Toward sustainable water governance:
Paradigms, context, and sustainability performance

By the School of Sustainability
of Leuphana University Lüneburg for the award of the degree of

Doctor of Economic, Social and Political Sciences

– Dr. rer. pol. –

approved dissertation by

Shahana Bilalova

born on 18.12.1995 in Baku (Azerbaijan)

Submitted on:	20.07.2024
Oral defense (disputation) on:	07.11.2024

First supervisor and reviewer:	Prof. Dr. Jens Newig, Leuphana University Lüneburg, Germany
Second supervisor and reviewer:	Dr. Sergio Villamayor-Tomas, Autonomous University of Barcelona, Spain
Third reviewer:	Prof. Dr. Claudia Pahl-Wostl, Osnabrück University, Germany

The individual contributions to the cumulative dissertation project are or will be published as follows:

Bilalova, S., Newig, J., & Villamayor-Tomas, S. 2024. Toward sustainable water governance? Taking stock of paradigms, practices, and sustainability outcomes. WIREs Water e1762. https://doi.org/10.1002/wat2.1762.[1]

Bilalova, S., Villamayor-Tomas, S., & Newig, J. Water-related problématiques: five archetypical contexts of water governance. Submitted to Ecology & Society.

Bilalova, S., Jager, N. W., Newig, J., & Villamayor-Tomas, S. Successful governance pathways across problem contexts: a global QCA analysis. Submitted to Ecology & Society.

Bilalova, S., Newig, J., Tremblay-Lévesque, L.-C., Roux, J., Herron, C., & Crane, S. 2023. Pathways to water sustainability? A global study assessing the benefits of integrated water resources management. Journal of Environmental Management 343(October):118179. https://doi.org/10.1016/j.jenvman.2023.118179.

Year of publication: 2024

[1] This contribution was under review when the cumulative dissertation was submitted and was published afterwards.

Table of Contents

Acknowledgements

Starting a PhD during a pandemic was especially challenging, with one lockdown after another. However, there have been many people to whom I am grateful for making this experience incredibly valuable, even during difficult times.

First, I would like to thank Jens Newig, my first supervisor, for his direction, support, and mentorship throughout this process. His insights were truly valuable, and I learned a lot from him. I also extend my gratitude to my second supervisor, Sergio Villamayor-Tomas, for his guidance, encouragement, and appreciation. I am grateful to Prof. Dr. Claudia Pahl-Wostl for serving on my doctoral committee, and to Andrea Gerlak for her valuable mentorship in helping me navigate the nuances of the PhD and the transition to postdoctoral life.

I am extremely grateful to the NEWAVE network for the invaluable learning experiences and fruitful collaborations it has provided me. I am particularly thankful to the NEWAVE ESRs for their immense support and for challenging me to think outside the box. It has been incredible how our regular Zoom meetings in the beginning created such a valuable community.

A very big thanks to my friends, both in Germany and abroad, who have supported me when needed and celebrated my achievements—even the small ones—as if they were their own. Many thanks to Gular, Turana, Helen, Johanna, and Kubra. I am truly grateful to Johanna, Anna, Michael, and Lisa for being wonderful friends and colleagues. Our regular Pomodoro sessions, coffee walks, picnics, and trips will always be fondly remembered. Thank you to all those mentioned above, as well as the many other friends who have played a role in my academic and personal development.

I am deeply grateful to my family. To my mom, for always being by my side and believing in me more than I believe in myself. To my dad, for listening with such interest to my research and for supporting me unwaveringly.

Finally, I am extremely grateful to you, Manuel, for always supporting and cherishing me during this journey.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie Innovative Training Network NEWAVE - grant agreement No 861509.

Abstract

The global water crisis, exacerbated by human activities and climate change, has reached critical levels. Recent studies and reports highlight the need for immediate action to protect threatened ecosystems and to ensure sustainable water resources. The current water crisis is widely argued to be a crisis of governance. With shifting societal priorities and increasing understanding of water systems, new and diverse governance approaches have emerged and spread. This is also reflected in the growing body of literature that examines different governance approaches in relation to the context in which they have been implemented.

This doctoral dissertation analyzes the existing empirical literature on water governance to explore the interactions between governance paradigms and characteristics, context, and water sustainability performance. Additionally, it provides important conceptual insights into water governance paradigms and presents novel empirical findings in the examination of Integrated Water Resources Management (IWRM). Focusing on paradigms is important as it offers a valuable lens to understand water governance better, allowing us to examine the underlying principles that may guide governance decisions, the role of context in shaping governance practices, and the dynamics within water governance. This dissertation aims to achieve three main objectives: (1) identify and examine water governance paradigms, (2) explore patterns in water sustainability performance associated with different governance paradigms and identify effective governance pathways, and (3) examine the role of context in water governance effectiveness, the relationship between context and governance paradigms, and the link between water-related problem contexts and governance. To address these objectives, the dissertation employs a mixed-method approach, integrating quantitative and set-theoretic methods, drawing from and contributing to two areas of research: water sustainability and water governance.

The results show that paradigms may play an important role in how water governance is structured, who is involved, and how problems are perceived. However, the relationship between paradigms and governance is not always linear, as governance systems often emerge from the complex interplay of several factors rather than being determined by a single paradigm. Paradigms are dynamic: co-occurring with other paradigms, appearing in different forms in different contexts, and evolving over time with shifting societal priorities while leaving legacies. Their emergence and spread result from the influence of diverse actors in shaping the discourse, practices, and evolving landscapes of water governance worldwide. Therefore, while these paradigms are not always well acknowledged in the literature, it is imperative to zoom into paradigms to understand water governance better.

Results on how governance systems perform regarding water sustainability show that certain paradigms, such as “participatory and collaborative governance,” “integrated approach to water management,” and “adaptive (co-)management or governance,” and “community-based management,” are reported to perform better. However, it is important to account for context-specific circumstances. Successful governance does not always have a straightforward design

and might involve aspects from different paradigms in response to the problem it addresses. Furthermore, the relationship between water governance and water sustainability performance is complex and influenced by the specific context within which water governance operates. Context shapes how the paradigms are translated on the ground, how they perform, and what is needed to address specific water problems, including how successful governance pathways relate to the nature of problématiques (i.e., problem contexts). This requires a nuanced understanding of context, as there are no simple, one-size-fits-all solutions to governance challenges.

The findings presented in this dissertation contribute to a deeper understanding of the water governance paradigms and the interactions between governance, context, and water sustainability performance within the water governance literature. The results emphasize the need for recognizing the shaping influence of the context within which governance operates. The insights into problem contexts provide policymakers with an entry point for developing tailored policies that effectively address specific challenges.

Framework paper

Toward sustainable water governance: Paradigms, context, and sustainability performance

1. Introduction

“No water, no life. No blue, no green” (Earle, 2009). These simple yet powerful words by American marine biologist Sylvia Earl capture the core of how water and life on Earth are intertwined. This message is especially relevant today, given the increasing pressure on water resources. Water crises continue to intensify globally, raising concerns within scientific and policy circles. Water resources worldwide face critical challenges due to climate change, environmental degradation, competing human activities, and ongoing global trends like urbanization and globalization (Cosgrove & Loucks, 2015). In March 2023, world leaders assembled in New York City for the first UN Water Conference in nearly half a century, marking a significant step forward in the international arena (“The Water Crisis Is Worsening. Researchers Must Tackle It Together,” 2023). A recent study by Richardson et al. (2023) reports that freshwater is among the six planetary boundaries transgressed out of nine. The 2023 World Water Development Report also warns against the imminent risk of a global water crisis (United Nations, 2023). Halfway through the 2030 deadline, we are off-track in achieving Sustainable Development Goals (SDGs) 6 and 14, which focus on sustainable and healthy aquatic ecosystems (United Nations, 2023). Meanwhile, freshwater ecosystems are declining rapidly: freshwater biodiversity has declined over twice as much as terrestrial or marine species, while wetlands disappear at a rate three times faster than forests (Tickner et al., 2020). These crises are likely to worsen due to growing populations and water demands, changing water consumption behavior, land-use transformations, and the impacts of climate change, among other factors (Kummu et al., 2016; Trimble et al., 2022).

The water crisis is mainly acknowledged as a governance crisis (Taylor & Sonnenfeld, 2017) rather than being related to a physical lack of resources (Biswas & Tortajada, 2023). This is also reflected in the growing body of literature that explores the role of governance in creating water crises and shaping how societies respond to the uncertainties surrounding their water futures (Taylor & Sonnenfeld, 2017). Governance failures are observed globally, manifesting in various forms. Issues such as weak civil societies, corruption, rigid bureaucracies, excessive regulations, fragmented sectors, unsustainable consumption patterns, and a predominant focus on economic concerns over environmental ones are challenges faced across different contexts (Pahl-Wostl et al., 2012). Effective water governance is widely advocated as a key to addressing water issues and ensuring sustainable water resource management (Araral & Wang, 2013; Özerol et al., 2018; Pahl-Wostl et al., 2012). With the emphasis on sustainable development, resilience, and adaptive capacity, new and diverse governance approaches—such as a greater emphasis on the role of government, an integrated and coordinated approach to managing water resources, and varying degrees of decentralization and participation—have emerged (Jiménez et al., 2020; Pahl-Wostl et al., 2012). Some governance approaches, such as shifting the provision of water services from the government to the private sector, adopting an integrated approach to managing water resources, and implementing participatory management systems, are widely adopted under the assumption of universal applicability (Meinzen-Dick, 2007; Pahl-Wostl et al., 2012), particularly when they align with prevailing paradigms (i.e., ideational underpinnings of water governance approaches [NEWAVE, n.d.]). However, a number of failures have been documented, mainly when these approaches were spread across diverse contexts (Meinzen-Dick, 2007; Ostrom, 2007; Pahl-Wostl et al., 2012). Understanding governance challenges and designing effective management practices require a closer inspection and scrutiny into paradigms as they may influence how policies are structured, which actors are involved, and the strategies they pursue (Hogan & Howlett, 2015).

The body of literature on various governance paradigms and how well they work to address water-related challenges, ensure sustainable water management, and maintain the health of water systems has increased since the 1990s. Among the empirical literature, some studies examine governance paradigms in specific cases, shedding light on their (in)effectiveness in unique contexts (e.g., Hegga et al., 2020; Rouillard et al., 2014). Others delve into specific governance paradigms across different contexts, examining several cases (e.g., Adams et al., 2020; Molle & Closas, 2020). Numerous studies have also been conducted which place particular emphasis on exploring the connection between governance and context. This includes examining how contextual factors shape governance and, ultimately, its effectiveness (e.g., Rowbottom et al., 2022; Suhardiman et al., 2021), as well as understanding the water-related problem context within which governance is embedded or implemented as a response (e.g., Kirschke et al., 2019; Srinivasan et al., 2012) and determining which governance arrangements are best suited to address them (e.g., Molle et al., 2018; Wuijts et al., 2018). While acknowledging the existing body of literature on water governance, this dissertation offers a synthesis and analysis of empirical findings to advance our understanding of the interactions between governance paradigms and characteristics, context, and water sustainability performance. Beyond synthesizing existing data, it provides significant conceptual insights into water governance paradigms and presents novel empirical findings in the examination of Integrated Water Resources Management (IWRM). Examining paradigms provides a valuable lens for a comprehensive understanding of water governance, enabling to explore the underlying principles guiding governance decisions, to examine the influence of context on governance practices as well as the dynamics within water governance. To achieve this objective, the dissertation is guided by the following aims:

Aim #1 Paradigms of water governance: Identify and examine the governance paradigms in empirical water governance literature.

Aim #2 Water sustainability performance: Explore patterns in water-related environmental sustainability performance[2] associated with different governance paradigms and identify

[2] This dissertation focuses on the performance in terms of water-related environmental sustainability. Specifically, it examines whether governance interventions lead to particular water-related environmental sustainability outcomes, such as changes in water quality, impacts on the quantity of water resources, and effects on water-

governance pathways that result in successful water sustainability performance in relation to the problem they address.

Aim #3 Water governance and context: Examine the role of context in achieving the effectiveness of water governance, explore the relation between context and governance paradigms, identify important water-related problem contexts (i.e., problématiques) that water governance addresses, and explore the link between these problem contexts and governance.

This cumulative dissertation is composed of the following four core contributions:

[A1] **Bilalova, S.**, Newig, J., & Villamayor-Tomas, S. Toward sustainable water governance? Taking stock of paradigms, practices, and sustainability outcomes. Submitted to WIREs Water.

[A2] **Bilalova, S.,** Villamayor-Tomas, S., & Newig, J. Water-related problématiques: five archetypical contexts of water governance." Submitted to Ecology & Society.

[A3] **Bilalova, S.,** Jager, N. W., Newig, J., & Villamayor-Tomas, S. Successful governance pathways across problem contexts: a global QCA analysis. Submitted to Ecology & Society.

[A4] **Bilalova, S.,** Newig, J., Tremblay-Lévesque, L.-C., Roux, J., Herron, C., & Crane, S. 2023. Pathways to water sustainability? A global study assessing the benefits of integrated water resources management. Journal of Environmental Management 343(October):118179.

The dissertation also refers to two supplementary papers that complement the arguments developed based on the core research papers and provide additional conceptual insights into the topic of interest:

[S1] **Bilalova, S.,** Valin, N., Burchard Levine, A., Geagea, D., Gerlak, A. K., Jager, N. W., Singh, R., Huitema, D., Koehler, J. K. L., Newig, J., Porada, H., & Rodríguez Ros, J. Now you see me, now you don't: the role and relevance of paradigms in water governance. Submitted to Ecology and Society.

[S2] **Bilalova, S.,** Jager, N. W., Newig, J., Huitema, D., & Koehler, J. K. L. Paradigms of water governance: A systematic review. Submitted to Ecology & Society.

This cumulative dissertation is structured as follows. Following this Introduction, **Section 2** introduces the concepts of water sustainability and water governance that this dissertation builds on and contributes to. **Section 3** briefly outlines the research design and methodology. The results are then described in accordance with the three central aims of this dissertation in **Section 4**. The dissertation concludes in **Section 5** by reflecting on the key insights and their theoretical and policy implications and suggesting avenues for future research.

related ecosystems, among others. Throughout the remainder of this paper, I will refer to this concept as "water sustainability performance."

2. Conceptual background

This cumulative dissertation builds on and contributes to two strands of literature: 1. Water sustainability and 2. Water governance. This section begins by introducing the concept of water sustainability, briefly touching on the broader concept of sustainability. It then discusses the complexities inherent in contemporary water issues as part of socio-ecological systems. The second part of this section elaborates on the concept of water governance, discussing how it is conceptualized and what it encompasses, its normative dimensions, including water governance paradigms as normative-cognitive frameworks, and the role of context.

2.1 Water sustainability

The concept of sustainability, first introduced as a global concern in 1972 at the United Nations Conference on the Human Environment, has travelled far, being used in a wide range of contexts and embraced by governments, international organizations, and grassroots social movements (Nightingale, 2019). It has also received extensive attention within the realm of water studies. Research has delved into diverse aspects of water sustainability, including the sustainability of water systems (e.g., Erős et al., 2023; Vollmer et al., 2016) and the management of water resources for sustainable development (e.g., McNabb, 2019; WWAP, 2015), among others. This focus extends into policy realms, notably through the Sustainable Development Goals (SDGs) 6 (clean water and sanitation) and 14 (life below water) as part of Agenda 2030. SDG 6 emphasizes access to drinking water, sanitation, hygiene, and sustainable management of freshwater resources, while SDG 14 aims to conserve oceans, seas, and marine resources sustainably, addressing issues such as acidification, eutrophication, declining fish stocks, and plastic pollution (United Nations, 2015). Among the targets within these goals, SDG 6.3 (improving water quality), 6.4 (increasing water-use efficiency and ensuring sustainable freshwater withdrawals and supply), and 6.6 (protecting and restoring water-related ecosystems), as well as 14.4 and 14.6 (sustainable fisheries management) are the targets that closely relate to sustainable freshwater systems.

Water sustainability can be understood as the design and management of water systems "to contribute fully to the objectives of society, now and in the future, while maintaining their ecological, environmental, and hydrological integrity" (Loucks 1997, p.518). Here, the maintenance of ecological and hydrological integrity can be understood as being related to "the quality and quantity of surface and groundwater as well as about the benefits and harms to the ecosystem resulting from diverse water uses" (Schneider et al., 2015, p.1584). While acknowledging water sustainability as a comprehensive concept encompassing diverse dimensions, such as environmental, social, and economic aspects, this dissertation narrows its focus to the environmental sustainability of water systems. Specifically, it examines the state of water-related ecosystems, including aspects such as water availability, quality, aquatic biodiversity, and basin condition, along with their associated services. The focus is primarily on freshwater systems such as lakes, rivers, groundwater, wetlands, etc., and transitional water bodies such as estuaries.

The current water issues are inherently complex, unpredictable, and difficult to control (Gain et al., 2021; Gupta et al., 2013). Often embedded in the intricate networks of socio-political, economic, and environmental dynamics, water systems have a complex relationship with society that shapes how water is viewed, used, shared, and managed (Fallon et al., 2021). Multiscalar and boundary-spanning characteristics of water resources, which involve various water users and other stakeholder groups over a large geographic area, further contribute to this complexity (M. M. García et al., 2019). Some of the water problems, such as non-point source pollution, have also been argued to be "wicked" (DeFries & Nagendra, 2017; Kirschke et al., 2019), defined as issues featuring high levels of complexity and interdependency of components, uncertainty of risks, unintended consequences, and changing patterns, and divergence in viewpoints, values, and strategic intentions (Head, 2008). Growing recognition of the complexity of social-hydrological systems has resulted in an increased application of the socio-ecological system as an analytical lens for understanding water-related problems and how to address them. Scientific research on social-ecological systems in the context of water has increased over the past two decades, from 1 publication in 1997 to 126 in 2023, based on a search on SCOPUS[3]. Social-ecological systems (SES) are multi-level, nested systems in which social and ecological components interact regularly with one another and through feedback loops (Gain et al., 2020). These systems are characterized by unidirectional or bidirectional relationships that occur both within and between humans and the natural world, creating mutual dependence where changes in one system influence the other (Bodin et al., 2019). This dissertation also considers water systems as social-ecological systems, using SES framing to identify contexts of water problems (A2).

2.2 Water governance

Water governance has gained popularity in policy and academic communities over the past few decades (Woodhouse & Muller, 2017; Zwarteveen et al., 2017). The emergence and rise of the term "water governance" signify two major shifts. Firstly, water has come to be recognized not only as a natural phenomenon but also as a social one, shifting the focus from infrastructure to organizational, financial, and institutional solutions for water issues. (Zwarteveen et al., 2017). Secondly, direct state control was diminished, with responsibilities for resource allocation, public service provision, and control and coordination shifting to the private sector and civil societies as part of neoliberal reforms (Zwarteveen et al., 2017). There are various interpretations of what the concept of water governance entails, with little consensus, which has manifested itself in several definitions (Lautze et al., 2011; Özerol et al., 2018; Whaley & Weatherhead, 2016; Woodhouse & Muller, 2017). In this dissertation, I build on the definition by Pahl-Wostl (2015) and define water governance as the social function that regulates the development, management, and provision of water resources in light of diverse water-related issues or broader water-related problématiques (i.e., the water-related context of the recurring "clusters" or "ensembles" of water-related issues), guiding water resources toward a sustainable state (A1). Despite being used interchangeably sometimes, water governance

[3] The search was conducted in May 2024 with the following search string: TITLE-ABS ("social-ecological system*") AND TITLE-ABS (freshwater* OR groundwater* OR water* OR river* OR basin* OR watershed* OR catchment* OR wetland* OR lake*).

differs from management as it “sets the rules under which management, ‘activities of analyzing and monitoring, developing and implementing measures to keep the state of a water resource within desirable bounds,’ operates” (Pahl-Wostl et al. 2012, p. 25).

Water governance encompasses institutions (e.g., rules and norms), governance structures (e.g., formal organizations, decision-making bodies, and informal networks), and processes (e.g., means for carrying out the functions and the performance of governance, such as defining institutional mandates, negotiating values, and resolving conflicts, formulating policies, etc.) that determine how actors exercise authority, make decisions, exercise responsibility, and ensure accountability (Bennett & Satterfield, 2018; Patterson et al., 2017; Sehring, 2009). Not all water institutions are formal, as there are also informal institutions. Formal institutions are established rules and procedures, usually documented and explicit, and enforced through official channels like executives or legislatures (e.g., water regulation, water use control, and policing), while informal institutions, such as social norms or traditional water-sharing practices in local communities, are typically unwritten, implicit, and enforced outside of official channels (Hassenforder & Barone, 2019). Formal and informal systems are acknowledged as interconnected and sometimes mutually reinforcing in the context of water governance (Misra, 2014). Informal institutions are local-level translations of formal institutions and can also gradually become part of formal institutions, while formal institutions derive from and depend on the informal ones for their stability and strength (Saleth & Dinar, 2004). Since informal institutions remain the foundation upon which formal institutions are built, designing efficient formal institutions requires considering their interactions (Lukat, Pahl-Wostl, et al., 2022; Saleth & Dinar, 2004). Although both formal and informal institutions and their interactions are recognized as necessary for achieving sustainable natural resource governance (Rahman et al., 2017; Yami et al., 2009), it is argued that they should be treated differently due to the divergence in their sources and rates of change (Saleth & Dinar, 2004). Unlike informal institutions, which evolve through sociocultural processes and change very slowly, formal institutions have identifiable origins and change through reforms (Saleth & Dinar, 2004). As studying formal institutions offers a basis for rigorous analysis and comparison across different contexts, this dissertation mainly focuses on formal institutional arrangements.

Water governance can take many different forms, each with its own constellation of characteristics related to governance structures and processes. For instance, governance can be driven from the top and by government agencies at various levels, or from the bottom by civil society (the public) and/or private actors, or with shared decision-making through the cooperation of government with private actors and/or civil society (Driessen et al., 2012). The institutional, structural, and procedural elements of water governance can be at various levels and scales (Bennett & Satterfield, 2018), with governing organizations established within jurisdictional, hydrological boundaries, or both (Moss & Newig, 2010). Governance can also be characterized by varying degrees of interactions across different levels of government (vertical interplay) and across policy sectors (horizontal interplay) (Lukat et al., 2023; Young, 2002). It can also be adaptive, characterized by power sharing among government levels and flexible institutions that facilitate learning and experimentation in response to change and uncertainty (Cleaver & Whaley, 2018). All these characteristics inform the ways in which governance is structured and implemented and water resources are developed, managed, and provisioned, as well as which actors are involved and how they interact.

The term "governance" in the context of water has primarily been used to normatively prescribe or help design institutional, organizational, and financial arrangements for decision-making and water regulation (Zwarteveen et al., 2017). Since water problems are perceived as governance crises, there has been widespread recognition of "good," "effective," or "sound" governance among international initiatives, primarily linked to the promotion of, for example, accountability, transparency, and integrity (Castro, 2007; Zwarteveen et al., 2017).

Wide acknowledgment of the role of governance in addressing water problems has also led to the emergence and promotion of a wide range of paradigms, defined as a set of more or less coherent normative ideas intersubjectively held by groups of actors about the problématiques that require public intervention, corresponding governance objectives, and appropriate means to achieve them (S2). Integrated Water Resources Management (IWRM) (Benson et al., 2015), water security (Bakker & Morinville, 2013), adaptive management (Chaffin et al., 2014), market environmentalism (Furlong, 2011), and the hydraulic mission (Molle et al., 2009) are some of the key water governance paradigms. Among them, IWRM stands out as the most influential globally (Challies & Newig, 2022), being integrated into the SDG indicator framework under Agenda 2030, which requires countries to measure the progress of its implementation through indicator 6.5.1 (Degree of integrated water resources management implementation). Paradigms play a role in shaping how problems are perceived, which policy goals to pursue, and which instruments to apply to attain these goals (Hall, 1993; Challies & Newig, 2022). For instance, the hydraulic mission aims at total water control through top-down, technocratic planning (Molle et al., 2009), while IWRM focuses on imbalances in water supply and demand, seeing the solution in demand management (Benson et al., 2015; L. E. García, 2008). IWRM promotes governance characteristics such as basin-scale governance and multi-level, multi-actor, and decentralized decision-making with vertical and horizontal interplay (Benson et al., 2015; Gerlak & Mukhtarov, 2015; Lukat, Schoderer et al., 2022). Setting the agenda for political actions at different levels (Challies & Newig, 2022), paradigms may also impact which options are accepted, disregarded, or ignored, as well as which groups are given greater power or are marginalized (Molle, 2008). In recognition of the foundational role of paradigms in water governance, three articles in this dissertation (A1, S1, and S2) focus on and problematize them as a means to understand water governance.

Some water governance paradigms like privatization, integrated water resources management (IWRM), user-based management like water users associations (WUAs), and river basin management have been widely promoted as blueprint solutions to water problems and have been implemented without considering context, long-term performance monitoring, or critical reflection on their effectiveness (Ingram, 2011; Meinzen-Dick, 2007; Moss, 2012; Pahl-Wostl et al., 2012). This approach of treating certain governance paradigms as universal remedies have been heavily criticized in the water governance literature, calling for more attention to contextual nuances and context-specific solutions (Ingram, 2011; Ribeiro & Johnsson, 2018).

Governance is context-sensitive, emerging from the internal dynamics of the system it is embedded in, as opposed to being external to the system in a way that can be extracted and plugged into different contexts (Aggarwal & Anderies, 2023). To prevent the unsuccessful transfer of blueprint approaches, it is important to consider the governance context in which they arose and the context to which they are being transferred (Bressers & de Boer, 2013). The context of a place, signified by its nexus of physical, natural, political, cultural, social, and economic characteristics, defines its distinctiveness, shaped by past events, technological and institutional developments, and the accumulation or decline of social capital, all within a temporal dimension (Ingram, 2011). Such contextual peculiarities, for example, existing path dependency or policy layering, political context and ideology, and resources available, define how paradigms manifest once they travel across various contexts (Benson, 2009; Lukat, Schoderer, et al., 2022; Mukhtarov, 2022; Sehring, 2009; Waylen et al., 2015). Therefore, in this dissertation, I go beyond only assessing the water sustainability performance of water governance paradigms to closely examine the governance characteristics we observe once these paradigms are put into practice.

As posed by the SES framework, socio-ecological outcomes in SES is a result of the interactions among resource systems, the resource units produced by these systems, actor groups, and governance systems that influence or are indirectly impacted by these interactions within the context of related ecological systems and broader social-political-economic settings (Ostrom, 2007). Embedded in a broader context, water-related problématiques reflect the interaction between resource systems and their users, specifically the use of resource units from these systems and the outcomes of this interaction concerning the (un)sustainability of these resource systems (A2). This dissertation focuses on water-related problématiques[4] as part of a broader context. It considers water-related problématiques as critical components of its analysis for understanding their interaction with governance and identifying governance pathways that effectively address them.

3. Research design & methodology

This dissertation is based on the four core contributions (Figure 1). The articles have been referred to as A1, A2, A3, A4 (for core publications), S1, and S2 (for supplementary publications) throughout the dissertation for ease of reference. Among the core publications, A4 has been published open access in the Journal of Environmental Management. A1 and A2 have been revised and resubmitted to WIREs Water and Ecology and Society, respectively, while A3 has been submitted to Ecology and Society. All articles have been written as a part of the project "NEWAVE - Next Water Governance." NEWAVE is a Marie Skłodowska-Curie Innovative Training Network (ITN) and received funding from the European Union's Horizon 2020 research and innovation programme.

This dissertation employs a mixed-method approach that includes a range of research methods to examine and analyze governance (i.e., paradigms and governance characteristics), water-

[4] Throughout the dissertation, I use "problématique" and "problem context" interchangeably.

related problématiques they address, and the governance pathways to achieving water sustainability (Figure 1). The research in A1, A2, and A4 is quantitative in nature. A1 and A2 provide insights by synthesizing and analyzing data collected through a systematic literature review. A4 employs a quantitative research approach and examines large-N data through statistical analysis. In A3, a set-theoretic approach explores governance pathways for successful water sustainability performance in relation to the problems they address using Qualitative Comparative Analysis (QCA). Combining methods allows to gain deeper insights into the research phenomenon that are not possible to completely understand when employing simply qualitative or quantitative methodologies (Dawadi et al., 2021).

	Article 1 [A1]	Article 2 [A2]	Article 3 [A3]	Article 4 [A4]
Title	Toward sustainable water governance? Taking stock of paradigms, practices, and sustainability outcomes	Water-related problématiques: five archetypical contexts of water governance	Successful governance pathways across problem contexts: a global QCA analysis	Pathways to water sustainability? A global study assessing the benefits of integrated water resources management
Research questions	What is the state of knowledge production in the empirical water governance literature reporting on sustainability outcomes? What are the key water governance paradigms identified, and how these paradigms relate to governance characteristics, water-related problématiques, and sustainability outcomes?	What are the prominent water-related problem contexts addressed by water governance systems?	What are the governance pathways that lead to successful water-related environmental sustainability performance in relation to the problems they address? Whether and how do these successful governance pathways relate to the nature of problem contexts?	How does the level of Integrated Water Resources Management (IWRM) implementation as well as its four dimensions associate with achieving water-related environmental sustainability indicators under SDG 6?
Type of research	Decsriptive and exploratory	Exploratory	Explanatory	Exploratory
Methodology	Quantitative	Quantitative	Set-theoretic	Quantitative
Research method	Systematic literature review with descriptive statistics and bibliometric analysis	Systematic literature review with cluster analysis	Case-survey analysis with QCA and qualitative assessment of example cases	Large-N study with regression analysis
Aims contributed	Aim 1- Aim 3	Aim 3	Aim 2 & Aim 3	Aim 2 & Aim 3

Figure 1 Research design and methodology of core publications included in this dissertation.

Articles 1-3 in this cumulative dissertation use a dataset built through the systematic literature review of empirical studies reporting on water governance and its water sustainability performance (Figure 2). Article 1, a systematic review, primarily reports on the almost entire dataset. While Article 2 covers specific coding items in the dataset for analysis, Article 3 focuses on particular cases rather than the dataset as a whole, which will be explained in the following paragraph. The dataset contains 223 cases from 165 studies published between 1985 and 2020, identified using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline (Moher et al., 2009). The data was extracted from the included publications based on a coding scheme covering six categories—bibliographic data, research framework, research design, case-related information, the characteristics of the water-related context, water governance, and water sustainability performance (see A1, supplementary material). For water sustainability performance, cases are categorized as successful, failed, or neutral/mixed based on the outcome of governance interventions. A case is considered successful if the intervention improves the sustainable use of water resources and the health of freshwater ecosystems. A case is classified as a failure when interventions do not address the problem or worsen water-related environmental issues. Cases where intervention improves one aspect but worsens another or brings no change are classified as neutral/mixed.

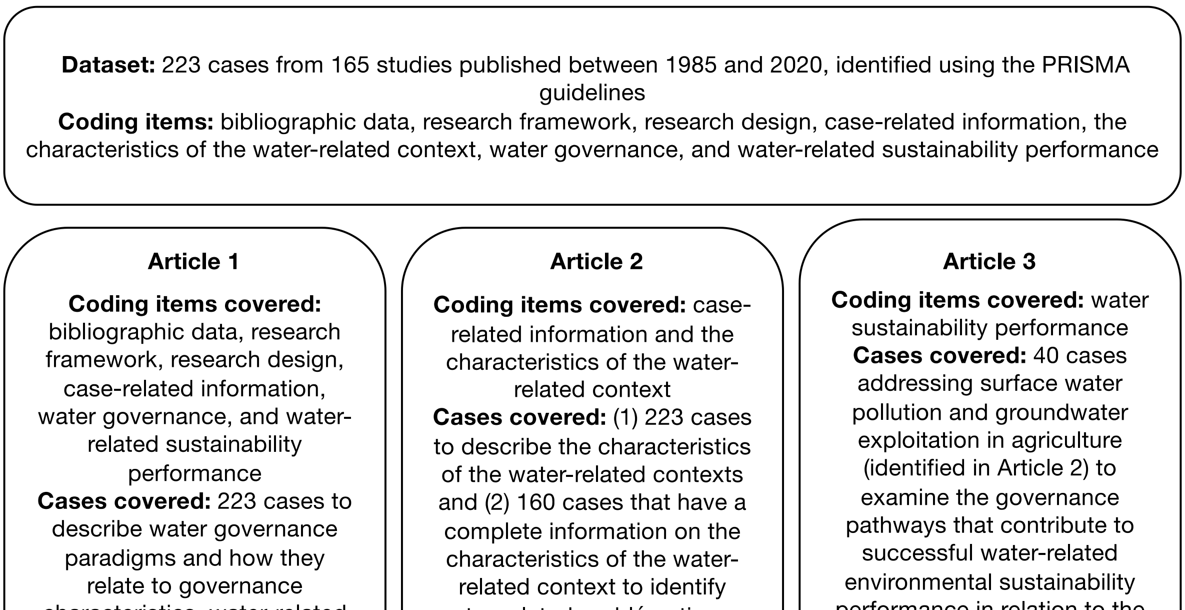


Figure 2 Use of the dataset built through a systematic literature review of empirical studies by three articles of this dissertation.

Article 1 is a systematic literature review examining empirical studies on water governance and its water sustainability performance. Socio-bibliometric information derived from the literature informs about the state of knowledge production in this body of literature. The study mainly looks at the type of produced knowledge and the state of knowledge accumulation. The review also explores water governance paradigms and examines how these paradigms relate to governance characteristics, water-related problématiques, and sustainability outcomes.

Article 2 focuses on the water-related problématiques addressed by water governance systems. It draws upon the data on three attributes of the water-related problem context—water use, water resources, and sustainability issues—from the previously described dataset. The study identifies five important water-related problématiques by clustering 160 cases according to these attributes using archetype analysis (Oberlack et al., 2019) as an analytical approach. The paper used agglomerative hierarchical clustering for the cluster analysis using Euclidean distance and Ward's method. Multiple correspondence analysis (MCA) was performed to reduce the dimensionality of the categorical data before performing the cluster analysis.

Article 3 studies governance pathways that lead to successful water-related sustainability performance and explores the link between these governance pathways and the nature of the problem context. It examines water governance across 43 cases addressing surface water pollution and groundwater exploitation in agriculture. It covers 40 cases from the original dataset. Among these, three cases exhibited mixed sustainability performance: governance interventions successfully addressed one issue but failed to address another. Consequently, each outcome was coded separately as a distinct case, resulting in a total of 43 cases. Article 3 used information on water-related sustainability performance extracted from the dataset. In addition, a deductive coding scheme gathered data on governance capacity, institutional fit and interplay, decentralization, participation, and adaptiveness/knowledge integration (see A3, supplementary material) via case surveys of original studies within the dataset. In cases where information was insufficient, supplementary data from grey literature and author surveys were included. The study used fuzzy set qualitative comparative analysis (fsQCA).

