The 2022 Drought Needs to be a Turning Point for European Drought Risk Management

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Abstract

The 2022 European drought has underscored critical deficiencies in European water management. This paper explores these shortcomings and suggests a way forward for European drought risk management. In particular, we focus on four key aspects: the increasing drought risk, its spatial and temporal impacts, current management approaches, and how these differ across Europe. We base our findings on a continent-wide survey of water managers involved in responding to the 2022 drought. The survey collected 481 responses from 30 European countries and contained 19 questions on perceived sectorial impacts and the drought risk management practices implemented by the respondents' organizations. Information from the survey was supported with climate-related data on drought severity as quantified by the Standardised Precipitation Evapotranspiration Index, to offer a comprehensive overview of how extreme historical droughts are managed across Europe. Our findings reveal a consensus on the growing risk of drought, driven by droughts' rising frequency and intensity. While the 2022 event affected most of the continent, our findings show significant regional disparities in management capacity. In many countries – particularly those with agriculture-dominated economies – drought responses remain short-term and reactive, often leading to potentially maladaptive practices. Despite these challenges, we also observe a positive shift, with organizations showing increased awareness and preparedness. Hence, the lessons learnt from the 2022 event may provide an ideal opportunity to mainstream European-wide drought risk management. To seize this opportunity, we advocate for a European Drought Directive, to harmonize and enforce risk management policies across the continent. This directive should promote a systemic, integrated, and long-term risk management perspective. It should also set clear guidelines at the national and sub-national level, and for cross-boundary drought collaboration. This study and its companion paper, "*From Crisis to Capacity: Institutional Preparedness and Response During the 2022 European Drought*", result from work carried out by the Drought in the Anthropocene network, an initiative of the International Association of Hydrological Sciences (IAHS).

1 Introduction

Just a few years after the exceptionally severe 2018-2019 drought (Moravec et al., 2021), large parts of Europe faced another record-breaking drought in 2022. Summer temperatures broke records across the continent (Copernicus Climate Change Service, 2022), exceeding previous extreme temperature observed in 2003, 2015-16, and 2018-19 (Rakovec et al., 2022). Dry weather persisted through spring, initially affecting hydrological systems in the Eastern Alps, followed by extremely dry conditions, soil moisture deficits, and streamflow drought in Central and Southern Europe (Montanari et al., 2023; Bonaldo et al., 2023). Sustained dry conditions triggered increased water withdrawals and, in countries such as Italy and France, water use restrictions were implemented (Avanzi et al., 2024; Bonaldo et al., 2023; Toreti et al., 2022). The Mediterranean was particularly affected, as a dry winter and spring compounded with the dry and hot summer, causing early soil moisture deficits and low river flow (Toreti et al., 2022), leading to wide-ranging impacts on society and nature (Faranda et al., 2023).

This study analyses the 2022 European drought, linking its physical characteristics as represented by the Standardised Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al., 2010), with sectoral impacts and current drought risk management practices. Based on a continent-wide survey of water managers involved in the 2022 drought response, we assess current limitations in Europe’s drought risk management framework and propose key areas for improvement. The study identifies the 2022 drought as a turning point for Europe, highlighting growing drought risks, diverse management capacities, and the urgent need for a unified, systemic, and legally binding approach to drought risk governance across the continent. This work was conducted by the Drought in the Anthropocene (DitA) network (https://iahs.info/Initiatives/Scientific-Decades/helping-working-groups/drought-in-the-anthropocene/) and builds on lessons learnt from the 2018-2019 drought (Blauhut et al., 2021). A companion paper titled “*From Crisis to Capacity: Institutional Preparedness and Response During the 2022 European Drought*” (Biella et al., 2025) reveals significant disparities in drought preparedness and response across the continent, highlighting that organizations with forecasting systems and drought management plans are generally more effective and faster in their actions, underscoring the urgent need for a European guidance in drought preparedness.

1.1 Droughts in Europe

Droughts are periods of extraordinary water deficit in the hydrological cycle (IPCC, 2021; Van Loon et al., 2016) that can significantly impact Socio-Ecological Systems (SES) (Van Loon et al., 2016). They are commonly defined as a deviation from normal conditions, it being below normal precipitation (meteorological drought) or climate water balance (precipitation less evapotranspiration) or below normal water availability on the ground (soil moisture, river flow and groundwater), referred to as hydrological drought (Tallaksen and Van Lanen, 2004). The possibility of damage and losses to society and ecosystems caused by a given drought is referred to as drought risk (IPCC, 2022a; Hagenlocher et al.,2023), which depends on the interactions between hazard severity, exposure and SES vulnerability (UNDRR, 2021), while drought impacts are the resulting effects of a specific drought event (Walker et al., 2024). Finally, water deficits—when water availability fails to meet SES demands—can result from both droughts and human activities (Van Loon et al., 2016).

Droughts present complex challenges that extend beyond the hydrological system, disrupting ecological, economic, and social systems (van Loon et al., 2016; Crausbay et al., 2017). Increasing population and reliance on water in drought-affected areas may exacerbate these impacts. Moreover, droughts often coincide with heatwaves and wildfires, forming compounding hazards that intensify risks (Sutanto et al., 2020; Rodrigues et al., 2023).

In Europe, climate change is intensifying drought hazards over most of the continent (Spinoni et al., 2018; Jaagus et al., 2021). Record high temperatures and altered rainfall patterns have led to an increasing drought risk in Europe (Vicente-Serrano et al., 2010). Europe-wide analysis has shown increasing drought frequencies in southern Europe and decreasing frequencies in northern Europe (Stagge et al., 2017). Whereas an increase in temperature and potential evaporation have enhanced droughts in southern Europe, it has counteracted increased precipitation in northern Europe. The pattern observed is likely to be further aggravated in the future (Faranda et al., 2023; Schumacher et al., 2022, 2024), leading to drier and more intense droughts notable in central, eastern and southern Europe (Ionita et al., 2022). The Mediterranean countries have long faced recurrent droughts and are considered the most drought-prone region in Europe (Caloiero et al., 2018, 2021) and is a global hot spot now and in the future (IPCC, 2022a). recent decades show a consistent increase in drought frequency not only in the Mediterranean, but also across central, northern, and eastern Europe, especially during summer (Caloiero et al., 2018; Spinoni et al., 2018; Markonis et al., 2021; Montanari et al., 2023; Semenova & Vicente-Serrano, 2024). Combined with an ever-increasing demand for water (Savelli et al., 2023), water scarcity has become an emerging threat to many European countries that requires revisiting water management strategies (Stein et al., 2016). In fact, more than 30% of all extreme droughts observed in Europe since 1950 occurred between 2012 and 2022 (van Daalen et al., 2022). This sharp increase stresses the importance of comprehensive and wider drought governance frameworks for effective drought risk management, including mitigation, adaptation, preparedness, and early warnings (Blauhut et al., 2021).

1.2 Systemic drought risk management

Drought in Europe often covers large regions and lasts for a few to several months – even years, causing severe socio-economic impacts on different SES, including agriculture, water supply, water quality, energy production, ecosystems, public health, tourism, and recreation (Stahl et al., 2016). Such impacts evolve slowly and tend to co-occur (Shyrokaya et al., 2023) and lead to cascading effects across sectors in different parts of the SES (de Brito, 2021). In recent decades, annual drought-related economic losses in the EU and UK have been estimated at around €9 billion, with the highest losses in Spain (€1.5 billion/year), Italy (€1.4 billion/year), and France (€1.2 billion/year) (Cammalleri et al., 2020). Climate change is projected to further increase these losses, with a projected €65 billion for the EU and UK combined by 2100 (Naumann et al., 2021). Depending on the region, 39-60% of these losses are in the agricultural sector, while 22-48% are in the energy sector, costs which are expected to rise with a warmer climate (Cammalleri et al., 2020). The European Drought Risk Atlas (Rossi et al., 2023) indicated extreme impacts on ecosystems and inland navigation compared to other sectors. They estimate the effect of droughts on aquatic and terrestrial ecosystems to be the highest in Finland and Croatia, respectively. Largest increases in drought risk are found for ecosystems in Italy and Spain. Yet, these figures represent only the quantifiable part excluding indirect or non-monetary impacts (de Brito et al., 2024). Consequently, the true extent of drought impacts is likely larger than currently estimated.

Traditional drought management approaches have largely been reactive, focusing on crisis management rather than risk management, often resulting in ineffective and poorly coordinated risk management. This can lead to unintended consequences and maladaptation (Biella et al., 2024; Di Baldassarre et al., 2017; Magnan et al., 2016), increasing the vulnerability of the system to droughts. Instead, drought management needs a systemic perspective that recognizes the complexities and interlinkages between elements and processes of the systems (Hagenlocher et al., 2023; Kallis, 2008; Van Loon et al; Wilhite, 2019), often underscoring the risks associated with infrastructural measures (Di Baldassarre et al., 2017), and the benefits provided by ecosystem-based adaptation (IPCC, 2022a; McVittie et al., 2018; Sudmeier-Rieux et al., 2021; Vignola et al., 2009). This perspective calls for continuous monitoring and adaptive management strategies that is responsive to changing conditions and focus on dependencies, non-linearities, feedback dynamics, compounding and cascading effects, tipping points, multi-level risk, and deep uncertainties (Hagenlocher et al., 2023, de Brito et al. 2024).

One example is Integrated Drought Management (IDM), which advocates for a proactive, risk-based approach incorporating monitoring, early warning systems, and vulnerability assessments (Grobicki et al., 2015; Wilhite, 2019). IDM strategies are essential for mitigating drought impacts and balancing water demand and supply while ensuring environmental sustainability (Wendt et al., 2021). Regional governments and local communities play an essential role in drought management, as drought resilience depends on the collective capacity of stakeholders across scales (Kchouk et al., 2023). Each country’s drought management strategy reflects its administrative arrangements, with countries like Spain, and Germany, leaving vast operational autonomy to regional authorities, while other countries, such as France and Hungary being more centralized (European Committee of the Regions, 2025; Rowbottom et al., 2022). This underscores the need for policies sensitive to local contexts that can mobilize resources and knowledge effectively across various governance levels. The Integrated Drought Management Programme (IDMP) launched by the Global Water Partnership (GWP) emphasizes regional cooperation and capacity building. The IDMP aims to create a coordinated drought monitoring and management framework involving several decision-making levels, from government officials to local stakeholders (Bokal et al., 2014; WMO & GWP, 2014). Finally, integrated and systemic drought risk management needs to account for the interplay between other hazards. In particular, there is a need for holistic approaches to managing drought and flood interactions ensuring that measures taken to mitigate one extreme do not exacerbate the other (Barendrecht et al., 2024; Di Baldassarre et al., 2017). Systemic approaches to drought risk management are crucial for developing effective drought policies and plans that can adapt to the region's specific needs.

1.3 European drought governance framework

> “*Water is not a commercial product like any other, but rather, a heritage which must be protected, defended and treated as such*”
>
> European Commission
> (DIRECTIVE 2000/60/EC Preface, Comma 1)

Overall, European drought awareness and preparedness have been following an upward trajectory, as drought governance has been mainstreamed across many countries (Biella et al., 2025; Kreibich et al., 2022; Publications Office of the European Union, 2023). However, drought risk awareness often peaks shortly after an extreme event, while slowly decreases in periods of “normality”. The scale of Europe's droughts and its interconnected socio-hydrological systems necessitate continent-wide drought risk management. Yet, Europe (where the EU represents the largest governance body) lacks a unified drought policy, relying instead on water-related directives and non-binding communications (Hervás-Gámez & Delgado-Ramos, 2019; Publications Office of the European Union, 2023; Stein et al., 2016). The 2000 European Commission’s (EC) *Water Framework Directive* (WFD) is considered one of the most ambitious and substantial pieces of legislation dealing with water resource management (Voulvoulis et al., 2017), instituting catchment-level water management, environmental output requirements, unified monitoring, and international collaboration for transboundary catchments (Publications Office of the European Union, 2023; Stein et al., 2016). The WFD promotes a precautionary approach, emphasizing water conservation and stating that water is “a heritage to be protected" (DIRECTIVE 2000/60/EC Preface, Comma 1). Further developments on drought risk management include the 2007 EC *Communication on Water Scarcity and Droughts* and the 2012 EC *Blueprint to Safeguard Europe's Water Resources*, which provide guidelines for Drought Management Plans (DMPs) and country-level drought risk management (Hervás-Gámez & Delgado-Ramos, 2019). The latter emphases water conservation, stating the need to prioritize demand-reduction over efficiency measures, especially over increased supply and/or infrastructural measures (Hervás-Gámez & Delgado-Ramos, 2019; Stein et al., 2016). Despite its guidelines and ambitions, the EU's drought risk governance framework has significant gaps: the WFD does not directly address drought risk management; EC Communications of 2007 and 2012 are non-binding, lacking mandatory action for member states; and the fragmentation of institutional provisions of regulations impede coordinated effort and clear guidance (Publications Office of the European Union, 2023; Stein et al., 2016). This is in contrast with the EC *Flood Directive*, which laid the basis for European-level flood governance, creating a precedent for integrated Europe-wide legislation on a hazard-specific risk management policy. Table 1 summarizes the content and relevance of the policy instruments described in this section.

