

Invited Perspective: Advancing knowledge co-creation in drought

impact studies

Silvia De Angeli^{1,2,3}, Lorenzo Villani^{4,5}, Giulio Castelli^{4,6,7}, Maria Rusca⁸, Giorgio Boni³, Elena Bresci⁴, Luigi Piemontese⁴

¹Université de Lorraine, CNRS, LIEC, F-54000 Nancy, France

²Université de Lorraine, LOTERR, F-57000 Metz, France

³Department of Civil, Chemical and Environmental Engineering, University of Genoa, Genoa, Italy

⁴Department of Agriculture, Food, Environment and Forestry (DAGRI), University of Florence, Florence, Italy

⁵Department of Water and Climate (HYDR), Vrije Universiteit Brussel, Brussel, Belgium

⁶UNESCO Chair in Hydropolitics, University of Geneva, Geneva, Switzerland

⁷Environmental Governance and Territorial Development Hub (GEDT), University of Geneva, Geneva, Switzerland

⁸Global Development Institute, The University of Manchester, Manchester, UK

Correspondence to: Silvia De Angeli (silvia.de-angeli@univ-lorraine.fr), Luigi Piemontese (luigi.piemontese@unifi.it)

Abstract. Drought impacts are increasingly recognised as interdisciplinary, socially influenced processes often resulting in uneven outcomes across different social groups, rather than mere hydro-climatic events. Yet, many drought impact studies do not fully integrate the knowledge and perspectives of those who directly experience the impacts of droughts. While knowledge co-creation represents a promising avenue to address this challenge, there still remains an ample margin of improvement in the depth and breadth of transdisciplinary approaches in drought impact studies: most studies either limit co-creation to specific phases of the research process (*breadth*) or fail to meaningfully incorporate non-academic knowledge within those phases (*depth*). Drawing from a diverse body of literature on transdisciplinarity in sustainability science, integrated water resources management, socio-hydrology, science and technology studies, and critical water studies, we delineate five key dimensions which can support broader and deeper knowledge co-creation processes in drought impact studies, including 1) setting up a collaborative space, 2) framing the co-modelling process, 3) shaping a shared knowledge of drought, 4) co-selecting and co-developing models to understand drought impacts, and 5) being aware of power biases and knowledge imbalances. Incorporating all five dimensions promotes broader and more comprehensive studies, while exploring each dimension in greater detail enhances their depth. Together, these dimensions provide conceptual guidance for developing transdisciplinary approaches that are more integrated, power-sensitive, inclusive, situated, and reflexive.

1 Introduction

30 Droughts are becoming increasingly widespread and impactful, with serious consequences for health, agriculture, societies, and the environment globally (Vicente-Serrano et al., 2021; Wilhite et al., 2007). Socioeconomic and environmental impacts of drought have long been studied (e.g., Wilhite and Glantz, 1985) based on drought hazards primarily assessed as meteorological and/or hydrological processes (Mishra and Singh, 2010, 2011). However, the social dimension of drought is very different from how it is represented in hydro-climatic models (Enenkel et al., 2020; Kchouk et al., 2022). In fact, droughts are increasingly conceptualised as complex socio-hydrological phenomena that affect societies across interdependent sectors and socio-economic groups (AghaKouchak et al., 2021; Ribeiro Neto et al., 2023; Mehta, 2007; Van Loon et al., 2016a, 2016b). In parallel, research in climate justice and political ecology has long conceptualised disasters as generated by the interplay of hydro-climatic and historical, socio-political, economic, and institutional dynamics (e.g., Collard et al., 2018; Kallis, 2008). From this standpoint, drought-related impacts, which often escalate into disasters, have been conceptualised as a social construction of water scarcity. This perspective highlights how different social groups experience the impacts of drought unevenly due to varying levels of power and influence. It also emphasises the variable “room for manoeuvre” of different socio-economic groups in responding and adapting to drought events (Alexandra and Rickards, 2021; Eriksen and Lind, 2009). Finally, this perspective draws attention to the underlying political and economic drivers, such as development pathways and policy visions, that shape the vulnerability of different groups and their exposure to hazards (Mehta, 2005; Rachunok and Fletcher, 2023; Rusca et al., 2023; Savelli et al., 2022; Usón et al., 2017; Piemontese et al., 2024).

The multidimensional nature of droughts has been addressed by recent interdisciplinary socio-hydrological research on water-related challenges (Vanelli et al., 2022), which aims at capturing the interplay between natural and social aspects (Rusca and Di Baldassarre, 2019; Wesselink et al., 2017). Yet, there is an increasing recognition of the need to include societal perspectives within socio-hydrological studies, such as those of non-academic actors directly experiencing the impacts of drought, through transdisciplinary studies (AghaKouchak et al., 2021; Arheimer et al., 2024; Hadorn et al., 2008; Weater and Gober, 2015). Transdisciplinary research brings “values, knowledge, know-how, and expertise from non-academic sources” (Klein, 2010) to the knowledge-creation process. This entails fostering mutual learning processes between science and society, reflecting a commitment to a science that collaborates with society rather than simply serving it (Seidl et al., 2013). Transdisciplinarity includes a variety of approaches to knowledge co-creation (Bennich et al., 2022; Brugnach and Özerol, 2019; Norström et al., 2020). In the field of integrated water resource management, knowledge co-creation is often addressed by referring to the concepts of collaborative modelling or co-modelling (Basco-Carrera et al., 2017). This concept involves the collaborative construction of models, which can be physical, conceptual, or computational representations of a system, process, or phenomenon. Co-creation provides the collaborative framework for ideation and value creation, while co-modelling offers the tools and methods to visualise, test, and refine these ideas into actionable solutions, enhancing the effectiveness of co-creation.

60 In this perspective paper, we discuss co-creation in drought impact studies from a broad standpoint and return to co-modelling

in Sect. 3.4 to examine its specific role and applications in greater detail, presenting co-modelling as one key dimension of the co-creation process.

65 Examples of drought or water scarcity studies that include a strong participation of non-academic stakeholders embrace co-creation of i) drought impacts, ii) water infrastructure planning, and iii) water use under scarcity conditions. The first body of literature includes studies aimed at increasing stakeholders' participation in drought plans with a variety of approaches. For example, Sodoge et al. (2024) develop individual causal loop diagrams to map cascading drought impacts from different stakeholders, which they ultimately combine to reveal emerging knowledge from multiple perspectives. Cid et al. (2024) use serious games to engage stakeholders in the creation of proactive drought plans, while revealing power imbalances and knowledge disparities. Giordano et al. (2013) use Cognitive Mapping and Bayesian Belief Networks to collect and analyze
70 stakeholders' perceptions of drought impacts, highlighting the challenges of trust and cooperation in knowledge integration for drought Early Warning Systems. Aldunce et al. (2016) apply the Resilience-Wheel tool combined with participatory methods to understand key determinants of drought resilience in urban Chile. Streefkerk et al. (2022) integrate farmers' local knowledge with seasonal climate forecasts to select the most relevant indicators for forecasting locally-relevant dry conditions in Malawi. The second group of studies focuses on evaluating the feasibility of water infrastructure by integrating knowledge and mediating the values and expectations of different stakeholders (Coletta et al., 2024; Gil-García et al., 2023; Masi et al., 2024). For example, Gil-García et al. (2023) include experts' knowledge and opinions to co-design scenarios within alternative adaptation strategies and guide policymakers when considering the construction of a dam. The third set of studies uses a variety of methods to provide guidance on mediating the use of water resources under scarcity conditions (Baker et al., 2015; Gwapedza et al., 2024; Ocampo-Melgar et al., 2022; Rojas et al., 2022). For example, Liguori et al. (2021) explore a
80 combination of storytelling and scientific data to guide the development of different co-designed narratives to support the planning of drought adaptation scenarios. The co-creation of adaptation scenarios is also the focus of a co-modelling approach proposed by Mustafa et al. (2021) to improve adaptation to hydrological extremes in the Limpopo River Basin. These approaches attempt to integrate some elements of knowledge co-creation, yet they often limit the transdisciplinary process to specific tasks, usually the definition of adaptation scenarios or the choice of indicators or model parameters (Luetskemeier et al., 2021).
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Although many studies involve stakeholders with a variety of participatory approaches, the limitation of current transdisciplinary approaches in drought research lies in the depth and breadth of knowledge integration. Most studies either limit co-creation to specific phases of the research process, such as problem definition, scenario development, or result validation (*breadth*), or fail to meaningfully incorporate non-academic knowledge within those phases, for instance by using
90 such knowledge only to validate predefined scientific assumptions rather than to shape core research questions, methodologies, or models (*depth*). This leaves room for improving knowledge co-creation with the implementation of more "mature" transdisciplinary work, building on a full engagement and integration of different stakeholders (and knowledge holders) in all the phases of the research process. Also, and very important, is the attention to power dynamics through the process, which is

largely analysed within social sciences, and which can substantially advance socio-hydrological studies within
95 transdisciplinary research.

Our contribution seeks to support hydrological and socio-hydrological modellers and practitioners in developing more
structured, power-sensitive, inclusive, situated, and reflexive co-created drought impact studies by providing essential
considerations for more effectively integrating diverse knowledge systems and perspectives into the process. In this paper, the
term “drought impact studies” is used to refer generically to studies and projects that not only evaluate the hazard dimension
100 of drought but also investigate, describe, or evaluate its impacts and support the identification and planning of drought
management or adaptation measures. Moreover, this paper approaches drought from a socio-hydrological perspective, offering
a framework tailored for transdisciplinary studies and projects that view drought as a result of feedback between water systems
and human activities.

Drawing from five different bodies of literature – socio-hydrology, Integrated Water Resources Management (IWRM),
105 Sustainability Science, Critical Water Studies, and Science and Technology Studies (STS) – we identify and discuss five key
dimensions of a comprehensive and structured co-creation process for assessing and adapting to drought impacts. These
dimensions address current limitations in both the breadth and depth of such approaches: incorporating all five promotes more
comprehensive and wide-ranging studies, while examining each in greater detail enhances their depth.

The paper proceeds as follows. In Sect. 2, we explore how an interdisciplinary perspective, drawing from five different bodies
110 of literature, contributes to a more comprehensive approach to knowledge co-creation in the context of drought. Then, in Sect.
3 we discuss each of the five identified key dimensions in detail. Next, in Sect. 4, we discuss the limitations of transdisciplinary
approaches to drought, related to the five key dimensions. To conclude, Section 5 offers insights into how the key dimensions
discussed in this paper can help develop more structured and holistic transdisciplinary approaches in the field.

2 An interdisciplinary perspective on knowledge co-creation

115 To enrich the drought co-creation process from an interdisciplinary perspective, we refer to and integrate knowledge developed
in five other scientific fields and disciplines: socio-hydrology, IWRM, Sustainability Science, Critical Water Studies, and STS.
Socio-hydrology (Di Baldassarre et al., 2013, 2015; Di Baldassarre, 2017; Sivapalan et al., 2012) focuses on the dynamic
interactions between hydrological processes and human behaviour, emphasizing how social systems influence water
management, which is particularly important in understanding the socio-economic impacts of drought.

120 IWRM advocates for a holistic approach to managing water resources that considers environmental, social, and economic
factors (Rahaman and Varis, 2005; Savenije, 1995; Savenije and Van der Zaag, 2008), fostering collaborative decision-making
and stakeholder engagement, which are crucial for effective drought management. Sustainability Science (Brandt et al., 2013;
Lang et al., 2012), particularly social-ecological systems research (Angelstam et al., 2013; Hummel et al., 2017), supports
transdisciplinary approaches and emphasizes integrating knowledge across sectors and disciplines, fostering inclusive
125 participation of non-academic actors to address complex environmental challenges like drought.

Critical Water Studies offer unique insights into power dynamics, vulnerabilities, and ethical considerations in drought impact studies. For the purpose of drought research, two areas of Critical Water Studies are particularly relevant: Hydrosocial Studies and Critical Disaster Studies. Hydrosocial Studies critiques mainstream hydrology for neglecting power dynamics and challenges the reliance on technoscientific solutions to water problems (Boelens et al., 2016; Linton and Budds, 2014). Critical Disaster Studies argue that vulnerability to natural hazards, such as droughts, is rooted in pre-existing inequalities, with social and economic structures exacerbating exposure and outcomes (Burton et al., 1993; White, 1945; Smith, 2006). Together, these fields highlight that water scarcity and droughts are not merely natural events but the result of deeply embedded power dynamics and social vulnerabilities.