Finally, Article 4 draws on open-source databases (see A4, supplementary material) to examine a particular water governance paradigm—IWRM—in terms of its effectiveness in achieving water-related sustainability indicators. More specifically, the paper studies the associations between SDG 6.5.1 (both IWRM total score and the dimensions of SDG 6.5.1) and key water-related environmental sustainability indicators: SDG 6.2.1a (access to basic sanitation), 6.3.1 (treated wastewater), 6.4.1 (water-use efficiency), 6.4.2 (water stress), 6.6.1 (freshwater ecosystems, although here the trophic state and turbidity variables were used), and 6.3.2 (ambient water quality). The study employed regression analysis, controlling for variables related to socio-political factors (i.e., regulatory quality, rule of law, government effectiveness, control of corruption, political stability and absence of violence or terrorism, voice and accountability, open data score, and population density), economic factors (GDP per capita), and environmental factors (i.e., relative forest area, average annual temperature change, national rainfall index (NRI) (mm/year), agricultural land area, and total harvested irrigated crop area). Multiple models were run for each SDG 6 indicator, sequentially examining the effects of individual control variables to prevent model overfitting. The final model group for all dependent variables controlled for the effects of only significant variables. The analysis covers 124 countries for all these SDGs, except for SDG 6.3.1 and 6.3.2, which cover 112 and 85 countries, respectively.

4. Results

The results section of this cumulative dissertation provides a comprehensive synthesis of findings from the contributing publications. The framework depicted in Figure 3 illustrates the relationships among water governance (i.e., governance paradigms and characteristics), context (including water-related problématiques), and water sustainability performance, which align with this dissertation's three core aims. The results presented in this section are organized according to this framework. The first sub-section centered around aim 1, presents paradigms of water governance, drawing extensively from A1 and supported by S1 and S2. The sub-section presents the identified governance paradigms, including their co-appearance patterns, temporal and spatial distributions, and what governance characteristics constitute them. Subsequently, the second sub-section, dedicated to aim 2, delves into the water sustainability performance of water governance systems, synthesizing findings from A1, A3, and A4. The final sub-section, addressing aim 3, examines the interplay between governance and context, drawing insights from all core publications (A1-A4). The results discuss the role of contextual factors in governance effectiveness and introduce the five water-related problématiques identified. This sub-section also discusses the interaction of problématiques with paradigms and presents how the nature of problématiques and successful governance pathways are linked.

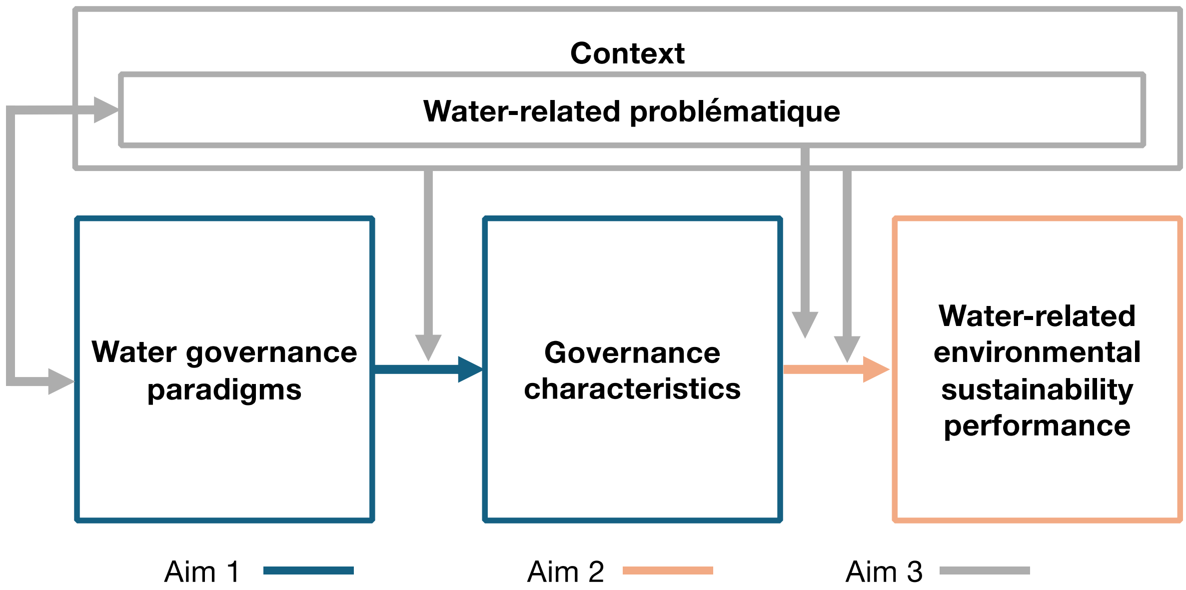


Figure 3 Framework depicting the relations among water governance paradigms, governance characteristics, water sustainability performance, and context.

4.1 Paradigms of water governance

Reviewing 93 studies on water governance paradigms revealed the existence of multiple paradigms (S2, Figure 4). Some of these paradigms are more prevalent and extensively studied than others (A1, S2). For instance, in a review of 223 cases of water governance, A1 found that 23% (n=52) focus on an "integrated approach to water management," while only 4% (n=9) focus on the "resilience" paradigm. The prevalence of an "integrated approach to water management" has also been observed in S2, being discussed in 76% of reviewed studies (n=71). This difference could be attributed to various factors, including the active promotion and implementation of specific paradigms by policy circles, such as the promotion of Integrated Water Resources Management (IWRM) under Agenda 2030 (A1). Various actors, such as government entities, civil society, international non-governmental organizations, scientific communities, citizens, multinational corporations, and global private environmental consultancy firms, play crucial roles in advocating for and implementing these paradigms (S1). The review of studies on water governance paradigms highlights the important role of government actors in promoting and implementing paradigms (S2). In addition to government actors, international funding and donor organizations deserve particular attention for their influence in promoting these paradigms (S1, S2). They often require significant governance adjustments and the acceptance of specific paradigms in exchange for financial support (S1). This further explains the widespread adoption of certain paradigms in diverse contexts. In summary, the differing degrees of attention given to various paradigms governing water resources points to the influence of diverse actors. These actors determine which paradigms are prioritized and widely implemented.

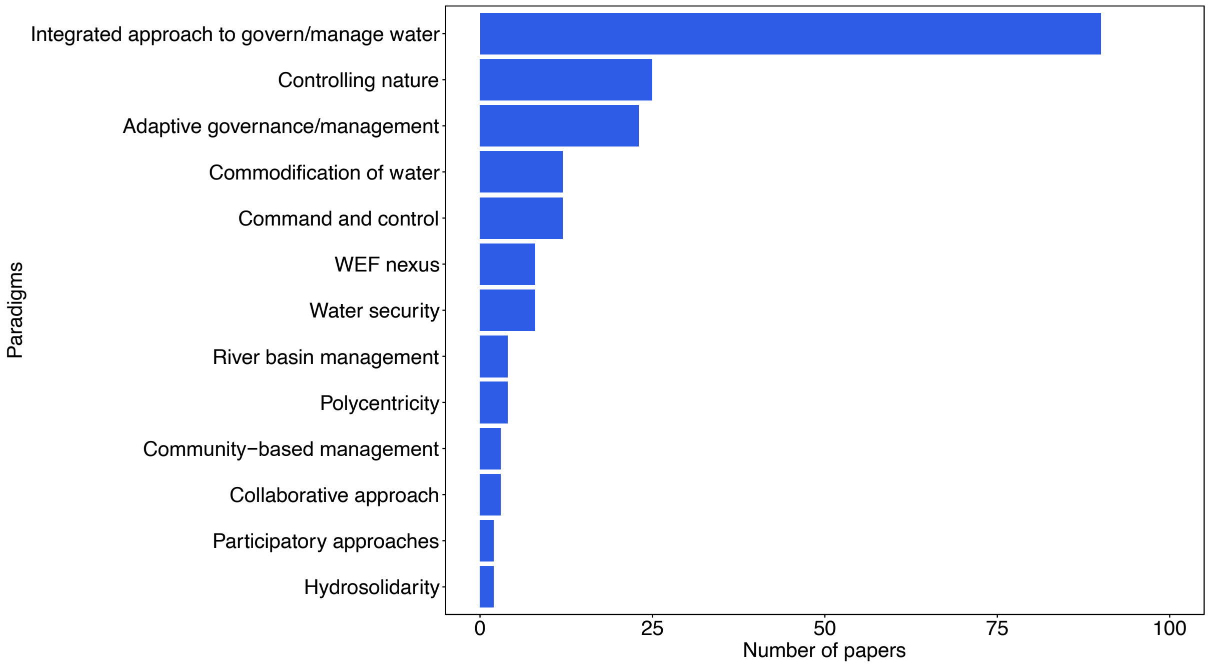


Figure 4 Paradigms identified across the included studies. Source: S2.

A1 also shows that that most paradigms co-occur with others. For instance, the "adaptive (co-)management or governance" paradigm appears with other paradigms in 96% of cases (n=26), and in 65% of these cases (n=17), more than two paradigms are observed together. Meanwhile, the "state-centric/command and control governance" paradigm is observed with other paradigms in 75% of cases, with 62% (n=13) co-appearing with more than two paradigms (A1). The observed pattern can be explained in two ways. First, it may inform us about the adaptable nature of paradigms (A1). This aligns well with institutional change theory, indicating that "new institutions" often build upon existing arrangements, creating complex interaction patterns rather than completely replacing "old" approaches (S1). Another explanation could be that the pattern emerges from applying specific paradigms discursively or metaphorically (A1).

Such co-appearance of paradigms mainly arises from the interplay between the paradigm and the context in which it is applied—a topic that will be discussed further in the final sub-section. These possible explanations underscore the need for future in-depth analysis to unpack these nuances and explore the implications for governance.

The spatial distribution of paradigms in water governance reveals interesting patterns across regions (A1). A1 shows that across European cases, prevalent paradigms such as the "integrated approach to water management," "river-basin/catchment management," and the paradigm of "water as a common good and/or heritage" shape the discourse. Some of these paradigms are often grounded in regional policies such as "river-basin management" in the case of WFD. Conversely, cases in Southern Asia are frequently observed with paradigms such as "community-based management" and "water as a resource seen by engineers" (A1). Here, the prevalence of paradigms, such as "community-based management," could be linked to the endurance of traditional, informal systems (A1). New ideas and paradigms on water governance are argued to be often developed and endorsed in the Global North, particularly by institutions such as the World Bank, before being mainly transferred to the Global South, where they may clash with existing systems (S1, Gupta, 2009; Meijerink & Huitema, 2010). Examining the spatial distribution of these paradigms helps to reveal the complex interplay of power and ideology within water governance worldwide.

The temporal evolution of water governance paradigms reveals a dynamic interplay with shifting societal goals and priorities (S1). Examining the temporal prevalence of paradigms within the reviewed empirical water governance literature from the 1980s until the end of 2010s, A1 reveals that from the 1980s to 1990s, "community-based management" prevailed until it yielded ground to "governance with diffusion of authority." By 1995, "market environmentalism" emerged as a dominant paradigm until 2000. Various global institutions, such as the OECD and World Bank, actively worked to incorporate neoliberal approaches and principles into discussions on water governance, effectively shaping water governance practices across diverse countries through measures such as commodification and privatization (S1). This was followed by the decade-long dominance of an "integrated approach to water governance" until 2010. Subsequently, "adaptive (co-)management or governance" took precedence for five years (A1), with the growing realization of the complexities of socio-ecological systems and the danger of simple solutions in water governance. This was later succeeded by "participatory and collaborative governance" from 2015 to 2020. While these paradigms reflect a progression mirroring societal shifts (S1), A1 reveals that no paradigm, once introduced, disappeared entirely from the reviewed water governance literature. All in all, water governance has an evolving nature with "new" paradigms emerging and becoming dominant over time; however, the observation of enduring legacies indicates that this evolution is more like a continuum rather than consisting of major or abrupt shifts.

Once paradigms are adopted and operationalized, they manifest themselves in a diverse mixture of governance characteristics. Some of these governance characteristics align with the embedded principles of the respective paradigms (A1). Paradigms may shape how stakeholders perceive and prioritize different problems, consequently influencing the solutions and governance structures these actors implement (S1). A1 shows that, for example, participation and collaboration in governance are often observed with the “participatory and collaborative governance” paradigm (36%; n=48) and the “integrated approach to water governance” paradigm (28%; n=37), both of which emphasize participatory decision-making to ensure that perspectives and interests of different stakeholders are considered. Similarly, governance capacity is frequently observed with “integrated approach to water governance” (29%; n=22), “governance with the diffusion of authority” (28%; n=21), and in over half of cases with “adaptive (co-)management” (58%; n=15), all of which recognize the complexities within water systems, necessitating the presence of governance capacity to address these complexities (A1). However, both A1 and S2 show that paradigms as well often encompass governance characteristics that do not necessarily align with the fundamental principles of the paradigm. This pattern emerges mainly due to the context in which the paradigm is implemented, which will be explained in the final sub-section.

The results reveal a nuanced relationship between paradigms and governance, challenging the notion of a simple and linear influence. While paradigms indeed have the potential to transform governance as a "source code" for arrangements (S2), governance systems often emerge from an interplay of multiple paradigms rather than being deterministically derived from a single one. The results on the co-occurrence of paradigms discussed earlier in this sub-section also contributes to this argument. Moreover, the direction of influence between paradigms and governance is also not always one way as existing contextual factors and governance practices may significantly shape which paradigms take hold and how they are implemented. This aspect will be further explored in the final sub-section, discussing how responsive paradigms are to the context. Regardless of whether a paradigm shapes how governance is structured and practiced, a closer examination of paradigms allows for a more comprehensive understanding of water governance dynamics. However, reviewing the literature in A1 reveals an interesting observation about the absence of direct references to water governance paradigms in most studies. Most papers cover paradigms without acknowledging them or problematizing them (S2). Furthermore, S2 also identified the absence of a common term to indicate a “paradigm,” in contrast to the multitude of terms used. This lack of explicit engagement with paradigms in the literature may limit our comprehensive understanding of water governance, including the design of more effective responses.

4.2 Water sustainability performance

Examining the water sustainability performance across governance paradigms, A1 shows that certain paradigms, such as “participatory and collaborative governance,” “integrated approach to water management,” and “adaptive (co-)management or governance,” and “community-based management,” among others, are reported to perform better than others. For instance, 63% of cases (n=31) exhibiting “participatory and collaborative governance” were successful, in contrast to only 32% (n=9) success cases observed under the “state-centric/command and control governance” paradigm. An example of a clearly successful case is the article by Pereira et al. (2009), who demonstrate the effectiveness of participatory river-basin management in the Sao Joao River basin in Brazil, addressing pollution and environmental challenges due to eutrophication. Similarly, the study by Cong et al. (2020) highlights the success of a polycentric wastewater governance model in the Binhai textile industrial park in China, which led to improved environmental outcomes through widespread acceptance of emission standards. Conversely, an example of an unsuccessful case is discussed by Mirnezami et al., (2020), who describe how monocentric governance and the exclusion of farmers from decision-making processes was ineffective in addressing the declining groundwater levels.

A4 delves further by examining the water sustainability performance of the dominant paradigm, IWRM, promoted as a universal blueprint within Agenda 2030 for addressing water-related problems across various contexts (Lukat, Schoderer, et al., 2022). The analysis reveals that IWRM, both its total score and its dimensions (i.e., enabling environment, institutions, and participation, management instruments, and financing) measured through SDG 6.5.1., is generally associated with positive outcomes in water-related sustainability indicators. These include SDG 6.2.1a (access to basic sanitation), 6.3.1 (treated wastewater), 6.4.1 (water-use efficiency), and 6.6.1 (health of freshwater ecosystems measured by the trophic state). For the remaining water-related sustainability indicators, the results show a positive association with water stress (SDG 6.4.2), potentially due to reverse causality. Countries experiencing water stress are more inclined to improve their implementation of IWRM (A3). No significant association was found between IWRM-related factors and two SDG 6 indicators: water quality (SDG 6.3.2) and turbidity (SDG 6.6.1). It is important to interpret these results cautiously. Firstly, this study found a strong influence of contextual factors as controlling variables, which will be further discussed in the following sub-section. Additionally, IWRM has often been applied symbolically, with many individuals and institutions using it to access more funds and gain greater acceptability and visibility while continuing past practices (Biswas, 2008). This is especially important considering the data collection method for assessing IWRM implementation, which relies on self-assessment surveys. This raises questions about objectivity, transparency, and comparability (Bertule et al., 2018). The lack of operationalization of the IWRM concept results in highly subjective assessments that stakeholders interpret the survey questionnaire on the enabling environment, institutions, management tools, and financing for IWRM differently (Benson et al., 2020).

A paradigm can be found in diverse forms, with different characteristics in each water governance case. Therefore, it is important to look beneath the paradigm and examine the characteristics. Examining the characteristics (i.e., how governance is structured and implemented, how decisions are made, and which actors are involved and how they interact) of 43 water governance cases through QCA, A3 reveals three successful governance pathways encompassing diverse characteristics. Two successful governance pathways address the problématiques of "surface water pollution": one adopts a more straightforward approach with centralized governance and sufficient governance capacity, while the other pathway is distinguished by a more intricate combination of factors, including increased interplay, participation of non-state actors, integration of adaptation/knowledge, and adequate capacity. The following subsection will discuss how these governance pathways relate to the nature of the problem context (i.e., problématique) they address. The third successful governance pathway, on the other hand, encompasses cases of both “groundwater exploitation for agriculture" and "surface water pollution" and requires governance with all the characteristics present—the presence of governance capacity and a higher degree of institutional fit, interplay, decentralization, and adaptation/knowledge integration. It shows that success in addressing any water problems results from multiple reinforcing governance characteristics (such as the importance of the governance capacity for successful adaptiveness, decentralization, and participation, or the role of interplay for a successful fit) rather than any single aspect. Finally, A3 emphasizes the importance of governance capacity.

Literature on the performance of water governance reveals notable gaps. First, only 19% (n=41) of the studies in A1 present qualitative and/or quantitative data on how water governance and/or interventions affect water sustainability outcomes, providing very detailed information. A similar pattern was also observed in S2, as almost half of the reviewed studies on water governance paradigms (41%; n=38) do not examine the effects (i.e., social, economic, and environmental) related to the introduction of paradigms in practice, not even to some extent. This observation extends beyond these two papers as the literature takes a broader focus on outputs (such as programs or plans) rather than impacts due to the time-intensive nature of studying governance effects as well as the numerous factors at play, such as environmental, social, political, and economic institutional, and administrative factors for affecting actual changes in water ecosystems (S1, S2; Akhmouch et al., 2022). However, investigating how governance paradigms actually perform would help to prevent the pitfall of labeling them as "successes" without clarifying "success of what" and "for whom" (S1). Furthermore, A1 reveals that there are very few studies (8%; n=13) that explore "what works (or does not work) to achieve a particular desired outcome or condition," which is crucial for evidence-based policymaking (Sanderson, 2002). Understanding which governance configurations improve, e.g., water availability, quality, and ecosystem health could guide policymakers toward effective actions and improve existing systems for desired outcomes (A1).

4.3 Water governance and context

The importance of context in water governance has been widely acknowledged in the literature, especially how context influences governance effectiveness (Bressers & de Boer, 2013; Ingram, 2011). The findings of A4 further contribute to this discussion, revealing that contextual factors such as socio-political, economic, and environmental factors play an essential role in the association between IWRM implementation and water-related sustainability indicators. For example, when controlling for government effectiveness and GDP per capita, the significance of IWRM-related variables diminishes for SDG 6.2.1a (access to basic sanitation) and SDG 6.4.1 (water-use efficiency), except for financing. Additionally, controlling for environmental factors such as forest cover and temperature results in an insignificant association between SDG 6.4.2 (water stress) and IWRM-related variables insignificant, while controlling for the national rainfall index (NRI) eliminates significant associations with SDG 6.4.2 (water stress) and SDG 6.6.1 (trophic state). These findings highlight the importance of context, suggesting that the effectiveness of IWRM-related variables in achieving specific SDG targets may be highly dependent on the broader socio-economic and environmental conditions of a country.

The interaction between paradigms and context is a dynamic process, as the functional aspects of a paradigm and the context within which it operates are deeply intertwined and co-evolve over time (S1). Contextual factors, such as cultural norms, socioeconomic conditions, and historical legacies, significantly shape a paradigm's formulations, interpretation, and implementation (S1). Although paradigms have certain intrinsic principles, they seldom exist in their purest form, often amalgamating with existing ideas to shape governance structures or routines once they are introduced due to contextual factors (S1). As such, their operationalization within specific contexts frequently results in different governance arrangements, incorporating a mix of diverse characteristics, some of which may not align with paradigms' original principles (A1, S2). For example, the distribution of governance characteristics across paradigms reveals dominance of participation and collaboration across all water paradigms, including "state-centric/command and control governance," which has a centralized governance structure (A1). Almost equal share of centralized and decentralized governance modes among the studies focusing on the paradigm of "integrated approaches to water management" also supports this observation (S2). Understanding water governance requires looking beyond the surface of paradigms to uncover the underlying actor structures, scalar dynamics, and power relations that mold their adaptation and application within different settings (S1).

Embedded within a broader context, problématiques define the nature of governance interventions required. Using archetype analysis as an analytical framework (Oberlack et al., 2019) to examine the interactions among water resources, their uses, and the related (un)sustainability issues associated with their use, A2 identifies five distinct problématiques that water governance addresses. Among these problématiques, "groundwater exploitation in agriculture" is the largest, comprising 35% of the cases (n=56). This problématique encompasses cases mainly dealing with water quantity issues in the context of groundwater withdrawal for agricultural use. The second-largest problématique, "land and water systems sustainability," accounts for 24% of the cases (n=38). Mainly focusing on the issues of landscape development and ecosystem conservation in the context of sustainability management of land and water systems, this problématique encompasses a broader range of sustainability issues and water uses compared to other problématiques. "Surface water pollution" is the third largest problématique, constituting 19% of the cases (n=30). The primary focus of these cases is the impact of pollutant discharge on the quality of surface water bodies. This problématique, separate from "land and water systems," is predominantly caused by point-source pollution through the direct discharge of pollutants into water bodies, whereas the issue of water quality in "land and water systems" primarily arises from landscape development and urbanization, often in a diffuse manner.

The final two problématiques are "industrial and household water security" and "hydropower vs. water ecology," which are less prevalent, encompassing 23% (n=23) and 8% (n=13) cases, respectively. Being the most diverse problématiques, "industrial and household water security" mainly focuses on the water quantity and quality issues related to household and industrial water uses. The focus on the household and industrial water supply distinguishes cases that address groundwater quantity issues from the cases within “groundwater exploitation in agriculture,” which solely focus on the volume of groundwater used for agricultural purposes. Finally, “hydropower vs. water ecology” is the least prevalent problématique and encompasses cases that examine the impacts of hydropower production on aquatic biodiversity and overall water ecosystem health. In this problématique, all cases focus on water quantity and aquatic biodiversity, with over half also examining basin conditions, which differ from the cases in “land and water systems sustainability,” where river developments are the primary driver of the issue of aquatic biodiversity in surface water bodies.

Examining problématiques, A2 reveals that geographically, certain problématiques have been more extensively studied in specific regions, such as south-eastern Asia cases being prominent in “hydropower production and water ecology,” while “surface water pollution” has more cases in Europe and eastern Asia, and North American cases stand out for “land and water systems sustainability” and “groundwater exploitation in agriculture.” Furthermore, while groundwater governance for agriculture appears to have been studied extensively, as observed in A2, limited focus on hydropower’s impact on water resources and its governance emphasizes a need for more attention, given the growing global trend of dam construction (Castro-Diaz et al., 2023).

The interplay between water-related problématiques and water governance paradigms suggests a possible two-way relationship (A1). A1 shows that the problématiques can drive the adoption of specific paradigms. The prevalence of the “community-based management” paradigm in the case of the “groundwater exploitation in agriculture” problématique illustrates this point. Here, the need for locally sensitive and participatory solutions in managing groundwater for agricultural needs leads to adopting a paradigm emphasizing community involvement. Meanwhile, paradigms are argued to play a pivotal role in framing how problems are understood and tackled, which can explain why certain problématiques are observed with specific paradigms (A1). For instance, cases within the “land and water systems sustainability” problématique have a higher share of the “integrated approach to water management” paradigm compared to the “state-centric/command and control governance” paradigm. The “integrated approach to water management” paradigm prompts researchers and policymakers to see land and water issues as an interconnected system, in contrast to the “state-centric/command and control governance” paradigm, which has a narrower focus on water resources and supply management without recognizing such interconnections.

The possible influence of problématiques is not only limited to the adoption of certain paradigms, as shown in A1, but A3 reveals the link between the nature of problématiques and the successful water governance pathways. For instance, A3 reveals two successful governance pathways for “surface water pollution,” but no specific one for “groundwater exploitation for agriculture,” possibly due to the complexity inherent in groundwater systems and the multi-faceted nature of groundwater problems. The invisible and movable nature of groundwater resources complicates the design of effective responses, making it challenging to characterize, monitor, and understand, often resulting in unnoticed problems or divergent perspectives among stakeholders regarding the severity of the issue (A3). All these factors collectively hinder the identification of a consistent governance pathway for successful sustainability performance (A3). On analyzing two successful governance pathways for addressing surface water pollution, notable differences emerge in the set of governance characteristics they encompass. One pathway follows a straightforward approach, while the other includes a relatively complex set of characteristics, as outlined in the previous sub-section. The qualitative review of the cases for each governance pathways shows that they align with the nature of the pollution problem addressed, such as the central government addressing municipal wastewater pollution in the Tlaxcala Atoyac sub-basin through wastewater plants (Flores et al., 2016) or addressing complex, multi-source pollution in the St. Lawrence River with a more comprehensive intervention (Villeneuve et al., 2006). The results in A4 also support the relation between the nature of the problem and governance intervention since indicators such as SDGs 6.3.1 (treated wastewater) and 6.4.1 (water-use efficiency), which rely more on socio-economic factors than environmental ones, demonstrate stronger associations with IWRM-related variables. This suggests that these indicators can be improved more quickly through straightforward policy interventions than others, such as SDGs 6.4.2 (water stress) and 6.6.1 (trophic state), which depend more on complex social-ecological dynamics.

The findings presented in this sub-section underscore the critical role of context in water governance, revealing a dynamic interplay between contextual factors and governance paradigms. As such, contextual factors significantly influence the implementation of water governance paradigms and their effectiveness. One-size-fits-all solutions are rarely effective in this dynamic system, necessitating the development of context-sensitive strategies. Furthermore, the results also show a strong link between the nature of the problem context and successful governance pathways, underscoring the importance of designing interventions tailored to the specific problem addressed. By recognizing and responding to these nuances, water governance can more effectively address the diverse and complex challenges faced globally.

5. Conclusion & way forward

This dissertation aimed to understand water governance and its effectiveness in ensuring the sustainable management and health of water systems. This was pursued through three central objectives: firstly, by identifying and analyzing water governance paradigms; secondly, by exploring patterns in water-related environmental sustainability performance associated with different governance paradigms and identifying successful governance pathways in relation to the problems they address; and thirdly, by examining the relationship between contextual factors and governance paradigms and the influence of these factors on water sustainability performance. The role of paradigms in water governance is complex and non-linear, significantly influencing how governance is approached and practiced, but also being shaped by existing contextual factors and governance practices. The emergence and manifestation of paradigms reflect the influence of diverse actors in shaping the discourse, practices, and evolving landscapes of water governance worldwide. Water governance paradigms exhibit a dynamic nature, co-occurring in diverse contexts and manifesting in varied forms in different settings. They are also dynamic, evolving over time with shifting societal priorities; however, this process is more of a continuum of change, with each paradigm leaving enduring legacies even as new ones emerge.

Regarding water sustainability performance, our results show that some paradigms such as "integrated approach to water management," "participatory and collaborative governance," and "community-based management" are reported to be successful. However, there are issues to be cautious about, especially considering how paradigms can manifest very differently than was envisioned and their symbolic application. Successful performance of these paradigms across the reviewed studies does not imply that these paradigms should be applied indiscriminately as one-size-fits-all solutions. By studying water sustainability performance, results show that successful governance does not always have a simple design but may involve characteristics from several different paradigms. The relation between water governance and performance is not straightforward as context plays an essential role in how the paradigms are translated on the ground, how they perform, and what is needed to address specific water problems, including how the nature of problématiques influences the successful governance pathways.

Based on these results, three overarching conclusions for water governance can be drawn. First, although not always "visible" or explicit to the scholars or practitioners who work with them, there is a need to acknowledge and understand the paradigms underpinning water governance and their influences to understand water governance itself better. The findings show how paradigms may influence characteristics of governance (e.g., observation of participation and collaboration across paradigms of "participatory and collaborative governance" and "integrated approach to water governance" in A1) and shape how problems are framed (e.g., observing more cases with "land and water systems sustainability" problématiques in "integrated approach to water management" paradigm compared to the "state-centric/command and control governance" as the former has a systemic approach to seeing problems recognizing connection in A1). Although paradigms are often understudied, examining them alone is insufficient; it is crucial to also consider the broader context and interactions. This brings us to the second conclusion, that context plays an important role. Paradigms may not always define how governance is structured and practiced since they interact dynamically with the context in which they are implemented. The findings in this dissertation show how paradigms can manifest differently in diverse contexts, blending with already existing governance ideas and structures (S1), being translated differently by different actors, or even being implemented only "symbolically" without actual implementation (e.g., IWRM as argued by Biswas (2008)). The significance of capacity for the success of governance systems is emphasized by the findings (A3), which is important given that successful transfer of a paradigm to practice depends on the resources available in the new context (Benson, 2009). Finally, the results again reaffirm that no simple or one-size-fits-all solutions exist. Designing successful governance systems requires a nuanced understanding of the context in which governance is implemented. The success or failure of the governance system is influenced by the unique circumstances, such as the strong impact of contextual factors on the association between the IWRM implementation and water-related sustainability indicators as shown in A4. The results in A3 indicate the link between the nature of problem context and successful governance pathways and how designing successful water governance to address all problems requires multiple reinforcing governance characteristics rather than a single one.

This dissertation offers valuable insights into water governance and the broader environmental governance literature. First, the findings contribute to the critiques of policy transfer research on its assumptions of a linear and rational process and policy models being immutable (Mukhtarov, 2022). Rather than a linear process, the findings emphasize the complexity of policy translation, where paradigms interact and transform within specific contexts, leading to changes on both ends. Furthermore, the results underscore the significant mutation of paradigms as they traverse different contexts, which differs from the assumed immutability in traditional policy transfer literature. Additionally, this dissertation adds to the research niche in water governance literature on problem context (e.g., Kirschke et al., 2019; Srinivasan et al., 2012) as well as the literature on problem-driven governance (e.g., Fritz et al., 2009; Jiménez et al., 2014; Mayne et al., 2020). Insights on the nature of water-related problématiques, as well as governance responses that are best suited to address them, contribute to advancing the diagnostic approach in water governance (Cox, 2011; Ostrom, 2007). These insights also provide a deeper understanding of "what works (or does not work) to achieve a particular desired outcome or condition," which remains an area with limited attention (A2). Future research can expand on this dissertation's findings and integrate political and socioeconomic factors as part of the problématiques, aiming to improve the tailoring of governance responses.

The results of this dissertation have several policy implications. One of the most important implications is that the results of this dissertation encourage the adoption of a problem-driven approach when designing governance solutions, by tailoring strategies to the specific challenges posed by different problématiques. This approach necessitates learning about problems and their evolvement and adapting the practices and institutional arrangements accordingly (Mayne et al., 2020). The findings on the difference between the governance pathways for water problems with different characteristics and complexity levels can particularly serve as an entry point for policymakers to understand the nature of a problem and prioritize areas of intervention by identifying the most effective combination of governance characteristics. Finally, by focusing on problems, policymakers can draw lessons from effective and ineffective policy interventions across various contexts when addressing similar issues. Similarities in problem definition and goals between the originating and the borrowing contexts are argued to be critical for successful policy transfers (Mossberger & Wolman, 2003). Using problématiques in this dissertation as a guide for examining common problems and respective policy responses in different contexts can serve evidence-based policymaking, leading to more effective policy designs.

This dissertation had some limitations. First, while examining a large number of cases enable the identification of cross-sectional patterns and generalization, which is not easily achievable with a single case study (Larsson, 1993), this approach also has drawbacks. Working with a large number of cases can minimize attention to the unique factors or processes within individual cases (Yin & Heald, 1975). Due to this trade-off between breadth and depth, the study may have overlooked some nuanced, context-specific details that could have offered more in-depth understanding of particular cases. Another limitation was the contextual factors considered in this dissertation, which mainly covered water-related problématiques (A1, A2, A3) and a range of socio-political, economic, and environmental factors (A4). Previous research also extensively discusses the significance of power asymmetries, path dependency, political-economic interests, and prevailing discourses as crucial contextual factors influencing processes within water governance (e.g., Lukat, Schoderer, et al., 2022; Méndez et al., 2019; Sehring, 2009). The potential impact of these contextual factors on water governance outcomes underscores the need for more comprehensive approaches studying water governance. Finally, this dissertation relies to a large extent on secondary data, which may be subject to biases, such as a tendency to publish statistically significant results or to seek, interpret, and publish findings that align with pre-existing beliefs, viewpoints, and hypotheses (i.e., confirmation bias; Zvereva & Kozlov, 2021). Working with secondary data also involves possible issues related to data quality, including the quality of original case studies and the data collection method (e.g., self-assessment surveys mentioned earlier in the context of IWRM).

On the other hand, these limitations offer promising avenues for future research. Future studies can undertake an in-depth case study or process tracing to examine the conclusions drawn here and understand the underlying mechanisms. Moreover, incorporating additional contextual factors such as power asymmetries, path dependency, and political-economic interests could offer a more comprehensive understanding of water governance sustainability performance. Exploring the influence of these factors on the interpretation, implementation, and performance of paradigms and their role in shaping problem perceptions and prioritization can enrich our understanding of governance dynamics. Furthermore, comparative analyses and qualitative methodologies can enhance the robustness of research findings, mitigating potential biases associated with secondary data sources. Expanding upon the insights from this dissertation and delving into these research avenues, scholars can contribute to advancing knowledge in the field of water governance and informing more effective policy interventions and management strategies.

References

Adams, E. A., Zulu, L., & Ouellette-Kray, Q. (2020). Community water governance for urban water security in the Global South: Status, lessons, and prospects. *WIREs Water*, *7*(5). https://doi.org/10.1002/wat2.1466

Aggarwal, R. M., & Anderies, J. M. (2023). Understanding how governance emerges in social-ecological systems: Insights from archetype analysis. *Ecology and Society*, *28*(2), 25–26. https://doi.org/10.5751/ES-14061-280202

Akhmouch, A., Roche, P. A., Romano, O., & Salvetti, M. (2022). Can measuring the impact of water governance turn the tide? *Water International*, *47*(2), 153–159. https://doi.org/10.1080/02508060.2022.2050624

Araral, E., & Wang, Y. (2013). Water Governance 2.0: A Review and Second Generation Research Agenda. *Water Resources Management*, *27*(11), 3945–3957. https://doi.org/10.1007/s11269-013-0389-x

Bakker, K., & Morinville, C. (2013). The governance dimensions of water security: A review. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *371*(2002), 20130116. https://doi.org/10.1098/rsta.2013.0116

Bennett, N. J., & Satterfield, T. (2018). Environmental governance: A practical framework to guide design, evaluation, and analysis. *Conservation Letters*, *11*(6). https://doi.org/10.1111/conl.12600

Benson, D. (2009). Review article: Constraints on policy transfer. *Working Paper - Centre for Social and Economic Research on the Global Environment*, *1*, 1–18.

