Baseline Assessment of Drought Impact Monitoring

WEATHER CLIMATE WATER

WORLD
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WMO-No. 1355

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We thank the following reviewers for their thoughtful comments and contributions:

Micha Werner, IHE Delft Institute for Water Education (UN-IHE), Kingdom of the Netherlands
Hanna Plotnykova, United Nations Economic Commission for Europe (UNECE)
Yutae Lee, K-water, Republic of Korea
Marthe Wens, Vrije Universiteit (VU) Amsterdam, Kingdom of the Netherlands
Frederik Pischke, Umwelt Bundesamt, Germany
Marcelo Uriburu Quirno, National Commission on Space Activities (CONAE), Argentina
Richard Heim, National Oceanic and Atmospheric Administration, United States of America
Mario López Pérez, International water consultant, Mexico
Caroline King-Okumu, The Borders Institute, Kenya
Andrea Toreti and Dario Masante, European Commission Joint Research Centre
Kerstin Stahl, University of Freiburg, Germany
Monika Bláhová, CzechGlobe, Czechia

Recommended citation: Smith, K.; Walker, D.; Zhang, B. et al. *Baseline Assessment of Drought Impact Monitoring*; Integrated Drought Management Programme (IDMP), Integrated Drought Management Tools and Guidelines Series 3; World Meteorological Organization (WMO) and Integrated Drought Management Programme (IDMP): Geneva, 2025.

WMO-No. 1355

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ISBN 978-92-63-11355-9

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INTRODUCTION

Why monitor drought impacts?

Drought can undermine human health, livelihoods and communities, and reduce the ability of natural systems to provide wildlife habitat and ecosystem services. Drought caused more than 700 000 deaths from 1970 to 2019, mostly in Africa (*2021 State of Climate Services: Water* (WMO No. 1278)), with a disproportionate burden falling on women and girls (UNCCD, 2022).

There are three main reasons to track the effects of drought: (1) to understand and reduce vulnerability and *increase resilience* to future droughts, (2) to be able to provide timely, relevant *relief*, and (3) to enhance scientific understanding and knowledge through *research*, which can ultimately lead to further reductions in the root causes of vulnerability.

Increasing resilience: Tracking the negative effects of drought in detail flags systems with underlying vulnerability or unsafe conditions that need attention, and these systems become opportunities to mitigate the impacts of future drought.

Relief: Knowing where drought is having an impact and whom or what it is affecting makes it easier to get assistance to people in time to support recovery from the impacts.

Research: A more detailed understanding of the impacts of drought can translate into more certainty for decision makers.

WMO and the International Federation of Red Cross and Red Crescent Societies have proposed the use of impact-based forecasting to anticipate the effects of hazards. This would enable improved planning and implementation of targeted preparatory actions to reduce impacts (Harrowsmith et al., 2020; *WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services – Part II: Putting Multi-Hazard IBFWS into Practice* (WMO No. 1150). Drought impact data availability is a limiting factor (Boult et al., 2022).

Drought researchers have called for calibrating drought indices by comparing them with drought impacts (that is, by using drought impacts to bring meaning to physical measurements and calculations of drought) (Redmond, 2002; Stahl et al., 2023).

Defining drought impacts

The Global Water Partnership Central and Eastern Europe (2015) defines a drought impact as “a specific effect of drought on the economy, society, and/or environment, which is a symptom of vulnerability.” The United States (US) Drought Impact Reporter (DIR) defines a drought impact as “a loss or change at a specific place and time due to drought.” The European Drought Impact Report Inventory (EDII) definition is “negative environmental, economic or social effects experienced as a consequence of drought” (Stahl et al., 2016).

Challenges in identifying drought impacts are that the connection to drought may not always be apparent, drought may be one of many contributing causes, or drought may be an indirect cause (Kallis, 2008). Often, the focus is solely on agricultural impacts, but drought can affect many different sectors, including public water supply, energy, health, tourism, transport, infrastructure and industrial production. Drought exacerbates food and water insecurity and can trigger or multiply political instability, migration and conflict. Drought also affects ecosystems and can diminish the services that a specific ecosystem is providing to society. Examples include losses in plant growth, increases in fire and insect outbreaks, increases in soil erosion, and reduction in capacity to store water. Long-term losses in ecosystem productivity may result in desertification, an increase in less-productive, desert-like land area. The United Nations Office for Disaster Risk Reduction (UNDRR), in its *Special Report on Drought 2021* (UNDRR, 2021), depicts interconnections and the potential for cascading impacts between 10 different sectors: water supply, subsidence, energy, livestock, groundwater, transport, farming, health, ecosystems and social.

Drought impacts are highly context-specific and may arise from an interrelated set of human decisions and natural conditions (Van Loon et al., 2016). For example, increased rates of West Nile Virus have been tied to drought in certain regions (Paull et al., 2017), but drought interacts with several biological processes and is not the sole determinant. Temperature and lack of precipitation may work together to intensify conditions such as aquatic habitat degradation (Jonsson and Jonsson, 2009). Conditions such as poor forage may result from a combination of fluctuating temperature extremes and intermittent drought, as documented in Missouri in 2018 (Smith et al., 2021). However, drought impacts can be seen as a failure in the management or distribution of water as a temporarily scarce resource. Savelli et al. (2021) documented the uneven distribution of socially constructed vulnerability to water shortage in Cape Town, South Africa, 2015–2017, where water use restrictions implemented to avert "Day Zero," when the city would run out of water, disproportionately affected people with limited resources and exacerbated inequalities. In the United States of America (USA), dry wells for household water may result from increased pumping of groundwater for irrigated agriculture. In developing countries where people depend on subsistence agriculture, drought can lead to famine or mass migration, particularly when national governments do not have the will or means to protect their citizens.

Drought can also have direct or indirect impacts in areas far from the actual precipitation shortfall. For example, food prices and volatility may increase if one or more of the key breadbaskets of the world are affected by drought. Bar-Yam et al. (2015) reported that insecurity in South Africa in 2012 was triggered by an inability to afford food due to drought in the USA increasing the global maize price. Drought can also affect the supply chain for specific goods. During a drought in Taiwan in 2021, water use restrictions curtailed production of semiconductors, with severe effects on the production chain in many sectors globally, including electronics and the automotive industry (Narvaez et al., 2022).

In many cases, the complexity of societal and environmental drought impacts, including time lags and spatial diffusion, makes it difficult to attribute them to drought. A recent World Bank study bypassed the complex causality by comparing drought with gross domestic product (GDP), finding substantial effects in arid developing countries (Zaveri et al., 2023). These findings underscore the need to understand and monitor the full drought impact chain, so that actions may be implemented to reduce vulnerability. This provides a specific focus for political action. In some cases, there is even limited political will to attribute certain impacts to drought, since this might imply responsibility for a government to better protect the population from droughts or provide support during and after a drought. Conversely, some leaders may use the idea that drought is an unpreventable natural hazard or an act of God to absolve themselves of any responsibility for the well-being of their citizens. All these aspects are considered in the definition of drought impacts for the purpose of this publication, which is a rather wide understanding. Drought impacts are direct and indirect negative environmental, economic and/or social effects experienced under drought conditions.

Finding data on drought impacts requires at least an understanding of causal chains within sectors. Quantitative data may or may not exist. Even where there is no focused effort to collect quantitative data on drought impacts, drought-related quantitative data are likely to exist for other reasons, such as tracking agricultural production or sustainability metrics. In the absence of quantitative data, news stories, agency reports or gray literature may provide valuable information about the effects of drought over time (Stahl et al., 2023).

Local and contextual knowledge

Contextual knowledge is critical to understanding how drought affects a particular system. In fact, the concept of a "drought impact" is abstract, and probably makes more intuitive sense to climatologists or others who start from the vantage point of drought. In day-to-day life, people experience low well levels, crops wilt or die, hydropower produces less electricity, more animals congregate around fewer sources of water, and so on. Impacts related to agricultural commodities, hydropower and wildfire may be some of the most readily documented and quantified, because markets, methods and incentives are in place to assign economic valuation to losses (Lackstrom et al., 2013). A global survey by Bachmair et al. (2016a) found that crop yield and media reports were the types of drought impact data most frequently collected as part of drought early warning or monitoring systems. Most of this systematic drought impact monitoring occurs in an economic and/or technical context in countries with sufficient resources. Impacts such as famine and mass migration are more likely to be tracked by global humanitarian organizations in a context that is not specific to drought. For example, drought is just one of several predicting variables tracked by the Famine Early Warning Systems Network (FEWS NET). From the standpoint of the Sustainable Development Goals and human and ecosystem health, it is critical to address famine, migration and ecosystem health, although drought is just one driver of these complex phenomena.

Much valuable knowledge about the impacts of drought may appear first or only in narrative or textual information (Stahl et al., 2016; Lam et al., 2023). News reports or assessments by local sector experts forwarded to national coordinating bodies may include information from someone knowledgeable about local conditions who can confidently attribute an effect to drought. From that initial assessment or understanding of the system affected by drought, if resources and will are available, it may be useful to measure and record conditions over time, to understand the difference between normal and drought years. In this sense, impact indicators are similar to climate indicators. For example, what are normal well levels? What is normal crop yield? How many people need food assistance in a normal year compared with a drought year? How much time and energy do people expend getting water? How many wildfires occur in a wet or normal year compared with a dry year? How does hydropower production vary from dry to wet years? How much river navigation is normal? These questions suggest the importance of continual, rather than event-based, monitoring to establish a baseline of "normal" conditions.

In many cases the impacts of drought and water scarcity may be the same, especially from the perspective of those experiencing the impacts (IDMP, 2022). People with fewer socioeconomic advantages tend to bear the most dramatic impacts of drought and water scarcity, such as food or water insecurity, loss of livelihood or migration from rural areas. Drought impacts are symptoms of the vulnerabilities of systems, societies and individuals. Focusing on sustainable water resources development and on implementing the human right to water (United Nations, 2010) can reduce the impacts of water shortage, whether the shortage is due to strictly meteorological causes, chronic water scarcity or a combination of the two. From a management standpoint, addressing water scarcity is more under human control than drought itself, although drought monitoring and early warning should be incorporated into water management and planning.

It is important to note that a focus on drought impacts alone may yield interesting scientific results, but protecting people from the worst consequences of drought also requires contextual knowledge and resource mobilization. Regions with elevated vulnerability are often data-scarce or have no systematic data collection systems in place, perpetuating and exacerbating scientific attention inequality. Vulnerability assessments may be better able to focus on community-level vulnerability (at the level of "resource users") than post-drought impact assessments, which tend to be more top-down (UNCCD, 2019).

The populations most vulnerable to drought impacts may not be those involved in setting scientific research agendas on drought, which lean towards focusing on physical drivers and indicators of drought (Kchouk et al., 2022). Incorporation of local and traditional knowledge can help connect indicators of physical drought with the experiences and practices of farmers, livestock producers and others, but finding ways to express local knowledge in terms that are meaningful to decision makers requires effort, and vice versa (Giordano et al., 2013). Researchers such as Baudoin et al. (2016) recommend community-centric rather than expert-driven processes. Kchouk et al. (2022) recommend more effort to orient drought impacts research around sustainable development and human welfare.

The Hyogo Framework for Action, adopted in 2005, is a global blueprint for achieving "[t]he substantial reduction of disaster losses, in lives and in the social, economic and environmental assets of communities and countries." It calls for:

> ... early warning systems that are people centered, in particular systems whose warnings are timely and understandable to those at risk, which take into account the demographic, gender, cultural and livelihood characteristics of the target audiences, including guidance on how to act upon warnings... (UN, 2007).

The successor instrument of the Hyogo Framework, the Sendai Framework for Disaster Risk Reduction 2015–2030 also took this call for early warning systems in its Priority 4 calls on global actors up and developed it further:

> To invest in, develop, maintain and strengthen people-centred multi-hazard, multisectoral forecasting and early warning systems, disaster risk and emergency communications mechanisms, social technologies and hazard-monitoring telecommunications systems; develop such systems through a participatory process; tailor them to the needs of users, including social and cultural requirements, in particular gender; promote the application of simple and low-cost early warning equipment and facilities; and broaden release channels for natural disaster early warning information (UNISDR, 2015).

Also highlighting the need for attention to protect vulnerable people, the United Nations Secretary-General in March 2022 launched Early Warnings for All (*Early Warnings for All*), calling for every person on Earth to be protected by multi-hazard early warning systems by 2027. The associated action plan notes that a third of the world's people, mostly in developing countries, are not covered by disaster early warning systems (*Early Warnings for All*).

Purpose and capacity

To make data collection as effective as possible, it helps to consider the purpose for which data are being collected. Key questions in monitoring drought impacts relate to intent:

(1) WHY? What are you trying to prevent/mitigate? This is typically based on past experience with drought. It directly addresses the consequences of known vulnerabilities to drought and water scarcity.

(2) WHAT? What types of impact are you looking at? Direct or indirect? Using a holistic lens or focusing on specific sectors or systems? If you focus on this impact, which ones are ignored and why? What are the consequences of this choice for policymaking?

(3) TO WHOM? Who is impacted by this impact? And who is in general impacted by droughts? Are all voices, especially the most vulnerable ones, considered when monitoring this impact?

(4) FOR WHOM? Does the drought impact data collection scheme produce information of use to farmers, livestock producers, water suppliers or other grassroots, community-level decision makers? How can decision makers use this information? When and how do they need it? In addition to planning ahead to reduce the impacts of drought, decision makers may use real-time information to respond to emerging drought.

(5) HOW? What format are the data in? Are narrative accounts sufficient, or do decision makers need quantitative detail to respond? Is it important that impacts be clearly attributed to drought? Sometimes drought is one of many stressors contributing to a loss, which may complicate insurance or relief payments that are based on drought. But from the standpoint of the people experiencing the impact, the cause may be immaterial.

(6) WHEN and WHERE? Do the temporal and spatial scales of data collection and the unit of analysis allow local impacts to be identified? Drought impact monitoring at larger spatial scales or longer temporal scales may tend to mask impacts on individuals, households and livelihoods, particularly if the focus is economic (UNCCD, 2019).

(7) Lastly, it is critical to consider what information already exists about the impact. Is the impact already monitored consistently over time? Are there regular, recorded measurements of the impact itself or a relevant variable? Where does the information come from? Is it publicly available, selectively shared or closely guarded? Is there a centralized collection point? Do we need more eyes on the ground in more places? What is the temporal resolution of the existing data collection systems?

Degree of coordination or support

Collecting data that are sufficiently consistent in content, frequency and quality requires coordination (Redmond, 2002) and typically some form of institutional support. Citizen scientists need training and support, and crowdsourcing contributors need well-defined guidelines for participation. Research indicates that regular feedback is necessary for retention of participants, and a diverse range of motivations should be expected and nurtured (Walker et al., 2021; Lam, 2022). An institution may develop reporting infrastructure and then work with established networks to collect reports, or it may depend on the efforts of a handful of staff members to enter data. Evidence from drought impacts monitoring programmes in the USA and Brazil described later in this document showed that expecting the public to stumble across online surveys and submit impact reports is initially optimistic (until the programme has sufficient visibility); designating particular groups (such as an agricultural extension office) is more likely to lead to regular data submission, though at the expense of diversity in data contributors and contributions (Meadow et al., 2013). Also, the question of how to incentivize reporters is not trivial. Certain incentives or uses of the data, such as release of insurance payments, might compromise the quality of the results or raise a question about credibility in the eyes of those who are interpreting financially motivated reports. Building a system to archive and display data is a relatively straightforward computer science or geographical information system (GIS) task. Getting the information to flow is another question, involving allocating staff time, persuading people to take on additional responsibility, motivating volunteers, or accounting for volunteers' possibly self-interested motivation.

Transboundary issues

Droughts do not recognize borders; thus, transboundary cooperation will make drought management more efficient. Droughts and water scarcity became one of the biggest challenges leading to food insecurity in 2022 in different regions and transboundary basins across the world. For instance, according to the *State of the Global Climate 2022* (WMO No. 1316), in East Africa, home to such transboundary basins as the Nile, the Shebelle, Lake Victoria and Lake Tanganyika, rainfall has been below average for five consecutive wet seasons, the longest sequence in 40 years. Across the region, 20 million people faced acute drought-related food insecurity in January 2023. An estimated 60 000 of the 1.2 million people in Somalia displaced by the impacts of drought on pastoral and farming livelihoods migrated into Ethiopia and Kenya, with another 512 000 people in Ethiopia displaced due to drought. In Asia, China had the second-driest summer on record and the Yangtze River at Wuhan reached its lowest recorded level for August. In Europe drought conditions were also at their most severe in August, when rivers including the Rhine, the Loire and the Danube fell to critically low levels. The *State of the Global Climate 2023* (WMO No. 1347) documented continuing and intensifying issues, with prolonged climate-related displacement increasing vulnerability: migrants entering Somalia were stranded in the city of Bossaso in June and July, waiting for weather conditions that would allow them to cross the Gulf of Aden. In Hargeisa, extreme heat affected migrants, some of whom died from dehydration.