STS provides an insightful self-reflection of the co-production process, challenging the notion of science as unbiased, and highlighting that the process of knowledge development is in itself influenced by power relations that determine which knowledge claims are considered valid and actionable (Budds, 2009; Goldman et al., 2019; King and Tadaki, 2018; Turner, 2011; Zwartveen et al., 2017). This perspective prompts critical reflection on research practices, particularly regarding the inclusivity and legitimacy of knowledge in drought impact studies.

3 Five key dimensions for drought impact knowledge co-creation

We discuss five key dimensions that provide coherent theoretical guidance for advancing transdisciplinary approaches in drought impact studies. These dimensions are derived from the five research fields introduced in Sect. 2 and reflect how insights from these disciplines offer critical perspectives on the role of knowledge integration, power dynamics, and ethical considerations in co-creation approaches for drought impact studies. The dimensions are not sequential and do not need to be addressed in a specific order. Moreover, they are highly interconnected, and decisions or actions related to one dimension may iteratively influence others. The five key dimensions are graphically depicted in Fig. 1, along with their interconnections. They are discussed in detail in Sects. 3.1 to 3.5, with explicit reference to the papers that informed each of them.

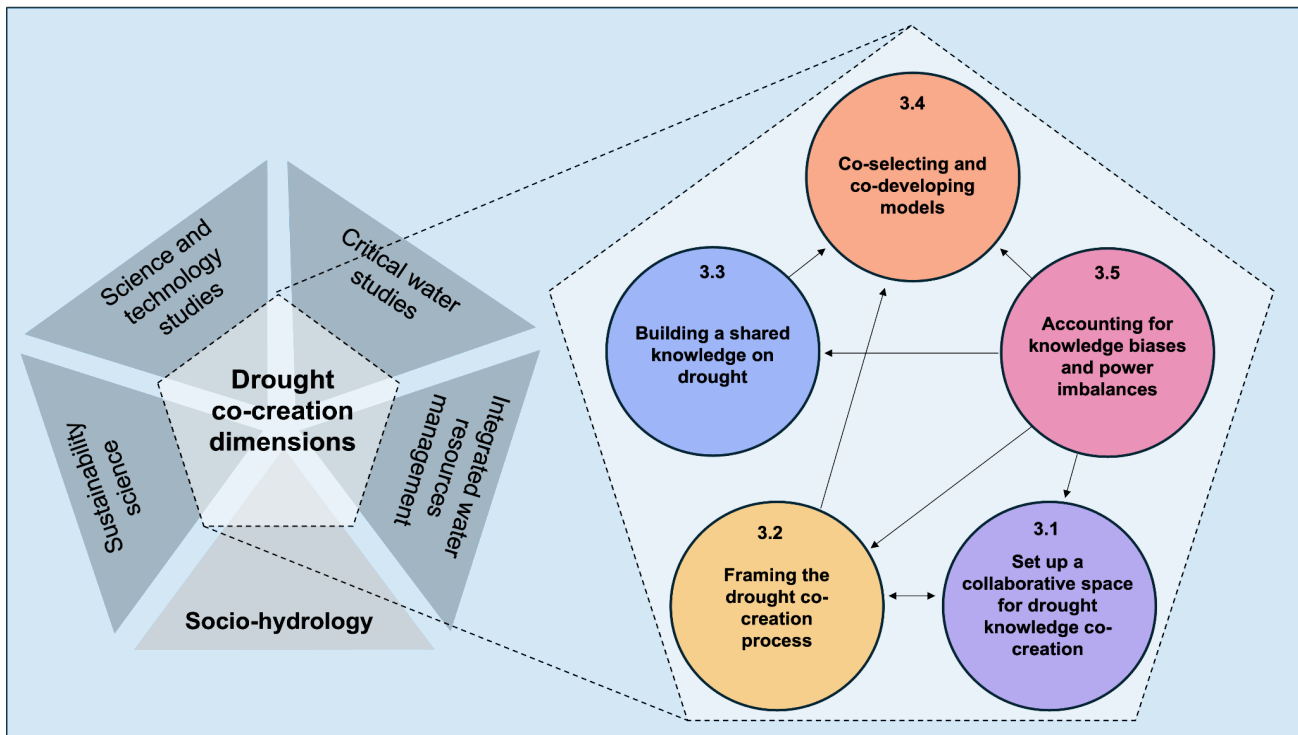


Figure 1: Conceptual framework: A graphical representation of the theoretical background (on the left) and the five key dimensions of knowledge co-creation for socio-hydrological drought impact studies, along with their interconnections (on the right).

3.1 Setting up a collaborative space for drought knowledge co-creation

Setting up a collaborative space includes identifying and establishing relationships among relevant stakeholders in the co-creation process (Reed et al., 2009). It ensures that all the parties that are affected by drought or influence the mitigation process are involved in the decision-making and knowledge generation. Stakeholders' identification is an iterative process where additional stakeholders are incorporated as the analysis unfolds. Setting clear boundaries for the study (Sect. 3.2) facilitates this process. Attention should be paid to verifying that these boundaries will not be too restricted to avoid unintentionally overlooking any relevant individuals associated with the phenomenon (Clarkson, 1995). For example, since the agricultural sector is often the major water consumer, it is typically overrepresented in water-related policy discussions (Paneque et al., 2018). Conversely, the boundaries cannot be too blurred. It is often impractical to include every stakeholder, requiring the establishment of well-founded criteria by the researchers and stakeholders to determine a cutoff point (Clarke and Clegg, 1998). A dynamic interplay between stakeholder identification and boundary-setting ensures that the co-creation process remains relevant and comprehensive without excluding important knowledge and perspectives.

In transdisciplinary research, involving stakeholders serves multiple purposes (Stirling, 2008). Firstly, it upholds democratic ideals by emphasising inclusive processes. Secondly, it taps into stakeholders' insights and risk assessments to improve the quality of process outcomes. Lastly, it enhances the legitimacy of predetermined decisions, ultimately increasing their

165 effectiveness in informing policy processes. However, despite the reported efforts of many drought-related studies, the effective involvement of stakeholders in participatory activities remains limited, as well as their contribution to policies (Hervás-Gámez and Delgado-Ramos, 2019). In this regard, the direct involvement of public authorities as elicitors of the procedure could facilitate stakeholders' participation (Hervás-Gámez and Delgado-Ramos, 2019; Kim et al., 2019).

170 When involving stakeholders, drought studies often consider broad categories such as the scientific community, public sector, civil society, and private sector (Aldunce et al., 2016; Lillo-Ortega et al., 2019). While this categorisation is certainly useful, it might fall short in fully capturing the complex drought dynamics. Some studies further deepened the stakeholder involvement by focusing on specific groups, such as vulnerable residents of informal settlements (Mpofu-Mketwa et al., 2023), or by including historically marginalised actors, such as representatives of the Indian pueblos as observers in the whole water planning process (Lewis et al., 2005). Rangelcroft et al. (2018) differentiated among water users in a rural context by involving, 175 among others, young married mothers, elderly women and unemployed, while Mukherjee et al. (2023) analyzed urban water security by contextualizing the opinions of the participants considering the ethnicity, religion, caste and gender (with a focus also on the perspective of hijra/trans people).

In addressing drought impacts, the failure to include marginalised groups, especially indigenous populations and low-income communities, can significantly hinder effective decision-making. Drought conditions often exacerbate existing inequalities, 180 making it even more crucial to incorporate diverse perspectives and local knowledge into resource management strategies (Rusca et al., 2024). Yet, we argue that available methods remain rooted in a "functionalist orientation and a distinct preference for quantification", limiting their ability to meaningfully integrate stakeholder input (Bachmair et al., 2016; Lemos and Morehouse, 2005; Venot et al., 2022, p. 92). As a result, these methods often lead to decisions that neglect local conditions and reinforce existing power imbalances. A systematic approach to engaging all stakeholders is essential for developing more equitable and effective responses to drought and ensuring that resource management is truly reflective of community needs 185 and experiences (Hargrove and Heyman, 2020). Ensuring inclusivity is closely tied to reducing knowledge biases and power imbalances (Sect. 3.5). By actively involving diverse stakeholders, particularly those from historically marginalised groups, the co-creation process can begin to challenge dominant narratives, integrate local knowledge and ensure that decision-making reflects a broader range of experiences, leading to more balanced and effective outcomes.

190 **3.2 Framing the drought co-creation process**

Framing the scope of the co-creation process involves establishing clear boundaries, both for the study itself and for the collaborative process (Daré et al., 2018). Additionally, it requires conducting a 'situation analysis' (Beek and Arriens, 2016), which includes co-analysing the current situation, co-identifying key problems to address, and co-defining the main goals of the study.

195 The boundaries of the study define the specific aspects of the research that will be investigated. This includes the a) thematic boundaries, which determine the sectors, types of impacts, and affected units or groups that the study will focus on; b) geographical boundaries, which define the spatial scale of the study, specifying the region, country, or ecosystem where the

research would take place; and c) temporal boundaries, which specify the period covered by the research, whether it focuses on past events, current conditions, or future projections.

To set up the thematic boundaries, it is essential to co-define the topics, themes, and areas of focus for the study. This involves identifying the specific sectors, types of impacts, and the units or groups that will be affected by the study:

- **Sectors:** These are broad categories or fields that the study will address, such as agriculture, health, education, environment, drinking water supply, and energy production.
- **Types of impacts:** This includes the nature of the impacts the study aims to investigate or address, such as economic, social, or environmental impacts, and the distribution thereof across space and socio-economic groups.
- **Impacted units or groups:** These are the specific entities or populations that will be affected by the study. They can be individuals, households, communities, organisations, or ecosystems.

Setting up the geographical boundaries requires the identification of the spatial scale in which drought impacts are investigated, which can vary from local to global. The boundaries are often drawn based on physical (e.g., hydrological units or ecological systems – Ballesteros-Olza et al., 2022; Mustafa et al., 2021), administrative (e.g., municipalities, countries, regions – Lillo-Ortega et al., 2019; Nielsen-Gammon et al., 2020), or socio-cultural and economic criteria (e.g., Ayantunde et al., 2015, Pham et al., 2020). Setting up the temporal boundaries refers to defining the specific period within which the drought impacts and mitigation strategy are studied. To illustrate, examining the impacts of a historical drought requires setting temporal boundaries to focus on a specific range of years or decades in the past. When studying the potential impacts of climate change on drought, temporal boundaries could be set to include projections for a future time horizon, such as the next 50 years (Sampson et al., 2020). Another relevant aspect of a transdisciplinary process for drought impact studies is to perform a ‘situation analysis’ (Beek and Arriens, 2016), which encompasses (i) the co-analysis of the current situation (e.g. if drought is a current issue or a future concern, if mitigation measures already in place are effective and, if not, why, etc.), (ii) a co-identification of the main problems and issues to be addressed, as well as (iii) the co-definition of the main goals of the study. As an example, some co-creation processes may aim at developing a shared vision of a water management plan (Gwapedza et al., 2024). Other studies might aim to predict future short-term impacts to suggest preventive strategies or quantify current and future drought impacts to define effective drought mitigation measures. Defining goals and outcomes together is essential to ensure transparency and prevent stakeholders' expectations from going unmet at the study's end.

In contrast, the boundaries of the co-creation process are concerned with how the research is conducted collaboratively. These boundaries define how the co-creation team, including both academic and non-academic stakeholders, will engage with the research, how they will contribute, and how their input will influence the research outcomes. This includes setting the rules of engagement, determining how power and influence are distributed among stakeholders, and establishing decision-making processes to guide the collaboration.

Co-creation processes envision the development in partnership of not only methods, data collection, and interpretation of results, but also research questions themselves. From a transdisciplinary perspective, a crucial aspect of this step is aligning the research questions with societal knowledge demands (Sarewitz and Pielke, 2007). Thus, framing the scope of the co-

creation process is crucial, as societal problems often lack clear boundaries, involve multiple stakeholders, and are deeply interconnected with other challenges, especially when dealing with complex and multifaceted phenomena, such as droughts. This step requires continual interaction and refinement, involving an iterative process of adding new stakeholders and adjusting the scope as the co-creation process evolves.