Benson, D., Gain, A. K., & Giupponi, C. (2020). Moving beyond water centricity? Conceptualizing integrated water resources management for implementing sustainable development goals. *Sustainability Science*, *15*(2), 671–681. https://doi.org/10.1007/s11625-019-00733-5

Benson, D., Gain, A. K., & Rouillard, J. J. (2015). Water governance in a comparative perspective: From IWRM to a "nexus" approach? *Water Alternatives*, *8*(1), 756–773.

Bertule, M., Glennie, P., Bjørnsen, P. K., Lloyd, G. J., Kjellen, M., Dalton, J., Rieu-Clarke, A., Romano, O., Tropp, H., Newton, J., & Harlin, J. (2018). Monitoring Water Resources Governance Progress Globally: Experiences from Monitoring SDG Indicator 6.5.1 on Integrated Water Resources Management Implementation. *Water*, *10*(12), 1744. https://doi.org/10.3390/w10121744

Biswas, A. K. (2008). Integrated water resources management: Is it working? *International Journal of Water Resources Development*, *24*(1), 5–22. https://doi.org/10.1080/07900620701871718

Biswas, A. K., & Tortajada, C. (2023). Global crisis in water management: Can a second UN Water Conference help? *River*, *2*(2), 143–148. https://doi.org/10.1002/rvr2.40

Bodin, Ö., Alexander, S. M., Baggio, J., Barnes, M. L., Berardo, R., Cumming, G. S., Dee, L. E., Fischer, A. P., Fischer, M., Mancilla Garcia, M., Guerrero, A. M., Hileman, J., Ingold, K., Matous, P., Morrison, T. H., Nohrstedt, D., Pittman, J., Robins, G., & Sayles, J. S. (2019). Improving network approaches to the study of complex social–ecological interdependencies. *Nature Sustainability*, *2*(7), 551–559. https://doi.org/10.1038/s41893-019-0308-0

Bressers, H., & de Boer, C. (2013). Contextual Interaction Theory for assessing water governance, policy and knowledge transfer. *Water Governance, Policy and Knowledge Transfer: International Studies on Contextual Water Management*, 36–54. https://doi.org/10.4324/9780203102992

Castro-Diaz, L., García, M. A., Villamayor-Tomas, S., & Lopez, M. C. (2023). Impacts of hydropower development on locals' livelihoods in the Global South. *World*

Development, *169*, 106285. https://doi.org/10.1016/j.worlddev.2023.106285
Castro, J. E. (2007). Water Governance in the 21st Century. *Ambiente & Sociedade Campinas*, *10*(2), 97–118. http://www.iatp.org/files/2013_03_27_WaterTrading_SV_0.pdf
Chaffin, B. C., Gosnell, H., & Cosens, B. A. (2014). A decade of adaptive governance scholarship: Synthesis and future directions. *Ecology and Society*, *19*(3). https://doi.org/10.5751/ES-06824-190356
Challies, E., & Newig, J. (2022). Water, rivers and wetlands. In *Routledge Handbook of Global Environmental Politics* (Vol. 46, Issue 2, pp. 512–525). Routledge. https://doi.org/10.4324/9781003008873-43
Cleaver, F., & Whaley, L. (2018). Understanding process, power, and meaning in adaptive governance: a critical institutional reading. *Ecology and Society*, *23*(2), art49. https://doi.org/10.5751/ES-10212-230249
Cong, W., Li, X., Qian, Y., & Shi, L. (2020). Polycentric approach of wastewater governance in textile industrial parks: Case study of local governance innovation in China. *Journal of Environmental Management*, *280*. https://doi.org/10.1016/j.jenvman.2020.111730
Cosgrove, W. J., & Loucks, D. P. (2015). Water management: Current and future challenges and research directions. *Water Resources Research*, *51*(6), 4823–4839. https://doi.org/10.1002/2014WR016869
Cox, M. (2011). Advancing the diagnostic analysis of environmental problems. *International Journal of the Commons*, *5*(2), 346–363. https://doi.org/10.18352/ijc.273
Dawadi, S., Shrestha, S., & Giri, R. A. (2021). Mixed-Methods Research: A Discussion on its Types, Challenges, and Criticisms. *Journal of Practical Studies in Education*, *2*(2), 25–36. https://doi.org/10.46809/jpse.v2i2.20
DeFries, R., & Nagendra, H. (2017). Ecosystem management as a wicked problem. *Science*, *356*(6335), 265–270. https://doi.org/10.1126/science.aal1950
Driessen, P. P. J., Dieperink, C., van Laerhoven, F., Runhaar, H. A. C., & Vermeulen, W. J. V. (2012). Towards a Conceptual Framework for The Study of Shifts in Modes of Environmental Governance – Experiences From The Netherlands. *Environmental Policy and Governance*, *22*(3), 143–160. https://doi.org/10.1002/eet.1580
Earle, S. (2009). *My wish: Protect our oceans [Video]*. TED. https://www.ted.com/talks/sylvia_earle_my_wish_protect_our_oceans?language=en
Erős, T., Hermoso, V., & Langhans, S. D. (2023). Leading the path toward sustainable freshwater management: Reconciling challenges and opportunities in historical, hybrid, and novel ecosystem types. *WIREs Water*, *10*(3). https://doi.org/10.1002/wat2.1645
Fallon, A. L., Lankford, B. A., & Weston, D. (2021). Navigating wicked water governance in the "solutionscape" of science, policy, practice, and participation. *Ecology and Society*, *26*(2). https://doi.org/10.5751/ES-12504-260237
Flores, C. C., Vikolainen, V., & Bressers, H. (2016). Water governance decentralisation and river basin management reforms in hierarchical systems: Do they work for water treatment policy in Mexico's Tlaxcala Atoyac sub-basin? *Water (Switzerland)*, *8*(5). https://doi.org/10.3390/w8050210
Fritz, V., Kaiser, K., & Levy, B. (2009). *Problem driven governance and political economy analysis: Good practice hankbook*.
Furlong, K. (2011). Neoliberal Water Management: Trends, Limitations, Reformulations. *Environment and Society*, *1*(1), 46–75. https://doi.org/10.3167/ares.2010.010103
Gain, A. K., Giupponi, C., Renaud, F. G., & Vafeidis, A. T. (2020). Sustainability of complex social-ecological systems: methods, tools, and approaches. *Regional Environmental Change*, *20*(3), 102. https://doi.org/10.1007/s10113-020-01692-9
Gain, A. K., Hossain, S., Benson, D., Di Baldassarre, G., Giupponi, C., & Huq, N. (2021).

Social-ecological system approaches for water resources management. *International Journal of Sustainable Development & World Ecology*, *28*(2), 109–124. https://doi.org/10.1080/13504509.2020.1780647
García, L. E. (2008). Integrated water resources management: A "small" step for conceptualists, a giant step for practitioners. *International Journal of Water Resources Development*, *24*(1), 23–36. https://doi.org/10.1080/07900620701723141
García, M. M., Hileman, J., & Bodin, Ö. (2019). Collaboration and conflict in complex water governance systems across a development gradient: Addressing common challenges and solutions. *Ecology and Society*, *24*(3). https://doi.org/10.5751/ES-11133-240328
Gerlak, A. K., & Mukhtarov, F. (2015). 'Ways of knowing' water: integrated water resources management and water security as complementary discourses. *International Environmental Agreements: Politics, Law and Economics*, *15*(3), 257–272. https://doi.org/10.1007/s10784-015-9278-5
Gupta, J. (2009). Driving Forces Around Global Fresh Water Governance. In D. Huitema & S. Meijerink (Eds.), *Water Policy entrepreneurs: A Research Companion to the Water Transitions around the Globe* (pp. 37–57). Edward Elgar.
Gupta, J., Akhmouch, A., Cosgrove, W., Hurwitz, Z., Maestu, J., & Ünver, O. (2013). Policymakers' reflections on water governance issues. *Ecology and Society*, *18*(1). https://doi.org/10.5751/ES-05086-180135
Hassenforder, E., & Barone, S. (2019). Institutional arrangements for water governance. *International Journal of Water Resources Development*, *35*(5), 783–807. https://doi.org/10.1080/07900627.2018.1431526
Head, B. (2008). Wicked Problems in Public Policy. *Public Policy*, *3*, 101–118.
Hegga, S., Kunamwene, I., & Ziervogel, G. (2020). Local participation in decentralized water governance: insights from north-central Namibia. *Regional Environmental Change*, *20*(3), 105. https://doi.org/10.1007/s10113-020-01674-x
Hogan, J., & Howlett, M. (2015). Reflections on Our Understanding of Policy Paradigms and Policy Change. In *Policy Paradigms in Theory and Practice* (pp. 3–18). Palgrave Macmillan UK. https://doi.org/10.1057/9781137434043_1
Ingram, H. (2011). Beyond universal remedies for good water governance: a political and contextual approach. In A. Garrido & H. Ingram (Eds.), *Water for Food in a Changing World* (p. 21). Routledge. https://doi.org/10.4324/9780203828410
Jiménez, A., Mtango, F. F., & Cairncross, S. (2014). What role for local government in sanitation promotion? Lessons from Tanzania. *Water Policy*, *16*(6), 1104–1120. https://doi.org/10.2166/wp.2014.203
Jiménez, A., Saikia, P., Giné, R., Avello, P., Leten, J., Lymer, B. L., Schneider, K., & Ward, R. (2020). Unpacking water governance: A framework for practitioners. *Water (Switzerland)*, *12*(3). https://doi.org/10.3390/w12030827
Kirschke, S., Franke, C., Newig, J., & Borchardt, D. (2019). Clusters of water governance problems and their effects on policy delivery. *Policy and Society*, *38*(2), 255–277. https://doi.org/10.1080/14494035.2019.1586081
Kummu, M., Guillaume, J. H. A., de Moel, H., Eisner, S., Flörke, M., Porkka, M., Siebert, S., Veldkamp, T. I. E., & Ward, P. J. (2016). The world's road to water scarcity: shortage and stress in the 20th century and pathways towards sustainability. *Scientific Reports*, *6*(1), 38495. https://doi.org/10.1038/srep38495
Larsson, R. (1993). Case Survey Methodology: Quantitative Analysis of Patterns across Case Studies. *Academy of Management Journal*, *36*(6), 1515–1546. https://doi.org/10.2307/256820
Lautze, J., De Silva, S., Giordano, M., & Sanford, L. (2011). Putting the cart before the horse: Water governance and IWRM. *Natural Resources Forum*, *35*(1), 1–8.

https://doi.org/10.1111/j.1477-8947.2010.01339.x
Loucks, D. P. (1997). Quantifying trends in system sustainability. *Hydrological Sciences Journal*, *42*(4), 513–530. https://doi.org/10.1080/02626669709492051
Lukat, E., Lenschow, A., Dombrowsky, I., Meergans, F., Schütze, N., Stein, U., & Pahl-Wostl, C. (2023). Governance towards coordination for Integrated Water Resources Management: The effect of governance modes. *Unpublished Manuscript*, *141*(December 2022), 50–60. https://doi.org/10.1016/j.envsci.2022.12.016
Lukat, E., Pahl-Wostl, C., & Lenschow, A. (2022). Deficits in implementing integrated water resources management in South Africa: The role of institutional interplay. *Environmental Science & Policy*, *136*, 304–313. https://doi.org/10.1016/j.envsci.2022.06.010
Lukat, E., Schoderer, M., & Castro Salvador, S. (2022). When international blueprints hit local realities: Bricolage processes in implementing IWRM in South Africa, Mongolia, and Peru. *Water Alternatives*, *15*(2), 473–500.
Mayne, Q., de Jong, J., & Fernandez-Monge, F. (2020). State Capabilities for Problem-Oriented Governance. *Perspectives on Public Management and Governance*, *3*(1), 33–44. https://doi.org/10.1093/ppmgov/gvz023
McNabb, D. E. (2019). Water's Role in a Sustainable Future. In *Global Pathways to Water Sustainability* (pp. 17–30). Springer International Publishing. https://doi.org/10.1007/978-3-030-04085-7_2
Meijerink, S., & Huitema, D. (2010). Policy Entrepreneurs and Change Strategies: Lessons from Sixteen Cases. In *Ecology and Society* (Vol. 15, Issue 2).
Meinzen-Dick, R. (2007). Beyond panaceas in water institutions. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(39), 15200–15205. https://doi.org/10.1073/pnas.0702296104
Méndez, P. F., Amezaga, J. M., & Santamaría, L. (2019). Explaining path-dependent rigidity traps: increasing returns, power, discourses, and entrepreneurship intertwined in social-ecological systems. *Ecology and Society*, *24*(2). https://doi.org/10.5751/ES-10898-240230
Mirnezami, S. J., de Boer, C., & Bagheri, A. (2020). Groundwater governance and implementing the conservation policy: the case study of Rafsanjan Plain in Iran. *Environment, Development and Sustainability*, *22*(8), 8183–8210. https://doi.org/10.1007/s10668-019-00488-0
Misra, K. (2014). From formal-informal to emergent formalisation: Fluidities in the production of urban waterscapes. *Water Alternatives*, *7*(1), 15–34.
Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Medicine*, *6*(7), e1000097. https://doi.org/10.1371/journal.pmed.1000097
Molle, F. (2008). Nirvana concepts, narratives and policy models: Insights from the water sector. *Water Alternatives*, *1*(1), 131–156.
Molle, F., & Closas, A. (2020). Why is state-centered groundwater governance largely ineffective? A review. *Wiley Interdisciplinary Reviews: Water*, *7*(1), 1–17. https://doi.org/10.1002/wat2.1395
Molle, F., López-Gunn, E., & van Steenbergen, F. (2018). The local and national politics of groundwater overexploitation. *Water Alternatives*, *11*(3), 445–457.
Molle, F., Mollinga, P. P., & Wester, P. (2009). Hydraulic bureaucracies and the hydraulic mission: Flows of water, flows of power. *Water Alternatives*, *2*(3), 328–349.
Moss, T. (2012). Spatial fit, from panacea to practice: Implementing the EU water framework directive. *Ecology and Society*, *17*(3). https://doi.org/10.5751/ES-04821-170302
Moss, T., & Newig, J. (2010). Multilevel water governance and problems of scale: Setting the

stage for a broader debate. In *Environmental Management* (Vol. 46, Issue 1, pp. 1–6). https://doi.org/10.1007/s00267-010-9531-1
Mossberger, K., & Wolman, H. (2003). Policy Transfer as a Form of Prospective Policy Evaluation: Challenges and Recommendations. *Public Administration Review*, *63*(4), 428–440. http://www.jstor.org/stable/977399
Mukhtarov, F. (2022). A Review of Water Policies on the Move: Diffusion, Transfer, Translation or Branding? *Water Alternatives*, *15*(2), 290–306.
NEWAVE. (n.d.). *About NEWAVE*. https://nextwatergovernance.net/about-newave
Nightingale, A. J. (2019). *Environment and Sustainability in a Globalizing World* (A. J. Nightingale (ed.)). Routledge. https://doi.org/10.4324/9781315714714
Oberlack, C., Sietz, D., Bürgi Bonanomi, E., de Bremond, A., Dell'Angelo, J., Eisenack, K., Ellis, E. C., Epstein, G., Giger, M., Heinimann, A., Kimmich, C., Kok, M. T., Manuel-Navarrete, D., Messerli, P., Meyfroidt, P., Václavík, T., & Villamayor-Tomas, S. (2019). Archetype analysis in sustainability research: meanings, motivations, and evidence-based policy making. *Ecology and Society*, *24*(2), art26. https://doi.org/10.5751/ES-10747-240226
Ostrom, E. (2007). A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(39), 15181–15187. https://doi.org/10.1073/pnas.0702288104
Özerol, G., Vinke-De Kruijf, J., Brisbois, M. C., Flores, C. C., Deekshit, P., Girard, C., Knieper, C., Mirnezami, S. J., Ortega-Reig, M., Ranjan, P., Schröder, N. J. S., & Schröter, B. (2018). Comparative studies of water governance: A systematic review. *Ecology and Society*, *23*(4). https://doi.org/10.5751/ES-10548-230443
Pahl-Wostl, C. (2015). Conceptual and Analytical Framework. In *Water Governance in the Face of Global Change: From Understanding to Transformation* (pp. 25–50). Springer International Publishing. https://doi.org/10.1007/978-3-319-21855-7_3
Pahl-Wostl, C., Lebel, L., Knieper, C., & Nikitina, E. (2012). From applying panaceas to mastering complexity: Toward adaptive water governance in river basins. *Environmental Science and Policy*, *23*, 24–34. https://doi.org/10.1016/j.envsci.2012.07.014
Patterson, J., Schulz, K., Vervoort, J., van der Hel, S., Widerberg, O., Adler, C., Hurlbert, M., Anderton, K., Sethi, M., & Barau, A. (2017). Exploring the governance and politics of transformations towards sustainability. *Environmental Innovation and Societal Transitions*, *24*, 1–16. https://doi.org/10.1016/j.eist.2016.09.001
Pereira, L. F. M., Barreto, S., & Pittock, J. (2009). Participatory river basin management in the São João River, Brazil: A basis for climate change adaptation? *Climate and Development*, *1*(3), 261–268. https://doi.org/10.3763/cdev.2009.0026
Rahman, H. M. T., Saint Ville, A. S., Song, A. M., Po, J. Y. T., Berthet, E., Brammer, J. R., Brunet, N. D., Jayaprakash, L. G., Lowitt, K. N., Rastogi, A., Reed, G., & Hickey, G. M. (2017). A framework for analyzing institutional gaps in natural resource governance. *International Journal of the Commons*, *11*(2), 823–853. https://doi.org/10.18352/ijc.758
Ribeiro, N. B., & Johnsson, R. M. F. (2018). Discussions on water governance: patterns and common paths. *Ambiente & Sociedade*, *21*. https://doi.org/10.1590/1809-4422asoc0125r2vu18l1ao
Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S. E., Donges, J. F., Drüke, M., Fetzer, I., Bala, G., von Bloh, W., Feulner, G., Fiedler, S., Gerten, D., Gleeson, T., Hofmann, M., Huiskamp, W., Kummu, M., Mohan, C., Nogués-Bravo, D., … Rockström, J. (2023). Earth beyond six of nine planetary boundaries. *Science Advances*, *9*(37). https://doi.org/10.1126/sciadv.adh2458
Rouillard, J. J., Benson, D., & Gain, A. K. (2014). Evaluating IWRM implementation

success: are water policies in Bangladesh enhancing adaptive capacity to climate change impacts? *International Journal of Water Resources Development*, *30*(3), 515–527. https://doi.org/10.1080/07900627.2014.910756

Rowbottom, J., Graversgaard, M., Wright, I., Dudman, K., Klages, S., Heidecke, C., Surdyk, N., Gourcy, L., Leitão, I. A., Ferreira, A. D., Wuijts, S., Boekhold, S., Doody, D. G., Glavan, M., Cvejić, R., & Velthof, G. (2022). Water governance diversity across Europe: Does legacy generate sticking points in implementing multi-level governance? *Journal of Environmental Management*, *319*(July 2021). https://doi.org/10.1016/j.jenvman.2022.115598

Saleth, R. M., & Dinar, A. (2004). Evaluating institutional linkages: toward an alternative methodology. In *The Institutional Economics of Water*. Edward Elgar Publishing. https://doi.org/10.4337/9781845421496.00011

Sanderson, I. (2002). Evaluation, Policy Learning and Evidence-Based Policy Making. *Public Administration*, *80*(1), 1–22. https://doi.org/10.1111/1467-9299.00292

Schneider, F., Bonriposi, M., Graefe, O., Herweg, K., Homewood, C., Huss, M., Kauzlaric, M., Liniger, H., Rey, E., Reynard, E., Rist, S., Schädler, B., & Weingartner, R. (2015). Assessing the sustainability of water governance systems: the sustainability wheel. *Journal of Environmental Planning and Management*, *58*(9), 1577–1600. https://doi.org/10.1080/09640568.2014.938804

Sehring, J. (2009). Path dependencies and institutional bricolage in post-Soviet water governance. *Water Alternatives*, *2*(1), 61–81.

Srinivasan, V., Lambin, E. F., Gorelick, S. M., Thompson, B. H., & Rozelle, S. (2012). The nature and causes of the global water crisis: Syndromes from a meta-analysis of coupled human-water studies. *Water Resources Research*, *48*(10), 1–16. https://doi.org/10.1029/2011WR011087

Suhardiman, D., Karki, E., & Bastakoti, R. C. (2021). Putting power and politics central in Nepal's water governance. *Development Policy Review*, *39*(4), 569–587. https://doi.org/10.1111/dpr.12519

Taylor, P. L., & Sonnenfeld, D. A. (2017). Water Crises and Institutions: Inventing and Reinventing Governance in an Era of Uncertainty. *Society & Natural Resources*, *30*(4), 395–403. https://doi.org/10.1080/08941920.2017.1274208

The water crisis is worsening. Researchers must tackle it together. (2023). *Nature*, *613*(7945), 611–612. https://doi.org/10.1038/d41586-023-00182-2

Tickner, D., Opperman, J. J., Abell, R., Acreman, M., Arthington, A. H., Bunn, S. E., Cooke, S. J., Dalton, J., Darwall, W., Edwards, G., Harrison, I., Hughes, K., Jones, T., Leclère, D., Lynch, A. J., Leonard, P., McClain, M. E., Muruven, D., Olden, J. D., … Young, L. (2020). Bending the Curve of Global Freshwater Biodiversity Loss: An Emergency Recovery Plan. *BioScience*, *70*(4), 330–342. https://doi.org/10.1093/biosci/biaa002

Trimble, M., Olivier, T., Anjos, L. A. P., Dias Tadeu, N., Giordano, G., Mac Donnell, L., Laura, R., Salvadores, F., Santana-Chaves, I. M., Torres, P. H. C., Pascual, M., Jacobi, P. R., Mazzeo, N., Zurbriggen, C., Garrido, L., Jobbágy, E., & Pahl-Wostl, C. (2022). How do basin committees deal with water crises? Reflections for adaptive water governance from South America. *Ecology and Society*, *27*(2), art42. https://doi.org/10.5751/ES-13356-270242

United Nations. (2015). *Transforming our world: the 2030 Agenda for Sustainable Development.*

United Nations. (2023). *The United Nations World Water Development Report 2023: Partnerships and Cooperation for Water*.

Villeneuve, S., Painchaud, J., & Dugas, C. (2006). Targeted sustainable development: 15 years of government and community intervention on the St. Lawrence River.

Environmental Monitoring and Assessment, *113*(1–3), 285–301. https://doi.org/10.1007/s10661-005-9085-5
Vollmer, D., Regan, H. M., & Andelman, S. J. (2016). Assessing the sustainability of freshwater systems: A critical review of composite indicators. *Ambio*, *45*(7), 765–780. https://doi.org/10.1007/s13280-016-0792-7
Waylen, K. A., Blackstock, K. L., & Holstead, K. L. (2015). How does legacy create sticking points for environmental management? Insights from challenges to implementation of the ecosystem approach. *Ecology and Society*, *20*(2). https://doi.org/10.5751/ES-07594-200221
Whaley, L., & Weatherhead, E. (2016). Managing water through change and uncertainty: comparing lessons from the adaptive co-management literature to recent policy developments in England. *Journal of Environmental Planning and Management*, *59*(10), 1775–1794. https://doi.org/10.1080/09640568.2015.1090959
Woodhouse, P., & Muller, M. (2017). Water Governance—An Historical Perspective on Current Debates. In *World Development* (Vol. 92, pp. 225–241). Elsevier Ltd. https://doi.org/10.1016/j.worlddev.2016.11.014
Wuijts, S., Driessen, P. P. J., & van Rijswick, H. F. M. W. (2018). Towards more effective water quality governance: A review of social-economic, legal and ecological perspectives and their interactions. *Sustainability (Switzerland)*, *10*(4). https://doi.org/10.3390/su10040914
WWAP. (2015). *The United Nations World Water Development Report 2015: Water for a Sustainable World*. UNESCO.
Yami, M., Vogl, C., & Hauser, M. (2009). Comparing the effectiveness of informal and formal institutions in sustainable common pool resources management in sub-saharan Africa. *Conservation and Society*, *7*(3), 153–164. https://doi.org/10.4103/0972-4923.64731
Yin, R. K., & Heald, K. A. (1975). Using the Case Survey Method to Analyze Policy Studies. *Administrative Science Quarterly*, *20*(3), 371. https://doi.org/10.2307/2391997
Young, O. R. (2002). Environmental Change: Institutional Drivers, Institutional Responses. In *The institutional dimensions of environmental change: Fit, Interplay, and scale* (pp. 3–28). The MIT Press. https://doi.org/10.7551/mitpress/3807.001.0001
Zvereva, E. L., & Kozlov, M. V. (2021). Biases in ecological research: attitudes of scientists and ways of control. *Scientific Reports*, *11*(1), 226. https://doi.org/10.1038/s41598-020-80677-4
Zwarteveen, 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., … Wesselink, A. (2017). Engaging with the politics of water governance. *WIREs Water*, *4*(6), 1–9. https://doi.org/10.1002/wat2.1245

Annex

Article 1:

Toward sustainable water governance? Taking stock of paradigms, practices, and sustainability outcomes

Abstract

Governance is key to ensuring the sustainability of water systems in the long run. With the recognition of the complexities inherent in governing water resources, new and diverse governance models have started to emerge and be diffused to various contexts. This systematic review explores 223 cases from 165 studies on water governance and sustainability. We assess the cases based on water governance paradigms and how these paradigms relate to governance characteristics, water-related problématiques, and sustainability outcomes. Our results indicate a lack of knowledge cumulation and patterns connecting problématiques (e.g., "groundwater exploitation in agriculture") and paradigms (e.g., "community-based management"). We found that the "integrated approach to water management" was the most common paradigm, and paradigms might manifest with various governance characteristics, some of which may not fully align with the paradigm's fundamental principles. While certain paradigms, such as "integrated approach to water management," "participatory and collaborative governance," and "community-based management," are mostly associated with better sustainability outcomes, these successes should be interpreted cautiously due to the context-sensitive nature of paradigms and potential biases in the reviewed studies. These findings provide a basis for further diagnostic work and suggest the need for more nuanced approaches to water governance and sustainability.

Wiley Interdisciplinary Reviews: Water

WILEY

WIREs WATER

ADVANCED REVIEW OPEN ACCESS

Toward Sustainable Water Governance? Taking Stock of Paradigms, Practices, and Sustainability Outcomes

Shahana Bilalova[1] | Jens Newig[1] | Sergio Villamayor-Tomas[2]

[1]Faculty of Sustainability, Institute of Sustainability Governance (INSUGO), Research Group Governance, Participation and Sustainability, Leuphana University Lüneburg, Luneburg, Germany | [2]Institute of Environmental Science and Technology (ICTA-UAB), Autonomous University of Barcelona, Barcelona, Spain

Correspondence: Shahana Bilalova (shahana.bilalova@leuphana.de)

Received: 28 November 2023 | **Revised:** 27 August 2024 | **Accepted:** 15 September 2024

Funding: This project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie Innovative Training Network NEWAVE—grant agreement No 861509.

Keywords: effectiveness | review | sustainability outcomes | water governance paradigms | water governance traits

ABSTRACT

Governance is key to ensuring the sustainability of water systems in the long run. With the recognition of the complexities inherent in governing water resources, new and diverse governance models have started to emerge and be diffused to various contexts. This systematic review explores 223 cases from 165 studies on water governance and sustainability. We assess the cases based on water governance paradigms and how these paradigms relate to governance characteristics, water-related problématiques, and sustainability outcomes. Our results indicate a lack of knowledge cumulation and patterns connecting problématiques (e.g., "groundwater exploitation in agriculture") and paradigms (e.g., "community-based management"). We found that the "integrated approach to water management" was the most common paradigm, and paradigms might manifest with various governance characteristics, some of which may not fully align with the paradigm's fundamental principles. While certain paradigms, such as "integrated approach to water management," "participatory and collaborative governance," and "community-based management," are mostly associated with better sustainability outcomes, these successes should be interpreted cautiously due to the context-sensitive nature of paradigms and potential biases in the reviewed studies. These findings provide a basis for further diagnostic work and suggest the need for more nuanced approaches to water governance and sustainability.

1 | Introduction

The global water crisis, as argued by the Global Water Partnership (GWP 2000), as well as scholars and policymakers, is largely a crisis of governance. Governance is key not only to addressing water supply and demand misfits but also to ensuring the long-term well-being of water ecosystems (Hall 2003; Özerol et al. 2018; Pahl-Wostl et al. 2012; Rogers and Hall 2003; Tropp 2007). For several decades, scholars have aimed to address the social and ecological complexities of water via different governance solutions (Challies and Newig 2022; Pahl-Wostl 2019; Tropp 2007). The emphasis on sustainable development and resilience has led to a significant shift in water governance, from technocratic strategies neglecting complexities and human dimensions to more integrated approaches underpinning good governance (Jiménez et al. 2020).

The literature has also specialized in and explored water governance in light of different paradigms, problems, and sustainability outcomes. Despite the growing diversity of this body of literature and some theoretically targeted syntheses, there is no general overview that brings different paradigms

Edited by: Jan Seibert, Co-Editor-in-Chief and Wendy Jepson, Co-Editor-in-Chief

and contexts together. Such a synthesis can contribute to a better understanding of the opportunities and limits of governance in the water context, and help identify gaps for further research.

This paper provides such an overview by systematically reviewing the body of empirical literature on water governance and its water-related sustainability outcomes. We understand water-related sustainability outcomes[1] in terms of the sustainable use of water resources and the well-being of freshwater ecosystems. Specifically, the aim of the paper is twofold: (a) to unveil the state of knowledge production in the literature by examining its socio-bibliometric characteristics and (b) to identify and explore water governance paradigms and their co-appearance with governance characteristics, water-related problématiques, and sustainability outcomes.

Water governance, following Pahl-Wostl (2015), regulates the development, management, and provision of water resources in light of diverse water-related issues or broader *problématiques* (i.e., the water-related context of the recurring "clusters" or "ensembles" of water-related issues), guiding water resources toward a sustainable state. A *water governance system* is an interconnected and dynamic ensemble of political, social, economic, and administrative elements—institutions, actors, and their interactions—that performs the function of water governance (Pahl-Wostl 2015). It encompasses the constellation of *characteristics* that indicate the ways in which governance is structured and implemented on the ground, how water resources are developed, managed, and provisioned, and which actors are involved and the interactions among them. In this paper, *governance characteristics* cover the role and involvement of actors (e.g., participation and collaboration), the governance mode (e.g., centralization, decentralization, partnership, and self-governance), the level of interaction (e.g., multi-level governance, sectoral integration, fragmentation, and polycentricity), scale (e.g., scale-adapted governance and governance on an administrative scale), the management of uncertainties and risks (e.g., adaptiveness), and information and knowledge management (e.g., evidence-based governance).

Water governance characteristics are often influenced by larger *paradigms*. For example, the "integrated approach to water management" emphasizes governance on a hydrological scale and sectoral integration, while "state-centric/command and control governance" emphasizes centralized decision-making and regulatory enforcement. Functioning as a symbolic and ideational device, paradigms can be understood as the frameworks of "normative-cognitive ideas" that focus attention on how problems are perceived, which policy goals to pursue, and which instruments to apply to attain these goals (Hall 1993; Challies and Newig 2022). Being important agenda-setters for political actions at all scales, water governance paradigms play a significant role in framing problems and providing solutions (Challies and Newig 2022). They also shape policy objectives and instruments by establishing and maintaining certain formal institutions, as well as the mandates that they work toward (Kern, Kuzemko, and Mitchell 2014). Paradigms also play an important role in which options are favored, disregarded, or ignored and which groups are empowered or sidelined (Molle 2008). Hence, paradigms may, in fact, "explain the enactment of certain local policies better than a functional necessity or the strategic considerations of involved parties" (Challies and Newig 2022, 513).

We address the paper's first objective by exploring the type of knowledge produced and analyzing how cumulative this knowledge is. To address the second objective of the paper, we present descriptive statistics on the distribution and co-appearance of water governance paradigms and their associated problématiques, governance characteristics, and sustainability outcomes across the literature. Problematizing the relationship between problématiques, governance paradigms, and sustainability outcomes allows this study to serve as an entry point for the diagnosis of water governance situations, to identify complementarities between these components, and to present informed hypotheses for further testing.

2 | Methods

To compile the relevant publications for our analysis, we conducted a systematic literature review, following the PRISMA guidelines (Moher et al. 2009), adapted to our research question. The review stages are illustrated in Figure A1 (see Appendix 4 in the Supplementary Material for additional figures).

We restricted our search to journal articles listed in Scopus, one of the most prominent peer-reviewed literature databases, providing broad coverage of the fields of environmental and social sciences (Frohlich et al. 2018). Focusing on international discourse, we searched for English-language articles that contained water and governance-related terms in the titles and terms in the titles or abstracts indicating empirical studies of sustainability outcomes (see Appendix 1 in the Supplementary Material for full search string).

Running our search string yielded a total of 8761 studies. Following manual screening of the abstracts and titles and eligibility assessments based on the exclusion criteria presented in Figure A1, we retained 165 papers, covering 1985–2020, for coding and analysis. We extracted the data from the included publications based on a coding scheme developed in consultation with existing literature on water governance and water governance scholars in the NEWAVE network.[2] The coding scheme covers six categories: bibliographic information, research framework, research design, case-related information, the characteristics of the water-related context and water governance, and sustainability outcomes (see Appendix 2 in the Supplementary Material).

The units of analysis in our systematic review were both the papers and the empirical cases within these papers. While the bibliographic information and information regarding the research frameworks and designs of the papers were assessed at the level of the papers, the remaining categories in our coding scheme were assessed at the level of the empirical cases reported in the papers. Within a paper, there could be separate (geographical) case studies, as well as distinct changes of governance within a geographically confined case; and we coded both as separate cases. We only included cases reporting sustainability outcomes linked to a water governance system. So, we excluded papers that did not provide any empirical information, qualitative or quantitative, on the sustainability outcomes observed in relation to the water governance system. For instance, Ananda, McFarlane, and Loh (2020) discuss institutional barriers to social learning in Western Australia without delving into how the governance system leads to specific sustainability outcomes. We also included cases in which the assessment of water governance impacts was based on the authors' interpretations, rather than any hard empirical evidence. We also did not include studies that lacked sufficient description of the water governance system, such as the governance structure, decision-making process, or overarching governance paradigm. One of the examples excluded with this criterion is the study by He et al. (2020) presenting the impacts of water transfer policy implementation on lake eutrophication on the Shandong Peninsula but does not provide information on the institutional arrangements governing water management in the region. As we were interested in real-world cases of water governance and their sustainability outcomes, hypothetical case scenarios were also excluded from the coding.

Finally, we restricted coding to six empirical cases per paper and included only the first six cases or those cases with complete information. In total, we identified 223 cases across the 165 studies (Bilalova, Newig, and Villamayor-Tomas 2024), with 23 studies reporting more than one case and one study reporting more than six, omitting five cases in total.

Following intensive test screening and coding by all authors, which showed high reliability for the test coding (r(WG) = 0.88), the final screening (i.e., to exclude non-valid papers) and coding were undertaken by the first author. To minimize the risk of reviewer bias and possible errors, trial steps were completed by all authors during all stages of the review process, until a common understanding had been reached regarding the exclusion criteria and coding scheme.