The Sendai Framework and other international commitments emphasize the value of transboundary data collection and water management (UNISDR, 2018). The Seventh Meeting of the Global Network of Basins Working on Climate Change Adaptation in 2023 included examples of drought management and drought impacts in several transboundary regions: Central Asia, Southern Africa, Europe, the Meuse Basin, the Niger Basin, the Cubango–Okavango Basin and the Lower Mekong Basin (https://unece.org/info/Environmental-Policy/Water-Convention/events/374647).

Centralized drought data collection

Some of the most systematic data showing the impacts of drought may serve specific purposes, such as providing a basis for evidence-based drought relief.

Departments and ministries of agriculture track and anticipate crop progress, including the impacts of drought. Examples include Intersucho from Czechia (https://old.intersucho.cz/en/), Drought Watch from a coalition of Central and Eastern European countries (Crocetti et al., 2020), India's Department of Agriculture and Farmers' Welfare, the US Department of Agriculture (USDA) Weekly Weather and Crop Report (https://usda.library.cornell.edu/), and Agriculture in Drought (https://agindrought.unl.edu), a joint effort of the USDA and the US National Drought Mitigation Center.

The USDA provides drought-related assistance to agricultural producers. The USDA's Risk Management Agency (RMA) provides crop insurance to protect against various causes of loss, including drought. The RMA's indemnified losses are a good source of data on drought impacts (Reyes et al., 2019), and may be the only systematically collected, readily accessible, quantitative dataset on drought impacts in the US. These data are incorporated into the annual Billion Dollar Disasters list compiled by the US National Oceanic and Atmospheric Administration (Smith and Katz, 2013). In Brazil, data are available from government sources, such as the Ministry of Integration and Regional Development (*Ministério da Integração e do Desenvolvimento Regional*), that are useful for locating and determining the severity of certain drought impacts. Such data include: the locations and numbers of crop insurance payouts (the *Garantia Safra*

Drought and related phenomena

A general definition of drought is a period of dry weather that goes on long enough to have noticeable impacts. The dryness can relate to a shortfall of precipitation – rain or snow – as well as heat and wind. Drawing from definitions used by United Nations organizations, the Integrated Drought Management Programme (IDMP) Glossary defines drought as follows: "(1) Prolonged absence or marked deficiency of precipitation. (2) Period of abnormally dry weather sufficiently prolonged for the lack of precipitation to cause a serious hydrological imbalance" (Integrated Drought Management Programme Glossary). Climatology-based drought indicators define drought relative to what is normal for a given place and time of year, using indicators such as percent of normal precipitation, or indices such as the Standardized Precipitation Index (Svoboda and Fuchs, 2016), incorporating only physical observations and mathematical calculations, without taking impacts into account. But others who use water in specific ways, such as farmers, livestock producers, water suppliers or fishers, may have other very specific understandings of drought, conceptually defining it based on lived experience or impacts. Ecosystems and natural environments may also function differently in the absence of normal amounts of water. In contrast to indices that are solely based on physical observations, the US Drought Monitor at least nominally incorporates impact information into weekly expert assessments of the effects of dry weather and heat.

Managers of water systems and others who make drought-related decisions frequently adopt operational definitions of drought based on specific, relevant observations, such as streamflow at a certain gauge. Taking it a step further, some predefine triggers, that is, thresholds of drought linked to specific actions.

A key characteristic of drought is that it comes and goes with weather patterns. Even though it may sometimes last for years, it is considered a temporary condition. In contrast:

- **Water scarcity** is socially constructed. The IDMP Glossary defines water scarcity as:

  > An imbalance between supply and demand of freshwater in a specified domain (country, region, catchment, river basin, etc.) as a result of a high rate of demand compared with available supply, under prevailing institutional arrangements (including price) and infrastructural conditions (Integrated Drought Management Programme Glossary).

  A classic example is the Colorado River Basin in the western USA, where water use agreements assume unrealistically high amounts of precipitation. The impacts of drought and water scarcity may be the same, for practical purposes, with drought exacerbating scarcity.

- **Desertification** is a process that drought may intensify. According to the United Nations Convention to Combat Desertification (UNCCD):

  > [Desertification is] the degradation of land in arid, semi-arid, and dry sub-humid areas. It is a gradual process of soil productivity loss and the thinning out of the vegetative cover because of human activities and climatic variations such as prolonged droughts and floods" (https://www.unccd.int/unccd-faq).

- **Aridity** – dry or desert-like conditions – is a permanent condition of some landscapes. When drought leads to ecosystem regime change, or desertification, it increases the amount of land with less productive vegetation. The IDMP Glossary's definition of aridity is as follows:

  > Characteristic of a climate relating to insufficiency or inadequacy of precipitation to maintain vegetation (*International Meteorological Vocabulary* (WMO No. 182)). Aridity is measured by comparing long-term average water supply (precipitation) to long-term average water demand (evapotranspiration). If demand is greater than supply, on average, then the climate is arid (Integrated Drought Management Programme Glossary).

programme), the quantities and routes of water tanker trucks, and the municipalities that have declared a state of emergency with the justifications. In Andean countries, disaster management agencies such as Instituto Nacional de Defensa Civil/Centro Nacional de Estimación, Prevención y Reducción del Riesgo de Desastres of Perú; Secretaría Nacional de Gestión de Riesgos of Ecuador; and Departamento de Gestión del Riesgo en Emergencias y Desastres of Chile have databases of historical drought impacts, along with other natural hazards.

DATA CHARACTERISTICS

Certain questions consistently arise in devising data collection schemes related to drought impacts. These are addressed in the sections that follow.

System/sector/category

The first question, related to the question of intent or purpose, is defining what impact or impacts to track. Who or what feels the impacts? Drought impacts occur within sectors and specific contexts. Sector-specific data that can be tracked longitudinally – consistently over time – could include crop yield, how much river depth affects cargo transport in dry conditions, how much hydroelectric energy a dam produces, area lost to wildfire, the number of river rafting trips or the number of water systems with restrictions.

Narrative data may be particularly useful in describing or evaluating compound impacts within a single system, especially if it is not possible to quantify each element separately. For example, farmers may experience reduced crop yield, dry wells, respiratory irritation from an increase in dust, and stress. Data collection could focus on the overall effect of drought on farmers, or on a single variable such as crop yield. Similarly, complex, indirect impacts such as the impacts of drought on river navigation and ultimately microchip production may be best accounted for individually, with descriptive narrative augmented by quantification where possible. A narrative account may also clarify what numerical data it would be useful to collect.

Several key distinctions arise in drought impact monitoring. One way to categorize drought impacts, derived from tenets of sustainability, is by whether they affect the economy, the environment or people. Sometimes people distinguish between direct impacts, such as crop loss, and indirect impacts, such as the loss of income from crop loss. Impacts may be tallied by economic sector, such as losses to agriculture, energy, river navigation, tourism or other business, or by broader categories that may not have an economic association, such as municipal water supply, wildlife habitat and other ecosystem services, forced migration or famine. It is generally easiest to find longitudinal numerical data on drought impacts that have an associated market and/or insured value, with a government agency or producer organization coordinating and supporting centralized data collection.

Sector-driven data such as tourism industry records, health and epidemiological data, hydropower generation data and crop yield records may show the impacts of drought. Likewise, a number of citizen science databases and other records may show a drought signal, particularly for those with the expertise to interpret domain-specific data, such as timing and location of sightings of different species. Over time, numerical data help quantify the impacts of drought – how much crop yield or energy production was lost to drought, or how much disease burden increased. The simplest and most effective tallies of drought impacts are probably produced by professional bureaucracies charged with managing or tracking a resource, such as hydropower or crop yield. They have the records and the expertise to compare dry-year production with normal production.

Event-driven versus longitudinal data

Many drought impact databases are event-driven, with records of specific impacts that occurred due to drought. Event-driven databases such as the US Drought Impact Reporter (DIR), the European Drought Impact Report Inventory (EDII) and the Caribbean Climate Impacts Database, discussed below, are typically populated with data that first appeared in narrative form, in news stories, reports from governments or non-governmental organizations (NGOs), or in scientific literature. One of the advantages of this type of data is that by definition, the events are attributed to drought, via local and/or expert knowledge (Lackstrom et al., 2013; Stahl et al., 2016).

Event-driven records of drought impacts may or may not include quantification, depending in part on available information. In order to quantify a drought impact – to measure the effect of drought – we need quantitative data, over time, to be able to contrast drought and non-drought conditions. Crop yield and hydropower production are examples of processes where the connection to drought is more obvious, and where incentives such as recouping insured losses and selling energy create methods and incentives to quantify losses and assign economic value.

Collecting data over time (these are known as longitudinal data) allows for assessment of baseline conditions and measuring change. Only with such baseline data can the relative severity of drought impacts be appreciated. Comparing longitudinal data with drought indices can produce an estimate of effect size. Alternatively, consultation with domain experts may provide a good sense of what normal yield or production would be, and if numerical data exist, drought years may be compared with normal ones. In addition, longitudinal monitoring reveals when drought is becoming a new normal and how certain vulnerabilities to drought change over time.

Scale

Depending on the application, national or global datasets, such as products of remote sensing, may not come in a resolution that would allow for detailed impact assessment. Subnational and local or community levels are necessary for thorough resolution (Bachmair et al., 2016a; Torelló-Sentelles and Franzke, 2022).

The question of scale also relates to the question of who or what is feeling the effect of drought. Producers in one area may lose crop yield and income due to drought, producers in another area may gain income as prices rise in response to reduced supply, and prices may rise for consumers. Drought may be devastating for the farmers losing crops and income, be beneficial for farmers whose crops sell for higher prices, and create hardship for consumers, particularly those least able to afford higher prices. Insurance may protect farmers, but when government-subsidized, may pass costs along through higher taxes.

Place

Drought impacts and conditions need location information. Depending on the unit of aggregation – national, regional, city, local administrative jurisdiction, farm, park or nature reserve, tribal lands, etc. – location information may be associated with a specific latitude–longitude point or with a set of geopolitical or natural boundaries. Drought impacts gathered from news accounts may incorporate a variety of spatial scales and jurisdictions. An additional challenge here is that drought events are hard to delineate in space and time, as the location and intensity of a drought may shift during its lifetime.

Time

Data on drought impacts or conditions include a time element. It may be a single annual date for crop loss, or it may involve observations over time with a start and end date. It could also be observations on intermediate conditions that may lead to a conclusive impact, such as stressed crops resulting in lower yields or declining water levels leading to later shortage. The dynamic nature of drought events, which can have gradual onsets or endings, with impacts sometimes offset in time or space from the drought itself, poses further challenges in reporting drought impacts.

For data that have start and end dates, only reporting the year for start date may not provide enough information to use in an analysis (Bachmair et al., 2016a). End dates are often left out of event-driven impact reporting, such as databases relying on news stories, leading to issues in data analysis and causing the dataset to lack uniformity (Torelló-Sentelles and Franzke, 2022). When considering rapid onset or short duration events, such as flash droughts, timely impact monitoring becomes more important for increased understanding of these phenomena and appropriate response (Walker et al., 2024a).

DROUGHT IMPACT DATA COLLECTION EFFORTS

Appendix A provides an overview of operational systems for tracking drought impacts or related issues such as food and water security. It includes all systems known to the authors and the network of collaborators who commented on this report. The main criterion for inclusion is that the system is currently available or that its existence could be documented.

Event-driven databases

Some of the most visible, readily publicly discoverable drought impact databases are event driven. Entries are prompted by the occurrence of drought, and depend on someone documenting the impacts of drought, and on someone else finding that record and entering it into a database. The original documentation of impacts comes most frequently from governments or NGOs, scholarly publications or news stories. Although there may be an effort to quantify monetary losses or loss of life, the impacts themselves may be the unit of analysis. The US Drought Impact Reporter (DIR), the European Drought Impact Report Inventory (EDII), the Emergency Events Database (EM-DAT), DesInventar Sendai and the Caribbean Climate Impacts Database all work this way (for more information, see Appendix A, which provides a list of systems for monitoring drought impacts). As these systems are quite labour-intensive, they may lean towards fully realized, summative impacts, such as final crop loss tallies at the end of a growing season. The records provide:

- An excellent beginning for research into drought impacts. A systematic review of research using EM-DAT records since 1996 found a steady increase in citation and use of the database over time, with initial use by health disciplines expanding into natural sciences, economics and other fields (CRED, 2022).
- Data for logistic analysis, examining whether a certain level of drought led to an impact (Blauhut et al., 2015; Stagge et al., 2015).
- The first stage of mixed methods research or response, highlighting issues that require further attention, such as systematic collection of numerical data. Many narrative impact reports also include information relevant for defining impact chains, the sector-specific models of drought risk that frame numerical analysis.

Drawbacks of event-driven databases are:

- Events across the world do not receive comparable amounts of attention (Bachmair et al., 2016a; Panwar and Sen, 2020).
- They highlight extremes, and do not provide data on evolving conditions leading to impacts (Lackstrom et al., 2013). Depending on staffing and protocol, they may be mainly retroactive.
- Different understandings of drought impacts hinder the comparability of drought impacts across countries and regions.

A comparison of disasters recorded in EM-DAT and DesInventar, including drought, found that the different data collection schemes and methodologies produced different damage estimates, and highlighted the need for a standardized approach (Panwar and Sen, 2020).

Caribbean Climate Impacts Database

Caribbean Institute of Meteorology and Hydrology
https://rcc.cimh.edu.bb/

Climate service providers in the Caribbean launched the Caribbean Climate Impacts Database (CCID) to help provide climate context to studies of damages and losses from severe weather. The Caribbean Institute of Meteorology and Hydrology (CIMH) worked with the Caribbean Disaster Emergency Management Agency and its partners, 2013–2015, to develop and launch the database, "an inventory of geo-referenced, climate-related impacts extending from 1780 to present in nineteen Caribbean states" (Mahon et al., 2018). CIMH staff go through official reports that have documented climate impacts, including impacts of drought, and enter impacts into the CCID. Drought impacts documented in the CCID provided valuable data for a recent drought scenario planning exercise for Grenada and St. Lucia.

DesInventar Sendai

United Nations Office for Disaster Risk Reduction
https://www.desinventar.net/DesInventar/ or https://www.desinventar.net/

DesInventar is a conceptual and methodological approach for framing and recording disasters, including those of small and medium scale. The approach originated in Latin America in the mid-1990s with researchers linked to the Network of Social Studies in the Prevention of Disasters in Latin America (Red de Estudios Sociales en Prevención de Desastres en América Latina (LA RED)). According to the DesInventar Sendai website:

> These groups conceptualised a system of acquisition, collection, retrieval, query and analysis of information about disasters of small, medium and greater impact, based on pre-existing official data, academic records, newspaper sources and institutional reports in nine countries in Latin America. This effort was then picked up by UNDP and UNDRR who sponsored the implementation of similar systems in the Caribbean, Asia and Africa. The developed conceptualisation, methodology and software tool is called Disaster Inventory System - DesInventar (Sistema de Inventario de Desastres) (https://www.desinventar.net/whatisdesinventar.html).

Lessons learned

In keeping with its mission, the DesInventar methodology emphasizes disaggregating spatial data to the most local level possible. The website's description of the methodology notes:

> One of the major lessons learned from the work done so far in the project is that the challenge of disaggregating the data is definitely the major difficulty that an inventory research faces.
>
> ...
>
> Researchers face the problem of disaggregating data very frequently and there are many instances where the problem has simply no solution, especially when going back in time many years and in cases where the original files are not available anymore. The methodology suggests several workarounds, some of them controversial or with severe implications in the usability of the data during the analysis phase (https://www.desinventar.net/methodology.html).

DesInventar's documentation includes a valuable discussion of sources of disaster information: official emergency management agencies, sectoral institutions such as ministries of agriculture or of public works, archives of relief organizations, academic data archives such as seismological (or in the case of drought, meteorological) records, and newspaper reports. Furthermore, the documentation provides a robust defense of the practice of using newspaper reports as a source: small disasters are not recorded anywhere else, media reports from different outlets can be cross-checked against each other, news media both report on and contribute to other official reports, newspapers keep organized and relatively accessible archives that often provide a longer historical record than other sources, locals have a good sense of newspapers' credibility, and "serious" media sources serving as the local paper of record provide a continuous history of events (https://www.desinventar.net/data_sources.html).

The methodology for systematically recording disasters at all scales provides data to support risk management discussions across institutions, from local to national level.

DesInventar Sendai is associated with the periodic Global Assessment Report on Disaster Risk Reduction.

A query for drought-related disasters across all countries, years and categories produced 27 081 results.