Table 1: Summary of the drought-related major policy instruments enacted by the EU and discussed in this paper.

Policy Instrument	Purpose	Legal Status	Scope	Relevance to Drought Risk	Identified Gaps	Official Document
Water Framework Directive (WFD) (2000)	Achieve good status for all EU waters by integrating water management.	Binding (Directive)	Broad: water quality, quantity, ecological health	Indirectly relevant: promotes sustainable water use, but drought is not explicitly addressed.	Lacks specific mechanisms for drought prevention, preparedness, and coordinated response.	WFD 2000/60/EC
EC Communication on Water Scarcity and Drought (2007)	Provide guidance and propose measures to address water scarcity and drought.	Non-binding (Communication)	Drought-specific focus	Key reference for raising drought awareness and proposing policy responses.	No legal enforcement; recommendations largely unimplemented or inconsistently applied across Member States.	COM (2007) 414 final
Blueprint to Safeguard Europe's Water Resources (2012)	Update on WFD progress; includes drought risk in water policy planning.	Non-binding (Communication)	Broad: includes drought among other challenges	Highlights need for improved water efficiency and drought risk integration.	Lacks mandatory implementation; limited follow-up or operationalization of drought-related actions.	COM (2012) 673 final

Policy Instrument	Purpose	Legal Status	Scope	Relevance to Drought Risk	Identified Gaps	Official Document
Floods Directive (2007)	Reduce and manage flood risks through risk assessment and planning.	Binding (Directive)	Flood-specific	Demonstrates EU capacity for targeted disaster directives.	No provisions for drought; illustrates asymmetry in EU treatment of water-related hazards.	Floods Directive 2007/60/EC

1.4 Objective of this research

In this study, we provide an overview of the 2022 European drought, demonstrating the linkage between its physical aspects, sectoral impacts, as well as adopted risk management measures. More specifically, we explore four main questions: (1) "*Is drought risk increasing?*"; (2) "*What was the spatial and temporal evolution of drought impacts in 2022?*"; (3) "*What are the drought risk management measures in place in 2022?*"; and (4) "*How is drought risk management changing across Europe?*". To answer these, we employ a survey targeting water managers across Europe (described in Sec. 2.2). The survey results provide insights into the status and trends in drought risk management and drought impacts (Sec.3.1, Sec 3.2, and Sec. 3.3). Additionally, two case studies ("regional spotlights") are used to provide insights on various aspects of drought risk management during the 2022 event, combining results from the questionnaire with knowledge on the severity of the event as quantified using the SPEI and information on the local context (Sec. 3.4). to the two case studies are both located in the Mediterranean region, which was severely impacted by the 2022 event and where there is also a long tradition in drought risk management. Furthermore, the drought in this region lasted several years, exceeding the duration of the campaign analysed here. In the discussion (Sec. 4) we underline the need for unified drought risk management coordination at the continent level. Echoing findings by Blauhut et al. (2021), we advocate for the development of an EC *Drought Directive*, inspired by the EC *Flood Directive* of 2007 (Sec. 5). This directive should offer a legally-binding policy mix that enshrines into law integrated and systemic drought risk management, placing equity, sustainability, and environmental needs at its centre, while acknowledging the differences in risk and capacity across the continent.

2 Methods and data

2.1 Climate data and Drought Assessment

Meteorological drought refers to prolonged abnormally low precipitation, often combined with higher-than-normal evaporation, leading to a climatic water deficit, which if sustained may manifest itself as a deficit in soil moisture and water resources (streamflow and groundwater). The Standardized Precipitation-Evapotranspiration Index (SPEI; Vicente-Serrano et. al., 2010) measures the climatic water balance by considering both precipitation and potential evapotranspiration. Similar to the Standardised Precipitation Index (SPI; McKee et al., 1993), it relies on selecting a suitable probability distribution that normalises the climate data (Vicente-Serrano et al., 2010). Positive SPEI values indicate wetter conditions, while negative values suggest drier conditions, with values below -1 typically indicating moderate drought, below -1.5 severe drought, and below -2 extreme drought. Shorter accumulation periods of SPEI (e.g., SPEI-1 and SPEI-3) are used as proxies for meteorological and agricultural droughts, while longer accumulation periods (e.g. SPEI-6 and SPEI-12) are commonly taken to represent hydrological drought. Seasonality of drought can be represented using SPEI-3. Winter is defined by calendar months from December to February, with the SPEI-3 for February used to assess this period (representing the wet/dry anomaly three months back, i.e., the calendar winter months). Similarly, SPEI-3 in May represents the spring (March to May), SPEI-3 in August represents the summer (June to August), and SPEI-3 in November represents the autumn (September to November). SPEI estimates are derived from monthly precipitation (PP), mean air temperature (TT), and potential evapotranspiration (PET) based on data from the Climatic Research Unit (CRU) TS v. 4.07 dataset (Harris et al., 2020),. The CRU TS dataset is a global land climate record (excluding Antarctica) on a 0.5° grid, offering monthly data since 1901. It includes ten observed variables like temperature, precipitation, humidity, cloud cover, sunshine, frost, and wind speed, along with derived variables such as potential evapotranspiration and the self-calibrating Palmer Drought Severity Index (Harris et al., 2020).We obtained Potential Evapotranspiration (PET) time series from the CRU TS dataset, where PET is calculated based on the Penman-Monteith formula (Monteith, 1965) based on monthly gridded values of mean temperature, vapor pressure, and cloud cover, as well as a static 1961–90 average wind field (with an annual cycle) (Harris et al, 2020).

The climatological period 1971 – 2000, is used here as a reference period for the computation of SPEI. We selected the 1971–2000 period as our reference to facilitate comparison with existing research (e.g., Ionita et al., 2017). We acknowledge that employing a more recent 30-year reference period could lead to slightly other results, especially in light of prevailing trends like overall warming. To this end, we use the R package "SPEI" (https://cran.r-project.org/web/packages/SPEI/index.html), which is based on the probability distribution of the difference between PP and PET.

2.2 Impact and management data

2.2.1 Questionnaire targeting water managers

To collect data on drought impact and management measures, a questionnaire targeting water managers responding to the 2022 European drought was designed by drought experts of the DitA working group of the IAHS-HELPING initiative (https://iahs.info/Initiatives/Scientific-Decades/HELPING/). Topics covered in the questionnaire include sectoral impacts of the drought, the occurrence of compounding and concurrent hazards, the measures taken by the respondents' organizations (along with their effectiveness and timeliness), the presence and use of preparedness measures, and developments in drought risk management across Europe. The questionnaire comprises 19 questions (24 including additional clarification options), of which 14 (17 including clarifications) are analysed in this study. The selected questions (listed in Table 2) focus specifically on drought impacts and risk management, as well as general questions regarding the respondents' organizations background and function.

To minimize misunderstandings, a glossary of terms like "drought risk management," "drought risk," and "drought risk management plans" was provided at the beginning of each relevant questionnaire section. The team translated the questionnaire into 19 languages (listed in supplement, Sec. S1.2) and distributed it from March to October 2023. The sampling strategy utilized the DitA group's network. Key contacts in various European countries received the questionnaire through personal connections or web searches for experts, academics, and public organization contacts, who then disseminated it further via snowball sampling (or chain sampling)- nonprobability sampling where existing participants recruit future subjects through their social network. No personal information was automatically collected, ensuring compliance with the General Data Protection Regulation (GDPR). An overview of the questions included in the questionnaire is provided in the supplement (Sec. S1).

Table 2: Questions included in the questionnaire to water managers. *Open-ended questions* have a field where the respondents could leave their answers in text. *Multiple choices* were provided as either single, or matrixes (i.e. multiple choice for multiple options of the question). *Multiple choice + open-ended* means that multiple-choice questions have one option that can be answered as an open-ended question if selected.

Question number	Question	Type
1	What type of organization do you belong to?	Multiple choice
2	At which level does your organization operate?	Multiple choice
3	In which country is your organization located?	Multiple choice + open
4	In which municipality/region do you operate (name, region, country)?	Open-ended question
6	Which sectors does your organization operate in?	Multiple choice + open
7	How severe was the impact of the 2022 drought on a scale from 1 (Not affected) to 5 (Severe)? [by sector]	Multiple choice matrix
9a	When were the impacts first seen (month)? [by sector]	Multiple choice matrix
9b	When did the 2022 drought end (month)? [by sector]	Multiple choice matrix
10	Which sectors were prioritized in the distribution of water resources? [by sector]	Multiple choice
12	What were the main measures taken by your organization?	Open-ended question
13	When did your organization first take measures to mitigate the impact of the 2022 drought?	Multiple choice
14	How effective were the measures taken?	Multiple choice
17	Compared to the 2018-2019 drought, your organization was… [More; Less; Same]; [Aware; Prepared; Effective in response]	Multiple choice matrix
18a	Do you think that the risk posed by droughts is… [Increasing; Same; Decreasing]	Multiple choice matrix
18b	Elaborate (optional)	Open-ended question
19a	Do you expect the drought to become a more significant risk to manage for your organization in the future?	Multiple choice

19b	If yes, how is drought management changing in your organization (optional)	Open-ended question

2.2.2 Dataset

The questionnaire gathered 487 responses, of which 481 were deemed within the study area. Responses were received from 30 European countries, predominantly Italy, Sweden, Croatia, Romania, and Serbia. Notably, high number of responses came from the Alpine and Adriatic regions, central Balkan Peninsula, Rhine Valley, Southern Sweden, and the Pyrenees Region. Fifteen countries each have ten or more respondents, collectively accounting for 89% of the total responses (Fig. 1b). Most respondents (76%) are employed in public and governmental organizations, while fewer work in private companies (8%), research institutes (7%), NGOs (4%), and unspecified organizations (4%). The majority of respondents operates regionally (65%) with an additional 27% at the national level and 6% internationally (Fig. 1a). Respondents are involved in various sectors (based on EDII categories, Stahl et al., 2016) considered critical to drought management, especially water quality, public water supply, and agriculture, with 47%, 46%, and 39% responses, respectively. This include also several ecosystem-related areas (Fig. 1c).

As a survey-based dataset, several limitations are inherent. For example, measures describing drought risk management, such as response effectiveness or awareness, should thus be understood as perceived effectiveness and awareness of a professional role in drought risk management. Hence their subjective observations are considered relevant and valid measures. Second, snowball sampling may limit the representativeness of the data, particularly when aggregated into sub-groups (such as by country, sector, or type of organization). This study assumes that the sub-group samples represent their larger groups, although this cannot be confirmed. Finally, the different response rate per country limited the comparisons that could be done between countries. To accommodate this bias, the study only displays information from countries with more than 10 valid responses to a specific question. Additionally, information is also presented at the regional level (adapting the classification in *The World Factbook* (https://www.cia.gov/the-world-factbook/). Information presented at the regional level includes the responses from all countries in a region, not only those from countries with more than 10 valid responses. This allows accounting for the perspectives of countries that would otherwise be excluded from the analysis. We have adjusted the division of Southern Europe to obtain a more equal distribution of the responses: consequently, Italy, Vatican, and San Marino are grouped with the South Western region together with the countries of the Iberian Peninsula, whereas Greece and Cyprus are imbedded in the South Eastern region together with the Balkans countries. In figures and tables, the regions are referred to using acronyms: Norther-Western (NW), North-Eastern (NE), Western (W), Central (C), Eastern (E), South-Western (SW) and South-Eastern (SE). An overview of the regions used in this study and the acronyms used for each country can be found in Sec. S2 of the supplement.