3 | State of Knowledge Production

Our systematic literature review reveals several underlying issues connected to knowledge production. After presenting a general overview of the included studies, we will discuss these in terms of two major questions: (1) what type of knowledge is produced? (2) how cumulative is the produced knowledge?

Examining the publications, we observe a substantive increase in the number of empirical articles reporting on the sustainability outcomes of water governance, increasing from one or fewer up to 1995 to 18 in 2020. The papers included in the review are published in 93 different journals. A quarter of these journals ($n = 23$) are water-specific, accounting for 41% ($n = 67$) of the included papers. The three most frequently observed journals are water-related: *International Journal of Water and Resources Development* (11 publications), *Water Policy* (9 publications), and *Water International* (7 publications). For non-water journals, the *Journal of Environmental Management* (6 publications), *Environmental Management* (3 publications), *Environmental Science and Policy* (3 publications), the *International Journal of Environmental Research and Public Health* (3 publications), *Land Use Policy* (3 publications), and the *Natural Resources Forum* (3 publications) are the most frequently observed, each with three or more publications included in our review.

Concerning the knowledge producers, the sex composition for the publications in our systematic review is notably skewed. Only 32% of the first authors are female ($n = 52$), while 63% of the papers are led by male authors ($n = 104$). An assessment of the countries of the first authors' affiliated institutions revealed that the top six countries—the USA, China, Canada, Germany, India, and the UK—accounted for more than half of the papers ($n = 87$). In terms of countries where empirical cases are located, almost half of all cases (43%; $n = 126$) relate to seven countries: the USA, China, India, Canada, Germany, Thailand, and Spain. We also observe a difference in relation to the geographical locations of the first authors' institutions and the locations of the empirical cases. Following Gupta (2012), we treated all OECD members as the "Global North" and all non-OECD countries as the "Global South." Our data show that in both regions, more countries are cited in empirical cases than are identified as the locations of the first authors' institutions. However, in the Global South, this difference ($n = 111$) is twice that seen in the Global North ($n = 20$). Despite this difference, there is a diverse distribution of both publications and cases across world regions, including North America, Europe, Asia, Africa, South America, and Oceania.

3.1 | Type of Produced Knowledge

Regarding the type of knowledge produced, the literature is dominated by "evaluation" and "description"—as opposed to "explanation" questions (Table 1). The considerable share of papers presenting evaluative research hints at the potential usefulness of the studies for policymakers. The question of "what works (or does not work) to achieve a particular desired outcome or condition," which is also important for scholars and practitioners with strong instrumental policy orientations (Sanderson 2002), is only evident in 8% of the papers. The reviewed papers with evaluative, descriptive, and "what works" questions predominantly focus on effectiveness and impact as their evaluative criteria. Generally, effectiveness ($n = 113$) and impact ($n = 52$) are the two most frequent evaluative criteria used in the reviewed publications (Figure A2). In comparison, the resilience and adaptive capacity of water systems as evaluative criteria are less prevalent among the reviewed studies, with each identified in only 7% of the reviewed publications.

3.2 | Cumulative Nature of the Produced Knowledge

To become policy-relevant, knowledge produced by water governance scholarship should be cumulative—meaning that the research builds on the findings of older research, such that the understanding of water governance research advances by either challenging, confirming, or adding nuance to previous research—for example, by specifying the context under which a

TABLE 1 | Governance-related research questions, frameworks, methods, and data used across the included studies. [Correction added on 28 October 2024, after first online publication: Table 1 has been reformatted.]

	Number of papers
Governance-related research questions	
Evaluation of a (or multiple) governance system(s)	134
Thick description of a governance system(s)	117
Explanation of the genesis of a governance system(s)	42
What works to achieve a particular desired outcome or condition	13
Look for patterns in data, or build a typology	4
Analytical frameworks	
No clear framework	106
Using a pre-existing framework (i.e., with or without adaptation)	46
Developing a framework through a deductive approach	13
Methods	
Qualitative observational method	87
Other/Not clear	58
Quantitative observational method	53
Systematic review/meta-analysis	4
Set-theoretic method	2
Experimentation	1
Data	
Primary	108
Secondary	77
Not clear	40

previously studied governance intervention might work (Newig and Rose 2020).

To assess whether the knowledge in the reviewed literature was cumulative, we conducted a network analysis of citations and co-authorship. Using VOSviewer (van Eck and Waltman 2010), we performed a citation analysis based on the bibliographic data of the included studies, using documents as units of analysis. Clusters were determined based on the number of times that the documents cited each other. The analysis reveals 16 clusters of just 52 documents, comprising 32% of all publications (Figure 1). The results point toward a relatively high level of fragmentation in the studied set of empirical water governance publications.

This fragmentation in the citation networks suggests a lack of knowledge cumulation (as found by Goyal and Howlett (2018) for a different research community). This may be driven by the fact that many studies draw on narrow case-based analyses that are too contextually specific to be applied to other contexts (Cox et al. 2020). A related explanation could be that there is no intuitive way of making comparisons across studies due to a lack of common understanding of key concepts and sets of variables, which leads to inconsistencies in the selection and measurement of these variables (Cox et al. 2020, 2021).

A similarly fragmented pattern is observed in the co-authorship networks. Co-authorship analysis, determined by the number of co-authored documents, was performed with VOSviewer, with the authors as units of analysis. As presented in Figure 1, the analysis reveals seven clusters, accounting for just 14% ($n = 55$) of all authors. Looking closely at these clusters of co-authorship (Figure A3), we identified some factors that accounted for each cluster, including shared knowledge of an empirical case, a shared governance paradigm, and a shared conceptual framework. The analysis also reveals one cluster with no common theme between its two papers; instead, the cluster was formed through an institutional affiliation.

The fragmented pattern detected in co-authorship analysis provides further support for the argument that there is limited potential for knowledge cumulation. This shows that while scholars have studied diverse water governance systems in different contexts and reported on their sustainability outcomes, there is a lack of sustained collaborative work that would allow us to identify the core concepts and move the research forward within the field (Goyal and Howlett 2018).

Another piece of evidence pointing to the lack of knowledge cumulation is that only 59 studies in our sample employ an analytical framework to conceptualize a relationship between water governance and its sustainability outcomes. Frameworks organize relevant variables according to general relationships and can, for this reason, be instrumental when comparing cases and cumulating knowledge (Ostrom 2009). Of the few analytical frameworks used by the papers in our sample, only three are applied more than once: Elinor Ostrom's Institutional Analysis and Development (IAD; $n = 11$), the Socio-ecological Systems (SES) framework ($n = 2$), which builds on the IAD framework (Schlager and Villamayor-Tomas 2013), and the Integrative Framework for Collaborative Governance ($n = 2$) by Emerson, Nabatchi, and Balogh (2012). The dominance of the IAD framework hints at Elinor Ostrom's influence on water governance and her focus on sustainability outcomes. Nonetheless, the absence of commonly used analytical frameworks adds to the overall impression of a relatively fragmented field of research.

In summary, our systematic review uncovers significant issues in knowledge production within water governance scholarship. Despite a notable increase in empirical studies on sustainability outcomes, the literature remains dominated by evaluative and descriptive research, with limited attention to explanatory questions. Moreover, our analysis suggests a lack of cumulative knowledge, as evidenced by fragmented citation and co-authorship networks, as well as the limited use of analytical frameworks.

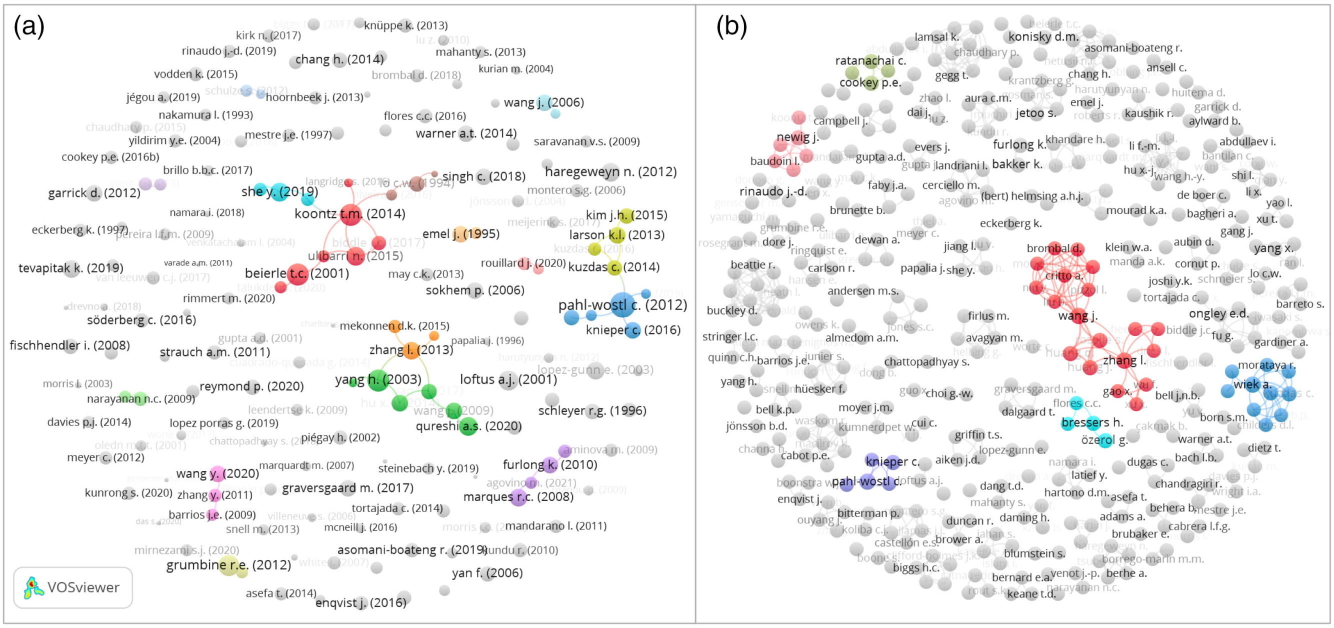


FIGURE 1 | (a) Citation analysis (unit of analysis: Documents; weights: Total number of citations) and (b) co-authorship analysis (unit of analysis: Authors; weights: Documents) of the included studies.

4 | Water Governance Paradigms, Governance Characteristics, Water-Related problématiques, and Sustainability Outcomes

4.1 | Overview of Water Governance Paradigms

The water governance paradigms were coded according to a predefined list, based on inputs from the water governance scholars in the NEWAVE network and the existing literature on water governance. If we encountered paradigms not on our list during coding, we added them to the list (i.e., new public management). We observed during coding paradigms that most authors did not explicitly mention or address water governance paradigms. In such cases, we interpreted the papers based on our common knowledge of the specific characteristics of the paradigm, rather than seeking explicit naming. Therefore, the co-appearance of paradigms, governance characteristics, problématiques, and sustainability outcomes—discussed below—should be interpreted as artifacts of the coding process.

The distribution of these paradigms across papers varies, with some being more commonly discussed than others (Figure A4). For example, the "integrated approach to water management" was prevalent in 23% of cases ($n=52$), while "resilience" was only present in 4% ($n=9$). This could be attributed to several factors, potentially including the wide promotion of certain paradigms in policy and/or scientific spaces (e.g., IWRM and river-basin management [RBM]).

We also identified several patterns relevant to the paradigms, pointing to the dynamic, adaptable, and context-sensitive nature of water governance paradigms. First, 57% of the cases with a paradigm ($n=101$ out of 176) observe more than one paradigm, with certain paradigms appearing more prone to combinations than others (Figure A5). For instance, "adaptive (co-)management or governance" co-appears with other paradigms in 96% of the cases ($n=26$). In 65% of these cases ($n=17$), more than two paradigms co-appear. Similarly, the "state-centric/command and control governance" paradigm co-appears with other paradigms in 75% of the cases, 62% of which ($n=13$) have more than two paradigms.

The presented results might hint at the adaptable nature of paradigms, including their complementary (i.e., reinforcing each other) or competing (i.e., balancing each other) features (Halbe et al. 2013). However, the co-appearance of paradigms might also result from "just" the discursive or metaphorical application of certain paradigms. For instance, Biswas (2008) argues that, due to its fuzziness, IWRM is subject to various interpretations, and many people and institutions have used it just to obtain additional funds and greater acceptability and visibility, while continuing to pursue their existing practices. While these findings suggest the adaptable nature of paradigms, further in-depth analysis and interpretation are necessary to fully unpack their nuances and implications.

Regional differences are also observed, with certain paradigms being more common in cases from specific regions (Figure A6). For example, paradigms like "integrated approach to water management," "river-basin/catchment management," and "water as a common good and/or heritage" are more prevalent in European cases, while "community-based management" and "water as a resource seen by engineers" are more common in cases from Southern Asia (Figure A6). The observed patterns in the geographical distribution of certain paradigms might be related to policy enactment (e.g., RBM being a central tenet of mainstream water policies, such as the water-framework directive) or the long-standing existence of traditional and informal systems (e.g., community-based management).

Looking at the temporal prevalence of paradigms from the 1980s until the 2010s, we found that no paradigm once introduced, had completely disappeared from the reviewed water governance literature (Figure 2). Different paradigms dominated during different periods, with shifts occurring over time. For instance, from 1980 to 1990, "community-based management" was the dominant paradigm, which was followed by "governance with diffusion of authority." Subsequently, "market environmentalism" prevailed from 1995 to 2000, after which the "integrated approach to water governance" dominated from 2000 to 2010. "Adaptive (co-)management or governance" was prominent for the next half-decade, and from 2015 to 2020, "participatory and collaborative governance" became the leading paradigm.

4.2 | Governance Characteristics Observed Across Water Governance Paradigms

As presented in the Introduction, each paradigm, once introduced, comes with governance characteristics, in line with

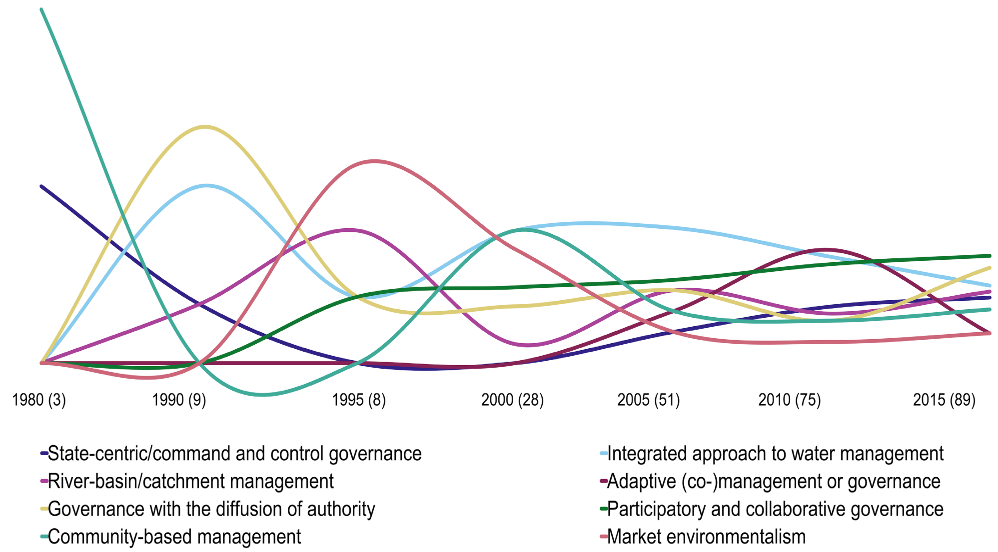


FIGURE 2 | Temporal dynamics of the studied water governance paradigms. Vertical (y-axis) and horizontal (x-axis) axes represent years and number of cases, respectively. For every half-decade, the relative shares of the paradigms are depicted. The numbers in brackets correspond to the total number of paradigms mentioned in that half-decade.

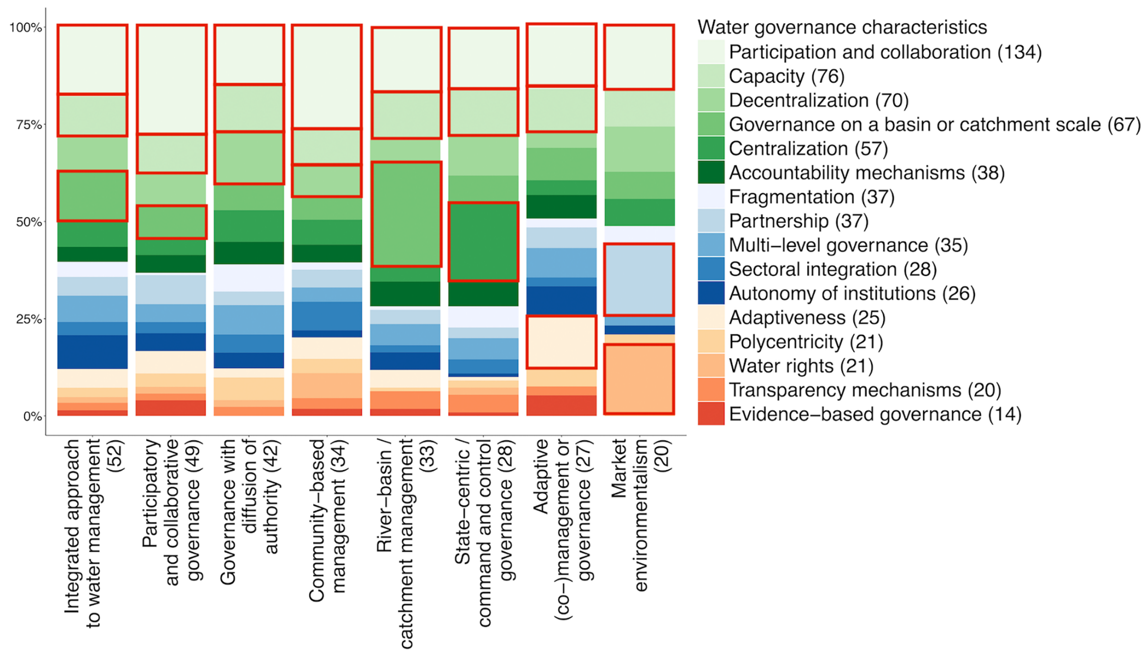


FIGURE 3 | Governance characteristics by water governance paradigms. The numbers in brackets correspond to the numbers of cases with the respective governance characteristics or paradigms. The red rectangles in the figure indicate the three most frequently observed paradigms for each governance characteristic. A gradient color scale was chosen to improve the readability of the figure, especially for those with color blindness. The colors in the figure do not correspond to variations in values. [Correction added on 28 October 2024, after first online publication: Figure 3 caption has been updated.]

certain principles they promote (Figure 3). For instance, the paradigms emphasizing participation and collaboration, like "participatory and collaborative governance" (36%; $n=48$) and "integrated approach to water governance" (28%; $n=37$), are consistently associated with these characteristics, reflecting their emphasis on involving stakeholders in decision-making. Similarly, capacity-building is most frequently coded together with the "integrated approach to water governance" (29%; $n=22$) and "governance with the diffusion of authority" (28%; $n=21$), as well as in more than half of the cases with "adaptive (co-)management" (58%; $n=15$). This observation is as expected given the recognition of water system complexities (i.e., scalar or system) by these paradigms. Another example is water rights, which is identified as a common characteristic in the cases with the paradigms of "market environmentalism" and "community-based management," while 38% of the cases ($n=8$) with water rights also have one of these paradigms. Both of these paradigms include water rights for their users.

However, the results also indicate that while each paradigm may have specific principles, their implementation in practice often leads to diverse governance arrangements. These arrangements are comprised of various governance characteristics, some of which may not fully align with the paradigm's fundamental principles. For example, we identified participation and collaboration in more than half of the cases for all paradigms, except "market environmentalism," where this governance characteristic is observed in 40% of the cases (n=7). This shows that most water governance cases involve a certain degree of participation, irrespective of how centralized a governance structure might be (e.g., "state-centric/command and control governance"). A larger share of participation and collaboration is expected, considering the steady increase in participatory, deliberative, and collaborative approaches to water governance implemented by governments, international donors, and organizations with different goals (van Buuren, van Meerkerk, and Tortajada 2019).

The diversity within each paradigm may stem from how institutional changes happen when a new paradigm is introduced. Streek and Thelen (2005) identified four types of changes: displacement (i.e., replacement of old institutional elements with new ones), layering (i.e., attaching new institutional elements to old ones), drift (i.e., keeping old elements by neglecting the changes in circumstances that alter their effects), and conversion (i.e., re-interpretation of old elements). The constellation of diverse governance characteristics within a paradigm may be attributed to the latter three of these four types of changes. This means that when a new paradigm arises, old institutional elements may continue alongside new ones or be reinterpreted in light of them.

A similar pattern is observed in the distribution of policy instruments. Despite network-style governance paradigms, like the "integrated approach to water management," being prevalent, regulatory policy instruments—associated more with hierarchical governance—are more commonly used across cases (Figure A7). Regulatory instruments are also dominant across all paradigms, with the exceptions of "market environmentalism" and "grassroots 'empowerment' (or commoning)."

4.3 | Water Governance Paradigms in Relation to Water-Related problématiques

We draw water-related problématiques from the cluster analysis of 155 empirical cases, excluding those without any

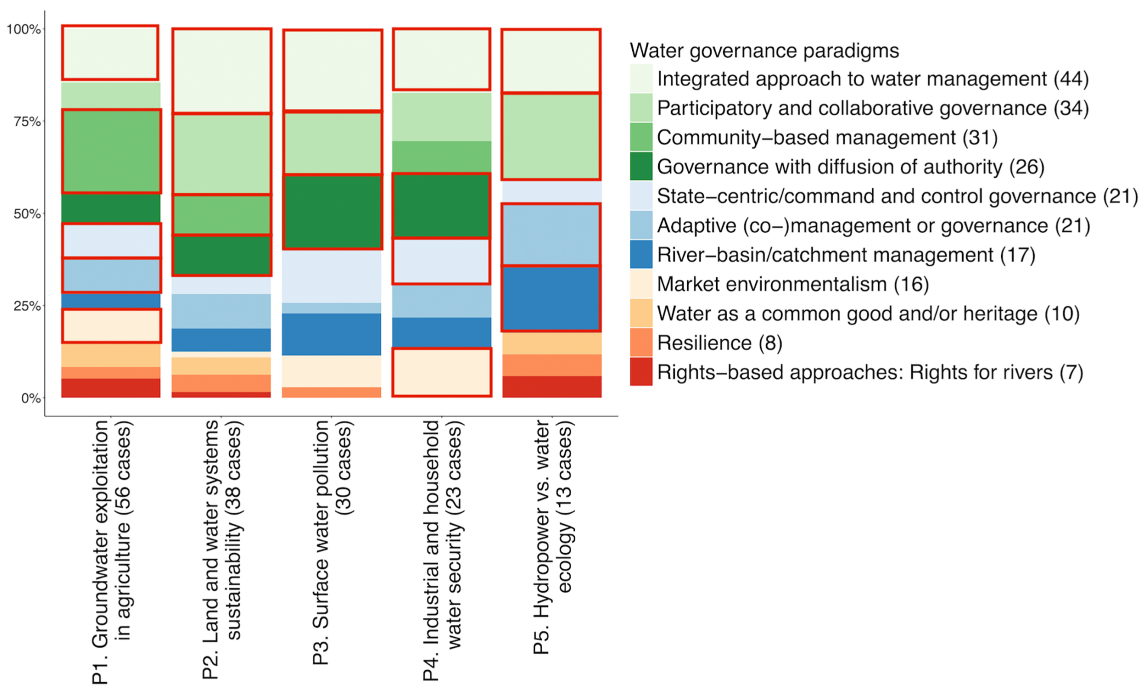


FIGURE 4 | Distribution of paradigms across problématiques. Red rectangles in the figure indicate the most frequently observed three paradigms for each problématiques. The colors in the figure do not correspond to variations in values. A gradient color scale is chosen to improve the readability of the figure and make it easier to be read by those with color blindness.

information on water resources, water use, or water-related sustainability issues (Bilalova et al., unpublished manuscript). Using agglomerative hierarchical clustering with Euclidean distance and Ward's method, we identified five distinct problématiques: "groundwater exploitation in agriculture," "land and water systems sustainability," "surface water pollution," "industrial and household water security," and "hydropower vs. water ecology." The largest problématique, "groundwater exploitation in agriculture," comprises 35% of cases and focuses on groundwater quantity associated with agricultural water use. "Land and water systems sustainability" includes 24% of cases and encompasses a broad range of sustainability issues and diverse water uses, addressing landscape development or ecosystem conservation. "Surface water pollution" covers 19% of cases, primarily addressing the water quality issues of surface water bodies linked to the discharge of pollutants. "Industrial and household water security" and "hydropower vs. water ecology" represent 14% and 8% of cases, respectively, with the former focusing on water supply for industrial and household uses and the latter on the impacts of hydropower production on water resources, including impacts on aquatic biodiversity and water quantity.

Figure 4 shows the distribution of water governance paradigms across the five problématiques, revealing some hotspots and gaps. While 65% of cases (22 out of 34) with the paradigm of "community-based management" fall within "groundwater exploitation in agriculture," no cases of that particular paradigm fall into the category of "surface water pollution." Additionally, our findings suggest that problématiques might motivate the employment of particular water governance paradigms (Figure 4). For instance, in "land and water systems sustainability" and "hydropower vs. water ecology," the participatory and collaborative governance paradigm is much stronger than in the other problématiques. One explanation might be that these problématiques deal with the complexities of water systems, which require both horizontal and vertical collaboration.

Such patterns across problématiques might indicate the responsiveness of governance paradigms to water problématiques. However, as presented in the introduction, paradigms play an important role in problem definition, so the explanation could also go the other way around. For instance, a lower share of cases with the "state-centric/command and control governance" paradigm in the "land and water systems sustainability" problématique could result from the paradigm's sole focus on water resources and its lack of holistic approach to comprehending water systems. In contrast, the cases in this problématique have a larger share of governance in the "integrated approach to water management" paradigm, which encourages a holistic and comprehensive approach to water governance through cross-sectoral integration.

Distinct governance characteristics are also evident across problématiques (Figure A8). For instance, in the "hydropower vs. water ecology" problématique, governance is characterized by capacity (43%; $n = 3$), governance on a basin or catchment scale (43%; $n = 3$), and multi-level governance (43%; $n = 3$). Governance in this particular problématique had no characteristics—such as water rights or sectoral integration—that might support the main argument that transboundary governance does not integrate with local agendas (Schulze 2012). The results also show that the "land and water systems sustainability" issue is mostly observed with the cases (13 out of 38) of governance on the basin and catchment scale across all problématiques. Additionally, we observe that decentralization is most prevalent in the "surface water pollution" problématique, likely due to the need for action on multiple scales, depending on the extent of the problem. Finally, we found that the "industrial and household water security" problématique lacks evidence-based governance structures, revealing a gap in evidence-based urban water governance.

4.4 | Sustainability Outcomes in Relation to Water Governance Paradigms

To assess the cases in terms of their sustainability outcomes, we coded each case as to whether the study authors reported it predominantly as a "success" (i.e., positive impact of governance on sustainability) or a "failure" (negative impact or failure of governance to adequately address a sustainability issue). We coded the ambiguous cases (not positive, negative, or mixed) as "neutral/mixed." About 42% ($n = 94$) are identified as "success" cases, 32% ($n = 72$) as "failure" cases, and 26% ($n = 57$) as neutral. The cases in the publications are well-distributed across the three types of outcome indicators that we coded.

The findings in this section must be interpreted with care, given that few of the studies (18%; $n = 41$) in our sample provide very detailed information about the impacts of water governance/interventions on sustainability outcomes by presenting qualitative/quantitative data on outcome results. However, this observation is not specific to our sample, as most studies reporting on the outcomes of water governance focus on outputs (e.g., program or plan), rather than impacts, primarily because a longer time horizon is required to study the impacts of certain governance or interventions (Akhmouch et al. 2022). Moreover, assessing how and to what extent governance affects sustainability is a daunting task, as actual changes in water ecosystems depend on a variety of environmental, social, political, historical, economic, institutional, and administrative factors (Akhmouch et al. 2022). These factors can also go beyond hydrological boundaries (Luetkemeier et al. 2021; Yang et al. 2016). Overall, there is no universal or harmonized set of measuring indicators that could capture all these complexities (Akhmouch et al. 2022), which raises a question about the measurability of the impacts of water governance.

Generally, we observe that certain paradigms, such as "participatory and collaborative governance," "integrated approach to water management," "adaptive (co-)management or governance," and "community-based management," among others, have been reported to result in better sustainability outcomes (Figure 5). For instance, Pereira, Barreto, and Pittock (2009) show how participatory river-basin management in the Sao Joao River basin in Brazil, implemented as a response to a eutrophication problem, has helped to address pollution and other environmental challenges. Another example could be the study by Brombal et al. (2018), discussing the integrated watershed management (IWM) program in China. The study shows how the implementation of the IWM program, coordinating water

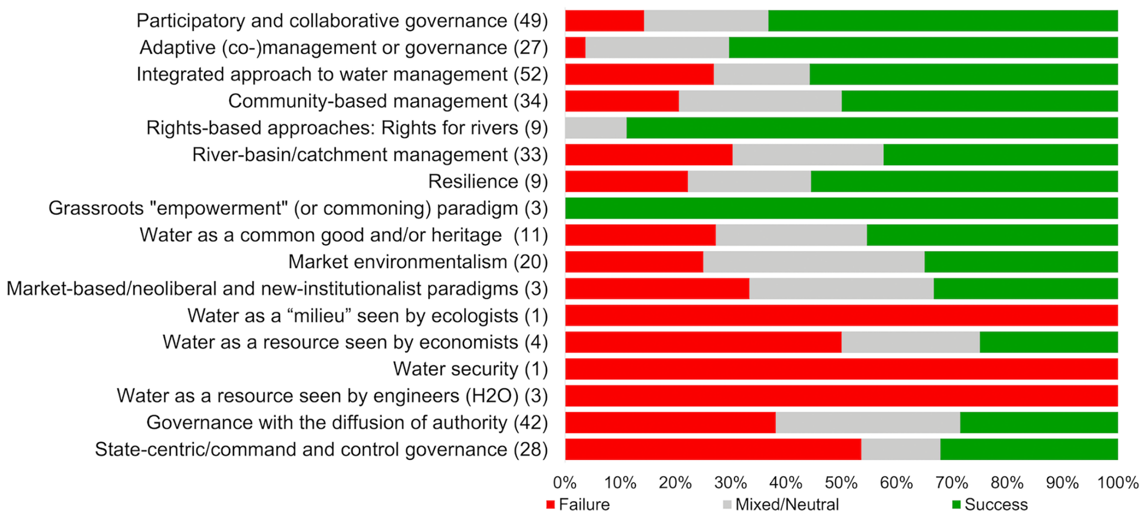


FIGURE 5 | Water-related sustainability outcomes across water governance paradigms. The numbers in brackets correspond to the number of cases with the respective governance characteristics.

environmental management measures with urban planning, resulted in better environmental outcomes in terms of water quality (Cong et al. 2020).

Finally, we were also interested in intermediate outcomes in our cases, particularly their relation to paradigms. Intermediate outcomes are the short-to medium-term effects or changes that occur as a result of a governance intervention before the sustainability outcomes are realized and serve as important precursors to the sustainability outcomes. Examining their distribution, we note that an enabling (or challenging) environment and enhanced (or weakened) coordination and cooperation were major determinants of sustainability outcomes across all paradigms (Figure A9). Notably, we found no instances of behavioral change as an intermediate outcome in the “state-centric/command and control governance” paradigm.

In summary, our analysis of water governance paradigms highlights the prevalence of certain paradigms over others and reveals how they are mostly observed in combination. While each paradigm is linked to specific governance characteristics, they may sometimes be observed with characteristics diverging from their fundamental principles. Moreover, our findings suggest that paradigms exhibit responsiveness to water-related challenges. Finally, certain paradigms demonstrate better sustainability outcomes, although these outcomes are sensitive to other contextual factors.

5 | Conclusions and Ways Forward in the Scientific Understanding of Water Governance

Assessing 223 cases published in 165 academic papers, this study provides the first large-scale attempt to take stock of the multitude of water governance paradigms and how they relate to governance characteristics, problématiques, and outcomes. Although most of the studies in the reviewed literature are predominantly evaluative, which is useful for policymakers, the literature is largely fragmented, and many studies did not use explicit analytical frameworks, both of which hinder knowledge accumulation. The review also reveals how paradigms align with diverse governance arrangements and interact with water-related problématiques. Additionally, we found that paradigms like “integrated approach to water management,” “participatory and collaborative governance,” and “community-based management” are associated with better sustainability outcomes. Based on these findings and other reflections, we identify four areas where further research could enhance knowledge production in the water governance literature.

The review reveals that the research question concerning “what works (or does not work) to achieve a particular desired outcome or condition,” which has a great potential to support evidence-based policymaking (Sanderson 2002), has received only limited attention in the studied literature. However, a better understanding of which configurations of governance systems have enhanced water availability, quality, and ecosystem well-being could inform policymakers about the policy actions to take. Further investigation into the 41 cases with detailed sustainability outcomes could provide valuable insights into the factors contributing to successful or unsuccessful outcomes in water governance.

Our results reveal that some paradigms, such as “integrated approach to water management,” “participatory and collaborative governance,” and “community-based management,” are mostly associated with successful outcomes. However, this does not imply that these paradigms should be applied indiscriminately, as doing so would fall into the panacea trap argued by Ostrom, Janssen, and Anderies (2007), where one-size-fits-all solutions are inappropriately applied to diverse problems. We are also aware that the identified patterns in the sustainability outcomes of governance may be subject to biases, including a tendency to publish more statistically significant results or to seek out, interpret, and publish results that align with one's existing beliefs, viewpoints, and hypotheses (i.e., confirmation bias; Zvereva and Kozlov 2021). Also, it is important to emphasize that our study maps the literature on these governance paradigms and their reported sustainability outcomes without delving deeply into the context-specific details of each case. Therefore, while we observe positive outcomes, it is possible that our findings reflect some biases inherent in the studies reviewed. As such, this study's results should be further examined by comparing a set of these cases, using in-depth qualitative analyses. Such analysis should also consider interactions between governance configurations and contextual factors that might influence sustainability outcomes (Gupta, Pahl-Wostl, and Zondervan 2013). One potential approach is to employ qualitative comparative analysis to break down water governance into its constituent building blocks, identifying governance configurations and contextual factors that are necessary but not sufficient for achieving sustainable outcomes.

Furthermore, it is important to emphasize that governance characteristics not only emerge from the rational responses of actors but also result from political struggles over different interests, as power asymmetries substantially shape the process by influencing rule-setting, issue problematizing, and policy implementation (Morrison et al. 2019; Schlager and Blomquist 2008). To this end, integrating political-economic interests, discourse, institutional entrepreneurship, and power dynamics into the dialogue—and situating them within a historical context—would certainly enhance understanding of how water governance operates and whether it ensures the wellbeing of water systems (Clement 2010; Méndez, Amezaga, and Santamaría 2019; Sehring 2009).

As a way forward, this work offers a starting point for the development of a "diagnostic approach" (Cox 2011; Ostrom 2007) to identify a combination of governance characteristics that lead to certain sustainability outcomes under diverse contextual factors. Unlike overly simplified prescriptions for environmental problems, the diagnostic approach recognizes the nestedness of socio-ecological systems and the contextual nature of generalizations (Cox 2011; Pahl-Wostl et al. 2010). It identifies the causes of a particular outcome in the case by exploring the conditions that could lead to it and devises theories, hypotheses, and prescriptions that are generalizable or specific to one set of cases by comparing them to others (Cox 2011). Thus, future studies could explore interlinkages among the four elements presented in this paper—water-related problématiques, paradigms, governance characteristics, and sustainability outcomes—and incorporate them into a diagnostic assessment of the sustainability outcomes of water governance systems. These elements could be further unpacked into multiple conceptual tiers, depending on guiding policy or empirical questions (Ostrom 2007).