EDDI$_{ALPS}$

Alpine Drought Observatory
https://ado.eurac.edu/impacts

EDDI$_{ALPS}$ builds on and adds to EDDI (Figure 1) to tailor a drought impact dataset for the Alpine region (Stephan et al., 2021, 2023). The Alpine Drought Observatory was funded during 2019–2022 by the Interreg Alpine Space programme. Impacts data through 2020 are incorporated into the Alpine Drought Observatory tool. Users can filter and read impacts. In addition to reported impacts, the tool provides impact probabilities and vulnerabilities, calculated via logistic regression. A user could check drought status using one of the updated indices, and then consult the impact probabilities data to see how likely it is that impacts are occurring. EDDI$_{ALPS}$ classifies impacts as being related to either soil moisture or hydrology. The probability of soil-moisture impacts, mainly to agriculture or forestry, are computed based on the soil moisture anomalies dataset. The probability of hydrologic impacts, such as impacts on water supply, water quality and freshwater ecosystems, is calculated with the three-month Standardized Precipitation Evapotranspiration Index.

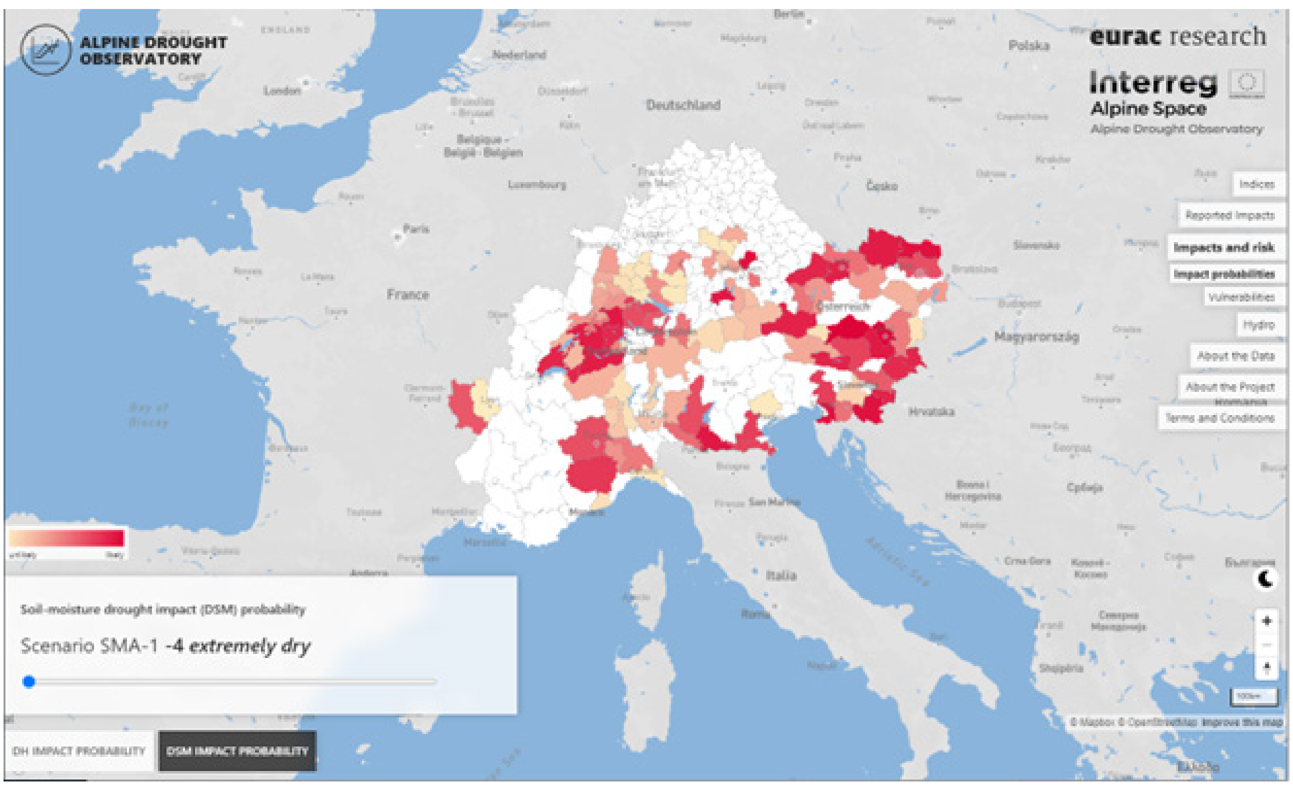


Figure 1. The Alpine Drought Observatory uses EDDI$_{ALPS}$ data to model probabilities of impacts. Shown here is the likelihood of soil-moisture-related impacts occurring under extremely dry conditions.

Source: Third party map. This map was taken from https://ado.eurac.edu/impacts on 31 May 2024 and may not fully align with United Nations and WMO map guidance.

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

EM-DAT

Center for Research on the Epidemiology of Disasters (CRED)
https://public.emdat.be/

Drought is one of the natural hazards tracked in EM-DAT, the Emergency Events Database of the Center for Research on the Epidemiology of Disasters (CRED). It was initially created with support from the World Health Organization and the Government of Belgium (https://emdat.be). Per UNCCD's Rapid Review (2019):

> The information is sourced from national governments as well as United Nations agencies (OCHA, IRIN, WFP, FAO), other international organizations (World Bank, IFRC), reinsurance companies (SwissRe, MünichRe, AON Benfield) and press agencies. The database therefore relies on methods used by these agencies and organizations.

The dataset includes information from a wide range of sources, including government agencies, NGOs, international organizations, media reports and other sources. Criteria for defining a disaster in EM-DAT are that an appeal for international assistance or a declaration of a state of emergency has been made, or 100 or more people have been reported affected or 10 or more people have been reported killed. CRED staff compile the data.

A query of EM-DAT in June 2023 found more than 800 drought-related disasters around the world from 1900 to 2022.

European Drought Impact Report Inventory (EDII)

(Blauhut et al., 2022)

The European Drought Impact Report Inventory (EDII) was compiled as part of the European Union-funded Drought – Research & Science Policy Interfacing (DROUGHT-R&SPI) project and was primarily intended for research on impacts and impact-to-indicator modelling. This meant that it had a very detailed classification scheme, with 15 impact categories and multiple impact types within each category. EDII's definition of drought impacts is "negative environmental, economic or social effects experienced as a consequence of drought" (Stahl et al., 2016). Like the DIR, EDII primarily collected information on negative environmental, economic or social consequences of drought, as opposed to the actual shortfalls of precipitation. There are no plans to continue the EDII at a pan-European level. Individual national or regional efforts may choose to use and archive impacts on a project basis (D. Masante, personal communication, 31 October 2023).

Researchers using EDII have been able to describe sector-specific likelihood of drought impacts occurring at different levels of drought (Blauhut et al., 2015) and characterize regional differences, such as more agricultural and water supply impacts in southern Europe, and forestry or energy impacts in northern Europe (Stahl et al., 2016).

European Drought Impact Database (EDID)

European Commission Joint Research Centre
http://edid-test.eu/

The European Commission Joint Research Centre launched the European Drought Impact Database (EDID) in 2024, incorporating impacts from EDII, the Irish Drought Impacts Database, the Czech database Intersucho and other efforts. As of October 2023, it included more than 14 000 unique records from 1970 to 2022 from countries across Europe, with the largest portion imported from EDII. Developers of the first phase of EDID report that their initial compilation of pan-European data reflects the geographic emphases of preceding efforts, with a disproportionate number of reports from Germany and Czechia. They also cite differences stemming from national reporting behaviours, language barriers, data availability and drought impact perception. The amount of data increases for more recent decades, as online news and information have become increasingly available over time (Szillat et al., 2023). EDID uses a more streamlined impacts classification system than EDII, with nine main categories: annual crops, perennial (permanent) crops,

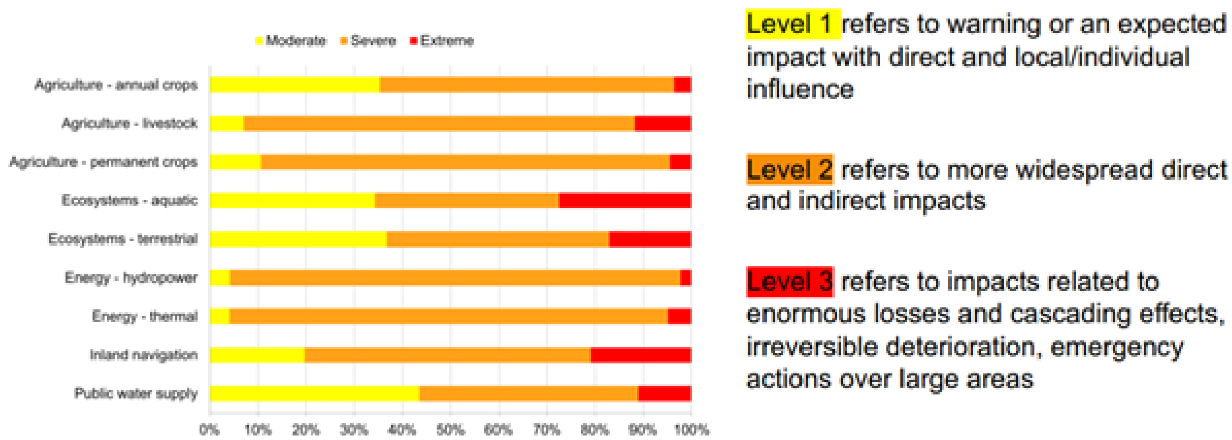


Figure 2. The European Drought Impact Database (EDID) includes a severity score to assess the intensity of impacts

livestock, hydropower energy, thermal energy, aquatic ecosystems, terrestrial ecosystems, inland (river) navigation and public water supply. The data model of EDID is impact-based rather than report-based. It defines a set of basic common features required for all records (such as georeferencing) in order to guarantee a basic amount of information and compatibility regardless of the sectors/systems. In addition, it provides a set of system-specific features, to allow for more detailed reporting and for customization.

Its developers anticipate that EDID will ultimately incorporate information from a greater variety of sources, and that accredited institutional or industrial partners from across the European Union will submit drought impact reports that will be validated by moderators (D. Masante, personal communication, 26 October 2023). To foster impact data collection, the database infrastructure will benefit from an open-source policy, so that stakeholders (for example, national agencies) can set up their own instances of the database and maintain records independently. One of the fields that they are asked to fill out is an assessment of the severity of the drought impact (Figure 2). Web media crawling will supplement manually entered information, especially for under-represented countries and for (near) real-time monitoring.

Irish Drought Impacts Database

https://zenodo.org/records/7216126

A similar approach has been used in Ireland to develop a historical drought impact database. The Irish Drought Impacts Database (IDID) was developed by Jobbová et al. (2022) from the Irish Newspaper Archive

Source Reference	Date of publication (ymd)	Description [quote]	Impact category	Type of Impact	Associated Impacts	Response measure
Freemans Journal	1768-06-07	"Extract of a letter from Carrickonshire, dated June 4. - This Day a most terrible Fire broke out at a Smith's Forge in New-street, which immediately communicated itself to the adjoining Houses, and burned with such Violence and Rapidity, that in the Space of about an Hour and a Half, there were upwards of one hundred thatched Houses burned to the Ground. The Great Drought we have had, together with the Want of Water seemed to favour this dreadful Conflagration.- We do not hear of any Lives being lost except a Child of Six Years Old."	C7_Public Water Supply	Local water supply shortage / problems (drying up of springs/wells, reservoirs, streams)	Fire (100 houses burned)	
Freemans Journal	1778-09-08	"The want of a proper supply of fresh water has for some days past very much disstressed the inhabitants of Dublin; and we are very sorry to acquaint our readers that since yesterday morning no a drop of water has come into the pipes from the Bafon, the old aqueduct from Templeoge being by the drought of the season reduced to so slender a rill that it would not supply a three inch ?bore, which the evaporation on so wide a surface as the City Bafon is computed in a sunny day nearly to waste as much water."...	C7_Public Water Supply	Local water supply shortage / problems (drying up of springs/wells, reservoirs, streams)	lack of water supply by Bafon aqueduct in Dublin	
Freemans Journal	1785-04-05	"Vegetation for culinary purposes was never as effectually burned up, as it is at present in all the gardens about Dublin. The continuance of a severe season, and the present drought, have scarcely left a vestige of Spring, in a country called *the land of zephyrs*."	C1_Agriculture and Livestock farming	[illegible] cultivation, damage to crop quality or crop failure due to dieback, premature ripening, drought induced pest infestations or diseases etc.	vegetation and gardens burned up	
Freemans Journal	1785-04-19	"Last Sunday morning prayers were offered in all Roman Catholic chapels in this city for rain, and in this season of drought when the earth is parched and the fruits of the soil choaked in their growth, it is incumbent on every individual to supplicate the All-bestowing Powers of goodness for a refreshment on the labours of her husbandmen."	C10_ Terrestrial Ecosystem: Habitats, Plants and Wildlife	Reduced plant growth		prayers offered for rain in all Roman Catholic Churches

Figure 3. A sample of the Irish Drought Impacts Database (IDID) revealing drought impacts and responses from newspapers in the 1700s

spanning the period 1733–2019 (Figure 3). The newspaper archive consists of over 6 million pages from over 100 newspapers from the island of Ireland from which searches resulted in over 6 000 drought-related articles. Impacts are categorized based on a modified version of the EDII rubric. The database has been used to relate hydrometeorological drought indices to reported impacts, revealing regional sensitivities to drought and trends towards more severe drought categories being required to trigger impact reports (O'Connor et al., 2023).

US Drought Impact Reporter (DIR)

National Drought Mitigation Center, University of Nebraska (USA)
https://droughtreporter.unl.edu

The US National Drought Mitigation Center established the Drought Impact Reporter (DIR) in 2005 to be the nation's comprehensive archive of drought impacts (Wilhite et al., 2007). A moderator reads the results of a daily automated web search of news stories to find events that meet the definition of a drought impact, "a loss or change at a specific place and time due to drought," and enters any impacts into the database. All impacts have start dates; some have end dates. Impacts are assigned one or more geopolitical scales, from city to nationwide, and categorized into one or more of nine sectors, including response. One of the

DIR evolution and lessons learned

The DIR has evolved over time. It is now the cornerstone of the Drought Impacts Toolkit (https://droughtimpacts.unl.edu), in recognition of the complexity of drought impacts. Drought impacts are like fractal geometry in that new detail emerges as the scope of inquiry zooms in or out. Without a defined perspective, impacts take on amorphous complexity.

One initial concept was that US dollars would be the unit, but it turned out that impacts are difficult to quantify consistently, particularly in a comprehensive, multi-sectoral context (Smith et al., 2014a). Associating a dollar value with losses is a separate, abstract economic exercise unless it is in context, such as insured crops or structures or lost hydropower production. Associating specific dollar values with impacts such as loss of habitat or reduced air and water quality requires assumptions and calculations that are well beyond the scope of scanning news articles for evidence of drought-related losses. It is also a question of scale or who actually bears the cost. Producers' drought-related losses in one area may constrict supplies and boost prices for producers in other areas. Or crop subsidies may offset losses from agricultural producers to the general population.

However, it is worth noting that the work of the moderator includes inferring as much spatial detail as possible from news articles, so impacts are associated with specific cities, counties and/or states, as well as sectors. For purposes such as drought planning, it is possible to quantify the number of drought impacts that have affected a single location, and to compare them with the occurrence of drought. Thus, the unit of analysis is "impact-sector-locations," that is, the unique combinations of impacts, sectors and locations.

Another initial idea was that a single comprehensive database could contain drought impacts derived from different sources. Ultimately, this proved suboptimal. The DIR is optimized and staffed for entering and displaying moderated information from daily media monitoring. Entering information from other sources was less effective, particularly for the time-sensitive map display of DIR data, in that the scale and frequency of impacts varies by source. In the case of media monitoring, looking at the rise and fall of chatter is a way to detect evolving conditions (Smith et al., 2020, 2021). This signal and other spatial and temporal patterns are most meaningful when each channel of information is recorded and tracked separately.

Efforts to add condition monitoring to the mix highlighted the need to keep different types of information separate, particularly for purposes of mapping. In order to detect emerging impacts, condition monitoring asks observers to submit reports at regular intervals in time, regardless of dry or wet conditions, and avoids asking them whether what they are seeing is because of drought (Lackstrom et al., 2017; Meadow et al., 2013).

The results of daily moderated media monitoring are now the sole source of information in the DIR, but the Drought Impacts Toolkit includes several forms of condition monitoring, as well as a Drought Impacts Multi-tool that makes it possible to display impacts from all sources as different layers on a single map. Ideally, advances in technology and understanding of drought impacts will eventually allow these separate sources of information to be combined into a composite drought impacts layer.

strengths of the DIR is the consistent effort since 2005 to scan media and record drought impacts, and the growing length of its period of record increases its value as a source of longitudinal data. It is updated in near-real time, and serves as an input to the US Drought Monitor process. As of June 2023, the DIR had 30 098 impact reports, each associated with one or more sectors and locations. The DIR is used in drought planning, in researching the connection between drought indicators and drought impacts, and to answer queries from media, elected officials and others.