Although most of these framing elements might be considered somehow along participatory engagements, they are often absent in scientific articles, meaning they can often be overlooked or at least rarely explicitly reported or discussed. This contributes to lowering the standard of the co-creation process or eventually compromising the soundness of the process. For example, while most studies are explicit about their geographical boundaries (Aldunce et al., 2016; Giordano et al., 2013), they seldom select stakeholders iteratively and dynamically. The iterative nature of co-creation, where stakeholders and research questions evolve over time, can lead to significant expansion, requiring considerable time, effort, and commitment from researchers, stakeholders, and funding bodies. This process can introduce delays and uncertainties in decision-making, particularly when addressing complex issues like droughts, where the intersection of environmental, social, and economic factors demands continuous reassessment. To keep the process manageable and focused, it is crucial to establish clear boundaries that define the limits of time, resources, and engagement, ensuring that co-creation leads to meaningful and actionable outcomes (Thompson et al., 2017).

The framing of the boundaries of the study is particularly important in the context of drought impact studies because the driving mechanisms of drought and its impacts, as well as drought governance strategies, can vary across spatial and temporal scales and among sectors (i.e., health, agriculture, energy production, drinking water supply, etc.), with impacts often cascading across sectors and highlighting the interconnected nature of drought (Hagenlocher et al., 2023; Rossi et al., 2023).

The setting of the boundaries for the study itself and for the collaborative process are closely connected to two other dimensions of the co-creation process. To ensure that the research questions and scope align with societal knowledge demands, it is crucial to have a representative group of engaged stakeholders in the process (Sect. 3.1). Framing the problem and setting the research agenda to encompass diverse understandings and perspectives may require expanding the co-creation team to include additional disciplines or engaging with other stakeholders to find the right mix. From a practical perspective, this would lead to an iterative initial phase in which a first set of stakeholders is identified, the scope of the process is framed, and then potential additional stakeholders can be added, requiring further refinement of the scope. Moreover, the setting of the thematic, spatial, and temporal boundaries of the drought impact study would finally influence the development of the co-modelling of the drought impacts (Sect. 3.4). These boundaries help define modelling scenarios that reflect diverse perspectives and align with the study's objectives. By establishing well-defined boundaries from the start, the co-creation process can proceed smoothly and ensure the creation of contextually appropriate models.

3.3 Building a shared knowledge of drought

Successfully co-creating knowledge requires building a shared understanding of drought and its impacts (Grainger et al., 2021). This involves recognising that drought is conceptualised differently across disciplines, as well as between academics,

265 practitioners, and local communities. It is well recognised that there is no single, universally accepted definition of drought (Krueger and Alba, 2022). While hydrological sciences are often rooted in positivist paradigms, there is growing recognition that drought is a complex phenomenon arising from the interplay between biophysical and socio-economic factors (AghaKouchak et al., 2021; Wilhite and Glantz, 1985). Mpandeli et al. (1985) provide early attempts to include a non-academic perspective into drought impact studies, yet building on a top-down quantification of drought from hydroclimatic thresholds.

270 In contrast, the interpretative and critical social sciences focus on the social construction of water insecurity and scarcity, examining the power relations and political economies that shape the uneven outcomes of droughts and the diverse experiences of their impacts (see, e.g., Mehta, 2001; Kaika, 2003; Alharahsheh and Pius, 2020; Rusca et al., 2023). These different conceptualisations are underpinned by distinct knowledge paradigms, which may hinder the development of inclusive and productive collaborations (Wesselink et al., 2017). Additionally, stakeholders who directly experience the impacts of drought

275 and who are involved in the co-creation process are likely to have alternative ways of knowing and defining drought, based on their “mental models” (Gray et al., 2012). For example, for urban dwellers in informal settlements, drought may be experienced and conceptualised as water shortages, water insecurity, waterborne diseases, or even as a source of physical and psychological stress, especially for women responsible for domestic water collection, rather than as a large-scale geophysical event (Rusca et al., 2023).

280 While the diversity of definitions and plural knowledges can complicate the process of co-creating a shared understanding of drought and its impacts (Landström et al., 2023), it also has the potential to generate a richer and more inclusive evaluation. Thus, developing a shared understanding of drought should involve embracing and engaging with these different ways of knowing, rather than privileging one over another or creating a hierarchy between them. Moreover, as noted by Beck and Krueger (2016), depoliticised analyses of hydrological phenomena risk reproducing “authoritative representations of dominant

285 perceptions of the world.” Here, interdisciplinary impact evaluations that work through epistemological and ontological differences have the potential to generate more nuanced and power-sensitive understandings of drought, exploring how power relations shape changes in hydrological flows and the distribution of hydrological risk (Rusca and Di Baldassarre, 2019), including drought risk. In this perspective, drought impact studies can serve as boundary objects between different ways of knowing socio-climatic phenomena (Garb et al., 2008).

290 The process of developing a shared understanding of drought is closely intertwined with the co-modelling process (Sect. 3.4). On the one hand, co-modelling can serve as a tool to “redistribute expertise” (Landström et al., 2011), incorporating multiple perspectives and frameworks to create a more comprehensive and inclusive understanding of droughts. On the other hand, a shared knowledge of drought provides a crucial starting point for engaging in the co-modelling process. Thus, we view this as an iterative cycle in which building a shared understanding of drought (this Sect.) initiates the co-modelling process (Sect.

295 3.4), which, in turn, refines and deepens the shared understanding. This iterative process also ensures that knowledge generation is dynamic and responsive to evolving perspectives.

Finally, the meaningful development of a shared definition of drought also requires addressing knowledge biases and power imbalances (Sect. 3.5). This involves confronting epistemic injustice by acknowledging that certain forms of knowledge on

water, particularly those rooted in physical sciences, are often prioritised over other valuable knowledge systems, such as those held by local communities (Zwarteveen et al, 2017; Rusca et al., 2024). By recognising and addressing these imbalances, we aim to ensure that all forms of knowledge and actors are treated equitably in the co-creation of drought-related knowledge.

3.4 Co-selecting and co-developing models of drought impacts

Co-creating knowledge in drought impact studies, and even more so in projected adaptation scenarios, very often relies on some levels of modelling (Baumgärtner et al., 2008). From a transdisciplinary perspective, co-modelling integrates non-scientist actors throughout the modelling process, irrespective of its purpose, whether forecasting, prescribing, explaining, describing, learning, or communicating (Srinivasan et al., 2016). With the term “model”, we refer to any simplified representation of a real-life situation, thus including the whole range of qualitative conceptual models to predictive hydrological computational models. In transdisciplinary settings, the concept of "constructing models" can take on diverse interpretations. It can result in the co-creation of a conceptual model able to capture all the variables and processes relevant for describing the chain of problems and the study goals, or even include computations, algorithms, and dedicated modelling tools and platforms (Smetschka and Gaube, 2020). Whenever the co-modelling involves computations, algorithms, and dedicated modelling tools and platforms, stakeholders might be involved in the co-selection of the most appropriate tool, by considering not only the type of expected outcome but also the skills and background of the people involved in the modelling process, as well as other contextual factors related to the availability of economic resources and other implementation constraints. Even when consolidated models or software are preferred over fully co-created ones, which is the most common case (Addor and Melsen, 2019), setting up and configuration tasks of the modelling process could include the participation of stakeholders to avoid modellers’ pre assumption and black box implementations (Melsen et al., 2018). Through co-modelling, given a suitable interactive environment, non-specialized people can collaboratively produce models that are meaningful to them, fostering valuable discussions and the creation of new knowledge (Biggs et al., 2021).

Drought impact co-modelling might also require a shared definition of modelling scenarios. Essentially, scenarios represent a collection of narratives or stories, which collectively depict various coherent future scenarios for a specific system (Biggs et al., 2021). A fundamental aspect of scenario development involves the co-creation of hypothetical future situations (Iwaniec et al., 2020; Raudsepp-Hearne et al., 2020), as well as conditions of the present or the past, that can be used for the co-modelling. These scenarios can encompass a range of variables, such as climate patterns, land use changes, socio-economic factors, or policy decisions.

In water scarcity and drought-related research, stakeholders ideally engage in participatory co-modelling by directly constructing models and tools, formulating scenarios and policy options, and assessing the effectiveness of identified solutions against jointly defined performance indicators or targets, often focusing on selecting alternative strategies or refining the application of technical solutions (Basco-Carrera et al., 2017). For example, Masi et al. (2024) applied an extended and highly participatory multi-criteria decision-making analysis to optimize the siting of artificial reservoirs in Central Italy, while Piemontese et al. (2023) identified best sites for sand dams in remote Angolan drylands, including indigenous knowledge.

Wens et al. (2020) integrated an agent-based model with a process-based crop model to simulate alternative adaptation strategies, drawing from information collected through participatory methodologies. While these illustrative studies have the merit of including stakeholders' opinions, the conceptualization, modelling approaches, and sometimes even the proposed solutions are established by the researchers, often hydrologists (Fischer et al., 2021). An interesting alternative was demonstrated by Baker et al. (2015), who applied a process-based hydrological model while involving stakeholders in the input generation phase. This approach emphasised the different needs and values of women and men in an Ethiopian catchment. Bayesian networks (e.g., Carmona et al., 2013; Kneier et al., 2023; Singto et al., 2020) and conceptual system dynamics models (e.g., Hossain et al., 2020) are often more suited to perform a transdisciplinary drought impact study because they facilitate the integration of knowledge from multiple disciplines and enable collaboration across sectors by modelling interdependencies. Moreover, Bayesian networks and system dynamics models account for uncertainty, feedback loops, and complex system interactions, making them suitable for implementing adaptive, context-sensitive adaptation strategies and responding to the multifaceted challenges of droughts.

3.5 Accounting for knowledge biases and power imbalances

This dimension focuses on the role of power and differential agency in shaping the co-creation of knowledge. We identify two key areas of influence. Knowledge biases refer to power dynamics within the knowledge production process itself. Mainstream interpretations of science often frame the development of knowledge as neutral, objective, and unbiased, especially in fields that prioritize quantitative methods. However, scholarship in STS and political ecology challenges this view, arguing that knowledge is shaped by power relations that determine which forms of knowledge and expertise are recognized as more scientifically valid and actionable (Budds, 2009; Goldman et al., 2019; King and Tadaki, 2018; Mukherjee, 2022; Turner, 2011; Zwarteveen et al., 2017; Rusca et al., 2024). Power imbalances refer to the unequal influence exerted by different stakeholders. Research in political ecology and critical disaster studies has shown how these power imbalances can generate and perpetuate uneven outcomes, including disparities in water allocations and adaptation to natural hazards across regions, intra-urban spaces, rural–urban populations, identities (e.g., gender, race), and income groups (see, e.g., Boelens et al., 2016; Collard et al., 2018; Sultana, 2020; Swyngedouw, 2004, 2009).