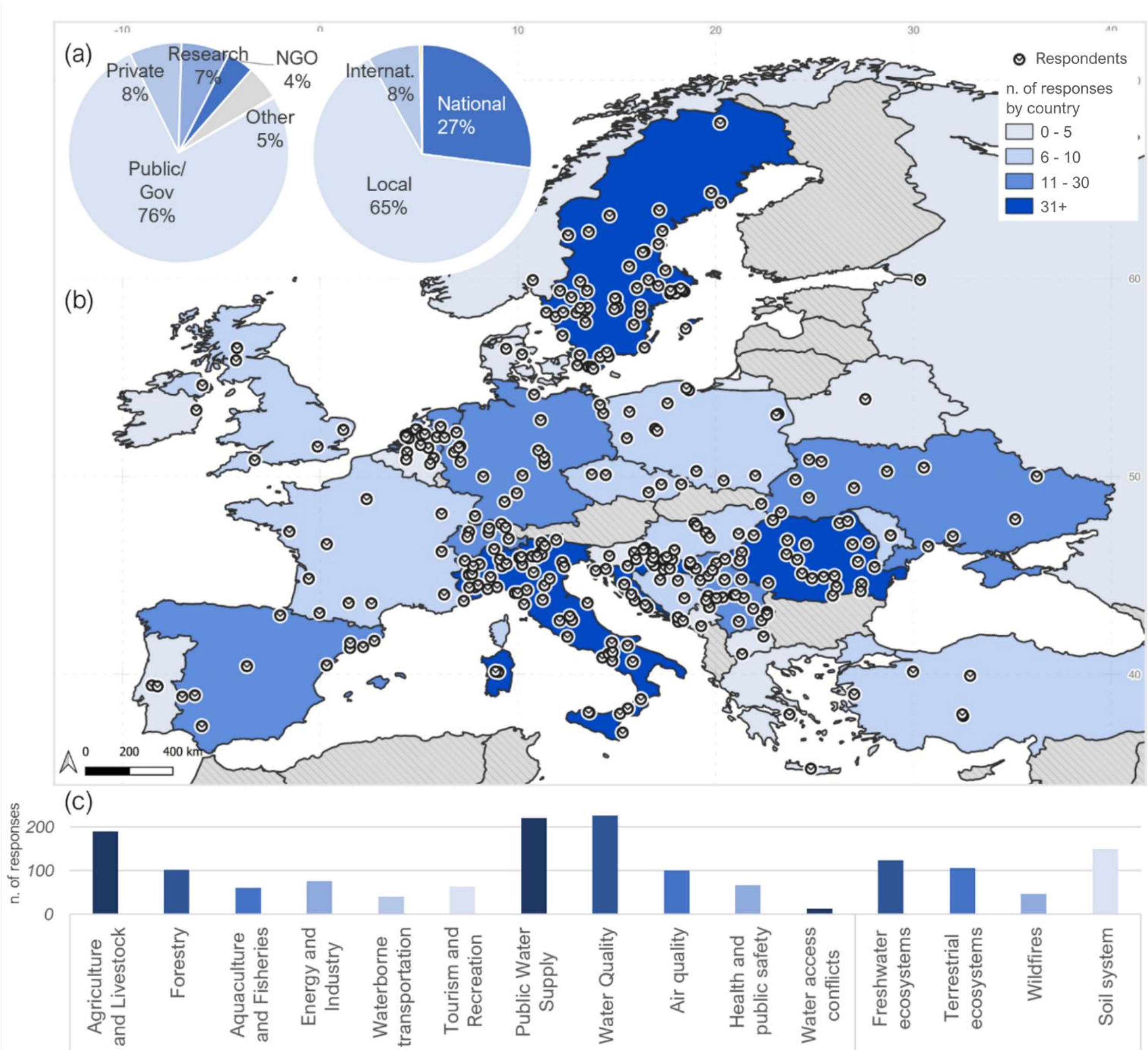


Figure 1: Overview of the number of respondents as grouped by (a) type of organization and operational level, (b) country, and (c) sector. The total number of responses to the questionnaire was 481.

2.2.3 Drought impact

Observed (sectoral) drought impacts were raised in questions 9a and 9b, with blank options if the sectors were not relevant to respondents. The start and end of the observed impact are reported on a monthly basis covering the period March to September 2022 with additional options “before March 2022” and “after September 2022” available. Respondents were required to indicate the severity of the impact by sector on a scale from 1 (not severe) to 5 (very severe) (question 7, see Table 2), as well as the prioritization that each sector received in response to the drought as “low priority”, “medium priority”, or “high priority” (question 9, see Table 1).

2.2.4 Drought risk management

Respondents detailed their organizations' drought risk management measures in an open-ended question (question 12, Table 2). The responses to this question were reclassified using a typology devised by Reckien et al. (2023), which in turn is based on the IPCC AR6 GAMI (Ch. 16) (IPCC, 2022b). Responses were first translated from their original language to English using ChatGPT (chatgpt.com) to facilitate reclassification. Native speakers then validated these translations. Additional classification of the measures taken was applied following recommendations outlined in the EC *Blueprint to Safeguard Europe’s Water Resources* of 2012. The Blueprint prioritizes different types of drought risk management measures, placing demand decrease as the highest priority, followed by prioritization and efficiency measures, and assigning the lowest priority to supply increase measures and infrastructural measures. Based on this, three categories were established to evaluate responses in this study: “Decrease Demand”; “Prioritization and Efficiency”; “Increase Supply”. Demand-side measures refer to those reducing water demand to match the decreased supply. Conversely, supply-side measures attempt to integrate water supply through additional or alternative water sources (e.g. groundwater) to meet demand. Two researchers were involved in the classification process to ensure the validity of the classification, with an inter-annotator agreement of 86% (Table S3).

Question 14 prompted respondents to rate the *effectiveness* of measures taken during the 2022 drought on a scale from 1 (not effective) to 5 (very effective). Respondents also had the option to indicate unknown effectiveness or leave the question blank. This option was initially intended for respondents whose actions, like monitoring and data collection, do not directly impact drought management or those who took no measures. To prevent misinterpretation (inferring “not relevant” as “not effective at all”), this option (less than 1) was placed separately from the 1-to-5 scale in the questionnaire.

Finally, question 17 allowed respondents to indicate the overall change of drought risk management for their organizations by indicating whether their organizations were more, less, or equally aware of drought risk in 2022 compared to 2018 (i.e. the year of the previous large-scale European drought). They were also asked to indicate the preparedness and effectiveness of their organization’s management in 2022 compared to 2018.

3 Results

3.1 Drought occurrence

3.1.1 Development of the 2022 drought in Europe

The onset of the 2022 drought was already visible in the winter of 2021-2022 (Fig. 2a), which was unusually warm and dry across the southern and eastern parts of Europe (Avanzi et al., 2024). The Alps, a crucial source of freshwater for central and southern part of Europe, received significantly less snowfall than average (Carrer et al., 2023; Montanari et al., 2023). Snowpack and seasonal snow cover act as natural reservoirs, slowly releasing water throughout the spring and summer. The lack of snow means that rivers and streams are deprived of their usual replenishment, leaving them vulnerable as temperatures and evaporative demand (i.e. the water needed for evapotranspiration processes) rose, especially for the Rhine and Danube rivers, which are essential rivers for inland waterways navigation and drinking water (Van Loon et al., 2024).

Warm and dry conditions across most of Europe characterized spring 2022 (Faranda et al., 2023), further exacerbating the dry conditions (Fig. 2b). The most affected countries were France, Italy, Germany, Poland, Czech Republic and the Balkan countries. High temperatures accelerated evaporation from soils and water bodies, impacting ecosystems, and increased the demand for irrigation. This early onset of warm and dry weather stressed water resources, raising concerns for the months ahead. In summer, a high-pressure system persisted over Europe, creating a heat dome that trapped warm air and blocked moisture-bearing weather systems (Bakke et al., 2023). Temperatures soared to record highs, drying out soils, wilting crops, and fuelling wildfires. The summer period witnessed the drought moving northward, affecting the UK and the Republic of Ireland, the Netherlands, Germany, Northern Poland, Belarus, and Ukraine (Fig. 2c), whereas the most northern parts remained unaffected, except for southern Scandinavia in the spring. In autumn (Fig. 2d), only a small region was still affected by extremely dry weather conditions, namely the southern and eastern parts of Spain, Turkey, Greece and Bulgaria, the north-eastern part of Germany and the western part of Poland, and the Baltic states.

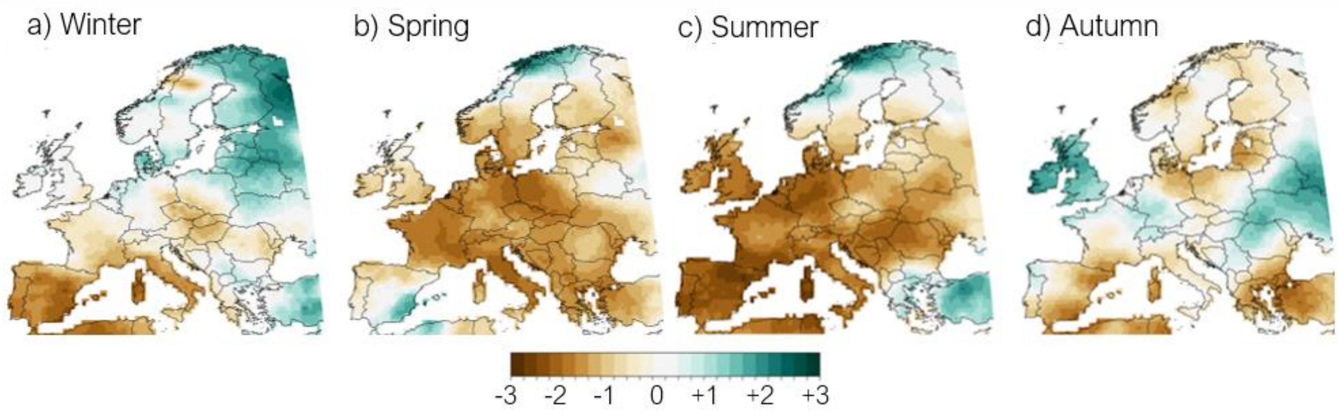


Figure 2: Seasonal evolution of the Standardized Potential Evapotranspiration Index for 3-month accumulation (SPEI-3) for 2022; a) Winter (SPEI-3 February); b) Spring (SPEI-3 May); c) Summer (SPEI-3 August) and d) Autumn (SPEI-3 November).

The SPEI-6 for September (Fig. 3, top row) indicates the wet/dry condition over the growing season for four major droughts in Europe over the past two decades (i.e., 2003, 2015, 2018, and 2022). The corresponding drought severity ranks (Fig.3, bottom row) highlight the seven lowest SPEI-6 values recorded for each event. A rank of one means that SPEI indicates a record-breaking drought, i.e., the lowest observed in the study period. The location, extent, and severity of drought varied across events. In 2003, record-low SPEI values were centred over Central Europe (Fig. 3a and 3b), whereas in 2015, the most affected regions were in Eastern Europe (e.g., eastern Poland and Ukraine) (Fig. 3c and 3d). In 2018, the core of the drought was over Germany, Poland and Scandinavia (Fig. 3e and 3f). Despite Fig.3 not clearly showing it due to the choice of SPEI-6 for September as the reference indicator, Scandinavia in particular experienced one of its worst recorded droughts (Bakke et al. 2020). In 2022, northern Spain and southwestern France experienced record-breaking meteorological droughts from March to September. No single event affected the entire Europe, but in most cases, more than 50% of the continent experienced at least moderate drought conditions. Notably, the two most recent events (2018 and 2022) show the highest continuous area of record-high SPEI values (dark brown colour in Fig. 3e and g).