Finally, the case repository of this systematic review and the data extracted from the review of the included studies present an opportunity for researchers working on similar issues or interested in the in-depth exploration of certain cases and meta-research. The repository allows the examination of a diverse range of cases, such as those with positive and negative sustainability outcomes, as well as governance operating in similar and different water-related contexts and cases with water governance systems that have experienced shifts. Overall, we hope that this review and the case repository will contribute to an improved understanding of water governance and its outcomes, which will ultimately be central to water governance practitioners and researchers alike.

Author Contributions

Shahana Bilalova: conceptualization (equal), data curation (lead), formal analysis (lead), investigation (equal), methodology (equal), visualization (lead), writing – original draft (lead), writing – review and editing (lead). **Jens Newig:** conceptualization (equal), investigation (equal), methodology (equal), supervision (equal), writing – review and editing (supporting). **Sergio Villamayor-Tomas:** conceptualization (equal), investigation (equal), methodology (supporting), supervision (equal), writing – review and editing (supporting).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The datasets generated and/or analyzed during the current study will be available after the paper published in the Leuphana University repository, https://doi.org/10.48548/pubdata-235.

Related Wires Articles

Comanagement of groundwater: A review

Why is state-centered groundwater governance largely ineffective? A review

Community water governance for urban water security in the Global South: Status, lessons, and prospects

Toward a contextualized research agenda: Governance challenges of the wastewater treatment policy in Mexico and the role of subnational governments

Endnotes

[1] Throughout the paper, we will refer to "water-related sustainability outcomes" as "sustainability outcomes."

[2] NEWAVE is an EU Horizon 2020-funded project that aims to develop and implement a cutting-edge research agenda addressing crucial water governance priorities and future trends. The project also focuses on providing extensive interdisciplinary training to early-stage researchers (ESRs) (NEWAVE n.d.).

References

Akhmouch, A., P. A. Roche, O. Romano, and M. Salvetti. 2022. "Can Measuring the Impact of Water Governance Turn the Tide?" *Water International* 47, no. 2: 153–159. https://doi.org/10.1080/02508060.2022.2050624.

Ananda, J., D. McFarlane, and M. Loh. 2020. "The Role of Experimentation in Water Management Under Climate Uncertainty: Institutional Barriers to Social Learning." *Environmental Policy and Governance* 30, no. 6: 319–331. https://doi.org/10.1002/eet.1887.

Bilalova, S., J. Newig, and S. Villamayor-Tomas. 2024. "Water Governance and Sustainability Outcomes: Dataset From Systematic Review of 165 Empirical Water Governance Research Articles." https://doi.org/10.48548/pubdata-235.

Biswas, A. K. 2008. "Integrated Water Resources Management: Is It Working?" *International Journal of Water Resources Development* 24, no. 1: 5–22. https://doi.org/10.1080/07900620701871718.

Brombal, D., Y. Niu, L. Pizzol, et al. 2018. "A Participatory Sustainability Assessment for Integrated Watershed Management in Urban China." *Environmental Science and Policy* 85: 54–63. https://doi.org/10.1016/j.envsci.2018.03.020.

Challies, E., and J. Newig. 2022. "Water, Rivers and Wetlands: Governance Paradigms and Principles." In *Routledge Handbook of Global Environmental Politics*, vol. 46, 512–525. London, UK: Routledge. https://doi.org/10.4324/9781003008873-43.

Clement, F. 2010. "Analysing Decentralised Natural Resource Governance: Proposition for a "Politicised" Institutional Analysis and Development Framework." *Policy Sciences* 43, no. 2: 129–156. https://doi.org/10.1007/s11077-009-9100-8.

Cong, W., X. Li, Y. Qian, and L. Shi. 2020. "Polycentric Approach of Wastewater Governance in Textile Industrial Parks: Case Study of Local Governance Innovation in China." *Journal of Environmental Management* 280: 111730. https://doi.org/10.1016/j.jenvman.2020.111730.

Cox, M. 2011. "Advancing the Diagnostic Analysis of Environmental Problems." *International Journal of the Commons* 5, no. 2: 346–363. https://doi.org/10.18352/ijc.273.

Cox, M., G. G. Gurney, J. M. Anderies, et al. 2021. "Lessons Learned From Synthetic Research Projects Based on the Ostrom Workshop Frameworks." *Ecology and Society* 26, no. 1. https://doi.org/10.5751/ES-12092-260117.

Cox, M., S. Villamayor-Tomas, N. C. Ban, et al. 2020. "From Concepts to Comparisons: A Resource for Diagnosis and Measurement in Social-Ecological Systems." *Environmental Science and Policy* 107, no. July 2019: 211–216. https://doi.org/10.1016/j.envsci.2020.02.009.

Emerson, K., T. Nabatchi, and S. Balogh. 2012. "An Integrative Framework for Collaborative Governance." *Journal of Public Administration Research and Theory* 22, no. 1: 1–29. https://doi.org/10.1093/jopart/mur011.

Frohlich, M. F., C. Jacobson, P. Fidelman, and T. F. Smith. 2018. "The Relationship Between Adaptive Management of Social-Ecological Systems and Law: A Systematic Review." *Ecology and Society* 23, no. 2: art23. https://doi.org/10.5751/ES-10060-230223.

Goyal, N., and M. Howlett. 2018. "Lessons Learned and Not Learned: Bibliometric Analysis of Policy Learning." In *Learning in Public Policy*, 27–49. Cham, Switzerland: Springer International Publishing. https://doi.org/10.1007/978-3-319-76210-4_2.

Gupta, J. 2012. "Changing North-South Challenges in Global Environmental Politics." In *Handbook of Global Environmental Politics*, 2nd ed., 97–112. Cheltenham, UK: Edward Elgar Publishing. https://doi.org/10.4337/9781849809412.00017.

Gupta, J., C. Pahl-Wostl, and R. Zondervan. 2013. "'Glocal' Water Governance: A Multi-Level Challenge in the Anthropocene." *Current Opinion in Environmental Sustainability* 5, no. 6: 573–580. https://doi.org/10.1016/j.cosust.2013.09.003.

GWP. 2000. "Towards Water Security: A Framework for Action Foreword."

Halbe, J., C. Pahl-Wostl, J. Sendzimir, and J. Adamowski. 2013. "Towards Adaptive and Integrated Management Paradigms to Meet the Challenges of Water Governance." *Water Science and Technology* 67, no. 11: 2651–2660. https://doi.org/10.2166/wst.2013.146.

Hall, A. W. 2003. "Dialogues on Water Governance." *Source: Water Resources IMPACT* 5, no. 4: 9–12. https://doi.org/10.2307/wateresoimpa.5.4.0009.

Hall, P. A. 1993. "Policy Paradigms, Social Learning, and the State: The Case of Economic Policymaking in Britain." *Comparative Politics* 25, no. 3: 275. https://doi.org/10.2307/422246.

He, J., J. Yao, A. Li, et al. 2020. "Potential Impact of Water Transfer Policy Implementation on Lake Eutrophication on the Shandong Peninsula: A Difference-In-Differences Approach." *Hydrology Research* 51, no. 5: 1063–1076. https://doi.org/10.2166/nh.2020.047.

Jiménez, A., P. Saikia, R. Giné, et al. 2020. "Unpacking Water Governance: A Framework for Practitioners." *Water (Switzerland)* 12, no. 3: 2–21. https://doi.org/10.3390/w12030827.

Kern, F., C. Kuzemko, and C. Mitchell. 2014. "Measuring and Explaining Policy Paradigm Change: The Case of UK Energy Policy." *Policy and Politics* 42, no. 4: 513–530. https://doi.org/10.1332/030557312X655765.

Luetkemeier, R., F. Frick-Trzebitzky, D. Hodžić, A. Jäger, D. Kuhn, and L. Söller. 2021. "Telecoupled Groundwaters: New Ways to Investigate Increasingly De-Localized Resources." *Water* 13, no. 20: 2906. https://doi.org/10.3390/w13202906.

Méndez, P. F., J. M. Amezaga, and L. Santamaría. 2019. "Explaining Path-Dependent Rigidity Traps: Increasing Returns, Power, Discourses, and Entrepreneurship Intertwined in Social-Ecological Systems." *Ecology and Society* 24, no. 2. https://doi.org/10.5751/ES-10898-240230.

Moher, D., A. Liberati, J. Tetzlaff, and D. G. Altman. 2009. "Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement." *PLoS Medicine* 6, no. 7: e1000097. https://doi.org/10.1371/journal.pmed.1000097.

Molle, F. 2008. "Nirvana Concepts, Narratives and Policy Models: Insights From the Water Sector." *Water Alternatives* 1, no. 1: 131–156.

Morrison, T. H., W. N. Adger, K. Brown, et al. 2019. "The Black Box of Power in Polycentric Environmental Governance." *Global Environmental Change* 57: 101934. https://doi.org/10.1016/j.gloenvcha.2019.101934.

NEWAVE. n.d. "About NEWAVE." https://nextwatergovernance.net/about-newave.

Newig, J., and M. Rose. 2020. "Cumulating Evidence in Environmental Governance, Policy and Planning Research: Towards a Research Reform Agenda." *Journal of Environmental Policy and Planning* 22, no. 5: 667–681. https://doi.org/10.1080/1523908X.2020.1767551.

Ostrom, E. 2007. "A Diagnostic Approach for Going Beyond Panaceas." *Proceedings of the National Academy of Sciences of the United States of America* 104, no. 39: 15181–15187. https://doi.org/10.1073/pnas.0702288104.

Ostrom, E. 2009. "A General Framework for Analyzing Sustainability of Social-Ecological Systems." *Science* 325, no. 5939: 419–422. https://doi.org/10.1126/science.1172133.

Ostrom, E., M. A. Janssen, and J. M. Anderies. 2007. "Going Beyond Panaceas." *Proceedings of the National Academy of Sciences* 104, no. 39: 15176–15178. https://doi.org/10.1073/pnas.0701886104.

Özerol, G., J. Vinke-De Kruijf, M. C. Brisbois, et al. 2018. "Comparative Studies of Water Governance: A Systematic Review." *Ecology and Society* 23, no. 4. https://doi.org/10.5751/ES-10548-230443.

Pahl-Wostl, C. 2015. "Conceptual and Analytical Framework." In *Water Governance in the Face of Global Change: From Understanding to Transformation*, 25–50. Cham, Switzerland: Springer International Publishing. https://doi.org/10.1007/978-3-319-21855-7_3.

Pahl-Wostl, C. 2019. "The Role of Governance Modes and Meta-Governance in the Transformation Towards Sustainable Water Governance." *Environmental Science & Policy* 91: 6–16. https://doi.org/10.1016/j.envsci.2018.10.008.

Pahl-Wostl, C., G. Holtz, B. Kastens, and C. Knieper. 2010. "Analyzing Complex Water Governance Regimes: The Management and Transition Framework." *Environmental Science and Policy* 13, no. 7: 571–581. https://doi.org/10.1016/j.envsci.2010.08.006.

Pahl-Wostl, C., L. Lebel, C. Knieper, and E. Nikitina. 2012. "From Applying Panaceas to Mastering Complexity: Toward Adaptive Water

Governance in River Basins." *Environmental Science and Policy* 23: 24–34. https://doi.org/10.1016/j.envsci.2012.07.014.

Pereira, L. F. M., S. Barreto, and J. Pittock. 2009. "Participatory River Basin Management in the São João River, Brazil: A Basis for Climate Change Adaptation?" *Climate and Development* 1, no. 3: 261–268. https://doi.org/10.3763/cdev.2009.0026.

Rogers, P., and P. A. Hall. 2003. "Effective Water Governance."In *TAC Background Papers, No. 7.* Global Water Partnership. https://doi.org/10.1128/AAC.03728-14.

Sanderson, I. 2002. "Evaluation, Policy Learning and Evidence-Based Policy Making." *Public Administration* 80, no. 1: 1–22. https://doi.org/10.1111/1467-9299.00292.

Schlager, E., and W. Blomquist. 2008. "The Essentials of Watershed Politics: Boundaries, Decision-making, and Accountability." In *Embracing Watershed Politics*, 55–88. Boulder, CO: University Press of Colorado. https://doi.org/10.1353/book.2688.

Schlager, E., and S. Villamayor-Tomas. 2013. "The IAD Framework and Its Tools for Policy and Institutional Analysis." In *Theories of the Policy Process*, edited by C. M. Weible, 196–229. New York, NY: Routledge.

Schulze, S. 2012. "Public Participation in the Governance of Transboundary Water Resources? Mechanisms Provided by River Basin Organizations." *L'Europe En Formation* 365, no. 3: 49–68. https://doi.org/10.3917/eufor.365.0049.

Sehring, J. 2009. "Path Dependencies and Institutional Bricolage in Post-Soviet Water Governance." *Water Alternatives* 2, no. 1: 61–81.

Streek, W. and K. Thelen. 2005. "Introduction: Institutional Change in Advanced Political Economies." *In Beyond Continuity: Institutional Change in Advanced Political Economies*, edited by W. Streek and K. Thelen, 3–39. Oxford: Oxford University Press.

Tropp, H. 2007. "Water Governance: Trends and Needs for New Capacity Development." *Water Policy* 9, no. S2: 19–30. https://doi.org/10.2166/wp.2007.137.

van Buuren, A., I. van Meerkerk, and C. Tortajada. 2019. "Understanding Emergent Participation Practices in Water Governance." *International Journal of Water Resources Development* 35, no. 3: 367–382. https://doi.org/10.1080/07900627.2019.1585764.

van Eck, N. J., and L. Waltman. 2010. "Software Survey: VOSviewer, a Computer Program for Bibliometric Mapping." *Scientometrics* 84, no. 2: 523–538. https://doi.org/10.1007/s11192-009-0146-3.

Yang, W., D. W. Hyndman, J. A. Winkler, et al. 2016. "Urban Water Sustainability: Framework and Application." *Ecology and Society* 21, no. 4: art4. https://doi.org/10.5751/ES-08685-210404.

Zvereva, E. L., and M. V. Kozlov. 2021. "Biases in Ecological Research: Attitudes of Scientists and Ways of Control." *Scientific Reports* 11, no. 1: 226. https://doi.org/10.1038/s41598-020-80677-4.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.

Supplementary material for: Toward sustainable water governance? Taking stock of paradigms, practices, and sustainability outcomes

Appendix 1. Search string

A search for papers that provide empirical information on how certain water governance systems perform in delivering water-related sustainability was conducted on Scopus without limiting it to any particular study region or publication date. The review aimed at covering the subject areas of Environmental Sciences and Social Sciences considering the relatability to the primary review question and components.

The search string was developed with the consideration of the compiled test papers and feedback from the scholars. Keywords in the search string correspond to the four components of the review question which are water-related terms, terms defining water governance, terms relevant to water-related sustainability, and outcome-related terms. The first and second parts of the search string are concerning water and governance-related terms, respectively, which are limited to a title only. Meanwhile, the following parts encompass water-related sustainability and outcome-related terms which are limited to a title and abstract.

The search was limited to publications in English encompassing articles and reviews. The run was performed on January 01, 2020 which yielded 8,761 results.

Search string

Run (January 01, 2020):

TITLE (freshwater* OR groundwater* OR water* OR river* OR basin* OR watershed* OR catchment* OR irrigation* OR wastewater* OR wetland* OR lake* OR hydropower* OR dam* OR reservoir* OR infrastructure*) AND TITLE (govern* OR policy* OR politi* OR policies* OR institution* OR privat* OR market* OR "Water User Association*" OR participat* OR collaborat* OR iwrm* OR "Water Resource* Management" OR "River Basin Management" OR "Catchment Management" OR "Watershed Management" OR planning* OR law* OR decree* OR agreement* OR treaty OR treaties OR "River Basin Organi?ation*") AND TITLE-ABS (sustainab* OR quality* OR quantity* OR security* OR stress* OR ecolog* OR ecosystem* OR environ* OR standard* OR drought* OR scarcity* OR overuse* OR overdraw*) AND TITLE-ABS (outcome* OR perform* OR success* OR fail* OR challeng* OR effect* OR impact* OR implement* OR assess* OR evaluat* OR evidence* OR empirical* OR study* OR studies* OR case* OR analys* OR result* OR finding* OR output* OR enforce* OR efficienc*) AND (LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "SOCI")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re"))

Appendix 2. Coding scheme

Criteria	Type of information	Categories or possible options	Reference (where applicable)
1. Bibliometric information			
1.1 Title of the publication	Text field		
1.2 Author(s)	Text field		
1.3 First author's sex	Multiple choice (select an option)	1. Female 2. Male 3. Could not identify	
1.4 Country of the first author's affiliation	Dropdown	A dropdown list of countries	
1.5 Publication year	Numbered field (four digits)		
2. Research framework and design			
2.1. Research question of the paper	Text field	*To quote the research question directly from the paper*	
2.2. What is/are the main governance-related research questions about?	Checkboxes (check all that apply)	1. Evaluation of a (or multiple) governance system(s) (Does it work? Why does it (not) work? In which contexts does it work? Is it legitimate? ...) 2. Explanation of the genesis of a governance system(s) (how did it come about....) 3. What works (= which factors) (or does not work) to achieve a particular desired outcome or condition, e.g., water savings, nitrate reduction, etc. 4. Look for patterns in data, or build a typology of... 5. Thick description of a governance system(s) 6. Other (please specify)	
2.3 Type of framework for analysis Definition framework (Ostrom et al. 2014, p.25): "The development and use of a general framework help to identify the elements and relationships	Multiple choice (select an option)	1. Using a pre-existing framework (i.e., with and without adaptation) 2. Developing a framework through a deductive approach	

among these elements that one needs to consider for institutional analysis. Frameworks organize diagnostic and prescriptive inquiry. They provide the most general list of variables that should be used to analyze all types of institutional arrangements. Frameworks provide a metatheoretical language that can be used to compare theories. They attempt to identify the universal elements that any theory relevant to the same kind of phenomena would need to include. […] The elements contained in a framework help analysts generate the questions that need to be addressed when they first conduct an analysis."		3. Developing a framework through an inductive approach 4. No/unclear framework	
	Text field	*If there is a framework, please specify it*	
2.4 Type of data	Checkboxes (check all that apply)	1. Primary (data, which is original and collected afresh, e.g., observation, interview, questionnaire) 2. Secondary (data, which has already been available, e.g., publications, public records and statistics, historical documents, and other sources of published information) 3. Other	Kothari (2008)
2.5 Main unit of analysis	Text field	*What is a main case/unit of analysis (e.g., governance system, country, people,)?*	
	Numbered field	*Number of cases/units studied*	
2.6 Methods	Checkboxes (check all that apply)	1. Qualitative observational method 2. Quantitative observational method 3. Experimentation 4. Set-theoretic method 5. Systematic review/meta-analysis 6. Other	
3. Case, location, and scale (i.e., case-specific information – data will be coded for each case, which reports on the outcome, within a study separately)			
3.1 Name of the case	Text field		
3.2 Name(s) of country/countries, the case locates in	Dropdown	1. A dropdown list of countries (specifying particular sets of countries, e.g., OECD, EU, ASEAN, NAFTA, OPEC, ..., as a separate option) 2. Not (clearly) defined	
4. Characteristics of a water-related sustainability issue (i.e., case-specific information – data will be coded for each case within a study, separately)			

4.1 Water source associated with the environmental/water-related sustainability issue	Checkboxes (check all that apply)	1. Surface water (e.g., rivers, lakes, ponds, wetlands, transitional water, etc.) 2. Groundwater 3. (Reclaimed) wastewater 4. Desalinized seawater and brackish water 5. Harvested rainfall-runoff water 6. Other non-conventional water sources 7. No clear water source targeted	
4.2 Water uses		1. Water for the living environment (sustaining flora and fauna) 2. Water for domestic use 3. Water for agricultural use (e.g., irrigation, drainage, livestock, etc.) 4. Water for industrial use, which means water used directly or indirectly for the production of economic goods and services (for instance, cooling as an indirect use or production of mineral water as a direct use) 5. Water for hydropower production (as a particular form of economic production) 6. Water resource as a medium for discharge of pollutants 7. Water as an infrastructure for tourism, leisure, recreation, sports, or medical use (e.g., bathing, swimming, skating, leisure navigation, sports fishing, windsurfing) 8. Water as an infrastructure for commercial navigation, fishing, gravel extraction, mining, or other commercial uses 9. Water as an infrastructure for land use (especially use of flood plains and basins for water storage, landscape development, urban development, settlement, etc.) 10. No clear water use indicated	Bressers and Kuks (2004)

4.3 Environmental/water-related sustainability issue studied/addressed in the paper	Checkboxes (check all that apply)	1. Water quality (e.g., pollution level, sedimentation, eutrophication, treatment) 2. Water quantity (e.g., water use efficiency, water allocation, water stress, water flow, recycling and reusing, treatment) 3. Aquatic biodiversity (e.g., fish biomass, macroinvertebrates, status of freshwater biodiversity) 4. Basin condition (e.g., land cover, channel modification) 5. Water-related ecosystem services (i.e., the ability of water resources provisioning ecosystem services) 6. General (e.g., protection, conservation, adaptation, resilience, ecological integrity, environmental status, environmental sustainability) 7. Other (please specify)	
5. Characteristics of a water governance (i.e., case-specific information – data will be coded for each case within a study, separately)			

5.1 Water governance paradigm Definitions of paradigm (Challies & Newig, 2022): "[Water governance] paradigms simultaneously imply a particular problem framing and suggest a particular set of solutions. As such, they have served as important agenda-setters for political action at different scales. Paradigms thus function as symbolic, 'normative–cognitive ideas' and focal points for joint action, whose circulation may even explain the enactment of certain local policies better than functional necessity or strategic considerations of the involved parties (Blatter and Ingram 2000)." "Paradigms — allows to engage with the ideational underpinnings of water governance, making it possible to understand why proponents of certain approaches have come to accept and embrace them, why they propagate them, and how the global circulation of ideas about governance works" (NEWAVE, n.d.).	Checkboxes (check all that apply)	1. State-centric/command and control governance (State-centric bureaucratic paradigm) 2. Integrated approach to water management (e.g., IWRM, IRBM, IWM, ICM, ICZM, etc.) 3. Scale-adapted governance (e.g., river-basin/catchment management) 4. Adaptive (co-)management or governance 5. Governance with the diffusion of authority (including multi-level governance, multi-tiered governance, polycentric governance, fragmentation, etc.) 6. Grassroots "empowerment" (or commoning) paradigm 7. Co-governance paradigm 8. Participatory and collaborative governance 9. Community-based management (e.g., Water User's Association (WUA), etc.) 10. Market-based/neoliberal and new-institutionalist paradigms 11. Market environmentalism 12. Nexus approach 13. Resilience 14. Water security 15. (Human- or nature-based) rights paradigm 16. Rights-based approaches: Human rights to water and sanitation 17. Rights-based approaches: Rights for rivers (incl. personhood, environmental flows, etc.) 18. Water as a resource seen by engineers (H2O) 19. Water as a resource seen by economists 20. Water as a "milieu" seen by ecologists 21. Water as a common good and/or heritage 22. Other (please specify)	
5.2 Water governance characteristics (i.e., ways in which governance is structured and implemented, and water resources are developed, managed, and provisioned, as well as determining which actors are involved and the interactions among them)	Checkboxes (check all that apply)	1. Centralization 2. Decentralization 3. Participation and/or collaboration	Extended from Pahl-Wostl (2020)

		4. Multi-level governance (incl. vertical coordination) 5. Polycentricity 6. Fragmentation 7. Governance on a basin or catchment scale 8. Evidence-based governance 9. Adaptiveness (i.e., flexibility (i.e., contrary to strict guidelines and norms), experimentation, and monitoring) 10. Sectoral integration (e.g., water, energy, ecosystems....) 11. Autonomy of institutions 12. Capacity (financial, human, technical, knowledge, etc.) 13. Partnership (e.g., civil society-business, business-government, government-civil society, etc.) 14. Water rights (i.e., existence of legal entitlements allowing individuals or entities to use water) 15. Accountability mechanisms (i.e., processes and systems in place to ensure that roles and responsibilities are clearly defined which make institutions and decision-makers accountable to public and other institutional stakeholders) 16. Transparency mechanisms (i.e., processes and systems in place to ensure the openness and accessibility of information and decision-making processes) 17. Other (please specify)	
5.3 Policy instruments are defined as "the myriad techniques at the disposal of governments to implement their policy objectives' [Howlett, 1991: 2]	Checkboxes (check all that apply)	1. Regulatory instruments 2. Market-based instruments 3. Voluntary agreements 4. Informational devices	Jordan et al. (2003)

5.4 Policy	Text field	*If the paper mentions a certain water-related policy, please specify*	
5.5 Dynamics of change in water governance (i.e., change from one governance mode to another one, or the introduction of particular governance arrangements/instruments)	Multiple choice (select an option) & Text field (to code the cases of governance modes separately if they report on outcome)	1. No 2. Yes *If yes, please specify*	
5.6 Start year of the governance considered	Numbered field (four digits)		
5.7 End year of the governance considered		If end year is mentioned, please insert the year in a four digits form. Otherwise, please mark as "ongoing" (i.e., if the end year is not mentioned in the paper) or leave blank (i.e., if the end year is not clear)	
5.8 Scale of the institutional arrangement dealing with the water-related sustainability issue mentioned in the study	Checkboxes (check all that apply)	1. Jurisdictional border 2. Hydrological border 3. Not (clearly) defined	
	Multiple choice (Select an option if the scale corresponds to **jurisdictional units**)	1. Global 2. International 3. Supranational/Continental/Regional 4. National 5. Sub-national (e.g., regional, inter-state, inter-provincial) 6. Local (e.g., state, provincial, city, municipal, county, inter-municipal, village)	
	Multiple choice (Select an option if the scale corresponds to **hydrological units**)	1. Whole transboundary river basin 2. Whole domestic river basin 3. Sub-basin of a transboundary river basin 4. Sub-basin of a domestic river basin 5. Aquifer 6. Wetland 7. Lake 8. Estuary	Özerol et al (2018)

6. Water-related sustainability outcomes (i.e., case-specific information – data will be coded for each case within a study, separately)			
6.1 Evaluative criteria: Which criteria are used in the paper concerning the performance of water governance system/intervention	Checkboxes (check all that apply)	1. Effectiveness: criteria used to indicate the extent to which a set objective concerning water-related sustainability is (likely to be) achieved by a governance system/intervention 2. Efficiency: criteria used to indicate a unit of resources needed for a governance system/intervention to deliver a set objective 3. Impact: criteria used to indicate the extent to which a governance system/intervention results in positive or negative, intended or unintended effects 4. Coherence: criteria used to indicate the extent to which another governance system/intervention undermines or support a governance system/intervention in place/introduced dealing with water-related sustainability issue 5. Adaptability/adaptive capacity (of a water system): criteria used to indicate the extent to which a governance system/intervention impacted capacity of a water resources system to adjust its responses to changing circumstances 6. Adaptability/adaptive capacity (of a governance system/intervention): criteria used to indicate the adaptive capacity of a governance system/intervention 7. Resilience/Robustness (of a water system): criteria used to indicate the extent to which a governance system/intervention impacted capacity of a water resources system to remain stable and functional under internal or external disturbances 8. Resilience/Robustness (of a governance system/intervention): criteria used to indicate the capacity of a water governance system/intervention to remain stable and	Extended from OECD (2021)

		functional in the face of water-related sustainability challenges 9. Sustainability: criteria used to indicate the extent to which benefits of a governance system/intervention will last financially, economically, socially, and environmentally 10. Equity/Justice: criteria used to indicate distribution of benefits, costs, and risks of outcomes and processes emerged as a result of a governance system/intervention 11. Legitimacy: criteria used to indicate to what extent a governance system/intervention and its decisions are recognized and accepted 12. Other (please specify)	
6.2 Water-related sustainability outcomes: Impact of water governance intervention on water-related sustainability issue (i.e., changes in environmental/water-related sustainability issues in terms of improvements or deteriorations)	Multiple choice (select an option)	1. More of a success: water governance system/intervention resulted in positive changes in environmental/water-related sustainability issue/water resources in terms of improvements 2. Neutral/Mixed: water governance system/intervention resulted in no/mixed changes in environmental/water-related sustainability issue/water resources in terms of deterioration 3. More of a failure: water governance system/intervention resulted in negative changes in environmental/water-related sustainability issue/water resources in terms of deterioration or failed to properly address a sustainability issue	
6.3 Nature of an intermediate outcome (if there is an outcome): short-medium term results of a governance intervention	Checkboxes (check all that apply)	1. Enabling environment: creation of an enabling (or challenging) ground for water governance system/intervention to address water-related sustainability issue (e.g., policy, legislation, regulation, implementation plan, financing, etc.) 2. Behavioral change: change in the behavior of water governance stakeholders	Extended from Granit et al. (2017) and Kochskämper et al. (2021)

		3. Learning and knowledge (co-) production: ecological and social learning by stakeholders and societal actors and (co-) production of knowledge 4. Conflict: water governance system/intervention leading to (or resolving) a conflict among/between stakeholder 5. Coordination and cooperation: enhancing (or weakening) coordination and cooperation among/between stakeholders 6. Other (please specify)	
6.4 How detailed authors explain the outcome results	Multiple choice (select an option)	1. Very detailed: authors provide detailed information by presenting qualitative/quantitative data on outcome results 2. Detailed: authors provide detailed information on how water governance system performs in terms of water-related sustainability by presenting qualitative/quantitative data on outcome results 3. Not detailed: authors briefly present how water governance system performs in terms of water-related sustainability in few sentences without any elaboration on the level of the outcome	

References

Bressers, J. T. A., & Kuks, S. M. M. (2004). Integrated Governance and Water Basin Management. In J. T. A. Bressers, & S. M. M. Kuks (Eds.), *Integrated Governance and Water Basin Management* (pp. 247-265). Kluwer Academic Publishers.

Challies, E., & Newig, J. (2022). Water, rivers and wetlands: Governance paradigms and principles. In *Routledge Handbook of Global Environmental Politics (Vol. 46, Issue 2, pp. 512–525)*. Routledge. https://doi.org/10.4324/9781003008873-43

Granit, J., Liss Lymer, B., Olsen, S., Tengberg, A., Nõmmann, S., & Clausen, T. J. (2017). A conceptual framework for governing and managing key flows in a source-to-sea continuum. *Water Policy*, *19(4)*, 673–691. https://doi.org/10.2166/wp.2017.126

Howlett, M. (1991). Policy Instruments, Policy Styles, and Policy Implementation: National Approaches to Theories of Instrument Choice. *Policy Studies Journal, 19(2)*, 1-21.

Jordan, A., Wurzel, R.K.W. & Zito, A.R. (2003). New instruments of environmental governance: patterns and pathways of change. *Environmental Politics*, *3(1),* 3-24.

Kochskämper, E., Koontz, T. M., & Newig, J. (2021). Systematic learning in water governance: insights from five local adaptive management projects for water quality innovation. *Ecology and Society*, *26(1)*, art22. https://doi.org/10.5751/ES-12080-260122

Kothari C. R. (2008). *Research methodology: Methods and Techniques*. New Age International Ltd.

NEWAVE. (n.d.). About NEWAVE. https://nextwatergovernance.net/about-newave

Newig, J., Schulz, D., & Jager, N. W. (2016). Disentangling Puzzles of Spatial Scales and Participation in Environmental Governance—The Case of Governance Re-scaling Through the European Water Framework Directive. *Environmental Management*, *58(6)*, 998–1014. https://doi.org/10.1007/s00267-016-0753-8

OECD. (2021). Applying Evaluation Criteria Thoughtfully. OECD Publishing. Paris. https://doi.org/10.1787/543e84ed-en

Ostrom, E., Cox, M., & Schlager, E. (2014). An Assessment of the Institutional Analysis and Development Framework and Introduction of the Socio-Ecological Systems Framework. In P.A. Sabatier & C.M. Weible (Eds.), *Theories of the Policy Process*. Westview Press, 3rd. edition.

