females for each drought intensity class.

These steps are described in more detail below.

Table 11

Example of data derived from analysis of the population overlay with drought intensity classes shown in Figure 4

Reporting Year	1		2		3		4	
Total population	23,906,200		24,281,300		24,550,120		24,697,500	
Drought intensity class	Count	%	Count	%	Count	%	Count	%
No drought	107,020	0.0	114,767	0.0	24,550,120	100	15,123,605	61.2
Mild drought	18,359,965	76.8	2,598,206	10.7	0	0	9,335,683	37.8
Moderate drought	4,298,522	17.9	9,514,157	39.3	0	0	231,969	0.9
Severe drought	1,101,441	4.6	5,059,895	20.9	0	0	6,243	0
Extreme drought	39,252	0.1	699,4275	28.9	0	0	0	0
Exposed population	**23,799,180**	**99.6**	**24,166,533**	**99.5**	**0**	**0**	**9,573,895**	**38.8**

2.2.2.1 Step 1: Overlay sex-disaggregated population data on to Level 1 Indicator spatial output

Using population datasets that also include sex-disaggregated data (see the data requirements listed in Section 2.3.1), overlay the sex-disaggregated population data on to the spatial output derived for the Level 1 Indicator (Section 1.2.2). Note that to avoid discrepancies in population totals, population data and sex-disaggregated data should be gathered from the same source.

2.2.2.2 Step 2: Calculate the number of people for each sex within each drought intensity class

For each sex, calculate the number of people that lie within each of the four levels of drought intensity as given by the Level 1 Indicator. Record these data, and using these counts, sum the total number of people exposed for each drought intensity class and record for each reporting year.

2.2.2.3 Step 3: Calculate the percentage share between males and females for each drought intensity class

Using Equation 3 and the count data calculated in Step 2, calculate the percentage share of both sexes within each of the four drought intensity classes; note that the share within each drought intensity class should equal 100%. These data can be recorded as in Table 11, with the addition of exposure by sex.

$$\%\,ePop_{ijk} = \left(\frac{\%\,ePop_{ijk}}{Total\ Pop\ exposed_{ij}} \right) \times 100$$

Equation 3 Equation to calculate the percentage of the population exposed (%ePop) to each drought intensity class (i), where ePop is the number of people exposed within each sex k for year j, and Total Pop exposed is the total number of people exposed to drought for the corresponding reporting year and drought intensity class.

Again, both the tabular data and the mapped spatial outputs should be produced for the Level 2 national reporting. The extent of the sex-disaggregated population exposed should be clearly visible on the output maps for each reporting year, for example using the circles shown in Figure 10.

The steps outlined above will produce spatial outputs and information at the grid-cell scale. These can be aggregated to administrative and regional boundaries if desired for further analysis, where local spatial relationships between population, sex and drought occurrence and/or intensity can be better quantified and visualized.

2.2.3 Creating a gridded spatial summary of the Level 2 Indicator for the reporting period

In addition to the Level 2 Indicator outputs described above, a gridded spatial summary for the current reporting period should also be produced. This gridded spatial summary output gives an indication of the number of people exposed to the most extreme drought intensity class over the four-year reporting period at the scale of the grid cell.

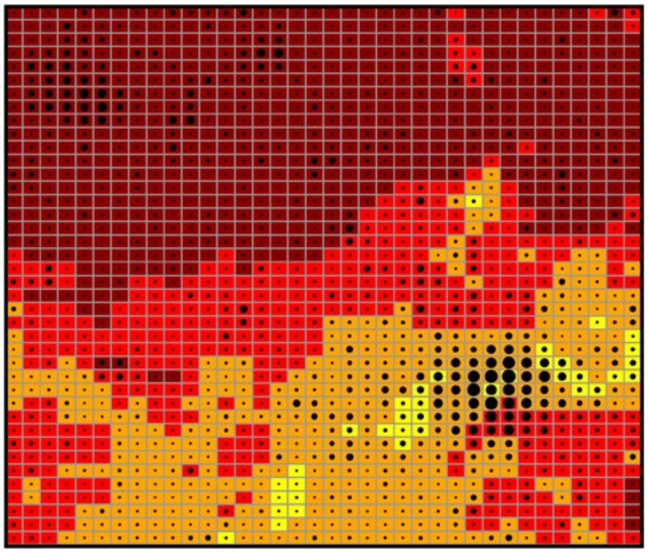
To summarize the reporting period spatially for the Level 2 Indicator, the most recent population dataset from the current reporting period should be overlaid on to the Level 1 Indicator gridded spatial summary produced in Section 1.2.5. For example, for the reporting period of 2016-2019, population data for 2019 should be used. Where these data are not available, the next most recent year should be used, e.g. 2018, and so on.

The number of people exposed to each drought intensity class should be clearly represented on the summary map, for example using circles as shown in Figure 11, or other approaches, such as bi-variate choropleth maps,[43] which would combine the drought intensity class and population data in one legend. Note that sex-disaggregated outputs are not required as part of the summary output.

[43] For example, see Strode et al. (2020) and this 'how-to guide': https://www.joshuastevens.net/cartography/make-a-bivariate-choropleth-map/

Figure 11

Summary map for the Level 2 Indicator, showing the most extreme drought intensity class a population was exposed to within the four-year reporting period



2.2.4 Calculating the Level 2 Indicator for the baseline period

This section describes how the Level 2 Indicator should be calculated for the UNCCD baseline period of 2000-2015, in line with the reporting requirements for all strategic objectives included in the 2018-2030 Strategic Framework. Calculating the Level 2 Indicator for this period provides context for Parties to understand their drought exposure over time for SO3 monitoring, as well as for the other Strategic Objectives.

The baseline period for the Level 2 Indicator should be taken as a record of the status of drought exposure over this period. The Level 2 Indicator is based upon the Level 1 Indicator, which characterizes the drought hazard. Drought is a periodic event, and climate variability means it is possible drought may or may not have occurred in either the baseline period or the reporting period (see Section 1.2.6). Any observed changes or trends in the proportion of the population exposed to drought over this short timeframe should therefore be interpreted with caution.

The Level 2 Indicator baseline period should be calculated during the first round of national reporting to UNCCD.

There are some instances when the baseline period (and any previous reporting periods) may need to be recalculated; these are as follows:

- If WMO guidance on the standard climate normal period is updated, the SPI should be recalculated using this new standard as the reference period and the Level 1 Indicator re-derived for the baseline in addition to any subsequent reporting periods.
- If new and/or improved precipitation datasets used to calculate the SPI, and so the Level 1 Indicator, become available, the baseline period and any reports from subsequent reporting periods should be recalculated using the new precipitation dataset.
- If new and/or improved population datasets used in the calculation of the Level 2 Indicator become available, the baseline and any reports from subsequent reporting periods should be recalculated using the new population dataset.
- If the methodology for deriving or reporting the Level 2 Indicator for SO3 monitoring changes in the future.

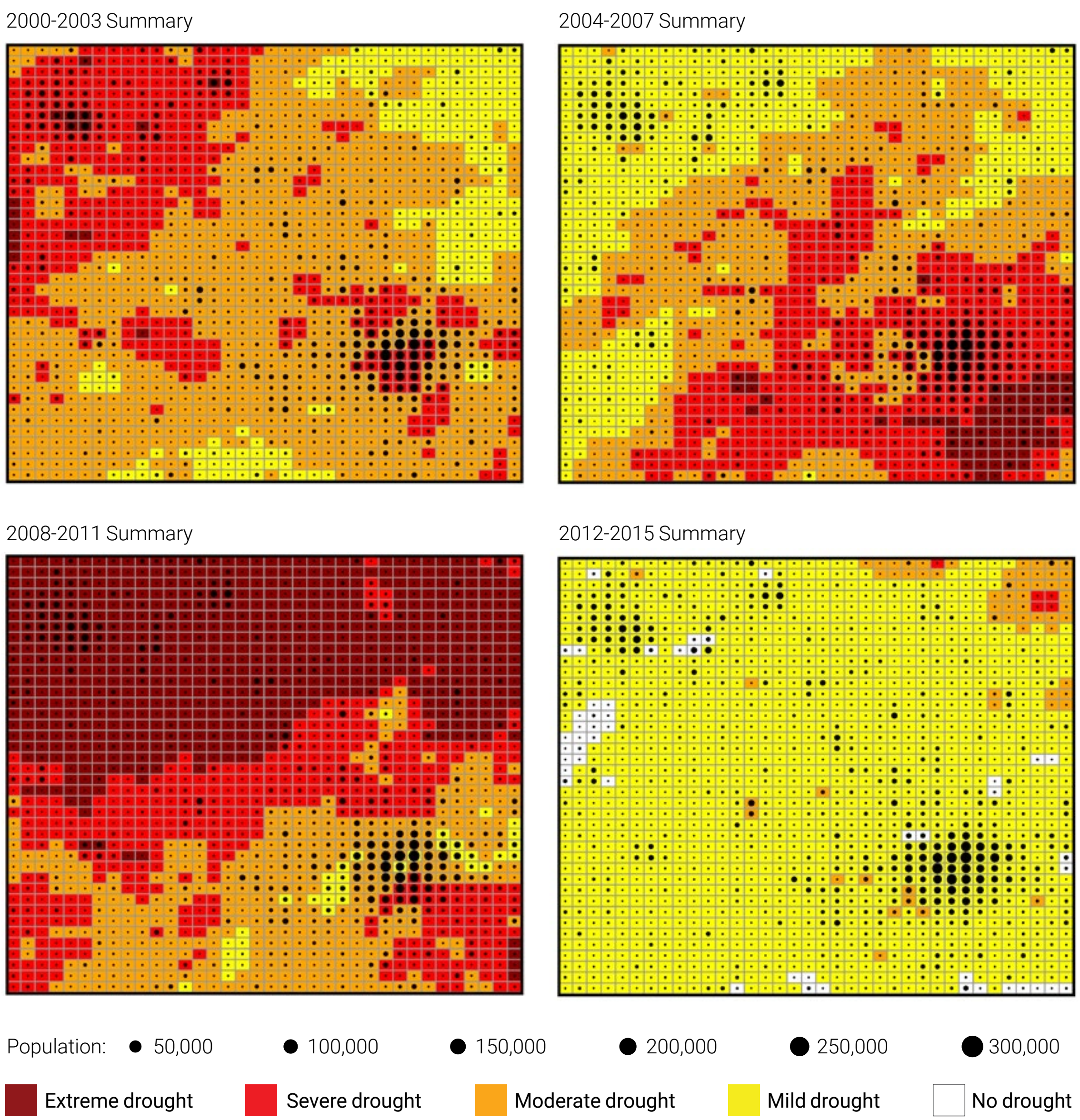
The method of computation for the Level 2 Indicator baseline is similar to that of the calculation of the output of people exposed to drought for the most recent reporting period, as described in Sections 2.2.1-2.2.3. A summary equivalent to that shown in Table 11 should be produced for the baseline period, tabulating the exposed population for each of the 16 years in the baseline period.

A series of four baseline exposure summary maps also need to be provided alongside the tabular output, equivalent to that outlined in Section 2.2.3. To summarize the baseline period spatially for the Level 2 Indicator for each four-year baseline period (i.e., 2000-2003, 2004-2007, 2008-2011 and 2012-2015), the most recent population data within the four-year period should be selected. For example, for the period 2000-2003, population data for 2003 should be used. Where these data are not available, the next most recent year should be used, e.g., 2002, and so on.

These data should then be overlaid on to the gridded spatial summary output produced for the equivalent Level 1 Indicator baseline period; see Section 1.2.6 and Figure 7 for Level 1 Indicator summary output. The number of people exposed to each drought intensity class should be clearly represented on these summary maps, for example using circles as seen in Figure 12, or other approaches, such as bi-variate choropleth maps, which would combine the drought intensity class and population data in one legend.

Figure 12

Summary maps for the Level 2 Indicator for the four-year baseline periods, showing the most extreme drought intensity class a population was exposed to for the corresponding four-year period



2.3 Data sources

This section outlines the requirements of the data needed for the calculation of the Level 2 Indicator, along with two recommended datasets. For further information on these and related data, see Pricope et al. (2020).

2.3.1 Population data requirements

In order to ensure a consistency in quality and comparability within and between Parties, datasets used for the derivation of the Level 2 Indicator need to meet a number of basic criteria.

1. Data should be spatially gridded or at a sub-national resolution, i.e., at a spatial disaggregation level that is policy relevant (e.g., administrative boundaries; Sims et al., 2021; Pricope et al., 2020).
2. Data need to be spatially complete, covering the full geographic extent of the country Party, with limited missing data entries.
3. Data need to contain either a full-population count, or a population density that can be converted to a count.
4. Data need to have a temporal range within the current four-year reporting period, along with a resolution fine enough to capture change both within and between the present and previous reporting periods.
5. The data should use a consistent method of mapping census-derived data. Methods of data processing and data sources need to be documented and validated, with a clear methodology of how these data are derived and the calculations used to produce the final counts for each grid cell.
6. Parties should ideally exploit existing data wherever possible, where the source data is identified and the methodology of collation and processing are clearly outlined, validated and verified for accuracy and transparency (Sims et al., 2021).
7. Where possible, and without detriment to the other criteria outlined here, data should be disaggregated by sex.
8. Data need to have an update frequency adequate for representing changes between reporting periods, and enabling them to be accessed in future reporting years and so ensuring consistency through time.

2.3.2 Recommended population datasets

A fine-scale/sub-national spatial dataset should be selected, derived from either an official validated national source, or where more appropriate a global/regional dataset. There are a number of publicly available, fine resolution population datasets available at the global scale (e.g. see Pricope et al., 2020). Many of these data meet the criteria outlined for the national assessment of hazard exposure. Two of these datasets, WorldPop and Gridded Population of the World, version 4 (GPWv4), are summarized in Table 12 and discussed.

Table 12
Recommended gridded global population datasets for deriving the Level 2 Indicator

Population Dataset	Organization	Source	Spatial resolution	Temporal resolution	Sex-disaggregated data	Update frequency
WorldPop[44]	WorldPop	Country-official estimates	3-arc seconds (~100 m)	2000-2020 globally and country specific years	Yes	Annually
		UNPD estimates and projections				
Gridded Population of the World – version 4 (GPW v4)[45]	CIESIN; SEDAC; EOSDIS	Country census	30-arc seconds (~1 km)	2000, 2005, 2010, 2015 and 2020	2010 only	Every 5 years
		Estimates from UNWPP				

[44] https://www.worldpop.org/
[45] https://sedac.ciesin.columbia.edu/data/collection/gpw-v4

2.3.2.1 WorldPop

WorldPop is a high-resolution global dataset on population distributions, demographics and dynamics. WorldPop's spatially disaggregated layers are gridded at a resolution of 3 arc-seconds and 30 arc-seconds (approximately 100 m and 1 km at the equator, respectively), and incorporate inputs such as population census tables and national geographic boundaries. The input data are modelled to produce annual population estimates for the years 2000-2020. A set of estimates adjusted to national-level population predictions from the United Nations Population Division (UNPD) are also produced for the same set of years (Pricope et al., 2020). The population estimation method used (known as dasymetric mapping) is multivariate, incorporating a high number of predictors. It is, therefore, considered to be 'highly modelled', and as a result can be tailored to match data conditions and the geographical nature of each individual country and region. The data are also disaggregated by sex. It is important to note that the annual product covering the period 2000-2020 is unconstrained, meaning every pixel has equal potential to host inhabitants. In reality, this is not the case; e.g. in the unconstrained version, rural pixels with no population might erroneously be coded as inhabited in this dataset.[46]

It should also be noted that utilization of such complex interpolation models with sparse census data may, in some cases, lead to highly uncertain population estimates in some sub-national and rural regions. In countries where a census has not taken place in a long time, or where there have been substantial changes due to migration, infertility, mortality etc., such uncertainty will be higher. WorldPop tries to limit this uncertainty by employing a 'bottom-up' approach, utilizing local surveys and satellite-derived feature extractions (WorldPop, 2020). Where census data are more readily available, WorldPop employs a 'top-down' methodology, disaggregated from global administrative unit-based census and projection counts. As such, these estimates are in line with those of the United Nations.

2.3.2.2 Gridded Population of the World, version 4

The Gridded Population of the World, version 4 (GPWv4) is a gridded, global population dataset developed by the Centre for International Earth Science Information Network (CIESIN) at Columbia University. It has a spatially disaggregated layer gridded with an output resolution of 30 arc-seconds (approximately 1 km at the equator), incorporating inputs such as population census tables and national geographic boundaries, protected areas and water bodies. The input data are weighted and extrapolated to produce population estimates (counts and densities) for the years 2000, 2005, 2010, 2015 and 2020. A set of estimates adjusted to national-level population predictions from the United Nations World Population Prospects report are also produced for the same set of years. Raster (gridded) maps are available for demographic characteristics including age and sex for the year 2010 only.

In comparison to WorldPop, the population estimation method of areal-weighting is relatively straightforward, i.e., it can be considered 'lightly modelled', providing fidelity to the input census data. The disadvantage of using areal-weighting is that the spatial disaggregation method leads to a high variability of grid-level estimates. Consequently, for Parties where the input (e.g. administrative) units are relatively large, the precision of population estimates for individual grids within that unit can be compromised (Doxsey-Whitfield et al., 2015).

2.3.3 Use of national/regional population data products

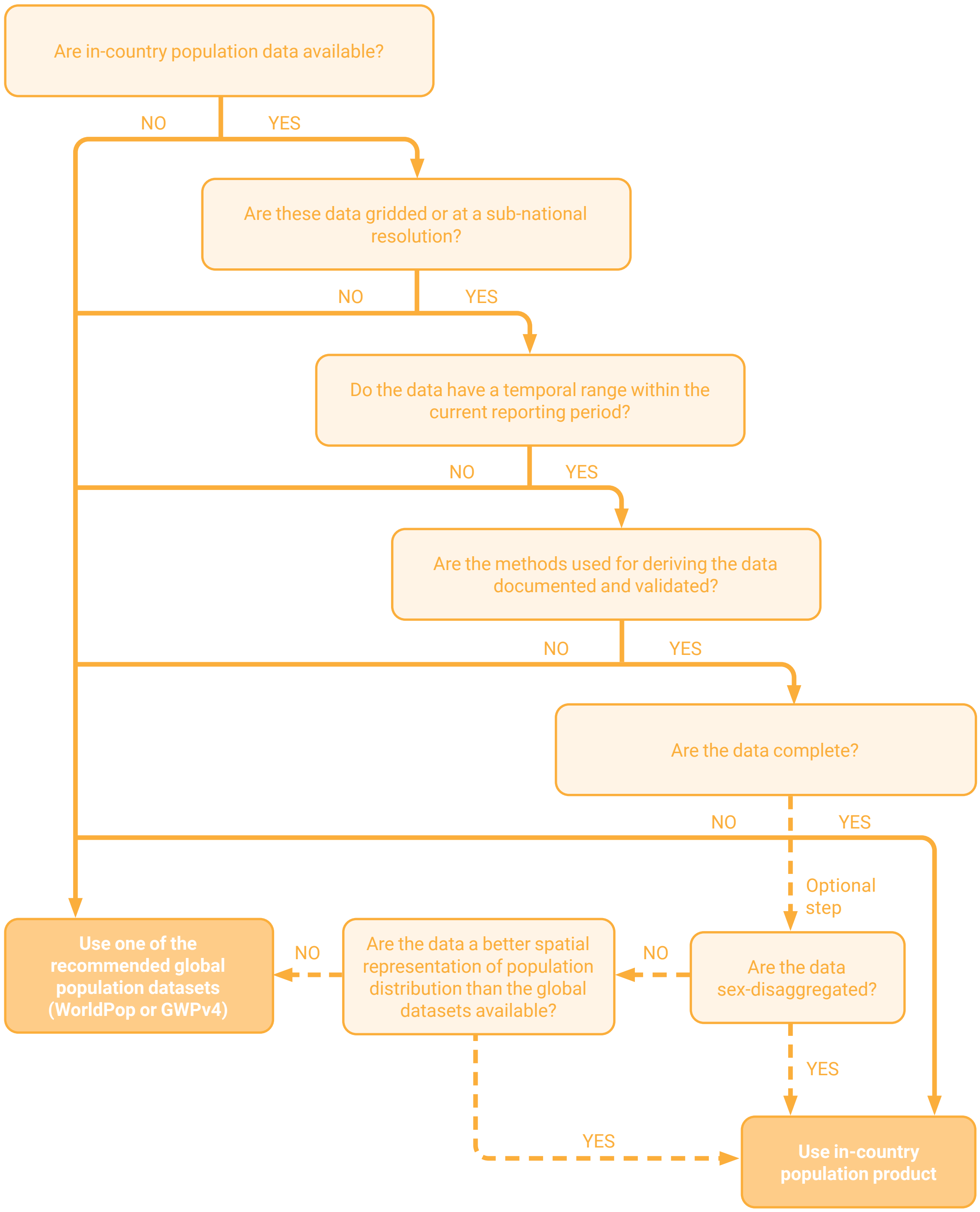
The freely accessible, global geospatial datasets recommended here, i.e., WorldPop and GPWv4, contribute significantly toward improving reporting on SO3. Where feasible, Parties also have the option to use their own/regional datasets. This may offer some advantages, including providing data at a higher resolution, less reliance on modelling approaches, and validation based on local data collection leading to a greater confidence in the outputs produced. As such, Parties may feel that these datasets provide a better representation of the population count within their country, and reduce uncertainty related to global data (Mondal and Tatem, 2012).