From a hydrological perspective, in 2022, many prominent European rivers, including the Rhine, Danube, Po, and Ebro experienced one of the most severe droughts in recent decades (more details in Fig. S3 in the supplement). By the end of winter 2022, these rivers faced prolonged drought conditions that persisted until the end of summer for the Rhine and Danube, and even longer for the Po and Ebro.

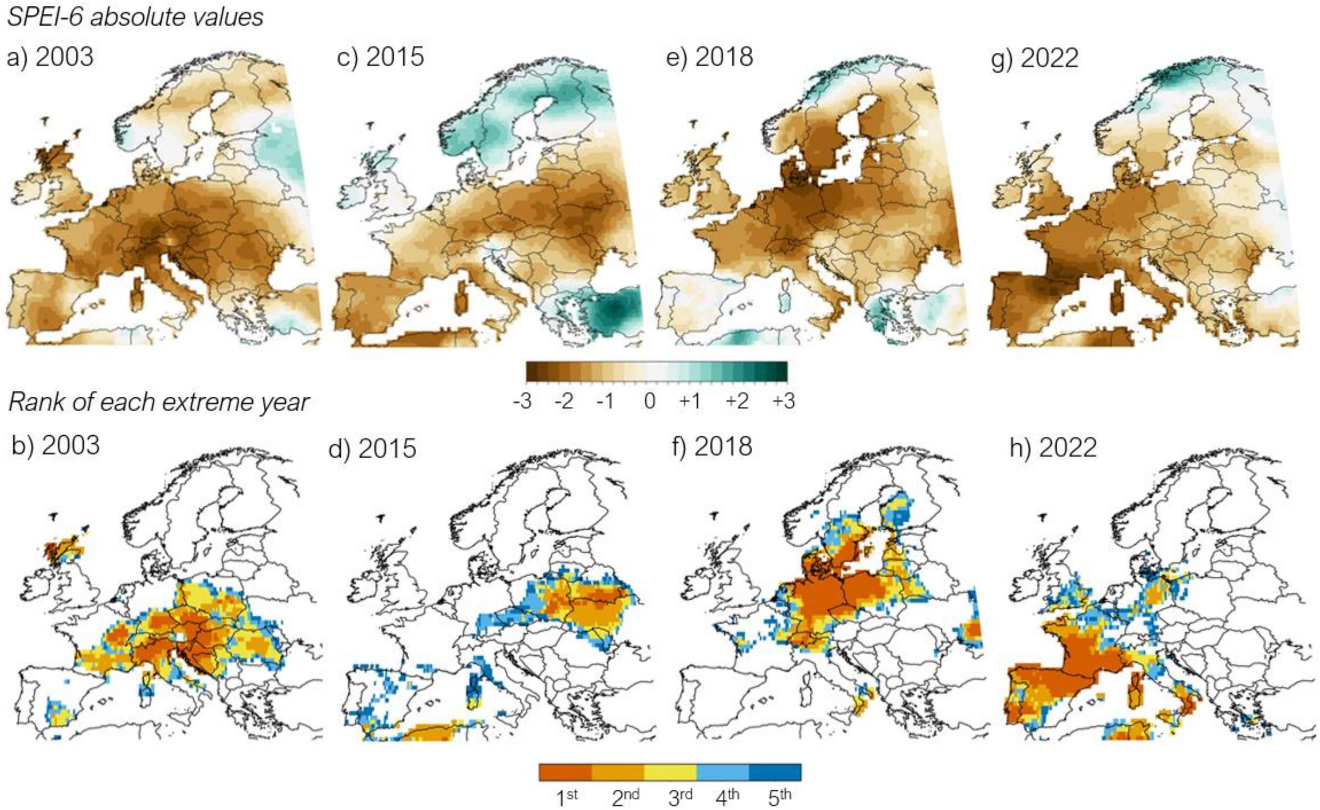


Figure 3: Comparison of the SPEI6 for September of the main Europe-wide droughts since 2000: Namely, 2003, 2015, 2018, and 2022 (top row) and their associated ranking (bottom row). The period analysed is 1950–2022. A rank of one signifies that SPEI6 September for a given year (i.e. 2003, 2015, 2018 or 2022) is record-breaking, i.e. the lowest value during the analysed period.

3.1.2 Observed and perceived change in drought risk

Over the last 70 years, droughts have become more frequent, more extreme, and more extensive in Europe particularly in the last decade (Fig. 4). Moderate (SPEI between -1 and -1.5) and severe (SPEI between -1.5 and -2) droughts, in particular, have intensified at the European level, especially after 2000's, in agreement with previous studies (Ionita and Nagavciuc, 2021). SPEI values lower than -2 are referred to as extreme drought (Vicente-Serrano et. al., 2010). As for the 2022 drought, this event was the most extreme summer drought that the continent has experienced since 1954 (Fig. 4).

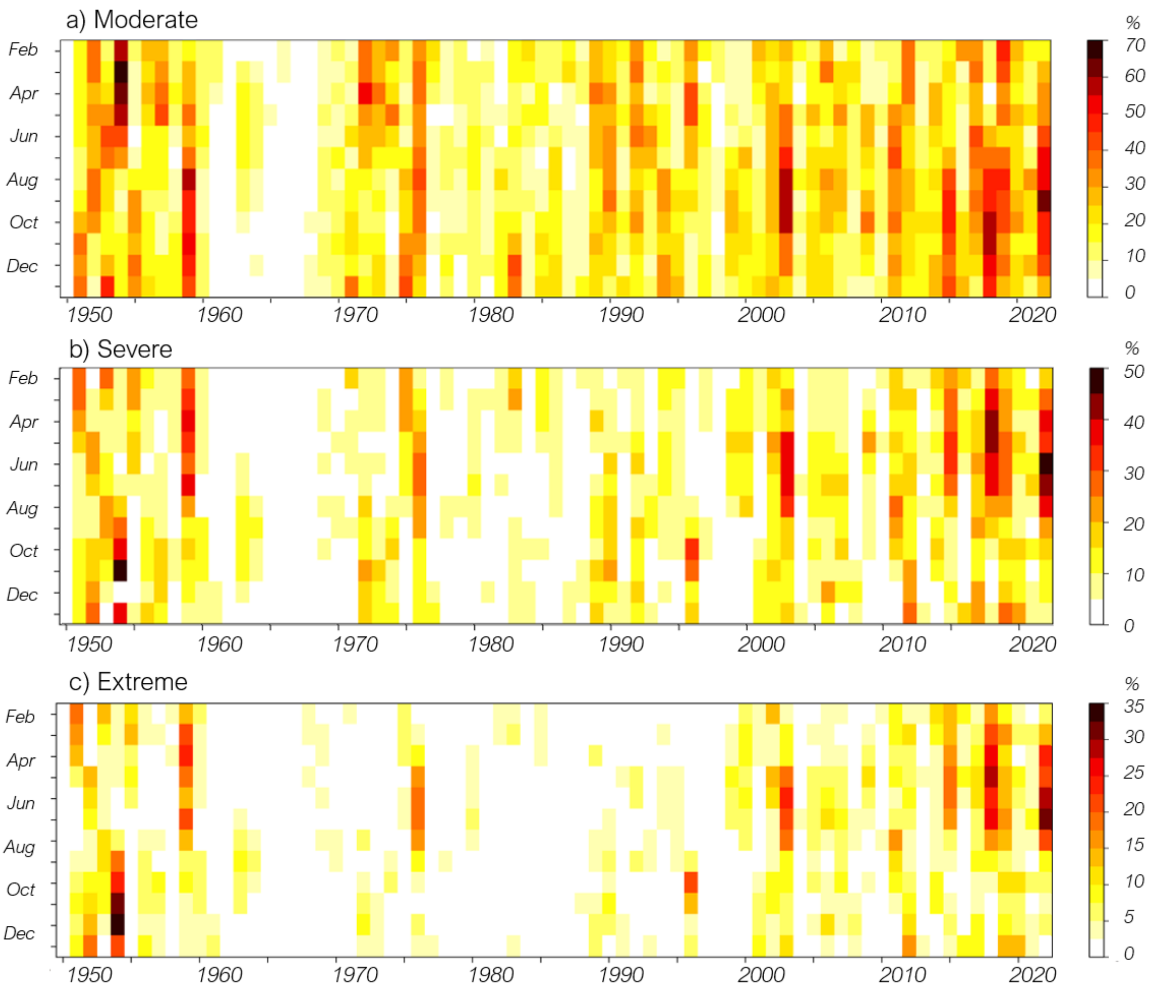


Figure 4: Temporal evolution of the percentage of area affected by drought at European level for three drought severity categories: moderate (a; SPEI-6 between -1 and -1,5), severe (b; SPEI6 between -1,5 and -2), and extreme (c; SPEI6 below -2). The colour of the cell indicates the percentage of the European area covered by a drought (i.e. below SPEI6) of the corresponding intensity.

According to the survey, most respondents (87%) believe drought risk is increasing. In contrast, 9% think the risk has remained the same, and only 1% believe it is decreasing. Another 2% are unsure (i.e., responded "*I don't know*"). Concern about rising drought risk is strongest among respondents working in water management for ecosystem-related fields. For Terrestrial

Ecosystems, 92% see an increase in drought risk, and in Freshwater Ecosystems, 91% report the same. Participants from the Energy and Industry sectors show the highest concern (92%), followed by Air Quality (89%). Tourism and Recreation (83%), Human Health (84%), and Forestry (86%) show the lowest shares of respondents who think drought risk is rising. These sectors also have the highest percentage of respondents who believe the risk has not changed — 14% in Tourism and Recreation and 13% in both Human Health and Waterborne Transportation. Countries with the highest percentage of respondents indicating that drought risk is increasing are France and the UK (both 100% out of 15 and 14 answers, respectively), Serbia (93% out of 29 answers) and the Netherlands (93% out of 28 answers). Respondents from Sweden (73%), Romania (74%), and Germany (79%) indicated the smallest increase in drought risk. Drought risk was reported unchanged in Sweden by 21% of respondents, Romania at 14%, and Germany, and Switzerland both at 12%. The largest share of respondents indicating decreasing risk are from Sweden (5%), Croatia (2%), and Romania (2%).

3.2 Drought impact

3.2.1 Impact duration

According to respondents, impacts of the 2022 drought were initially observed in Southern Europe (Fig. 5a). In particular, most sectors in Spain showed signs of drought impacts before March 2022, while in Italy, agriculture was the key sector displaying early signs of impact (before March). Central and Eastern Europe (i.e. Hungary, Poland and Ukraine), also exhibited an early onset of drought impacts, particularly in sectors like Agriculture, Fishery and, in some cases, Forestry. The remaining part of Europe (excluding northern Europe, which was not affected by the event) experienced the drought impact in summer, typically not earlier than June or July. Even later impacts (after September) were observed in certain sectors, notably Forestry, Energy and Industry, Tourism and Recreation, Air Quality, and Water Conflict. This confirms that Forestry drought impact may require a longer period to become apparent, given that dieback results from prolonged dry conditions, diminishing pest and disease resistance over time (Shyrokaya et al. 2023; Bastos et al. 2020; Messori et al. 2021; Wu et al. 2022). Hydropower production depends on reservoir (and snow) storage, short and long-term weather forecasts, and the energy market, all of which are also influenced by drought (Okkan et al., 2023). Survey reports also indicated that the drought lasted longest in Southern, Central, and Western Europe (the Netherlands, Germany, and France), with respondents reporting that is was still ongoing after September 2022. Consequently, Southern Europe emerges as the region experiencing the longest-lasting impacts, persisting for over nine months in some cases (the entire observation period covered by our questionnaire). This number and severity of drought impacts, as reported across much of Southern Europe, mirrors the drought extent and severity as depicted by SPEI-3 and SPEI-6 indices (Fig. 5b, lower left panel), starting as early as March. Overall, many countries show a delayed response between the drought hazard (represented by the SPEI) and impact occurrences, ranging from 0 months in Spain (suggesting that the drought started prior to March) to 5 months in France. As for drought termination, several countries reported drought impacts beyond the drought period as defined by SPEI-3 (Fig. 5b, lower right panel). The main reason is that rainfall during summer may terminate meteorological and agricultural droughts, represented by SPEI-3, while hydrological droughts (represented by SPEI-6 and SPEI 12) may persist longer depending on the memory and storage properties of the hydrological system (Sutanto et al., 2024).