Overlooking knowledge biases and power imbalances risks marginalising certain actors and forms of knowledge while prioritising dominant, hegemonic ones in processes of knowledge co-creation (Krueger et al., 2016; Macpherson et al., 2024; Reed, 2008; Rusca et al., 2024; Thaler and Levin-Keitel, 2016). This is likely to undermine meaningful co-creation by silencing alternative perspectives and reinforcing existing inequalities, as shown by Cid et al. (2024) in their drought-related serious game, revealing power imbalances and knowledge disparities. Ensuring meaningful co-creation, therefore, requires reflecting on knowledge production itself, recognizing biases in what is deemed legitimate knowledge, and acknowledging that co-creation *per se* does not inherently eliminate existing power dynamics. First, determining what counts as 'scientific' knowledge is particularly relevant in the context of co-creation for drought studies. While co-creation approaches have been argued to foster more inclusive and equitable knowledge, and thereby more just water management (Basco-Carrera et al., 2017; Falconi

365 and Palmer, 2017), the power-laden nature of scientific knowledge can still lead to the dominance of scientific expertise in the
co-creation process. Giordano et al. (2013) highlight how mistrust and a lack of cooperation challenge knowledge integration
among stakeholders with different perceptions of droughts. Second, power imbalances among stakeholders can further
undermine inclusive and equitable knowledge production processes. Dominant actors such as government agencies,
international organisations, large NGOs, or scientific communities typically possess more time and resources to lead
370 participatory processes and set the parameters for participation. Their knowledge claims are typically regarded as more credible
or valuable (Turnhout et al., 2020). Co-creation of water knowledge is also shaped by pre-existing relationships and histories
of conflict (Budds, 2009), which are likely to influence the process. Embarking on a co-creation process requires engaging
with different actors bringing their worldviews and goals. For instance, a drought can be framed differently, depending on the
actors' histories, interests, and experiences (Kaika, 2003). Powerful actors, like multinational, or political leaders, may exploit
375 participatory context to legitimise hegemonic drought narratives that support specific outcomes or adaptation strategies,
exacerbating the pre-existing power inequalities and benefitting those who are already more powerful (Alexandra and
Rickards, 2021; Kallis, 2010, 2008; Mehta, 2001; Savelli, 2023). However, involving powerful stakeholders could be necessary
to drive a change towards sustainable adaptation strategies. To that end, powerful stakeholders need to be made aware of the
importance of engaging in the co-creation of solutions to drought. In fact, although benefiting from certain power dynamics in
380 the short term, they could face long-term consequences as these dynamics evolve. For example, Gwapedza et al. (2024) show
that, if large farmers are made aware of potential long-term drought impacts, they may remain interested in being engaged in
the co-creation process and cooperating towards a shared drought adaptation plan.

This dimension acts as an ethical compass that fosters a power-sensitive and reflexive approach to the co-creation process. It
is inherently relevant to all other dimensions of knowledge co-creation, as it seeks to dismantle the epistemic hegemony of
385 scientific knowledge in drought studies while incorporating diverse perspectives and ways of knowing throughout the co-
creation process. First, recognizing power dynamics and epistemic biases is essential for establishing collaborative spaces
(Sect. 3.1), which can only be truly inclusive if power imbalances are made explicit and addressed. Similarly, defining the
scope of co-creation (Sect. 3.2) and building shared knowledge of drought (Sect. 3.3) often reflects the interests of powerful
actors. A reflexive and power-sensitive approach seeks to pluralise narratives by creating space for alternative framings,
390 especially those of marginalised groups. Last, a reflexive and power-sensitive approach is crucial for ensuring that co-
modelling practices remain inclusive and equitable. As highlighted by ter Horst et al. (2024), this involves integrating
reflexivity into every stage of the modelling process, from co-selecting and co-developing models to iteratively reviewing
definitions, scenarios, and outcomes (Sect. 3.4).

4 Limitations of knowledge co-creation approaches

395 Knowledge co-creation involves a series of inherent challenges and limitations that can significantly affect its application.

Including all relevant stakeholders or their representatives from a given “impacted group” — whether individuals, households, communities, organisations, or ecosystems (Sect. 3.2) — in the co-creation process is crucial. However, in cases where impacts are widespread over large areas, the implementation of a fully representative co-creation process may be challenging due to the large number of people involved. This represents one of the limitations of applying transdisciplinary approaches.

Furthermore, even when the number of participants is manageable, the process may still face obstacles due to a lack of economic resources, time constraints, or limited knowledge of the study area. Although highly motivated stakeholders are a prerequisite to a successful co-creation approach, some stakeholder categories might not consider drought as an urgent problem or simply might not have enough time or interest in collaborating on the process. In some cases, the local political motivation and capabilities are key to ensuring a successful co-creation process. Vedeld (2022) explains the so-called “co-creation paradox”, for which local political institutions that would benefit the most from co-creating solutions with local stakeholders lack the political capacity and leadership to do so. Another key aspect of knowledge co-creation is acknowledging and involving holders of the different types of knowledge to ensure tackling the locally relevant problems and approaches (Brugnach and Ingram, 2012). Transdisciplinary studies require that goals and methodologies be collaboratively developed with stakeholders to ensure relevance, buy-in, and effectiveness. However, stakeholders are often only actively engaged after the research has received funding. By that point, the researchers have usually already defined key aspects, such as study goals and methodologies, which limits the scope for stakeholder input and collaboration. Donors' expectations might also limit the possibility of fully involving stakeholders in decision-making. Finally, the promoters of the co-creation approach - typically academics, institutions, and NGOs - have a specific background, which inevitably influences the whole process, either by prioritising some impacts, disciplines, or sectors as well as in the model selection, among other aspects (Melsen, 2022).

Co-creating knowledge has great potential to improve drought impact studies and to promote proactive and effective drought management, but cannot be considered a panacea. Some of the most relevant shortcomings related to co-creation are also related to the fact that it is considered an approach that is suitable for any context (Lemos et al., 2018). In particular, it is evident how the involvement of stakeholders in all kinds of research projects has become an indicator and a must-do by many funding agencies, regardless of its suitability for a project (Cleaver, 1999; Spaapen and van Drooge, 2011). This, in turn, may lead to co-creation approaches that, due to time and resource limitations, tend to focus only on the same groups of stakeholders, prioritising familiarity over diversity, due to the high amount of time needed for building trust and engaged participants in the research approach (Porter and Dessai, 2017). This, in turn, can generate knowledge biases and exacerbate power imbalances (Sect. 3.5).

5 Advancing transdisciplinary drought research

Our five key dimensions offer a comprehensive framework to address the limitations in breadth and depth of current transdisciplinary approaches to drought impacts research. They promote the inclusion of a wider range of actors and perspectives across all phases and aspects of the research process, rather than restricting participation to isolated moments (breadth), and support the meaningful, iterative integration of non-academic knowledge within each phase (depth). While these

430 five key dimensions are a valuable reference to everyone involved in studying drought impacts, they are specifically discussed to support hydrologists to effectively utilise transdisciplinary methods in the socio-hydrology of drought in a thorough and informed manner. Table 1 outlines actions for each dimension's depth across the breadth of the five key dimensions discussed in Sects. 3.1 to 3.5, ensuring the meaningful integration of non-academic knowledge and its influence on every phase of the research process.

435 From our perspective, two key aspects are crucial to overcoming current gaps in the development of transdisciplinary approaches to drought impact studies. The first is the need to implement iterative processes that incorporate feedback throughout the different phases of the research. For example, most studies seldom continuously adapt and evaluate the stakeholder engagement process, rarely reassess stakeholder involvement, or improve or refine the shared understanding of drought impacts along the processes. These feedback mechanisms, identified in each dimension and highlighted in italics in Table 1, are essential for ensuring greater depth and increasing coherence of the study. Reassessing periodically the stakeholder engagement (Sect. 3.1) assures that all relevant actors, including marginalised groups, are involved in co-defining and assessing the drought impacts. This inclusive approach ensures that the socio-political factors, such as governance structures, power imbalances, and access to resources, are accounted for in the assessment impact evaluation process. Ideally, stakeholder conceptualizations of drought would inform co-modelling efforts (Sect. 3.4), while the modelling outcomes would, in turn, refine and challenge the collective understanding of drought (Sect. 3.3), reinforcing the cyclical nature of the process.

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Table 1. Matrix for drought impacts knowledge co-creation, structured along two axes: breadth (key process dimensions) and depth (practical actions to ensure meaningful inclusion of non-academic knowledge in each dimension).

	← BREADTH →				
	Set up a collaborative space for drought knowledge co-creation (Sect. 3.1)	Framing the drought co-creation process (Sect. 3.2)	Building a shared knowledge of drought (Sect. 3.3)	Co-selecting and co-developing models of drought impacts (Sect. 3.4)	Accounting for knowledge biases and power imbalances (Sect. 3.5)
D E P T H ↓	- Implement a stakeholder analysis to identify and map all relevant stakeholders, including those traditionally marginalised or underrepresented. - Develop transparent criteria for stakeholder inclusion, balancing comprehensiveness with practical feasibility. - <i>Continuously adapt and evaluate the engagement process, regularly reassessing stakeholder involvement to include emerging perspectives and ensure inclusivity and relevance throughout.</i>	- Engage stakeholders early and iteratively to shape the study's scope and boundaries. - Co-define research questions and themes to ensure alignment with societal knowledge demands. - Identify relevant sectors, impacts, and affected units to guarantee a comprehensive coverage. - <i>Continuously refine the thematic, geographical, and temporal boundaries as the co-creation process progresses, incorporating new insights from stakeholders, ensuring alignment with the study's intended outcomes.</i>	- Acknowledge multiple knowledge systems (e.g., academic, local, and practitioner knowledge) and work to integrate them into the study, rather than privileging one over another. - Foster interdisciplinary collaboration to integrate geophysical, socio-economic, and political conceptualizations of drought and its impacts. - <i>Iterate and refine the shared understanding through a cyclical process where stakeholder insights inform co-modelling, and modelling outcomes, in turn, deepen and challenge that understanding.</i>	- Define modelling goals and select suitable approaches and tools collaboratively, considering stakeholders' needs, capacities, and available resources. - Co-develop models, integrating diverse knowledge systems to represent relevant variables, processes, and feedback. - Co-define and explore drought impact scenarios, using stakeholder-driven inputs to ensure the selection of plausible futures. - <i>Iteratively refine the modelling process by discussing and evaluating potential winners and losers of the anticipated impacts and drought mitigation strategies, making adjustments to the approach or specific aspects, until a consensus is reached.</i>	- Recognize power dynamics in knowledge production, and ensure that diverse knowledge systems (local, indigenous, experiential) are valued alongside dominant ones. - Create spaces in the co-creation process to openly discuss power dynamics and biases, reflecting on how social and economic factors shape relationships between actors. - Acknowledge the unequal influence of dominant stakeholders and actively amplify marginalized voices to prevent their exclusion. - <i>Continuously reflect on and make explicit the power dynamics to prevent the marginalization of alternative perspectives and ensure equitable influence in defining study boundaries, framing drought, integrating dynamics into modelling, and interpreting outcomes.</i>

The second essential aspect is the need to acknowledge and address knowledge biases and power imbalances by continuously reflecting on and making explicit the underlying power dynamics. This is crucial to preventing the marginalization of alternative perspectives and ensuring equitable influence in defining study boundaries, framing drought, integrating dynamics into modelling, and interpreting outcomes. To address this, our framework recommends accounting for knowledge biases and power imbalances (Sect. 3.5), which critically examines how power relations influence both the co-creation process and the interpretation of outcomes. This dimension encourages transparency about the political and social influences on knowledge production, ensuring that more powerful stakeholders, such as governments or large institutions, do not dominate the process. Finally, by fostering an inclusive, iterative process through framing the scope of the co-creation process (Sect. 3.2) and setting up iteratively a collaborative space (Sect. 3.1), the framework ensures that all voices, particularly those from marginalized communities, are heard and that knowledge production is not skewed by unequal power relations.

Data availability. No data sets were used in this article.

Appendix A: Literature mapping

Table A1. Relationship between the literature in the five analysed bodies of literature and the key dimensions (breadth) they inform. Some studies appear in more than one body of literature due to their interdisciplinary nature.