Özerol, G., Vinke-De Kruijf, J., Brisbois, M. C., Flores, C. C., Deekshit, P., Girard, C., Knieper, C., Mirnezami, S. J., Ortega-Reig, M., Ranjan, P., Schröder, N. J. S., & Schröter, B. (2018). Comparative studies of water governance: A systematic review. *Ecology and Society*, *23(4)*. https://doi.org/10.5751/ES-10548-230443

Pahl-Wostl, C. (2019). The role of governance modes and meta-governance in the transformation towards sustainable water governance. *Environmental Science & Policy*, *91*. https://doi.org/10.1016/j.envsci.2018.10.008

Pahl-Wostl, C., Jeffrey, P., Isendahl, N., & Brugnach, M. (2011). Maturing the New Water Management Paradigm: Progressing from Aspiration to Practice. *Water Resources Management*, *25(3),* 837–856. https://doi.org/10.1007/s11269-010-9729-2

Pahl-Wostl, C., Knieper, C., Lukat, E., Meergans, F., Schoderer, M., Schütze, N., Schweigatz, D., Dombrowsky, I., Lenschow, A., Stein, U., Thiel, A., Tröltzsch, J., & Vidaurre, R. (2020). Enhancing the capacity of water governance to deal with complex management challenges: A framework of analysis. *Environmental Science & Policy, 107*, 23–35. https://doi.org/10.1016/j.envsci.2020.02.011

Appendix 3. Publications included for coding

1. Yildirim, Y. E., & Çakmak, B. (2004). Participatory irrigation management in Turkey. *International Journal of Water Resources Development*, *20*(2), 219–228. https://doi.org/10.1080/0790062042000206101
2. Rouillard, J., & Rinaudo, J. D. (2020). From State to user-based water allocations: An empirical analysis of institutions developed by agricultural user associations in France. *Agricultural Water Management*, *239*. https://doi.org/10.1016/j.agwat.2020.106269
3. Sokhem, P., & Sunada, K. (2006). The governance of the Tonle Sap Lake, Cambodia: Integration of local, national and international levels. *International Journal of Water Resources Development*, *22*(3), 399–416. https://doi.org/10.1080/07900620500482642
4. Salthouse, C. (2000). Making the most of the Mersey estuary: A partnership approach to catchment management. *International Journal of Urban Sciences*, *4*(2), 129–138. https://doi.org/10.1080/12265934.2000.9693472
5. Eckerberg, K. (1997). Comparing the local use of environmental policy instruments in nordic and baltic countries - The issue of diffuse water pollution. *Environmental Politics*, *6*(2), 24–47. https://doi.org/10.1080/09644019708414326
6. Kuzdas, C., Wiek, A., Warner, B., Vignola, R., & Morataya, R. (2014). Sustainability appraisal of water governance regimes: The case of Guanacaste, Costa Rica. *Environmental Management*, *54*(2), 205–222. https://doi.org/10.1007/s00267-014-0292-0
7. Oledn, M. T. T. (2001). Challenges and opportunities in watershed management for Laguna de Bay (Philippines). *Lakes and Reservoirs: Research and Management*, *6*(3), 243–246. https://doi.org/10.1046/j.1440-1770.2001.00154.x
8. Wang, J., Huang, J., Rozelle, S., Huang, Q., & Zhang, L. (2009). Understanding the water crisis in Northern China: What the government and farmers are doing. *International Journal of Water Resources Development*, *25*(1), 141–158. https://doi.org/10.1080/07900620802517566
9. Yu, Y., Ohandja, D. G., & Bell, J. N. B. (2012). Institutional Capacity on Water Pollution Control of the Pearl River in Guangzhou, China. *International Journal of Water Resources Development*, *28*(2), 313–324. https://doi.org/10.1080/07900627.2012.669704
10. Saravanan, V. S. (2009). Decentralisation and water resources management in the indian himalayas: The contribution of new institutional theories. *Conservation and Society*, *7*(3), 176–191. https://doi.org/10.4103/0972-4923.64735
11. Mestre, J. E. (1997). Integrated approach to river basin management: Lerma-chapala case study—attributions and experiences in water management in mexico. *Water International*, *22*(3), 140–152. https://doi.org/10.1080/02508069708686693
12. Silveira, A., Junier, S., Hüesker, F., Qunfang, F., & Rondorf, A. (2016). Organizing cross-sectoral collaboration in river basin management: case studies from the Rhine and the Zhujiang (Pearl River) basins. *International Journal of River Basin Management*, *14*(3), 299–315. https://doi.org/10.1080/15715124.2016.1170692
13. Lopez-Gunn, E. (2003). The Role of Collective Action in Water Governance: A Comparative Study of Groundwater User Associations in La Mancha Aquifers in Spain. *Water International*, *28*(3), 367–378. https://doi.org/10.1080/02508060308691711
14. Agovino, M., Cerciello, M., Garofalo, A., Landriani, L., & Lepore, L. (2020). Corporate governance and sustainability in water utilities. The effects of decorporatisation in the city of Naples, Italy. *Business Strategy and the Environment*, *30*(2), 874–890. https://doi.org/10.1002/bse.2659
15. Cobbing, J. E. (2008). Institutional linkages and acid mine drainage: The case of the Western Basin in South Africa. *International Journal of Water Resources Development*, *24*(3), 451–462. https://doi.org/10.1080/07900620802127374
16. Worte, C. (2017). Integrated watershed management and Ontario's conservation authorities. *International Journal of Water Resources Development*, *33*(3), 360–374. https://doi.org/10.1080/07900627.2016.1217403
17. Horinkova, V., & Abdullaev, I. (2003). Institutional aspects of water management in Central Asia: Water users associations. *Water International*, *28*(2), 237–245. https://doi.org/10.1080/02508060308691689
18. Steinebach, Y. (2019). Water quality and the effectiveness of European Union Policies. *Water (Switzerland)*, *11*(11). https://doi.org/10.3390/w11112244
19. Cookey, P. E., Darnsawasdi, R., & Ratanachai, C. (2016). Critical analysis of water governance challenges of Songkhla Lake Basin, Thailand. *Lakes and Reservoirs: Research and Management*, *21*(4), 293–314. https://doi.org/10.1111/lre.12155

20. Kuzdas, C., Warner, B. P., Wiek, A., Vignola, R., Yglesias, M., & Childers, D. L. (2016). Sustainability assessment of water governance alternatives: the case of Guanacaste Costa Rica. *Sustainability Science*, *11*(2), 231–247. https://doi.org/10.1007/s11625-015-0324-6
21. Ongley, E. D., & Wang, X. (2004). Transjurisdictional water pollution management in china: The legal and institutional framework. *Water International*, *29*(3), 270–281. https://doi.org/10.1080/02508060408691781
22. Marquardt, M., & Russell, S. (2007). Community governance for sustainability: Exploring benefits of community water schemes? *Local Environment*, *12*(4), 437–445. https://doi.org/10.1080/13549830701412521
23. Flores, C. C., Vikolainen, V., & Bressers, H. (2016). Water governance decentralisation and river basin management reforms in hierarchical systems: Do they work for water treatment policy in Mexico's Tlaxcala Atoyac sub-basin? *Water (Switzerland)*, *8*(5). https://doi.org/10.3390/w8050210
24. Schleyer, R. G., & Rosegrant, M. W. (1996). Chilean water policy: The role of water rights, institutions and markets. *International Journal of Water Resources Development*, *12*(1), 33–48. https://doi.org/10.1080/713672192
25. Jönsson, B. L. (2004). Stakeholder participation as a tool for sustainable development in the Em River Basin. *International Journal of Water Resources Development*, *20*(3), 345–352. https://doi.org/10.1080/0790062042000248583
26. Leendertse, K., Mitchell, S., & Harlin, J. (2009). IWRM and the environment: A view on their interaction and examples where IWRM led to better environmental management in developing countries. *Water SA*, *34*(6), 691–698. https://doi.org/10.4314/wsa.v34i6.183671
27. Mahanty, S., & Dang, T. D. (2013). Crafting Sustainability? The Potential and Limits of Institutional Design in Managing Water Pollution from Vietnam's Craft Villages. *Society and Natural Resources*, *26*(6), 717–732. https://doi.org/10.1080/08941920.2012.708822
28. Lopez Porras, G., Stringer, L. C., & Quinn, C. H. (2019). Corruption and conflicts as barriers to adaptive governance: Water governance in dryland systems in the Rio del Carmen watershed. *Science of the Total Environment*, *660*, 519–530. https://doi.org/10.1016/j.scitotenv.2019.01.030
29. Kim, J. H., Keane, T. D., & Bernard, E. A. (2015). Fragmented local governance and water resource management outcomes. *Journal of Environmental Management*, *150*, 378–386. https://doi.org/10.1016/j.jenvman.2014.12.002
30. Knieper, C., & Pahl-Wostl, C. (2016). A Comparative Analysis of Water Governance, Water Management, and Environmental Performance in River Basins. *Water Resources Management*, *30*(7), 2161–2177. https://doi.org/10.1007/s11269-016-1276-z
31. Tortajada, C., & Joshi, Y. K. (2014). Water quality management in Singapore: the role of institutions, laws and regulations. *Hydrological Sciences Journal*, *59*(9), 1763–1774. https://doi.org/10.1080/02626667.2014.942664
32. Gupta, A. Das. (2001). Challenges and opportunities for water resources management in southeast Asia. *Hydrological Sciences Journal*, *46*(6), 923–935. https://doi.org/10.1080/02626660109492886
33. Warner, A. T., Bach, L. B., & Hickey, J. T. (2014). Restoring environmental flows through adaptive reservoir management: planning, science, and implementation through the Sustainable Rivers Project. *Hydrological Sciences Journal*, *59*(3–4), 770–785. https://doi.org/10.1080/02626667.2013.843777
34. Manda, A. K., & Klein, W. A. (2014). Rescuing degrading aquifers in the Central Coastal Plain of North Carolina (USA): Just process, effective groundwater management policy, and sustainable aquifers. *Water Resources Research*, *50*(7), 5662–5677. https://doi.org/10.1002/2013WR015242
35. Nakamura, L., & Born, S. M. (1993). Substate institutional innovation for managing lakes and watersheds: a wisconsin case study. *JAWRA Journal of the American Water Resources Association*, *29*(5), 807–821. https://doi.org/10.1111/j.1752-1688.1993.tb03240.x
36. Loftus, A. j., & Mcdonald, D. a. (2001). Of Liquid Dreams: A Political Ecology Of Water Privatization In Buenos Aires. *Environment & Urbanization*, *13*(2), 179–199. https://doi.org/10.1177/095624780101300215
37. Drevno, A. (2018). From fragmented to joint responsibilities: Barriers and opportunities for adaptive water quality governance in California's urban-agricultural interface. *Resources*, *7*(1), 22. https://doi.org/10.3390/resources7010022

38. Cuadrado-Quesada, G. (2014). Groundwater governance and spatial planning challenges: examining sustainability and participation on the ground. *Water International*, *39*(6), 798–812. https://doi.org/10.1080/02508060.2014.962650
39. Özerol, G. (2013). Institutions of farmer participation and environmental sustainability: A multi-level analysis from irrigation management in Harran Plain, Turkey. *International Journal of the Commons*, *7*(1), 73–91. https://doi.org/10.18352/ijc.368
40. Graversgaard, M., Jacobsen, B. H., Kjeldsen, C., & Dalgaard, T. (2017). Stakeholder engagement and knowledge co-creation in water planning: Can public participation increase cost-effectiveness? *Water (Switzerland)*, *9*(3). https://doi.org/10.3390/w9030191
41. Ouyang, J., Zhang, K., Wen, B., & Lu, Y. (2020). Top-down and bottom-up approaches to environmental governance in China: Evidence from the river chief system (RCS). *International Journal of Environmental Research and Public Health*, *17*(19), 1–23. https://doi.org/10.3390/ijerph17197058
42. Koontz, T. M., & Newig, J. (2014). From Planning to Implementation: Top-Down and Bottom-Up Approaches for Collaborative Watershed Management. *Policy Studies Journal*, *42*(3), 416–442. https://doi.org/10.1111/psj.12067
43. Kundu, R., Aura, C. M., Muchiri, M., Njiru, J. M., & Ojuok, J. E. (2010). Difficulties of fishing at lake Naivasha, Kenya: Is community participation in management the solution? *Lakes and Reservoirs: Research and Management*, *15*(1), 15–23. https://doi.org/10.1111/j.1440-1770.2010.00419.x
44. Ngonyani, H., & Mourad, K. A. (2019). Role of water user associations on the restoration of the ecosystem in Tanzania. *Water (Switzerland)*, *11*(1). https://doi.org/10.3390/w11010141
45. Kurian, M., Dietz, T., & Murali, K. S. (2004). Public-private partnerships in watershed management - Evidence from the Himalayan foothills. *Water Policy*, *6*(2), 131–152. https://doi.org/10.2166/wp.2004.0009
46. Conallin, J., Wilson, E., & Campbell, J. (2018). Implementation of Environmental Flows for Intermittent River Systems: Adaptive Management and Stakeholder Participation Facilitate Implementation. *Environmental Management*, *61*(3), 497–505. https://doi.org/10.1007/s00267-017-0922-4
47. Meyer, S. M., & Konisky, D. M. (2007). Local institutions and environmental outcomes: Evidence from wetlands protection in Massachusetts. *Policy Studies Journal*, *35*(3), 481–502. https://doi.org/10.1111/j.1541-0072.2007.00234.x
48. Marques, R. C. (2008). Comparing private and public performance of Portuguese water services. *Water Policy*, *10*(1), 25–42. https://doi.org/10.2166/wp.2007.033
49. Lee, S., & Choi, G. W. (2012). Governance in a River Restoration Project in South Korea: The Case of Incheon. *Water Resources Management*, *26*(5), 1165–1182. https://doi.org/10.1007/s11269-011-9952-5
50. Fischhendler, I. (2008). Institutional conditions for IWRM: The Israeli case. *Ground Water*, *46*(1), 91–102. https://doi.org/10.1111/j.1745-6584.2007.00383.x
51. Kunrong, S., & Gang, J. (2020). The Policy Effects of the Environmental Governance of Chinese Local Governments: A Study Based on the Progress of the River Chief System. *Social Sciences in China*, *41*(3), 87–105. https://doi.org/10.1080/02529203.2020.1806475
52. Rinaudo, J. D., & Donoso, G. (2019). State, market or community failure? Untangling the determinants of groundwater depletion in Copiapó (Chile). *International Journal of Water Resources Development*, *35*(2), 283–304. https://doi.org/10.1080/07900627.2017.1417116
53. Dombrowsky, I. (2008). Institutional design and regime effectiveness in transboundary river management - The Elbe water quality regime. *Hydrology and Earth System Sciences*, *12*(1), 223–238. https://doi.org/10.5194/hess-12-223-2008
54. Chang, H., Thiers, P., Netusil, N. R., Yeakley, J. A., Rollwagen-Bollens, G., Bollens, S. M., & Singh, S. (2014). Relationships between environmental governance and water quality in a growing metropolitan area of the Pacific Northwest, USA. *Hydrology and Earth System Sciences*, *18*(4), 1383–1395. https://doi.org/10.5194/hess-18-1383-2014
55. Cui, C., & Yi, H. (2020). What drives the performance of collaboration networks: A qualitative comparative analysis of local water governance in China. *International Journal of Environmental Research and Public Health*, *17*(6). https://doi.org/10.3390/ijerph17061819
56. Montero, S. G., Castellón, E. S., Rivera, L. M. M., Ruvalcaba, S. G., & Llamas, J. J. (2006). Collaborative governance for sustainable water resources management: The experience of the Inter-municipal Initiative for the Integrated Management of the Ayuquila River Basin, Mexico. *Environment and Urbanization*, *18*(2), 297–313. https://doi.org/10.1177/0956247806069602

57. Jégou, A., & Sanchis-Ibor, C. (2019). The opaque lagoon. Water management and governance in L'albufera de València Wetland (Spain). *Limnetica*, *38*(1), 503–515. https://doi.org/10.23818/limn.38.29
58. Meyer, C., & Thiel, A. (2012). Institutional change in water management collaboration: Implementing the European Water Framework Directive in the German Odra river basin. *Water Policy*, *14*(4), 625–646. https://doi.org/10.2166/wp.2012.011
59. Owens, K., & Zimmerman, C. (2013). Local Governance Versus Centralization: Connecticut Wetlands Governance as a Model. *Review of Policy Research*, *30*(6), 629–656. https://doi.org/10.1111/ropr.12050
60. Mandarano, L., & Paulsenb, K. (2011). Governance capacity in collaborative watershed partnerships: Evidence from the Philadelphia region. *Journal of Environmental Planning and Management*, *54*(10), 1293–1313. https://doi.org/10.1080/09640568.2011.572694
61. Reymond, P., Chandragiri, R., & Ulrich, L. (2020). Governance Arrangements for the Scaling Up of Small-Scale Wastewater Treatment and Reuse Systems – Lessons From India. *Frontiers in Environmental Science*, *8*. https://doi.org/10.3389/fenvs.2020.00072
62. Guo, X. (2017). Application of Public Private Partnerships on urban river management in China: A case study of Chu River. *International Review for Spatial Planning and Sustainable Development*, *5*(4), 32–41. https://doi.org/10.14246/irspsd.5.4_32
63. Chaudhary, P., Chhetri, N. B., Dorman, B., Gegg, T., Rana, R. B., Shrestha, M., Thapa, K., Lamsal, K., & Thapa, S. (2015). Turning conflict into collaboration in managing commons: A case of Rupa lake watershed, Nepal. *International Journal of the Commons*, *9*(2), 744–771. https://doi.org/10.18352/ijc.561
64. Narayanan, N. C., & Venot, J. P. (2009). Drivers of change in fragile environments: Challenges to governance in Indian wetlands. *Natural Resources Forum*, *33*(4), 320–333. https://doi.org/10.1111/j.1477-8947.2009.01255.x
65. Mudliar, P. (2020). Polycentric to monocentric governance: Power dynamics in Lake Victoria's fisheries. *Environmental Policy and Governance*. https://doi.org/10.1002/eet.1917
66. Namara, I., Hartono, D. M., Latief, Y., & Moersidik, S. S. (2018). Institution and legal aspect based river water quality management. *International Journal of Engineering and Technology(UAE)*, *7*(3), 86–88. https://doi.org/10.14419/ijet.v7i3.9.15283
67. Aminova, M., & Abdullayev, I. (2009). Water management in a state-centered environment: Water governance analysis of Uzbekistan. *Sustainability*, *1*(4), 1240–1265. https://doi.org/10.3390/su1041240
68. Bitterman, P., & Koliba, C. J. (2020). Modeling Alternative Collaborative Governance Network Designs: An Agent-Based Model of Water Governance in the Lake Champlain Basin, Vermont. *Journal of Public Administration Research and Theory*, *30*(4), 636–655. https://doi.org/10.1093/jopart/muaa013
69. Qureshi, A. S. (2020). Groundwater governance in pakistan: From colossal development to neglected management. *Water (Switzerland)*, *12*(11), 1–20. https://doi.org/10.3390/w12113017
70. Libanio, P. A. C. (2014). The use of goal-oriented strategies in the building of water governance in Brazil. *Water International*, *39*(4), 401–416. https://doi.org/10.1080/02508060.2014.910433
71. Morris, J. C., Gibson, W. A., Leavitt, W. M., & Jones, S. C. (2014). Collaborative federalism and the emerging role of local nonprofits in water quality implementation. *Publius*, *44*(3), 499–518. https://doi.org/10.1093/publius/pju019
72. Haregeweyn, N., Berhe, A., Tsunekawa, A., Tsubo, M., & Meshesha, D. T. (2012). Integrated watershed management as an effective approach to curb land degradation: A case study of the enabered watershed in northern Ethiopia. *Environmental Management*, *50*(6), 1219–1233. https://doi.org/10.1007/s00267-012-9952-0
73. Mekonnen, D. K., Channa, H., & Ringler, C. (2015). The impact of water users' associations on the productivity of irrigated agriculture in Pakistani Punjab. *Water International*, *40*(5–6), 733–747. https://doi.org/10.1080/02508060.2015.1094617
74. McNeill, J. (2016). Scale Implications of Integrated Water Resource Management Politics: Lessons from New Zealand. *Environmental Policy and Governance*, *26*(4), 306–319. https://doi.org/10.1002/eet.1719
75. Brubaker, E. (1998). Privatizing water supply and sewage treatment: how far should we go? *Journal Des Économistes et Des Études Humaines*, *8*(4), 441–454. https://doi.org/10.1515/jeeh-1998-0404

76. Kapembwa, S., Gardiner, A., & Pétursson, J. G. (2020). Governance assessment of small-scale inland fishing: The case of Lake Itezhi-Tezhi, Zambia. *Natural Resources Forum*, *44*(3), 236–254. https://doi.org/10.1111/1477-8947.12198
77. Meijerink, S., & Huitema, D. (2017). The institutional design, politics, and effects of a bioregional approach: Observations and lessons from 11 case studies of river basin organizations. *Ecology and Society*, *22*(2). https://doi.org/10.5751/ES-09388-220241
78. Aubin, D., Cornut, P., & Varone, F. (2007). Access to water resources in Belgium: Strategies of public and private suppliers. *Water Policy*, *9*(6), 615–630. https://doi.org/10.2166/wp.2007.026
79. Das, S., Behera, B., & Mishra, A. (2020). Property Rights and Institutional Arrangements of a Man-Made Wetland in Dryland Area of West Bengal, India. *Wetlands*, *40*(6), 2553–2560. https://doi.org/10.1007/s13157-020-01360-y
80. Wang, Y., & Chen, X. (2020). River chief system as a collaborative water governance approach in China. *International Journal of Water Resources Development*, *36*(4), 610–630. https://doi.org/10.1080/07900627.2019.1680351
81. van Leeuwen, C. J. (2017). Water governance and the quality of water services in the city of Melbourne. *Urban Water Journal*, *14*(3), 247–254. https://doi.org/10.1080/1573062X.2015.1086008
82. Singh, C. (2018). Is participatory watershed development building local adaptive capacity? Findings from a case study in Rajasthan, India. *Environmental Development*, *25*, 43–58. https://doi.org/10.1016/j.envdev.2017.11.004
83. Hoornbeek, J., Hansen, E., Ringquist, E., & Carlson, R. (2013). Implementing Water Pollution Policy in the United States: Total Maximum Daily Loads and Collaborative Watershed Management. *Society and Natural Resources*, *26*(4), 420–436. https://doi.org/10.1080/08941920.2012.700761
84. Larson, K. L., Wiek, A., & Withycombe Keeler, L. (2013). A comprehensive sustainability appraisal of water governance in Phoenix, AZ. *Journal of Environmental Management*, *116*, 58–71. https://doi.org/10.1016/j.jenvman.2012.11.016
85. Hu, X. J., Xiong, Y. C., Li, Y. J., Wang, J. X., Li, F. M., Wang, H. Y., & Li, L. L. (2014). Integrated water resources management and water users' associations in the arid region of northwest China: A case study of farmers' perceptions. *Journal of Environmental Management*, *145*, 162–169. https://doi.org/10.1016/j.jenvman.2014.06.018
86. Asefa, T., Adams, A., & Kajtezovic-Blankenship, I. (2014). A tale of integrated regional water supply planning: Meshing socio-economic, policy, governance, and sustainability desires together. *Journal of Hydrology*, *519*(PC), 2632–2641. https://doi.org/10.1016/j.jhydrol.2014.05.047
87. Furlong, K., & Bakker, K. (2010). The contradictions in "alternative" service delivery: Governance, business models, and sustainability in municipal water supply. *Environment and Planning C: Government and Policy*, *28*(2), 349–368. https://doi.org/10.1068/c09122
88. Charlton, G., & Brunette, B. (2011). Sustainable development and water use in New Zealand: Water priority and allocation under section 5 of the resource management act 1991 and the national policy statement on freshwater management 2011. *WIT Transactions on Ecology and the Environment*, *153*, 355–373. https://doi.org/10.2495/WS110321
89. Furlong, K., & Bakker, K. (2011). Governance and sustainability at a municipal scale: The challenge of water conservation. *Canadian Public Policy*, *37*(2), 219–237. https://doi.org/10.3138/cpp.37.2.219
90. Pahl-Wostl, C., Lebel, L., Knieper, C., & Nikitina, E. (2012). From applying panaceas to mastering complexity: Toward adaptive water governance in river basins. *Environmental Science and Policy*, *23*, 24–34. https://doi.org/10.1016/j.envsci.2012.07.014
91. Harutyunyan, N. (2012). State versus private sector provision of water services in Armenia. *Frontiers of Environmental Science and Engineering in China*, *6*(5), 620–630. https://doi.org/10.1007/s11783-012-0425-8
92. Schulze, S., & Schmeier, S. (2012). Governing environmental change in international river basins: The role of river basin organizations. *International Journal of River Basin Management*, *10*(3), 229–244. https://doi.org/10.1080/15715124.2012.664820
93. Wang, J., Huang, J., Huang, Q., & Rozelle, S. (2006). Privatization of tubewells in North China: Determinants and impacts on irrigated area, productivity and the water table. *Hydrogeology Journal*, *14*(3), 275–285. https://doi.org/10.1007/s10040-005-0482-1

94. Cong, W., Li, X., Qian, Y., & Shi, L. (2020). Polycentric approach of wastewater governance in textile industrial parks: Case study of local governance innovation in China. *Journal of Environmental Management*, *280*. https://doi.org/10.1016/j.jenvman.2020.111730
95. Villeneuve, S., Painchaud, J., & Dugas, C. (2006). Targeted sustainable development: 15 years of government and community intervention on the St. Lawrence River. *Environmental Monitoring and Assessment*, *113*(1–3), 285–301. https://doi.org/10.1007/s10661-005-9085-5
96. Villamayor-Tomas, S., Avagyan, M., Firlus, M., Helbing, G., & Kabakova, M. (2016). Hydropower vs. fisheries conservation: A test of institutional design principles for common-pool resource management in the lower Mekong basin social-ecological system. *Ecology and Society*, *21*(1). https://doi.org/10.5751/ES-08105-210103
97. Mirnezami, S. J., de Boer, C., & Bagheri, A. (2020). Groundwater governance and implementing the conservation policy: the case study of Rafsanjan Plain in Iran. *Environment, Development and Sustainability*, *22*(8), 8183–8210. https://doi.org/10.1007/s10668-019-00488-0
98. Shiferaw, B., Bantilan, C., & Wani, S. (2008). Rethinking policy and institutional imperatives for integrated watershed management: Lessons and experiences from semi-arid India. *Journal of Food, Agriculture and Environment*, *6*(2), 370–377. https://www.scopus.com/inward/record.uri?eid=2-s2.0-52949152893&partnerID=40&md5=23adbb545d8d8d5b9d182d4333f664b8
99. Kirk, N., Brower, A., & Duncan, R. (2017). New public management and collaboration in canterbury, New Zealand's freshwater management. *Land Use Policy*, *65*, 53–61. https://doi.org/10.1016/j.landusepol.2017.03.034
100. Yao, L., Zhao, M., & Xu, T. (2017). China's water-saving irrigation management system: Policy, implementation, and challenge. *Sustainability (Switzerland), 9(12)*. https://doi.org/10.3390/su9122339
101. Biggs, H. C., Clifford-Holmes, J. K., Freitag, S., Venter, F. J., & Venter, J. (2017). Cross-scale governance and ecosystem service delivery: A case narrative from the Olifants River in north-eastern South Africa. *Ecosystem Services, 28,* 173–184. https://doi.org/10.1016/j.ecoser.2017.03.008
102. Zhang, Y., Fu, G., Yu, T., Shen, M., Meng, W., & Ongley, E. D. (2011). Trans-jurisdictional pollution control options within an integrated water resources management framework in water-scarce north-eastern China. *Water Policy, 13(5)*, 624–644. https://doi.org/10.2166/wp.2011.009
103. Barrios, J. E., RodríGuez-Pineda, J. A., & De La Maza Benignos, M. (2009). Integrated river basin management in the Conchos river basin, Mexico: A case study of freshwater climate change adaptation. *Climate and Development, 1(3)*, 249–260. https://doi.org/10.3763/cdev.2009.0024
104. Brombal, D., Niu, Y., Pizzol, L., Moriggi, A., Wang, J., Critto, A., Jiang, X., Liu, B., & Marcomini, A. (2018). A participatory sustainability assessment for integrated watershed management in urban China. *Environmental Science and Policy, 85*, 54–63. https://doi.org/10.1016/j.envsci.2018.03.020
105. Martinez, R., Green, K. M., & DeWan, A. (2013). Establishing reciprocal agreements for water and biodiversity conservation through a social marketing campaign in Quanda watershed, Peru. Conservation Evidence, 10, 42–47. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84898494123&partnerID=40&md5=ec84d60cb05759b5183232410d38d961
106. Saldías, C., Speelman, S., van Koppen, B., & van Huylenbroeck, G. (2016). Institutional arrangements for the use of treated effluent in irrigation, Western Cape, South Africa. *International Journal of Water Resources Development, 32(2),* 203–218. https://doi.org/10.1080/07900627.2015.1045970
107. Yang, X., Lu, X., & Ran, L. (2016). Sustaining China's large rivers: River development policy, impacts, institutional issues and strategies for future improvement. *Geoforum, 69*, 1–4. https://doi.org/10.1016/j.geoforum.2015.11.019
108. Cookey, P. E., Darnswasdi, R., & Ratanachai, C. (2016). Local people's perceptions of Lake Basin water governance performance in Thailand. *Ocean and Coastal Management, 120*, 11–28. https://doi.org/10.1016/j.ocecoaman.2015.11.015
109. Sinclair, A. J., Kumnerdpet, W., & Moyer, J. M. (2013). Learning sustainable water practices through participatory irrigation management in Thailand. *Natural Resources Forum, 37(1)*, 55–66. https://doi.org/10.1111/1477-8947.12012
110. Knüppe, K., & Pahl-Wostl, C. (2013). Requirements for adaptive governance of groundwater ecosystem services: Insights from Sandveld (South Africa), Upper Guadiana (Spain) and

Spree (Germany). *Regional Environmental Change, 13(1),* 53–66. https://doi.org/10.1007/s10113-012-0312-7
111. May, C. K. (2013). Power across scales and levels of fisheries governance: Explaining the active non-participation of fishers in Two Rivers, North Carolina. *Journal of Rural Studies, 32,* 26–37. https://doi.org/10.1016/j.jrurstud.2013.04.002
112. Iwasaki, S. (2013). Fishers-based watershed management in Lake Saroma, Japan. *Ocean and Coastal Management, 81*, 58–65. https://doi.org/10.1016/j.ocecoaman.2012.07.019
113. Davies, P. J., & Wright, I. A. (2014). A review of policy, legal, land use and social change in the management of urban water resources in Sydney, Australia: A brief reflection of challenges and lessons from the last 200 years. *Land Use Policy, 36*, 450–460. https://doi.org/10.1016/j.landusepol.2013.09.009
114. Emel, J., & Roberts, R. (1995). Institutional Form and Its Effect on Environmental Change: The Case of Groundwater in the Southern High Plains. *Annals of the Association of American Geographers, 85(4)*, 664–683. https://doi.org/10.1111/j.1467-8306.1995.tb01819.x
115. Papalia, J. (1996). An initial assessment of coastal watershed management in new south wales, australia. *Coastal Management, 24(4)*, 365–384. https://doi.org/10.1080/08920759609362303
116. Zhang, L., Heerink, N., Dries, L., & Shi, X. (2013). Water users associations and irrigation water productivity in Northern China. *Ecological Economics, 95*, 128–136. https://doi.org/10.1016/j.ecolecon.2013.08.014
117. Andersen, M. S. (1999). Governance by green taxes: implementing clean water policies in Europe 1970–1990. *Environmental Economics and Policy Studies, 2(1)*, 39–63. https://doi.org/10.1007/BF03353902
118. Lo, C. W., & Tang, S. -Y. (1994). Institutional contexts of environmental management: Water pollution control in Guangzhou, China. *Public Administration and Development, 14(1)*, 53–64. https://doi.org/10.1002/pad.4230140104
119. Özerol, G., & Bressers, H. (2015). Scalar alignment and sustainable water governance: The case of irrigated agriculture in Turkey. *Environmental Science and Policy, 45*, 1–10. https://doi.org/10.1016/j.envsci.2014.09.002
120. Garrick, D., & Aylward, B. (2012). Transaction costs and institutional performance in market-based environmental water allocation. *Land Economics, 88(3),* 536–560. https://doi.org/10.3368/le.88.3.536
121. Lu, Z., Zhao, L., & Dai, J. (2010). A study of water resource management in the Tarim Basin, Xinjiang. *International Journal of Environmental Studies, 67(2)*, 245–255. https://doi.org/10.1080/00207231003693274
122. Strauch, A. M., & Almedom, A. M. (2011). Traditional Water Resource Management and Water Quality in Rural Tanzania. *Human Ecology, 39(1)*, 93–106. https://doi.org/10.1007/s10745-011-9376-0
123. Varade, A. M., Wankhade, H., Mawale, Y. K., & Khandare, H. (2011). Watershed management as a tool for changing the Kaleidoscope of central India: A case study from Jhabua district of Madhya Pradesh, India. *Nature Environment and Pollution Technology, 10(4)*, 589–594. https://www.scopus.com/inward/record.uri?eid=2-s2.0-83255171092&partnerID=40&md5=6457f00c3463384efa6bd5d118ede30d
124. Vodden, K. (2015). Governing sustainable coastal development: The promise and challenge of collaborative governance in Canadian coastal watersheds. *Canadian Geographer, 59(2),* 167–180. https://doi.org/10.1111/cag.12135
125. Molle, F., & Mamanpoush, A. (2012). Scale, governance and the management of river basins: A case study from Central Iran. *Geoforum, 43(2)*, 285–294. https://doi.org/10.1016/j.geoforum.2011.08.004
126. Ratna Reddy, V., Srinivasa Reddy, M., & Rout, S. K. (2014). Groundwater governance: A tale of three participatory models in Andhra Pradesh, India. *Water Alternatives, 7(2)*, 275–297. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84902339100&partnerID=40&md5=bd588e9d9487bf333cf351b00a7ce76b
127. Venkatachalam, L. (2004). Sources of government failure and the environmental externality: Analysis of groundwater pollution in Tamil Nadu, India. *Water Policy, 6(5),* 413–426. https://doi.org/10.2166/wp.2004.0027
128. Talukder, B., & Hipel, K. W. (2020). Diagnosis of sustainability of trans-boundary water governance in the Great Lakes basin. *World Development,* 129. https://doi.org/10.1016/j.worlddev.2019.104855

129. Beierle, T. C., & Konisky, D. M. (2001). What are we gaining from stakeholder involvement? Observations from environmental planning in the Great Lakes. E*nvironment and Planning C: Government and Policy, 19(4),* 515–527. https://doi.org/10.1068/c5s
130. Manou, D., & Papathanasiou, J. (2009). Exploring the potential failure of the regulatory framework and management tools which govern the conservation of biodiversity: The case of artificial lake kerkini in Greece. *Journal of Environmental Assessment Policy and Management, 11(2)*, 213–243. https://doi.org/10.1142/S1464333209003324
131. White, I., Melville, M., Macdonald, B., Quirk, R., Hawken, R., Tunks, M., Buckley, D., Beattie, R., Williams, J., & Heath, L. (2007). From conflicts to wise practice agreement and national strategy: cooperative learning and coastal stewardship in estuarine floodplain management, Tweed River, eastern Australia. *Journal of Cleaner Production, 15(16),* 1545–1558. https://doi.org/10.1016/j.jclepro.2006.07.049
132. Taylor, P. L., MacIlroy, K., Waskom, R., Cabot, P. E., Smith, M., Schempp, A., & Udall, B. (2019). Every ditch is different: Barriers and opportunities for collaboration for agricultural water conservation and security in the Colorado River Basin. *Journal of Soil and Water Conservation, 74(3)*, 281–295. https://doi.org/10.2489/jswc.74.3.281
133. Sixt, G. N., Klerkx, L., Aiken, J. D., & Griffin, T. S. (2019). Nebraska's natural resource district system: Collaborative approaches to adaptive groundwater quality governance. *Water Alternatives, 12(2)*, 676–698. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85069518279&partnerID=40&md5=32a2e94a8359fad8ae5e5178d4f0bb72
134. Jetoo, S. (2018). Barriers to effective eutrophication governance: A comparison of the Baltic Sea and North American Great Lakes. *Water (Switzerland), 10(4)*. https://doi.org/10.3390/w10040400
135. Piégay, H., Dupont, P., & Faby, J. A. (2002). Questions of water resources management. Feedback on the implementation of the french SAGE and SDAGE plans (1992-2001). *Water Policy, 4(3)*, 239–262. https://doi.org/10.1016/S1366-7017(02)00008-9
136. Gensemer, M. K., & Yamaguchi, M. (1985). Successful water quality planning: an areawide perspective (California). *Journal of Soil & Water Conservation, 40(1)*, 76–78. https://www.scopus.com/inward/record.uri?eid=2-s2.0-0022212844&partnerID=40&md5=6e0134f13c4c213b7de85cbff1d3da64
137. Yan, F., Daming, H., & Kinne, B. (2006). Water resources administration institution in China. *Water Policy, 8(4)*, 291–301. https://doi.org/10.2166/wp.2006.041
138. Yang, H., Zhang, X., & Zehnder, A. J. B. (2003). Water scarcity, pricing mechanism and institutional reform in northern China irrigated agriculture. *Agricultural Water Management, 61(2)*, 143–161. https://doi.org/10.1016/S0378-3774(02)00164-6
139. Pereira, L. F. M., Barreto, S., & Pittock, J. (2009). Participatory river basin management in the São João River, Brazil: A basis for climate change adaptation? *Climate and Development, 1(3)*, 261–268. https://doi.org/10.3763/cdev.2009.0026
140. Sithirith, M., Evers, J., & Gupta, J. (2016). Damming the Mekong tributaries: Water security and the MRC 1995 Agreement. *Water Policy, 18(6)*, 1420–1435. https://doi.org/10.2166/wp.2016.003
141. Enqvist, J., Tengö, M., & Boonstra, W. J. (2016). Against the current: rewiring rigidity trap dynamics in urban water governance through civic engagement. *Sustainability Science, 11(6),* 919–933. https://doi.org/10.1007/s11625-016-0377-1
142. Tevapitak, K., & (Bert) Helmsing, A. H. J. (2019). The interaction between local governments and stakeholders in environmental management: The case of water pollution by SMEs in Thailand. *Journal of Environmental Management, 247*, 840–848. https://doi.org/10.1016/j.jenvman.2019.06.097
143. Somma, M. (1997). Institutions, ideology, and the tragedy of the commons: West Texas groundwater policy. *Publius, 27(1),* 1–11. https://doi.org/10.1093/oxfordjournals.pubjof.a029887
144. Jahan, S., Islam, I., Takao, K., & Kanegae, H. (2008). Shrinkage of the wetlands of Dhaka: A study from an institutional perspective. *Studies in Regional Science, 38(4)*, 861–875. https://doi.org/10.2457/srs.38.861
145. Jetoo, S., Thorn, A., Friedman, K., Gosman, S., & Krantzberg, G. (2015). Governance and geopolitics as drivers of change in the Great Lakes-St. Lawrence basin. *Journal of Great Lakes Research, 41(S1)*, 108–118. https://doi.org/10.1016/j.jglr.2014.11.011
146. Boone, S., & Fragaszy, S. (2018). Emerging scarcity and emerging commons: Water management groups and groundwater governance in Aotearoa New Zealand. *Water Alternatives, 11(3),* 795–823.

