SCIENCE FOR POLICY BRIEF

The European Drought Observatory for Resilience and Adaptation (EDORA)

HEADLINES

- In recent years, droughts have had increasing impacts on various interconnected **socio-economic sectors and ecosystems** throughout the EU. Impacts are projected to further increase under anthropogenic **climate change** for many sectors and regions.
- Structural collaboration between different **Drought Observatories**, impacted sectors and experts is necessary to enhance technical and scientific support for plans and measures to increase **drought resilience and adaptation** in the EU, especially with respect to developing common assessment approaches and enhancing data collection.
- The **European Drought Impact Database (EDID)** provides an inventory of direct and cascading drought impacts in Europe and is an instrument for data collection. The EDID sets the ground for a systematic monitoring of drought impacts and further designing impact-mitigating water management strategies.
- The **European Drought Risk Atlas** maps hotspots and risk drivers across different systems and regions of the EU. It builds on conceptual risk models (impact chains) and on innovative quantitative drought risk assessment, as a further step towards impact-driven drought risk assessment.

'As droughts jeopardize European water resources, understanding the complex impacts and the risks they pose is the first step to safeguard access to water for all people and ecosystems, now and in the future.'

Drought in the EU

Droughts are becoming recurrent events in Europe, with recent ones that have been widespread and have caused severe impacts throughout the EU, notably in 2003, '07, '11-'12, '15, '17-'20, and '22.

Average annual economic losses in the EU are estimated at €8.36 billion and projected to rise to €60.2 billion with unmitigated 4 °C global warming (Naumann *et al.*, 2021), without accounting for non-monetised or intangible impacts such as on ecosystems and wellbeing.

Recent droughts in the EU have had impacts of varying severity on both rain-fed and irrigated agriculture, public water supply, inland shipping, production of hydropower and thermoelectric energy, terrestrial and freshwater ecosystems, tourism, and infrastructure, among others.

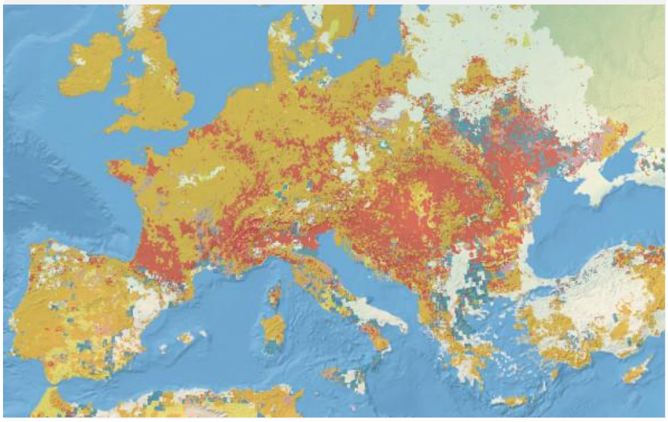
Joint Research Centre

Box 1: The drought of 2022

Over the winter of 2021-'22, a persistent lack of precipitation driven by a positive phase of the North Atlantic Oscillation impeded normal snow accumulation and groundwater recharge over large areas of Europe and especially in France, Italy, and Spain (e.g. Figure 1).

Dry conditions persisted throughout spring and summer, and were further exacerbated by high temperatures, leading to an extreme drought (Toreti *et al.,* 2022), estimated as the worst in 500 years meteorologically. At its peak in summer (Figure 2), the drought affected one third of Europe and caused severe socio-economic impacts on agriculture, energy production and river transport, in addition to impacts on natural systems, with 63% of rivers experiencing below-average flows (Copernicus Climate Change Service (C3S), 2023).

Figure 1 – Combined Drought Indicator – 1-10 August 2022



Combined Drought Indicator v3.0. Main colours are associated with the following conditions: watch (yellow), warning (orange), alert (red). Source: Copernicus EMS, European Drought Observatory.