Dimensions/ bodies of literature	Transdisciplinary Sustainability science	Socio-hydrology	Critical Water Studies (Hydrosocial Studies, and Critical Disaster Studies)	Science and Technology Studies (STS)	Integrated Water Resources Management (IWRM)
Setting up a collaborative space for drought knowledge co- creation (Sect. 3.1)	- Clarke and Clegg, 1998 - Clarkson, 1995 - Reed et al., 2009 - Aldunce et al., 2016 - Lillo-Ortega et al., 2019		- Rusca et al., 2024 - Mukherjee et al., 2023 - Mpofu-Mketwa et al., 2023	- Stirling, 2008	- Hargrove and Heyman, 2020 - Rangelcroft et al., 2018 - Paneque et al., 2018 - Lewis et al., 2005 - Hervás-Gámez and Delgado-Ramos, 2019 - Kim et al., 2019

Framing the drought co-creation process (Sect. 3.2)	- Lillo-Ortega et al. 2019 - Mustafa et al., 2021 - Pham et al. 2020 - Sampson et al. 2020	- Mustafa et al., 2021 - Pham et al. 2020 - Gwapedza et al. 2024 - Giordano et al. 2013 - Aldunce et al. 2016 - Hagenlocher et al., 2023 - Rossi et al., 2023	- Ayantunde et al. 2015 - Thompson et al., 2017	- Sarewitz and Pielke, 2007	- Ballesteros-Olza et al., 2022 - Beek and Arriens, 2016 - Daré et al., 2018 - Nielsen-Gammon et al. 2020
Building a shared knowledge of drought (Sect. 3.3)	- Grainger et al., 2021 - Gray et al., 2012	- Rusca and Di Baldassarre, 2019 - Wesselink et al., 2017 - AghaKouchak et al. 2021	- Beck and Krueger 2016 - Kaika, 2003 - Mehta, 2001 - Rusca and Di Baldassarre, 2019 - Rusca et al., 2023 - Rusca et al., 2024 - Zwarteveen et al., 2017 - Wesselink et al., 2017	- Alharahsheh and Pius 2020 - Beck and Krueger 2016 - Garb et al., 2008 - Krueger and Alba, 2022 - Landström et al., 2011 - Landström et al., 2023	- Mpandeli et al. 1985 - Wihite and Glantz 1985
Co-selecting and co-developing models to understand drought impacts (Sect. 3.4)	- Baumgärtner et al., 2008 - Biggs et al., 2021 - Iwaniec et al., 2020 - Raudsepp-Hearne et al., 2020 - Smetschka and Gaube, 2020 - Hossain et al., 2020	- Melsen et al., 2018 - Srinivasan et al., 2016 - Masi et al., 2024 - Piemontese et al., 2023 - Wens et al., 2020 - Fischer et al., 2021 - Baker et al., 2015 - Addor and Melsen 2018		- Melsen et al., 2018	- Basco-Carrera et al., 2017 - Carmona et al., 2013 - Kneier et al., 2023 - Singto et al., 2020
Accounting for knowledge biases and power imbalances (Sect. 3.5)		- Gwapedza et al. 2024 - Cid et al. 2024 - Giordano et al. 2013	- Alexandra and Rickards, 2021 - Boelens et al., 2016 - Budds, 2009 - Collard et al., 2018 - Kallis, 2010 - Kallis, 2008 - Kaika, 2003 - King and Tadaki, 2018 - Krueger et al., 2016 - Macpherson et al.,	- Goldman et al., 2019 - Turner, 2011 - ter Horst et al., 2024	- Basco-Carrera et al., 2017 - Falconi and Palmer, 2017

			2024 - Mehta, 2001 - Mukherjee, 2022 - Reed, 2008 - Rusca et al., 2024 - Savelli, 2023 - Sultana, 2020 - Swyngedouw, 2004 - Swyngedouw, 2009 - Thaler and Levin-Keitel, 2016 - Turnhout et al., 2020 - Zwartveen et al., 2017		
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505 **References**

Addor, N. and Melsen, L. A.: Legacy, Rather Than Adequacy, Drives the Selection of Hydrological Models, Water Resour. Res., 55, 378–390, <https://doi.org/10.1029/2018WR022958>, 2019.

- AghaKouchak, A., Mirchi, A., Madani, K., Di Baldassarre, G., Nazemi, A., Alborzi, A., Anjileli, H., Azarderakhsh, M., Chiang, F., Hassanzadeh, E., Huning, L. S., Mallakpour, I., Martinez, A., Mazdiyasn, O., Moftakhari, H., Norouzi, H., Sadegh, M., Sadeqi, D., Van Loon, A. F., and Wanders, N.: Anthropogenic Drought: Definition, Challenges, and Opportunities, *Rev. Geophys.*, 59, e2019RG000683, <https://doi.org/10.1029/2019RG000683>, 2021.
- Alexandra, J. and Rickards, L.: The Contested Politics of Drought, Water Security and Climate Adaptation in Australia's Murray-Darling Basin, *Water Altern.*, 14, 773–794, 2021.
- Aldunce, P., Bórquez, R., Adler, C., Blanco, G., and Garreaud, R.: Unpacking Resilience for Adaptation: Incorporating Practitioners' Experiences through a Transdisciplinary Approach to the Case of Drought in Chile, *Sustainability*, 8, 905, <https://doi.org/10.3390/su8090905>, 2016.
- Alharahsheh, H. H. and Pius, A.: A Review of key paradigms: positivism VS interpretivism, *Glob. Acad. J. Humanit. Soc. Sci.*, 2, 39–43, <https://doi.org/10.36348/gajhss.2020.v02i03.001>, 2020.
- Angelstam, P., Andersson, K., Annerstedt, M., Axelsson, R., Elbakidze, M., Garrido, P., Grahn, P., Jönsson, K. I., Pedersen, S., Schlyter, P., Skärbäck, E., Smith, M., and Stjernquist, I.: Solving Problems in Social–Ecological Systems: Definition, Practice and Barriers of Transdisciplinary Research, *AMBIO*, 42, 254–265, <https://doi.org/10.1007/s13280-012-0372-4>, 2013.
- Arheimer, B., Cudennec, C., Castellarin, A., Grimaldi, S., Heal, K. V., Lupton, C., Sarkar, A., Tian, F., Kileshye Onema, J.-M., Archfield, S., Blöschl, G., Chaffe, P. L. B., Croke, B. F. W., Dembélé, M., Leong, C., Mijic, A., Mosquera, G. M., Nlend, B., Olusola, A. O., Polo, M. J., Sandells, M., Sheffield, J., van Hateren, T. C., Shafiei, M., Adla, S., Agarwal, A., Aguilar, C., Andersson, J. C. M., Andraos, C., Andreu, A., Avanzi, F., Bart, R. R., Bartosova, A., Batelaan, O., Bennett, J. C., Bertola, M., Bezak, N., Boeke, J., Bogaard, T., Booij, M. J., Brigode, P., Buytaert, W., Bziava, K., Castelli, G., Castro, C. V., Ceperley, N. C., Chidepudi, S. K. R., Chiew, F. H. S., Chun, K. P., Dagnew, A. G., Dekongmen, B. W., del Jesus, M., Dezetter, A., do Nascimento Batista, J. A., Doble, R. C., Dogulu, N., Eekhout, J. P. C., Elçi, A., Elenius, M., Finger, D. C., Fiori, A., Fischer, S., Förster, K., Ganora, D., Gargouri Ellouze, E., Ghoreishi, M., Harvey, N., Hrachowitz, M., Jampani, M., Jaramillo, F., Jongen, H. J., Kareem, K. Y., Khan, U. T., Khatami, S., Kingston, D. G., Koren, G., Krause, S., Kreibich, H., Lerat, J., Liu, J., Madruga de Brito, M., Mahé, G., Makurira, H., Mazzoglio, P., Merheb, M., Mishra, A., Mohammad, H., Montanari, A., Mujere, N., Nabavi, E., Nkwasa, A., Orduna Alegria, M. E., Orieschnig, C., Ovcharuk, V., Palmate, S. S., Pande, S., Pandey, S., Papacharalampous, G., Pechlivanidis, I., et al.: The IAHS Science for Solutions decade, with Hydrology Engaging Local People IN a Global world (HELPING), *Hydrol. Sci. J.*, null-null, <https://doi.org/10.1080/02626667.2024.2355202>, 2024.
- Ayantunde, A. A., Turner, M. D., and Kalilou, A.: Participatory analysis of vulnerability to drought in three agro-pastoral communities in the West African Sahel, *Pastoralism*, 5, 13, <https://doi.org/10.1186/s13570-015-0033-x>, 2015.
- Bachmair, S., Stahl, K., Collins, K., Hannaford, J., Acreman, M., Svoboda, M., Knutson, C., Smith, K. H., Wall, N., Fuchs, B., Crossman, N. D., and Overton, I. C.: Drought indicators revisited: The need for a wider consideration of environment and society, *WIREs Water*, 3, 516–536, <https://doi.org/10.1002/wat2.1154>, 2016.

- 540 Baker, T. J., Cullen, B., Debevec, L., and Abebe, Y.: A socio-hydrological approach for incorporating gender into biophysical models and implications for water resources research, *Appl. Geogr.*, 62, 325–338, <https://doi.org/10.1016/j.apgeog.2015.05.008>, 2015.
- Ballesteros-Olza, M., Blanco-Gutiérrez, I., Esteve, P., Gómez-Ramos, A., and Bolinches, A.: Using reclaimed water to cope with water scarcity: an alternative for agricultural irrigation in Spain, *Environ. Res. Lett.*, 17, 125002, <https://doi.org/10.1088/1748-9326/aca3bb>, 2022.
- 545 Basco-Carrera, L., Warren, A., van Beek, E., Jonoski, A., and Giardino, A.: Collaborative modelling or participatory modelling? A framework for water resources management, *Environ. Model. Softw.*, 91, 95–110, <https://doi.org/10.1016/j.envsoft.2017.01.014>, 2017.
- Baumgärtner, S., Becker, C., Frank, K., Müller, B., Quaas, M.: Relating the philosophy and practice of ecological economics: The role of concepts, models, and case studies in inter- and transdisciplinary sustainability research, *Ecological Economics*, 384-393, <https://doi.org/10.1016/j.ecolecon.2008.07.018>, 2008
- 550 Beck, M. and Krueger, T.: The epistemic, ethical, and political dimensions of uncertainty in integrated assessment modeling, *WIREs Clim. Change*, 7, 627–645, <https://doi.org/10.1002/wcc.415>, 2016.
- Beek, E. van and Arriens, W. L.: *Water Security: Putting the Concept into Practice*, Global Water Partnership (GWP), 2016.
- 555 Bennich, T., Maneas, G., Maniatakou, S., Piemontese, L., Schaffer, C., Schellens, M., and Österlin, C.: Transdisciplinary research for sustainability: scoping for project potential, *Int. Soc. Sci. J.*, 72, 1087–1104, <https://doi.org/10.1111/issj.12245>, 2022.
- Biggs, R., De Vos, A., Preiser, R., Clements, H., Maciejewski, K., and Schlüter, M.: *The Routledge handbook of research methods for social-ecological systems*, Taylor & Francis, 2021.
- 560 Boelens, R., Hoogesteger, J., Swyngedouw, E., Vos, J., and Wester, P.: Hydrosocial territories: a political ecology perspective, *Water Int.*, 41, 1–14, <https://doi.org/10.1080/02508060.2016.1134898>, 2016.
- Brandt, P., Ernst, A., Gralla, F., Luederitz, C., Lang, D. J., Newig, J., Reinert, F., Abson, D. J., and von Wehrden, H.: A review of transdisciplinary research in sustainability science, *Ecol. Econ.*, 92, 1–15, <https://doi.org/10.1016/j.ecolecon.2013.04.008>, 2013.
- 565 Brugnach, M. and Ingram, H.: Ambiguity: the challenge of knowing and deciding together, *Environ. Sci. Policy*, 15, 60–71, <https://doi.org/10.1016/j.envsci.2011.10.005>, 2012.
- Brugnach, M. and Özerol, G.: Knowledge Co-Production and Transdisciplinarity: Opening Pandora’s Box, *Water*, 11, 1997, <https://doi.org/10.3390/w11101997>, 2019.
- Budds, J.: Contested H2O: Science, policy and politics in water resources management in Chile, Themed Issue Gramscian *Polit. Ecol.*, 40, 418–430, <https://doi.org/10.1016/j.geoforum.2008.12.008>, 2009.
- 570 Burton, I., Kates, R., and White, G.: *Environment as Hazard*, Oxford University Press, 1993.