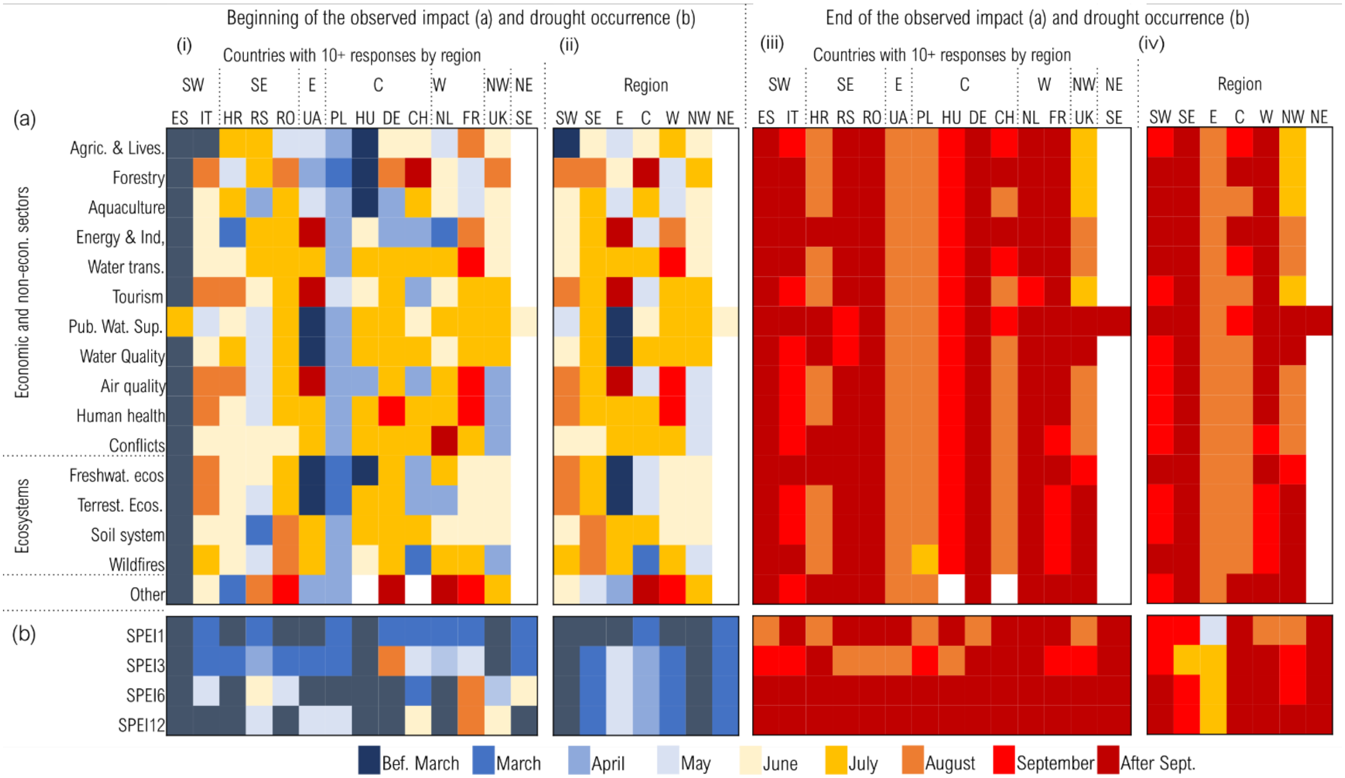


Figure 5: Most commonly reported beginning (left) and end month (right) of drought impacts in Europe listed from south to north (a). The lower plot (b) indicates the onset of the drought defined as the first month when more than 50% of the territory was under drought conditions (SPEI < -1) for SPEI-1, SPEI-3, SPEI-6, and SPEI-12 of each month. Only countries with 10 or more responses are shown. The European regions are described using the acronyms: SE (southeast), SW (southwest), E (east), C (central), W (west), N (Northwest), NE (northeast). Countries are indicated using their two-letter country code. White cells indicate missing data.

3.2.2 Impact severity and prioritization

Southern Europe experienced earlier and longer-duration droughts with more severe consequences as compared to fewer and less severe impacts in the North. In particular, sectors such as Agriculture, Forestry, and Public Water Supply were highly impacted in Central and Southern Europe, with increased wildfires and soil degradation as examples. Conversely, Northern Europe witnessed less severe impacts (Fig. 6), as expected, due to the less severe drought conditions or even no drought at all. Notably, some of the highly impacted sectors, including Forestry in Germany and Energy and Industry and Fisheries in Italy, received low priority water allocation. This forms a sharp contrast to high priority sectors that perceived milder impacts, such as Public Water Supply and Water Quality, Water Transportation, and Tourism and Recreation according to respondents across multiple countries. However, these less severe impacts may also result from prioritizing and applying mitigation and timely adaptation measures and the benefits-to-cost that these measures provide for each sector. As prioritization affects drought impacts, a high priority is likely linked to a less severe impact within certain sectors (e.g. Public Water Supply), and as such indicating an effective response. Sectors where impacts generally take longer to materialise, such as Forestry, are likely to receive lower prioritization (Fig. 6). Still, this prioritization discrepancy highlights the nuanced approach to managing diverse impacts across sectors in response to varying degrees of impact and drought severity (Fig. 2 and 3). Table S2 in the Supplement shows information on reported impact by country and sector.

Figure 6: Impact severity (on a scale from 1 to 5; where 5 is the most severe level) on the various sectors. Only countries with 10 or more responses are presented. Countries are grouped into geographical regions. The panel to the right shows the value for the entire geographical region. These include countries with less than 10 responses. The European regions are described using the acronyms: SE (southeast), SW (southwest), E (east), C (central, W (west), N (Northwest), NE (northeast). Countries are indicated using their two-letter country code.

3.3 Drought risk management

3.3.1 Types of drought measures taken

Most measures taken fall into two primary categories: those related to water supply (27%) (i.e., increasing (reservoir / groundwater) sources to meet demand or prioritizing users), and those concerning water use and demand (19%) that aim to reduce demand to meet availability (i.e introducing restrictions) (Fig. 7). This trend is observed across all sectors, although differences are evident between countries. Countries in Southern Europe (and the Netherlands) tended to favour water supply management, while Central and Western Europe predominantly focussed on water demand management. Other prevalent measures included awareness raising (19%), which was common across all sectors and many countries and monitoring (9%), which is most common in the Public Water Supply and Water Quality sectors. Monitoring was also particularly notable in Sweden (where the drought was less severe). Germany, France, the Netherlands, and Croatia also implemented ‘incentive and compensations’ schemes to tackle drought impacts. Farm-related management practices were common in Romania and Turkey. Ecosystem-based measures were only common in Poland, where many responses came from natural park management authorities, which were notably underrepresented in other countries). Sweden and Ukraine most frequently reported that few or no measures were taken. In Sweden, the milder manifestation of the drought led many respondents to deem drought management unnecessary (in agreement with the two respondents from Norway). This is reflected in the Public Water Supply and Water Quality sectors, which show the highest recurrence of no measures taken, as most Swedish responses originated from these two sectors. In Ukraine, in addition to the 2022 drought being milder than in the previous two years, one may acknowledge that the war and consequent prioritization needs have limited response to the questionnaire.

Reclassification of the responses on the bases of the recommendations from the EC Blueprint (Sec. 1.3) showed that respondents mainly employed ‘demand reduction’ and ‘supply increase’ measures (13% and 14%), while efficiency and prioritization measures were underused (6.3%) (Fig. 7). Respondents in France (40%), Spain (37%), and the UK (35.7%) showed the largest adoption of demand reduction measures, whereas the Netherlands (43%), the UK (28.6%), Hungary (27%), and Italy (23%) showed a large use of supply-side measures. Prioritization and efficiency measures remained underreported except in Italy where they constituted 19% of the responses. This contrasts guidelines of the EC Communication, which clearly states the need to prioritize demand reduction measures, followed by improving efficiency, and only as a last measure, increasing supply.

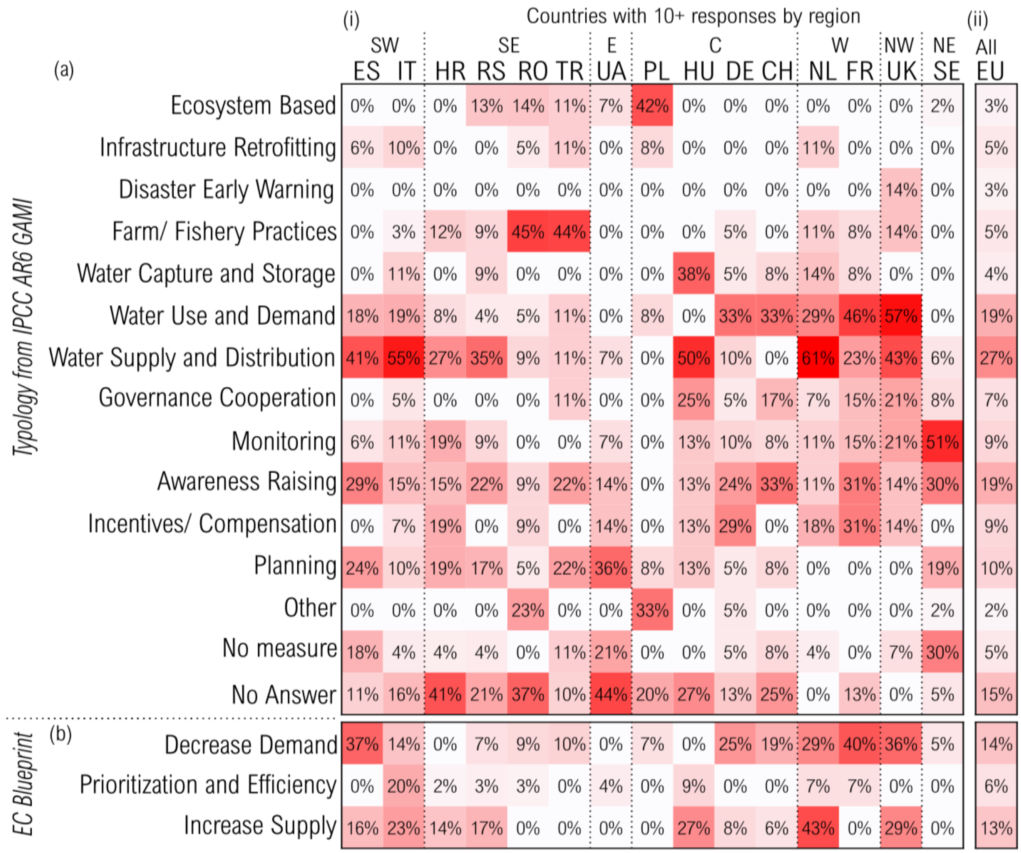
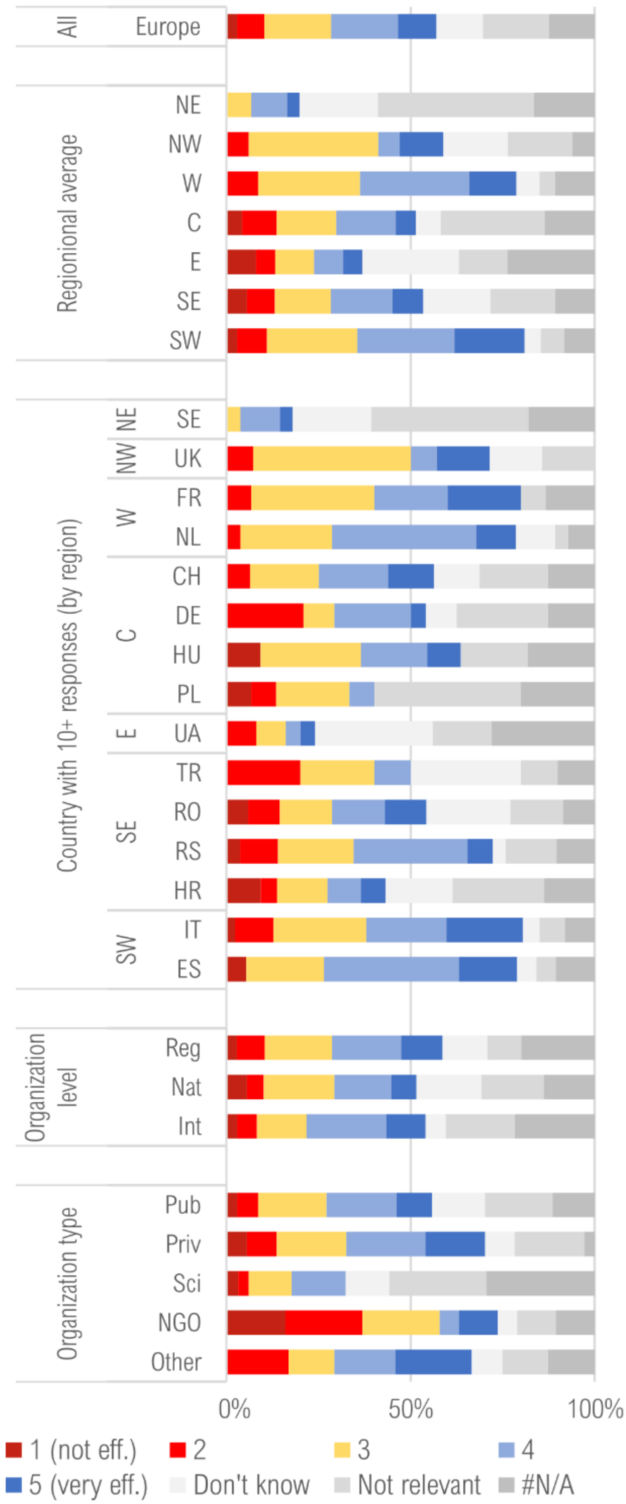