[46] For more information see: https://www.worldpop.org/methods/top_down_constrained_vs_unconstrained

Figure 13 sets out the recommended decision-making process when assessing the suitability of in-country (or regional) population data products over the globally available products listed in Table 12, for the derivation of the Level 2 Indicator. As with all data types, national, regional and global population products should not be considered mutually exclusive. Rather, it is recommended that products be used to cross-validate others to achieve greater confidence at the national level and to understand any discrepancies in data. It is the decision of each country Party as to which dataset they use based on this analysis, alongside data availability. Note that the provision of sex-disaggregated data is optional, and the merits of its inclusion should be considered alongside the criteria outlined in Section 2.3.1.

Figure 13

Decision tree to help Parties choose the best data source to derive the Level 2 Indicator



2.4 Rationale and interpretation

Whether a population suffers from water excess or water deficit depends upon where it is located geographically. Coupled with the Level 1 Indicator, the calculation of the Level 2 Indicator establishes who is exposed to drought based on their geographical location, and the level of drought intensity experienced.

The output produced for the Level 2 Indicator is purposefully simplistic. It gives a clear indication of where a population is most likely to be subjected to the direct effects of drought, and enables patterns of drought exposure to be identified from the spatial output. In this way, its interpretation is also relatively easy to understand and should allow for a clear assessment of where exposure to drought is most prevalent within a country.

The figures associated with these spatial outputs (e.g. Figure 10) can be used to quantify the number of people, including information for both sexes, exposed to each drought intensity class (see example in Table 11). The larger the percentage of a population that lies within a particular drought intensity class, the more people are exposed to the potential impact of that class of drought intensity.

The baseline summary assessment of a population's exposure to drought provides an initial drought exposure status, which will be added to with every subsequent reporting period. As mentioned in Section 2.2.4, caution should be exercised in the interpretation of any changes or trends in the Level 2 Indicator due to the effect of natural climate variability on the occurrence of droughts. In addition to this, the expected natural increase of a Party's population should also be taken into account when assessing the change in the number of people exposed to drought.

The quantification of drought exposure is an important step in identifying the potential impact of drought upon a Party's population. By identifying the percentage of a population's exposure to each drought intensity class, including specific population demographics, a Party is able to assess where its population is experiencing drought, and quantify both total and sex-disaggregated population information at a spatial and temporal scale relevant to practitioners and policy makers.

2.5 Comments and limitations

The methodology outlined here assesses exposure in relatively simple terms with regard to population and sex. However, there are additional factors that could also be considered to provide means of assessing drought exposure (IPCC, 2014b). A more comprehensive measure of drought exposure may take into account not only the spatial distribution of the population, but other physical entities at risk, such as agricultural yields, livestock counts, sectoral water stress and vegetation type (Carrão et al., 2016; Laurent-Lucchetti et al., 2019; Pricope et al., 2020). Such factors play a part in recognizing that drought increasingly impacts larger numbers of people, livelihoods, ecosystems, and economies worldwide (Sims et al., 2021).

There are, however, additional considerations to be made with the inclusion of such factors. Data that describe these factors are not always as readily available as population data at the global/quasi-global scale, with coverage between countries often being inconsistent. There are further limitations in terms of both the spatial and temporal resolutions at which data are available, i.e., data are too coarse (e.g. national to regional-level data) or not frequently updated. Therefore, whilst there are datasets currently available for such factors, for example, from FAO or the International Food Policy Research Institute (IFPRI), they are often not available at a sub-national scale, or coverage may not be complete for all country Parties, therefore limiting their application within the methodology of the GPG. At the national scale, there may also be limitations on the capacity of Parties to generate the necessary data. Pricope et al. (2020) also note that many of these factors are not disaggregated by sex, with such information often being unattainable. Methods for integrating additional factors would require further research and validation before incorporation into the methodological framework set out here, and this is discussed further in Appendix A.

It is, therefore, important to balance the need for simplicity against necessity in the calculation of the Level 2 Indicator. In line with Decision 11/COP.14, the UNCCD recommends at this stage to assess drought exposure on human population data only. Therefore, in this GPG, exposure is identified solely where populations coincide with a drought intensity class from the Level 1 Indicator. Proximal, or distant, exposure to the hazard is not considered. The simplistic calculation used here is unable to capture levels of exposure outside of the hazard class boundaries. This is a commonly accepted limitation acknowledged in the literature (Christenson et al., 2014; Naumann et al., 2014; Carrão et al., 2016). Due to the complexities and dependencies within each country, such criteria are difficult to apply universally and so, for the time being, the simpler approach is recommended in this GPG.

Being exposed to drought also does not equate to drought vulnerability. Within this methodology, the two are considered mutually distinct. It should be noted that the same status of the Level 2 Indicator – whether at different locations within a single country Party or between country Parties – may subsequently lead to different levels of drought vulnerability due to differences in economic, social, and environmental factors. It is, therefore, important that once exposure has been assessed, country Parties move on to the calculation of the Level 3 Indicator of vulnerability, as outlined in Chapter 3.

©Unsplash

3

©Unsplash

3.

LEVEL 3 INDICATOR

TRENDS IN THE DEGREE OF DROUGHT VULNERABILITY

This chapter describes the methodology, data sources, interpretation and limitations of the Level 3 Indicator for assessing trends in the degree of drought vulnerability of populations. When used in conjunction with the Level 1 and Level 2 Indicators, this indicator can more comprehensively address drought risk and the human component of SO3 outlined in UNCCD 2018-2030 Strategic Framework.

The UNCCD definition of vulnerability, which is contained in ICCD/COP(14)/CST/7 and sourced from the 2016 Report of the Open-ended Intergovernmental Expert Working Group on Indicators and Terminology Related to Disaster Risk Reduction (A/71/644),[47] is used here: “the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards, such as drought.” In addition, Decision 11/COP.14 sets out that the Level 3 Indicator should be a ‘composite index of relevant economic, social, physical and environmental factors that contribute to drought vulnerability’.

On this basis, a composite indicator, the Drought Vulnerability Index (DVI), is proposed that incorporates ssocial, economic and infrastructural components that reflect the vulnerability of the population of an individual country or region (Figure 14; UNISDR, 2004). The DVI does not, at present, address the other aspects of SO3, namely ecological or ecosystem vulnerability.

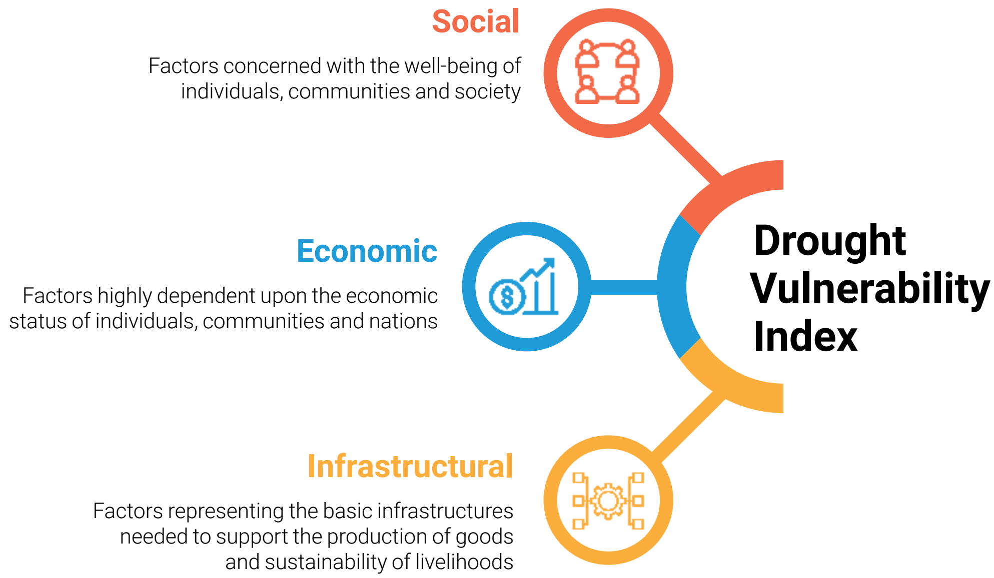
3.1 Summary

The assessment of drought vulnerability is essential for the identification of underlying causes of drought impacts, and in turn the development of appropriate policy responses (ICCD/COP(14)/CST/7). However, as outlined in ICCD/COP(14)/CST/7, “there is no single metric or proxy that can adequately represent the complexity of drought vulnerability, which means that this indicator would need to be a composite of the physical, social, economic, and environmental factors contributing to community and ecosystem vulnerability to drought, ideally collected at both the national and subnational levels.” In response to this, and in light of the scientific literature on the topic of drought (and disaster) risk and vulnerability assessments, this GPG proposes a composite indicator to enable country Parties to monitor trends in the degree of drought vulnerability of their populations over time.

[47] https://www.preventionweb.net/files/50683_oiewgreportenglish.pdf

Figure 14

Components used to derive the Drought Vulnerability Index (DVI) for the Level 3 Indicator



In assessing vulnerability, the scientific community has generally taken two approaches in choosing the components of such composite vulnerability indicators. These two theoretical frameworks are:

a) the impact approach, which uses impacts as a proxy of the vulnerability of a system; and

b) the factor approach, which is of a more contextual nature and uses a set of intrinsic socio-economic and other factors that are considered root causes of vulnerability to drought (Blauhut et al., 2016; Vogt et al., 2018).

The former is more prevalent in climate change adaptation communities, and the latter in disaster risk reduction contexts. A hybrid model that combines both the impact and factor approaches has also been developed, which has some benefits – not least that more robust validation has been applied, as reviewed in Blauhut (2020). However, in the context of this GPG, the hybrid model was not considered, mainly due to the more complex mathematical and statistical methodology (see Appendix A for more information). Thus far, the factor approach methodology has been more commonly used in the scientific literature (Blauhut, 2020; Hagenlocher et al., 2019) and for the purposes of this GPG it was considered more methodologically straightforward and pragmatic, and so is being recommended for Level 3 Indicator reporting. The methodologies developed and assessed by Naumann et al. (2014) and further modified and expanded by Carrão et al. (2016) and applied most recently to agricultural systems by Meza et al. (2020) have been drawn upon to provide the composite indicator proposed here, which aims to appraise vulnerability at the country level.

This composite indicator (DVI) captures both short-term coping capacity and long-term adaptive capacity of the population through the incorporation of three components: social, economic and infrastructural (Carrão et al., 2016; Vogt et al., 2018; King-Okumu, 2019; King-Okumu et al., 2020). The DVI does not include an ecological or ecosystem component, as it is important that methods that have been applied and validated at the global scale are recommended in the GPG. Currently, only a small number of studies have included an ecosystem component in drought vulnerability and risk assessment studies, as outlined in reviews by González Tánago et al. (2016), Hagenlocher et al. (2019) and Blauhut (2020), and the methodology presented in this GPG has, thus, only been expanded to include ecological factors for global agricultural systems (Meza et al., 2020). Furthermore, there is no consensus in the literature on methods or factors for ecosystem vulnerability assessments that go beyond ecosystem services (that are by definition more human than ecosystem-centric; De Lange et al., 2010; Hagenlocher et al., 2018; Weißhuhn et al., 2018). Future research is required on an ecosystem component in order to properly fulfil the requirements of the SO3 monitoring framework agreed in Decision 11/COP.14; this is discussed further in Appendix A.

According to UNISDR (2004), the state of the social, economic and infrastructural components, either at the country level or for a specific region, reflects the vulnerability of the population of the country or region, respectively. Each of the three components of the DVI presented here is represented by one or more factors, which are observable or measured variables available as global and/or national datasets. Due to challenges around availability of country-level and/or sub-national-level datasets and the capacity to process data, this GPG has applied a similar tier structure to that defined in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, whereby 'a tier represents a level of methodological complexity' (IPCC, 2006), the use of which was approved through UNFCCC Decision 20/CP.7.

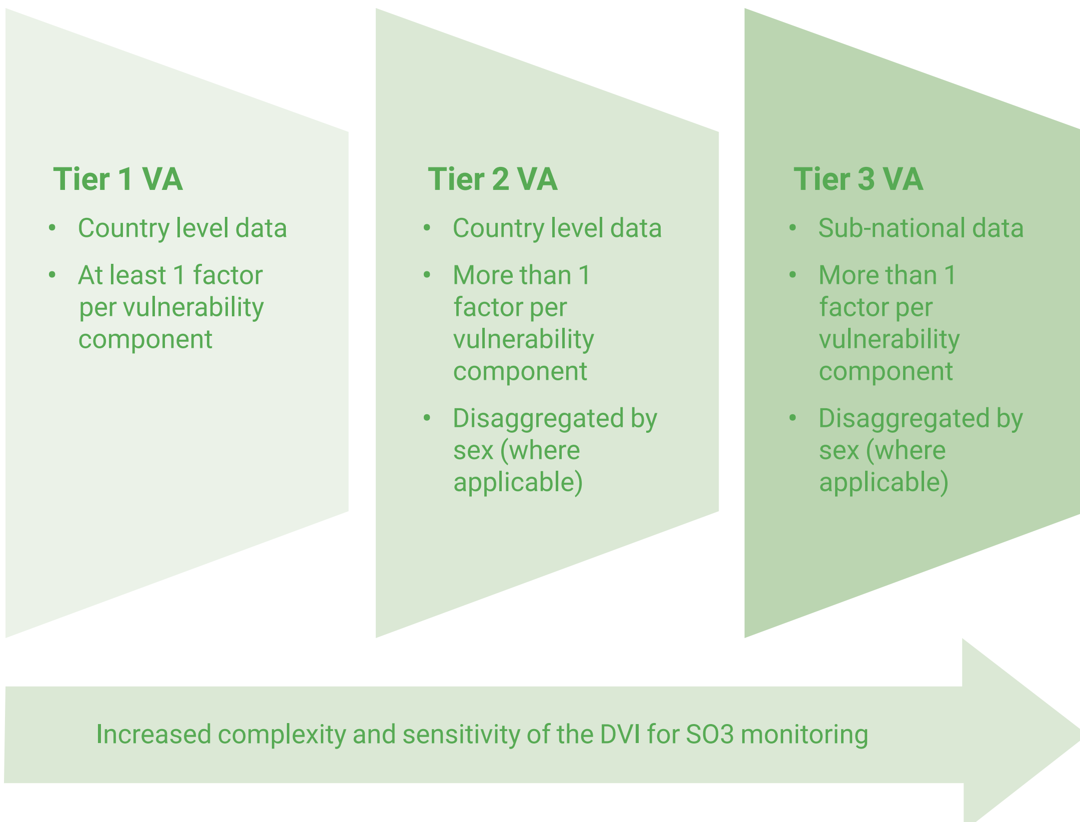
Not to be confused with the tiered approach for the establishment of an indicator and monitoring framework for UNCCD SO3 as set out in Decision 11/COP.14, the three tiers of a vulnerability assessment (VA) recommended in this GPG represent increasing levels of methodological complexity and data requirement for the calculation of the DVI (Figure 15) as follows:

- Tier 1 VA – uses, at the minimum, one factor per vulnerability component, represented by country-level metrics;
- Tier 2 VA – uses more than one factor per vulnerability component, where the factors are represented by country-level metrics, with the inclusion of sex-disaggregated data (where applicable); and
- Tier 3 VA – uses more than one factor per vulnerability component, where factors are represented by sub-national metrics (which may be gridded or for administrative regions), with the inclusion of sex-disaggregated data (where applicable).

Figure 15

Tiers of vulnerability assessment recommended for calculation of the Drought Vulnerability Index (DVI)

Country-level data is a single value provided for the whole country, whereas sub-national data are data from smaller spatial units within the country

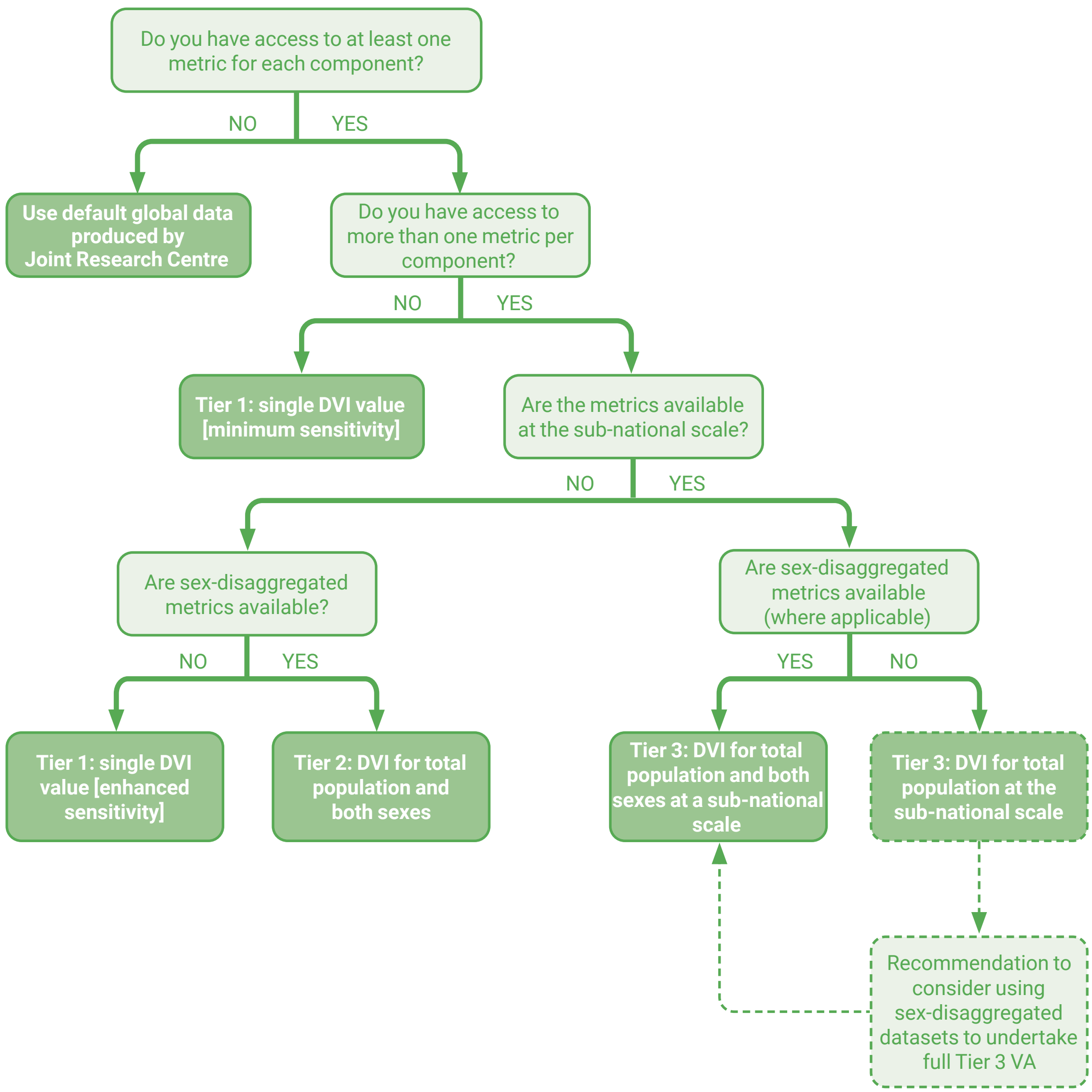


A key benefit to this tiered system is that Parties are able to select an approach most suitable to their current capacity to collect and process data and/or data availability. The main drawback of the system is that the smaller the number of factors used, the lower the 'sensitivity' of the DVI, as defined in ICCD/COP(14)/CST/7 and set in Decision 11/COP.14. Hence, when a Tier 1 VA is the best approach for a country Party, it is recommended that, if at all possible, the number of factors used to derive the DVI is increased from the minimum three factors recommended. All efforts should be made over successive reporting processes to progress up the tiers of VA, from Tier 1 to Tier 3, to enable Parties to develop the most effective drought mitigation, adaptation and resilience plans by increasing the 'sensitivity' of the DVI and improving the granularity of the assessment as advised in the Drought Resilience, Adaptation and Management Policy (DRAMP) framework technical guidelines (Crossman, 2019). A simple decision tree is provided in Figure 16 for Parties to use in order to determine which tier of VA they should conduct and what the relative benefits of each tier are in terms of the sensitivity of the DVI.

The factors proposed for each component in the DVI are outlined in Figure 17, with the three recommended for the minimum Tier 1 VA highlighted. The rationale behind the choice of these three factors for Tier 1 VA is outlined in Section 3.4.2, and for more information about the recommended data sources for Tier 1 and Tier 2 VA assessments see Table 14 and Section 3.3.

