



COMMENTARY

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Key Points:

- Accounting for both power relations and cognitive heuristics is key to unravel the interplay of floods, droughts and human societies
- Flood and drought predictions are complicated by the increasing impact of human activities on the water cycle
- We propose the integration of multiple research methods as a way to cope with uncertainty and develop policy-relevant science

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Integrating Multiple Research Methods to Unravel the Complexity of Human-Water Systems

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Abstract Predicting floods and droughts is essential to inform the development of policy in water management, climate change adaptation and disaster risk reduction. Yet, hydrological predictions are highly uncertain, while the frequency, severity and spatial distribution of extreme events are further complicated by the increasing impact of human activities on the water cycle. In this commentary, we argue that four main aspects characterizing the complexity of human-water systems should be explicitly addressed: feedbacks, scales, tradeoffs and inequalities. We propose the integration of multiple research methods as a way to cope with complexity and develop policy-relevant science.

Plain Language Summary Several governments today claim to be following the science in addressing crises caused by the occurrence of extreme events, such as floods and droughts, or the emergence of global threats, such as climate change and COVID-19. In this commentary, we show that there are no universal answers to apparently simple questions such as: Do levees reduce flood risk? Do reservoirs alleviate droughts? We argue that the best science we have consists of a plurality of legitimate interpretations and a range of foresights, which can be enriched by integrating multiple disciplines and research methods.

1. Premise

Scientific knowledge about floods and droughts, that is, hydrological extremes, provides essential input for policy and decision-making processes in water management, climate change adaptation and disaster risk reduction (AghaKouchak et al., 2021; Kundzewicz et al., 2014; Montanari et al., 2013; Takeuchi, 2004; Ward et al., 2020). Hydrologists are often challenged by a range of policy-relevant questions in relation to floods and droughts, including: How are they affected by anthropogenic activities and/or global warming? What will be their frequency, severity and spatial distribution in the coming decades? What are the best strategies to reduce vulnerability and alleviate their negative impacts?

Hydrologists alone cannot address these questions. Thus, a very long history of collaboration has evolved across disciplines dealing with water-related issues. Scholars engaged in water resources systems, which started with the Harvard Water Program in the 1960s, provided well-established examples of such interdisciplinary collaborations (Brown et al., 2015). Over the past decade, more and more hydrologists have argued for further engagement with social scientists, including political ecologists and behavioral economists (Blair & Buytaert, 2016; Di Baldassarre et al., 2019; Liu et al., 2014; Montanari et al., 2013; Rusca & Di Baldassarre, 2019; Sivapalan et al., 2012). Political ecology has uncovered the major role played by politics and power relations in shaping the complex dynamics of human-water systems (Swyngedouw, 1999). Behavioral economists have demonstrated how cognitive heuristics and biases (Slovic, 1987; Tversky & Kahneman, 1974) influence human behavior and attitude, as well as the way in which people and decision makers think about hydrological risks (Aerts et al., 2018). As such, accounting for both power relations and cognitive heuristics is key to unravel the interplay of floods, droughts and human societies.

In this commentary, we first discuss the challenge of predicting floods and droughts in today's human-dominated world, and then propose the integration of multiple research methods as a way to cope

with complexity and develop policy-relevant science. In particular, we argue for the need to go beyond what-can-be-quantified.

2. The Complexity of Human-Water Systems

Flood and drought predictions are affected by several sources of uncertainty (Beven, 2016; Blöschl et al., 2019; Parthasarathy, 2018). They range from the chaotic nature of weather to the complex propagation of hydrological extremes, which is further complicated by the increasing influence of human activities in the Anthropocene (AghaKouchak et al., 2015; Best, 2019; Brunner et al., 2021; Di Baldassarre et al., 2017; Sivapalan et al., 2012; Van Loon et al., 2016; Vörösmarty et al., 2013). To cope with this uncertainty, we argue that four main aspects characterizing the complexity of human-water systems should be considered.

First, feedbacks between social and physical processes can generate unintended consequences (Lansing, 2003). Water infrastructure, such as levees or reservoirs, can help reduce the frequency of hydrological extremes, but can also: (a) generate complacency or a false sense of security, that is, safe-development paradox (Ferreira et al., 2013; Kates et al., 2006; Montz & Tobin, 2008); (b) fuel urbanization of floodplains (Pinter et al., 2016; White, 1945); and (c) enable increasing water consumption (Di Baldassarre et al., 2018; Gohari et al., 2013; Kallis, 2010). Research in sociohydrology (Sivapalan et al., 2012) has shown how large water infrastructure can worsen the negative impacts of floods or droughts (Di Baldassarre et al., 2021; Garcia et al., 2020; Viglione et al., 2014; Ward et al., 2020).