In-situ condition and impact monitoring

In contrast to centralized databases of drought events, systems for monitoring ongoing drought-related conditions may provide early warning of emerging drought impacts and indicate where drought responses are required and what those responses should be. These employ citizen science, crowdsourcing, observer networks or similar systems for organizing human contributions. They provide eyes on the ground, collecting data from networks of individual observers with more spatial granularity than would otherwise be possible (Smith et al., 2014a). Many countries incorporate information from observer networks into their drought monitoring efforts. Condition monitoring in low- and middle-income countries requires additional caution because the impacts of drought tend to have greater consequences for lives and livelihoods. Citizen science and crowdsourcing approaches must be planned and managed more carefully because the motivations and ability of people to participate are likely to be different than in higher-income countries. In developed countries, citizen science is more likely to be conducted and framed as a leisure activity, with participants skewing male, middle-class and well-educated (Haklay, 2013). In lower-income regions, it is crucial both ethically and for programme sustainability to ensure that participation does not add another burden to those with marginal livelihoods and is beneficial in terms of, for example, increasing human, social and political capital (Walker et al., 2021).

Monitoring drought-related conditions that may lead to impacts is often an inherent part of national drought monitors. These drought monitoring systems commonly have ground-based validation in the form of a questionnaire that is completed at specified frequencies and spatial scales matching the output of the drought map. Two ground-truthing systems are associated with the US Drought Monitor – Condition Monitoring Observer Reports (CMOR) and the Collaborative Community Rain, Hail and Snow Network (CoCoRaHS) condition monitoring reports. However, most drought monitors do not have openly accessible data, and details of the ground-truthing are rarely provided on the hosting websites. Examples are provided in this section of several national drought monitors and their incorporated drought impacts monitoring programmes. Despite the varying success of the programmes, it would appear that incorporation into a national drought monitor is an effective way to establish drought impacts monitoring.

It is inherently challenging to integrate different types of data that are collected at different spatiotemporal scales, especially subjective narratives and perceptions, with quantitative hydrometeorological and remote sensing indices. However, this challenge is worth taking up because it can help drought monitors more accurately represent experiences on the ground, which is crucial where drought monitors are utilized to inform policy and emergency response.

Andean countries: Plurinational State of Bolivia, Chile, Colombia, Ecuador, Peru, Bolivarian Republic of Venezuela

The International Research Centre on El Niño (CIIFEN) hosts the WMO-sponsored Regional Climate Centre for South America. With support from Euroclima+, CIIFEN developed drought monitors and drought bulletins for the six Andean countries, based on the North American Drought Monitor methodology. CIIFEN developed and supports the Volunclima programme for collecting observations from volunteers in the six countries. Observers are provided with manual rain gauges and trained to provide daily rainfall measurements via an app (https://volunclima.ciifen.org/). They are also asked to complete a drought impact perception report within the first 10 days of each month on soil condition, vegetation condition, precipitation perception, precipitation temporality, observed temperature and water availability for livestock (López Pérez, 2022).

Central and Eastern Europe – Intersucho

Farmers and others with long-term knowledge of local growing conditions in Czechia, Slovakia and the rest of the Danube region are prompted each week to respond to a questionnaire, including expected crop yield and soil moisture (Trnka et al., 2020) (https://questionnaire.intersucho.cz/en/). The effort is closely associated with the Czech Drought Monitor (CzechDM). In 2018, results from the reporting network were used to justify receiving relief funds from the European Union, which provided practical validation of the system's utility (M. Bláhová, personal communication, 11 May 2023).

Droughtwatch developed from the DriDanube project offering a web interface to enable more accurate and efficient drought monitoring and early warning to the entire Danube region. The platform provides Earth observation data from satellite remote sensing, meteorological stations and drought impact reports.

Middle East and North Africa (MENA)

In 2016, government agency representatives and other stakeholders in Jordan, Tunisia, Morocco and Lebanon reported collecting a variety of agricultural, ecological and socioeconomic indicators as part of formal drought monitoring programmes (for example, range conditions, livestock (birth weight, mortality and sales) and crop progress, and municipal water availability), although more work was necessary to produce timely information through shared platforms to support decision-making (Fragaszy et al., 2020). To help address this need, newly written drought adaptation plans for Jordan and Lebanon call for enhanced drought impact monitoring, which could facilitate more formal drought impact reporting networks when formally adopted (Jobbins et al., 2022).

Australia

The Australia Drought Monitor is modelled on the US Drought Monitor and applies a Combined Drought Indicator to produce monthly maps of drought severity (https://www.nacp.org.au/drought_monitor). The Drought Monitor is managed by the Northern Australia Climate Program (NACP) and commenced in 2021, though the website includes drought maps hindcast to 1999. As is the case for the Brazilian Drought Monitor described below, a system is in place to validate the drought maps based on ground observations by extension officers, "Climate Mates" and other local experts. SurveyMonkey is used to collect drought-related condition and impact information from people on the ground to produce drought condition and impact reports. A short multiple choice questionnaire requests information on dryness/wetness and on crop and livestock production, as well as allowing participants to rate how well the Drought Monitor matches current conditions.

Plurinational State of Bolivia

Similarly, the Bolivian Drought Monitor (El Monitor de Sequías de Bolivia, http://monitorsequias.senamhi.gob.bo/#/home), implemented in 2020 through the Pilot Program for Climate Resilience (PPCR), produces monthly maps of drought severity. In addition to utilizing ground observation and satellite data, there is also consideration of vulnerability, exposure and impact data by different sectoral experts. For example, the Civil Defense provides data on the number of people who received assistance, revealing the severity of drought impacts in an area.

Brazil

Brazil has two independently produced drought monitors. Each drought monitor presents a monthly map of drought conditions, and each has a programme to collect drought impacts data to ground-truth the maps.

The Monitor de Secas (https://monitordesecas.ana.gov.br/mapa) is led by the National Water Agency (Agência Nacional de Águas (ANA)) and contributed to by state-level governmental institutions. The Monitor de Secas initially covered the drought-prone semiarid north-east of Brazil when it commenced in 2014 and has since expanded to incorporate the south-east, west and north. Efforts are underway to incorporate the whole of Brazil. The drought monitor directly informs policy, in particular the targeting of emergency response when drought severity reaches a particular level, such as the provision of water trucks supplying potable water and payouts of crop insurance. Each state has a designated "validator", typically a hydrometeorological agency, and "observers", who are typically affiliated with an agricultural extension office. Short questionnaires are completed by the observers with multiple choice queries concerning spatiotemporal distribution of rainfall, rainfed agriculture status and availability of different water resources. There is also an open question requesting information on any other drought impacts observed or reported in the municipality. Questionnaires are (ideally) completed at a frequency of one per month per municipality, thus providing an overview of the reported month. Completion of the questionnaires and sharing of information have been rather sporadic across and within states. Various reasons for this have been mooted, including: a lack of a network of observers in some states, underfunding and insufficient staff at some observer institutions, covid-19-related fieldwork restrictions, and a lack of confidence in the value of the data being collected leading to hesitancy in sharing. Therefore, validation remains focused on hydrometeorological and remote sensing vegetation condition indices. However, several years of rich qualitative data have been obtained concerning the agricultural and socioeconomic impacts of drought. The longitudinal and spatially distributed nature of the data allows for assessment of the heterogeneity of drought impacts. Additionally, non-correlation between impacts and drought severity on the drought monitor suggests anthropogenic, or at least non-extreme-climatic, drivers of drought impacts (Walker et al., 2024b). Such drivers, or causes of vulnerability, may be more feasibly managed than climatic drought drivers.

The second drought monitor, the Monitoramento de Secas e Impactos no Brasil (https://www.gov.br/cemaden/pt-br/assuntos/monitoramento/monitoramento-de-seca-para-o-brasil/), is developed by the National Centre for Monitoring and Alerts of Natural Disasters (Centro Nacional de Monitoramento e Alertas de Desastres Naturais (CEMADEN)). As with the previously described drought monitor, the monthly maps of drought severity are computed from hydrometeorological drought indices and remote sensing vegetation condition indices. The drought monitor is nationwide and has been produced since 2018. The drought monitor is used proactively by various institutions for their drought preparation, including the

Figure 4. The drought monitor questionnaire of Brazil's CEMADEN aiming to crowdsource drought impact information (https://docs.google.com/forms/d/e/1FAIpQLScSPEuaJWhUiJKZ3va2Uky7xGVxIhD73_PL5SH7icX4P33tmA/viewform)

request for additional government finance (D. Walker, personal communication). The website presenting the drought map has a link requesting public contributions concerning the occurrence of drought (https://docs.google.com/forms/d/e/1FAIpQLSct3c8lkUqR0oHtSiPusWkrDF9TvL3Dg9RqD50QDrHz_qfVnw/viewform). The programme is essentially an open crowdsourcing model akin to the US CMOR drought programme. A short questionnaire asks for information on the responder, observed agricultural and socioeconomic drought impacts, estimated financial losses and number of affected people (Figure 4). While some responses have been received, they are infrequent and sparse (D. Walker, personal communication).

Canada

Canada's Agroclimate Impact Reporter (https://agriculture.canada.ca/en/agricultural-production/weather/agroclimate-impact-reporter) similarly provides an opportunity for agricultural producers to provide information about the conditions they are experiencing. An online survey designed to be completed by producers each month during the growing season asks what they produce (horticulture, seed crops, livestock, etc.), what type of impact they are experiencing (pasture/rangeland, crop/hay, crop stage, surface water supply, groundwater supply, water quality, feed supply), how feed production compares with other years, what soil moisture condition is, and what adaptation measures they have implemented. Producers can sign up to be prompted to complete a survey each month or can answer the online survey. The tool is intended to help producers manage climate risk and to support their requests under Canada's Livestock Tax Deferral Provision (Bronson and Knezevic, 2016) (https://agriculture.canada.ca/en/agricultural-production/weather).

India

Established in 2021, the India Drought Monitor provides drought condition and drought forecasts (https://indiadroughtmonitor.in/). The programme is a research effort run from the Indian Institute of Technology Gandhinagar (IIT Gandhinagar). The drought maps are based on standardized precipitation, runoff and soil moisture indices (SPI, SRI and SSI) though the website has an option for the public to submit reports on the drought-related condition and impacts in their area (Figure 5).

United States of America

In the USA, "condition monitoring" arose in response to the need to monitor conditions leading to drought impacts in the USA (Lackstrom et al., 2017). Although a national crop monitoring network exists through the US Department of Agriculture's Farm Service Agency, privacy of agricultural producers is a paramount

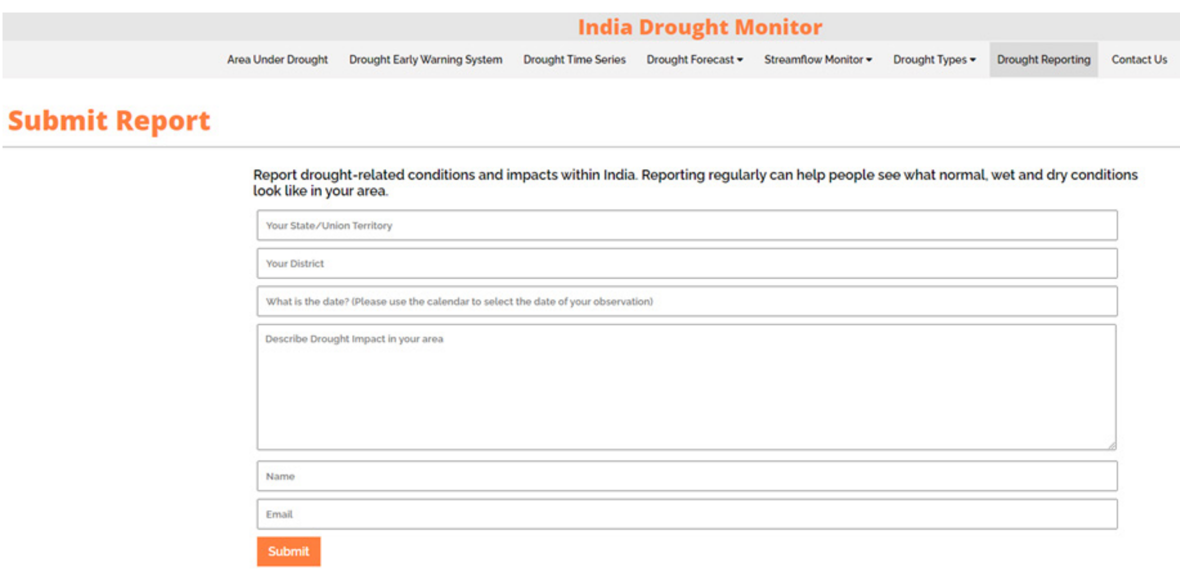


Figure 5. The India Drought Monitor's questionnaire aiming to crowdsource drought impact information (https://indiadroughtmonitor.in/#/drought-reporting)

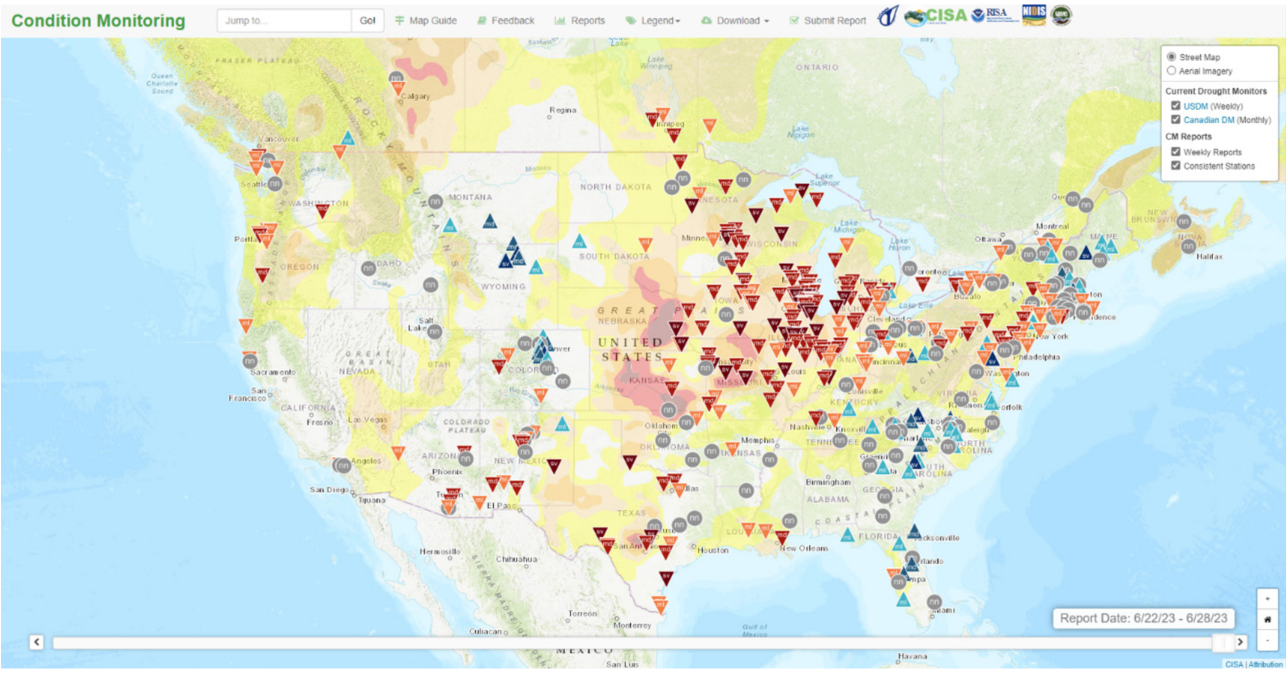


Figure 6. The CoCoRaHS condition monitoring dashboard overlain on the US Drought Monitor map

Source: Third party map. This map was taken from https://www.cocorahs.org/Maps/conditionmonitoring/ on 31 May 2024 and may not fully align with United Nations and WMO map guidance.

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

concern, and those reports are not shared with enough spatial detail to be valuable in the US Drought Monitor process. In addition to providing information on conditions that may lead to impacts, condition monitoring serves to ground-truth data-driven drought maps.

The Collaborative Community Rain, Hail and Snow Network (CoCoRaHS) works with citizen scientists across the USA to collect daily data on precipitation. Since 2010, CoCoRaHS observers have the option to submit an additional "condition monitoring" report to detail how dry or wet conditions are affecting their surroundings. In 2016, the interface expanded to include rating conditions on a 7-point scale from severely dry to severely wet (https://www.cocorahs.org/content.aspx?page=condition). Condition monitoring reports include affected sectors, modelled after the Drought Impact Reporter, as well as a field for text description (Lackstrom et al., 2017), all of which is presented on a drought map, as shown in Figure 6.