Figure 16

Decision tree to help Parties choose the best tier of vulnerability assessment for Level 3 Indicator reporting according to data availability



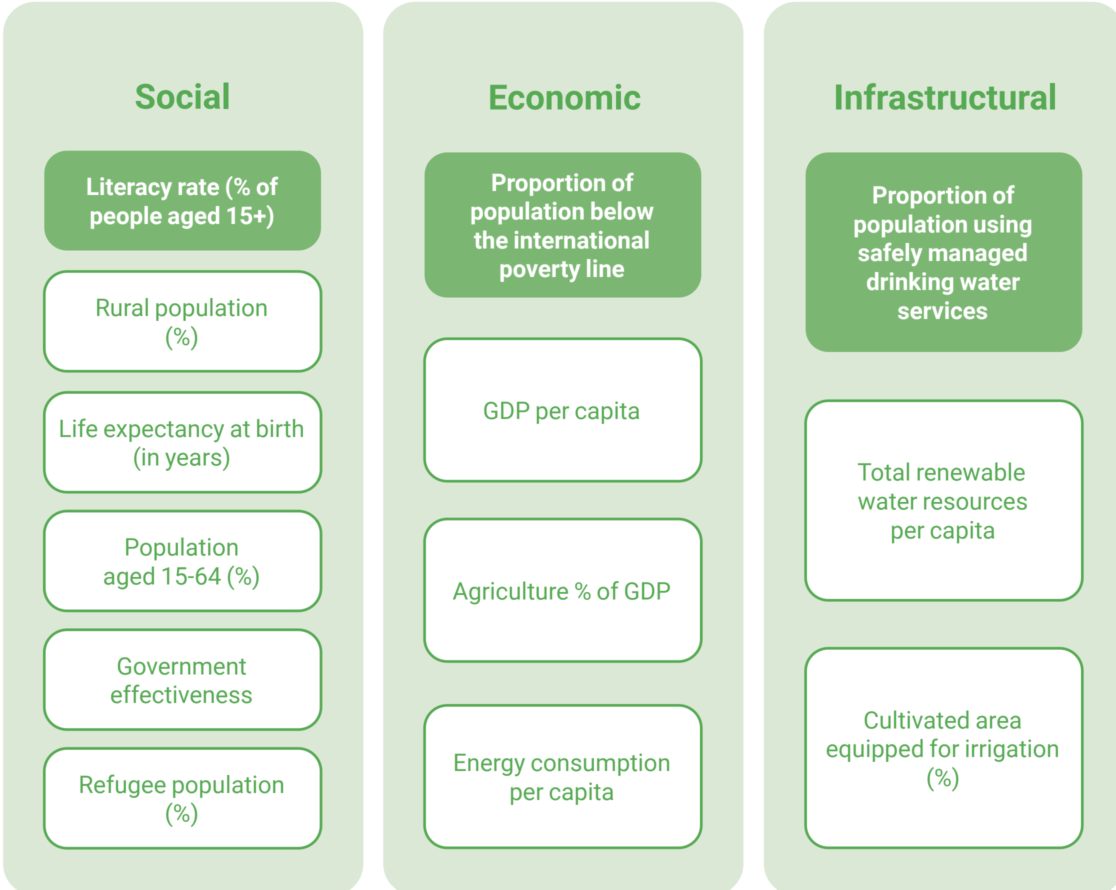


Figure 17

Social, economic, and infrastructural components and their associated factors recommended for calculating the Drought Vulnerability Index (DVI)

Factors highlighted in green are the three factors recommended for a minimum Tier 1 vulnerability assessment (VA)

A composite indicator is generally derived through a mathematical combination of factors that determine the outcome for the property in question (in this case vulnerability) and that have no common unit of measurement (Vogt et al., 2018). A composite indicator is not, therefore, an absolute measure of economic loss or damage to the society. The DVI outlined in this section of the GPG is a relative statistic, which, in the first instance, provides a snapshot of a Party's socio-economic vulnerability to drought for the reporting period. The vulnerability of a population is shaped continually by attitudinal, behavioural, cultural, socio-economic and political influences on individuals, families and communities within a country (UNISDR, 2004). Changes can, therefore, be expected in the value of the DVI over time. These may reflect the efficacy of national or regional drought mitigation and adaptation strategies and, in turn, help to inform future plans for tackling vulnerability. The DVI will also evolve through time due to a host of social and economic changes completely disconnected with drought management, and may be impacted by ecological changes that are not accounted for within the DVI (as explained above), so caution is needed in interpreting and attributing changes in the DVI.

In the following sections, the methodology and data sources selected to calculate the DVI are detailed, along with the rationale for using the approach and data sources. Guidance is provided on how individual country Parties can utilize their own datasets to enhance their assessments and progress through the tiers of VA, as well as outlining the limitations of the proposed approach.

3.2 Methodology

In this section, the recommended method for calculating the DVI for use in Level 3 Indicator reporting is described. In summary, it is a three-step process:

1. Normalization of individual factors per component (shown in Figure 17), as selected by a country Party for inclusion in the DVI;
2. Calculation of the social, economic and infrastructural components of vulnerability using the selected normalized factors; and
3. Calculation of the DVI using the arithmetic mean of the three components of vulnerability.

The UNCCD Secretariat, as directed under Decision 22/COP.11, will provide a global default dataset of drought vulnerability to Parties that do not have data available to calculate the minimum Tier 1 VA described in this GPG (Figure 15). These data are described in Section 3.3.2.

The first time the Level 3 Indicator is reported to UNCCD, DVI values should be calculated for the baseline period (i.e., 2000-2015) and any reporting periods that follow. Guidance on producing the baseline is provided in Section 3.2.4.

3.2.1 Step 1: Factor normalization

In all tiers of VA, factors should be normalized before they can be compared and aggregated, as the vulnerability factors used are all measured using different units.

The normalization method implemented here is based on Naumann et al. (2014). However, whilst Naumann et al. normalize data against all countries in the study, here it is recommended that data are normalized using the maximum and minimum values within the country Party using all historic data up to, and including, the reporting period. This provides the largest range possible, ensuring that the maximum and minimum values are representative for the country (or as representative as possible; true representativeness is dependent upon the number of data points available) and without Parties needing to obtain data for all countries – see Sections 3.4.3 and 3.5 for more information.

Each time the DVI is calculated to report the Level 3 Indicator, the factor range (i.e., the minimum and maximum values) used to normalize each respective factor should be recorded. If in future reporting periods the minimum or maximum factor value is outside of the range used in previous reporting processes, the factor should be re-normalized using the new range, and the DVI recalculated for the baseline period and any previous reporting periods (as described in Section 3.2.4) to ensure that the DVI is comparable over time.

Two equations are presented below to normalize the vulnerability factors depending on the correlation of the factor with vulnerability. Table 13 lists the 13 vulnerability factors recommended according to their relationship with vulnerability.

Table 13
Relationship of the 13 recommended factors with vulnerability
The minimum recommended factors for Tier 1 VA are highlighted in bold

Component	Factors with a positive correlation with vulnerability	Factors with a negative correlation with vulnerability
Social	Rural population (%) Refugee population (%)	**Literacy rate (% of people age 15+)** Life expectancy at birth (years) Population aged 15-64 (%) Government effectiveness
Economic	**Proportion of population below the international poverty line** Agriculture % of GDP	GDP per capita Energy consumption per capita
Infrastructure		**Proportion of population using safely managed drinking water services** Total renewable water resources per capita Cultivated area equipped for irrigation (%)

Where there is a positive correlation/relationship between vulnerability and the factor (i.e., if the factor value increases, vulnerability also increases) the data should be normalized using Equation 4. Where there is an inverse relationship/negative correlation between the factor and vulnerability, the data should be normalized using Equation 5.

$$Fact = \frac{X_i - X_{min}}{X_{max} - X_{min}}$$

Equation 4 Equation to normalize vulnerability factors with a positive relationship with vulnerability, where Fact is the normalized factor, X is the factor value for the current period i, and X_{min}/X_{max} is the historical minimum/ maximum value of the factor from the start of the data series up to and including the current reporting period.

$$Fact = 1 - \left(\frac{X_i - X_{min}}{X_{max} - X_{min}} \right)$$

Equation 5 Equation to normalize vulnerability factors that have a negative relationship with vulnerability, where Fact is the normalized factor, X is the factor value for the current period i, and X_{min}/X_{max} is the historical minimum/maximum value of the factor for the period from the start of the data series up to and including the current reporting period.

The normalization process (using either Equation 4 or Equation 5) means that all normalized factors (*Fact*) will have a value between zero and one and are relative to the historical maximum and minimum values within country *i* (the reporting Party).

3.2.1.1 Normalizing sex-disaggregated, sub-national and gridded data

For Tier 2 and 3 VAs it is recommended that sex-disaggregated factors are used (where applicable). Normalization of sex-disaggregated data should be done in the same way as for factors where only country-level data are available, i.e., one number for the whole country, where Equation 4 and Equation 5 are used for factors positively and negatively correlated to vulnerability, respectively. X_i will now be the current sex-specific factor value for the country, and X_{min} and X_{max} will be the corresponding minimum and maximum gender-specific historical values for the period from the start of the data series to the most recent date of data collection. *Fact* will then give the normalized factor for the specific sex.

For a Tier 3 VA assessment, normalization would follow the same process as already described above, but for each of the spatial units used (e.g. administrative level or grid cell, as applicable). In this case, X_i will be the current factor value for the spatial unit, and X_{min} and X_{max} are the minimum and maximum values across all spatial units up to and including the current reporting period. *Fact* will then give the normalized factor for the given spatial unit.

3.2.2 Step 2: Component derivation

If only one factor per component of vulnerability (i.e., social, economic and infrastructural) is used, which is the minimum Tier 1 VA, the normalized values derived in Step 1 provide the values for C_{social}, $C_{economic}$ and $C_{infrastructural}$, and Step 2 should be skipped.

Where more than one factor is used for each component, i.e., in the case of more extensive Tier 1, or Tier 2 and Tier 3 VAs, each component is calculated after each factor has been normalized. This is done by calculating the arithmetic mean of the normalized factors relevant for the given component, as shown in Equation 6.

$$C_i = \frac{(Fact_1 + Fact_2 + Fact_3 + ... + Fact_n)}{n}$$

Equation 6 Vulnerability component (C) calculation, where i is the component (social, economic or infrastructural), Fact is a factor used for calculation of component i, and n is the total number of factors used.

An example calculation of the economic component is shown in Equation 7. This equation sets out the method using all four vulnerability factors for the economic component (Figure 17). Parties should ensure that the sum of the factors is divided by the number of factors used in the calculation of each component.

$$C_{economic} = \frac{(GDP + Poverty + Energy + AgGDP)}{4}$$

Equation 7 Example calculation to calculate the economic vulnerability component using all the recommended economic vulnerability factors, where GDP is GDP per capita, Poverty is proportion of population below the international poverty line and AgGDP is Agriculture % of GDP.

3.2.2.1 Weighting of vulnerability factors and components

In this GPG, the factors are all given equal weighting. However, it is acknowledged that using equal weighting for factors, although the simplest method to apply, may not accurately reflect the importance of one factor over another for the particular conditions of a country. If a country Party knows which factors are most relevant to their situation or has the capacity to establish a weighting scheme, it is recommended that these weightings are applied to the selected vulnerability factors used in their calculations of the DVI (e.g. Meza et al., 2020), in order to most accurately represent their vulnerability to drought. See Section 3.4.4 for more details.

Weighting has not been applied to the three components of vulnerability in the methods described here. It is acknowledged that no perfect weighting or aggregation convention exists for such applications (e.g. Arrow, 2012; Naumann et al., 2014). This is discussed further in Sections 3.4.4 and 3.5.

3.2.2.2 Deriving components for sex-disaggregated, sub-national, and gridded data

When calculating the components (C_{social}, $C_{economic}$ and $C_{infrastructural}$) using a combination of sex-disaggregated and non-disaggregated factors, as will be the case for Tier 2 and 3 VAs, it is recommended that the country Party derive the component for the total population and each sex using the corresponding normalized factors. This would eventually lead to a DVI being calculated for each sex and the total population.

Where Parties use sub-national and gridded datasets for a Tier 3 VA, the normalized factors for each component would need to be overlaid (e.g. using GIS) so that values for each of the three components can be derived at the smallest common spatial scale using the methods outlined above. In the instance that data for a factor is not available at the smaller spatial resolution, normalized country-level data should be used.

3.2.3 Step 3: Calculating the Drought Vulnerability Index

In all tiers of VA, the three components (C_{social}, $C_{economic}$ and $C_{infrastructural}$) derived in the previous steps should be used to produce the Drought Vulnerability Index (DVI). The DVI is simply the mean of the three drought vulnerability components (Carrão et al., 2016), and is derived as shown in Equation 8.

$$DVI = \frac{(C_{social} + C_{economic} + C_{infrastructural})}{3}$$

Equation 8 Calculation of Drought Vulnerability Index (DVI) using social, economic and infrastructural components.

The DVI will range from a value of 0 to 1, with 1 being most vulnerable. A Tier 1 VA would result in one DVI at country-level, per reporting period. For Tier 2 and 3 VAs, country Parties would calculate more than one DVI, as explained in more detail in Section 3.2.3.1.

3.2.3.1 Deriving the DVI for sex-disaggregated and sub-national, and gridded data

For both Tier 2 and 3 VAs, where sex-disaggregated factors are used, it is recommended that sex specific DVIs are also calculated, in addition to the country-level DVI. Hence, a Party would report at least three DVI values for each reporting period, i.e., for the total, female and male populations. This level of assessment will provide specific information on which sex within the population is more vulnerable to drought. Over time, Parties would therefore be able to assess trends in vulnerability for each sex, as well as the total population, as outlined above.

For Tier 3 VAs where sub-national or gridded components have been derived, it is recommended that the DVI be calculated, as shown in Equation 8, for the smallest spatial unit used. The median DVI across the country for the reporting period should be reported to UNCCD. Parties could also use other summary statistics (such as the minimum, maximum and mean) to better understand the spatial variation and range of drought vulnerability within the country and over time.

For Tier 3 VAs, where sex-disaggregated data are available at the sub-national level or in gridded format, we recommend that country Parties derive DVI for separate sexes in addition to the population as a whole, at the smallest spatial scale used. DVI for each sex should be reported in tabular format using summary statistics as described above for each reporting period.

Spatial outputs should also be produced, at the spatial scale used (i.e., grid cell, administrative area etc.), to identify where the most vulnerable populations are located for the total population, and each sex individually. These outputs can be used to compare to the baseline period (as described in Section 3.2.4), as well as supporting targeted drought management and planning activities. The DVI for each spatial unit should be coloured using a continuous colour scale, whereby the colours are assigned to DVI values on a linear scale from one colour to another. There are many colour scales available;[48] however, Parties should endeavour to avoid colour scales that use red and green together (including 'rainbow' palettes) to ensure that those with colour blindness can interpret the maps (e.g. Crameri et al., 2020). A continuous colour scale from green to purple has been used in the Land Degradation (SDG 15.3.1, 2001-2015) visualization in Trends.Earth,[49] and as such it is recommended that Parties map the DVI using a similar scale from green (0, not vulnerable) to purple (1, most vulnerable) such as the example shown in Figure 18.

3.2.4 Calculating the Level 3 Indicator for the baseline period

This section describes how the baseline for the Level 3 Indicator should be established for the UNCCD baseline period of 2000-2015, in line with the reporting requirements for all strategic objectives included in the 2018-2030 Strategic Framework. Calculating the DVI values for the Level 3 Indicator reporting for this period will enable comparisons with future vulnerability assessments, thereby providing context for Parties to understand their drought vulnerability over time – i.e., whether it is decreasing, increasing, or staying stable over time, for the purposes of SO3 monitoring, as well as providing context for the other Strategic Objectives. Additionally, the baseline period can be used to verify the sensitivity of the DVI.

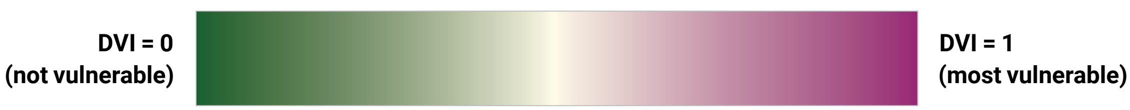


Figure 18

Example of a continuous colour scale that could be used for mapping Drought Vulnerability Index (DVI) values for a gridded spatial summary of a Tier 3 VA

[48] For example see the guidance and examples provided here: https://colorbrewer2.org/# and https://developers.arcgis.com/javascript/latest/visualization/best-practices/

[49] https://developers.arcgis.com/javascript/latest/visualization/best-practices/

The Level 3 Indicator baseline should be calculated the first time a Party includes Level 3 monitoring in national reporting to UNCCD.

There are some instances whereby the baseline period (and any previous reporting periods) may need to be recalculated to ensure that the DVI can be compared over time in order to monitor the Level 3 Indicator:

- When the maximum or minimum value of a factor change and the data are re-normalized;
- When improvements in capacity and/or data availability allow Parties to move up the tiers of VA, which changes the number of factors used in the DVI calculations; and
- When a different dataset is used (e.g. the data source changes and/or improves, or a dataset used previously is no longer available);
- If the methodology for deriving or reporting the Level 3 Indicator for SO3 monitoring changes in the future.

In these cases, the DVI should be recalculated from the baseline period to the current reporting period. All the recalculated DVIs should then be reported to UNCCD in addition to those for the current reporting period.

When the maximum or minimum value of a factor changes, the data should be re-normalized using the methods described in Section 3.2.1.1, the component recalculated using the methods in Section 3.2.2 and the DVI recalculated using the methods shown in Section 3.2.3.

Where factors are added as a Party moves up the tiers of VA, datasets should be selected with records that include the baseline period (i.e., 2000-2015) where possible.

It is recommended that the factors and datasets used for each component of the DVI, in addition to the ranges used to normalize each factor, are documented by country Parties to ensure that the DVI, and so the Level 3 Indicator, is comparable over time.

In order to calculate the baseline, the methodological steps outlined in Section 3.2 should be completed for each of the four-year intervals in the baseline period (i.e., 2000-2003, 2004-2007, 2008-2011 and 2012-2015) at the tier of VA most suitable for the Party (as discussed in Section 3.1); and in the case of a Tier 3 VA, the DVI should be mapped at the relevant spatial scale (see Section 3.2.3.1).

Calculating four DVI values over the baseline period also provides country Parties with the opportunity to verify the sensitivity of their DVI (and the factors used therein) against country data of socio-economic impacts of drought for the same period. This in turn enables a Party to adjust the combination of vulnerability factors they are using in their DVI calculations to better represent their overall vulnerability (see Section 3.5 and Appendix A for more information).

It is reiterated that any future changes in the datasets used will require recalculation of all DVIs from the baseline period onwards, as outlined above. Parties should endeavour to be thorough in their recording of changes to datasets and related assumptions when they either move up tiers of VA (and therefore use additional factors), and/or change datasets used in their DVI calculations. This is to ensure that when DVI values are considered over time, the interpretation of the trend in the degree of drought vulnerability for the country continues to be comparable.

3.3 Data sources

Figure 17 sets out the recommended vulnerability factors for each component that should be used to derive the Drought Vulnerability Index (DVI). The selection of these factors is further explained in Section 3.4.2.

The recommended data sources for each of these factors were selected based on them meeting three main criteria (Figure 19):

1. Be hosted by international organizations with a mandate for data collection, maintenance and regular update;
2. Be available for all countries (or, as many as possible); and
3. Be openly available.

This is in addition to those criteria set in Decision 11/COP.14 for harmonization/comparability, sensitivity, readiness, disaggregation by sex and adaptability (see Figure 2). Where possible, datasets that are already being collected and used for existing reporting activities were prioritized (Table 14).

By introducing the tiers of VA (Figure 15), Parties can choose the best path to calculate their DVI based on the data they have access to (Figure 16). This system promotes 'sensitivity' and 'adaptability' for country Parties, whilst encouraging improvements in 'comparability' and 'readiness' in line with criteria set in Decision 11/COP.14.

Tier 1 and Tier 2 VAs, which require country level statistics, are more readily available via the World Bank Open Data database and the FAO Aquastat database. However, globally available data for Tier 3 VA are limited and, as such, Parties should explore the availability of in-country (or regional) data, which enable sub-national, sex-disaggregated vulnerability assessments.

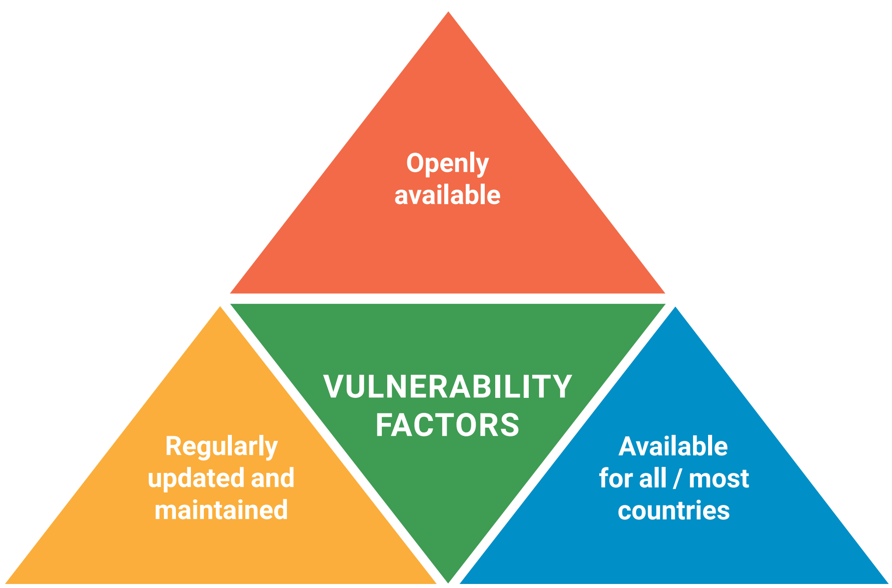
The Tier 1 VA requires a minimum of three factors, one for each component of vulnerability. The recommended factors for the minimum Tier 1 VA were chosen due to their use in the majority of the scientific literature (Table 15) and use for other reporting requirements such as Strategic Objective 2 (SO2) and SDGs, and are as follows:

- Social: Literacy rate (per cent of people age 15 and above), a version of this metric is used for SDG indicator 4.6.1 reporting;
- Economic: Proportion of population below the international poverty line, which is used in both SDG indicator 1.1.1. and SO2 reporting; and
- Infrastructure: Proportion of population using safely managed drinking water services, which is used in both the SDG Indicator 6.1.1 and SO2 reporting.

Figure 19

Three main criteria used for the selection of datasets for each vulnerability factor

Where possible, datasets that are already being used for existing reporting activities were prioritized



This simple approach acknowledges the practical challenges of access to data, analysis and reporting to the UNCCD for SO3 monitoring. However, recognizing the complexity of vulnerability, and the interplay between adaptive capacity and coping capacity, no one factor can truly represent societies' vulnerability to drought. Numerous papers in the scientific literature have used anywhere between 15 (Carrão et al., 2016) and 64 (Blauhut et al., 2016) factors for their global/ regional assessments of drought vulnerability. The 13 factors introduced in (Figure 17), and further elaborated on in Table 14, have been used in global scientific studies, and, as such, it is recommended that they should all be used where possible for a more comprehensive assessment of vulnerability under each tier of VA, as described in Section 3.2. Where Parties have more informative or applicable datasets to their own circumstances, these are recommended as long as they meet the criteria specified in Section 3.3.1. For Tier 3 VA, however, many of the datasets in Table 14 are not suitable as they are not available at the subnational scale. Globally available datasets with potential for Tier 3 VA monitoring are described in Pricope et al. (2020). However, as many are not maintained and/or updated regularly, they are not currently recommended for Tier 3 VA, and, as such, in-country data may be more appropriate.