Figure 2 – Varying regional and sectoral impacts of the '22 drought

Top: The Almendra reservoir in Castilla y León, Spain is at critical lows after an exceptionally dry spring and summer. Source: European Union, Copernicus Sentinel-2 imagery. Bottom: After an exceptionally dry and hot spring, 90 out of 96 "départments" in France are imposing water restrictions. Source: European Union, Copernicus Sentinel-3 imagery

Drought impacts often have cascading effects across sectors and systems (Hagenlocher *et al.*, 2023). Because of their complexity and limited data availability, drought risks and impacts remain difficult to assess and quantify. All the while, new drought-related risks emerge in regions or sectors that were not considered drought-prone before. This evolving challenge necessitates a EU-wide strategy for drought impact and risk assessment that will support the development of resilience and adaptation strategies in the face of more frequent droughts and droughts of longer duration and intensity.

The complex nature of droughts and drought risks

Droughts originate as hydroclimatic anomalies, driven primarily by a precipitation deficit and often by the increased evapotranspiration due to high temperatures and wind, and can result in temporary water deficits, which can ultimately result in water scarcity and impacts. Droughts can also further increase - in some places already excessive - water demand.

However, from the policy, management and adaptation perspectives, droughts and water scarcity need to be seen as complex human-natural interactions, driven by the anomalies of the hydrological cycle in combination with human use and water management.

A drought can manifest itself at different levels, usually indicated as meteorological, agricultural, and hydrological, with socio-economic and ecological impacts at each level (UNISDR, 2021). Droughts propagate through the water system and often cause cascading impacts along the many and highly interconnected systems that depend on water (Hagenlocher *et al.*, 2023).

Droughts can affect nearly all sectors of society and ecosystems, but impacts can be hard to identify and attribute; the impacts may be delayed in time, manifest in locations different from the occurrence of the driving precipitation deficit, or result from the interplay with non-drought-related hazard and vulnerability factors. Furthermore, droughts often co-occur with other hazards such as heatwaves and forest fires, and paradoxically can even exacerbate floods (UNISDR, 2021).

These inherent systemic and cascading impacts and risks (Hagenlocher *et al.*, 2023) make droughts a complex and severe climate-related hazard (UNISDR, 2021). Adding to this complexity, drought frequency, intensity and duration are projected to further increase due to the increasing meteorological extremes and variability caused by climate change (Cammalleri *et al.*, 2020; Naumann *et al.*, 2021) and projected increases in water use related to population growth, changes in diet and socio-economic conditions.

While the monitoring and analysis of hydro-meteorological drivers have a longstanding tradition and are advancing fast (e.g. Mishra and Singh, 2010, 2011; AghaKouchak *et al.*, 2015; Cammalleri *et al.*, 2023), a more diverse set of knowledge is needed to better understand, manage, reduce, prepare for, and adapt to drought impacts and risks affecting social, economic and ecological systems. In particular, it is paramount to develop an impact-based risk assessment, in conjunction with impact-based early warning systems.

An impact-based understanding of drought risks in the EU

While risk assessment methods for drought already exist (e.g. Carrão, Naumann and Barbosa, 2016), these are relatively limited in scope with respect to the socio-economic systems covered, the regional disaggregation and the integration of drought loss data (Hagenlocher *et al.*, 2019; Blauhut, 2020). Furthermore, the application of drought indices as proxies for drought impacts and risk is not straightforward (Bachmair, Kohn and Stahl, 2015).

A pragmatic approach to drought management and adaptation planning requires and an impact-based risk assessment, which in turn should rely on observations of drought impacts. In time, these should allow impact-based forecasting and early action for droughts.

The European Drought Impact Database

Drought impacts are defined as the direct and indirect negative effects of a drought on environmental (Figure 3), economic, and social systems. Drought impacts vary significantly depending on the systems that are affected and can be of varying severity.

Therefore, collecting and characterising the full range of drought impacts is essential for many applications such as impact-based drought risk assessment (AghaKouchak *et al.*, 2023). Currently, this remains a challenge due to a lack of generally agreed upon impact characterisation standards, widely available data recording tools, and resources to collect a comprehensive body of data. Hence, there remains a need for a comprehensive collection and analysis of drought impacts.