In 2018 the Drought Impact Reporter's option for users to submit observations was replaced with Condition Monitoring Observer Reports (CMOR) (Figures 7 and 8). CMOR (https://go.unl.edu/cmor_drought) uses the same 7-point scale as CoCoRaHS, but differs in that it accepts photos, and its impacts and categories have been allowed to evolve over time based on user response and on the needs of state drought assessment teams. It also differs in that it lists potential impacts within sectors for observers to check, as well as providing a field for a text description. Anyone can submit a CMOR report, although in practice, they generally come from states where the drought assessment team has worked with one or more groups to publicize the opportunity to submit reports. CMOR reports tend to be clustered in time but have produced denser spatial coverage when states have made a concerted effort to channel grassroots interest into reporting. Grassroots interest tends to be highest during times of change or stress, as when intensifying the level of drought on the US Drought Monitor map would result in increased relief payments to livestock producers. Thus, developers of the CMOR system are considering ways to validate CMOR reports, or to establish the credibility of reporting networks or observers (Smith et al., 2021). Although US Drought Monitor map makers can review CMOR reports, it appears that they are most actively used by the state climatologists or state drought assessment teams that pointed observers toward the CMOR network or that recruited participants. Teams that use CMOR reports in their recommendations to Drought Monitor authors typically do so in combination with other data. CMOR reports alone do not change the Drought Monitor map, but they can prompt a closer look at an area by state and national drought assessment groups.

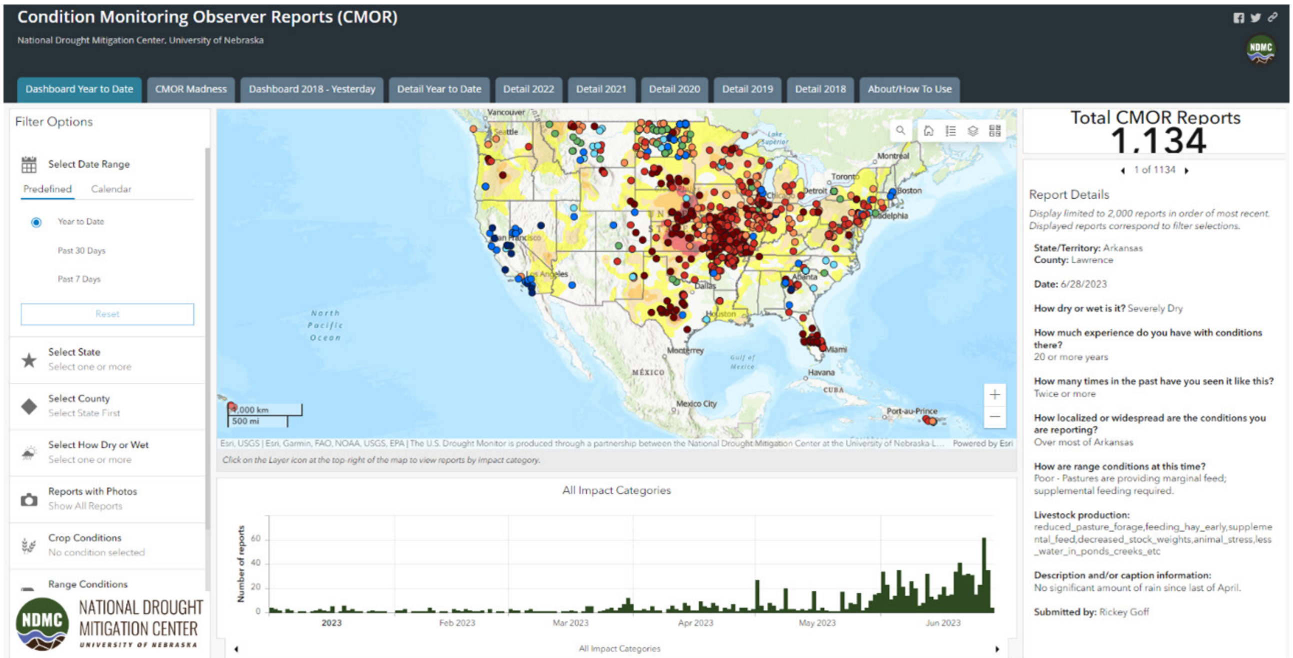


Figure 7. The CMOR drought dashboard

Source: Third party map. This map was taken from https://go.unl.edu/CMORmap on 31 May 2024 and may not fully align with United Nations and WMO map guidance.

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

Figure 8. CMOR promotion meme

Media monitoring

Monitoring media in real time is a means of collecting information on drought impacts, with varying spatial specificity. Some stories are clearly about drought impacts in a single location, while others may generalize across broad regions.

United States of America

In addition to maintaining the fully moderated Drought Impact Reporter, the US National Drought Mitigation Center conducts weekly searches for news stories (https://go.unl.edu/droughtnews) and social media posts on X (https://go.unl.edu/droughttweets) about drought, filters them for in-state content and shares the results via an interactive map (Smith et al., 2020). These semi-automated processes provide additional information for state drought assessment teams that help ground-truth the US Drought Monitor. These sources of data are likely to become increasingly valuable as natural language processing and similar methods develop. However, we note that the changing business model of X, formerly known as Twitter, has eliminated the most affordable options for academic researchers (Calma, 2023).

Global

Likewise, the European Commission Joint Research Centre monitors Drought in the Media globally (https://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1060).

CzechDM/Intersucho

Czech researchers in 2022 began using Python scripts to automate media mining, with the goal of gathering near-real-time information about global drought impacts, emphasizing reports from areas that may be underrepresented in other drought assessments. The information gathered with this tool is connected with reports collected through the global drought impacts questionnaire available at https://droughtimpacts.eu/en/ (M. Bláhová, personal communication, 11 May 2023).

FOOD AND WATER SECURITY AND LIVELIHOOD MONITORING SYSTEMS

Some systems monitor indicators of well-being such as food security, water security or livelihoods, with drought as one of several considerations, and are directly connected with relief efforts. These may be systematic institutional state, national or international monitoring programmes, such as those described below. There are also numerous examples in academic literature of citizen science programmes that collect socioeconomic, agricultural and behavioural information at individual or household scale. The examples described below involve water diaries and smartphone-based monitoring. Generally, these programmes were not established with a focus on drought, rather, drought is one of many factors, including other natural hazards, that affect livelihoods.

FEWS NET

The Famine Early Warning Systems Network (FEWS NET) incorporates drought and other climatic events along with other data to assess food security in vulnerable countries. Established by the United States Agency for International Development (USAID) in response to famine in the Horn of Africa in 1985, FEWS NET works with technical and in-country partners to anticipate food insecurity and inform humanitarian planning and response. Every four months, FEWS NET analysts project food insecurity for the coming eight months (Figure 9). They report food insecurity on the five-point Integrated Food Security Phase Classification (IPC) scale. The analysts incorporate many types of data, including food prices, harvest surveys and rainfall, and use the IPC to summarize it in consistent terms.

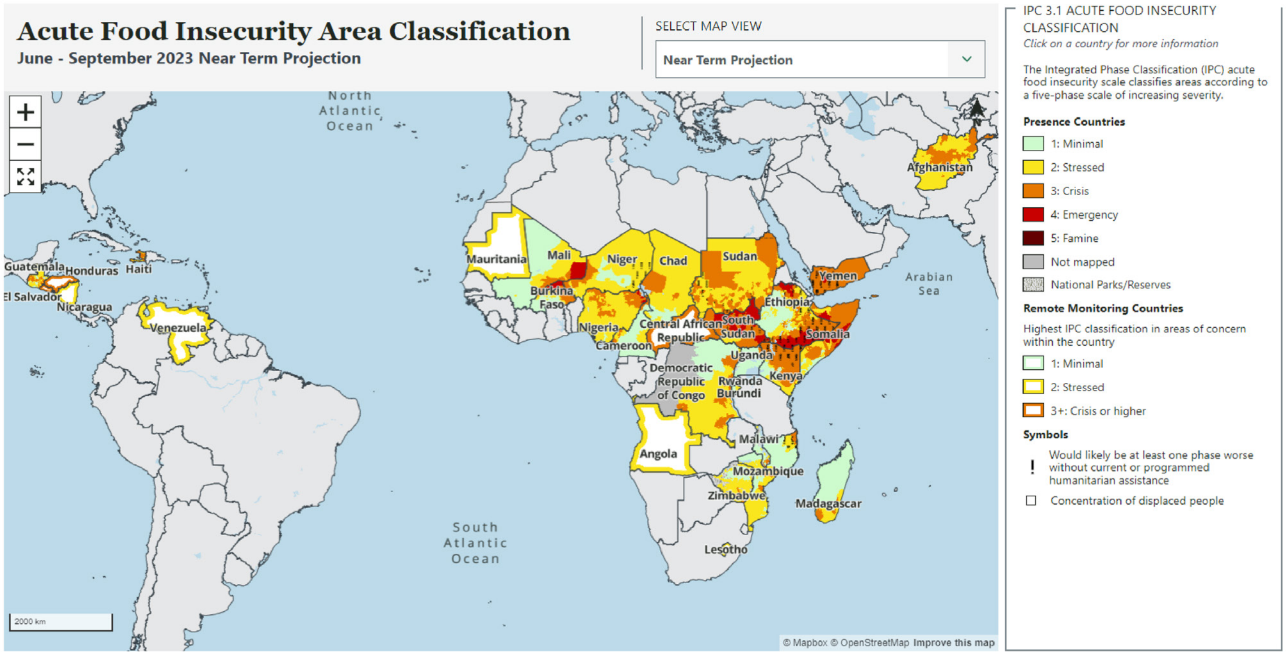


Figure 9. A FEWS NET map of acute food insecurity

Source: Third party map. This map was taken from https://fews.net/ on 31 May 2024 and may not fully align with United Nations and WMO map guidance.

Note: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by WMO or the United Nations. The background map has been modified to align with United Nations and WMO map guidance.

FSNAU and BRCiS

The Food and Agriculture Organization of the United Nations (FAO) Food Security and Nutrition Analysis Unit (FSNAU) is similar to FEWS NET in that it maps food security, but it is specifically for Somalia and uses contextualized indicators, combining socioeconomic indicators with physical indicators to provide early warning (https://dashboard.fsnau.org). Another platform in Somalia is the Building Resilient Communities in Somalia (BRCiS) early-warning dashboard used by a consortium of non-governmental organizations (NGOs) to monitor drought and food insecurity using socioeconomic indicators (https://brcis.shinyapps.io/EWEA_dashboard/). Further information on these systems in Somalia is presented in Appendix B.

GEOGLAM's Crop Monitors

After global food price shocks in 2007/2008 and 2010/2011, the G20 heads of State endorsed creation of the Group on Earth Observations Global Agricultural Monitoring Initiative (GEOGLAM) and the Agricultural Market Information System (AMIS). GEOGLAM's Crop Monitors (https://cropmonitor.org) are published monthly. Its Crop Monitor for AMIS assesses wheat, maize, soybean and rice crops for the countries that produce 80% of the world's supply. GEOGLAM also produces a Crop Monitor for Early Warning, focusing on more crops and emphasizing regional food security. Precipitation is one of several key variables that go into Crop Monitor reports.

Precipitation is one of the variables that goes into the warning classification algorithm that the Anomaly hot Spots of Agricultural Production (ASAP) system uses each month to flag regions that merit a closer look by agricultural analysts (Meroni, 2019). ASAP provides early warning for food security assessments and feeds into GEOGLAM (Becker-Reshef et al., 2019). ASAP first went public in 2016 and is a product of the European Commission Joint Research Centre (https://agricultural-production-hotspots.ec.europa.eu/index.php). ASAP triggers warnings during the growing season, based on combining the 3-month Standardized Precipitation Index, the Normalized Difference Vegetation Index (NDVI), a measure of soil moisture and the timing of anomalies.

Livelihood monitoring in Kenya

The National Drought Management Authority (NDMA) was established by the Government of Kenya with the aim of establishing and operating drought early warning systems and to develop drought preparedness strategies and contingency plans (https://www.ndma.go.ke/). Food security is assessed by looking at biophysical factors (such as vegetation conditions and rainfall) and socioeconomic factors (such as access to market and production). Field monitors measure certain variables, for example, children's mid-upper arm circumference (MUAC), to assess malnutrition, and they communicate with farmers in their district. Aspects related to agricultural yields – animal body condition, milk productions, livestock deaths, forage conditions, market access and food availability – are reported to assess food security threats (Lam et al., 2023). Further information on the NDMA is presented in Appendix B.

My Dry Well

The My Dry Well system in the US state of California provides a way for householders to report dry wells, so that state and community organizers know where to direct relief. After prolonged drought in the 2010s, California developed the system (https://mydrywell.water.ca.gov/) as part of a health-related push to enforce the human right to water, which the state adopted in 2012. The Community Water Center (https://www.communitywatercenter.org/) works to extend municipal water to underserved communities.

Smartphone-based monitoring

Smartphone-based monitoring of natural hazards may hold promise, especially in regions that lack reliable data on disasters to inform more effective disaster management. While the use of technology in citizen science can be exclusionary, specially designed apps can be picture based, allowing people with low levels of literacy to participate. An example is described by Jacobs et al. (2019), who present a case study in Uganda where "geo-observers" were trained to report, photograph and geolocate observed impacts, including from drought (Figure 10). Demie et al. (2011) report on a project established by Oxfam and local partners in Ethiopia and Somalia where pastoralists send drought impact information, including pasture availability, livestock condition and migration, that is utilized for a community-based early warning system.

Water diaries

The "water diary" method applied in Kenya and Bangladesh by Hoque and Hope (2018, 2020) involves households documenting daily sources, uses, cost and sufficiency of water, along with weekly household

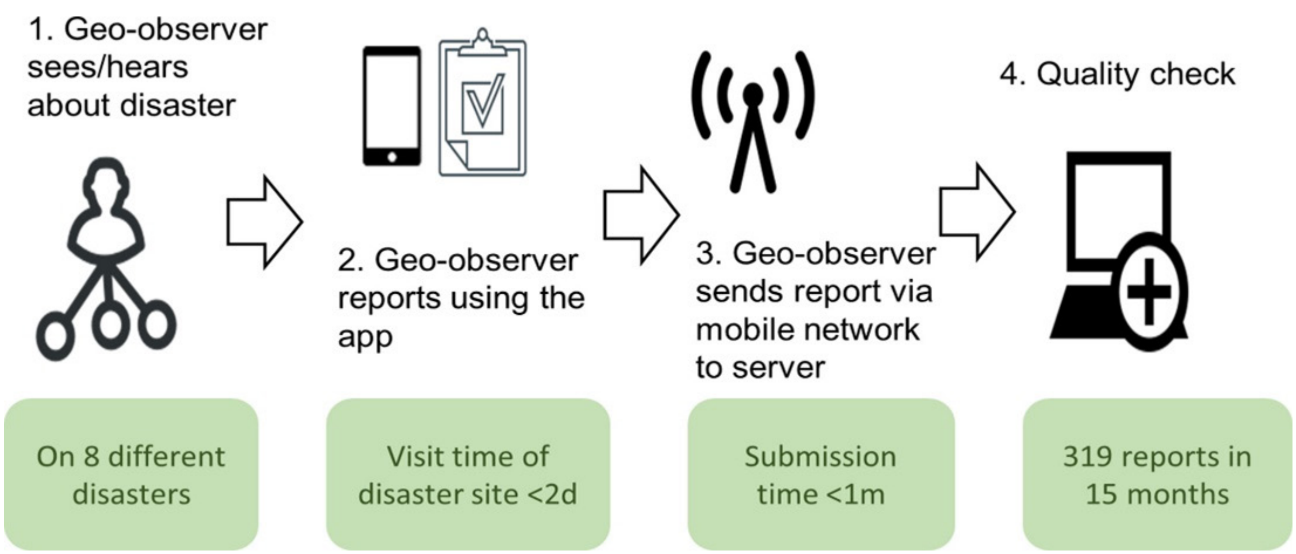


Figure 10. The "geo-observer" methodology from Uganda (from Jacobs et al., 2019)

expenditures. Findings revealed, for example, that in Kenya, water for hygiene uses is reduced during drought. The water diary method has also been utilized in Australia (Lahiri-Dutt and Harriden, 2008), Nicaragua (Smith et al., 2015) and Zambia (Bishop, 2015), among other places. Authors generally note that the intensity of the documenting means the programmes typically run for one to four weeks per season. Water diaries have been shown in high-income regions that experience water scarcity, notably in Australia, to increase sensitization of individual water use and consequently lead to water use reduction (Harriden, 2013). They could also help water agencies target specific water user groups in times of drought and develop effective public policy in a participatory manner with detailed household information (Lahiri-Dutt and Harriden, 2008).

DATA THAT MAY SHOW A "DROUGHT SIGNAL"

Some datasets may exist for other purposes, such as monitoring food security, monitoring health conditions that may or may not be related to drought or informing the public about fluctuations in hydropower supply and river navigation.