3.3.1 Use of national/regional data products

Table 14 highlights potential datasets for the calculation of the components needed to derive the DVI. These data are freely available with an extensive global coverage. Where a country Party has access to in-country data with fewer gaps and a larger historic range that can work as a close proxy for a recommended dataset, then these should be used. In addition, country Parties are encouraged to use their own/region-specific datasets, which offer higher spatial resolution and validation at the local level. As such, these data may offer a more comprehensive assessment of vulnerability, providing a better representation of the socio-economic situation within the country, and reducing uncertainty associated with global data, and increasing confidence in the outputs produced (Mondal and Tatem, 2012).

Table 14

Complete list of recommended vulnerability factors to calculate the DVI at country-level

The minimum recommended factors for Tier 1 VA are highlighted with an asterisk (*). Taken together the factors listed here are recommended for an extensive Tier 1 VA (without gender disaggregation) and for Tier 2 VA

Factor	Unit	Sex-disaggregated data available for Tier 2 and 3 VAs	Data Source	Notes
Social				
***Literacy rate, adult total, adult female, adult male (% age 15+)**	%	Yes	World Bank Open Data [50, 51, 52]	Alternative dataset: SDG Indicator 4.6.1 [53]
Rural population (% of total population)	%	No	FAO Aquastat[54]	Available in the FAO Aquastat database[55]
Life expectancy at birth (total, male and female, in years)	Years	Yes	World Bank Open Data[56, 57, 58]	
Population aged 15-64 (% of total population)	%	Yes	World Bank Open Data[59, 60, 61]	The proportion of the population aged 15-64 should be derived using the total population[62] (or total male[63]/female[64] population where sex-disaggregated data are being used).[65]
Government effectiveness	-2.5 (weak governance) to 2.5 (strong governance)	No	Worldwide Governance Indicators[66]	Alternative dataset: SDG indicator 16.6.1[67]
Refugee population (%, by country or territory of asylum) of total population	%	No	World Bank Open Data[68]	Refugee population is available via the World Bank Open Data database. Refugee population as a % of the total population should be calculated using the total population[69, 65]

50 Literacy rate, adult total: https://data.worldbank.org/indicator/SE.ADT.LITR.ZS
51 Literacy rate, adult male: https://data.worldbank.org/indicator/SE.ADT.LITR.MA.ZS
52 Literacy rate, adult female: https://data.worldbank.org/indicator/SE.ADT.LITR.FE.ZS
53 https://unstats.un.org/sdgs/metadata/files/Metadata-04-06-01.pdf
54 http://www.fao.org/nr/water/aquastat/data/query
55 http://www.fao.org/faoterm/en/?defaultCollId=7 [Collection: FAOTERM, Entry: 56112]
56 Life expectancy at birth, total (years): https://data.worldbank.org/indicator/SP.DYN.LE00.IN
57 Life expectancy at birth, male (years): https://data.worldbank.org/indicator/SP.DYN.LE00.MA.IN
58 Life expectancy at birth, female (years): https://data.worldbank.org/indicator/SP.DYN.LE00.FE.IN
59 Population aged 15-64, total: https://data.worldbank.org/indicator/SP.POP.1564.TO
60 Population aged 15-64, male: https://data.worldbank.org/indicator/SP.POP.1564.MA.IN
61 Population aged 15-64, female: https://data.worldbank.org/indicator/SP.POP.1564.FE.IN
62 https://data.worldbank.org/indicator/SP.POP.TOTL
63 https://data.worldbank.org/indicator/SP.POP.TOTL.MA.IN
64 https://data.worldbank.org/indicator/SP.POP.TOTL.FE.IN
65 The World Population Prospects (UNWPP) population datasets can also be used directly, though World Bank data are sourced from UNWPP as well as other country and regional sources; https://population.un.org/wpp/Download/Standard/Population/
66 https://info.worldbank.org/governance/wgi/
67 https://unstats.un.org/sdgs/metadata/files/Metadata-16-06-01.pdf
68 https://data.worldbank.org/indicator/SM.POP.REFG
69 % refugee pop= ((total refugee population)/(total population)) ×100

Table 14 continued

Complete list of recommended vulnerability factors to calculate the DVI at country-level

The minimum recommended factors for Tier 1 VA are highlighted with an asterisk (*). Taken together the factors listed here are recommended for an extensive Tier 1 VA (without gender disaggregation) and for Tier 2 VA

Factor	Unit	Sex-disaggregated data available for Tier 2 and 3 VAs	Data Source	Notes
Economic				
***Proportion of population below the international poverty line**	% of total population	No	World Bank Open Data[70]	SDG indicator 1.1.1[71] Sex-disaggregation possible and recommended: Alternative: income inequality as outlined in the UNCCD reporting process for SO2 Indicator 1[72]
GDP per capita (constant 2010 US$)	2010 US$	No	World Bank Open Data[73]	Alternative dataset: SDG indicator 8.1.1[74]
Agriculture % of GDP (Agriculture, value added)	% of GDP	No	FAO Aquastat[54]	Available in the FAO Aquastat database[75]
Energy use (kg of oil equivalent per capita)	Kg per capita	No	World Bank Open Data[76]	Note that total energy consumption[77] (in quad Btu[78]) is available via the Environmental Impact Assessment (EIA). This could be converted to a per capita energy use by dividing by the total population.[65]
Infrastructure				
***Proportion of population using safely managed drinking water services**	%	Yes	Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP)[79]	This is SDG Indicator 6.1.1. Disaggregation by place of residence (urban/rural) and socioeconomic status (wealth, affordability) is possible for all countries. Disaggregation by other stratifiers of inequality (subnational, sex, disadvantaged groups, etc.) available only where data permit.[80]
Cultivated area equipped for irrigation (%)	%	No	FAO Aquastat[54]	Calculated by dividing the area equipped for irrigation[81] by the cultivated area[82]
Total renewable water resources per capita	m^3/inhabitants/year	No	FAO Aquastat[54]	Available in the FAO Aquastat database[83]

70 https://data.worldbank.org/indicator/SI.POV.DDAY
71 https://unstats.un.org/sdgs/metadata/files/Metadata-01-01-01a.pdf
72 https://prais.unccd.int/node/7
73 https://data.worldbank.org/indicator/NY.GDP.PCAP.CD
74 https://unstats.un.org/sdgs/metadata/files/Metadata-08-01-01.pdf
75 http://www.fao.org/faoterm/en/?defaultCollId=7 [Collection: Organic agriculture Entry: 99393]
76 https://data.worldbank.org/indicator/EG.USE.PCAP.KG.OE
77 Total energy consumption includes consumption of petroleum, dry natural gas, coal, net nuclear, and hydroelectric and non-hydroelectric renewable electricity. It accounts for energy imports and exports; https://www.eia.gov/international/data/world/total-energy/total-energy-consumption.
78 Quadrillion British thermal units (quad Btu; https://www.eia.gov/energyexplained/units-and-calculators/british-thermal-units.php)
79 https://washdata.org/data
80 https://unstats.un.org/sdgs/metadata/files/Metadata-06-01-01.pdf
81 http://www.fao.org/faoterm/en/?defaultCollId=7 [Collection: Water, Entry: 100468]
82 http://www.fao.org/faoterm/en/?defaultCollId=7 [Collection: FAOTERM, Entry: 22510]
83 http://www.fao.org/faoterm/en/?defaultCollId=7 [Collection: Water, Entry: 100429]

However, if using in-country datasets to calculate the DVI, these datasets should meet several basic criteria in order to ensure consistency in quality across reporting Parties and over time.

1. Data need to be given in the units specified in Table 14, or allow for conversion to these units. This ensures that indicators remain generic and valid for all country Parties.

2. Data need to have a relevant temporal range and resolution, including a historical period in which to calculate the baseline DVI, and normalize against.

3. Methods and data sources need to be documented and validated, with a clear methodology of how these data are derived and the calculations used to produce the final figures for each dataset.

4. Data need to have an adequate update frequency relevant to the dataset and the reporting period, ensuring the option to use a similarly derived dataset for future reporting years.

5. Where relevant, data should be able to be disaggregated by sex.

6. For datasets that are at higher spatial resolution, these data:

    - Where possible, should be at a sub-national resolution, at a spatial disaggregation that is policy relevant and actionable (Sims et al., 2021; Pricope et al., 2020); and

    - Should be spatially complete, covering the full geographic extent of the reporting country Party, with limited missing data entries.

3.3.2 Default global data product

Where country Parties do not have data available to calculate the minimum Tier 1 VA described in this GPG (Figure 16), the UNCCD Secretariat, as directed under Decision 22/COP.11, will provide a global default dataset of drought vulnerability to Parties for the baseline and first reporting period. The global DVI has been produced by the European Commission (EC) Joint Research Centre (JRC) and is based on the methodology in Carrão et al. (2016).

The global DVI dataset can be viewed in the UNCCD Drought Toolbox, which was developed following a request at COP 13 to support drought stakeholders to design National Drought Policy Plans.[84] The Drought Toolbox has three modules, one of which covers drought vulnerability and risk assessment[85] and includes the Drought Risk Assessment Visualization Tool.[86] This tool hosts the pre-calculated DVI dataset. The tool combines global drought hazard, exposure, vulnerability and risk data for the period 2000-2018. All of the data are provided by the JRC. The current DVI dataset displayed in the Drought Toolbox is shown in Figure 20 and was calculated using 15 vulnerability factors as described in Carrão et al. (2016).

The method used to derive the pre-calculated DVI in the Toolbox was drawn upon for the calculation of the Level 3 Indicator in this GPG, and there are some key differences in terms of the normalization method and number of factors included.

The equations used for factor normalization used in the Toolbox are the same as those used in Section 3.2.1. However, for the pre-calculated DVI, each factor was normalized using the global maximum and minimum values, whereas the recommended normalization method in this GPG is carried out using the period of record data for each factor for the given country. The normalization at the global scale, as used in the pre-calculated DVI, means the resulting vulnerability assessment is less sensitive to the local/in-country situation than when the national range is used, as described in Section 3.4.3.

The datasets used in the pre-calculated DVI are the same as those recommended in this GPG, except for two factors. The Toolbox includes 'Disaster Prevention & Preparedness (US$/Year/Capital)' and 'Global map of Accessibility: Travel time to major cities', which are not included in this GPG; as explained in Section 3.4.2.

84 https://knowledge.unccd.int/drought-toolbox/page/about-drought-toolbox

85 https://knowledge.unccd.int/drought-toolbox/page/vulnerability-and-risk-assessment

86 https://maps.unccd.int/drought/

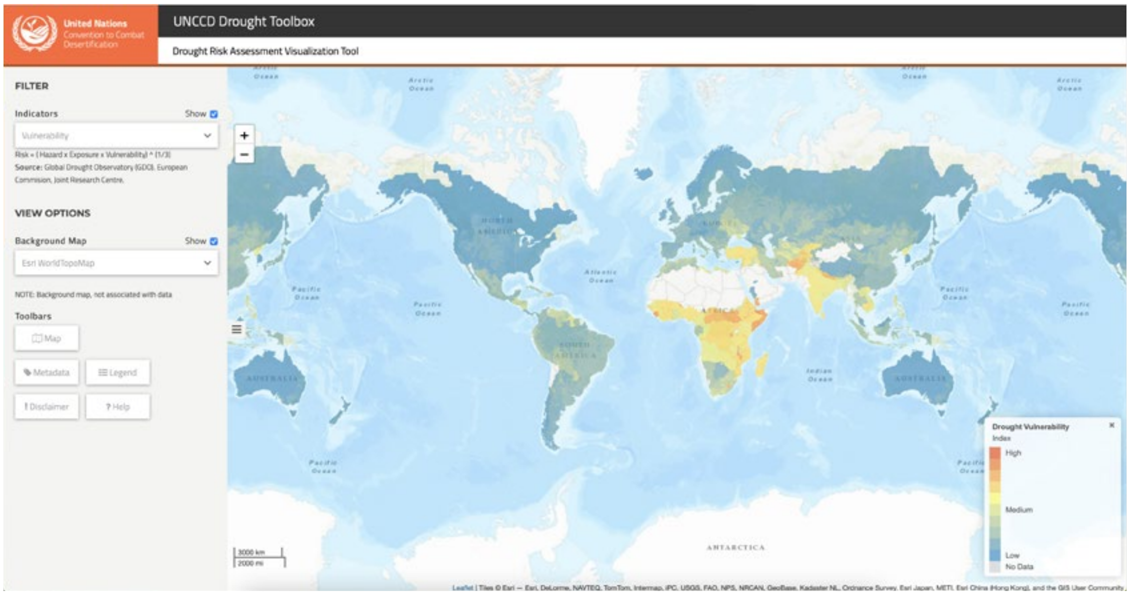


Figure 20

The UNCCD Drought Toolbox Drought Risk Visualization Tool

Country Parties will be given the option to use the pre-calculated DVI from the Drought Toolbox or calculate the DVI using the methodology described in this GPG using global or in-country datasets. Where the pre-calculated DVI is used, Parties would report the same set of values for the baseline period and first reporting period.

Where the default DVI data are used for Level 3 Indicator reporting, the median DVI across the country should be reported to UNCCD for Level 3 reporting. Note that this will be the median DVI for the whole period 2000-2018, i.e., combining the baseline period and the first reporting period. Parties could also use other summary statistics (such as the minimum, maximum and mean) to better understand the spatial variation and range of drought vulnerability within the country and over time.

The pre-calculated DVI is currently a static dataset for the period 2000-2018. There is a planned update later in 2021, which could be used in national reporting of the Level 3 Indicator in future reporting processes. However, it is recommended that efforts are made over successive reporting processes to move up the tiers of VA, as outlined in Section 3.2. In this case, the DVI for the baseline period and the first reporting period should be recalculated using the selected tier of VA to ensure DVI values are comparable and the trend in the degree of vulnerability can be assessed as described in Section 3.2.4.

3.4 Rationale and interpretation

3.4.1 Rationale for using DVI methodology

Decision 11/COP.14 sets out that the Level 3 Indicator should be a 'composite index of relevant economic, social, physical and environmental factors that contribute to drought vulnerability'.

Within the literature there are a number of approaches in quantifying vulnerability at various spatial and temporal scales (e.g. see the recent reviews of Hagenlocher et al., 2019 and Blauhut, 2020). Naumann et al. (2014) propose a composite DVI at the Pan-African level, where the multidimensional concept of vulnerability is divided into different subgroups or components, these being renewable natural capital, economic capacity, human and civic resources, and infrastructure and technology. Within these components are 17 representative variables, with Naumann et al. assuming that a society with institutional capacity and coordination, as well as with mechanisms for public participation, is less vulnerable to drought. The definition of the components is based on the relevance of each indicator (variable/factor) for policy development and the entire statistical structure of the data set.

This methodology was further developed by Carrão et al. (2016), where a framework is proposed for mapping drought risk at the global scale. The study sets out three components of social, economic, and infrastructure factors of a region. Carrão et al. state that the indicator within these component groups must represent a quantitative or qualitative aspect of vulnerability factors to drought (generic or specific to some exposed element), and public data need to be freely available at the global scale, ensuring that the final result can be validated, reproduced, and improved with new data.

Work by Meza et al. (2020) develops an integrated assessment of drought risk for irrigated and agricultural systems at the global scale, where vulnerability is assessed through a socioecological-system perspective, using socioecological susceptibility and lack of coping-capacity indicators. This essentially builds upon the work of Carrão et al. (2016) by tailoring the vulnerability index towards regions where agriculture is more prominent, and, as such, more vulnerable to drought.

For this GPG, a methodology that had been validated and evaluated was required. The framework of the method also needed to facilitate flexibility within the use and number of factors, allowing for a more tailored approach where data are not available or suitable for assessment, as reflected in the recommended tier of VA approach (see Section 3.2).

The framework set out by Carrão et al. (2016) was chosen as it meets these criteria. This framework also follows that proposed by UNISDR (2004) for drought vulnerability; that is, a reflection of the state of the individual and collective social, economic and infrastructure factors of a region at hand, in terms of their ability to cope with and/or reduce impacts of droughts. As such, the methodology takes a global approach that uses high-level factors of social, economic and infrastructural indicators, collected at both the national and sub-national levels. Multiple facets of vulnerability are included that reflect short- and long-term adaptive capacity, which it was felt should be reflected in the vulnerability factors used to derive the DVI.

It is important to note that vulnerability depends on the context of the analysis, and the factors that make a system vulnerable to a natural hazard will depend on the nature of the system and the type of hazard in question (Cutter et al., 2003). Knowing the most commonly used vulnerability factors is important in the construction of common drought vulnerability datasets (González Tánago et al., 2016) and the use of the same set of factors by Naumann et al. (2014) and Carrão et al. (2016) is the starting point from which we base the methodology presented here. This framework, however, also allows for a degree of flexibility, with the option of adding or removing factors within components, based upon their availability and relevance in assessing vulnerability for the country Party (Naumann et al., 2014; Meza et al., 2020). The additional factors (i.e., for extensive Tier 1, Tier 2 and Tier 3 VAs) were selected on the basis of their use in the scientific literature (Table 15), if they were considered critical to understanding vulnerability by experts (Meza et al., 2019) or their inclusion in the report by Pricope et al. (2020). Table 15 lists the recommended factors against the publications in which they were used, or cited as important. The approach recommended in this GPG may also allow for the addition of an ecosystem component for a more integrated assessment in future, which is discussed further in Appendix A.

Table 15

Review of factors used in previous drought risk and vulnerability assessment studies (including reports and scientific studies).*

Factor	Carrão et al. (2016)	Naumann et al. (2014)	Meza et al. (2020)	Blauhut et al. (2016)	Crossman (2019)*	Pricope et al. (2020)*	Meza et al. (2019)*
Focus of study	Global	Africa	Agriculture systems	Europe		SO3 monitoring	Agriculture systems and water supply
Social							
Literacy rate (% age 15 above)	✓	✓	✓	✓ (education)	✓	✓	✓
Rural population (%)	✓		✓		✓		✓
Life expectancy at birth	✓			✓ (human health and public safety)	✓	✓	✓ (agriculture systems only)
Population ages 15-64 (% of total population)	✓	✓	✓	✓ (population age)	✓	✓	✓
Government effectiveness	✓	✓	✓		✓	✓	✓
Refugee population country/ territory of asylum (%)	✓	✓			✓	✓	✓ (water supply only)
Economic							
Proportion of population below the international poverty line	✓ ($1.25/day)	✓ ($1.25/day)	✓ (national poverty line)	✓ (economic wealth and low wage earning)	✓	✓ (MPI/DHS Wealth[a])	✓ (national poverty line)
GDP per capita (US$)	✓	✓	✓	✓	✓	✓	✓
Agriculture, value added (%)	✓ (% of GDP)	✓			✓ (% of GDP)		✓ (% of GDP)
Energy use (kg of oil equivalent per capita)	✓	✓	✓ (electricity production from hydropower)		✓		✓ (water supply: electricity production from hydropower)

Table 15 continued

Review of factors used in previous drought risk and vulnerability assessment studies (including reports and scientific studies).*

Factor	Carrão et al. (2016)	Naumann et al. (2014)	Meza et al. (2020)	Blauhut et al. (2016)	Crossman (2019)*	Pricope et al. (2020)*	Meza et al. (2019)*
Infrastructure							
Proportion of population using safely managed drinking water services	✓ (% rural population with access to improved water source)	✓ (population without access to improved water)	✓ (improved water sources)	✓ (multiple datasets87)	✓	✓ (population using safely managed drinking water services)	✓ (population without access to clean water)
Cultivated area equipped for irrigation (%)	✓ (agricultural and irrigated land)	✓		✓ (irrigation by country)	✓	✓	✓
Total renewable water per capita	✓ (retained renewable water)		✓	✓ (multiple datasets)[87]	✓		✓ (% retained water)

[a] **Multidimensional Poverty Index (MPI)** is a score composed of three dimensions: health, education and living standards to assess multidimensional poverty at the individual level, where deprivation instead of possession is measured. The MPI was developed by Alkire and Santos (2014). **Demographic Health Surveys (DHS) Wealth Index** is a composite measure of a household's cumulative living standard, based on data collected in DHS household questionnaire, on assets.[88]

3.4.2 Rationale for choice of vulnerability factors

The requirement for the Drought Vulnerability Index (DVI) is that it "score highest on 'Sensitivity' and ... (has) the greatest capacity for 'Gender disaggregation'" (ICCD/COP(14)/CST/7). Being a composite indicator, this implies that the factors chosen would need to score similarly to enable the end-product, the DVI, to be of use to countries and to work towards SO3: "to mitigate, adapt to, and manage the effects of drought in order to enhance resilience of vulnerable populations (and ecosystems)", and more specifically, in the case of this GPG, realize "Expected impact 3.2: Communities' resilience to drought is increased".

Due to the practical challenges of implementing this approach for regular analysis and reporting to the UNCCD for SO3 monitoring, a minimum of three factors – one representing each of the three components (social, economic and infrastructural) – have been recommended as the starting point to developing the Index. It is therefore important that the 'Adaptability' criteria be applied in the near future to ensure that the indicator is "re-evaluated for appropriateness as monitoring and evaluation efforts mature, for [its] usefulness in decision-making, and because needs may change and scientific tools improve" (ICCD/COP(14)/CST/7).