Figure 3 – A wetland area lies dry at Doñana National Park, Spain.

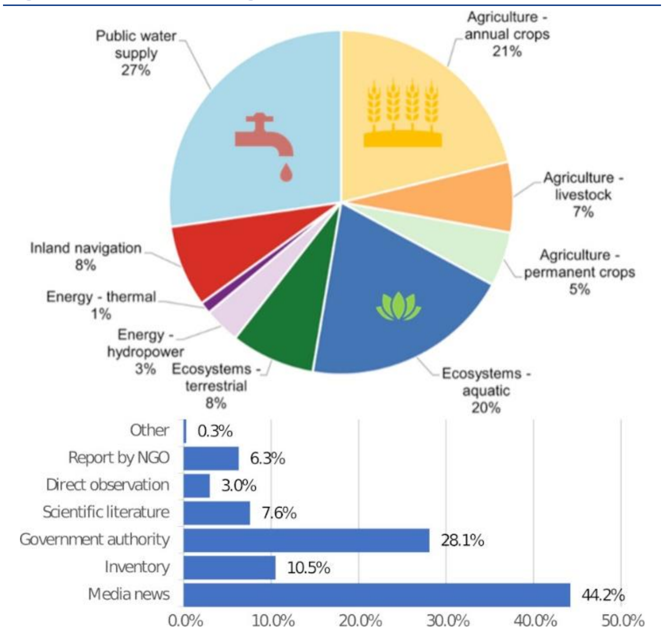
Source: EBD/CSIC.

Unlike the increasing consensus on the operational use of monitored physical indicators (e.g. precipitation, river flows, soil moisture, etc.), to date there is no generally accepted operational convention for drought impact data. This is a major barrier to understand drought risk and develop effective adaptation measures, because knowledge accumulated ad-hoc for individual drought event impacts can not easily be compared to previous events, to droughts in other regions or be used to assess the risk of future events. Moreover, without a systematic approach, no normal reference conditions can be established for evidence-based actions.

Responding to this gap, the European Drought Impact Database (EDID) was established, based on a flexible and open data model to record drought impact data, and filled with freely available data on drought impacts in Europe, retrieved from a variety of sources (Figure 4). This resulted in about 14 000 records across more than 30 European countries from 1970 to 2022, classified in terms of system affected (Figure 4, nine systems considered) and levels of severity (Figure 5).

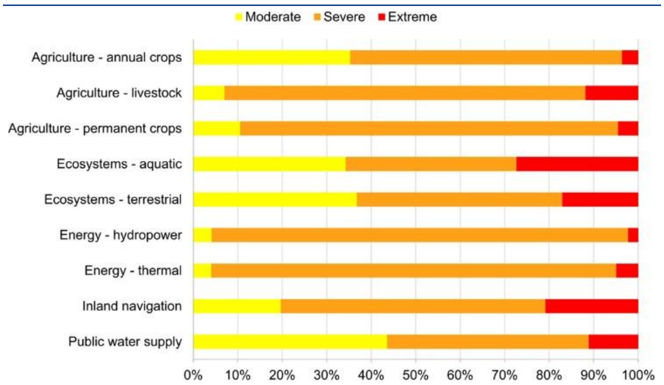
Among sectors and systems, impacts on public water supply and agriculture were reported the most, showing that these are the most tangible and visible impacts of droughts, while other systems are underrepresented (e.g. ecosystems, energy), or even overlooked (e.g. buildings and infrastructure, tourism). Most recorded impacts were classified as severe (Figure 5), suggesting that reporting tends to focus only on peak times of drought events. On the contrary, mild impacts might be recorded only by a structured and programmed monitoring activity, as regional examples have shown.

Figure 4 – European Drought Impact Database entries.



EDID entries by system (top) and data source (bottom). Source: EDORA.

Figure 5 – Severity of drought impacts in the EDID.



EDID entries by system and severity. Source: EDORA.