147. Chattopadhyay, S., & Thiruvananthapuram, K. (2018). Challenges of water governance in the context of water quality problem: Comparative study of India, Indonesia and Germany. *Transactions of the Institute of Indian Geographers, 40(2),* 171–183.
148. Langridge, R., & Ansell, C. (2018). Comparative analysis of institutions to govern the groundwater commons in California. *Water Alternatives, 11(3)*, 481–510.
149. Kajisa, K., & Dong, B. (2017). The effects of volumetric pricing policy on farmers' watermanagement institutions and their water use: The case of water user organization in an irrigation system in Hubei, China. *World Bank Economic Review, 31(1)*, 220–240. https://doi.org/10.1093/wber/lhv034
150. Xu, X., Wu, F., Zhang, L., & Gao, X. (2020). Assessing the effect of the Chinese river chief policy for water pollution control under uncertainty—using chaohu lake as a case. *International Journal of Environmental Research and Public Health, 17(9)*. https://doi.org/10.3390/ijerph17093103
151. Snell, M., Bell, K. P., & Leahy, J. (2013). Local institutions and lake management. *Lakes and Reservoirs: Research and Management, 18(1),* 35–44. https://doi.org/10.1111/lre.12017
152. Brillo, B. B. C., Quinones, E. C., & Lapitan, A. V. (2017). Restoration, development and governance of Dagatan Lake, San Antonio, Quezon, Philippines. *Taiwan Water Conservancy, 65(1),* 44–54.
153. Morris, L., & Cabrera, L. F. G. (2003). The involvement of the private sector in water servicing: Effects on the urban poor in the case of Aguascalientes, Mexico. *Greener Management International, 42*, 35–46. https://doi.org/10.9774/GLEAF.3062.2003.su.00006
154. Blumstein, S. (2017). Managing adaptation: international donors' influence on international river basin organizations in Southern Africa. *International Journal of River Basin Management, 15(4)*, 461–473. https://doi.org/10.1080/15715124.2017.1339354
155. Biddle, J. C. (2017). Improving the Effectiveness of Collaborative Governance Regimes: Lessons from Watershed Partnerships. *Journal of Water Resources Planning and Management, 143(9)*, 04017048. https://doi.org/10.1061/(asce)wr.1943-5452.0000802
156. Söderberg, C. (2016). Complex governance structures and incoherent policies: Implementing the EU water framework directive in Sweden. *Journal of Environmental Management, 183*, 90–97. https://doi.org/10.1016/j.jenvman.2016.08.040
157. Langridge, S. (2016). Social and biophysical context influences county-level support for collaborative watershed restoration: Case study of the Sacramento River, CA, USA. *Ecological Restoration, 34(4)*, 285–296. https://doi.org/10.3368/er.34.4.285
158. Rimmert, M., Baudoin, L., Cotta, B., Kochskämper, E., & Newig, J. (2020). Participation in river basin planning under the water framework directive-Has it benefitted good water status? *Water Alternatives, 13(3)*, 484–512
159. Delgado-Serrano, M. M., & Borrego-Marin, M. M. (2020). Drivers of innovation in groundwater governance. The links between the social and the ecological systems. *Land Use Policy, 91*. https://doi.org/10.1016/j.landusepol.2019.104368
160. Kaushik, R., Pattnaik, B. K., & Rath, B. (2019). Community participation in effective water resource management a comparative study in Alwar, Rajasthan. *Economic and Political Weekly, 54(35),* 53–58.
161. She, Y., Liu, Y., Jiang, L., & Yuan, H. (2019). Is China's River Chief Policy effective? Evidence from a quasi-natural experiment in the Yangtze River Economic Belt, China. *Journal of Cleaner Production, 220*, 919–930. https://doi.org/10.1016/j.jclepro.2019.02.031
162. Asomani-Boateng, R. (2019). Urban Wetland Planning and Management in Ghana: a Disappointing Implementation. *Wetlands, 39(2)*, 251–261. https://doi.org/10.1007/s13157-018-1105-7
163. Ulibarri, N. (2015). Tracing Process to Performance of Collaborative Governance: A Comparative Case Study of Federal Hydropower Licensing. *Policy Studies Journal, 43(2)*, 283–308. https://doi.org/10.1111/psj.12096
164. Yang, X., & Lu, X. X. (2013). Ten years of the Three Gorges Dam: A call for policy overhaul. *Environmental Research Letters, 8(4)*. https://doi.org/10.1088/1748-9326/8/4/041006
165. Grumbine, R. E., Dore, J., & Xu, J. (2012). Mekong hydropower: Drivers of change and governance challenges. *Frontiers in Ecology and the Environment, 10(2*), 91–98. https://doi.org/10.1890/110146

Appendix 4. Additional tables and figures

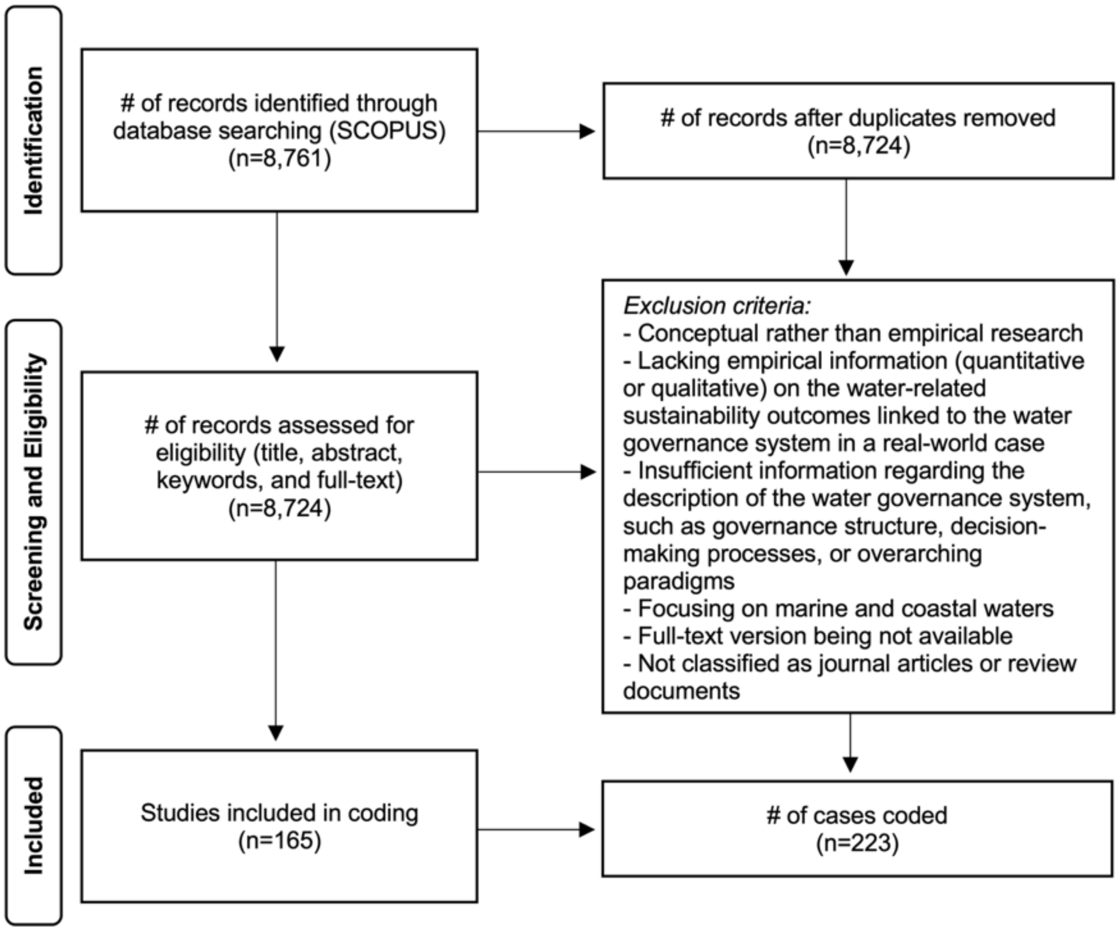


Figure A1 PRISMA flow diagram for the systematic review.

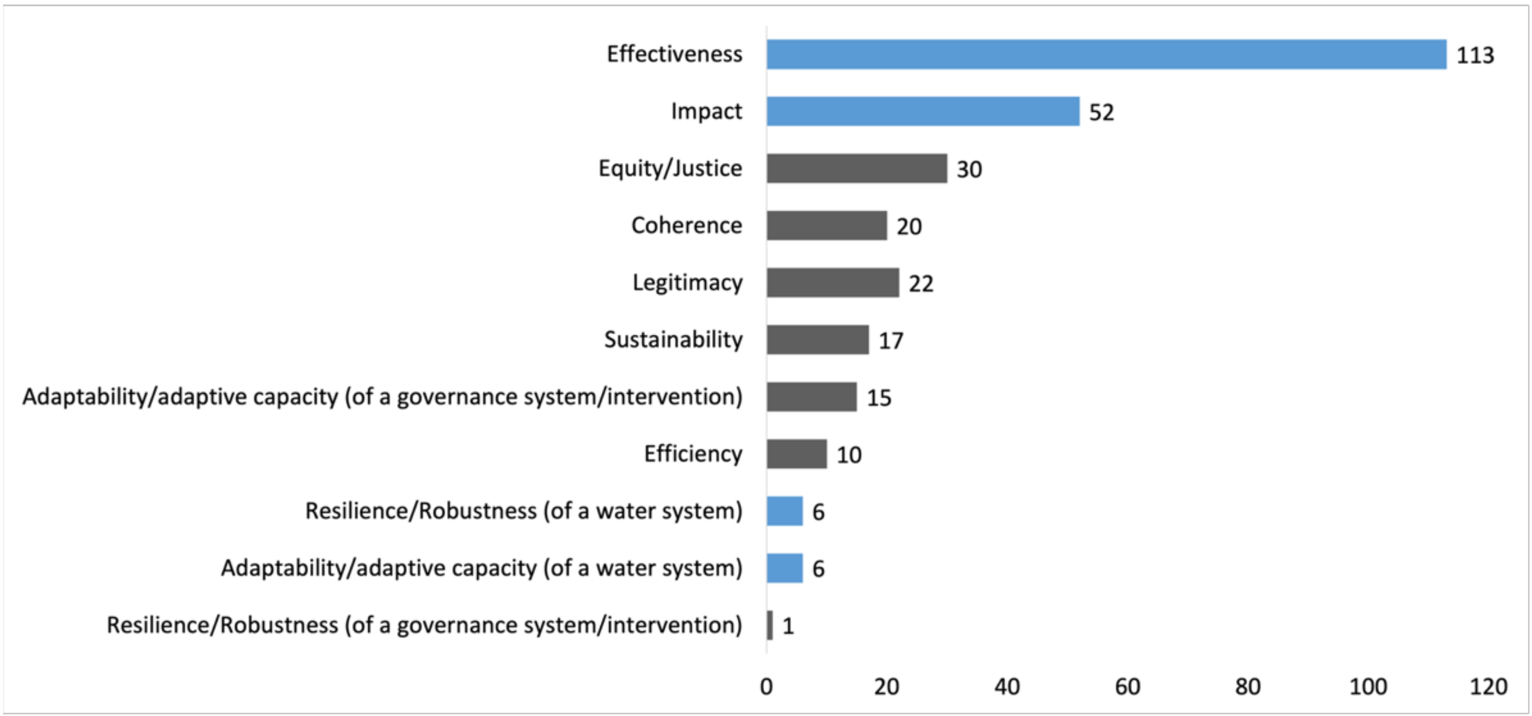
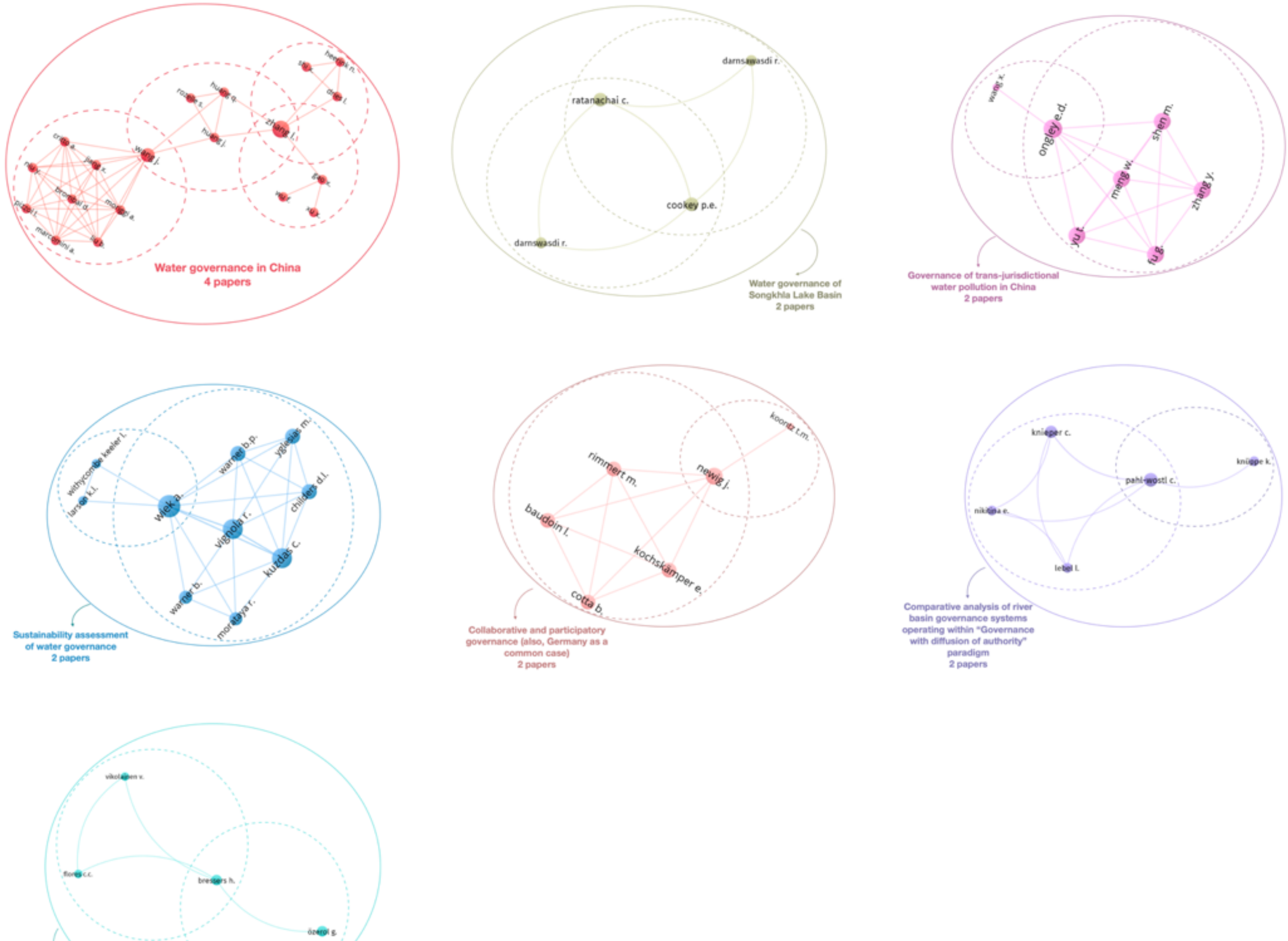


Figure A2 Evaluative criteria used by authors across included studies.



Co-authorship network: Close-up

Notes:
- Circle corresponds to clusters with a common theme
- Dashed line corresponds to co-authorship clusters resulted in a common publication
- Label corresponds to common themes among clusters, defined by screening titles and abstracts of publications

Figure A3 Co-authorship network: Close-up.

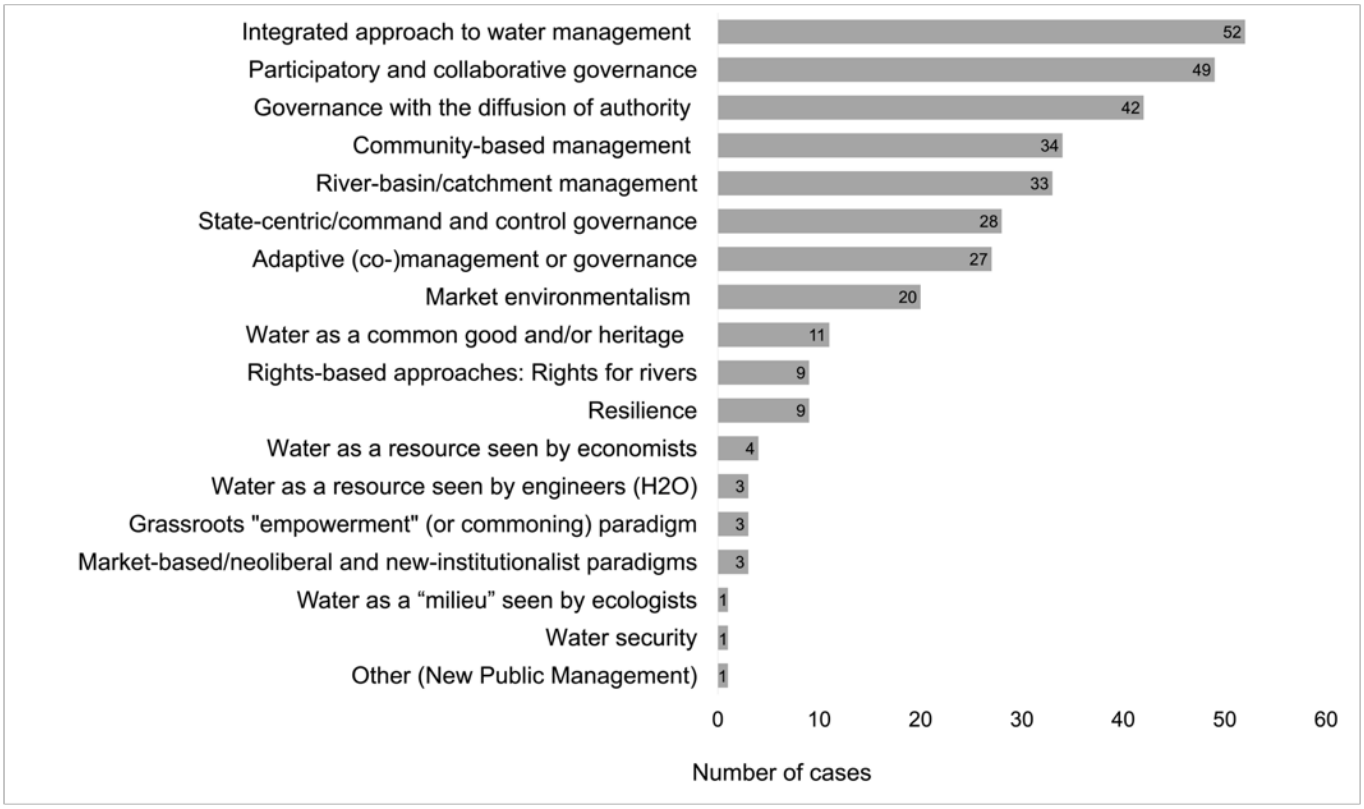


Figure A4 Water governance paradigms across the cases.

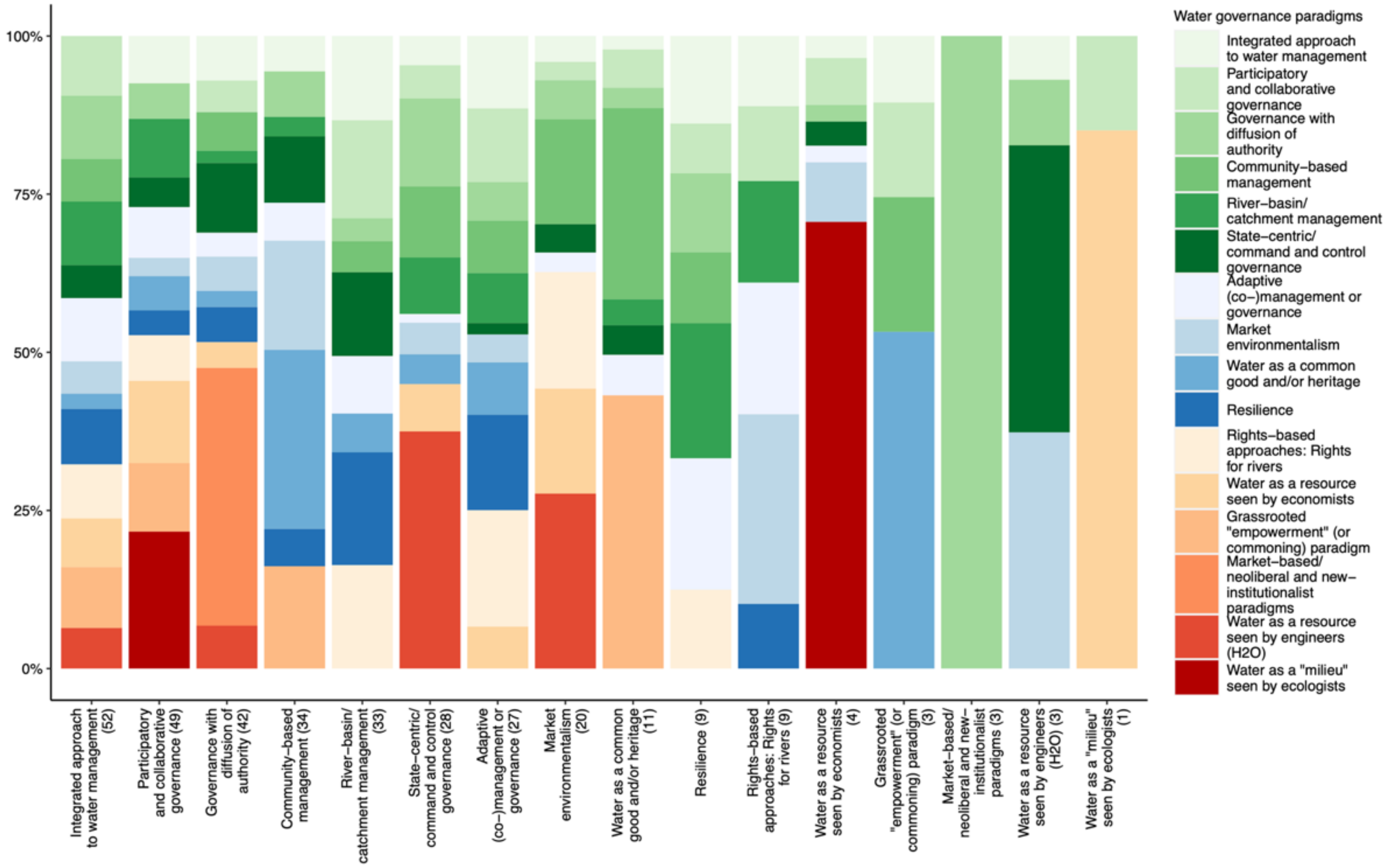


Figure A1 Frequency of co-appearance of paradigms across identified cases. Number in a bracket on a horizontal axis corresponds to the number of cases with respective paradigm while number in a bracket on a vertical axis corresponds to the number of cases with that respective paradigm only.

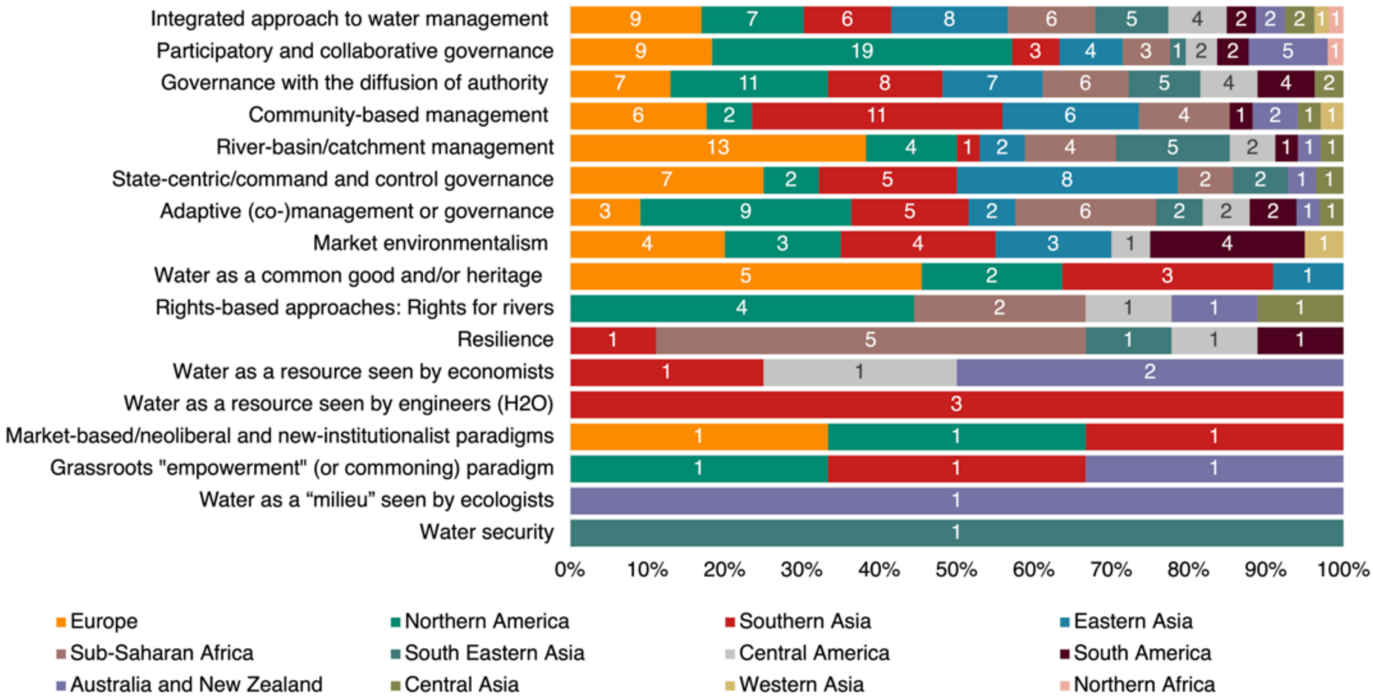


Figure A6 Regional distribution of paradigms. Cases in reviewed papers are grouped into geographic regions defined under the Standard Country or Area Codes for Statistical Use (known as M49) of the United Nations Statistics Division.

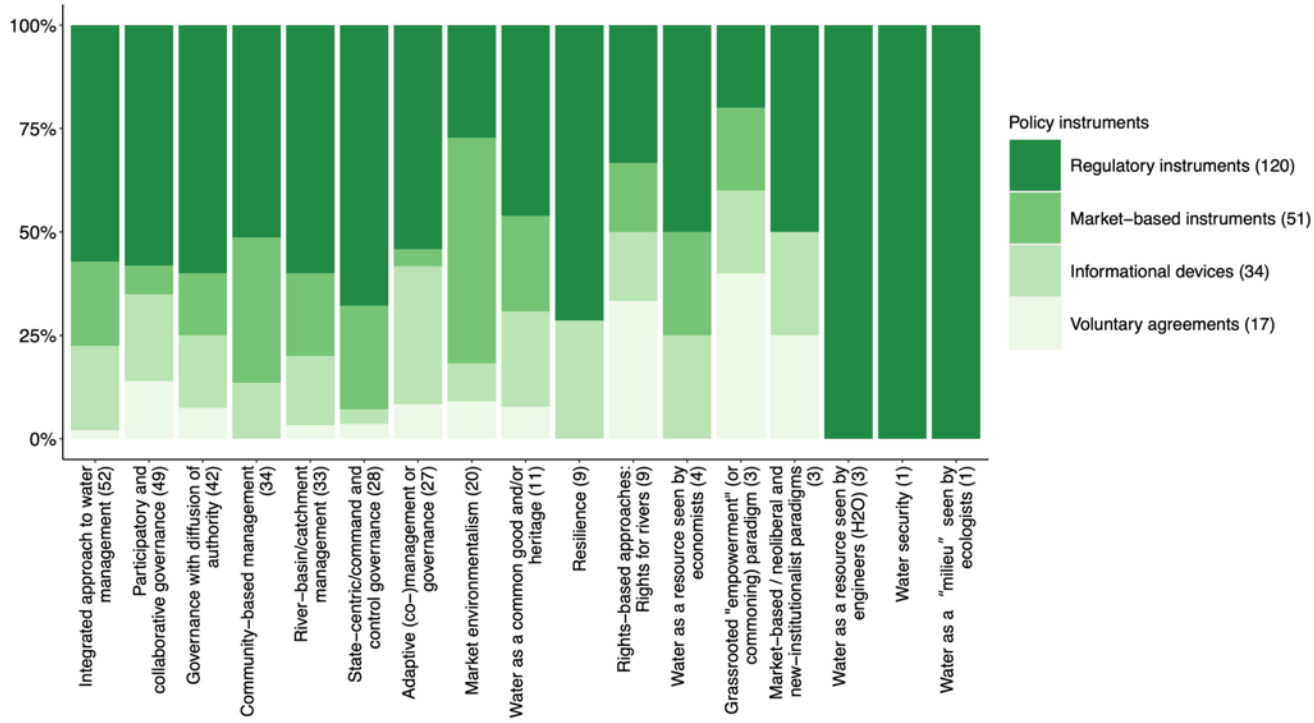


Figure A7 Distribution of policy instruments across paradigms. Number in a bracket in the legend corresponds to the number of cases with respective policy instruments.

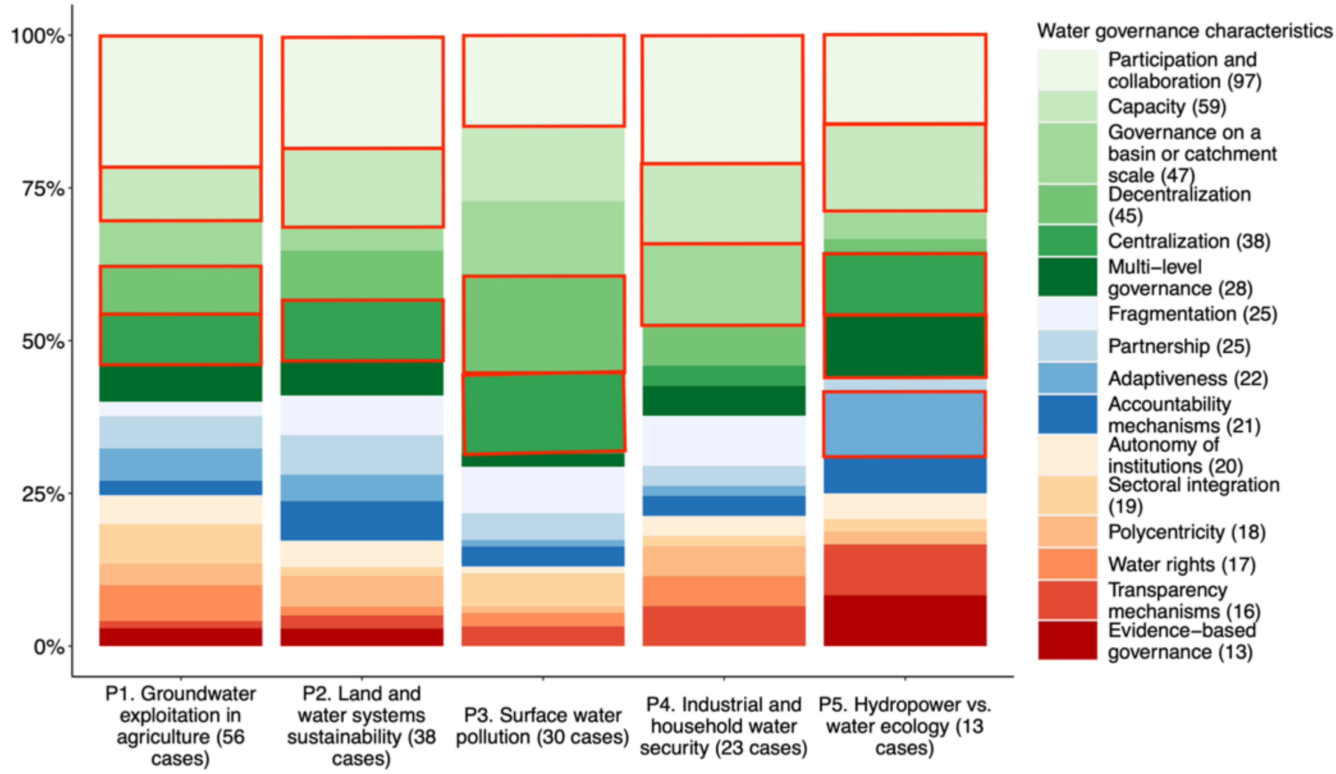


Figure A2 Distribution of governance characteristics across problématiques. Red rectangles in the figure indicate the most frequently observed three governance characteristics for each problématiques. The colors in the figure do not necessarily correspond to variations in values. Gradient color scale is chosen to improve readability of the figure and making it easier to be read by those with colorblindness.