- The Food and Agriculture Organization of the United Nations (FAO) records annual country-level data on crop production (https://www.fao.org/faostat/en/#home), although the quality of the data depends on national effort. Researchers using FAO data found that the combined impacts of temperature and drought significantly decreased yields of maize, soybeans and wheat (Matiu et al. 2017). The Eurostat database likewise tracks agricultural production for the European Union, and agencies in individual countries, such as the National Agricultural Statistical Service in the USA, may also maintain statistics.

- Datasets collected by the International Energy Agency (https://iea.org) and its national counterparts such as the US Energy Information Administration may include data on the impacts of drought on energy production, as either reduced hydropower production or reduced production due to lack of cooling water. At a smaller scale, in the USA, operators of river systems issue press releases on hydropower production and river navigation, which may provide a valuable record over time of how drought has affected operations (for example, the US Army Corps of Engineers: https://www.nwd.usace.army.mil/MRWM/MRWM-News/). Similarly in Brazil, data are available for hydropower generation and dam releases (Figure 11) (https://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx).

- Tourism industry statistics, such as ski resort stays, sales of lift tickets or rafting excursions, with due consideration of seasonality, may reveal the influence of drought (Wlostowski et al., 2022; https://www.seilbahnen.org/fr/La-branche/Statistiques/; https://www.bfs.admin.ch/bfs/fr/home/statistiques/tourisme.html), although the data may exist within industry organizations rather than publicly. The ski industry is a sector of the tourism industry that is increasingly impacted as snow drought occurs with greater frequency (Huning and AghaKouchak, 2020).

- Information on locations and extents of wildfires are available from both national institutions (for example, in Canada: https://cwfis.cfs.nrcan.gc.ca/interactive-map and Figure 12; and in Greece: http://ocean.space.noa.gr/diachronic_bsm/) and international institutions, such as global fire and smoke remote sensing products from Copernicus (https://atmosphere.copernicus.eu/global-fire-monitoring). Again, caution is needed, because drought may or may not be a factor in contributing to and sustaining wildfires.

- Health-related data may reveal the influence of drought, although establishing a definitive connection between drought and an adverse health effect may not be as obvious as for other drought impacts. Drought and heatwaves often co-occur, which complicates attributing health issues solely to drought. Statistical analyses have found connections between drought and health outcomes such as mortality (Abadi et al., 2022) and between drought, heat and West Nile virus (Paull et al., 2017; Smith et al., 2020). Data can be available at very high resolution from health ministries, providing the date and time of hospitalization, the particular ailment and the patient's home address. Such data make it possible to establish correlation (but not necessarily causation) with hydroclimatic variability, revealing for example, relationships between drought and dengue fever that could be useful for public health policymaking (Costa et al., 2022).

- The US Drought Impacts Toolkit includes a collection of "Emerging Impacts" links to different sources of information and data that may reflect emerging or historical drought (https://droughtimpacts.unl.edu/EmergingImpacts.aspx).

- Datasets that monitor the well-being of populations and economies may show the impacts of drought when compared analytically with data on drought itself. The Eurostat database (https://ec.europa.eu/eurostat/web/main/home) contains a wealth of statistics that may reflect the impacts of drought across many realms of life, such as agriculture, energy, health, transportation and tourism. A World Bank process for damage assessment relies on WorldPop data (https://worldpop.org). Post-disaster needs assessment guidelines created by the World Bank, the European Union and the United Nations distinguish between effects and impacts. Effects include disruptions of access to goods and services, such as water, and one of the impacts they emphasize is how disaster affects the quality of human life in the medium and long term (GFDRR, 2013). In this context, data such as food- and water-related metrics for the sustainable development goals could show a drought signal.

On the downside, data collected for other purposes may not be ideal for large-scale interpretation of drought's impacts: data are collected by multiple sources or groups based on sector, making it difficult to find data, and it may be challenging to translate data collected for various purposes into a broader understanding of societal impacts (Jennings et al., 2022). The European Drought Risk Atlas notes the value of a cross-sectoral approach for minimizing negative trade-offs when balancing water uses across sectors (Rossi et al., 2023). When providing such data, it is essential to also communicate the underlying uncertainty in a way that allows decision makers and stakeholders to understand the information.

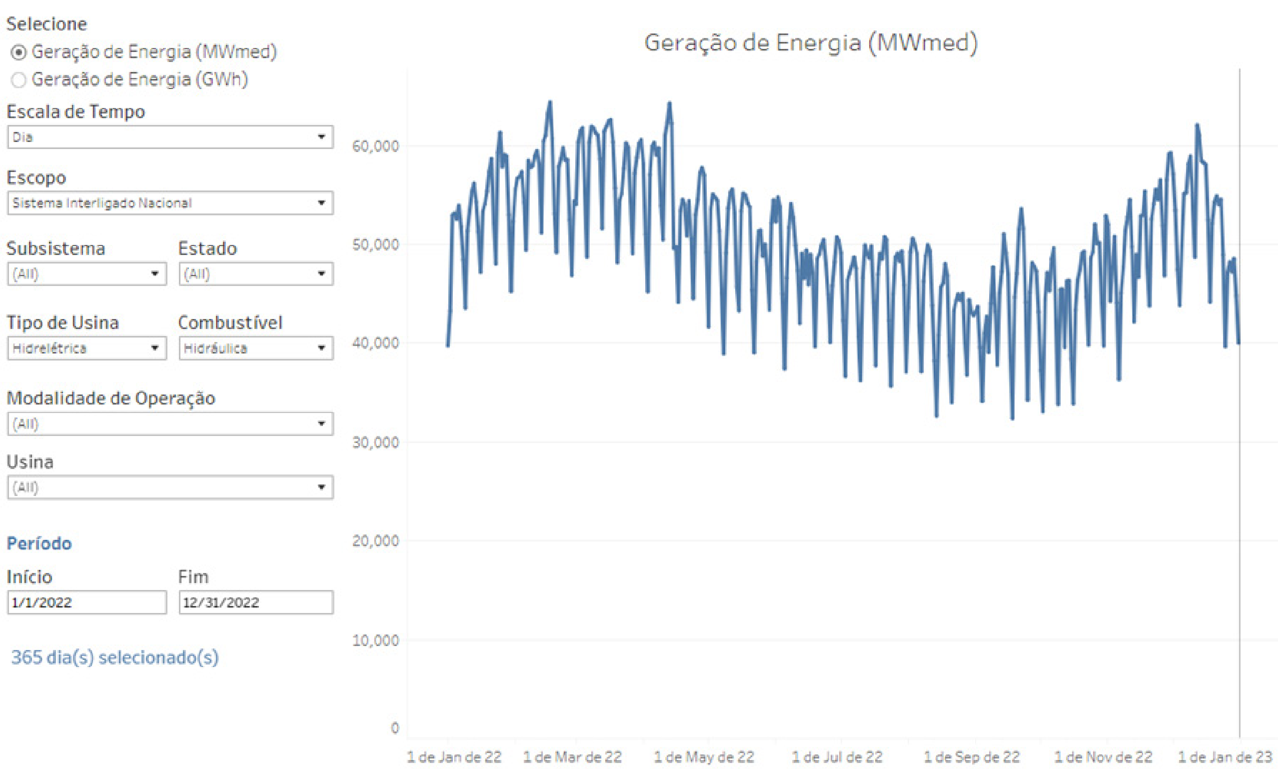


Figure 11. Time series of hydropower production in all of Brazil throughout 2022 (https://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx)

Figure 12. Map of active fires in Canada on 30 June 2023

Source: Third party map. This map was taken from https://cwfis.cfs.nrcan.gc.ca/interactive-map on 31 May 2024 and may not fully align with United Nations and WMO map guidance.

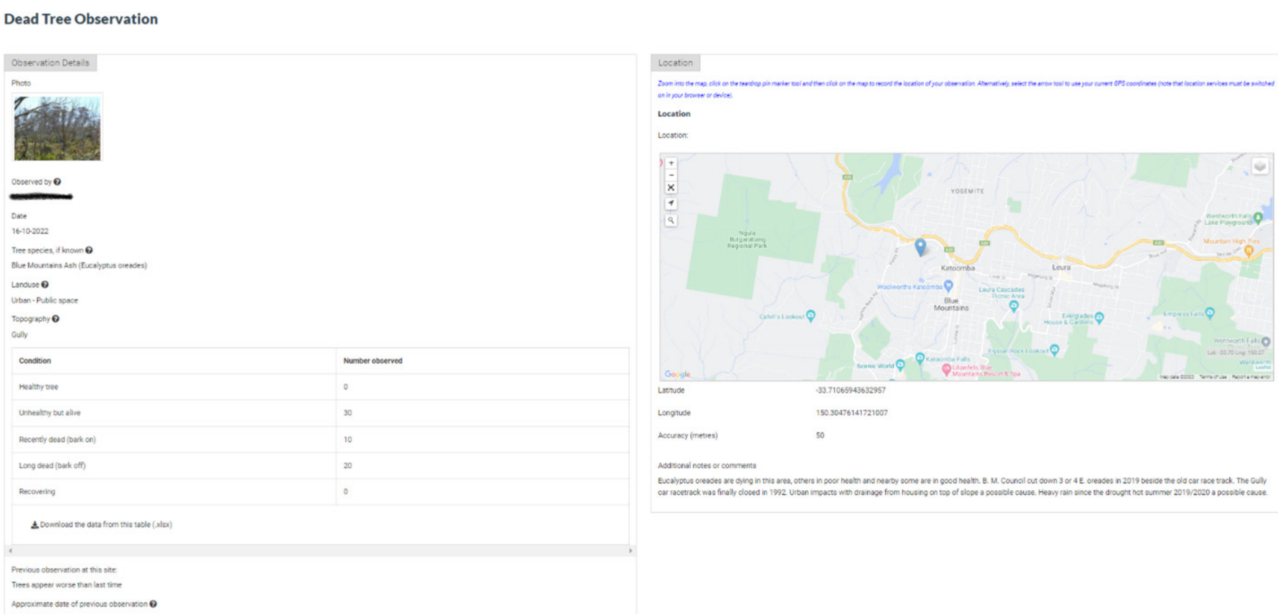
Note: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by WMO or the United Nations.

ECOLOGICAL DROUGHT IMPACTS

Disciplinary experts may also be able to find a drought signal in data related to various ecological phenomena. While many drought impact data collection schemes relate to protecting human livelihoods and well-being, functioning ecosystems are a fundamental requirement of life on Earth.

Forests are central to global ecosystem services and human economies, serving as habitats for life and ecosystem drivers for the cycling of water and carbon, and providing both structural and economic support for human civilization (Smith et al., 2014b). Drought-induced tree mortality is rising as climate change exacerbates stress on trees due to increased precipitation deficit and higher temperatures. However, similar dramatic declines in woody biomass have always occurred under natural climate fluctuations (Fensham et al., 2019). Recent warmer droughts have caused unprecedented forest die-off events in, for example, the western USA, Mediterranean Europe and south-east Australia (Hammond et al., 2022). A citizen science programme in Australia, the Dead Tree Detective, asks members of the public across the country to report observations of dead or dying trees (Figure 13) (https://biocollect.ala.org.au/acsa/project/index/77285a13-e231-49e8-b212-660c66c74bac). The aim is to map drought-affected trees to better understand the impact and extent of drought on forests and to identify areas of vulnerability for greater protection. The Na Sucha (On Drought) citizen science project in Czechia collects crowdsourced photographs of trees and other vegetation types, submitted via the iNaturalist app, to assess the state of vegetation in agricultural landscapes (https://eu-citizen.science/project/361).

Drought profoundly affects freshwater quality, with obvious implications for both ecosystems and water users. Reduced water flow and volume, commonly combined with higher temperatures, can increase salinity, nutrient load and algal levels, and turbidity. However, while a lack of flushing and reduced dilution often increase contaminant levels, diffuse pollution, such as agricultural runoff, is generally reduced during drought (Mosley, 2015). Presented here are examples of long-running citizen science water quality monitoring programmes in locations where drought is *commonly* the cause of the particular water quality issue, though care must be taken because there are almost always other factors involved. The Bloomin' Algae project is a citizen science smartphone app-based monitoring programme in the United Kingdom (https://www.ceh.ac.uk/



Dead Tree Observation

Observation Details

Photo

Observed by

[redacted]

Date

16-10-2022

Tree species, if known

Blue Mountains Ash (Eucalyptus oreades)

Landuse

Urban - Public space

Topography

Gully

Condition	Number observed
Healthy tree	0
Unhealthy but alive	30
Recently dead (bark on)	10
Long dead (bark off)	20
Recovering	0

Download the data from this table (.xlsx)

Previous observation at this site:

Trees appear worse than last time

Approximate date of previous observation

09-10-2022

Location

Zoom into the map, click on the teardrop pin marker tool and then click on the map to record the location of your observation. Alternatively, select the arrow tool to use your current GPS coordinates (note that location services must be switched on in your browser or device).

Location

Location:

Latitude -33.71065943632957

Longitude 150.30476141721007

Accuracy (metres) 50

Additional notes or comments

Eucalyptus oreades are dying in this area, others in poor health and nearby some are in good health. B. M. Council cut down 3 or 4 E. oreades in 2019 beside the old car race track. The Gully car racetrack was finally closed in 1992. Urban impacts with drainage from housing on top of slope a possible cause. Heavy rain since the drought hot summer 2019/2020 a possible cause.

Figure 13. An example of a report submitted to the Dead Tree Detective programme in Australia

Source: Third party map. This map was taken from https://biocollect.ala.org.au/acsa/bioActivity/index/573c8df1-5cc3-4b03-be68-ee165384035c?returnTo=%2Facsa%2Fproject%2Findex%2F77285a13-e231-49e8-b212-660c66c74bac on 31 May 2024 and may not fully align with United Nations and WMO map guidance.

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

our-science/projects/bloomin-algae). Participants submit geolocated observations that are quality checked by experts to identify potentially harmful blue-green algae (cyanobacteria) blooms. The Mini Stream Assessment Scoring System (miniSASS) (https://minisass.org/en/) focuses on macroinvertebrate identification and turbidity using a Secchi tube to determine water quality in South African streams. FreshWater Watch is a global citizen science project (https://www.freshwaterwatch.org/) that has collected tens of thousands of measurements from more than 30 countries. Measurements include nitrate and phosphate levels to assess eutrophication. Of course, many regions have formal monitoring networks collecting relevant water quality data, though the frequency and density of measurements is highly variable. Quarterly river water quality monitoring by a governmental environment agency in north-east Brazil was sufficient to show deteriorating water quality parameters in times of drought, despite measurement becoming impossible in extreme droughts when the rivers dried up (Freire et al., 2021).

As with the monitoring of changes in water quality, programmes designed to monitor biodiversity can also reveal, but rarely isolate, impacts caused by drought. For example, data from the venerable eBird project (https://ebird.org/home) can reveal declining bird numbers and changes to migratory patterns (Cohen et al., 2020). Similar to eBird are citizen science fish monitoring programmes that can reveal drought-induced fish die-off, which is not uncommon in Australia (MDBA, 2022) (see, for example, https://www.inaturalist.org/projects/australasian-fishes). There are a large number of additional locally relevant biodiversity monitoring programmes around the world that could be applicable to drought impact assessment, many of which can be found on https://www.inaturalist.org, ranging from observations of freshwater mussels in North America to those of macrofauna in southern Africa.

A further ecological impact of drought is the exacerbation of pest and disease outbreaks on crops and forests, potentially leading to further socioeconomic impacts. However, responses are not linearly correlated to drought severity, and interactions are often poorly understood, such as in the case of bark beetles and fungal pathogens in trees (Kolb et al., 2016). Relevant impacts data collection projects include: the ICP Forests programme (http://icp-forests.net/) that monitors forest health in 42 predominantly European countries; projects run by the US Forest Service, which presents information on various pests and diseases on a GIS map (https://www.fs.usda.gov/science-technology/forest-health-protection); bark beetle tracking programmes that exist in several European countries (for example, Germany, Austria and Switzerland) with openly available data showing quantities trapped and their locations (https://www.waldwissen.net/en/forestry/forest-protection/insects/tracking-the-bark-beetles); and integrated pest management (IPM) projects focusing on the periodic observation of crop parasites, the results of which could be very useful in cases where the data are archived and accessible (https://www.fao.org/pest-and-pesticide-management/ipm/integrated-pest-management/en/).

CONSIDERATIONS IN MODELLING AND FORECASTING DROUGHT IMPACTS

The *WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services, Part II* (WMO-No. 1150) propose impact-based forecasting for multiple hazards, including drought. However, compared to the progress in flood impact forecasting and operationalization in many countries, the progress for drought is still limited. This is due in part to the complex nature of drought.

Prior to quantifying or modelling drought impacts, it is necessary to decide what data to collect or associate with drought. Event-driven data in historical records can provide valuable insights on processes, mechanisms and attribution to drought. Using narrative data to shape quantitative analysis can be part of a mixed-methods analysis, which provides systematic means of using qualitative and quantitative research to answer a question (Creswell et al., 2003). The European Drought Risk Atlas uses sector-specific literature reviews, input from experts and more to create conceptual drought risk models (impact chains) that frame quantitative analyses (Rossi et al., 2023).