EDID provides Member States and other stakeholders with a template and useable tool for systematic and structured recording of drought impact data. It offers enough flexibility in the data structure to accommodate for specific needs, while maintaining a set of basic common features that allow to describe and compare drought impacts in a more standardised way. Ultimately, this activity is meant to support the technical and scientific work towards impact-based risk assessment and adaptation.

At present, the EDID reflects differences in national reporting behaviour, language barriers, data availability and differences in drought impact perception, resulting in markedly different representations and prevalence of drought impacts in different countries. Hence, despite being the largest database of drought impacts for Europe and providing a wealth of information, the data collected in EDID do not necessarily represent a comprehensive or representative catalogue of drought losses and impacts in Europe. In the database, the relative majority (~40%) of drought impacts was derived from media reports, as the most accessible and widespread data source. Organised institutional reporting frameworks could be a better source for consistent and comprehensive information, but these are currently mostly lacking.

The European Drought Risk Atlas

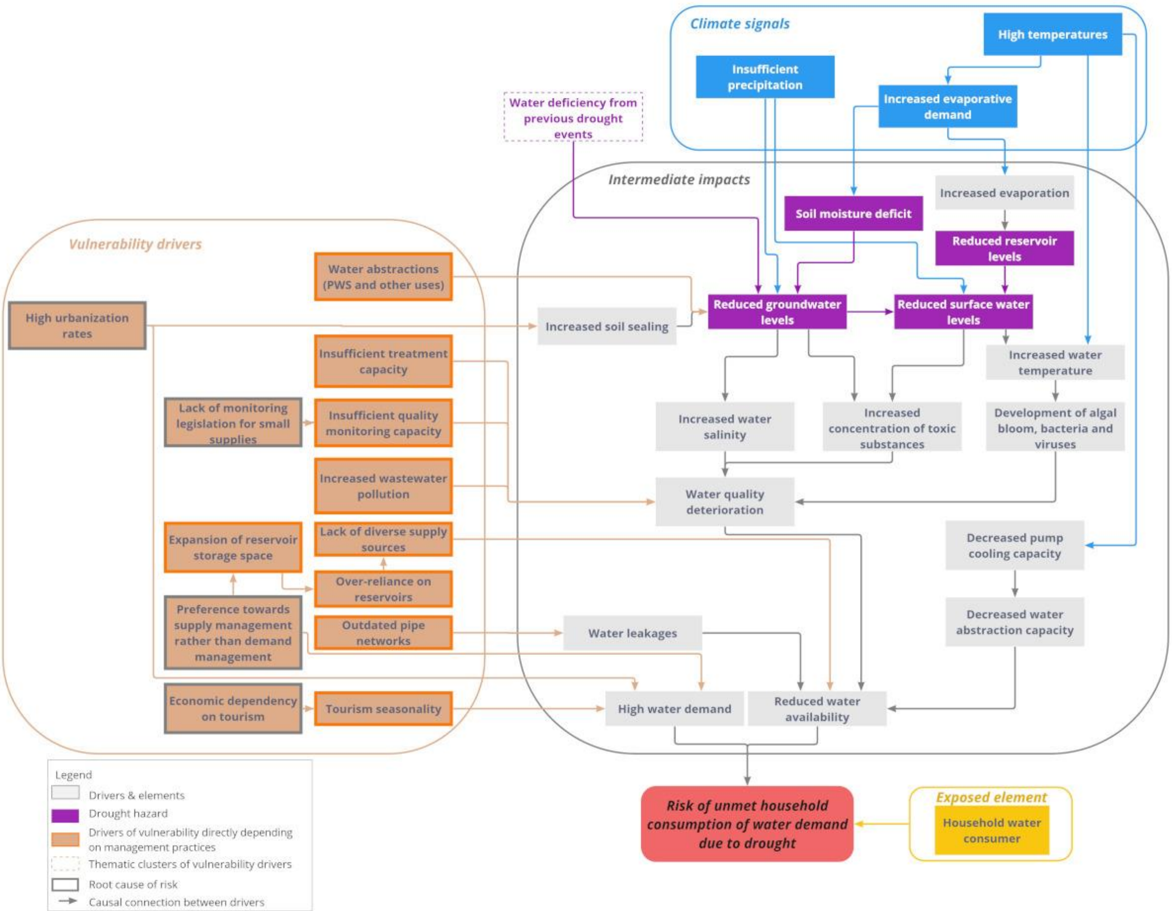
Drought risks can be understood as a function of hazard, exposure, and vulnerability (Vogt et al., 2018; UNISDR, 2021). As for other disaster risks, these three components interact with each other to create drought risks. Hazard refers to the type, probability of occurrence and severity of a hydroclimatic anomaly and its effects in the hydrologic cycle. Exposure indicates the presence of people and assets in places and settings that could be adversely affected (IPCC, 2023), which for drought can consist of the presence of people, infrastructure, agricultural land, productive assets, or ecosystems and the water resources upon which these rely.