- Carmona, G., Varela-Ortega, C., & Bromley, J. (2013). Participatory modelling to support decision making in water management under uncertainty: Two comparative case studies in the Guadiana river basin, Spain. *Journal of environmental management*, 128, 400–412.
- 575 Cid, D. A. C., Souza Filho, F. de A. de, Alves, R. da S., Pontes Filho, J. D. de A., Silva, D. C. da, and Martins, E. S. P. R.: Drought in play: A grounded socio-hydrological tool to increase social participation in drought plans, *J. Hydrol.*, 638, 131445, <https://doi.org/10.1016/j.jhydrol.2024.131445>, 2024.
- Clarke, T. and Clegg, S.: *Changing paradigms: The transformation of management knowledge for the 21st century*, Harper Collins, London, 1998.
- 580 Clarkson, M. B. E.: A Stakeholder Framework for Analyzing and Evaluating Corporate Social Performance, *Acad. Manage. Rev.*, 20, 92–117, <https://doi.org/10.2307/258888>, 1995.
- Cleaver, F.: Paradoxes of participation: questioning participatory approaches to development, *J. Int. Dev.*, 11, 597–612, [https://doi.org/10.1002/\(SICI\)1099-1328\(199906\)11:4<597::AID-JID610>3.0.CO;2-Q](https://doi.org/10.1002/(SICI)1099-1328(199906)11:4<597::AID-JID610>3.0.CO;2-Q), 1999.
- 585 Coletta, V. R., Pagano, A., Zimmermann, N., Davies, M., Butler, A., Fratino, U., Giordano, R., and Pluchinotta, I.: Socio-hydrological modelling using participatory System Dynamics modelling for enhancing urban flood resilience through Blue-Green Infrastructure, *J. Hydrol.*, 636, 131248, <https://doi.org/10.1016/j.jhydrol.2024.131248>, 2024.
- Collard, R.-C., Harris, L. M., Heynen, N., and Mehta, L.: The antinomies of nature and space, *Environ. Plan. E Nat. Space*, 1, 3–24, <https://doi.org/10.1177/2514848618777162>, 2018.
- 590 Daré, W., Venot, J.-P., Le Page, C., and Aduna, A.: Problemshed or Watershed? Participatory Modeling towards IWRM in North Ghana, *Water*, 10, 721, <https://doi.org/10.3390/w10060721>, 2018.
- Di Baldassarre, G., Viglione, A., Carr, G., Kuil, L., Salinas, J. L., and Blöschl, G.: Socio-hydrology: conceptualising human-flood interactions, *Hydrol. Earth Syst. Sci.*, 17, 3295–3303, <https://doi.org/10.5194/hess-17-3295-2013>, 2013.
- 595 Di Baldassarre, G., Viglione, A., Carr, G., Kuil, L., Yan, K., Brandimarte, L., and Blöschl, G.: Debates—Perspectives on socio-hydrology: Capturing feedbacks between physical and social processes, *Water Resour. Res.*, 51, 4770–4781, <https://doi.org/10.1002/2014WR016416>, 2015.
- Di Baldassarre, G.: Socio-Hydrology of Floods, in: *Oxford Research Encyclopedia of Natural Hazard Science*, <https://doi.org/10.1093/acrefore/9780199389407.013.264>, 2017.
- 600 Enenkel, M., Brown, M. E., Vogt, J. V., McCarty, J. L., Reid Bell, A., Guha-Sapir, D., Dorigo, W., Vasilaky, K., Svoboda, M., Bonifacio, R., Anderson, M., Funk, C., Osgood, D., Hain, C., and Vinck, P.: Why predict climate hazards if we need to understand impacts? Putting humans back into the drought equation, *Clim. Change*, 162, 1161–1176, <https://doi.org/10.1007/s10584-020-02878-0>, 2020.
- Eriksen, S. and Lind, J.: Adaptation as a Political Process: Adjusting to Drought and Conflict in Kenya’s Drylands, *Environ. Manage.*, 43, 817–835, <https://doi.org/10.1007/s00267-008-9189-0>, 2009.

605 Falconi, S. M. and Palmer, R. N.: An interdisciplinary framework for participatory modeling design and evaluation—What makes models effective participatory decision tools?, *Water Resour. Res.*, 53, 1625–1645, <https://doi.org/10.1002/2016WR019373>, 2017.

Fischer, A., Miller, J. A., Nottingham, E., Wiederstein, T., Krueger, L. J., Perez-Quesada, G., ... & Sanderson, M. R. (2021). A systematic review of spatial-temporal scale issues in sociohydrology. *Frontiers in Water*, 3, 730169.

610 Ribeiro Neto, G., Kchouk, S., Melsen, L. A., Cavalcante, L., Walker, D. W., Dewulf, A., Costa, A. C., Martins, E. S. P. R., and van Oel, P. R.: HESS Opinions: Drought impacts as failed prospects, *Hydrol. Earth Syst. Sci.*, 27, 4217–4225, <https://doi.org/10.5194/hess-27-4217-2023>, 2023.

Garb, Y., Pulver, S., and VanDeveer, S. D.: Scenarios in society, society in scenarios: toward a social scientific analysis of storyline-driven environmental modeling, *Environ. Res. Lett.*, 3, 045015, <https://doi.org/10.1088/1748-9326/3/4/045015>, 2008.

615 Gil-García, L., González-López, H., and Pérez-Blanco, C. D.: To dam or not to dam? Actionable socio-hydrology modeling to inform robust adaptation to water scarcity and water extremes, *Environ. Sci. Policy*, 144, 74–87, <https://doi.org/10.1016/j.envsci.2023.03.012>, 2023.

Giordano, R., Preziosi, E., and Romano, E.: Integration of local and scientific knowledge to support drought impact monitoring: some hints from an Italian case study, *Nat. Hazards*, 69, 523–544, <https://doi.org/10.1007/s11069-013-0724-9>, 620 2013.

Goldman, M. J., Nadasdy, P., and Turner, M. D.: *Knowing nature: Conversations at the intersection of political ecology and science studies*, University of Chicago Press, 2019.

Grainger, S., Murphy, C., and Vicente-Serrano, S. M.: Barriers and Opportunities for Actionable Knowledge Production in Drought Risk Management: Embracing the Frontiers of Co-production, *Front. Environ. Sci.*, 9, 625 <https://doi.org/10.3389/fenvs.2021.602128>, 2021.

Gray, S., Chan, A., Clark, D., and Jordan, R.: Modeling the integration of stakeholder knowledge in social–ecological decision-making: Benefits and limitations to knowledge diversity, *Ecol. Model.*, 229, 88–96, <https://doi.org/10.1016/j.ecolmodel.2011.09.011>, 2012.

Gwapedza, D., Barreteau, O., Mantel, S., Paxton, B., Bonte, B., Tholanah, R., Xoxo, S., Theron, S., Mabohlo, S., O’Keeffe, 630 L., Bradshaw, K., and Tanner, J.: Engaging stakeholders to address a complex water resource management issue in the Western Cape, South Africa, *J. Hydrol.*, 639, 131522, <https://doi.org/10.1016/j.jhydrol.2024.131522>, 2024.

Hadorn, G. H., Hoffmann-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., Wiesmann, U., and Zemp, E.: *Handbook of transdisciplinary research*, Springer, 2008.

Hagenlocher, M., Naumann, G., Meza, I., Blauhut, V., Cotti, D., Döll, P., Ehlert, K., Gaupp, F., Van Loon, A. F., Marengo, 635 J. A., Rossi, L., Sabino Siemons, A. S., Siebert, S., Tsehayu, A. T., Toreti, A., Tsegai, D., Vera, C., Vogt, J., and Wens, M.: Tackling Growing Drought Risks—The Need for a Systemic Perspective, *Earths Future*, 11, e2023EF003857, <https://doi.org/10.1029/2023EF003857>, 2023.

- Hargrove, W. L. and Heyman, J. M.: A Comprehensive Process for Stakeholder Identification and Engagement in Addressing Wicked Water Resources Problems, *Land*, 9, 119, <https://doi.org/10.3390/land9040119>, 2020.
- 640 Hervás-Gámez, C. and Delgado-Ramos, F.: Critical Review of the Public Participation Process in Drought Management Plans. The Guadalquivir River Basin Case in Spain, *Water Resour. Manag. Int. J. Publ. Eur. Water Resour. Assoc. EWRA*, 33, 4189–4200, 2019.
- ter Horst, R., Alba, R., Vos, J., Rusca, M., Godinez-Madrigal, J., Babel, L. V., Veldwisch, G. J., Venot, J.-P., Bonté, B., Walker, D. W., and Krueger, T.: Making a case for power-sensitive water modelling: a literature review, *Hydrol. Earth Syst. Sci.*, 28, 4157–4186, <https://doi.org/10.5194/hess-28-4157-2024>, 2024.
- 645 Hossain, M. S., Ramirez, J., Szabo, S., Eigenbrod, F., Johnson, F. A., Speranza, C. I., & Dearing, J. A. (2020). Participatory modelling for conceptualizing social-ecological system dynamics in the Bangladesh delta. *Regional environmental change*, 20, 1-14.
- Hummel, D., Jahn, T., Keil, F., Liehr, S., and Stieß, I.: Social Ecology as Critical, Transdisciplinary Science—Conceptualizing, Analyzing and Shaping Societal Relations to Nature, Sustainability, 9, 1050, <https://doi.org/10.3390/su9071050>, 2017.
- 650 Iwaniec, D. M., Cook, E. M., Davidson, M. J., Berbés-Blázquez, M., Georgescu, M., Krayenhoff, E. S., Middel, A., Sampson, D. A., and Grimm, N. B.: The co-production of sustainable future scenarios, *Landsc. Urban Plan.*, 197, 103744, <https://doi.org/10.1016/j.landurbplan.2020.103744>, 2020.
- Kaika, M.: Constructing Scarcity and Sensationalising Water Politics: 170 Days That Shook Athens, *Antipode*, 35, 919–954, <https://doi.org/10.1111/j.1467-8330.2003.00365.x>, 2003.
- 655 Kallis, G.: Droughts, *Annu. Rev. Environ. Resour.*, 33, 85–118, <https://doi.org/10.1146/annurev.enviro.33.081307.123117>, 2008.
- Kallis, G.: Coevolution in water resource development: The vicious cycle of water supply and demand in Athens, Greece, *Ecol. Econ.*, 69, 796–809, <https://doi.org/10.1016/j.ecolecon.2008.07.025>, 2010.
- 660 Kchouk, S., Melsen, L. A., Walker, D. W., and van Oel, P. R.: A geography of drought indices: mismatch between indicators of drought and its impacts on water and food securities, *Nat. Hazards Earth Syst. Sci.*, 22, 323–344, <https://doi.org/10.5194/nhess-22-323-2022>, 2022.
- Kim, G. J., Yoon, H. N., Seo, S. B., and Kim, Y. O.: Application of shared vision planning for drought mitigation climate change adaptation council in Korea, in: *Proc., 38th IAHR World Congress*. Panama City, Panama: International Association for Hydro-Environment Engineering and Research. <https://doi.org/10.3850/38WC092019-1599>, 2019.
- 665 King, L. and Tadaki, M.: A framework for understanding the politics of science (Core Tenet# 2), *Palgrave Handb. Crit. Phys. Geogr.*, 67–88, 2018.
- Klein, J. T.: A taxonomy of interdisciplinarity, in: *The Oxford Handbook of Interdisciplinarity*, vol. 15, edited by: Klein, J. T. and Mitcham, C., Oxford University Press, 2010.