Three primary goals of modelling drought impacts are: (1) to improve understanding of the relationships between drought and its impacts, across sectors and across spatial and temporal scales; (2) to forecast or improve the monitoring-based forecasting of drought impacts, based on drought indicators and vulnerability; and (3) to make sector-specific forecasts of drought impacts, such as water for crop yield, urban use or aquatic habitat. When longitudinal data on a single, drought-responsive variable exist, they can be compared with a drought indicator. For example, researchers have studied the relationships between drought indicators and crop yield by using regression models (Zipper et al., 2016; Lu et al., 2017).

Quantitative models for studying drought impacts across sectors began to evolve once platforms such as EDII in Europe and the DIR in the USA began systematically collecting multidimensional drought impact data. Consequently, most data-driven drought impact models have also focused on Europe or the USA. But the rapid development of artificial intelligence (AI) that can extract drought impact information from text or images is likely to enhance drought impact monitoring in less developed regions in the near future.

One major direction for modelling is to forecast the occurrence of various types of drought impacts, which is similar to a classification problem in predictive modelling. Event-based data lend themselves to presence-absence analysis, associating whether a drought impact happened with a certain level of a drought indicator. Traditional regression models, such as logistic regression, and machine learning (ML) models, such as decision trees, have been used to address such problems (Blauhut et al., 2015; Stagge et al., 2015; Bachmair et al., 2016b). Ensemble models, particularly random forest (RF) approaches, were considered some the best-performing ML models to predict the occurrence of drought impacts and weight drought indicators (Bachmair et al., 2016b; Hobeichi et al., 2022; Lam et al., 2023; Torelló-Sentelles and Franzke, 2022). A study in 2019 also built up an RF-based forecasting model between drought impacts and indicators up to 7 months before occurrence (Sutanto et al., 2019). When researchers applied a cutting-edge explainable ML pipeline based on extreme gradient boosting (XGBoost), it demonstrated better performance in predicting the occurrence of drought impacts and explaining the relationships between impacts and indicators than linear regression or random forest models (Zhang et al., 2023). The quantitative part of the methodology used in the European Drought Risk Atlas employs decision-trees to estimate relationships between drought and its impacts (Rossi et al., 2023).

Another important focus for developing models based on the event-based and ground-truthing datasets is using text mining and natural language processing (NLP) to analyze the vast amount of text, such as the descriptions of drought impacts, in the datasets. Because of their simplicity, the keyword matching and bag-of-words models are the two methods used most often (de Brito et al., 2020; Sodoge et al., 2023; Stephan et al., 2023). NLP is a subfield of AI that makes use of the power of deep learning (DL), which shows better capability to capture the context and underlying meaning of sentences. Zhang et al. (2021) successfully applied the Bidirectional Encoder Representations from Transformers (BERT) model, a DL-based NLP model, on data from the DIR and from social media monitoring to classify the types of drought impacts reflected from the analysed text. These initial studies indicated that text-based datasets are informative and valuable for studying the characteristics of various drought impacts. Current published work is based on the DIR and EDII because of data quality and availability. However, with the assistance of AI and NLP, the data collection and labelling process can be automated and deployed to a larger range of datasets, facilitating more studies and applications to address drought impacts.

Many other popular research directions on drought impacts, primarily focused on agricultural and ecological aspects, employ gridded remote sensing data at different spatial and temporal scales. Models based on computer vision (another subfield of AI) and ML/DL are the most prevalent. Overall, quantitative models based on longitudinal sector data such as crop yield, or drought-specific event-based, ground-truthing and media-derived datasets have shown promising results in predicting, assessing and analyzing drought impacts. Improving observational data collection and better algorithms will further advance this under-researched field. The outcomes, as well as the models, will support decision-making processes to mitigate drought impacts.

Table 1. Summary of primary objectives, popular methods, corresponding datasets, and references

Objective	Popular methods	Datasets	References
Predict the occurrence of drought impacts	Logistic regression (LR), random forest (RF), extreme gradient boosting (XGBoost)	DIR, EDII and other drought impact datasets with proper labels or annotations	Blauhut et al., 2015; Stagge et al., 2015; Bachmair et al., 2016a; Bachmair et al., 2016b; Hobeichi et al., 2022; Lam et al., 2023; Torelló-Sentelles and Franzke, 2022; Zhang et al., 2023
Classify event-based drought impacts	Bag-of-words, term frequency–inverse document frequency (TF-IDF), Bidirectional Encoder Representations from Transformers (BERT)	EDII, DIR, CoCoRaHS, CMOR and other text-based datasets	de Brito et al., 2020; Zhang et al., 2021; Sodoge et al., 2023; Stephan et al., 2023

Sector-specific modelling and forecasting of impacts of drought is done operationally for some sectors. For example, it is common practice in many countries to forecast agricultural yields – predictions by the private company CropProphet (https://cropprophet.com) are an example. These forecasts are often based on stochastic models for certain crops, comparing current conditions such as those documented in the USDA's Crop Progress and Condition reports with historical weather and hydrological conditions. There are also physical agricultural models such as the GEOGLAM Crop Monitors (https://www.cropmonitor.org/), which are mainly driven by satellite data and/or long-range forecasts, such as the European Centre for Medium-range Weather Forecasts Seasonal Forecast (ECMWF SEAS5).

For hydrology, subseasonal to seasonal (S2S) forecasts are operationalized in many countries to forecast streamflows for the management of infrastructure such as hydroelectric dams and to inform early warning systems for floods. For navigable rivers, such forecasts are also used to warn of low-flow conditions during drought. In the context of irrigated agriculture, the streamflow forecast can also be used to plan accordingly and react early. The model is usually a physical hydrological model driven by long-range weather forecasts, and the quality of the forecast mainly depends on the uncertainty of the S2S forecast (Pechlivanidis et al., 2017).

These sector-specific forecasts have in common that they are not done specifically to forecast drought conditions, but they capture it nevertheless and translate it directly into drought impact. There is a potential in many countries to make such products available for general drought information and include the information in decision-making.

PUTTING DROUGHT IMPACT DATA TO USE

The methods inventoried here for monitoring drought impacts fall into several broad categories that relate to the purpose for which data is gathered. These are described in the sections that follow.

Event databases

Event-driven databases such as the US Drought Impact Reporter (DIR), the European Drought Impact Report Inventory (EDII), the Emergency Events Database (EM-DAT), DesInventar Sendai and the Caribbean Climate Impacts Database record impacts that have been reported elsewhere. These databases are all retrospective, providing a valuable historical record. (The DIR is also continuously updated in near real time and provides some ground-truthing for the US Drought Monitor.) Event-driven databases are essentially disaggregated history – events logged as discrete observations rather than connected in narrative. This historical record can answer questions about drought's past impacts and people's experience of drought in a particular location. Practically speaking, a record of the different ways that drought has affected a location provides a list of vulnerabilities to investigate further. In a planning process, such a list and any accompanying detail may provide insight into which groups or stakeholders to involve, or which vulnerable populations may require additional support. Planners and stakeholders may want to prioritize some impacts over others, based on whether they affect livelihoods, ecosystems or production. Event databases can help identify hotspots or quantify risk via metrics such as estimated annual damage (Cammalleri et al., 2020).

Real-time condition monitoring, in-situ data collection

In-situ components of drought monitoring efforts, such as those discussed for North and South America, Australia, Central and Eastern Europe, India, and parts of Africa and Asia, incorporate geographically dispersed observations and may provide a way for grassroots stakeholders to have a voice in the process. In some cases, these are part of official ministry monitoring systems that anticipate fluctuations in crop yields. They incorporate elements of citizen science, crowdsourcing, or networks of observers, providing infrastructure to aggregate dispersed observations. Ground-truthing validates and provides context for numerical monitoring systems, which makes them more credible in decision-making.

Relief-driven efforts

For some of drought's worst impacts, such as famine in areas where people rely on subsistence farming for food and there are no social safety nets, drought is typically not the sole cause. Thus, a data collection scheme may need to incorporate other types of data in addition to those on drought, as exemplified by FEWS NET and more specific efforts in Somalia. Another example of collecting data to support a specific relief effort is California's collection of data on dry domestic wells. It is part of the state's effort to uphold the human right to water. The academic and development literature includes other examples of citizen science and crowdsourcing programmes to monitor water and livelihoods. Post-disaster needs assessments may be based on impact reporting, supporting response and recovery plans and aid requests.

RECOMMENDATIONS

This publication is meant to provide a baseline description of current systematic efforts to collect data on and understand impacts of droughts. It is not a guide on how to establish a regional or national drought impact monitor. Still, there are practices around the world implemented operationally or as research pilots which have demonstrated great value, as shown above. The following recommendations are a condensed version of the best practices identified in the preceding chapters, which are – in the opinion of the authors – worth considering when establishing or improving a drought impact monitoring mechanism:

(1) **Build drought impacts into drought monitoring systems according to the purpose of the system**. Based on underlying vulnerabilities and drivers of impacts, identify relevant metrics, and establish data collection systems if they do not already exist. For example, large-scale water management systems should include metrics across the major sectors of domestic water supply, agriculture and the environment, as well as others that are regionally important for livelihoods and the economy. Systems designed to anticipate and respond to food insecurity usually incorporate one or more metrics of drought, underlying vulnerability and real-time social data on food security or nutrition status.

(2) **Develop and periodically review the purpose of drought impact data collection**. As outlined in the Purpose and Capacity section above, an institution or group needs to consider the purpose for which data are being collected and keep the following key questions in mind when monitoring drought impacts: WHY? WHAT? TO WHOM? FOR WHOM? HOW? WHEN and WHERE?

(3) **Collect numerical drought impact data over time, in accord with the purpose of the system**. As early as 2002, Redmond recommended calibrating drought indicators by comparing them with drought impact data collected at regular time intervals and noted that such data typically do not exist without a coordinating presence (Redmond, 2002). Lackstrom et al. (2013) found that drought impacts monitoring was still the "missing piece" of drought research. Bachmair et al. (2016a) found that progress on drought indicators was outpacing progress on impact assessment. Authors of the European Drought Risk Atlas (Rossi et al., 2023) found that sparse or fragmented drought impact data were a limit in assessing risk and recommended systematic monitoring and collection of drought impacts data at pan-European scale.

(4) **Start small and develop your system stepwise**. Beginning with the information gathered for this document, establish and maintain a database following existing examples of drought impact databases and in-situ data collection systems around the world. This would ideally also include descriptions of drought monitoring and early warning systems. A starting point could be further comparison of the major global disaster databases, EM-DAT and DesInventar Sendai, which use different methodologies, as well as established efforts such as the US DIR and its European counterpart, EDID. A comparison focused on which decisions or modelling processes each database can support would be helpful.

(5) **Work with Integrated Drought Management Programme (IDMP) partners to develop standards and guidance.** There many IDMP partners that are working on drought impact reporting. As described in the conclusion, IDMP will begin developing guidance and possible standards on how to set up a drought impact monitoring system at national level, taking into account the specific country context and needs.

CONCLUSION

By tracking the impacts of drought, we can identify and understand underlying vulnerabilities, thereby working to *reduce vulnerability* to future droughts and strengthen sustained drought resilience.

This publication showcases examples of drought impact monitoring efforts from around the globe on different scales, from regional to basin-level and national, and for specific sectors. These efforts are currently not the norm, even though the coverage of drought monitoring is growing around the world. In contrast, impact data collection for fast-onset events such as floods and hurricanes is operationalized in many countries and basins. We are accustomed to learning about the "final cost" of floods just a few weeks after the event happened. This good practice allows policymakers, insurers and other relevant actors to take quick action to relieve the affected population and in a best case take measures so that future floods will cause less harm.

For slow-onset events like drought, the collection of impact data is more complex due to the reasons explained in the previous chapters: impacts are often indirect; drought impacts are not mono-causal; the impacts can occur far away from the location of the actual drought; impacts may not be fully realized until the end of a growing season; there is no uniform approach to define the onset and the end of a drought; drought impacts can continue even when the actual drought has already ended; and attribution of impacts either to drought or to socially constructed vulnerability may imply responsibility to act.

Understanding these challenges is a first step in overcoming them. This baseline report contains many positive examples that show how to collect meaningful information on drought impacts despite the challenges. Therefore, we call for strengthened efforts to capture and catalogue the impacts of drought as is done for floods, taking into account their complex nature. Both qualitative understanding and quantification of impacts contribute to the ability of stakeholders and decision makers to implement adequate drought response and strengthen drought resilience. Currently many decision makers are focused on water management or water as one element within a sector, such as agriculture or tourism, in contrast to a "climate" perspective that groups many cross-sector concerns as "drought impacts." Of course, for planners, stakeholders and decision makers, the ultimate goal of reducing impacts to people and the environment may be more important than parsing whether an impact is due to drought alone, to drought in combination with other conditions, or solely to other factors such as management decisions. This is in part because investments in human and environmental capacity, such as implementing sustainable development goals, have multiple benefits.

But another advantage of focusing on drought impacts is that it necessitates a very broad perspective, encompassing agriculture, urban water supply, and in-stream uses such as aquatic habitat, as well as many other sectors. This may spur the creation of more holistic, cross-sector institutions with comparably broad scope.

This publication shows how important it is to monitor drought impacts and describes the current state of knowledge and best practices around the globe. However, as indicated in the name, this is intended to be a baseline. As a next step, IDMP plans to publish concrete guidelines based on this report to provide guidance on how to set up a drought impact monitoring system at national level, taking into account the specific country context and needs.

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APPENDIX A. EVENT-BASED DROUGHT IMPACT DATABASES AND CONDITION MONITORING SYSTEMS

Name	Product(s)	Methods	Creating institute(s)
Event-driven databases			
The Caribbean Climate Impacts Database (CID) Caribbean nations (Contact the Caribbean Institute of Meteorology and Hydrology (CIMH))	Inventory of georeferences, climate-related impacts in 19 Caribbean States	Inventory of georeferenced, historical weather and climate-related impacts	Caribbean Institute of Meteorology and Hydrology (CIMH)
DesInventar Sendai Global	Database of disasters, including more than 27 000 for drought	Drought is one of several disasters tracked, based on reports disaggregated to finest possible spatial resolution	UN Office for Disaster Risk Reduction
$EDDI_{ALPS}$ Alpine region https://ado.eurac.edu/impacts	Expands EDDI database with more Alpine entries, through 2020	Classifies impacts as being related to either soil moisture or hydrology and current impact probability	Alpine Drought Observatory
Emergency Events Database (EM-DAT) Global https://public.emdat.be/	More than 800 drought-related disasters around the world from 1900 to 2022	Based on agency reports	Center for Research on the Epidemiology of Disasters (CRED)
European Drought Impacts Report Inventory (EDII) Europe https://doi.org/10.6094/UNIFR/230922	Based on scientific, media and other reports, 15 impact categories	Invites the public to contribute reports on drought impacts	Led by researchers at the University of Freiburg, part of Drought R&SPI project
European Drought Impact Database (EDID) http://edid-test.eu/	Incorporates data from EDII and others	Impact events based on media and other written sources, web crawling, stakeholder observations	European Commission Joint Research Centre
Irish Drought Impacts Database https://zenodo.org/records/7216126	Based on historical news accounts	Categorized based on modified EDII scheme	Irish Droughts: Environmental and Cultural Memories of a Neglected Hazard, University College Dublin
US Drought Impact Reporter (DIR) https://go.unl.edu/dirdash	Database of impacts mainly from media, categorized by sector, associated with place and date	Continuous moderation; impact events based on media reports	National Drought Mitigation Center, University of Nebraska

Name	Product(s)	Methods	Creating institute(s)
Event-driven databases			
Volunclima Andean countries: Plurinational State of Bolivia, Chile, Colombia, Ecuador, Peru, Bolivarian Republic of Venezuela https://volunclima.ciifen.org/	Volunteer observers make daily rainfall measurements and monthly drought impact perception reports	Survey via app asks about soil, vegetation, precipitation, temperature and livestock water	International Research Centre on El Niño (CIIFEN)
Czech Drought Monitor Central Europe https://old.intersucho.cz/en/ https://questionnaire.intersucho.cz/en/	Contributes to drought monitoring	Asks farmers about anticipated yield	Intersucho
Australia Drought Monitor Australia https://www.nacp.org.au/drought_monitor	Contributes to drought monitoring	Uses a survey form to collect observations on moisture conditions, crop and livestock production, and how well the drought monitor matches conditions	North Australia Climate Program
Bolivian Drought Monitor Plurinational State of Bolivia http://monitorsequias.senamhi.gob.bo/#/home	Monthly drought bulletin	Participatory approach	Pilot Program for Climate Resilience
The Monitoramento de Secas e Impactos no Brasil Brazil https://www.gov.br/cemaden/pt-br/assuntos/monitoramento/monitoramento-de-seca-para-o-brasil/ https://docs.google.com/forms/d/e/1FAIpQLSct3c8lkUqR0oHtSiPusWkrDF9TvL3Dg9RqD50QDrHz_qfVnw/viewform	Contributes to drought monitoring	Open crowdsourcing, a public form asks about observed impacts	National Centre for Monitoring and Alerts of Natural Disasters
Monitor de Secas Regions of Brazil https://monitordesecas.ana.gov.br/mapa	Contributes to drought monitoring	Observers complete monthly questionnaires	National Water Agency
AgriClimate Impact Reporter (AIR) Canada https://agriculture.canada.ca/en/agricultural-production/weather/agroclimate-impact-reporter	Assessment of weather and climate impacts on farms	AIR survey open during last week of the month over the growing season (April to October) – producers across Canada – citizen science	Agriculture and Agri-Food Canada (AAFC)

Name	Product(s)	Methods	Creating institute(s)
Event-driven databases			
India Drought Monitor India https://indiadroughtmonitor.in/#/drought-reporting	Contributes to drought monitoring	Option for public to submit reports on drought conditions and impacts	Indian Institute of Technology Gandhinagar
Condition Monitoring Observer Reports (CMOR) US, Puerto Rico, US Virgin Islands https://go.unl.edu/cmor_drought	Photos and observations of drought-related conditions	crowdsourced, open form on web to collect photos and drought-related observations	National Drought Mitigation Center, University of Nebraska
Collaborative Community Rain, Hail and Snow Network (CoCoRaHS) US, Puerto Rico, US Virgin Islands, Canada, the Bahamas, Guam https://www.cocorahs.org/content.aspx	Daily data on precipitation, optional condition monitoring reports	Citizen scientists who measure rainfall can submit an optional additional condition monitoring report	CoCoRaHS, Colorado State University

APPENDIX B. CASE STUDIES

Case study: Food insecurity monitoring in Somalia

By William Veness, Imperial College, London

In the wake of the devastating 2011 drought, which caused mass displacement and an estimated 258 000 excess deaths in Somalia, multiple platforms have been developed aiming to better monitor drought impacts and provide early warning information on areas at highest risk of food insecurity (BRCiS, 2021). However, none of these are solely dedicated to drought monitoring; instead, they cover food insecurity more broadly, as socioeconomic indicators of drought are also influenced by multiple, concurrent factors in Somalia, including other natural hazards, disease outbreaks, conflicts and changes in international supply chains. Therefore, drought impact monitoring in Somalia is presented indirectly through food insecurity monitoring platforms.