The three core factors that have been presented for the minimum Tier 1 VA: Literacy rate (% of people age 15 and above), Proportion of population below the international poverty line and the Proportion of population using safely managed drinking water services were selected because they were identified by experts as critical to understanding vulnerability in agricultural systems and water supply (Meza et al., 2019) and they have been used in the scientific literature for global and regional vulnerability studies (e.g. Naumann et al., 2014; Blauhut et al., 2016; Carrão et al., 2016; Meza et al., 2020; see Table 15). These data are also openly available to country Parties (Table 14), the two latter datasets are used for other reporting purposes, and all the datasets are hosted by organizations/institutions with a mandate to collect, maintain and update the data regularly.

[87] For example, used multiple datasets to characterize this vulnerability factor.

[88] https://dhsprogram.com/topics/wealth-index/Wealth-Index-Construction.cfm

The recommended Tier 1 VA economic factor is the Proportion of population below the international poverty line, which estimates the proportion of the population (%) living on less than $1.90 a day at 2011 international prices. It is the SDG 1.1.1 indicator and is also used for SO2 reporting. People living in poverty are more likely to live in areas and under conditions that increase their exposure and make them more susceptible to suffering from the impact of natural hazards, while decreasing their coping and adaptation capacities (Hagenlocher et al., 2019 supplementary information 3; Winsemius et al., 2018). Hence, this factor is positively correlated with vulnerability, since by combating poverty, the vulnerability of the population in general, and to drought, can be reduced. This indicator provides fundamental information for the elaboration of risk reduction and disaster management strategies (Hagenlocher et al., 2019; supplementary information 3). The recommended Tier 1 VA social factor, literacy rate (% of people age 15 and above), is the percentage of people ages 15 and above who can both read and write, and understand, a short simple statement about their everyday life. The accumulated achievement of education is fundamental for further intellectual growth, and social and economic development. The term 'literate women' implies that women can seek and use information for the betterment of the health, nutrition and education of themselves and their household members, and are empowered to play a meaningful role.[89] As such, this factor displays a negative correlation with the vulnerability of the population, as a populace with a higher literacy rate would be better equipped to cope with drought and implement drought mitigation and adaptation strategies. Finally, the recommended Tier 1 VA infrastructural factor, proportion of population using safely managed drinking water services, is SDG indicator 6.1.1, which reports the proportion of a country's population that has access to water that is free of faecal contamination, is sourced from taps and standpipes, groundwater extraction, protected springs, and/or packaged water, delivered water and rainwater, and is available when needed. The higher the value of this variable, the more people are being provided with safe water, which in turn, supports child survival, maternal and child health, family wellbeing and economic productivity. This variable is, therefore, negatively correlated to vulnerability, and continuing efforts to improve on this SDG indicator will directly improve the resilience and coping capacity of the population to drought.

Taken together, these factors, which represent economic, social and infrastructure components within the DVI proposed in this GPG, will provide a highly simplified snapshot of a country's socio-economic vulnerability over time. The 'sensitivity' of a minimum Tier 1 VA to reflect trends in the degree of vulnerability of the country and the efficacy of national or regional vulnerability mitigation and adaptation planning over time will be limited for two main reasons. First, due to the methodology proposed, the components (which will each comprise of one factor) will be equally weighted by default and, as such, a factor dataset with a small range will have a substantial influence on the component calculation and the resulting DVI. Second, the use of only three factors has not been scientifically validated. Hence, it is recommended that country Parties strive towards a more extensive Tier 1 VA, or, better still, move to Tier 2 or Tier 3 VAs, which have been validated in the scientific literature (Naumann et al., 2014; Carrão et al., 2016; Meza et al., 2020). The remaining ten vulnerability factors[90] and their relevance to drought vulnerability are outlined in the Definitions section of this GPG.

The selection of vulnerability factors included in this GPG was informed by Carrão et al. (2016). However, not all the vulnerability factors included in Carrão et al. were used here, the reasons for which are outlined following here:

89 https://data.worldbank.org/indicator/SE.ADT.LITR.ZS

90 i.e. % Rural population, Life expectancy at birth, % Population aged 15-64, Government effectiveness, % Refugee population, GDP per capita, Agriculture % of GDP, Energy consumption per capita, Total renewable water resources per capita, % Cultivated are equipped for irrigation.

- Road density (km of road per 100 sq. km of land area) was used as an infrastructure factor of vulnerability in Carrão et al. The Global Roads Open Access Data Set (gROADS), v1 (1980 2010),[91] GRIP global roads database,[92] or open Street Map data provide the length of roads in countries, but was not considered for inclusion here for two reasons:
    - It was not used in other studies, for example those in Table 15; and
    - The methodology to derive this information for a country, or sub-nationally, is challenging.
- Disaster prevention and preparedness (US$/year/capita) was used as a social factor of vulnerability. It is the amount of funding that a country reserves annually to prepare for and prevent disasters, including, but not specifically related to, droughts. Though it has been recommended in some of the papers cited in Table 15, the dataset is no longer available through the OECD as previously used (which also had issues of data coverage in the global context, only being relevant for OECD countries). Broadly equivalent data may be available on the EM-DAT International Disaster Database, but it is not currently systematized in the same way.[93] The use of SDG Indicator 1.5.2[94] could be used if drought-specific information could be separated from the total economic losses. However, estimating economic losses due to drought can be problematic (UNISDR, 2017), and the ease with which drought-specific reporting can be introduced would need to explored and validated.

3.4.3 Rationale for normalization methodology

The normalization of vulnerability factors is done using historical data ranges taken from the reporting country Party only. This differs from the approach taken by Naumann et al. (2014) and Carrão et al. (2016), where the values are normalized against a 'global' or 'regional' range. The departure from these scientifically reported methods was necessitated by the fact that country Parties would not have ready access to global or regional datasets against which to normalize over successive reporting periods, and no other normalization techniques recommended for development of indices (OECD and JRC, 2008) were considered suitable for the application in this GPG. Another issue with the 'global' normalization approach is the use of a larger geographical extent or region. The nature of the vulnerability factors means that some countries are more sensitive to certain factors than others. As such, defining a set of geographical boundaries based upon a commonality between countries adds a further element of subjectivity to the method, along with the issue of comparative value between these geographical regions, which in some cases will be minimal.

3.4.4 Rationale for type of weightings applied to vulnerability factors and components

Previous studies of drought or other hazard vulnerability have weighted vulnerability factors according to their contribution to overall vulnerability. However as explained in Section 3.2.2.1, no weighting is applied to individual vulnerability factors in this GPG for the DVI: all factors have equal weight. Using equal weighting for factors is the simplest method to apply, though may not accurately reflect a countries' vulnerability to drought (Crossman, 2019); this is further discussed in Section 3.5. However, the choice here to apply equal weights to factors is based on the lack of agreed methods/conventions to weight factors (Naumann et al., 2014) or a globally available dataset of factor weightings.

Similarly, no weights were applied to components due to the lack of an agreed weighting or aggregation convention (e.g. Arrow, 2012; Naumann et al., 2014). As weighting of components has a direct impact on the value of the DVI, this process needs to be informed by the importance of each component to the country Party in question. As such, taking in to account the purposes of this GPG, the methodology here specifies the use of equally weighted components.

[91] https://sedac.ciesin.columbia.edu/data/set/groads-global-roads-open-access-v1
[92] https://www.globio.info/download-grip-dataset
[93] https://www.emdat.be/
[94] https://unstats.un.org/sdgs/metadata?Text=&Goal=1&Target=1.5

3.4.5 Interpreting output DVI

The composite DVI used for SO3 monitoring here provides an indication of whether countries are more vulnerable (high DVI=1 value) or less vulnerable (low DVI=0 value). Due to the methods used for factor normalization (i.e., using in-country historic data), DVI values should not be compared between countries.

Individual, normalized vulnerability factors and/or social, economic and infrastructural components can be evaluated by country Parties, to identify the root of their vulnerability to drought. Extensive Tier 1 and Tier 2 VAs offer an advantage over the minimum Tier 1 VA in this case, providing more context to vulnerability assessments and helping with targeting of mitigation and adaption plans. The Tier 2 VA can provide gender disaggregated vulnerability assessments that are critical to identifying disparities between gender classes. The Tier 3 VA can provide additional sensitivity by highlighting vulnerability hotspots (spatially and by gender class where applicable) within a country, meaning mitigation and management activities (e.g. King-Okumu, in preparation) can be targeted to those most vulnerable, and when considered with the Level 2 Indicator, most exposed to drought.

The DVI values used for Level 3 Indicator reporting for the baseline provide a record of past vulnerability to drought against which future vulnerability can be compared, enabling Parties to assess whether the degree of vulnerability has increased, decreased or remained the same over time. For extensive Tier 1, Tier 2 and Tier 3 VAs, it may be possible to see if any mitigation or policy changes have reduced overall vulnerability to drought during the same period. Note that if using the global default data described in Section 3.3.2, only the median DVI value for the period 2000-2018 as a whole is reported, meaning it will not be possible to assess change in vulnerability between the baseline period and first reporting period.

3.5 Comments and limitations

The DVI proposed in this GPG has been derived using methodologies and global datasets that have been verified and validated for the geographical scales at which they were applied (Naumann et al., 2014; Carrão et al., 2016; Vogt et al., 2018). However, this method has not yet been validated at the local or national scale, and, as such, may not accurately characterize vulnerability at these scales, either in terms of the factors that are most relevant to each country or the most effective factor weighting scheme. As outlined by González Tánago et al. (2016), and later by Blauhut (2020), there are still areas around the globe where drought vulnerability and risk assessments have yet to be done.

As discussed in Section 3.4.3, the method of normalization that has been proposed is appropriate for within-country comparison, so that over time the trend in the relative degree of drought vulnerability for the country can be assessed, and progress towards achieving SO3 can be determined for the country Party. Comparisons should not be made between countries at regional or global levels, because the factors have not been normalized using the same range of data. In addition to this, where the range of data used for normalizing factors is small (perhaps due to missing or short records of data), there is the potential for small changes in the dataset over time to cause large changes in the DVI, which is especially problematic for minimum the Tier 1 VA where only one factor per component is used to calculate the DVI value. Therefore, Parties who need to start at the minimum Tier 1 VA are advised to use datasets with large data ranges.

Another point to consider is the distribution of the factor data. Ideally, data for each factor should be normally distributed (i.e., have a Gaussian distribution) across its range for use in the normalization method described in Section 3.2.1. However, transforming data to fit a normal distribution prior to the normalization step was not included in this GPG. This was because an understanding of the characteristics of a factor's data distribution (which could vary according to each factor and for each country) is required in order for a suitable method of transformation to be chosen. However, where capacity exists, Parties may choose to transform the distribution of data for each factor (where appropriate) to a normal distribution, before following the steps outlined in Section 3.2.1 to normalize factor data. Statistical tests can be used to summarize the distribution of each factor, and, following this, a suitable transformation can be applied. See, for example, Heumann et al. (2016), the R programming language 'bestNormalize' package and accompanying documentation[95] or other online materials[96] for examples of appropriate methods for the characterization and transformation of data.

As explained in Section 3.3, the factors that are available to calculate the DVI vary in availability, periodicity and geographical range. There may still be some country Parties that are unable to access all the factors recommended here (Table 14) or find similar metrics, which is why the tiers of VA allow flexibility in the number and combination of vulnerability factors. However, the 'sensitivity' of the DVI to SO3 monitoring, as defined in ICCD/COP(14)/CST/7, will be lowest for a minimum Tier 1 VA (i.e., with one vulnerability factor per component). Where Parties need to use the default global DVI data, as described in Section 3.3.2, their ability to compare their DVI values over time will be affected if they decide to revert to the datasets that are either recommended in this GPG or to proxies in future reporting processes. Recalculation of all DVI values from the baseline period onwards will then be required. In addition, Parties may find that the global DVI estimation is less sensitive in assessing the local conditions than if the DVI were calculated using country-level data and the methodology recommended in this GPG.

It is important to reiterate that no weighting was given to vulnerability components, as explained in Section 3.2.2.1 and Section 3.4.4. This decision was made because any weighting will affect the final DVI value for the country, and the importance of each component will vary from country to country. The purpose of this GPG is to provide a DVI methodology that is suitable for SO3 reporting across all countries and at present there is no consistent approach to weighting components in the scientific literature (e.g. Naumann et al., 2014; Carrão et al., 2016; Hagenlocher et al., 2018; Meza et al., 2020).

To further improve 'sensitivity' of the DVI to SO3, incorporation of one or more of the following suggestions could be considered:

95 https://cran.r-project.org/web/packages/bestNormalize/vignettes/bestNormalize.html

96 e.g. https://www.openintro.org/book/os/

1. **Follow the progression through the tiers of Vulnerability Assessment presented in Section 3.2.** If available, the use of local, gridded datasets, comparable to broader datasets and which are better able to capture local patterns or variability across geographies, sectors and populations so that hotspots of vulnerability can be identified, is recommended (Naumann et al., 2014; Vogt et al., 2018; Crossman, 2019; Pricope et al., 2020). However, it is also recommended that the underlying assumptions employed in selecting comparable datasets be made explicit in all reporting in order to ensure transparency and increase 'comparability' (González Tánago et al., 2016). The involvement of experts and stakeholders in determining the specific factors and sectors most affected by drought at the local level is also important. Furthermore, it is advised that simple qualitative or statistical correlation analyses be conducted to determine multi-collinearities between any new factors added and those on the recommended list (Table 14; Hagenlocher et al., 2018; Meza et al., 2020). If collinearities exist between two or more factors, then a judgement will need to be made as to whether the factor should be retained on the basis of its relevance to the vulnerability assessment.

2. **Involve the most vulnerable populations and underrepresented groups (e.g. indigenous groups) in the determination of the factors to be used to calculate the components** (King-Okumu et al., 2020). Although the inclusion of rural population as a social factor includes one possible vulnerable population, a country Party should aim to include other sub-national data that can improve spatial resolution. Furthermore, engaging underrepresented groups in the validation exercise is another way of improving the 'sensitivity' of the index.

3. **Use statistical methods or expert judgement and on-the-ground validation for weighting of factors and/or components.** The methodology proposed in this GPG does not weight vulnerability factors or components, as this requires in-depth knowledge of the system and differs from country to country and from region to region.

   Meza et al. (2019) have made advances in the weighting of factors. Through consultation with 78 experts, from academia and governments around the globe, they have developed a list of the most relevant indicators and related weightings for the agriculture and water supply sectors. However, expert judgement for weighting is constrained by the availability of such experts and/or resources to compile opinions more generally. Statistical weighting methods, for example, using Principle Components Analysis (PCA), are recommended by Crossman (2019), but these are dependent on the availability of resources and data to undertake such exercises. If a Party is able to undertake an exercise to weight factors used in their DVI, the underlying assumptions need to be made explicit in reporting (González Tánago et al., 2016).

   In the case of component weighting, at present there is no globally agreed convention on weighting or aggregation for index-based methodologies (e.g. Naumann et al., 2014; Hagenlocher et al., 2018; Meza et al., 2020). A country Party may choose to weight each component based upon their relative importance in the calculation of the DVI, as outlined in Naumann et al. (2014). Component weighting will influence the value of the DVI, and as such should be applied to all reporting processes and be stated explicitly in their reporting.

4. **Verify and validate the DVI values for the baseline period against drought impact data, where possible.** If drought-related impacts have been quantified, these can help provide further improvements in the composition of a Parties DVI (Karavitis et al., 2014; Blauhut, 2020; Meza et al., 2020). It is acknowledged that data on drought impact is not widely collected and that it is not always easy to identify the impacts of drought compared to other hazards (Blauhut, 2020; Meza et al., 2020). Still, where possible, Parties are encouraged to undertake simple qualitiative comparisons of their baseline period DVIs to on-the-ground drought impacts – in the future, harmonized protocols for ground-truthing and validating vulnerabilty assessments could be developed.

   A note of caution is necessary on the use of indices such as the Multidimensional Poverty Index (MPI) and the Demographic and Health Survey (DHS) Indices for wealth. These indices bring together factors that are considered to influence or contribute to a theoretical concept (for example, poverty, health, etc.) so that a complex problem can be reduced to a simple statistic. As quoted in Hinkel (2011), "On one hand, we use indicators because issues are complex and indicators reduce this complexity by describing complex systems in simple terms, at best in terms of single numbers. On the other hand, the very meaning of complexity is non-reducibility." Hence, in using these indices within the DVI, the 'sensitivity' is possibly being further reduced. It is, therefore, imperative that further examination of the effect of using indices within the DVI be examined.

REFERENCES

AghaKouchak, A. (2014) 'A baseline probabilistic drought forecasting framework using standardized soil moisture index: Application to the 2012 United States drought', Hydrology and Earth System Sciences, 18(7), pp. 2485–2492. doi: https://doi.org/10.5194/hess-18-2485-2014

Alkire, S. and Santos, M. E. (2014) 'Measuring Acute Poverty in the Developing World: Robustness and Scope of the Multidimensional Poverty Index', World Development, 59, pp. 251–274. doi: https://doi.org/10.1016/j.worlddev.2014.01.026

Arrow, K. J. (2012) Social Choice and Individual Values. Volume 12. Cowles Foundation; Yale University Press. https://cowles.yale.edu/sites/default/files/files/pub/mon/m12-all.pdf

Babaeian, E., Sadeghi, M., Jones, S. B., Montzka, C., Vereecken, H. and Tuller, M. (2019) 'Ground, Proximal, and Satellite Remote Sensing of Soil Moisture', Reviews of Geophysics, 57(2), pp. 530–616. doi: https://doi.org/10.1029/2018RG000618

Bachmair, S., Stahl, K., Collins, K., Hannaford, J., Acreman, M., Svoboda, M., Knutson, C., Smith, K. H., Wall, N., Fuchs, B., Crossman, N. D. and Overton, I. C. (2016a) 'Drought indicators revisited: The need for a wider consideration of environment and society', Wiley Interdisciplinary Reviews: Water, 3(4), pp. 516–536. doi: https://doi.org/10.1002/wat2.1154

Bachmair, S., Svensson, C., Hannaford, J., Barker, L. J. and Stahl, K. (2016b) 'A quantitative analysis to objectively appraise drought indicators and model drought impacts', Hydrology and Earth System Sciences. doi: https://doi.org/10.5194/hess-20-2589-2016

Bachmair, S., Tanguy, M., Hannaford, J. and Stahl, K. (2018) 'How well do meteorological indicators represent agricultural and forest drought across Europe?', Environmental Research Letters, 13(3). doi: https://doi.org/10.1088/1748-9326/aaafda

Bai, L., Shi, C., Li, L., Yang, Y. and Wu, J. (2018) 'Accuracy of CHIRPS Satellite-Rainfall Products over Mainland China', Remote Sensing. doi: https://doi.org/10.3390/rs10030362

Barker, L. J., Hannaford, J., Chiverton, A. and Svensson, C. (2016) 'From meteorological to hydrological drought using standardised indicators', Hydrology and Earth System Sciences, 20(6), pp. 2483–2505. doi: https://doi.org/10.5194/hess-20-2483-2016

Beguería, S. and Vicente-Serrano, S. M. (2017) 'Package "SPEI"', R-Package, p. 16. Available at: https://cran.r-project.org/web/packages/SPEI/SPEI.pdf

Birkmann, J., Cardona, O. D., Carreño, M. L., Barbat, A. H., Pelling, M., Schneiderbauer, S., Kienberger, S., Keiler, M., Alexander, D., Zeil, P. and Welle, T. (2013) 'Framing vulnerability, risk and societal responses: the MOVE framework', Natural Hazards, 67(2), pp. 193–211. doi: https://doi.org/10.1007/s11069-013-0558-5

Blauhut, V. (2020) 'The triple complexity of drought risk analysis and its visualisation via mapping: A review across scales and sectors', Earth-Science Reviews. doi: https://doi.org/10.1016/j.earscirev.2020.103345

Blauhut, V., Gudmundsson, L. and Stahl, K. (2015) 'Towards pan-European drought risk maps: Quantifying the link between drought indices and reported drought impacts', Environmental Research Letters, 10(1). doi: https://doi.org/10.1088/1748-9326/10/1/014008

Blauhut, V., Stahl, K., Stagge, J. H., Tallaksen, Lena M, De Stefano, L. and Vogt, J. (2016) 'Estimating drought risk across Europe from reported drought impacts, drought indices, and vulnerability factors', Hydrology and Earth System Sciences, 20, pp. 2779–2800. doi: https://doi.org/10.5194/hess-20-2779-2016

Bloomfield, J. P. and Marchant, B. P. (2013) 'Analysis of groundwater drought building on the standardised precipitation index approach', Hydrology and Earth System Sciences, 17(12), pp. 4769–4787. doi: https://doi.org/10.5194/hess-17-4769-2013

Breshears, D. D., Adams, H. D., Eamus, D., McDowell, N. G., Law, D. J., Will, R. E., Williams, A. P. and Zou, C. B. (2013) 'The critical amplifying role of increasing atmospheric moisture demand on tree mortality and associated regional die-off', Frontiers in Plant Science, 4, p. 266. doi: https://doi.org/10.3389/fpls.2013.00266

Cammalleri, C., Vogt, J. V, Bisselink, B. and de Roo, A. (2017) 'Comparing soil moisture anomalies from multiple independent sources over different regions across the globe', Hydrology and Earth System Sciences, 21(12), pp. 6329–6343. doi: https://doi.org/10.5194/hess-21-6329-2017

Cardona, O. D. et al. (2012) 'Determinants of risk: Exposure and vulnerability', Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change, 9781107025, pp. 65–108. doi: https://doi.org/10.1017/CBO9781139177245.005