Finally, given a certain hazard and exposure, drought-affected systems will suffer adverse consequences to different degrees depending on their vulnerabilities: these vulnerabilities can encompass ecosystem susceptibilities (e.g., the characteristics of soils and vegetation), or societal and infrastructural ones (activities or sectors strongly dependent on only one source of water, unstable food markets, lack of coping capacities, etc.)

The European Drought Risk Atlas (Rossi *et al.*, 2023) offers for the first time a detailed and disaggregated view on the risks that droughts pose to our societies and ecosystems and their underlying risk drivers. The Atlas characterises how drought hazard, exposure and vulnerability interact and affect different but interconnected systems: agriculture, public water supply, energy production, river transportation, and freshwater and terrestrial ecosystems. Ultimately, it aims to support the development and implementation of drought management and adaptation policies and actions across the EU.

To break down the complex dynamics of drought risks, the European Drought Risk Atlas features sectoral impact chains (e.g. Figure 6), i.e. conceptual risk models that were constructed based on an extensive review of literature and consultations with experts (Cotti *et al.*, 2023). These impact chains depict the interactions between the most relevant drivers of drought risk for different systems. They serve as a guideline for the construction of quantitative drought risk assessment models, and can also be used to identify entry points for drought impact prevention, management, recovery, and adaptation.

Figure 6 – Example of the impact chain for drought risk management for the public water supply system.



Impact chain for public water supply. Other impact chains can be consulted in the European Drought Risk Atlas. Source: EDORA.

As a further step towards impact-based drought risk assessment, a novel dynamic approach based on machine learning was developed: in this approach, the association of hydro-meteorological indicators with impact data across different regions and socio-economic and environmental systems was modelled, including system-specific vulnerabilities. Combined with sector-specific exposure data, this allowed for quantitative estimations of drought risk.