Figure 7: Measures taken by the respondents organised by country (only countries with 10+ responses), and region. Panel a) shows the measures classified according to the Ch. 16 of the IPCC AR6, while panel b) shows the same measure re-classified according to the EC Blueprint. Panel i) shows the results by country, while panel ii) shows the aggregates for the entire dataset. The numbers represent the percentage of respondents using a specific measure as relative to the total number of respondents for that country. Depending on the response, multiple measures could be identified for the same response. The European regions are described using the acronyms: SE (southeast), SW (southwest), E (east), C (central, W (west), N (Northwest), NE (northeast). Countries are indicated using their two-letter country code.

3.3.2 Perceived effectiveness of the response

Respondents were asked to rate the effectiveness of the measures taken during the 2022 drought on a scale from 1 (not effective) to 5 (very effective). The key features of results are depicted in Fig. 8. 28% of respondents rated the effectiveness of their measures between 1 and 3, meaning non-to moderately effective. Conversely, 18 % rated the measures as effective (4), and 10% very effective (5). A small share reported unknown (13%) or irrelevant (18%) effectiveness with some additional blank answers (12%). Sweden and Ukraine in particular show a high rate of non-valid answers, possibly reflecting the fewer (less severe) impacts of the 2022 drought for the former and the effects of the war for the latter. Respondents from NGOs generally rated their efforts as least effective in managing drought risk, with 57% rating effectiveness from 1 to 3. Respondents from scientific organizations also reported below-average effectiveness (18% reported effectiveness between 1 and 3). However, only 32% of the respondents rated their response, while many stating effectiveness is "not relevant" (26%). Both



private and public/governmental organizations reported effectiveness levels close to the European average, though only 27% of public/governmental organizations considered their measures effective or very effective. Organizations operating internationally were the most positive on the effect, with 32% rating measures as 4 or 5. Regional-level organizations followed (30%), with national-level organizations being less sure about the effect (22%). Despite these variations, the differences across organizational levels were overall minor and aligned closely with the overall assessment at the European level (excluding non-valid answers). Countries with the highest share of respondents indicating measures taken to be effective or very effective were Spain (53%), the Netherlands (50%), and Italy (42%). On the other hand, the highest share of effectiveness rated between 1 and 3, was found in the UK (50%), France (40%), and Italy (38%). A more detailed overview of the findings is available in the supplement (Table S3).

A notable share of respondents (18%) selected "not relevant" for their measures. This option was originally intended for organizations whose actions, like monitoring and data collection, do not directly impact drought management or for those who took no measures.. The responses indicate that 26% took no measures were also commonly reporting monitoring (17%) and awareness raising (9.5%). This suggests respondents correctly interpreted the question, though effectiveness may also be overestimated effectiveness (Fig. S2 in the supplement). Swedish respondents accounted for 31% of "not relevant" responses, reflecting their fewer and less severe drought impacts and focus on monitoring.

Figure 8: Effectiveness of organizational measures against drought. Responses range from 1 ("not effective") to 5 ("very effective"), plus options: "I don't know," "not relevant," and blank. The values displayed are the percentage of valid answers for each sub-group. The first row shows the values for all the responses received and is labelled as "All / Europe". The sub-groups presented are individual countries

with at least 10 answers grouped by region (see Sec. 2.1.3); and regional averages (including countries with less than 10 answers). The European regions are described using the acronyms while countries are indicated using their two-letter country code.

3.3.3 Changes in drought risk management

About 79% of the respondents considered that drought risk management will become more significant for their organisation with only 9.6% considering the opposite. Drought is expected to become a more significant risk to manage for all sectors, as indicated by the responses given for Freshwater Aquaculture and Fisheries (88%), Public Water Supply (86%), and Waterborne Transportation (85%). Again, water managers operating on ecosystems are among the most certain that drought risk management will become more relevant, with Terrestrial Ecosystems, Freshwater Ecosystems, and Wildfires indicating (87-88%). Respondents in Switzerland (27%), Romania (20%), and the Netherlands (18%) indicated that drought risk management will not become more important fin contrast to respondents from France (100%), Spain (95%), the UK (93%) and Italy (91%) stating increased importance of drought management.

Comparing the management of the 2022 drought with that of the 2018 drought, most organisations noticed increased drought awareness after the 2018-2019 drought, but not all could translate this into increased preparedness or a more effective response (Fig. 9). It is worth noting that there is a rather high correlation between 'more awareness' and 'more preparedness' or 'effective in the response' (correlation coefficient of 0.52 and 0.46 respectively). Among the organisations reporting increased awareness, 49% reported increased preparedness, and 46% reported increased effectiveness (40% reported both). The responses have an even stronger correlation (correlation coefficient of 0.7) between 'improved preparedness' and 'improved effectiveness'. Very few organisations were less aware/prepared/effective in 2022 than during the 2018-2019 drought event (respectively, 3%, 5%, %) (Table S5 in the supplement presents these results in more detail).

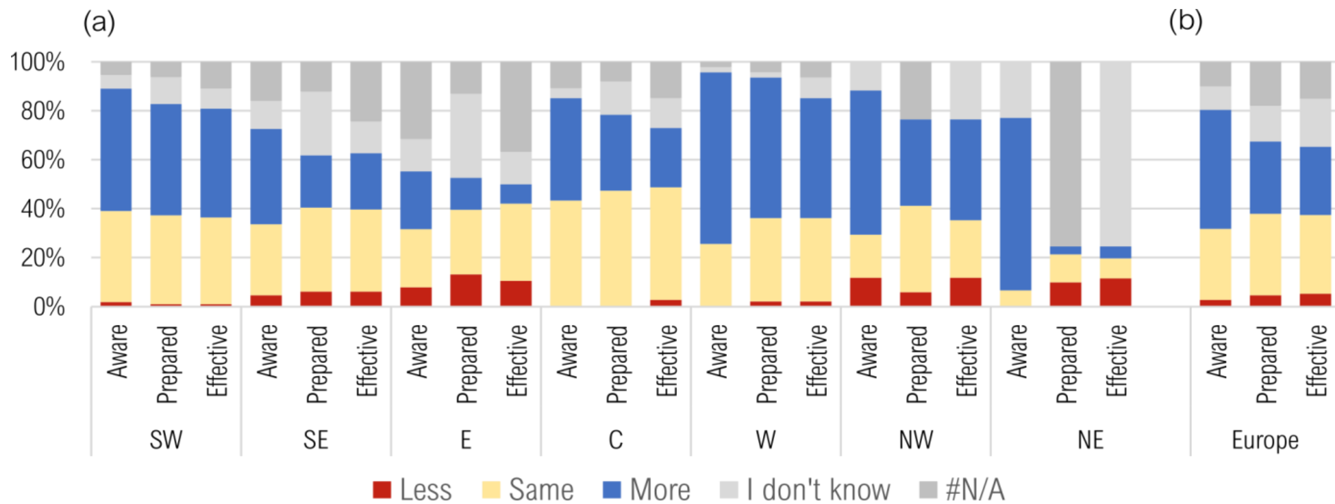


Figure 9: Changes in awareness, preparedness, and effectiveness in the response between the 2018 and 2022 drought events, according to the respondents. The respondents could answer "more", "same", or "less" to the three questions "How aware/prepared/effective was your organization in 2022 compared to 2018?". The option "I don't know" and the possibility to leave the question blank (i.e. "#N/A") were also available. The results are presented at the European level (i.e. all responses), and at the regional level. The European regions are described using the acronyms: SE (southeast), SW (southwest), E (east), C (central, W (west), N (Northwest), NE (northeast). Countries are indicated using their two-letter country code.

3.4 Regional Spotlights

Catalonia and Italy were selected to deepen the analysis and complement the questionnaire results with additional information on local water management. They both have a reasonably high number of respondents (Fig. 10) while having a different timing (Fig. 5) and sectorial severity (Fig. 6) of impacts. They also show rather different practices in terms of mitigation measures according to the EC Blueprint classification (Fig. 7).

3.4.1 Spain

In 2022, Spain experienced a widespread and prolonged drought, with the north-east of the country displaying already SPEI-6 values below -2 during the winter of 2021-2022 (Fig. 2a). Early indicators appeared in winter 2021–2022, and the situation worsened over summer despite slight improvements in spring. The drought continued well into 2023 and 2024, with some areas still affected as of 2025. Respondents confirmed the early onset, with several impacts reported before March 2022 and continuing beyond September. Catalonia, in particular, endured exceptional conditions, with SPI-12 dropping below -3 and reservoirs falling below 16% of capacity by early 2024.

Impacts were felt across environmental and socio-economic sectors, particularly in freshwater ecosystems, agriculture, and public water supply. Nearly 70% of respondents reported high severity (level 4 or 5) in sectors such as public water supply, freshwater ecosystems, and water quality. In Catalonia, emergency declarations were issued in over 230 municipalities, including Barcelona, affecting more than six million people. Drastic water use restrictions were imposed—limiting urban water use to 160 litres per person per day, cutting irrigation by up to 80%, and reducing industrial use by 25%. Emergency actions included reduced ecological flows, temporary bans on new high-water-use activities, and fines for exceeding consumption limits. Over time, traditional supply sources like dams were supplemented by groundwater, desalination, and for the first time, significant use of recycled water for human consumption.

To manage the crisis, organizations relied heavily on existing water infrastructure. Spain's 1,225 dams—372 of which are high-capacity—played a key role, though many aquifers were already over-exploited. Nearly all Spanish respondents (84%) believed drought risk is increasing, and 61% reported having both short- and long-term drought plans. Actions taken included the activation of special drought decrees, reduced allocations to agriculture, infrastructure retrofitting, and enhanced hydrological monitoring. The revised 2018 drought plans emphasized desalination, ecological flow management, nitrate pollution control, and improved planning. Spain also co-launched the International Alliance for Drought Resilience (IDRA) in 2022, supporting global coordination on drought preparedness. Despite these efforts, responses highlighted gaps in forecasting and planning, underscoring the need for a more integrated, long-term management approach.

3.4.2 Italy

In Italy, impacts of the 2022 drought were observed as early as March (depending on the sector), and persisted until after September 2022 (Fig. 5). The consequences ware severe and felt across social and economic sectors, particularly for the Public

Water Supply, Energy, Fisheries and Agriculture sectors (Fig. 6). The entire peninsula grappled with significant water balance deficit (Fig. 2), distinguishing the 2022 drought as more severe than the 2018/2019 event. Amid ongoing water scarcity, the Italian government responded with Decree-Law Drought No. 39 of 2023 (C.d.D., 2023), emphasizing urgent provisions to counter water scarcity and enhance water infrastructure. Mitigation measures included simplifying water infrastructure procedures, increasing reservoir storage, rainwater harvesting for irrigation, treated wastewater reuse, and desalination projects.