Carrão, H., Naumann, G. and Barbosa, P. (2016) 'Mapping global patterns of drought risk: An empirical framework based on sub-national estimates of hazard, exposure and vulnerability', Global Environmental Change, 39, pp. 108–124. doi: https://doi.org/10.1016/j.gloenvcha.2016.04.012

Carrão, H., Russo, S., Sepulcre-Canto, G. and Barbosa, P. (2016) 'An empirical standardized soil moisture index for agricultural drought assessment from remotely sensed data', International Journal of Applied Earth Observation and Geoinformation, 48, pp. 74–84. doi: https://doi.org/10.1016/j.jag.2015.06.011

Christenson, E., Elliott, M., Banerjee, O., Hamrick, L. and Bartram, J. (2014) 'Climate-Related Hazards: A Method for Global Assessment of Urban and Rural Population Exposure to Cyclones, Droughts, and Floods', International Journal of Environmental Research and Public Health, 11(2), pp. 2169–2192. doi: https://doi.org/10.3390/ijerph110202169

Collier, C. G. (2000) World Meteorological Organization Precipitation, Operational Hydrology Report No. 46, Precipitation Estimation and Forecasting. Geneva, Switzerland. Available at: https://library.wmo.int/doc_num.php?explnum_id=1708

Cook, E. R. et al. (2015) 'Old World Megadroughts and Pluvials during the Common Era', Science Advances, 1(10), p. e1500561. doi: https://doi.org/10.1126/sciadv.1500561

Crameri, F., Shephard, G. E. and Heron, P. J. (2020) 'The misuse of colour in science communication', Nature Communications, 11(1), p. 5444. doi: https://doi.org/10.1038/s41467-020-19160-7

Crausbay, S. D. et al. (2017) 'Defining Ecological Drought for the Twenty-First Century', Bulletin of the American Meteorological Society, 98(12), pp. 2543–2550. doi: https://doi.org/10.1175/BAMS-D-16-0292.1

Crossman, N. (2019) Drought resilience, adaptation and management policy framework. Edited by D. Tsegai. Bonn, Germany. Available at: https://catalogue.unccd.int/1246_UNCCD_drought_resilience_technical_guideline_EN.pdf

Cutter, S. L., Boruff, B. J. and Shirley, W. L. (2003) 'Social vulnerability to environmental hazards', Social Science Quarterly, 84(2), pp. 242–261. doi: https://doi.org/10.1111/1540-6237.8402002

Dai, A. (2011a) 'Characteristics and trends in various forms of the Palmer Drought Severity Index during 1900–2008', Journal of Geophysical Research: Atmospheres, 116(D12). doi: https://doi.org/10.1029/2010JD015541

Dai, A. (2011b) 'Drought under global warming: A review', Wiley Interdisciplinary Reviews: Climate Change, 2(1), pp. 45–65. doi: https://doi.org/10.1002/wcc.81

Dai, A., Zhao, T. and Chen, J. (2018) 'Climate Change and Drought: A Precipitation and Evaporation Perspective', Current Climate Change Reports, 4(3), pp. 301–312. doi: https://doi.org/10.1007/s10712-017-9416-4

De Lange, H. J., Sala, S., Vighi, M. and Faber, J. H. (2010) 'Ecological vulnerability in risk assessment - A review and perspectives', Science of the Total Environment, 408(18), pp. 3871–3879. doi: https://doi.org/10.1016/j.scitotenv.2009.11.009

Dewes, C. F., Rangwala, I., Barsugli, J. J., Hobbins, M. T. and Kumar, S. (2017) 'Drought risk assessment under climate change is sensitive to methodological choices for the estimation of evaporative demand', PLoS ONE, 12(3), p. e0174045. doi: https://doi.org/10.1371/journal.pone.0174045

Dinku, T., Funk, C., Peterson, P., Maidment, R., Tadesse, T., Gadain, H. and Ceccato, P. (2018) 'Validation of the CHIRPS satellite rainfall estimates over eastern Africa', Quarterly Journal of the Royal Meteorological Society, 144(S1), pp. 292–312. doi: https://doi.org/10.1002/qj.3244

Do, H. X., Gudmundsson, L., Leonard, M. and Westra, S. (2018) 'The Global Streamflow Indices and Metadata Archive (GSIM) – Part 1: The production of a daily streamflow archive and metadata', Earth System Science Data, 10(2), pp. 765–785. doi: https://doi.org/10.5194/essd-10-765-2018

Doxsey-Whitfield, E., MacManus, K., Adamo, S. B., Pistolesi, L., Squires, J., Borkovska, O. and Baptista, S. R. (2015) 'Taking Advantage of the Improved Availability of Census Data: A First Look at the Gridded Population of the World, Version 4', Papers in Applied Geography, 1(3), pp. 226–234. doi: https://doi.org/10.1080/23754931.2015.1014272

FAO (2012) Coping with water scarcity: An action framework for agriculture and food security. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO). Available at: http://www.fao.org/3/i3015e/i3015e.pdf

FAO (2017) The Impact of disasters and crises on agriculture and food security 2017. Rome, Italy. Available at: https://digitallibrary.un.org/record/1485337?ln=en

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A. and Michaelsen, J. (2015) 'The climate hazards infrared precipitation with stations – A new environmental record for monitoring extremes', Scientific Data, 2, pp. 1–21. doi: https://doi.org/10.1038/sdata.2015.66

Golian, S., Javadian, M. and Behrangi, A. (2019) 'On the use of satellite, gauge, and reanalysis precipitation products for drought studies', Environmental Research Letters, 14(7). doi: https://doi.org/10.1088/1748-9326/ab2203

González Tánago, I., Urquijo, J., Blauhut, V., Villarroya, F. and De Stefano, L. (2016) 'Learning from experience: A systematic review of assessments of vulnerability to drought', Natural Hazards, 80(2), pp. 951–973. doi: https://doi.org/10.1007/s11069-015-2006-1.

Gudmundsson, L. and Stagge, J. H. (2016) 'Package "SCI"'. Available at: https://cran.r-project.org/web/packages/SCI/SCI.pdf

Hagenlocher, M., Meza, I., Anderson, C. C., Min, A., Renaud, F. G., Walz, Y., Siebert, S. and Sebesvari, Z. (2019) 'Drought vulnerability and risk assessments: State of the art, persistent gaps, and research agenda', Environmental Research Letters. doi: https://doi.org/10.1088/1748-9326/ab225d

Hagenlocher, M., Renaud, F. G., Haas, S. and Sebesvari, Z. (2018) 'Vulnerability and risk of deltaic social-ecological systems exposed to multiple hazards', Science of the Total Environment, 631–632, pp. 71–80. doi: https://doi.org/10.1016/j.scitotenv.2018.03.013

Hannaford, J., Collins, K., Haines, S. and Barker, L. J. (2019) 'Enhancing drought monitoring and early warning for the United Kingdom through stakeholder coinquiries', Weather, Climate, and Society, 11(1), pp. 49–63. doi: https://doi.org/10.1175/WCAS-D-18-0042.1

Hannah, D. M., Demuth, S., van Lanen, H. A. J., Looser, U., Prudhomme, C., Rees, G., Stahl, K. and Tallaksen, L. M. (2011) 'Large-scale river flow archives: importance, current status and future needs', Hydrological Processes, 25(7), pp. 1191–1200. doi: https://doi.org/10.1002/hyp.7794

Hao, Z. and AghaKouchak, A. (2014) 'A Nonparametric Multivariate Multi-Index Drought Monitoring Framework', Journal of Hydrometeorology, 15(1), pp. 89–101. doi: https://doi.org/10.1175/JHM-D-12-0160.1

Hao, Z. and Singh, V. P. (2015) 'Drought characterization from a multivariate perspective: A review', Journal of Hydrology, 527, pp. 668–678. doi: https://doi.org/10.1016/j.jhydrol.2015.05.031

Harrigan, S., Zsoter, E., Alfieri, L., Prudhomme, C., Salamon, P., Wetterhall, F., Barnard, C., Cloke, H. and Pappenberger, F. (2020) 'GloFAS-ERA5 operational global river discharge reanalysis 1979-present', Earth System Science Data, 12(3), pp. 2043–2060. doi: https://doi.org/10.5194/essd-12-2043-2020

Hayes, M., Svoboda, M., Wall, N. and Widhalm, M. (2011) 'The Lincoln Declaration on drought indices: Universal meteorological drought index recommended', Bulletin of the American Meteorological Society, 92(4), pp. 485–488. doi: https://doi.org/10.1175/2010BAMS3103.1

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D., Simmons, A., Soci, C., Abdalla, A., Abellan, X., Balsamo, G., Bechtold, P., Biavati. G., Bidlot, J., Bonavita, M., De Chiara, G., Dahlgren, P., Dee, D., Diamantakis, M., Dragani, R., Flemming, J., Forbes, R., Fuentes, M., Geer, A., Haimberger, L., Healy, S., Hogan, R. J., Hólm, E., Janisková, M., Keeley, S., Laloyaux, P., Lopez, P., Lupu, C., Radnoti, G., de Rosnay, P., Rozum, I., Vamborg, F., Villaume, S. and Thépaut, J. (2020) 'The ERA5 global reanalysis', Quarterly Journal of the Royal Meteorological Society, 146(730), pp. 1999–2049. doi: https://doi.org/10.1002/qj.3803

Heumann, C., Schomaker, M. and Shalabh (2016) Introduction to Statistics and Data Analysis: With Exercises, Solutions and Applications in R. 1st edition. Springer International Publishing. doi: https://doi.org/10.1007/978-3-319-46162-5

Hinkel, J. (2011) '"Indicators of vulnerability and adaptive capacity": Towards a clarification of the science–policy interface', Global Environmental Change, 21(1), pp. 198–208. doi: https://doi.org/10.1016/j.gloenvcha.2010.08.002

IPCC (2006) 2006 IPCC guidelines for national greenhouse gas inventories. Edited by H. S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe. Japan: IGES. Available at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/

IPCC (2012) Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Edited by C. B. Field, V. Barros, T. F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, G. K. Plattner, S. K. Allen, M. Tignor, and P. M. Midgley. Cambridge, UK: Cambridge University Press. doi: https://doi.org/10.1017/CBO9781139177245.009

IPCC (2014a) Climate change 2014–Impacts, adaptation and vulnerability: Part A Global and sectoral aspects. Available at: https://www.ipcc.ch/report/ar5/wg2/

IPCC (2014b) Climate change 2014–Impacts, adaptation and vulnerability: Part B Regional aspects. Available at: https://www.ipcc.ch/report/ar5/wg2/

IPCC (2014c) Climate change 2014: synthesis report; IPCC - International Panel on Climate Change. Geneva, Switzerland. ISBN: 978-92-9169- 143-2. 7. Available at: https://www.ipcc.ch/report/ar5/syr/

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen, J., Zhu, Y., Chelliah, M., Ebisuzaki, W., Higgins, W., Janowiak, J., Mo, K. C., Ropelewski, C., Wang, J., Leetmaa, A., Reynolds, R., Jenne, R. and Joseph, D. (1996) 'The NCEP/NCAR 40-Year Reanalysis Project', Bulletin of the American Meteorological Society, 77(3), pp. 437–472. doi: https://doi.org/10.1175/1520-0477(1996)077<0437:TNYRP>2.0.CO;2

Karavitis, C. A., Tsesmelis, D. E., Skondras, N. A., Stamatakos, D., Alexandris, S., Fassouli, V., Vasilakou, C. G., Oikonomou, P. D., Gregorič, G., Grigg, N. S. and Vlachos, E. C. (2014) 'Linking drought characteristics to impacts on a spatial and temporal scale', Water Policy, 16(6). doi: https://doi.org/10.2166/wp.2014.205

Keller, V. D. J., Tanguy, M., Prosdocimi, I., Terry, J. A., Hitt, O., Cole, S. J., Fry, M., Morris, D. G. and Dixon, H. (2015) 'CEH-GEAR: 1 Km resolution daily and monthly areal rainfall estimates for the UK for hydrological and other applications', Earth System Science Data, 7(1), pp. 143–155. doi: https://doi.org/10.5194/essd-7-143-2015

King-Okumu, C. (2019) Drought Impact and Vulnerability Assessment: A Rapid Review of Practices and Policy Recommendations. Bonn, Germany. Available at: https://www.unccd.int/publications/drought-impact-and-vulnerability-assessment-rapid-review-practices-and-policy

King-Okumu, C., Tsegai, D., Pandey, R. P. and Rees, G. (2020) 'Less to lose? Drought impact and vulnerability assessment in disadvantaged regions', Water, 12(4). doi: https://doi.org/10.3390/W12041136

Kreibich, H., Blauhut, V., Aerts, J. C. J. H., Bouwer, L. M., Van Lanen, H. A. J., Mejia, A., Mens, M. and Van Loon, A. F. (2019) 'How to improve attribution of changes in drought and flood impacts', Hydrological Sciences Journal, 64(1), pp. 1–18. doi: https://doi.org/10.1080/02626667.2018.1558367

Laurent-Lucchetti, J., Couttenier, M., Vischel, T. and Vollenwieder, X. (2019) Droughts, Land Degradation and Migration; United Nations Convention to Combat Desertification. Bonn, Germany.

Lavell, A., Oppenheimer, M., Diop, C., Hess, J., Lempert, R., Li, J., Muir-Wood, R. and Myeong, S. (2012) 'Climate change: New dimensions in disaster risk, exposure, vulnerability, and resilience', in Field, C. B., Barros, V., Stocker, T. F., Qin, D., Dokken, D. J., Ebi, K. L., Mastrandrea, M. D., Mach, K. J., Plattner, G.-K., Allen, S. K., Tignor, M., and Midgley, P. M. (eds) Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change. Cambridge, UK, and New York, USA: Cambridge University Press, pp. 25–64. doi: https://doi.org/10.1017/CBO9781139177245.004

Legg, T. (2015) 'Uncertainties in gridded area-average monthly temperature, precipitation and sunshine for the United Kingdom', International Journal of Climatology, 35(7), pp. 1367–1378. doi: https://doi.org/10.1002/joc.4062

Lloyd-Hughes, B. (2014) 'The impracticality of a universal drought definition', Theoretical and Applied Climatology, 117(3–4), pp. 607–611. doi: https://doi.org/10.1007/s00704-013-1025-7

Lloyd-Hughes, B. and Saunders, M. A. (2002) 'A drought climatology for Europe', International Journal of Climatology, 22(13), pp. 1571–1592. doi: https://doi.org/10.1002/joc.846

McKee, T. B., Doesken, N. J. and Kleist, J. (1993) 'The relationship of drought frequency and duration to time scales', in Proceedings of the 8th Conference on Applied Climatology. Boston, pp. 179–183. Available at: https://www.droughtmanagement.info/literature/AMS_Relationship_Drought_Frequency_Duration_Time_Scales_1993.pdf

Meza, I., Hagenlocher, M., Naumann, G., Vogt, J. and Frischen, J. (2019) Drought vulnerability indicators for global-scale drought risk assessments, JUR 29824 EN, Publication Office of the European Union, Luxembourg. doi: https://doi.org/10.2760/73844

Meza, I., Siebert, S., Döll, P., Kusche, J., Herbert, C., Rezaei, E. E., Nouri, H., Gerdener, H., Popat, E., Frischen, J., Naumann, G., Vogt, J. V., Walz, Y., Sebesvari, Z. and Hagenlocher, M. (2020) 'Global-scale drought risk assessment for agricultural systems', Natural Hazards and Earth System Sciences, 20(2), pp. 695–712. doi: https://doi.org/10.5194/nhess-20-695-2020

Mishra, A. K. and Singh, V. P. (2010) 'A review of drought concepts', Journal of Hydrology, 391(1), pp. 202–216. doi: https://doi.org/10.1016/j.jhydrol.2010.07.012

Mondal, P. and Tatem, A. J. (2012) 'Uncertainties in Measuring Populations Potentially Impacted by Sea Level Rise and Coastal Flooding', PLoS ONE, 7(10), p. e48191. doi: https://doi.org/10.1371/journal.pone.0048191

Mukherjee, S., Mishra, A. and Trenberth, K. E. (2018) 'Climate Change and Drought: A Perspective on Drought Indices', Current Climate Change Reports, 4(2), pp. 145–163. doi: https://doi.org/10.1007/s40641-018-0098-x

Naumann, G., Barbosa, P., Garrote, L., Iglesias, A. and Vogt, J. (2014) 'Exploring drought vulnerability in Africa: An indicator based analysis to be used in early warning systems', Hydrology and Earth System Sciences, 18(5), pp. 1591–1604. doi: https://doi.org/10.5194/hess-18-1591-2014

Nawaz, M., Iqbal, M. F. and Mahmood, I. (2021) 'Validation of CHIRPS satellite-based precipitation dataset over Pakistan', Atmospheric Research, 248, p. 105289. doi: https://doi.org/10.1016/j.atmosres.2020.105289

Noel, M., Bathke, D., Fuchs, B., Gutzmer, D., Haigh, T., Hayes, M., Poděbradská, M., Shield, C., Smith, K. and Svoboda, M. (2020) 'Linking Drought Impacts to Drought Severity at the State Level', Bulletin of the American Meteorological Society, 101(8), pp. E1312–E1321. doi: https://doi.org/10.1175/BAMS-D-19-0067.1

Nogueira, M. (2020) 'Inter-comparison of ERA-5, ERA-interim and GPCP rainfall over the last 40 years: Process-based analysis of systematic and random differences', Journal of Hydrology, 583, p. 124632. doi: https://doi.org/10.1016/j.jhydrol.2020.124632

Núñez, J., Rivera, D., Oyarzún, R. and Arumí, J. L. (2014) 'On the use of Standardized Drought Indices under decadal climate variability: Critical assessment and drought policy implications', Journal of Hydrology, 517, pp. 458–470. doi: https://doi.org/10.1016/j.jhydrol.2014.05.038

OECD and JRC (2008) Handbook on Constructing Composite Indicators: Methodology and user guide. Paris, France. Available at: https://www.oecd.org/els/soc/handbookonconstructingcompositeindicatorsmethodologyanduserguide.htm

Orlowsky, B. and Seneviratne, S. I. (2013) 'Elusive drought: Uncertainty in observed trends and short-and long-term CMIP5 projections', Hydrology and Earth System Sciences, 17(5), pp. 1765–1781. doi: https://doi.org/10.5194/hess-17-1765-2013

Otkin, J. A., Svoboda, M., Hunt, E. D., Ford, T. W., Anderson, M. C., Hain, C. and Basara, J. B. (2018) 'Flash Droughts: A Review and Assessment of the Challenges Imposed by Rapid-Onset Droughts in the United States', Bulletin of the American Meteorological Society, 99(5), pp. 911–919. doi: https://doi.org/10.1175/BAMS-D-17-0149.1

Oudin, L., Hervieu, F., Michel, C., Perrin, C., Andréassian, V., Anctil, F. and Loumagne, C. (2005) 'Which potential evapotranspiration input for a lumped rainfall–runoff model?: Part 2—Towards a simple and efficient potential evapotranspiration model for rainfall–runoff modelling', Journal of Hydrology, 303(1), pp. 290–306. doi: https://doi.org/10.1016/j.jhydrol.2004.08.026

Pendergrass, A. G., Meehl, G. A., Pulwarty, R., Hobbins, M., Hoell, A., AghaKouchak, A., Bonfils, C. J. W., Gallant, A. J. E., Hoerling, M., Hoffmann, D., Kaatz, L., Lehner, F., Llewellyn, D., Mote, P., Neale, R. B., Overpeck, J. T., Sheffield, A., Stahl, K., Svoboda, M., Wheeler, M. C., Wood A. W., and Woodhouse, C. A. (2020) 'Flash droughts present a new challenge for subseasonal-to-seasonal prediction', Nature Climate Change, 10(3), pp. 191–199. doi: https://doi.org/10.1038/s41558-020-0709-0

Peng, J., Albergeld, C., Balenzano, A., Brocca, L., Cartus, O., Cosh, M. H., Crow, W. T., Dabrowska-Zielinska, K., Dadson, S., Davidson, M. W. J., de Rosnay, P., Dorigo,W., Gruber, A., Hagemann, S., Hirschi, M., Kerr, Y. H., Lovergine, F., Mahecha, M. D., Marzahn, P., Mattia, F., Pawel Musial, J., Preuschmann, S., Reichle, R. H., Satalino, G., Silgram, M., van Bodegom, P. M., Verhoest, N. E. C., Wagner, W., Walker, J. P., Wegmüller, U. and Loew, A. (2021) 'A roadmap for high-resolution satellite soil moisture applications – confronting product characteristics with user requirements', Remote Sensing of Environment, 252, p. 112162. doi: https://doi.org/10.1016/j.rse.2020.112162

Peng, J., Loew, A., Merlin, O. and Verhoest, N. E. C. (2017) 'A review of spatial downscaling of satellite remotely sensed soil moisture', Reviews of Geophysics, 55(2), pp. 341–366. doi: https://doi.org/10.1002/2016RG000543

Pereira, L. S., Cordery, I. and Iacovides, I. (2002) Coping with water scarcity. Technical Documents in Hydrology, Paris: International Hydrological Programme-UNESCO.