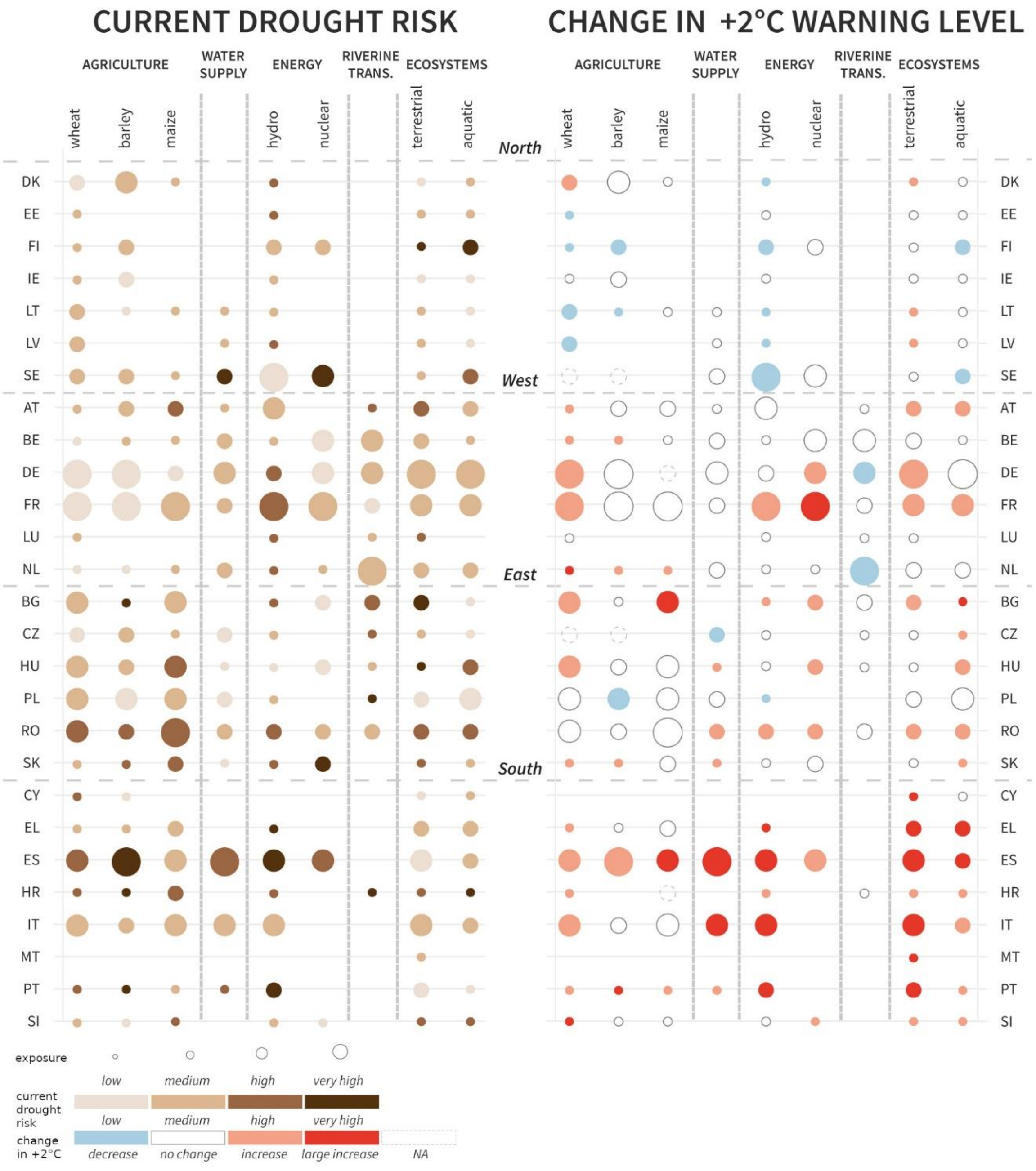
The European Drought Risk Atlas shows that current drought risks in the EU are already significant, with average annual losses posing both economic and environmental threats in nearly all regions of the EU and across different systems. The Mediterranean region, and in particular the Iberian Peninsula, is subject to high drought risk.

Climate change has already resulted in more intense and persistent meteorological droughts, especially in Southern Europe. More frequent and severe droughts are projected to occur at global warming levels of 2 °C or more above pre-industrial levels. Especially the Iberian Peninsula is projected to face droughts in the future due to a clear trend of increasingly dry conditions linked to climate change.

Besides, it is expected that almost the entire EU will be more affected by drought events with further global warming. Eastern and Western Europe may experience complex dynamics due to the interplay between a drying pattern in summer and wetting in winter. For some sectors such as agriculture and hydropower, a lower drought risk is expected in Northern Europe, particularly in the Baltics.

The European Drought Risk Atlas provides a detailed analysis of the drought risk in the EU for the individual systems (Figure 7).

Figure 7 – Drought risk in the EU for a warming level +2°C, compared to pre-industrial climate.



Current and future drought risks per country, according to socio-economic or environmental system and geographical region. Source: EDORA.