Regional and public administrations played a pivotal role in implementing drought management strategies, primarily focusing on Public Water Supply, Agriculture, and Water Quality. During the first half of 2022, approximately 60% of these sectors took proactive measures to address the impact of the drought. Respondents prioritized Public Water Supply, Agriculture, and Livestock Farming (Fig. 6). Most organizations (61%) initiated drought risk management measures during the first half of 2022. Still, despite legislative efforts, questionnaire responses indicated gaps in drought preparedness. Only 28% had both short- and long-term drought management plans, and 51% reported a complete lack of plans.

The most commonly implemented measure related to water distribution management, were Water Supply and Distribution (55%) and Water Supply and Demand (19%) (Fig. 7). This demonstrates a tendency for water managers to guarantee business-as-usual operations in times of water scarcity. This is exemplified by a respondent who stated: "Greater control and assessment of the situation through monitoring, elimination of [water] leaks or waste, exploration of new supply sources, and implementation of new storage facilities" to the question regarding which measures their organization took to mitigate the impact of the drought. Still, respondents also showed awareness of the need to reduce demand: "It is necessary for the authorities to allow extraordinary works and permits to prevent the loss of well zones. Even the sole reduction of withdrawals during hot periods along the riverbank would be a response". Other measures included: awareness rising (15%), water capture and storage (11%), monitoring (11%), infrastructure retrofitting (10%), and planning (10%). Despite challenges, respondents emphasized the relevance of ongoing efforts to enhance water resilience. Yet, the Italian context strongly prefers short-term and supply-side measures, emphasizing the need to meet water demand even during drought periods.

4 Discussion

4.1. Challenges of drought risk management

4.1.1 Increasing drought risk

One notable consensus among the survey respondents is the recognition that drought is increasingly becoming a more significant risk across Europe. They anticipate that their respective organizations will place drought risk management at higher priority in the future. This echoes the increase in frequency and intensity of drought hazards presented in this and in previous studies (Markonis et al., 2021; Moravec et al., 2021, Spinoni et al., 2018, Ionita et al., 2022, Jaguus et al., 2021, Semenova & Vicente-Serrano, 2024).

Beyond the higher frequency, this study highlights the extensive scale of drought impacts, prompting drought risk management measures across all European countries, underscoring the potential benefits of continent-wide coordination as indicated by previous research (Blauhut et al., 2021; Hervás-Gámez & Delgado-Ramos, 2019; Publications Office of the European Union, 2023; Rossi, 2009; Stein et al., 2016). This shared understanding of growing drought risk and the increasing need for drought risk management emphasizes the continent-wide scale of the challenge and further reinforces the need for collaborative initiatives and unified guidance. Our findings align with extensive research showing how droughts transcend national borders and emerge as cross-boundary challenges (Herrera-Estrada et al., 2019), impacting the entire European continent (Ionita et al., 2022; Rakovec et al., 2022; Schumacher et al., 2024; Spinoni et al., 2018; Toreti, et al., 2022). This requires a European-level direction in drought risk management and response (Blauhut et al., 2022; Hagenlocher et al., 2023; Stein et al., 2016; van Daalen et al., 2022).

The study stresses the need to assess water prioritization criteria, considering the impacts on various sectors and adjusting the allocation strategy to ensure a more equitable and effective distribution of water resources. The example of Catalonia highlights the challenges of prioritizing water use between sectors. Yet, observed/expected impact should not drive prioritization as this is a manifestation of prioritization and other measures itself. Sectors of key importance for human and environmental well-being (e.g. Public Water Supply and Aquatic Ecosystems) must be prioritized regardless of impact due to their importance in the functioning of the SES (Rossi et al., 2023).

4.1.2 Spatial and temporal evolution of drought

Droughts are long-lasting events that can span over several seasons and years. Their impact can affect different aspects of SES depending on the response time of the system in question (e.g. depletion of water supplies can last for years, while the forestry sector might only show visible effects years after the drought “event”, and governance effects may take years to materialize). This underscores drought as a complex crisis with long-term systemic ramifications (Van Loon et al. 2024).

Respondents indicated that the impact of the 2022 drought extended beyond the observation period covered by the questionnaire in 44% of cases (i.e. after September 2022), and spanned the entire observation period in 7% of all cases (i.e. from before March 2022 to after September 2022). This is exemplified in the autonomous region of Catalonia (ES), where the drought is continued until the end of 2024. It shows how a prolonged drought can impact different components of the wider system over time, from the hydrological, ecological, and socio-economic systems.

Still, drought risk management in Europe generally defines drought as an extraordinary, time-confined, event with a predominant seasonal occurrence (Stein et al., 2016). Consequently, monitoring and drought management teams are typically assembled on a seasonal basis and are disbanded once the crisis has subsided (this differs across European countries), with consequent overlooking of long-lasting and lingering impacts of drought. Additionally, a crisis approach to drought risk management frames drought as a crisis and justifies extreme measures that can have long-lasting adverse effects, as evident in the Italian case, where an ad-hoc drought commission is instituted to tackle the crisis but no permanent drought risk management coordination body exists.

Most European member states present some version of article 4(6) of the WFD in their national water basin management plans, allowing them to reduce or forego environmental outputs during drought (Publications Office of the European Union, 2023). This overlooks the complex nature of drought risk management and the ramifications that short-sighted measures can have. Instead, research shows that a systemic risk perspective is necessary to manage complex crises like droughts (Wilhite et al. 2019; Hagenlocher et al., 2023), and that European-level drought risk management should strive to implement it (Stein et al., 2016). Drought hazard and impact monitoring and forecasting should be strategic efforts that consider the physical aspects of drought and its relation with impacts (Sutanto et al., 2019; Shyrokaya et al., 2024). A systemic perspective, thus, is necessary to show how drought impacts can be worsened by decisions taken during "normal" times (Hagenlocher et al., 2023; Kallis, 2008; Wilhite et al. 2019; WMO, 2021). Moreover, to effectively implement the principles stated in the EC communications about drought and water scarcity, this systemic perspective must prioritize holistic measures that account for environmental conservation and water use reduction across all sectors and users.

4.1.3 Drought risk management measures

> "[In response to question 12 of the survey about the main measures taken:] *The main issue was high demand rather than supply shortfall - the distribution network encountered issues due to the high demand in May-July and eased off in August. All sources were utilising their peak output for 2-3months whilst planned outages were postponed.*" UK respondent

The measures taken by different sectors' organizations predominantly focus on immediate operational concerns, such as water supply management, to ensure business continuity during droughts. In particular, supply-side measures were the most commonly used, especially in countries where agriculture plays an important economic role (e.g. Italy, Spain, the Netherlands). This is in direct contrast with the recommendations from the EC communications *Blueprint to Safeguard Europe's Water Resources* and the *Water Scarcity and Drought Policy*, which instead stress the importance of prioritizing demand reduction and improving efficiency before opting for increasing supply (Stein et al., 2016). Additionally, both EC recommendations and research stress the importance of reducing water use in general. Simply providing water surplus by either increasing supply or improving efficiency leads to a systemic increased water-use, which nullifies the surplus, as demonstrated by the reservoir effect (Di Baldassarre et al., 2017, 2018). Instead, by prioritizing water demand reduction and increasing efficiency, organizations should reduce water consumption, and avoid maladaptive practices and path-dependencies.

As the Italian case exemplifies, short-term and supply-side measures are likely favoured as they address the immediate concerns of the responders and sectors involved (Teutschbein et al., 2023). This is an example of "salience-bias", where disproportionate weight is given to more immediate concerns due to proximity, memory, perspective, or deliberate choice, potentially leading to suboptimal decisions (Bordalo et al., 2020; Garcia et al., 2020; Garcia & Islam, 2021). Still, as the "hydro-illogical cycle" shows, it is challenging to mainstream drought risk management measures during periods of non-drought, depriving preparedness and mitigation measures of their effectiveness, making response measures more necessary (Wilhite et al., 2005). This situation can be further exacerbated by development policies that are not aligned with drought management policies and instead negatively impact them (Kallis, 2008). Rather, drought risk management should embrace an integrated and systemic approach, as proposed by IDM, by avoiding short-term measures when these are less effective than proactive, long-term, and systemic ones (Wilhite et al. 2019; Wendt et al. 2021).

The allocation of water resources during droughts presents a complex challenge, particularly in balancing the needs of highly impacted sectors against those less impacted, or where the risk seems more imminent. This was observed in the Forestry sector in Germany and Energy, Industry, and Fisheries sectors in Italy that all received a low priority for water allocation despite experiencing significant drought-related impacts. Conversely, sectors such as Public Water Supply, Water Quality, Water Transportation, and Tourism were considered high priority across multiple countries, even if their impact seems less severe, possibly as a result of the higher prioritization. However, it is crucial to acknowledge that the effect of prioritization itself may also influence the perception of milder impacts in certain sectors. Moreover, sectors like forestry, where the full extent of the impact may take longer to manifest (Shyrokaya et al., 2023), might receive lower priority despite their critical importance, especially with a significant increase in drought impacts in the forestry sector (Rossi et al., 2023). This prioritization discrepancy underscores the need for a nuanced approach to managing the diversity of drought impact across operational levels and sectors in response to varying degrees of drought severity. This in turn, highlights the need for a delicate balance between addressing immediate needs and ensuring equitable resource allocation across sectors considering the potential long-term consequences of drought impacts.

This study shows that during the 2022 European drought there was a lack of emphasis on longer-term adaptive measures expressed by water managers as evident in the Italian case. This is supported by research showing that despite the WFD supporting adaptive water management approaches, implementation generally follows a standard responsive approach as institutional practices, competencies, and skills are not aligned to what an adaptive approach would require (Voulvoulis et al., 2017). This suggests a potential strategy gap, with an opportunity for organizations to consider more sustainable and forward-looking approaches to drought risk management, such as ecosystem-based adaptation (IPCC, 2022a). This is also highlighted by the overall preference for sub-seasonal forecasting and short-term drought management plans over seasonal forecasting and long-term plans (Biella et al., 2025). Yet, research warns against the risk of maladaptation that reliance on short-term information alone can cause (Biella et al., 2024). A systemic and long-term perspective focusing on demand-reduction is instrumental in avoiding maladaptive outcomes and path-dependencies (Hagenlocher et al., 2023).

4.1.4 Shifts in drought risk management

We find clear regional and country-level differences in drought risk management across Europe, likely reflecting the diversity of drought impacts in the region and at the scale considered. These differences in drought risk management can be observed across all aspects, from the type of measures taken, to the effectiveness of these measures, to the reported changes in drought risk awareness and preparedness. Due to the limited sample size of some countries (see Table S1 in the supplement), and the high rate of “no answers” in some of the categories, it is not possible to draw a generalizable conclusion for all sub-groups. However, the consistency reported with respect to different aspects of drought risk management should be taken as strong evidence of the large differences currently present in European drought risk management. Similar differences in drought preparedness have been highlighted by water managers across European countries (Biella et al., 2025). This also is supported by reports showing the continent's diverse drought risk governance landscape (Publications Office of the European Union, 2023). This discrepancy in drought risk management capacity across European countries emphasizes the urgent need for continent-level guidance, acknowledging the diverse challenges different regions face. Despite the various EC communications on droughts and the inclusion of drought in many strategies, the lack of a unified policy with binding force means that the drought risk management landscape of the continent remains diverse (Stein et al., 2016). Factors, such as availability of resources and drought risk awareness, likely contribute to the disparities in drought risk management capacity observed. Developing a *European Drought Directive*, would be instrumental in levelling out the difference among countries (Blauhut et al., 2022).