Pietzsch, S. and Bissolli, P. (2011) 'A modified drought index for WMO RA VI', Adv. Sci. Res., 6(1), pp. 275–279. doi: https://doi.org/10.5194/asr-6-275-2011

Pricope, N., Mapes, K., Mwenda, K., Sokolow, G. and Lopez-Carr, D. (2020) A review of publically available geospatial datasets and indicators in support of drought: TOOLS4LDN technical report on monitoring progress towards SO3. Available at: https://www.tools4ldn.org/resources

Prudhomme, C., Giuntoli, I., Robinson, E. L., Clark, D. B., Arnell, N. W., Dankers, R., Fekete, B. M., Franssen, W., Gerten, D., Gosling, S. N., Hagemann, S., Hannah, D. M., Kim, H., Masaki, Y., Satoh, Y., Stacke, T., Wada, Y. and Wisser, D. (2014) 'Hydrological droughts in the 21st century, hotspots and uncertainties from a global multimodel ensemble experiment', Proceedings of the National Academy of Sciences, 111(9), pp. 3262 LP – 3267. doi: https://doi.org/10.1073/pnas.1222473110

Reichhuber, A., Gerber, N., Mirzabaev, A., Svoboda, M., López Santos, A., Graw, V., Stefanski, R., Davies, J., Vuković, A., Fernández García, M. A., Fiati, C. and Jia, X. (2019) The Land-Drought Nexus: Enhancing the Role of Land-Based Interventions in Drought Mitigation and Risk Management. A Report of the Science-Policy Interface. Bonn, Germany. Available at: https://knowledge.unccd.int/publication/land-drought-nexus-enhancing-role-land-based-interventions-drought-mitigation-and-risk

Rivera, J. A., Marianetti, G. and Hinrichs, S. (2018) 'Validation of CHIRPS precipitation dataset along the Central Andes of Argentina', Atmospheric Research, 213, pp. 437–449. doi: https://doi.org/10.1016/j.atmosres.2018.06.023

Rodell, M., Beaudoing, H. K., L'Ecuyer, T. S., Olson, W. S., Famiglietti, J. S., Houser, P. R., Adler, R., Bosilovich, M. G., Clayson, C. A., Chambers, D., Clark, E., Fetzer, E. J., Gao X., Gu, G., Hilburn, K., Huffman, G. J., Lettenmaier, D. P., Liu, W. T., Robertson, F. R., Schlosser, C. A., Sheffield, J. and Wood E. F. (2015) 'The Observed State of the Water Cycle in the Early Twenty-First Century', Journal of Climate, 28(21), pp. 8289–8318. doi: https://doi.org/10.1175/JCLI-D-14-00555.1

Schellekens, J., Dutra, E., Martínez-de la Torre, A., Balsamo, G., van Dijk, A., Sperna Weiland, F., Minvielle, M., Calvet, J.-C., Decharme, B., Eisner, S., Fink, G., Flörke, M., Peßenteiner, S., van Beek, R., Polcher, J., Beck, H., Orth, R., Calton, B., Burke, S., Dorigo, W., and Weedon, G. P. (2017) 'A global water resources ensemble of hydrological models: The eartH2Observe Tier-1 dataset', Earth System Science Data, 9(2), pp. 389–413. doi: https://doi.org/10.5194/essd-9-389-2017

Schneider, U., Becker, A., Finger, P., Meyer-Christoffer, A. and Ziese, M. (2018a) 'GPCC Monitoring Product: Near Real-Time Monthly Land-Surface Precipitation from Rain-Gauges based on SYNOP and CLIMAT data'. doi: https://doi.org/10.5676/DWD_GPCC/MP_M_V6_100

Schneider, U., Becker, A., Ziese, M. and Rudolf, B. (2018b) 'Global Precipitation Analysis Products of the GPCC', Global Precipitation Climatology Centre (GPCC), (June), pp. 1–14. Available at: ftp://ftp-anon.dwd.de/pub/data/gpcc/PDF/GPCC_intro_products_2008.pdf

Schneider, U., Becker, A., Finger, P., Meyer-Christoffer, A., Ziese, M. and Rudolf, B. (2014) 'GPCC's new land surface precipitation climatology based on quality-controlled in situ data and its role in quantifying the global water cycle', Theoretical and Applied Climatology, 115(1), pp. 15–40. doi: https://doi.org/10.1007/s00704-013-0860-x

Sheffield, J., Wood, E. F. and Roderick, M. L. (2012) 'Little change in global drought over the past 60 years', Nature, 491(7424), pp. 435–438. doi: https://doi.org/10.1038/nature11575

Shukla, S. and Wood, A. W. (2008) 'Use of a standardized runoff index for characterizing hydrologic drought', Geophysical Research Letters, 35(2). doi: https://doi.org/10.1029/2007GL032487

Sims, N. C., Newnham, G. J., England, J. R., Guerschman, J., Cox, S. J. D., Roxburgh, S. H., Viscarra-Rossel, R. A., Fritz, S. and Wheeler, I. (2021) Good Practice Guidance SDG Indicator 15.3.1: Proportion of land that is degraded over total land area. Version 2.0. United Nations Convention to Combat Desertification, Bonn, Germany. Available at: https://www.unccd.int/sites/default/files/relevant-links/2021-03/Indicator_15.3.1_GPG_v2_29Mar_Advanced-version.pdf

Slette, I. J., Post, A. K., Awad, M., Even, T., Punzalan, A., Williams, S., Smith, M. D. and Knapp, A. K. (2019) 'How ecologists define drought, and why we should do better', Global Change Biology, 25(10), pp. 3193–3200. doi: https://doi.org/10.1111/gcb.14747

Stagge, J. H., Kohn, I., Tallaksen, L. M. and Stahl, K. (2015a) 'Modeling drought impact occurrence based on meteorological drought indices in Europe', Journal of Hydrology, 530, pp. 37–50. doi: https://doi.org/10.1016/j.jhydrol.2015.09.039

Stagge, J. H., Tallaksen, L. M., Gudmundsson, L., Van Loon, A. F. and Stahl, K. (2015b) 'Candidate Distributions for Climatological Drought Indices (SPI and SPEI)', International Journal of Climatology, 35(13), pp. 4027–4040. doi: https://doi.org/10.1002/joc.4267

Strode, G., Morgan, J. D., Thornton, B., Mesev, V., Rau, E., Shortes, S. and Johnson, N. (2020) 'Operationalizing Trumbo's Principles of Bivariate Choropleth Map Design', Cartographic Perspectives, (94), pp. 5–24. doi: https://doi.org/10.14714/CP94.1538

Sun, Q., Miao, C., Duan, Q., Ashouri, H., Sorooshian, S. and Hsu, K. L. (2018) 'A Review of Global Precipitation Data Sets: Data Sources, Estimation, and Intercomparisons', Reviews of Geophysics, 56(1), pp. 79–107. doi: https://doi.org/10.1002/2017RG000574

Svensson, C., Hannaford, J. and Prosdocimi, I. (2017) 'Statistical distributions for monthly aggregations of precipitation and streamflow in drought indicator applications', Water Resources Research, 53(2), pp. 999–1018. doi: https://doi.org/10.1002/2016WR019276

Tallaksen, L. M. and Van Lanen, H. A. J. (2004) Hydrological drought: processes and estimation methods for streamflow and groundwater. Vol. 48. Elsevier. Available at: http://europeandroughtcentre.com/resources/

Tanguy, M., Fry, M., Svensson, C. and Hannaford, J. (2017) 'Historic Gridded Standardised Precipitation Index for the United Kingdom 1862-2015 (generated using gamma distribution with standard period 1961-2010) v4', Environmental Information Data Centre. doi: https://doi.org/10.5285/233090b2-1d14-4eb9-9f9c-3923ea2350ff

Teuling, A. J., Van Loon, A. F., Seneviratne, S. I., Lehner, I., Aubinet, M., Heinesch, B., Bernhofer, C., Grünwald, T., Prasse, H. and Spank, U. (2013) 'Evapotranspiration amplifies European summer drought', Geophysical Research Letters, 40(10), pp. 2071–2075. doi: https://doi.org/10.1002/grl.50495

Tijdeman, E., Stahl, K. and Tallaksen, L. M. (2020) 'Drought Characteristics Derived Based on the Standardized Streamflow Index: A Large Sample Comparison for Parametric and Nonparametric Methods', Water Resources Research, 56(10). doi: https://doi.org/10.1029/2019WR026315

Trenberth, K. E., Dai, A., van der Schrier, G., Jones, P. D., Barichivich, J., Briffa, K. R. and Sheffield, J. (2014) 'Global warming and changes in drought', Nature Climate Change, 4(1), pp. 17–22. doi: https://doi.org/10.1038/nclimate2067

UNCCD and FAO (2020) Land Degradation Neutrality for Water Security and Combatting Drought. Bonn, Germany. Available at: https://www.unccd.int/publications/land-degradation-neutrality-water-security-and-combatting-drought-briefing-note

UNESCO (2019) The United Nations World Water Development Report 2019. Paris, France. Available at: https://www.unwater.org/publications/world-water-development-report-2019/

UNISDR (2009) Drought Risk Reduction Framework and Practices: Contributing to the Implementation of the Hyogo Framework for Action. Geneva, Switzerland. Available at: http://www.unisdr.org/preventionweb/files/11541_DroughtRiskReduction2009library.pdf

UNISDR United Nations International Strategy for Disaster Reduction (2004) Living with risk: a global review of disaster reduction initiatives, UN Publications. Geneva, Switzerland. doi: https://doi.org/9211010640

UNISDR United Nations International Strategy for Disaster Reduction (2017) Technical Guidance for Monitoring and Reporting on Progress in Achieving the Global Targets of the Sendai Framework for Disaster Risk Reduction Collection of Technical Notes on Data and Methodology. Available at: http://www.preventionweb.net/drr-framework/open-ended-working-group

Van Loon, A. F. (2015) 'Hydrological drought explained', WIREs Water, 2(4), pp. 359–392. doi: https://doi.org/10.1002/wat2.1085

Vicente-Serrano, S. M., Beguería, S. and López-Moreno, J. I. (2010) 'A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index', Journal of Climate, 23(7), pp. 1696–1718. doi: https://doi.org/10.1175/2009JCLI2909.1

Vicente-Serrano, S. M., López-Moreno, J. I., Beguería, S., Lorenzo-Lacruz, J., Azorin-Molina, C. and Morán-Tejeda, E. (2012) 'Accurate computation of a streamflow drought index', Journal of Hydrologic Engineering, 17(2), pp. 318–332 doi: https://doi.org/10.1061/%28ASCE%29HE.1943-5584.0000433

Vicente-Serrano, S. M., Quiring, S. M., Peña-Gallardo, M., Yuan, S. and Domínguez-Castro, F. (2020) 'A review of environmental droughts: Increased risk under global warming?', Earth-Science Reviews, 201, p. 102953. doi: https://doi.org/10.1016/j.earscirev.2019.102953

Vicente-Serrano, S. M., Tomas-Burguera, M., Beguería, S., Reig, F., Latorre, B., Peña-Gallardo, M., Luna, M. Y., Morata, A. and González-Hidalgo, J. C. (2017) 'A High Resolution Dataset of Drought Indices for Spain', Data. doi: https://doi.org/10.3390/data2030022

Viglione, A., Borga, M., Balabanis, P. and Blöschl, G. (2010) 'Barriers to the exchange of hydrometeorological data in Europe: Results from a survey and implications for data policy', Journal of Hydrology, 394(1), pp. 63–77. doi: https://doi.org/10.1016/j.jhydrol.2010.03.023

Vogt, J. V, Naumann, G., Masante, D., Spinoni, J., Cammalleri, C., Erian, W., Pischke, F., Pulwarty, R. and Barbosa, P. (2018) Drought Risk Assessment and Management-A Conceptual Framework. Luxembourg. doi: https://doi.org/10.2760/057223

Wang, Yaxu, Lv, J., Hannaford, J., Wang, Yicheng, Sun, H., Barker, L. J., Ma, M., Su, Z. and Eastman, M. (2020) 'Linking drought indices to impacts to support drought risk assessment in Liaoning province, China', Natural Hazards and Earth System Sciences, 20(3), pp. 889–906. doi: https://doi.org/10.5194/nhess-20-889-2020

Weißhuhn, P., Müller, F. and Wiggering, H. (2018) 'Ecosystem Vulnerability Review: Proposal of an Interdisciplinary Ecosystem Assessment Approach', Environmental Management, 61(6), pp. 904–915. doi: https://doi.org/10.1007/s00267-018-1023-8

Wilhite, D. A. and Glantz, M. H. (1985) 'Understanding: the drought phenomenon: the role of definitions', Water International, 10(3), pp. 111–120. doi: https://doi.org/10.1080/02508068508686328

Wilks, D. S. (2011) Statistical methods in the atmospheric sciences. Third Edit. Oxford, UK: Elsevier.

Winsemius, H. C., Jongman, B., Veldkamp, T. I. E., Hallegatte, S., Bangalore, M. and Ward, P. J. (2018) 'Disaster risk, climate change, and poverty: Assessing the global exposure of poor people to floods and droughts', Environment and Development Economics, 23(3), pp. 328–348. doi: https://doi.org/10.1017/S1355770X17000444

World Meteorological Organization (1992) International Meteorological Vocabulary. Geneva, Switzerland. Available at: https://library.wmo.int/index.php?lvl=notice_display&id=220#.YI55NbVKhpg

World Meteorological Organization (2012) Standardized Precipitation Index User Guide, WMO-No. 1090. Geneva. Available at: https://public.wmo.int/en/resources/library/standardized-precipitation-index-user-guide

World Meteorological Organization (2017) Guidelines on the Calculation of Climate Normals, WMO-No. 1203. Geneva. Available at: https://library.wmo.int/doc_num.php?explnum_id=4166

World Meteorological Organization (2018) Guide to climatological practices, second edition. Geneva, Switzerland. Available at: https://library.wmo.int/doc_num.php?explnum_id=5541

World Meteorological Organization (2019) Manual on the High-quality Global Data Management Framework for Climate. WMO-No. 1238. 2019 edition. Geneva, Switzerland: World Meteorological Organization. Available at: https://library.wmo.int/?lvl=notice_display&id=21686#.YS-KUI5Khpg

World Meteorological Organization and Global Water Partnership (2016) Integrated Drought Management Programme Handbook of Drought Indicators and Indices. Integrated. Edited by M. Svoboda and B. Fuchs. Geneva: Integrated Drought Management Programme. Available at: https://www.droughtmanagement.info/find/guidelines-tools/handbook-drought-indicators-and-indices/

World Meteorological Organization and Global Water Partnership (2017) Benefits of Action and Costs of Inaction: Drought Mitigation and Preparedness – A Literature Review, Integrated Drought Management Programme (IDMP) Working Paper 1. WMO, Geneva, Switzerland and GWP, Stockholm, Sweden. doi: https://doi.org/10.1201/b22009-7

World Meteorological Organization and UNESCO (1998) International Glossary of Hydrology, IHP/OHP-Berichte. Available at: http://www.wmo.int/pages/prog/hwrp/publications/international_glossary/385_IGH_2012.pdf

World Resources Institute (2013) Water Stress by Country. Available at: https://www.wri.org/resources/charts-graphs/water-stress-country (Accessed: 13 December 2020)

WorldPop (2020) Open Spatial Demographic Data and Research. Available at: https://www.worldpop.org/

Worldwide Governance Indicators (2015) Government effectiveness. Available at: http://info.worldbank.org/governance/wgi/pdf/ge.pdf

Wu, H., Hayes, M. J., Wilhite, D. A. and Svoboda, M. D. (2005) 'The effect of the length of record on the standardized precipitation index calculation', International Journal of Climatology, 25(4), pp. 505–520. doi: https://doi.org/10.1002/joc.1142

Wu, H., Svoboda, M. D., Hayes, M. J., Wilhite, D. A. and Wen, F. (2007) 'Appropriate application of the standardized precipitation index in arid locations and dry seasons', International Journal of Climatology, 27(1), pp. 65–79. doi: https://doi.org/10.1002/joc.1371

Ziese, M., Schneider, U., Meyer-Christoffer, A., Schamm, K., Vido, J., Finger, P., Bissolli, P., Pietzsch, S. and Becker, A. (2014) 'The GPCC Drought Index – a new, combined and gridded global drought index', Earth Syst. Sci. Data, 6(2), pp. 285–295. doi: https://doi.org/10.5194/essd-6-285-2014

APPENDIX A

Opportunities for the future versions of SO3 Indicators

This appendix outlines how the indicators described in this GPG could be developed and improved in the future to more effectively monitor progress towards SO3. It also presents the science required in order to implement such changes. The progressive improvement of the global indicators and monitoring systems should be undertaken through continuous engagement with the UNCCD country Parties.

This appendix also aims to set out some potential ways forward given existing gaps, the state-of-the-art and current and emerging directions in the scientific literature. It sets out to open up, encourage and inform future debates, rather than advance a particular direction or formal 'roadmap' for change. The direction of future SO3 reporting, which is subject to a wide range of practical considerations, will be discussed and agreed by the UNCCD country Parties, as appropriate.

For each of the selected indicators and their overall application presented in the SO3 GPG, there are undoubtedly improvements that could be made in both the near- and long-term. The following sections consider the potential future evolution of SO3 reporting, focusing on near-term developments that could be prioritized. This is necessarily a constrained forward look, rather than a comprehensive appraisal of future developments in drought risk assessment in general.

We give greater weight to considerations of available global datasets and indicators to better characterize the drought hazard (i.e., the Level 1 Indicator), because there is greater scientific consensus in this area and immediate practical ways forward are available. Moreover, the scope of this indicator determines how the exposure to the hazard should be conceived and measured. The definition of vulnerability factors should then be relative both to the nature of drought hazard(s) and to the exposure of populations and ecosystems.

Generally, for future development of this GPG, only indicators that are generic and valid for all country Parties should be considered, so as to promote harmonization across Parties and to ensure reliability in the methods developed. The integration of additional facets of exposure and vulnerability factors would require additional work to undertake testing and validation before implementing.

Broader context and background

Drought monitoring and risk assessment are rapidly evolving areas of science (see, for example, the reviews of Bachmair et al., 2016a; Blauhut, 2020), and while there are some areas that are relatively 'standard practice' (e.g. the Lincoln Declaration for Meteorological Drought Monitoring; Hayes et al., 2011), there are otherwise wide divergences in the approaches taken in the research and applied literature – particularly for drought vulnerability assessments. In setting out this GPG, we have recommended a pragmatic approach that balances the current state-of-the-art, validated and scientifically reviewed methodologies and data availability, on the one hand, with the need for relative simplicity and global applicability on the other. This appendix considers some of the limitations and gaps in the present approach set out in this GPG, and ways forward emerging from current and near-future scientific developments.

Alongside the evolution of science, other relevant factors affecting the scope for the global indicators concern the increasing availability of global datasets through the SDG reporting processes. There will be a need to work with Parties and with the custodians of the various emerging national and global datasets to identify additional factors that could be used in future iterations of SO3 monitoring.

Efforts have been taken in this GPG to recommend methods that include sex-disaggregated assessments of exposure and vulnerability, and this will be important for future GPG iterations and reporting processes. However, Pricope et al. (2020) note limitations in data available to support the desirable levels of additional gender disaggregation. The pre-processing of data to achieve this requires an extra level of technical capacity in some cases, and ways to build this capacity need to be taken in to account.

Level 1: Drought hazard

To address the limitations of the current approach recommended for SO3 Level 1 Indicator monitoring outlined in Section 1.5, it is recommended that the base meteorological drought index used should incorporate evapotranspiration, noting, however, that this would require endorsement by WMO and NMHSs. Furthermore, in order to fully assess drought hazard, other drought types should be included in the assessment of hazard under Level 1 monitoring in the future. Within the context of this SO3 GPG, Parties may utilize existing national indicators compatible with their capacity to monitor and assess other types of droughts (for example, agricultural and hydrological droughts). However, where such capacity does not exist, assessments of agricultural and hydrological droughts at the global scale require specialist datasets, the availability and development of which are discussed below.

Meteorological drought monitoring

As noted in Section 1.5, evapotranspiration is a fundamental water cycle component that is pivotal for drought assessment. Its lack of inclusion places a major constraint on the sensitivity of the Level 1 Indicator at present. We therefore recommend the inclusion of evapotranspiration as a top priority for assessment of meteorological drought – noting that it is a key variable for assessment of agricultural, hydrological and ecological drought.

We recommend that the Standardized Precipitation Evapotranspiration Index (SPEI) be adopted in the future as the basis for Level 1 Indicator monitoring, which would incorporate evapotranspiration, specifically, incorporating potential evapotranspiration (PE). Given its simplicity and format, it could be readily incorporated in the same way as SPI at present. The barrier is in adopting a suitable evaporation dataset at the global scale. Given the lack of directly observed datasets of evaporation, PE is normally estimated from meteorological datasets (e.g. temperature, radiation, wind speed and so on) or inferred from hydrological or land surface models.

There is a long-standing debate in the scientific literature concerning the most appropriate formulation to use. The physically based Penman-Monteith (PM) formulation is preferred but requires a wide range of meteorological inputs that are not readily available on a global scale. This has led to widespread adoption of simpler, empirical temperature-based methods, of which there is a broad range (e.g. the Thornthwaite and Hargreaves formulations). Different temperature-based methods and the PM approach can all yield significantly different outcomes, even on a catchment scale (e.g. Oudin et al., 2005), and these differences become problematic at the global scale, making harmonization of methods and approaches challenging.

Moreover, the difference between PE assessment methods becomes of paramount importance in the context of anthropogenic warming. The last decade has seen vigorous debate on the evidence for observed anthropogenic climate changes in drought at the global scale, with some studies suggesting significant increases (Dai, 2011a, 2011b), and others providing evidence to the contrary (e.g. Sheffield, Wood and Roderick, 2012); see also the summary of this debate by Trenberth et al. (2014). These divergent trends are largely due to the drought indices and different evaporation formulations used. This has implications for the selection of an appropriate indicator for quantifying drought hazard under contemporary and future conditions. Several studies highlight the sensitivity of future drought evolution to the PE formulation used (e.g. Orlowsky and Seneviratne, 2013; Dewes et al., 2017) and other methodological considerations (e.g. the role of plant physiological changes in an increasing CO_2 environment; Prudhomme et al., 2014; Dai et al.,2018).