Towards a Community of Practice

Within the EU Member States, several actors are usually involved in drought monitoring, operational drought management, and drought mitigation and adaptation. The responsibility for drought matters is often shared across government ministries (e.g. agriculture, environment, transport), river basin authorities, (sub)national agencies, or meteorological or hydrological services. In many cases, also regional or supranational bodies play a role (e.g. River Basin organisations). Hydrometeorological services and research institutes are often involved in drought monitoring as well. Though not always officially recognised, they have de facto become important sources of knowledge on drought issues. In addition, research projects on droughts and water scarcity have been funded at the European (e.g. Framework Programme) and regional levels (e.g. Interreg) over the past decades. However, the results of these projects lack consolidation to some extent.

While droughts can and do affect different regions in the EU differently, the European Drought Risk Atlas (Rossi *et al.*, 2023) highlights similarities and common patterns across regions of Europe. Hence, it underscores the potential for knowledge transfer and regional cooperation when dealing with issues of drought management and adaptation, especially on a technical and scientific level. With this goal in mind, a permanent and organised Community of Practice to connect these different institutions and projects can significantly contribute to successful drought management and adaptation in Europe.

EDORA set a long-term goal of establishing a Network of Drought Observatories in the EU, as a technical and scientific network to enhance the capacity across the EU, the Member States, and other stakeholders to perform drought monitoring, early warning, and impact and risk assessment.

The network encourages and assists in the creation, continued operation, further development and increase of the compatibility of the services offered by Drought Observatories in the EU. It promotes knowledge exchange and aims to offer technical, scientific, and operational support for data and services related to drought monitoring, early warning, risk and impact assessment across different sectors and regions in the EU, including adaptation to climate change.

Furthermore, the network follows the activities of the Common Implementation Strategy for EU Water Law through the Ad-hoc Task Group Water Scarcity and Droughts and other relevant policy-oriented structures, which may draw upon the network for technical and scientific support.

Embedding drought resilience and adaptation into policy

Applications of scientific and technical developments in the areas of drought and water scarcity should be mostly aimed at supporting the development of drought policy, including drought management plans and adaptation plans, and assist operational drought monitoring and management.

The EDORA project included a stock-taking of drought management plans (Schmidt *et al.*, 2023) and adaptation actions (Benítez-Sanz, Schmidt and De Stefano, 2023) in the EU.

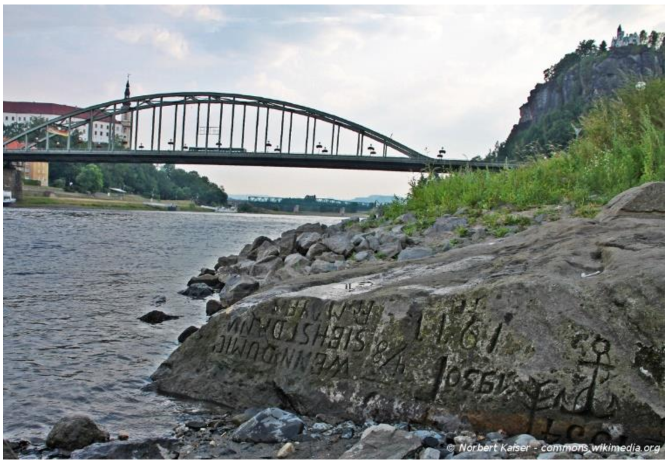
Drought resilience and adaptation through risk management, in contrast to crisis management, is implicit in several EU policies and regulations. On this, the most relevant EU policy is the Water Framework Directive (WFD), and 2021 EU Strategy on Adaptation to Climate Change. The 2019 Fitness Check of the EU water legislation found the current WFD prescriptive yet flexible enough to address also future challenges.

However, further scientific and technical developments have been found necessary to effectively support the implementation of these policies. This includes the enhancement of drought impact and risk assessment for and across the relevant sectors and systems to allow a more impact-oriented approach. Other issues requiring scientific and technical support are the further elaboration on the prerequisites for the WFD's exemptions under Article 4(6), and the determination of ecological flows (European Commission, 2015) as a requirement to achieve good ecological status, but these are currently not fully developed technically nor scientifically.