Second, scales matter (Brelsford et al., 2020) and what works at the smaller scale can fail at the larger scale (and vice versa). The irrigation efficiency paradox (Grafton et al., 2018) is a typical example of how undesirable outcomes at the large basin scale can result from supposedly efficient decisions at the farm scale (Dumont et al., 2013). More specifically, a range of technologies is increasingly used to improve irrigation efficiency with the goal of saving water at the farm scale (Grafton et al., 2018). Yet, saved water is often reallocated to expand irrigating areas elsewhere thereby increasing water consumptions at the large basin scale (Di Baldassarre et al., 2019).

Third, tradeoffs between competing interests are unavoidable (Chen & Olden, 2017; Reichstein et al., 2021). As a matter of fact, human societies do not merely aim to reduce drought and flood risks (Ward et al., 2020). Individuals, communities and institutions have multiple goals: eradicating poverty and hunger, promoting health and well-being, and reducing inequalities to mention only some of the UN's Sustainable Development Goals (SDGs, 2015). These tradeoffs cannot be neglected in developing policy-relevant science. For example, research work on human-flood interactions should not only address how societies impact (and respond to) flood events, but also explore the socioeconomic benefits of living in floodplain areas that offer desirable conditions, for example, livelihood, cultural organization, trade, and transportation (Collins, 2009; Ferdous et al., 2018).

Fourth, society is heterogeneous and some social groups have more influence than others on how water resources are governed (Andrijevic et al., 2020; Parthasarathy, 2018; Savelli et al., 2021; Verchick, 2012). To illustrate, the most powerful social groups have prevailing ideas on the development and operation of water infrastructure (Savelli et al., 2021), which often results in uneven distribution of hydrological risk (Thaler & Hartmann, 2016). Water security in Cape Town is emblematic of this. Water supply secured by massive reservoirs has been disproportionately used by the upper class, which could also quickly recover from the 2015–2017 drought and the Day Zero water crisis (Savelli et al., 2021). Moreover, low-income groups and minorities are often more severely affected by hydrological extremes (Carter et al., 2007; De Silva & Kawasaki, 2020; Finch et al., 2010; Hallegatte et al., 2020; Tovar Reaños, 2021). New Orleans is a case in point: race, class, age and gender played a role in the unequal consequences of the 2005 flooding following hurricane Katrina (Elliott & Pais, 2006; Kates et al., 2006; Rusca et al., 2021).

3. Integrating Research Methods

This complexity of human-water systems requires methodological and conceptual innovations to cope with uncertainty and develop policy-relevant science. Here, we argue for a combination of qualitative and quantitative approaches as well as an integration of models and observations (Figure 1).

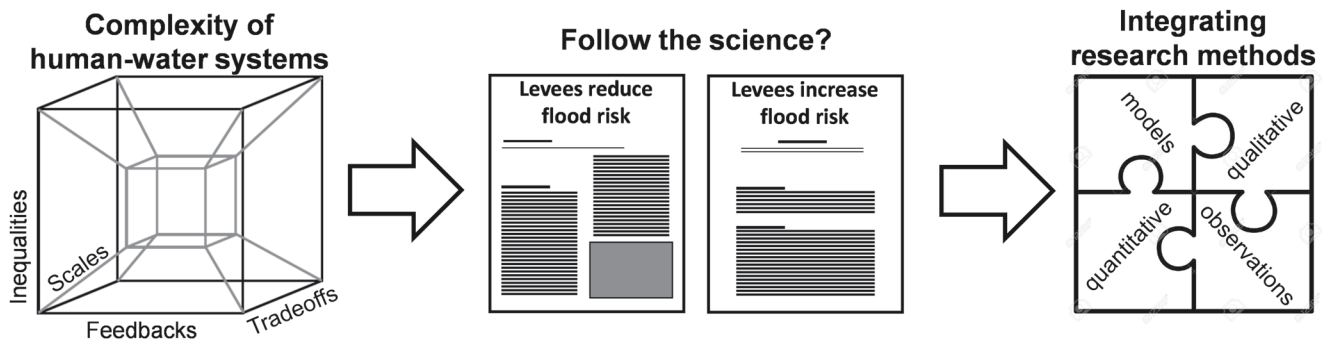


Figure 1. Integrating research methods to unravel the complexity of human-water systems and cope with uncertainty in sociohydrological predictions.