- 670 Kneier, F., Woltersdorf, L., Peiris, T. A., & Döll, P. (2023). Participatory Bayesian Network modeling of climate change risks and adaptation regarding water supply: Integration of multi-model ensemble hazard estimates and local expert knowledge. *Environmental modelling & software*, 168, 105764.
- Krueger, T., Maynard, C., Carr, G., Bruns, A., Mueller, E. N., and Lane, S.: A transdisciplinary account of water research, *WIREs Water*, 3, 369–389, <https://doi.org/10.1002/wat2.1132>, 2016.
- 675 Krueger, T. and Alba, R.: Ontological and epistemological commitments in interdisciplinary water research: Uncertainty as an entry point for reflexion, *Front. Water*, 4, <https://doi.org/10.3389/frwa.2022.1038322>, 2022.
- Landström, C., Whatmore, S. J., Lane, S. N., Odoni, N. A., Ward, N., and Bradley, S.: Coproducing Flood Risk Knowledge: Redistributing Expertise in Critical ‘Participatory Modelling,’ *Environ. Plan. Econ. Space*, 43, 1617–1633, <https://doi.org/10.1068/a43482>, 2011.
- 680 Landström, C., Sarmiento, E., and Whatmore, S. J.: Stakeholder engagement does not guarantee impact: A co-productionist perspective on model-based drought research, *Soc. Stud. Sci.*, 03063127231199220, <https://doi.org/10.1177/03063127231199220>, 2023.
- Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., and Thomas, C. J.: Transdisciplinary research in sustainability science: practice, principles, and challenges, *Sustain. Sci.*, 7, 25–43, [https://doi.org/10.1007/s11625-](https://doi.org/10.1007/s11625-011-0149-x)
- 685 011-0149-x, 2012.
- Lemos, M. C. and Morehouse, B. J.: The co-production of science and policy in integrated climate assessments, *Glob. Environ. Change*, 15, 57–68, <https://doi.org/10.1016/j.gloenvcha.2004.09.004>, 2005.
- Lemos, M. C., Arnott, J. C., Ardoin, N. M., Baja, K., Bednarek, A. T., Dewulf, A., Fieseler, C., Goodrich, K. A., Jagannathan, K., Klenk, N., Mach, K. J., Meadow, A. M., Meyer, R., Moss, R., Nichols, L., Sjostrom, K. D., Stults, M., Turnhout, E.,
- 690 Vaughan, C., Wong-Parodi, G., and Wyborn, C.: To co-produce or not to co-produce, *Nat. Sustain.*, 1, 722–724, <https://doi.org/10.1038/s41893-018-0191-0>, 2018.
- Lewis, A. C., Hilton, J., and Vocke, R.: Water Supply Options in a New Mexico Water Planning Region, *JAWRA J. Am. Water Resour. Assoc.*, 41, 635–643, <https://doi.org/10.1111/j.1752-1688.2005.tb03760.x>, 2005.
- Liguori, A., McEwen, L., Blake, J., and Wilson, M.: Towards ‘Creative Participatory Science’: Exploring Future Scenarios
- 695 Through Specialist Drought Science and Community Storytelling, *Front. Environ. Sci.*, 8, 2021.
- Lillo-Ortega, G., Aldunce, P., Adler, C., Vidal, M., and Rojas, M.: On the evaluation of adaptation practices: a transdisciplinary exploration of drought measures in Chile, *Sustain. Sci.*, 14, 1057–1069, <https://doi.org/10.1007/s11625-018-0619-5>, 2019.
- Linton, J. and Budds, J.: The hydrosocial cycle: Defining and mobilizing a relational-dialectical approach to water, *Geoforum*, 57, 170–180, <https://doi.org/10.1016/j.geoforum.2013.10.008>, 2014.
- 700 Luetkemeier, R., Mbidzo, M., and Liehr, S.: Water security and rangeland sustainability: Transdisciplinary research insights from Namibian–German collaborations, *South Afr. J. Sci.*, 117, <https://doi.org/10.17159/sajs.2021/7773>, 2021.
- Macpherson, E., Cuppari, R. I., Kagawa-Viviani, A., Brause, H., Brewer, W. A., Grant, W. E., Herman-Mercer, N., Livneh, B., Neupane, K. R., Petach, T., Peters, C. N., Wang, H.-H., Pahl-Wostl, C., and Wheeler, H.: Setting a pluralist agenda for

water governance: Why power and scale matter, *WIREs Water*, 11, e1734, <https://doi.org/10.1002/wat2.1734>, 2024.

705 Masi, M., Arrighi, C., Piragino, F., and Castelli, F.: Participatory multi-criteria decision making for optimal siting of multipurpose artificial reservoirs, *J. Environ. Manage.*, 370, 122904, <https://doi.org/10.1016/j.jenvman.2024.122904>, 2024.

Mehta, L.: The Manufacture of Popular Perceptions of Scarcity: Dams and Water-Related Narratives in Gujarat, India, *World Dev.*, 29, 2025–2041, [https://doi.org/10.1016/S0305-750X\(01\)00087-0](https://doi.org/10.1016/S0305-750X(01)00087-0), 2001.

710 Mehta, L.: The Politics and Poetics of Water: The Naturalisation of Scarcity in Western India, Orient Blackswan, 436 pp., 2005.

Mehta, L.: Whose scarcity? Whose property? The case of water in western India, *Explor. New Underst. Resour. Tenure Reform Context Glob.*, 24, 654–663, <https://doi.org/10.1016/j.landusepol.2006.05.009>, 2007.

Melsen, L. A.: It Takes a Village to Run a Model—The Social Practices of Hydrological Modeling, *Water Resour. Res.*, 58, e2021WR030600, <https://doi.org/10.1029/2021WR030600>, 2022.

715 Melsen, L. A., Vos, J., and Boelens, R.: What is the role of the model in socio-hydrology? Discussion of “Prediction in a socio-hydrological world”*, *Hydrol. Sci. J.*, 63, 1435–1443, <https://doi.org/10.1080/02626667.2018.1499025>, 2018.

Mishra, A. K. and Singh, V. P.: A review of drought concepts, *J. Hydrol.*, 391, 202–216, <https://doi.org/10.1016/j.jhydrol.2010.07.012>, 2010.

Mishra, A. K. and Singh, V. P.: Drought modeling – A review, *J. Hydrol.*, 403, 157–175, <https://doi.org/10.1016/j.jhydrol.2011.03.049>, 2011.

720 Mpandeli, S., Nesamvuni, E., and Maponya, P.: Adapting to the impacts of drought by smallholder farmers in Sekhukhun District in Limpopo Province, South Africa, *J. Agric. Sci.*, 7, 115, 2015.

Mpofu-Mketwa, T. J., Abrams, A., and Black, G. F.: Reflections on measuring the soundness of the digital storytelling method applied to three Cape Flats vulnerable communities affected by drought, fire and flooding in Cape Town, *Soc. Sci. Humanit. Open*, 7, 100407, <https://doi.org/10.1016/j.ssaho.2023.100407>, 2023.

725 Mukherjee, S. and Sundberg, T.: A transdisciplinary and collaborative urban water security framework: Developed through an interdisciplinary study in Kolkata, India, *World Water Policy*, 9, 519–549, <https://doi.org/10.1002/wwp2.12125>, 2023.

Mukherjee, J.: “Living systems infrastructure” of Kolkata: exploring co-production of urban nature using historical urban political ecology (HUPE), *Environ. Urban.*, 34, 32–51, <https://doi.org/10.1177/09562478221084560>, 2022.

730 Mustafa, S. Md. T., Van Loon, A., Artur, L., Bharucha, Z., Chinyama, A., Chirindja, F., Day, R., Franchi, F., Geris, J., Hussey, S., Nesamvuni, E., Nhacume, A., Petros, A., Roden, H., Rohse, M., Tirivarombo, S., and Comte, J.-C.: Multisector Collaborative Groundwater-Surface Water Modelling Approach to Improve Resilience to Hydrological Extremes in the Limpopo River Basin, in: *Advances in Geoethics and Groundwater Management: Theory and Practice for a Sustainable Development*, Cham, 397–400, https://doi.org/10.1007/978-3-030-59320-9_83, 2021.

735 Nielsen-Gammon, J. W., Banner, J. L., Cook, B. I., Tremaine, D. M., Wong, C. I., Mace, R. E., Gao, H., Yang, Z.-L., Gonzalez, M. F., Hoffpauir, R., Gooch, T., and Kloesel, K.: Unprecedented Drought Challenges for Texas Water Resources in a Changing

- Climate: What Do Researchers and Stakeholders Need to Know?, *Earths Future*, 8, e2020EF001552, <https://doi.org/10.1029/2020EF001552>, 2020.
- Norström, A. V., Cvitanovic, C., Löf, M. F., West, S., Wyborn, C., Balvanera, P., Bednarek, A. T., Bennett, E. M., Biggs, R.,
740 de Bremond, A., Campbell, B. M., Canadell, J. G., Carpenter, S. R., Folke, C., Fulton, E. A., Gaffney, O., Gelcich, S., Jouffray, J.-B., Leach, M., Le Tissier, M., Martín-López, B., Louder, E., Loutre, M.-F., Meadow, A. M., Nagendra, H., Payne, D., Peterson, G. D., Reyers, B., Scholes, R., Speranza, C. I., Spierenburg, M., Stafford-Smith, M., Tengö, M., van der Hel, S., van Putten, I., and Österblom, H.: Principles for knowledge co-production in sustainability research, *Nat. Sustain.*, 3, 182–190, <https://doi.org/10.1038/s41893-019-0448-2>, 2020.
- Ocampo-Melgar, A., Barría, P., Chadwick, C., and Rivas, C.: Cooperation under conflict: participatory hydrological modeling
745 for science policy dialogues for the Aculeo Lake, *Hydrol. Earth Syst. Sci.*, 26, 5103–5118, <https://doi.org/10.5194/hess-26-5103-2022>, 2022.
- Paneque, P., Lafuente, R., and Vargas, J.: Public Attitudes toward Water Management Measures and Droughts: A Study in Southern Spain, *Water*, 10, 369, <https://doi.org/10.3390/w10040369>, 2018.
- Pham, Y., Reardon-Smith, K., Mushtaq, S., and Deo, R. C.: Feedback modelling of the impacts of drought: A case study in
750 coffee production systems in Viet Nam, *Clim. Risk Manag.*, 30, 100255, <https://doi.org/10.1016/j.crm.2020.100255>, 2020.
- Piemontese, L., Terzi, S., Di Baldassarre, G., Menestrey Schwieger, D. A., Castelli, G., and Bresci, E.: Over-reliance on water infrastructure can hinder climate resilience in pastoral drylands, *Nat. Clim. Change*, 14, 267–274, <https://doi.org/10.1038/s41558-024-01929-z>, 2024.
- Piemontese, L., Castelli, G., Limones, N., Grazio, A., and Bresci, E.: Large-scale siting of sand dams: A participatory approach
755 and application in Angolan drylands, *Land Degrad. Dev.*, 34, 844–858, <https://doi.org/10.1002/ldr.4500>, 2023.
- Porter, J. J. and Dessai, S.: Mini-me: Why do climate scientists’ misunderstand users and their needs?, *Environ. Sci. Policy*, 77, 9–14, <https://doi.org/10.1016/j.envsci.2017.07.004>, 2017.
- Rachunok, B. and Fletcher, S.: Socio-hydrological drought impacts on urban water affordability, *Nat. Water*, 1, 83–94,
760 <https://doi.org/10.1038/s44221-022-00009-w>, 2023.
- Rahaman, M. M. and Varis, O.: Integrated water resources management: evolution, prospects and future challenges, *Sustain. Sci. Pract. Policy*, 1, 15–21, <https://doi.org/10.1080/15487733.2005.11907961>, 2005.
- Rangecroft, S., Birkinshaw, S., Rohse, M., Day, R., McEwen, L., Makaya, E., and Van Loon, A.: Hydrological modelling as a tool for interdisciplinary workshops on future drought, *Prog. Phys. Geogr.*, 42, 237–256,
765 <https://doi.org/10.1177/0309133318766802>, 2018.
- Raudsepp-Hearne, C., Peterson, G. D., Bennett, E. M., Biggs, R., Norström, A. V., Pereira, L., Vervoort, J., Iwaniec, D. M., McPhearson, T., Olsson, P., Hichert, T., Falardeau, M., and Aceituno, A. J.: Seeds of good anthropocenes: developing sustainability scenarios for Northern Europe, *Sustain. Sci.*, 15, 605–617, <https://doi.org/10.1007/s11625-019-00714-8>, 2020.

Reed, M. S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C. H., and Stringer, L. C.: Who's
770 in and why? A typology of stakeholder analysis methods for natural resource management, *J. Environ. Manage.*, 90, 1933–
1949, <https://doi.org/10.1016/j.jenvman.2009.01.001>, 2009.

Rojas, R., Castilla-Rho, J., Bennison, G., Bridgart, R., Prats, C., and Claro, E.: Participatory and Integrated Modelling under
Contentious Water Use in Semiarid Basins, *Hydrology*, 9, 49, <https://doi.org/10.3390/hydrology9030049>, 2022.

Rossi, L., Wens, M., de Moel, H., Cotti, D., Sabino Siemons, A.-S., Toreti, A., Maetens, W., Masante, D., Van Loon, A.,
775 Hagenlocher, M., Rudari, R., Naumann, G., Meroni, M., Avanzi, F., Isabellon, M., and Barbosa, P.: European Drought Risk
Atlas, European Commission, 2023.

Rusca, M. and Di Baldassarre, G.: Interdisciplinary Critical Geographies of Water: Capturing the Mutual Shaping of Society
and Hydrological Flows, *Water*, 11, <https://doi.org/10.3390/w11101973>, 2019.