FEWS NET is a USAID-funded, international platform operating in 36 countries (Funk et al., 2019).[1] It has a large network of FEWS NET Implementation Team (FIT) members in these countries who collate information, which is then prepared for 4-monthly food insecurity current situation and projection maps. It reports food insecurity on the Integrated Phase Classification (IPC) scale, scoring areas from 1 to 5 based on food insecurity risk. The final classification is formulated by committee based on evidence provided by socioeconomic indicators, including livestock holdings, crop yields, migration data, nutrition and health data, food prices and water prices. FEWS NET is internationally recognized, but it is less detailed in its country-specific data sourcing than the dedicated national platform (the Food and Agricultural Organization of the United Nations (FAO) Food Security Nutrition Analysis Unit (FSNAU)).

FSNAU is a dedicated unit for Somalia, initiated in 1994 and working closely with USAID and FEWS NET. It produces a quarterly report on food insecurity, mapped using the same IPC scale but based on a different combination of indicators (Figure 1) (https://fsnau.org/ipc/ipc-map). It also has a monthly Early Warning Early Action Dashboard (https://dashboard.fsnau.org/), which combines socioeconomic indicators with physical indicators – rainfall and a satellite-based vegetation index (Normalized Difference Vegetation Index (NDVI)). The dashboard maps the number of these indicators that have exceeded predefined thresholds to enter "alert" or "alarm" stages each month, enabling comparison of regions. Drought's contribution to each of these indicators is obscured by other influencing factors, however, significant increases in alarms have been observed during the 2017 and 2022 drought events (Figure 2).

Numerous other platforms and networks exist in Somalia to share information on drought impacts. The Building Resilient Communities in Somalia (BRCiS) early warning dashboard is a platform used by a consortium of NGOs to monitor drought and food insecurity using socioeconomic indicators (BRCiS, 2021, 2022). In contrast, the FAO Somalia Water and Land Information Management (SWALIM) unit produces a Combined Drought Indicator (CDI) monitoring physical drought, combining rainfall, temperature and satellite vegetation data into its index (https://cdi.faoswalim.org/index/cdi). Other more international platforms covering Somalia include the African Flood and Drought Monitor (https://hydrology.soton.ac.uk/apps/afdm/), the FAO Global Information and Early Warning System on Food and Agriculture (GIEWS) (https://www.fao.org/giews/en/) and the Humanitarian Data Exchange (HdX) (https://data.humdata.org/), a service provided by United Nations Office for the Coordination of Humanitarian Affairs.

There remains, therefore, a range of drought impact and food security monitoring networks in Somalia. A lack of top-down governance and coordination of these means data are not fully shared, and it can be difficult to triangulate the different indicators, which vary between these networks. It is even more difficult to attribute the individual contribution of droughts to changes in the indicators on these platforms due to correlations and interrelationships between drought and other food insecurity driving factors.

1 The current USAID funding freeze has resulted in FEWS NET (formerly accessible at https://fews.net/) being taken offline.

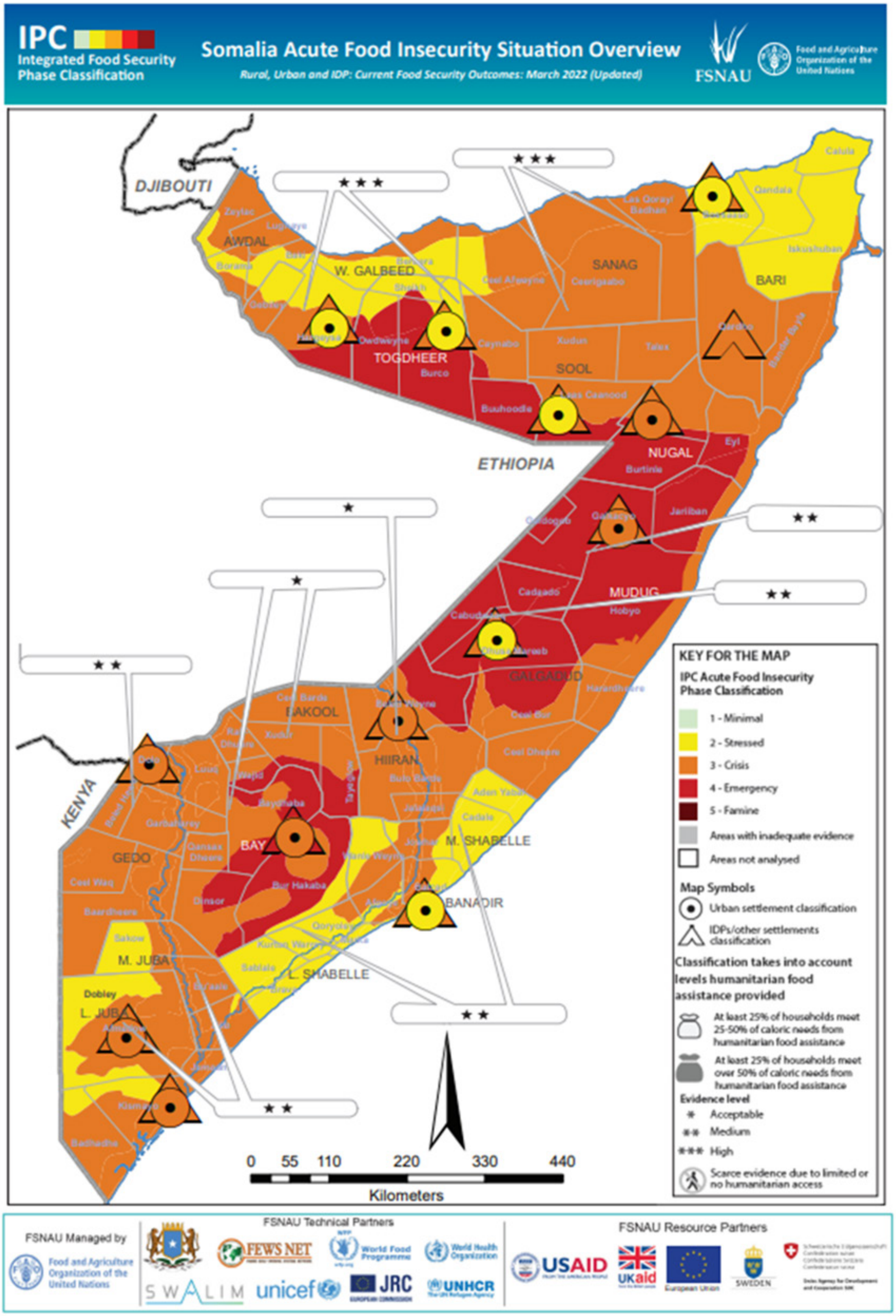

Figure 1. March 2022 food insecurity classification by FSNAU using the IPC scale

Source: Third party map. This map was taken from https://fsnau.org/ipc/ipc-map on 31 May 2024 and may not fully align with United Nations and WMO map guidance.

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

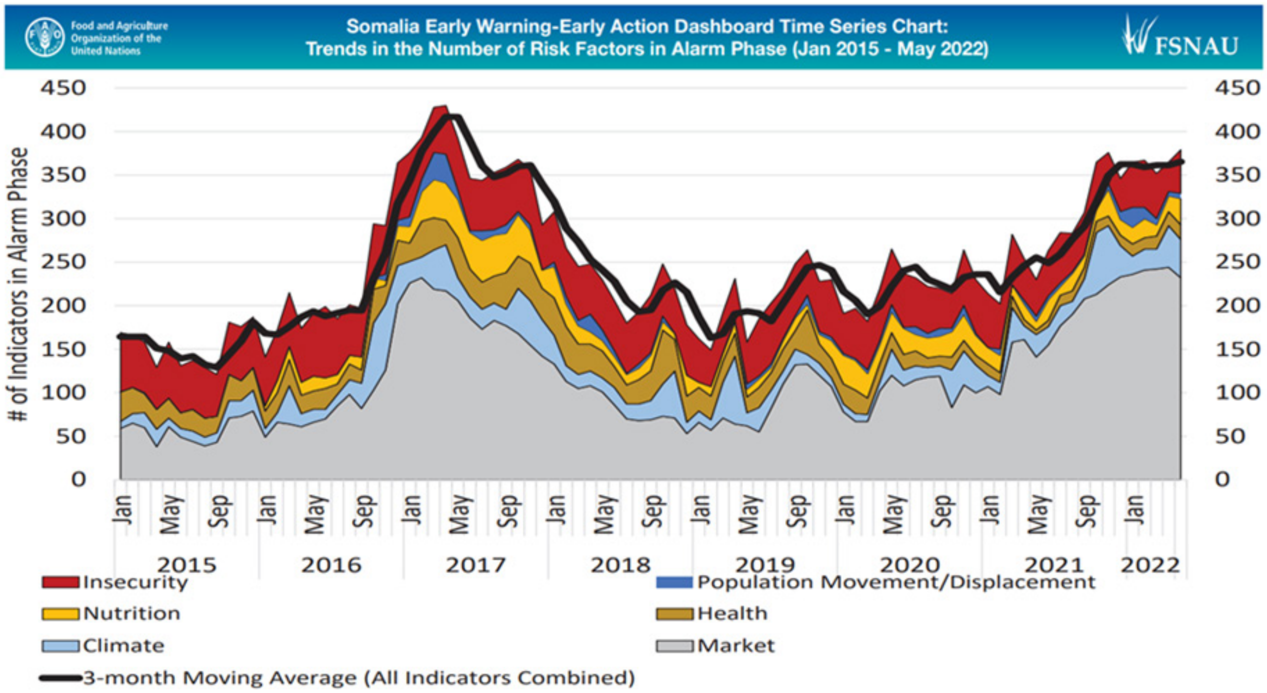

Figure 2. Monthly totals of all indicators in alarm phase across Somalia's administrative regions on the FSNAU Early Warning Early Action Dashboard (https://dashboard.fsnau.org/)

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Case study: Livelihood monitoring in Kenya

By Marleen Lam, Wageningen University, the Netherlands

Another initiative to monitor drought conditions and impacts by focusing on livelihoods is being conducted by the National Drought Management Authority (NDMA) in Kenya. The NDMA was established by the Government of Kenya in 2016 with the aim of establishing and operating drought early warning systems and to develop drought preparedness strategies and contingency plans. The first efforts on drought management strategies in Kenya date back to 1981, when a drought contingency planning system was established in Turkana in response to the catastrophic droughts in 1980 (Oduor et al., 2014). With support of the Netherlands Government, this system was extended to other arid regions. Through the Emergency Drought Recovery Project and the Arid Lands and Resource Management Project (ALRMP), implemented by the Government of Kenya with support from the World Bank, the system was expanded even further from 1992 (Ndegwa and Kinyua, 2018). With the development of the ALRMP, the drought management system became more embedded within the Government, eventually resulting in a permanent State corporation, the NDMA (Oduor et al., 2014).

The NDMA has offices in the 23 arid and semi-arid lands, regions whereby the Authority provides monthly county-specific bulletins assessing food security. Food security is assessed by looking at biophysical factors (for example, vegetation conditions and rainfall) and socioeconomic factors (for example, access to market, production). NDMA field monitors are designated to measure certain variables (such as children's mid-upper arm circumference (MUAC)) and to communicate with herders and farmers in their districts. Among others, aspects related to agricultural yields, animal body condition, milk production, livestock deaths, forage

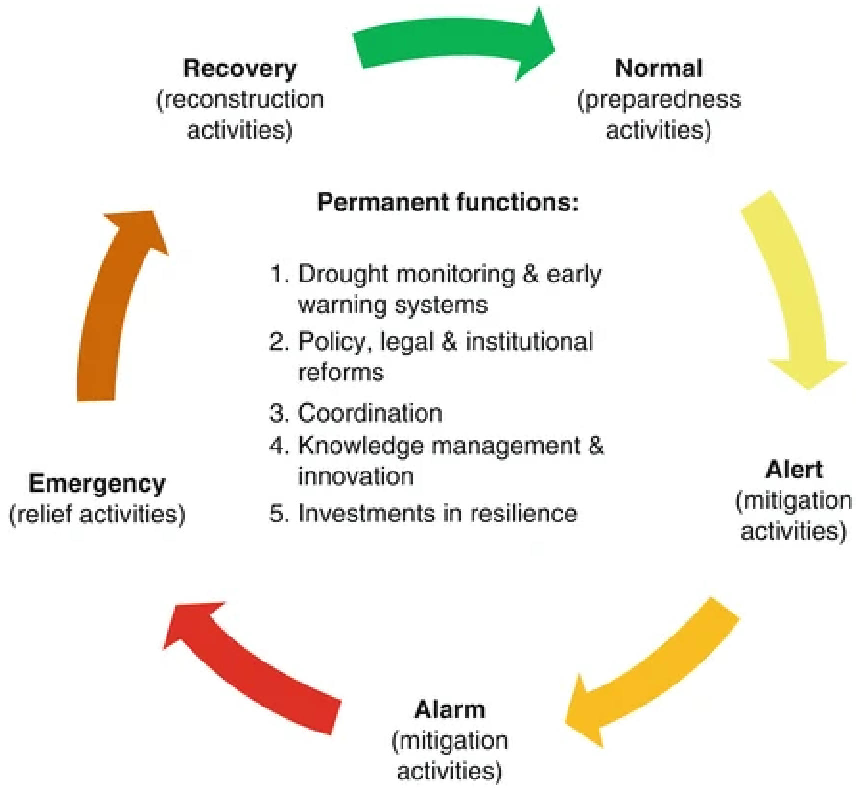

Figure 3. Drought early warning stages and drought management strategies (Oduor et al., 2014)

conditions, market access and food availability are reported to assess food security threats (Lam et al., 2023). The NDMA has an early warning system with five different warning stages, namely "normal", "alert", "alarm", "emergency" and "recovery". Corresponding to a particular warning stage, a set of preplanned actions are determined to prevent an expected drought–famine sequence from happening or to mitigate its effects, as visible in Figure 3 (Oduor et al., 2014). The particular stage is determined by assessing a common set of environmental, economic and nutritional indicators to evaluate the extent to which drought conditions deviate from the norm (Oduor et al., 2014). Since 2014, the NDMA has released disaster contingency funds received from the European Union to aid early response to drought threats (Klisch and Atzberger, 2016). In addition, the Authority implements social protection programmes for food insecure populations and strategic projects aiming to improve drought preparedness in the country (Ndegwa and Kinyua, 2018).

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