We posit that both qualitative and quantitative approaches are needed to advance scientific knowledge. While quantitative assessments allow us to mathematically describe dynamics, qualitative analyses are key to explain them (Rusca & Di Baldassarre, 2019). In the aforementioned example of Cape Town, quantitative analyses of precipitation data and reservoir water levels (Garcia et al., 2020) allowed the study of drought propagation (from meteorological to hydrological) and inequalities in water consumptions, but they could not explain the role of power relations in determining this outcome. A qualitative analysis of policy documents and interviews revealed how the long history of social injustice and the legacy of the apartheid influenced the uneven impacts of, and recovery from, the 2015–2017 drought (Savelli et al., 2021). Focusing only on what-can-be-quantified, for example, would have prevented a critical understanding of fundamental issues (the “why” question).

We also argue for a deeper integration of observations and models. In traditional hydrology, this integration mostly consists of model calibration and validation (or data assimilation), as the basic science of hydrological processes is rather solid. On the contrary, the interplay of water and society is globally recognized as one of the unsolved problems in hydrological science (Blöschl et al., 2019), and it includes behavioral and political aspects that cannot be quantified (Rangecroft et al., 2021). Thus, observations and models should be integrated in a different way.

Sociohydrological models consist of a set of hypotheses about the human-water interactions generating phenomena, crises and risks (Blair & Buytaert, 2016; Pande & Sivapalan, 2017; Sivapalan & Blöschl, 2015). For instance, the model of human-flood interactions developed by Di Baldassarre et al. (2013) explained the safe-development paradox (one of the empirically observed phenomena) as a result of the accumulation and decay of collective flood memory. While being inspired by empirical observations, sociohydrological models in turn inspire new types of data collections. The concept of collective flood memory, for example, motivated empirical studies and the collection of historical data exploring changes over time in the way in which people remember and perceive floods (Buarque et al., 2020; Mondino et al., 2020). New observations can then help evaluate the explanatory value of the model(s), or stimulate the development of a new set of hypotheses (Ridolfi et al., 2020) within iterative processes that ultimately produce new scientific knowledge.

Combining different approaches to researching hydrological extremes also helps derive many lines of evidence giving more credibility to research outcomes, that is, triangulation (Munafò & Smith, 2018). In other words, “if the results of different approaches all point to the same conclusion, this strengthens confidence in the finding” (Lawlor et al., 2016). Thus, mixed research methods can contribute to test alternative hypotheses about the human-water interactions generating sociohydrological phenomena. Moreover, they can help reveal whether hydrological risk dynamics observed in a specific place in the past might also happen elsewhere in the future, which is an essential step to develop policy-relevant science (Rusca et al., 2021). To this end, new opportunities are currently offered by the ongoing proliferation of global datasets and worldwide archives allowing studies to go beyond the observation and modeling of specific case studies (Lindersson et al., 2020; Mård et al., 2018; Mazzoleni et al., 2020).

4. Follow the Science?

Several governments today claim to be “following the science” (Bacevic, 2020) in addressing crises caused by the occurrence of extreme events, such as floods and droughts, or the emergence of global threats, such as climate change and COVID-19. As scientists, we should celebrate this moment. However, as discussed, there are no universal answers to apparently simple questions such as: Do levees reduce flood risk? Do reservoirs alleviate droughts? Concurrently, decision makers have incentives to downplay the aforementioned uncertainties and complexities (Pearce, 2020). Politicians can present “as scientific evidence” a specific outcome, picked ad-hoc from a broader range of results, which is then used “as a sound justification” for precise actions (Bacevic, 2020).

In this state of affairs, the need to cross methodological boundaries and go beyond what-can-be-quantified is even more pressing. Embracing and integrating multiple research methods is not only a means to advance policy-relevant science, but also the only way to keep our scientific integrity and honesty (Pielke, 2007). It allows us to explicitly recognize (and communicate) that we can only be approximately right while offering the best science we have, which consists of a plurality of legitimate interpretations and a range of foresights.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

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