Rusca, M., Savelli, E., Di Baldassarre, G., Biza, A., and Messori, G.: Unprecedented droughts are expected to exacerbate urban
780 inequalities in Southern Africa, *Nat. Clim. Change*, 13, 98–105, <https://doi.org/10.1038/s41558-022-01546-8>, 2023.

Rusca, M., Sverdlík, A., Acharya, A., Basel, B., Boyd, E., Comelli, T., Dodman, D., Fraser, A., Harris, D. M., Lindersson, S.,
Mazzoleni, M., Mbah, M. F., Mitlin, D., Ogra, A., Pelling, M., Raffetti, E., Sultana, F., Thompson, E., Tozzi, A., Zwarteveen,
M., and Messori, G.: Plural climate storylines to foster just urban futures, *Nat. Cities*, 1, 732–740,
<https://doi.org/10.1038/s44284-024-00133-6>, 2024.

785 Sampson, D. A., Cook, E. M., Davidson, M. J., Grimm, N. B., and Iwaniec, D. M.: Simulating alternative sustainable water
futures, *Sustain. Sci.*, 15, 1199–1210, <https://doi.org/10.1007/s11625-020-00820-y>, 2020.

Savelli, E., Rusca, M., Cloke, H., Flügel, T. J., Karriem, A., and Di Baldassarre, G.: All dried up: The materiality of drought
in Ladismith, South Africa, *Environ. Plan. E Nat. Space*, 25148486221126617, <https://doi.org/10.1177/25148486221126617>,
2022.

790 Savelli, E.: Us and them: Privileged emotions of Cape Town's urban water crisis, *Geoforum*, 141, 103746,
<https://doi.org/10.1016/j.geoforum.2023.103746>, 2023.

Sarewitz, D. and Pielke, R. A.: The neglected heart of science policy: reconciling supply of and demand for science, *Environ.*
Sci. Policy, 10, 5–16, <https://doi.org/10.1016/j.envsci.2006.10.001>, 2007.

Savenije, H. H. G.: Water Resources Management Concepts and Tools: Lecture Notes, Int. Inst. Infrastruct. Hydraul. Environ.
795 Eng. IHE Delft Neth., 170, 1995.

Savenije, H. H. G. and Van der Zaag, P.: Integrated water resources management: Concepts and issues, *Phys. Chem. Earth*
Parts ABC, 33, 290–297, <https://doi.org/10.1016/j.pce.2008.02.003>, 2008.

Seidl, R., Brand, F. S., Stauffacher, M., Krütli, P., Le, Q. B., Spörri, A., Meylan, G., Moser, C., González, M. B., and Scholz,
R. W.: Science with Society in the Anthropocene, *AMBIO*, 42, 5–12, <https://doi.org/10.1007/s13280-012-0363-5>, 2013.

800 Singto, C., Fleskens, L., Vos, J., & Quinn, C. (2020). Applying Bayesian belief networks (BBNs) with stakeholders to explore
and codesign options for water resource interventions. *Sustainable Water Resources Management*, 6, 1-17.

- Sivapalan, M., Savenije, H. H. G., and Blöschl, G.: Socio-hydrology: A new science of people and water, *Hydrol. Process.*, 26, 1270–1276, <https://doi.org/10.1002/hyp.8426>, 2012.
- Smetschka, B. and Gaube, V.: Co-creating formalized models: Participatory modelling as method and process in transdisciplinary research and its impact potentials, *Environ. Sci. Policy*, 103, 41–49, <https://doi.org/10.1016/j.envsci.2019.10.005>, 2020.
- Smith, N.: There’s no such thing as a natural disaster, Retrieved from: <http://understandingkatrina.ssrc.org/Smith/>, 2006.
- Sodoge, J., Reckhaus, Z., Kuhlicke, C., and Madruga de Brito, M.: Unified in diversity: Unravelling emerging knowledge on drought impact cascades via participatory modeling, *Clim. Risk Manag.*, 46, 100652, <https://doi.org/10.1016/j.crm.2024.100652>, 2024.
- Spaapen, J. and van Drooge, L.: Introducing ‘productive interactions’ in social impact assessment, *Res. Eval.*, 20, 211–218, <https://doi.org/10.3152/095820211X12941371876742>, 2011.
- Srinivasan, V., Sanderson, M., Garcia, M., Konar, M., Blöschl, G., & Sivapalan, M.: Prediction in a socio-hydrological world. *Hydrological Sciences Journal*, 62(3), 338–345. <https://doi.org/10.1080/02626667.2016.1253844>, 2016.
- Stirling, A.: “Opening Up” and “Closing Down”: Power, Participation, and Pluralism in the Social Appraisal of Technology, *Sci. Technol. Hum. Values*, 33, 262–294, <https://doi.org/10.1177/0162243907311265>, 2008.
- Streefkerk, I. N., van den Homberg, M. J. C., Whitfield, S., Mittal, N., Pope, E., Werner, M., Winsemius, H. C., Comes, T., and Ertsen, M. W.: Contextualising seasonal climate forecasts by integrating local knowledge on drought in Malawi, *Clim. Serv.*, 25, 100268, <https://doi.org/10.1016/j.cliser.2021.100268>, 2022.
- Sultana, F.: Embodied Intersectionalities of Urban Citizenship: Water, Infrastructure, and Gender in the Global South, *Ann. Am. Assoc. Geogr.*, 110, 1407–1424, <https://doi.org/10.1080/24694452.2020.1715193>, 2020.
- Swyngedouw, E.: Social power and the urbanization of water: flows of power, OUP Oxford, 2004.
- Swyngedouw, E.: The Political Economy and Political Ecology of the Hydro-Social Cycle, *J. Contemp. Water Res. Educ.*, 142, 56–60, <https://doi.org/10.1111/j.1936-704X.2009.00054.x>, 2009.
- Thaler, T. and Levin-Keitel, M.: Multi-level stakeholder engagement in flood risk management—A question of roles and power: Lessons from England, *Environ. Sci. Policy*, 55, 292–301, <https://doi.org/10.1016/j.envsci.2015.04.007>, 2016.
- Thompson, M. A., Owen, S., Lindsay, J. M., Leonard, G. S., and Cronin, S. J.: Scientist and stakeholder perspectives of transdisciplinary research: Early attitudes, expectations, and tensions, *Environ. Sci. Policy*, 74, 30–39, <https://doi.org/10.1016/j.envsci.2017.04.006>, 2017.
- Turner, M. D.: Production of environmental knowledge: Scientists, complex natures, and the question of agency, *Knowing Nat. Conversat. Intersect. Polit. Ecol. Sci. Stud. Univ. Chic. Press Chic.*, 25–29, 2011.
- Turnhout, E., Metze, T., Wyborn, C., Klenk, N., and Louder, E.: The politics of co-production: participation, power, and transformation, *Curr. Opin. Environ. Sustain.*, 42, 15–21, <https://doi.org/10.1016/j.cosust.2019.11.009>, 2020.
- Usón, T. J., Henríquez, C., and Dame, J.: Disputed water: Competing knowledge and power asymmetries in the Yali Alto basin, Chile, *Geoforum*, 85, 247–258, <https://doi.org/10.1016/j.geoforum.2017.07.029>, 2017.

- Van Loon, A. F., Stahl, K., Di Baldassarre, G., Clark, J., Rangelcroft, S., Wanders, N., Gleeson, T., Van Dijk, A. I. J. M., Tallaksen, L. M., Hannaford, J., Uijlenhoet, R., Teuling, A. J., Hannah, D. M., Sheffield, J., Svoboda, M., Verbeiren, B., Wagener, T., and Van Lanen, H. A. J.: Drought in a human-modified world: reframing drought definitions, understanding, and analysis approaches, *Hydrol. Earth Syst. Sci.*, 20, 3631–3650, <https://doi.org/10.5194/hess-20-3631-2016>, 2016a.
- 840 Van Loon, A. F., Gleeson, T., Clark, J., Van Dijk, A. I. J. M., Stahl, K., Hannaford, J., Di Baldassarre, G., Teuling, A. J., Tallaksen, L. M., Uijlenhoet, R., Hannah, D. M., Sheffield, J., Svoboda, M., Verbeiren, B., Wagener, T., Rangelcroft, S., Wanders, N., and Van Lanen, H. A. J.: Drought in the Anthropocene, *Nat. Geosci.*, 9, 89–91, <https://doi.org/10.1038/ngeo2646>, 2016b.
- Vanelli, F. M., Kobiyama, M., and de Brito, M. M.: To which extent are socio-hydrology studies truly integrative? The case of natural hazards and disaster research, *Hydrol. Earth Syst. Sci.*, 26, 2301–2317, <https://doi.org/10.5194/hess-26-2301-2022>, 2022.
- 845 Vedeld, T.: The Co-creation Paradox: Small Towns and the Promise and Limits of Collaborative Governance for Low-Carbon, Sustainable Futures, *Scand. J. Public Adm.*, 26, 45–70, <https://doi.org/10.58235/sjpa.v26i3.7006>, 2022.
- Venot, J.-P., Vos, J., Molle, F., Zwartveen, M., Veldwisch, G. J., Kuper, M., Mdee, A., Ertsen, M., Boelens, R., Cleaver, F., 850 Lankford, B., Swatuk, L., Linton, J., Harris, L. M., Kemerink-Seyoum, J., Kooy, M., and Schwartz, K.: A bridge over troubled waters, *Nat. Sustain.*, 5, 92, <https://doi.org/10.1038/s41893-021-00835-y>, 2022.
- Vicente-Serrano, S. M., Peña-Angulo, D., Murphy, C., López-Moreno, J. I., Tomas-Burguera, M., Domínguez-Castro, F., Tian, F., Eklundh, L., Cai, Z., Alvarez-Farizo, B., Noguera, I., Camarero, J. J., Sánchez-Salguero, R., Gazol, A., Grainger, S., Conradt, T., Boincean, B., and El Kenawy, A.: The complex multi-sectoral impacts of drought: Evidence from a mountainous 855 basin in the Central Spanish Pyrenees, *Sci. Total Environ.*, 769, 144702, <https://doi.org/10.1016/j.scitotenv.2020.144702>, 2021.
- Wens, M., Veldkamp, T. I. E., Mwangi, M., Johnson, J. M., Lasage, R., Haer, T., and Aerts, J. C. J. H.: Simulating Small-Scale Agricultural Adaptation Decisions in Response to Drought Risk: An Empirical Agent-Based Model for Semi-Arid Kenya, *Front. Water*, 2, <https://doi.org/10.3389/frwa.2020.00015>, 2020.
- 860 Wesselink, A., Kooy, M., and Warner, J.: Socio-hydrology and hydrosocial analysis: toward dialogues across disciplines, *WIREs Water*, 4, e1196, <https://doi.org/10.1002/wat2.1196>, 2017.
- Wheater, H. S. and Gober, P.: Water security and the science agenda, *Water Resour. Res.*, 51, 5406–5424, <https://doi.org/10.1002/2015WR016892>, 2015.
- White, G. F.: Human adjustment to floods: Department of geography research paper No. 29, Chic. IL Univ. Chic., 1945.
- 865 Wilhite, D. A., and Glantz, M. H.: Understanding: the drought phenomenon: the role of definitions. *Water international*, 10(3), 111-120, <https://doi.org/10.1080/02508068508686328>, 1985
- Wilhite, D. A., Svoboda, M. D., and Hayes, M. J.: Understanding the complex impacts of drought: A key to enhancing drought mitigation and preparedness, *Water Resour. Manag.*, 21, 763–774, <https://doi.org/10.1007/s11269-006-9076-5>, 2007.

870 Zwartveen, M., Kemerink-Seyoum, J. S., Kooy, M., Evers, J., Guerrero, T. A., Batubara, B., Biza, A., Boakye-Ansah, A.,
Faber, S., Cabrera Flamini, A., Cuadrado-Quesada, G., Fantini, E., Gupta, J., Hasan, S., ter Horst, R., Jamali, H., Jaspers, F.,
Obani, P., Schwartz, K., Shubber, Z., Smit, H., Torio, P., Tutusaus, M., and Wesselink, A.: Engaging with the politics of water
governance, *WIREs Water*, 4, e1245, <https://doi.org/10.1002/wat2.1245>, 2017.