Moreover, the EU Member States differ in the way drought is defined and regulated – or not regulated - by legislation, whether and how risk management and water scarcity are included in those regulations, and the way drought management and adaptation plans are drawn up (see e.g. *Climate Adapt*). Different Member States approach the scientific and technical tasks to design drought policies in different ways, e.g. through mandating their own (environment) agencies and ministries, or through cooperation with universities, research institutes, or other entities.

Approaches to drought policy at both the EU and Member State level may benefit from wider international approaches too, such as the The Three Pillars of Drought Management adopted by the Integrated Drought Management Programme (Sivakumar *et al.*, 2014) and the United Nations Office for Disaster Risk Reduction's Sendai Framework for Disaster Risk Reduction (UNISDR, 2015).

Figure 8 – Acute drought in Europe: a long and still evolving history.



Hunger stone in the Elbe river at Děčín, Czechia bearing markings of historical low water episodes. Source: Wikimedia Commons, Norbert Kaiser.

Conclusions

In recent years, droughts have had substantial impacts on nearly all regions of the EU, affecting several critical systems such as agriculture, water supply, energy, river transport, and ecosystems, prompting several EU Member States to implement or further develop drought management plans.

Climate change is set to exacerbate drought risks for most systems and most regions of the EU, and especially the Mediterranean, calling for the development and implementation of drought adaptation plans and measures. The responsibility for these is relatively dispersed across different entities and institutions in the EU Member States.

While many Member States have consolidated their approach to droughts in recent years with the development of monitoring systems and management and adaptation policies and plans, there remains a need to build a community of practice to exchange technical and scientific knowledge and experience, and to improve transboundary and regional cooperation for drought monitoring and analysis.

The network of Drought Observatories in the EU, initiated in the EDORA project, established first contacts for this community, which is yet to develop further activities on data harmonisation, impact data collection, the further development and application of seasonal to decadal forecasting, improving hydrological models for drought conditions and analysing the output of those models, both in the current and future climates. These technical and scientific developments will also provide valuable support for addressing ongoing governance issues like prerequisites for the WFD's exemptions under Article 4(6) to apply, the determination of ecological flows, and water allocation priorities. To successfully inform and support drought management and adaptation, substantial development of impact-based drought risk assessment is required, to complement current drought hazard monitoring and forecasting.

The European Drought Impact Database (EDID) addresses this by establishing operational conventions and procedures for the collection and categorisation of drought impact data, and compiling and assigning a severity to about 14 000 records of drought impacts across more than 30 European countries since 1970.

The European Drought Risk Atlas (Rossi *et al.*, 2023) offers for the first time a detailed and regionally disaggregated view of drought risk in different but interconnected systems, by means of impact chains that visualise the most relevant drought drivers for different systems and how they interact to determine risk and impacts, and provide entry points to increase drought resilience and adaptation.

The Atlas shows substantial drought risks throughout the EU, with losses posing both economic and environmental threats. The Mediterranean region, and especially the Iberian Peninsula, was found to be at high risk at present and worsening drought impacts with increasing anthropogenic climate change projections. Eastern and Western Europe are estimated to experience more diverse and compounded effects, especially for complex systems such as riverine transportation or hydropower, due to the interplay between drying/wetting dynamics and precipitation variability.

In conclusion, the EDORA initiatives represent an urgently needed first step in the transition from a mostly hazard-based assessment of drought risks to a more impact-based assessment as the EU develops plans and implements measures to become more resilient and adapt to the risk posed by droughts and water scarcity, both in the current climate and in the future climate.

However, as drought management and adaptation plans are being developed and implemented in an increasing number of Member States, further drought impact data collection and analysis, and tailored sectoral and a regionally disaggregated drought risk assessments are urgently required to properly dimension these plans.

MORE INFORMATION

European Drought Risk Atlas: *https://publications.jrc.ec.europa.eu/repository/handle/JRC135215*
European Drought Impacts Database: *https://edid-test.eu/*

SUGGESTED CITATION

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