The survey results point to a shift where organizations are becoming more conscious of the risks posed by drought and suggest that time is ripe for mainstream drought risk management in Europe's policies. While awareness of drought risk increases across Europe, preparedness and effectiveness lag behind. The survey demonstrates clear differences at the regional level, with respondents from Eastern, South-Eastern, and Northern Europe displaying minor changes in drought risk management compared to their counterparts in South-Western, Central, and Western Europe. Research shows that mainstreaming drought risk management is most effective after times of crisis, when awareness is high (Cavalcante et al 2023, Kreibich et al 2023). This is evident in the EU, as several countries with drought legislation have promoted it following the sever, large-scale droughts of the last decade (Publications Office of the European Union, 2023; Bartholomeus et al., 2023). Still, EU-level policy mainstreaming is often a complex, lengthy, and highly political process and compromising (Deters, 2018; Kaika, 2003). The results of this study clearly show that European water managers display high levels of drought risk awareness, while preparedness has room for improvement. This means taking advantage of this mainstreaming window to promote drought risk management policy across Europe is essential. It is the role of research to ensure that awareness remains high in times of non-crisis, avoiding the hydro-illogical cycle.

5 Recommendations for European drought risk governance

5.1 Gaps in European drought governance

This research underscores the necessity for cohesive, European-wide coordination in addressing the increasing drought risk, the scale of the threat posed by drought, and the interconnectedness and co-dependence of ecosystems and socio-economic sectors across the continent. The regional differences and the differences in the adaptive pathways across countries show the need for a coordinated approach to address shared vulnerabilities, foster collaboration and coordination, and increase equity (EC et al., 2015; Hagenlocher et al., 2023; Publications Office of the European Union, 2023; Stein et al., 2016).

Nevertheless, the EU lacks a unified drought policy, and the reliance on a framework of other water-related directives and non-binding communications limits progress (Hervás-Gámez & Delgado-Ramos, 2019; Publications Office of the European Union, 2023; Stein et al., 2016). The 2000 WFD remains the only existing binding directive loosely dealing with drought; yet it does not specifically address it or define it, only mentioning drought and floods (Publications Office of the European Union, 2023; Stein et al., 2016). Furthermore, the WFD's framing of droughts (and floods) as "force majeure" can justify non-compliance with environmental needs (DIRECTIVE 2000/60/EC). This is in contrast with a vast body of research showing that viewing droughts as exceptional events overlooks their lasting and systemic impacts and increased risk (Hagenlocher et al., 2023; Van Loon et al., 2024; Walker et al., 2024; Markonis et al., 2021; Moravec et al., 2021; Spinoni et al., 2018; Ionita et al., 2022). Still, the WFD offers a solid base on which European drought risk management can be developed, as it crucially defines catchment-level water management, environmental output requirements, unified monitoring, and international collaboration for transboundary basins (Publications Office of the European Union, 2023; Stein et al., 2016). The catchment-centred perspective (instead of administrative borders) suits the need for cross-country drought risk management. Finally, its cross-sectorial focus and the adaptability of its 6-year revision cycles align with the needs of a systemic drought risk management approach.

Following the WFD, the 2007 EC communication on water scarcity and droughts and the 2012 Blueprint to Safeguard Europe's Water Resources (also an EC Communication) have also been instrumental in defining DMPs, and promoting country-level drought risk management through a clear emphasis on the importance of water conservations measures (Hervás-Gámez & Delgado-Ramos, 2019; Stein et al., 2016). However, despite their ambitious principles, the EC Communications of 2007 and 2012 remain non-binding, crucially lacking mandatory power over EU member states' legislation and diverse, binding policy options (Stein et al., 2016).

Droughts are recognized as a priority in other EU policy frameworks dealing with specific sectorial issues; adding to the need of cross-sectoral policy. The *European Green Deal* and the 2021 *EU Strategy on Adaptation to Climate Change* have a dedicated *Group on Water Scarcity and Drought* in the 2022-2024 *Programme for the Common Implementation Strategy for the Water Framework and Floods Directives*. Other relevant directives include the EC *Flood Directive* (2007), *Groundwater Directive* (2006), and *Habitats Directive* (1992). Moreover, the EU's *Common Agriculture Policies* (CAP), a vast framework governing agriculture since the 1950s, also defines tools for drought governance (Stein et al., 2016). However, these directives only deal with drought within the boundaries of their sectors. For example, although CAP includes many ecosystem-focused principles, it also includes stabilization mechanisms that might encourage risky agricultural practices during droughts, which clearly indicates/points to a lack of systematic/holistic perspective (Stein et al., 2016). Similarly, flood risk management and reservoir management measures can indirectly affect drought risk management. Consequently, without unified guidance, taking a systemic, sustainable, and long-term approach to drought risk management strategies may risk incurring maladaptation, especially when competing with the economic development interests of other sectors.

5.2 A way forward: The European Drought Directive

This study completes a series of research efforts highlighting the need to establish European coordination and guidance on drought risk management (Blauhut et al. 2021, Moravec et al. 2021, Stein et al 2016, Rossi 2009, Hervás-Gamez & Delgado-Ramos 2019, European Drought Atlas 2023). Supporting the recommendations by Blauhut et al., (2022), we advocate for the development of an *EU Drought Directive*. While the EC communications on drought (namely, the WS&D and the Blueprint) already present many ambitious principles, a legally-binding directive is necessary to ensure their implementation and create consistency among different countries. This *EU Drought Directive* should establish principles of drought risk management, provide coordination, and guidance at the EU level, and set up cooperation agreements with third countries of interest (e.g. Switzerland, the UK, Norway, Ukraine, and the western Balkans). Its implementation should be carried out at the member state level, being tailored to the local context and operational needs accounting for differences in drought risk, as well as risk management capacity. This approach is similar to that already provided in the *Floods Directive*. Additionally, we suggest amending the WFD to include clear drought risk management principles as a necessary first step, as the framework already introduces valid water resource management principles that can be effectively applied to drought risk management (e.g. catchment-based management, and international coordination guidance). The WFD can also provide the ideal governance framework for a holistic and integrated approach that assists managing the increasing drought and flood risk. We believe a European *Drought Directive* should:

1. *Define the principles that guide drought risk management*. These have already been indicated in the non-binding EC Communications, have counterparts in the Flood Directive, or have been defined by research. These principles are:
    a. *Managing drought risk, not drought hazards*. While drought cannot be prevented, reducing its adverse impacts on human health, the environment, and socio-economic activities are possible. A risk approach to drought risk management requires considering all aspects of risk and not focussing on the hazard alone.
    b. *Drought is a continuum*. Droughts are not entirely exceptional events. They are recurrent feature of the climate, and their impacts propagate through the socio-economic system. Hence, drought risk management should not merely be responsive, seasonal, and crisis-based. Instead, it should adopt systemic, integrated, and long-term risk management perspectives that address water scarcity and stresses even during non-drought periods. This approach helps avoid path-dependency, lock-ins, and maladaptation.
    c. *Environment-centred drought risk management*. Environmental needs should also be prioritized during drought periods, especially in case of long-term adverse effects on ecosystems. This means that drought should not constitute a valid reason to forego environmental needs in favour of economic activity. Instead, drought risk management should ensure and protect the ecosystem's capacity to support natural and human activity (ecosystem services).
    d. *First reduce demand, second improve efficiency, last increase supply*. The measures aimed at managing drought risk need to prioritize reducing water demand and reducing dependencies. A second priority is to increase water use efficiency in the system. Yet this increased efficiency should come hand in hand with demand reduction. Lastly, supply increase measures and infrastructural measures should only be considered where the first two options are not feasible. Maladaptive outcomes such as increased water dependence and the reservoir effect should be avoided.
2. *Provide guidance and coordination for drought risk management.*

a. *Provide guidelines for the definition of drought*. The directive contains a general definition of drought, allowing Member States to tailor it to their contexts. This requires including indices representing different types of drought (meteorological, soil moisture/agriculture, hydrological droughts) in response to the wide range of drought impacts encountered.

b. *Provide guidance for international coordination in drought risk management*. Drought risk management should be carried out on shared/transboundary river basin principles already defined in the WFD. To do so, amending the WFD to include drought is necessary. The Directive must also guide collaboration with countries that are not members of the EU due to the sectorial cross-border dependencies and shared river basins. The flood directive offers an example of such guidance.

c. *Provide guidelines for the revision, development and implementation of national drought risk management policies* following the 10 steps process detailed in the National Drought Management Policy Guidelines: A Template for Action (WMO & GWP, 2014).

d. *Provide deadlines for key steps in the development of national drought risk management policies:*
    i. *Carry out preliminary drought risk assessment.*
    ii. Carry out drought risk assessment and draw drought risk maps.
    iii. Develop Drought Risk Management Plans at the national and regional level.
    iv. Mandate the development of Drought Risk Management Plans for private actors in key sectors.

6 Conclusion

The 2022 European drought, a continent-wide event, exposed critical deficiencies in Europe's water management framework. This study provides an overview of the 2022 European drought by linking its physical aspects (the hazard), with perceived sectoral impacts by water managers and the drought risk management strategies employed by water authorities.

Findings show that drought is increasingly recognized as a major risk across Europe, with growing awareness, institutional preparedness, and response capacity. However, droughts are still frequently addressed as exceptional crises, resulting in reactive and often maladaptive responses. In the context of a warming climate where droughts are becoming more frequent and severe, such short-term approaches are no longer adequate. Lessons learned from countries with a history of frequent droughts such as Spain and Italy, can help informing drought management strategies in other parts of Europe that are now experiencing greater exposure to drought hazards as the continent becomes warmer and drier.

Hence, a shift toward a systemic, integrated, and long-term strategy is urgently needed. Drought risk management must prioritize demand reduction and ecosystem health, moving beyond emergency response. To support this, a *European Drought Directive* is recommended to unify and enforce drought risk management policies at the national, regional and catchment scales, ensuring coordinated efforts across the continent. This directive should guide the development of drought management plans, emphasize risk management over crisis response, and prioritize environmental outputs and water demand reduction.

Coordinated European-level action is essential to address the shared vulnerabilities and complex nature of droughts, ensuring effective and sustainable management of this escalating risk on the climate resilient pathway for all European countries.

Competing interests

At least one of the (co-)authors is a member of the editorial board of Natural Hazards and Earth System Sciences Journal.

Code Availability

All codes used for the statistical analysis can be made available upon individual request.

Data availability

The data collected during the survey contains information that might allow to identify some of the respondents. Hence, all data collected through the survey has been stored on DitA's workspace and can be made available upon request. Climate-related data is freely available as described in Sec. 2.1.

Interactive computing environment

No interactive computer environment is available.

Sample availability

No physical samples were collected.

Video supplement

No video supplement was developed.

Supplement link

The link to the supplement will be included by Copernicus, if applicable.

Author contribution

Conceptualization: The conceptualization of the article involved a large group of authors as the initial idea was developed during the *Drought in the Anthropocene* annual workshop in Uppsala in July 2022 and was defined during a first online meeting in October the same year. All the following authors were involved in the conceptualization of this manuscript as they were present and actively participated during either of those events: AM, AS, AT, AvL, BM, CT, DC, ER, ES, FR, FT, GDB, IP, J-PV, LMT, LB, MW, MI, PT, RH, RB, SS, SH, SC, SM, SJB, SK and VN. *Methodology and Data Collection:* The following authors were involved in the designing, translation, and dissemination of the survey: AM, AS, AT, AvL, BM, CT, DC, ER, ES, FR, IP, MCL, MMdB, ML, MW, MI, PT, PA, RH, RV, RB, SS, SC, SJB and VN. Additionally, the following authors were involved in the collection and handling of climate data: IP, MI, PA, RH and SS. *Project Administration:* AS, MI, and RB were responsible of management and coordination of the team's research activities throughout the development of the study. *Supervision: GDB* and LMT offered invaluable supervision at various stages of the development of the manuscript. *Visualization:* The figures, tables and maps present in the manuscript were created by: AS, MI, PA, RB and SS. *Writing:* The original draft was mostly prepared by a core team composed by: AS, LMT, MI, RV and RB. Additionally, other authors were involved in writing specific sections of the manuscript: AM, BM, DC, ER, FR, IP, MCL and SC. Other authors were involved in the reviewing and editing process, offering commentary and suggestions to the original draft: AT, CT, DW, FT, MMdB, ML, MW, PA, SS, SJMG and SK.

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