In terms of current global availability, a monthly updated global SPEI monitor based on the SPEI using the Thornthwaite formulation is available.[97] For longer-term applications, an SPEI database using PM is available up to 2019 using the CRU_TS gridded meteorological data,[98] but this is not routinely updated. Global reanalysis products (e.g. NCEP/NCAR: Kalnay et al., 1996; ERA5: Hersbach et al., 2020) can, in principle, provide the variables needed for the PM formulation with an acceptable latency for a four-year reporting process for SO3 monitoring, but such global datasets have significant uncertainties and have not been fully appraised for their suitability for global PE estimation to support drought index calculation.

97 https://spei.csic.es/map/maps.html
98 https://spei.csic.es/database.html

In summary, we recommend future investigations to appraise suitable PE data pipelines for incorporation into an SPEI based variant of the current Level 1 Indicator. Pricope et al. (2020) have reviewed currently available global temperature datasets, but there remains a need for an intercomparison and assessment of PE based on these datasets. This should be done alongside PM-based estimation using estimated or reanalysis-based products outlined above. In all cases, the uncertainties of these approaches must be considered as well as the practicalities of application.

Agricultural drought monitoring

As noted in the drought definition in Box 1, 'agricultural drought' can be taken as a broad term, embracing both the hazard (primarily through soil moisture) as well as impacts (e.g. impacts on crop growth). Soil moisture is a fundamental variable for assessment of agricultural drought, as well as being key for understanding propagation from meteorological to hydrological drought. In situ soil moisture observations are generally very limited in their spatial coverage – while detailed monitoring campaigns are common at a field to catchment scale, and some national observatories exist, there are no large-scale international archives. For global applications, soil moisture datasets are typically based on earth observations (EO), using a range of satellite retrievals, or hydrological model or land surface model outputs (e.g. Cammalleri et al., 2017). Some products use a combination of these sources, blending EO and model outputs. This is beneficial as both sources have inherent limitations: satellite retrievals typically only sample a very narrow surface layer and are affected by vegetation and other confounding factors; large-scale models are, inevitably, subject to many uncertainties.

Future work should appraise current EO and model-based soil moisture products for their potential inclusion. These datasets are routinely used in some global drought-risk mapping initiatives by UNDRR, JRC, IPCC and others. However, global soil moisture datasets from EO or hydrological/land surface models are subject to major limitations and there are significant barriers to their application on the ground. A review of both ground-based and satellite soil moisture products, and their various strengths and weaknesses, is provided by Peng et al. (2017) and Babaeian et al. (2019), while Peng et al. (2021) consider the state-of-the art and advances in satellite soil moisture on the horizon. Future work should also appraise the suitability of soil moisture indices for application in the GPG. There are many soil moisture indicators and specific indices that have been proposed for drought monitoring, including various versions of a Standardized Soil Moisture Index (AghaKouchak, 2014; Carrão et al., 2016). While these and other approaches to quantifying anomalies may be readily integrated into the scheme used for the current Level 1 Indicator, there are many other ways of representing soil moisture status relevant for particular purposes (e.g. soil moisture deficits, as commonly used in agricultural and hydrological applications), which may be more meaningful. Agricultural drought monitoring would also benefit from appraisal of datasets and indices dealing with vegetation conditions, which are a readily monitored indicator from space. Vegetation condition can be used as a hazard indicator but also an 'impact' indicator (e.g. Bachmair et al., 2018) and could, therefore, also be useful for exposure and vulnerability appraisal. A number of optical earth observation missions are available and numerous vegetation indicators, notably the NDVI, Vegetation Condition Index (VCI) and Vegetation Health Index (VHI) are available and have been tested to determine suitability for drought impacts monitoring at national to continental scales (e.g. Bachmair et al., 2018). Vegetation indicators such as these are central to national and regional drought monitoring across North America and Europe, and most parts of sub-Saharan Africa as well as in other drought-affected regions. These datasets and indices would also be advantageous for ecological drought monitoring.

Hydrological drought monitoring

Hydrological drought depletes river flows and ground water levels, and is one of the mechanisms through which drought impacts manifest themselves most severely on societies and ecosystems. Indicators for hydrological drought are readily available and widely used in research and practice (e.g. see the review of Van Loon, 2015). A Standardized Runoff Index (for modelled gridded runoff) and Standardized Streamflow Index (SSI) have been proposed and are increasingly widely used for monitoring and risk assessment. A major limitation for the characterization of hydrological droughts is the availability of adequate global data sets of hydrological variables. Given acute barriers to data exchange (Viglione et al., 2010), even regional or continental-scale databases of streamflow are limited and generally not fit for purpose for hydrological assessments at global scales (Hannah et al., 2011). While there has been significant effort

invested in collating global datasets (notably the Global Runoff Data Centre (GRDC)[99]) and making them available (e.g. the GISM archive; Do et al., 2018), these are rarely available with suitable latency, with most of the world not updated on even an annual basis. They are also limited in their spatial coverage and biased inevitably towards data-rich countries, with sparse coverage in large areas of Africa and Asia.

An alternative approach, in principle, would be to use gridded model outputs from global hydrological models (GHMs) or land surface models (LSMs), which have the advantage of providing continuous fields of runoff, analogous to the gridded precipitation products currently used in the Level 1 Indicator. Such an approach would allow routine annual updating, although in practice this is rarely yet possible in an operational setting given the requirement of these models for up-to-date meteorological datasets that are needed to drive the GHMs or LHMs. Moreover, the uncertainties in such models are very high, and there are very real scientific barriers to their widespread adoption. Global models provide a wide spread of outcomes for even simple indicators like annual mean flows of major rivers. Nevertheless, they are continually improving (e.g. Prudhomme et al., 2014; Schellekens et al., 2017). Future work should appraise these sources for their potential to support a hydrological drought indicator. There is a large range of potential models available, but there have been efforts to consolidate these through intercomparison studies with large model ensembles (e.g. Earth2Observe; Schellekens et al., 2017) which provide a good foundation for evaluation of model outputs for suitability for drought monitoring.

In practice, updated global runoff estimates may most readily emerge from global hydrological status monitoring efforts, notably the Global Flood Awareness System (GLOFAS) (Harrigan et al., 2020) and the WMO-sponsored Hydrological Status and Outlooks System (HydroSOS).[100] Of course, while future models may provide a route to obtaining global coverage and the capability for routine annual updates, the runoff projections are likely to be subject to high uncertainties for the foreseeable future. The accuracy of model projections and fitness-for-purpose for drought estimation will therefore need to be rigorously assessed and ground-truthed against observations in those areas where this is possible.

Bringing together monitoring of drought types

Future inclusion of different drought indices for meteorological, agricultural and hydrological droughts will undoubtedly lead to a more nuanced picture of the drought hazard that better reflects drought as a multi-faceted phenomenon. However, it inevitably raises an important question: how should the hazard be represented – through a single combined, integrated indicator that blends each source indicator, or via a system of separate indicators? This is a question which has exercised drought monitoring programmes for many years, with significant debate between the 'combined' indicator approach and the 'basket-of-indicators' approaches (e.g. Lloyd-Hughes, 2014; Hannaford et al., 2019). The motivation behind the 'basket' approach is to provide sensitivity to different impacts to ensure relevance to different sectors, so any effort to combine the indicators risks degrading this granularity; equally, policymakers may be more inclined towards a single indicator.

Practically, this question has been addressed by the development of multivariate methods, which are reviewed extensively by Hao and Singh (2015). A number of approaches are taken to blending hazard indicators. Many approaches employ multivariate statistical analysis to perform some merging and weighting of individual indicators, while others rely on subjective combinations, and still others use a combination. From an applied perspective, notable examples of composite indicators are the European Drought Observatory (EDO) Combined Drought Indicator (CDI), which uses a quantitative blending approach; and the US Drought Monitor (USDM), which integrates objective indicators (including the SPI) alongside expert judgment. In addition to the USDM, the latter has formed the basis for several national and regional drought monitoring programmes globally.

While these provide a useful conceptual basis for integration, if combined indicators are adopted as a way forward, future work would need to focus on appropriate schemes for integration of the chosen hazard indicators. There would be wider benefits to this endeavour – as well as integrating different drought 'types', it would also allow potential integration of different timescales rather than just the SPI-12 as featured at present.

99 https://www.bafg.de/GRDC/EN/Home/homepage_node.html

100 https://public.wmo.int/en/our-mandate/what-we-do/application-services/hydrosos

Finally, the 'composite' and 'basket-of-indicators' approaches are not mutually exclusive, and the greatest benefits accrue from adopting both to balance high-level appraisal of drought hazard with the finer-scale and impact-based/sectoral-focused detail emerging from having a multiplicity of indicators. Future SO3 reporting could be hierarchical, with some reporting focused on a high-level single combined indicator – perhaps utilizing the GDCS, under development through GMAS (as described in Section 1.4.1). This would also enable Parties to assess the status of the different hazard indicators in relation to drought impacts in order to plan more specific and effective mitigation and adaptation strategies. Ideally, exposure and vulnerability indicators would also be disaggregated in an analogous way.

Level 2: Drought exposure

Alongside the exposure of populations, SO3 and intended impacts also refer to effects on the ecosystems that the populations depend on. As discussed in Section 2.5, this was not included in this iteration of the GPG, which was based on the Decision 11/COP.14 interpretation of the Level 2 Indicator as the 'population exposed to drought'. However, emphasis is placed on both populations and ecosystems in the wording of SO3, and ideally both should play an important role in the assessment of drought exposure in future reporting processes.

The need for an ecosystem component in assessing drought exposure is acknowledged by Hagenlocher et al. (2019) and Meza et al. (2020), and in ICCD/COP(14)/CST/7. Meza et al. call for a socioecological-system (SES) perspective, especially when assessing drought risk in the context of agricultural systems and where livelihoods depend on ecosystems and their services. This can help to better understand the role of ecosystems and their services not only as a driver of drought risk, but also as an opportunity for drought risk reduction.

The Good Practice Guidance for SDG indicator 15.3.1 already presents methods and datasets available to subset the land area under drought according to a series of land cover or ecosystem types (Sims et al., 2021), with the relevant global datasets already integrated to the Trends.Earth platform.

A range of gridded global datasets are available from FAO to quantify the assets that are associated with different production systems – e.g. livestock, irrigation systems, productive trees, and others. For the next iteration of this GPG, it may be useful to consider whether some guidance on the application of the landscape approach could be developed.

The expected impact of SO3 concerns not only populations made up of individuals, but also communities that interact with nature as part of the ecosystems. Therefore, it is important also to characterize the exposure of communities at different scales. Identifying the communities that are more or less exposed is enables more effective targeting of national strategies. As such, the categorization of land use could also be extended to include urban and rural population classifications. At a sub-national level, the outcome of the Level 2 Indicator is determined by the distribution of the population, which, in turn, is likely to be influenced by the distribution of the rural and urban populations. The inclusion of these classifications would help to identify the regions and associated activities where exposure is more prominent, such as, for example, agricultural and farming activities in rural areas. Relevant data is already available in the form of demographic statistics from the World Bank, and gridded spatial data such as the Global Urban-Rural Mapping Project (GRUMP) produced by the Gridded Population of the World (GPW). The inclusion of a rural-urban category would, therefore, be a relatively straightforward process for future iterations of the GPG, and would add value to the interpretation of the Level 2 Indicator.

The mapping of ecosystem types can be helpful to further identify the populations in extensive rangeland systems and production landscapes that are affected by drought. Many of these are transboundary in nature. Precipitation deficits in one area of these production landscapes can cause people and livestock to migrate into other areas – meaning that the event of a meteorological drought in one part of the landscape can be expected to affect people and production systems across other parts of the same landscape or region. Transboundary rivers, catchments and aquifer systems can cut across ecosystems and continents – carrying the effects of drought from one area to another, and affecting different sectors of the economy. These can transfer problems including water stress and quality threats from upstream to downstream areas.

There is a well-established consensus (reflected in the work of Carrão et al. and others) that people who are already living with water stress are exposed (and more vulnerable) to drought. Carrão et al., the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) and others recommend the use of available global datasets on Baseline Water Stress to map the areas and populations concerned (WRI, 2020). Furthermore, all countries are committed to applying the available global methods for monitoring water stress under SDG indicator 6.4.2.[101] The SDG indicator 6.4.2 guidance is useful for defining the exposure of different sectors, livelihoods, and ecosystems to drought risk. It uses generic classifications for economic activities and calculation of their annual water requirements, and more recently provides guidance on assessing the water requirements for ecosystems, also known as environmental flows.[102] Some further review may be needed to fully assess the extent to which countries are already using the SDG indicator 6.4.2 monitoring methods – and where capacity needs may still remain; the last global review of this SDG indicator was conducted in 2018.[103]

The decrease in availability of water resources is seen as another important sub-indicator in the classification of exposure to drought. However, consideration needs to be given to the current limitations of the data needed to support this component. The Baseline Water Stress dataset (World Resources Institute, 2013) currently represents the year 2013 only, with the frequency of updates not specified. Therefore, the inclusion of this component in any future methodology should fully explore such limitations in regard to a four-year reporting process, and how useful and appropriate this would be. An alternative proxy could be the availability of drinking water; however this is again reliant on the availability of data, which is likely to be variable between countries.

In cases where countries wish to describe exposure to economic loss and damage that could occur in the event of a drought, they can elect to do so using the methods provided for reporting on SDG target 1.5 and the Sendai target C on economic losses due to droughts and other disasters. However, there is a need to select only the drought-related aspects of the existing global datasets. The challenges of isolating the impacts of drought on society and the environment – which is particularly the case for direct (and indirect) economic losses – is recognized in UNISDR (2017). For guidance on the economic value of productive ecosystems, countries may choose whether or not to make use of the guidelines that are available through the Initiative on the Economics of Land Degradation.[104] The World Bank Wealth Accounting and the Valuation of Ecosystem Services (WAVES) partnership is also working with some countries on their national systems for valuation of ecosystem services, and the UN General Assembly has recently adopted, in March 2021, a revised global system for ecosystem accounting.[105]

Level 3: Drought vulnerability

Drought vulnerability assessments are intrinsically multi-dimensional in nature, which is why a composite indicator is recommended in this GPG. However, in order for this indicator to be of use for monitoring progress on the ground, the components and factors used should be relevant to the needs of the assessed system (country, sector, population). In turn, physical and institutional capacity is needed to undertake the assessments at an appropriate level. Vulnerability is an inherent characteristic of a population (or ecosystem) that increases the risk of negative impact in the case of the exposure to the hazard. As such, improvements in hazard and exposure assessments in line with improvements in vulnerability assessments will significantly improve the overall understanding of risk to humans and ecosystems (as illustrated in Figure 1).

[101] The custodian of the guidance, reporting and available datasets is the FAO.
[102] https://www.unwater.org/publications/incorporating-environmental-flows-into-water-stress-indicator-6-4-2/
[103] http://www.unwater.org/publications/progress-on-level-of-water-stress-642/
[104] https://www.eld-initiative.org/en/who-we-are/about-eld/
[105] https://seea.un.org/content/seea-experimental-ecosystem-accounting-revision

The Drought Vulnerability Index (DVI) proposed in Chapter 3 of this GPG describes vulnerability factors that relate to the social, economic and infrastructural vulnerability of populations to drought. The suggested components and factors were selected based on their use in peer-reviewed studies, which provide scientific validation to the methods. Future refinement of the DVI should focus on more effectively defining both the components and the factors within them that are more relevant to the needs of individual Parties, such that the drought vulnerability assessment provides a clearer view of the populations and ecosystems that are more (or less) likely to suffer loss and damage due to drought, and the effectiveness of drought mitigation, adaptation and resilience planning at country level.

This refinement can be supported through multi-lateral agreement on best factors to use at regional levels, where possible. This includes meeting the harmonization/standardization criteria set in Decision 11/COP.14. This would improve the 'comparability' criteria of the DVI, also set in Decision 11/COP.14, but would more importantly begin to improve the 'sensitivity' of the DVI to the specific needs of a country Party. These processes should go hand-in-hand with further research on sector, context and scale-specific indicators, and the development of an indicator library that could be used for different contexts, as recommended by Hagenlocher et al. (2019).

Ideally, the selection of factors and the definition of the components should be done at country level through a validation process. Factor validation and weighting scheme methods suggested by Crossman (2019) include conducting field surveys, community meetings and interviews; gathering expert opinions; and consulting specialized literature. However, these are time and resource heavy processes, especially when done correctly (such as involving the most vulnerable populations in the surveys), and the expertise is not always available. Further research on the sensitivity of the contribution of individual factors to an overall vulnerability assessment is advised. Similarly, further research and validation is needed to develop a global approach and method for the weighting of vulnerability factors (Hagenlocher et al., 2019).

Recent reviews have suggested the use of impact information to verify and validate vulnerability assessments (González Tánago et al., 2016; Blauhut, 2020). Factor-based vulnerability assessment studies have used this method of verification of results, (e.g. Naumann et al., 2014; Kreibich et al., 2019; Meza et al., 2020), but all highlight the lack of impact data in general, and especially the poor availability of impacts caused by droughts specifically. Droughts are slow-onset, long-term hazards, which means that assigning impacts can be challenging (UNISDR, 2017), particularly at the global scale. However, reporting for the purposes of Sendai Targets A to D, in principle, provides global-level drought-specific impact data. Such data could support the verification of vulnerability assessments and methods, in turn significantly improving them and enabling them to be better tailored to specific sectors and regions. In addition, the input from vulnerable populations who have been (and should increasingly be) supported to address drought challenges (King-Okumu, 2019) can be another conduit of information to help verify and validate vulnerability assessments.

Improved availability of spatially explicit vulnerability data (for example at sub-national levels or data in a gridded format; Meza et al., 2020) would enable Parties to more readily use the Tier 3 VA, and greatly improve the sensitivity of the DVI and usefulness of their assessment. Linked with improvements in assessing the hazard of different drought types, the vulnerability assessment would be able to provide a larger number of Parties vulnerability information on the key sectors that could be at a higher risk from drought, and hence develop appropriate policies and plans towards mitigating, adapting, or enhancing resilience to drought. Greater availability of gender-disaggregated information would further enable Parties to decide whether particular types of drought (e.g. hydrological or agricultural) disproportionately affect women, or particular production systems that are associated with women's activities and sources of income (e.g. in countries with lack of access to water during hydrological droughts).

In order to capture the efficacy of the drought policies and plans at national, local and municipal levels, future versions of this GPG may consider the inclusion of a factor related to the existence of these plans for drought, following the established guidelines provided for Target E of the Sendai Framework (UNISDR, 2017) and SDG target 1.5, which focuses on disaster risk reduction planning more broadly.[106] This could capture the extent to which Parties are proactively taking steps to address drought risk and are building their relevant social institutions. UNCCD is already working with Parties to develop management plans, and it is with this in mind that the recommendation is being made; but as stated in Section 3.4.2, drought-specific reporting would need to be explored and validated. The UNEP Adaptation Gap Report 2020 provides guidance on how to define the effectiveness of each Party's policies and adaptation plans.[107] The global datasets and inventories of policies and plans for adaptation to climate change (including drought) emerging from these activities could also be leveraged.

The final but critical opportunity for the future of the Level 3 Indicator reporting is the inclusion of an ecosystem component to the DVI. There is evidence for the strong link between ecosystem services and human vulnerability to drought. For example, Hagenlocher et al. (2019) showed that drought risk for agricultural systems is exacerbated by land degradation and soil erosion, but a better understanding of the role of ecosystems (and their services) as both a driver of drought risk and an opportunity for increasing resilience is required. As stated in UNISDR (2004), "As natural resources become more scarce the range of options available to communities becomes more limited, reducing the availability of coping solutions and decreasing local resilience to hazards or recovery following a disaster. Over a period of time, environmental factors can increase vulnerability further by creating new and undesirable patterns of social discord, economic destitution and eventually forced migration of entire communities." This statement clearly demonstrates the need for ecosystem vulnerability assessments from the human perspective.

The method outlined in this GPG for Level 3 Indicator monitoring could allow for the addition of other components, which could include ecosystems, but as explained in Section 3.1 this was not done due to the lack of scientifically approved and globally validated methods and factors for meaningful assessments of ecosystem vulnerability. In order to properly address ecosystem vulnerability, and address SO3 fully, we need to consider vulnerability from the perspective of the ecosystem, as well as the services it provides to the population. At present, only a few studies include environmental factors (Hagenlocher et al., 2019), which were predominantly aligned to ecosystem services. Ecosystems are diverse, differ in their resilience to drought, and are directly impacted by human-activity, and research on ecosystem vulnerability to climate change have shown the complexity of assessing ecosystem vulnerability (De Lange et al., 2010; Hagenlocher et al., 2018; Weißhuhn et al., 2018), much like the complexities of assessing human vulnerability. Hence, moving forward, future research needs to establish and validate methods and factors to monitor ecosystem vulnerability more comprehensively for this component to be added to future versions of the GPG. In the short term, future reporting rounds may consider including a complete, separate drought vulnerability assessment for ecosystems in addition to that of populations. Such activities could build on existing monitoring and reporting activities, such as SDG indicators 6.4.2, 15.3.1,[108] UNCCD Strategic Objectives 1 and 2 monitoring, and the revised global system for ecosystem accounting adopted by the UN General Assembly in March 2021.

A note of caution to future research, however, is that transparency in the whole process of vulnerability (and risk) assessments, from the definition of vulnerability, to the conceptual frameworks, methods, selection of factors, and weighting, has to be improved to enable comparability and thus progress this area of research (González Tánago et al., 2016; Hagenlocher et al., 2019; Blauhut, 2020) for the benefit of country Parties.

[106] https://unstats.un.org/sdgs/metadata?Text=&Goal=1&Target=1.5

[107] https://www.unenvironment.org/resources/adaptation-gap-report-2020

[108] https://unstats.un.org/sdgs/metadata?Text=&Goal=15&Target=15.3

©Unsplash

United Nations
Convention to Combat
Desertification

Platz der Vereinten Nationen 1
53113, Bonn
Germany

www.unccd.int