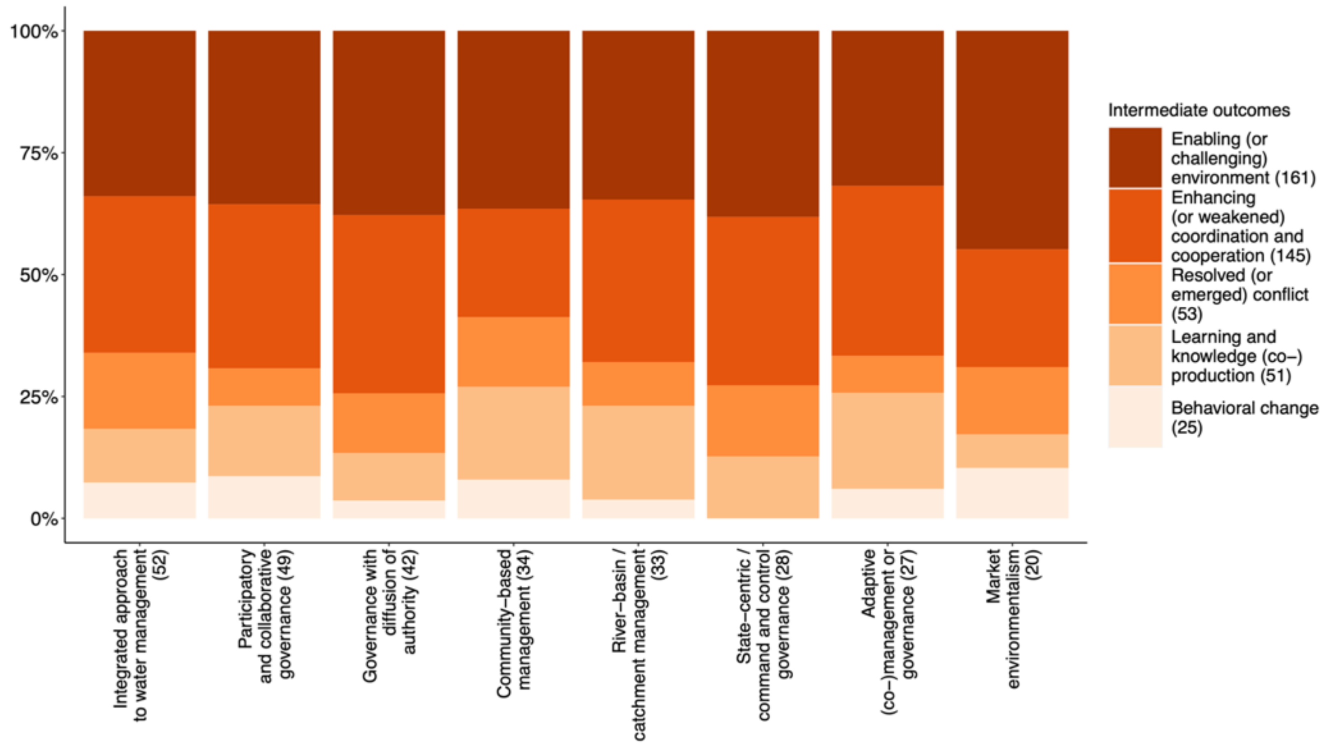


Figure A9 Intermediate outcomes across paradigms. Number in a bracket in the legend corresponds to the number of cases with respective intermediate outcomes.

Article 2:

Water-related problématiques: five archetypical contexts of water governance

Abstract

For a comprehensive understanding of the performance of water governance systems, it is necessary to consider the contextual factors surrounding them. We conducted a review of 165 empirical studies and 223 cases in water governance literature to investigate water-related contexts. Our analysis is based on an archetype analysis of three dimensions of water-related contexts across 160 cases: water resources, related water uses, and sustainability issues. Our results show that there are five distinct water-related problématiques: "groundwater exploitation in agriculture," "land and water systems sustainability," "surface water pollution," "industrial and household water security," and "hydropower vs. water ecology." These problématiques often exhibit geographical patterns and regional associations. Noteworthy insights from the analysis of problématiques include the prominence of "groundwater exploitation in agriculture" problématique contrary to arguments that groundwater is understudied, and the limited coverage of hydropower governance compared to other problématiques. Overall, this study contributes to enhancing our understanding of contextual factors in water governance and suggests potential avenues for developing middle-range theories and advancing water governance diagnostics.

Water-related problématiques: five archetypical contexts of water governance

Paper submitted to Ecology and Society[1]
Manuscript type: Research

Shahana Bilalova [1], Sergio Villamayor-Tomas [2], Jens Newig [1]

[1] Faculty of Sustainability, Institute of Sustainability Governance (INSUGO), Research Group Governance, Participation and Sustainability, Leuphana University Lüneburg, Germany, [2] Institute of Environmental Science and Technology (ICTA-UAB), Autonomous University of Barcelona, Spain

ABSTRACT

For a comprehensive understanding of the performance of water governance systems, it is necessary to consider the contextual factors surrounding them. We conducted a review of 165 empirical studies and 223 cases in water governance literature to investigate water-related contexts. Our analysis is based on an archetype analysis of three dimensions of water-related contexts across 160 cases: water resources, related water uses, and sustainability issues. Our results show that there are five distinct water-related problématiques: "groundwater exploitation in agriculture," "land and water systems sustainability," "surface water pollution," "industrial and household water security," and "hydropower vs. water ecology." These problématiques often exhibit geographical patterns and regional associations. Noteworthy insights from the analysis of problématiques include the prominence of "groundwater exploitation in agriculture" problématique contrary to arguments that groundwater is understudied, and the limited coverage of hydropower governance compared to other problématiques. Overall, this study contributes to enhancing our understanding of contextual factors in water governance and suggests potential avenues for developing middle-range theories and advancing water governance diagnostics.

Keywords: water governance; water problems; context; archetype; cluster analysis

[1] This version of the manuscript is the one we have resubmitted after addressing the reviewers' comments.

INTRODUCTION

Over the past decades, water governance has experienced the implementation of idealized approaches, leading to success in some places and failure in others (Young et al. 2018). Scholars have criticized these idealized approaches, or "panaceas" (Ingram 2011, Meinzen-Dick 2007, Pahl-Wostl et al. 2012), and called for more systematic attention to contextual nuances (Ostrom 2007). In particular, decision-making needs to consider the respective problem context—what we call here problématique—when designing or implementing water governance. The fact that context matters (Armitage 2008, Gupta et al. 2013, Ingram 2011) becomes especially important when governance approaches are transferred across jurisdictions. Bressers and de Boer (2013) suggest considering both the sender and receiver's governance contexts to avoid the unsuccessful transfers of blueprint approaches. In order to be successful, governance needs to be sensitive and adapted to (local) contexts (Aggarwal and Anderies 2023).

Some frameworks focusing on water governance indeed integrate contextual factors. Examples include the Management and Transition Framework (Pahl-Wostl et al. 2010), the Contextual Interaction Theory (Bressers and de Boer 2013), and the Social-Ecological Systems (SESs) framework (Meinzen-Dick 2007). Similarly, several empirical studies have attempted to disentangle contextual influences in a comparative manner (e.g., Garrick et al. 2009, Knieper and Pahl-Wostl 2016, Pahl-Wostl and Knieper 2014, Yu 2016). However, while these studies, often small to medium-sized, have generally concluded that context is a significant factor, theorizing about how it matters remains challenging.

Human-water systems are widely acknowledged as involving complex interactions between human and natural components (Di Baldassarre et al. 2013, Liu et al. 2007, Sivapalan et al. 2012). Water-related problem contexts emerging from these complex interactions within coupled human-water systems are highly diverse. They encompass numerous variables, making it challenging to untangle and comprehensively grasp the effects of each. Different studies have focused on different sets of variables, hindering the accumulation of knowledge and comparability of governance solutions.

Archetype analysis is a promising approach that allows for cumulative learning from a multitude of cases (Oberlack et al. 2019). Over the years, there have been several efforts to develop archetypes in the field of water governance at different scales (Aggarwal and Anderies 2023, Oberlack and Eisenack 2018, Srinivasan et al. 2012). With specific reference to water governance, Villamayor-Tomas et al. (2020) studied drought adaptation of 37 irrigation associations in northern Spain. They identified four water user association (WUA) archetypes, consolidated into the American and Asian archetypes, and noted a lack of alignment between these archetypes and two types of adaptation institutions (i.e., specific and generic adaptation institutions) (Villamayor-Tomas et al. 2020). Another study (Kirschke et al. 2019) identified four clusters of water governance problems based on their levels of complexity, uncertainty, and wickedness in the realm of implementing the European Water Framework Directive in Germany, reporting clear associations between problem complexity and policy delivery. However, none of these attempts to develop archetypes address the problem context of water governance on a broader scale.

In this paper, we employ archetype analysis to examine problem contexts, which are characterized by the relationships between water resources, their uses, and the associated issues representing the (un)sustainability of these resources addressed by water governance systems.

Specifically, this study explores the following research question: What are the prominent water-related problem contexts addressed by water governance systems? With the present research, we go beyond the existing efforts at clustering water governance problems in two respects: First, we take an explicitly global approach, including water governance settings from all continents. With that, our identification of problématiques shows a wider scope and applicability than the cited earlier studies. Second, we more explicitly recognize the "problématique" aspects of water governance contexts, as we will elaborate below.

The three aforementioned aspects are central to our analysis as they enable us to identify water-related problem contexts, embedded in coupled human-water systems while capturing the diversity of these contexts by providing a broader framing. Having a broader lens is important, especially considering how diverse water problems are. As posed by the SES framework, socio-ecological outcomes emerge as attributes of resource systems, the resource units produced by these systems, actor groups, and governance systems influence or are indirectly impacted by interactions (Ostrom 2007). In this study, we deliberately formulate our problem contexts by examining the interaction between resource systems and their users, specifically focusing on the use of resource units from these systems and the outcomes of this interaction in relation to the (un)sustainability of these resource systems. Disentangling the problem context from the governance system creates an opportunity to take a closer look at the interactions between governance and problem contexts, as well as to identify the configurations of governance characteristics that effectively address or aggravate different water-related problématiques.

This paper introduces five distinct archetypes, which we term "water-related problématiques" in line with the overall terminology of the NEWAVE[2] project this research is embedded. The concept of water-related problématiques is rooted in the idea of "problematique" introduced by Hasan Ozbekhan, referring to the cluster of long-term and global-scale problems that the Club of Rome aimed to address in the late 1960s and which became central to *The Limits to Growth* report (Ison et al. 2015). This study defines water-related problématiques as recurring "clusters" or "ensembles" of water-related issues (or problems) in relation to water resources and the (un) sustainability of these resources connected to their use. While akin to the concepts such as "tame" or "wicked" problems (Rittel and Webber 1973) and "syndromes" (Srinivasan et al. 2012), water-related problématiques encompass a broader range of issues, not restricted by their complexity level and refrains from placing emphasis solely on outcomes related to human well-being. We identified the problématiques through the cluster analysis of 160 water governance cases identified through a systematic literature review. These problématiques provide a guiding framework for comparative empirical studies and lay the foundation for further theorization regarding the role of context. In doing so, this paper contributes to a broader understanding of contextual factors in water governance research.

METHODS

Data collection

This research relies on data collected through a systematic review of the empirical water governance literature reporting on water-related sustainability. The review has been conducted following PRISMA guidelines (Moher et al. 2009) as shown in Figure 1.

---

[2] NEWAVE is an EU Horizon 2020 Innovative Training Network (ITN) project funded through Marie Skłodowska-Curie actions (MSCA).

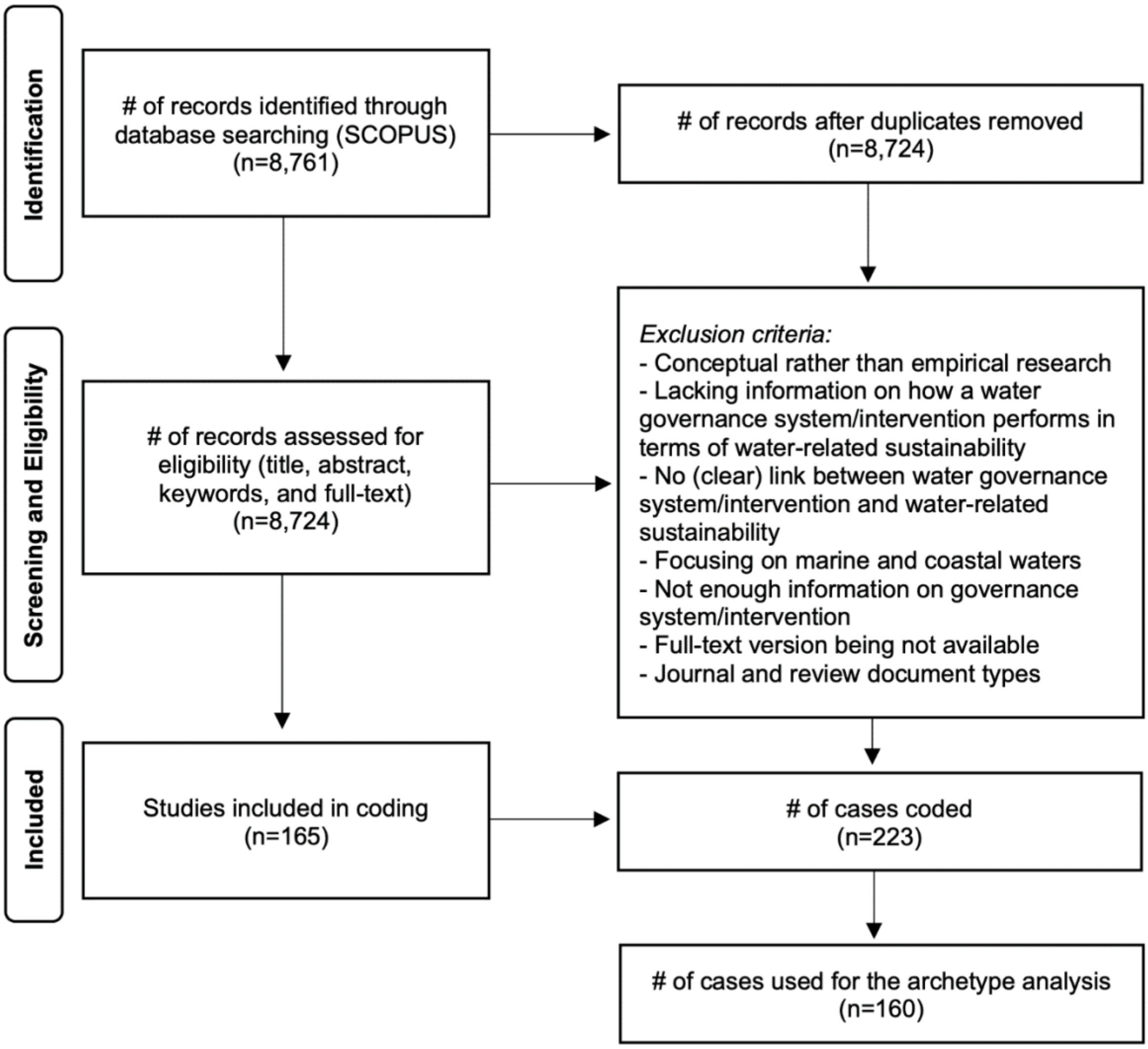


Figure 1 PRISMA flow diagram for the systematic literature review.

We limited our search to English-language review and journal articles listed in Scopus. Scopus provides the broadest coverage of environmental and social sciences journal publications (Frohlich et al. 2018). The search string was formulated after reviewing relevant test papers and considering the opinions of scholars within the NEWAVE network. The keywords used in the search string reflect the four aspects of the review question, including water-related terms, water governance terms, water-related sustainability terms, and outcome terms (Table 1). Water-related terms were carefully selected to encompass both natural and managed states of freshwater systems, while water-related sustainability terms were chosen specifically to address the environmental health of water systems. Water governance and outcome-related terms were designed to target studies on water governance that potentially link water-related problems to governance. We restricted water-related and water governance-related terms to titles. Using the same search string without this limitation would have produced over 67,000 hits, whereas our approach yielded 7,909 results. We did not make any restrictions on the publication date or study region. The review focused on two subject areas: Environmental Sciences and Social Sciences, relevant to the primary research question and its components. The last run was conducted on January 01, 2020, yielding 8,761 results.

Table 1 Search string stratified by the four aspects of the review question, connected with AND operator.

Water-related terms	Water governance terms	Water-related sustainability terms	Outcome terms
TITLE (freshwater* OR groundwater* OR water* OR river* OR basin* OR watershed* OR catchment* OR irrigation* OR wastewater* OR wetland* OR lake* OR hydropower* OR dam* OR reservoir* OR infrastructure*)	TITLE (govern* OR policy* OR politi* OR policies* OR institution* OR privat* OR market* OR "Water User Association*" OR participat* OR collaborat* OR iwrm* OR "Water Resource* Management" OR "River Basin Management" OR "Catchment Management" OR "Watershed Management" OR planning* OR law* OR decree* OR agreement* OR treaty OR treaties OR "River Basin Organi?ation*")	TITLE-ABS (sustainab* OR quality* OR quantity* OR security* OR stress* OR ecolog* OR ecosystem* OR environ* OR standard* OR drought* OR scarcity* OR overuse* OR overdraw*)	TITLE-ABS (outcome* OR perform* OR success* OR fail* OR challeng* OR effect* OR impact* OR implement* OR assess* OR evaluat* OR evidence* OR empirical* OR study* OR studies* OR case* OR analys* OR result* OR finding* OR output* OR enforce* OR efficienc*)

After screening the results, we selected 165 publications covering the period from 1985 to 2020 for coding and analysis. Our coding scheme, based on existing water governance literature, aimed at collecting data on three categories for this paper: bibliographic information, case-related information, and characteristics of water-related context (Appendix 1). This study mainly draws on data concerning water-related context attributes, such as case country, water source, water utilization, and environmental sustainability issues[3]. The term “water resource” refers to the origin of water—whether from natural sources like surface water or groundwater, or man-made sources like reclaimed wastewater, desalinated seawater, brackish water, harvested rainfall-runoff water, or other non-conventional resources. Our focus is specifically on freshwater sources. “Water use” describes the ways in which people utilize water, such as water use for the living environment, domestic consumption, agriculture, industrial production, hydropower generation, the discharge of pollutants, recreational activities, commercial purposes, and land development. Lastly, “sustainability issues” pertain to issues characterizing the (un)sustainability of these resources addressed or studied in the paper, in connection with the water resources and their respective uses. These issues primarily concern the environmental health of freshwater systems. This includes issues such as water quality problems resulting from pollutant discharge into surface water bodies, water quantity challenges related to

[3] Throughout the paper, we will refer to “environmental sustainability issues” as “sustainability issues.”

inefficient water use and allocation, threats to aquatic biodiversity including declines in fish biomass and macroinvertebrate populations, degradation of basin conditions through land cover changes and channel modifications, and impacts on water-related ecosystem services crucial for supporting human and ecological needs. Additionally, sustainability issues encompass broader concerns such as the protection and conservation of freshwater resources, adaptation to changing environmental conditions, resilience of freshwater ecosystems, and the overall ecological integrity and environmental sustainability of water systems.

The units of analysis in this review were empirical case studies. We considered individual (geographical) case studies and distinct governance changes within a geographically confined area as separate cases. Moreover, our coding was limited to a maximum of six empirical cases per paper. The final dataset contains 223 cases across 165 studies, wherein 23 studies documented multiple cases. One study examined more than six cases. Here, we only selected the cases with complete information.

All authors participated in intensive test screening and coding to minimize reviewer biases and possible errors. These trial steps also helped to build a shared understanding regarding the exclusion criteria and coding scheme. Subsequently, the first author performed the final screening and coding.

As common with systematic reviews, our study evaluates the state of knowledge within the field rather than the actual state of affairs. Nevertheless, we believe that our results are still relevant and informative for researchers and practitioners in water governance. Primarily, our emphasis on empirical studies suggests that the current state of the field might already partially reflect on-ground realities. Moreover, the existing state of knowledge within the field, revealed through systematic review, serves as a reflection of our understanding and provides a foundation upon which we can further develop our insights.

Analysis

Archetype analysis has gained popularity in sustainability research as a novel approach to understanding and comparing recurring global patterns that shape the (un)sustainability of social-ecological systems (Eisenack et al. 2021). We examined water-related problématiques from the perspective of water governance by using archetypes as our analytical framework. Archetypes have been used in various ways across sustainability research, e.g. serving as building blocks of cases, models, patterns, diagnostics, and scenarios (Oberlack et al. 2019). In this paper, we used archetypes as “type of cases” (Oberlack et al. 2019), following studies that have taken a similar approach (Levers et al. 2018, Sietz et al. 2017, Václavík et al. 2013, Villamayor-Tomas et al. 2020). With this approach, we strive to identify distinct problem contexts that would further help us understand why and how certain water governance approaches work for certain water-related problématiques but not for others. From an empirical point of view, our objective is to minimize similarities within archetypes while maximizing differences across them (Oberlack et al. 2019, Villamayor-Tomas et al. 2020). Sets of archetypes as a “typology of cases” imply that each case is classified as belonging to a specific archetype depending on its characteristics and those of other cases (Oberlack et al. 2019, Villamayor-Tomas et al. 2020). This approach differs from the building blocks approach, where archetypes serve as the components of cases (with cases potentially accommodating multiple archetypes that recur across cases) and the validity of archetypes is assessed by their presence across cases (Eisenack et al. 2019). In that regard, the main difference lies in the level at which similarities are identified, whether it is the processes or causal mechanisms that explain the issue of interest (building blocks) or entire cases of that phenomenon (case typology) (Oberlack et al. 2019).

To identify problématiques based on water-related contexts (i.e., water resources, water uses, and sustainability issues), we conducted agglomerative hierarchical clustering using Euclidean distance and Ward's method. Clusters were chosen based on the highest relative loss of within-group inertia, indicating homogeneity within clusters (Husson et al. 2010). Further details are provided in Appendix 4. We focused solely on cases with complete data for this analysis, which comprised 160 out of 223 cases. Prior to conducting the cluster analysis, we undertook multiple correspondence analysis (MCA) to reduce the dimensionality of categorical variables in the water-related context, namely water resources, water uses, and sustainability issues. MCA can be understood as a variant of Principal Component Analysis (PCA) designed specifically for categorical data (van der Heijden and de Leeuw 1989). PCA is a technique that allows for the reduction of the dimensionality of a large dataset while retaining as much variation as possible (Jolliffe and Cadima 2016). Following MCA, we identified clusters and examined "typical" cases—those situated near the center of gravity within a cluster but distant from others. For MCA and statistical clustering analyses, we used the FactoMineR package (Lê et al. 2008) in R (R Core Team 2021). We evaluated cluster quality through an assessment of case sets within each cluster.

The derived archetypes satisfy some of the quality criteria for archetype analysis proposed by Piemontese et al. (2022). Firstly, our analysis meets the conceptual validity criterion as our research is guided by appropriate scientifically sound research framing and a research problem that is relevant to society (Piemontese et al. 2022), namely the sustainability of water resources. The selection of the variables used in the analysis is informed by the interaction between the components of the socio-ecological system, which aligns with the construct validity criterion. In terms of ensuring the internal validity of our analysis, we report on the data process, cases that are included in our analysis, as well as the analysis steps, which ensure transparency and replicability. We have also measured within-archetype variation, as outlined in Appendix 4, and evaluated cluster quality through an assessment of case sets within each cluster.

RESULTS

Below, we begin by outlining our findings concerning water resources, water uses, and sustainability issues across all 223 reviewed cases. Following that, we present the results of our cluster analysis of 160 cases, which led to the identification of five distinct water-related problématiques.

Water resources, uses, and sustainability issues

The majority of cases (70%; n=155) focus on a single resource. 19% (n=43) of the remaining cases address two resources, while only three cases simultaneously examine three resources. Among these, surface and groundwater are the resources that appear together most frequently (n=42). Surface water is a dominant resource (73%; n=162), followed by groundwater (35%, n=78). Both of them display a broad geographical distribution. Besides these two primary water resources, some studies address reclaimed (wastewater) (n=9) and harvested rainfall-runoff water (n=1). 10% of cases (n=22) do not focus on any specific water resource.

Most cases report on water use (77%, n=171), with 46% (n=79) addressing only one use. Among the cases mentioning multiple uses, only 33 cases focus on two uses, while 59 cases address three or more. In 64% of the cases reporting on water use (n=109), agricultural (n=86) and domestic water uses (n=54) are observed, and these two uses also frequently appear together (n=31). Other human water uses—water as an infrastructure (i.e., cultural, recreational, medical, commercial, and land uses) (n=100), water for energy and industry (n=35), and water as a medium for the discharge of pollutants (n=50)—are identified in 65% of the cases reporting on water use (n=112). On the other hand, water for the living environment, which concerns both provisioning (i.e., freshwater) and supporting (i.e., habitat for species) ecosystem services, appears in 23% of the cases reporting on water use (n=40), with just two cases referring exclusively to water use for living environment.

Across all uses, surface water predominates in most cases, except for agricultural water use, which mainly relies on groundwater (n=53) alongside surface water (n=51). Concerning (reclaimed) wastewater, more cases address its domestic use (n=7) followed by agricultural use (n=6). Lastly, harvested rainfall-runoff water is mainly used for living environment (n=1) and domestic purposes (n=1).

Regarding sustainability issues, we observe that these issues often appear together rather than being addressed in isolation. Water quality (n=130) and quantity (n=115) are the most frequently addressed. They are addressed in 84% of the cases and have a diverse geographic distribution (Figure 2). Other sustainability issues covered include aquatic biodiversity (n=60), basin condition (n=50), and water-related ecosystem services (n=17), identified in 39% of the cases (n=87). Finally, 22% of the cases within the included studies (n=48) have more general coverage regarding sustainability issues.

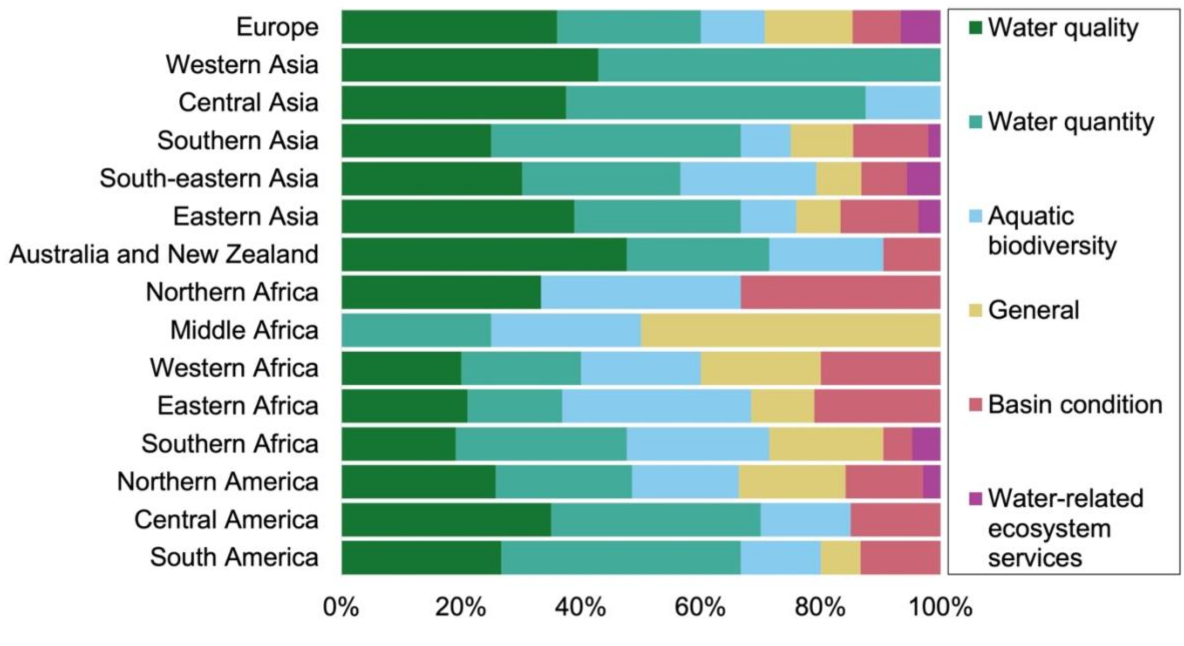


Figure 2 Studied sustainability issues by case study region, as defined under the Standard Country or Area Codes for Statistical Use (known as M49) of the United Nations Statistics Division.

Cross-tabulation of sustainability issues and water uses (Figure 3) indicates that water quality issues frequently link to the use of water as a medium for pollutant discharge (37%; n=48), as well as agricultural (27%; n=35), domestic (28%; n=36), and land (23%; n=30) purposes. Regarding water quantity, it is primarily tied to agricultural (68%; n=78) and domestic (38%;

n=44) uses. In terms of aquatic biodiversity, water for commercial activities (42%; n=25) and the living environment (42%; n=25) are identified as the primary associated uses. Regarding basin condition, the main associated use is water for land uses (62%; n=31). Finally, water-related ecosystem service issues mainly appear together with the use of water for and living environment (53%; n=9), commercial purposes (47%; n=8), and land uses (35%; n=6).

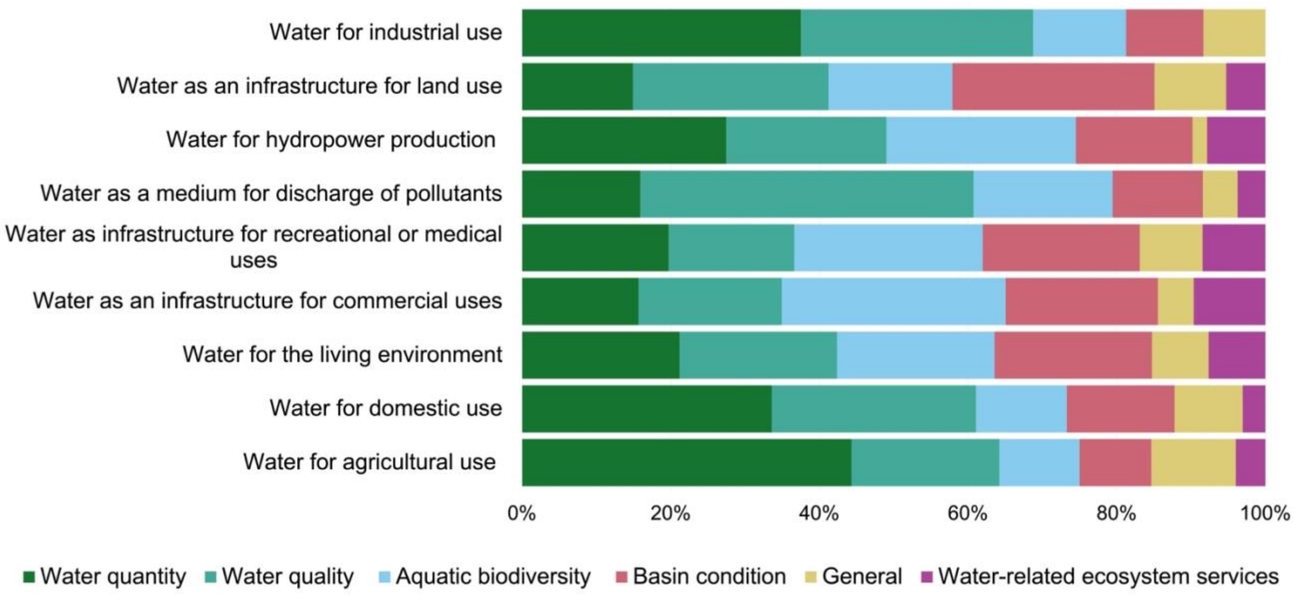


Figure 3 Water uses by sustainability issues in the studied cases.

Water-related problématiques

The cluster analysis yielded five distinct water-related problématiques, which we labeled as follows: (1) “groundwater exploitation in agriculture”; (2) “land and water systems sustainability”; (3) “surface water pollution”; (4) “industrial and household water security”; and (5) “hydropower vs. water ecology,” as presented in Table A4.2 (Appendix 4). When we speak of “exploitation” in one cluster, and of “sustainability” in another, we do not imply better water governance or better status of waters in the latter; rather, we only point to the respective issues at stake. In the following section, we describe the individual water-related problématiques in more detail.

Problématique 1: Groundwater exploitation in agriculture

Constituting 56 (35%) cases, “groundwater exploitation in agriculture” is the largest cluster. Cases predominantly address the water quantity aspects of agricultural groundwater withdrawal. A typical case is presented in the study by Ratna Reddy et al. (2014), which analyzes the functioning and efficacy of groundwater management institutions in Andhra Pradesh state in South India. Here, groundwater resources, which are scarce in the state, significantly support agriculture, and the authors discuss how a farmer-managed groundwater system contributed to a reduction in groundwater pumping through water-saving techniques (Ratna Reddy et al. 2014). Another case, studied by Hu et al. (2014), explores farmers' perceptions of integrated water resources management (IWRM) and the factors underpinning the ineffectiveness of Water Users Associations (WUAs) in the Minqin oasis. This oasis, situated in the northwest of China, relies heavily on groundwater as a primary irrigation source and is confronted with environmental degradation due to the excessive exploitation of groundwater resources (Hu et al. 2014).

Some cases within this problématique do not exactly align with the ideal cluster profile but still exhibit some similarities. For example, some cases focus on the quantity of surface water resources (n=12), predominantly in relation to agricultural water use (n=11). Others address surface (n=3) or groundwater resources (n=2) quantity, linked to commercial (n=1) or domestic water uses (n=1) as well as water uses for living environment (n=3). Finally, we encountered a few cases addressing general water-related sustainability issues (n=4), water quality (n=1), and the state of water-related ecosystems (n=1), particularly in the context of groundwater resources.

Problématique 2: Land and water systems sustainability

The second largest cluster, representing 24% of cases (n=38), is "land and water systems sustainability." This cluster mainly encompasses cases dealing with landscape development and cases addressing ecosystem conservation, closely connected to sustainable management of land and water systems. For instance, in the Lynnhaven watershed, U.S., Morris et al. (2014) explore how local grassroots environmental organizations enhance water quality in a densely populated and urbanized region experiencing non-point source pollution from residential run-offs. In two other typical cases in this problématique, Chang et al. (2014) examine the relationship between governance and water quality in Burnt Bridge Creek in Vancouver and Johnson Creek in Portland. Despite facing rapid population growth and development pressure, both watersheds sustain ambient stream temperature due to the implementation of land use management policies that focus on the protection and restoration of riparian areas in both cities (Chang et al. 2014).

The "land and water systems sustainability" problématique encompasses a wider scope of sustainability issues and water uses compared to other problématiques. Sustainability issues within this problématique span from basin condition and aquatic biodiversity to water quantity. The range of water uses includes water as infrastructure for land, tourism, leisure, recreation, sports or medical use, and commercial purposes as well as water for living environment and agriculture.

Problématique 3: Surface water pollution

"Surface water pollution," accounting for 19% of the sample (n=30), primarily consists of cases addressing water quality concerns related to pollutant discharge into surface water resources. One example is the case study by Namara et al. (2018), which explores water quality governance in the Cisadane watershed in Tangerang. This watershed, a major source of water for the community's drinking water supply, experiences relatively high pollution, largely stemming from domestic wastewater and waste dumping into rivers (Namara et al. 2018). As another example of the cases in this problématique, McNeill (2016) compares regional and national level regulatory agencies and collaborative initiatives in the Manawatu River catchment in New Zealand in terms of their stakeholder diversity and policy effectiveness. The catchment is mainly characterized by its poor water quality due to the discharge of treated effluent from four riparian municipalities (McNeill 2016).

The issue of surface water quality, distinct from the "land and water systems" problématique, primarily stems from point-source pollution with direct discharge of pollutants into freshwater bodies. Conversely, for "land and water systems," the primary cause of water quality problems is associated with landscape development and urbanization, mainly in a diffuse manner.

Some cases in this problématique also delve into water quality issues stemming from domestic (n=3), agricultural (n=2), and commercial (n=1) water uses, along with water as a medium for pollutant discharge. A subset of cases in this cluster also touches on water quantity alongside water quality, representing 17% of all cases within this problématique (n=5).

Problématique 4: Industrial and household water security

This problématique, consisting of 23 cases, is the most diverse among all, primarily containing cases addressing the issue of water supply for industrial and household uses. These cases revolve around groundwater and unconventional water resources (such as harvested rainfall-runoff water and [reclaimed] wastewater). The central focus lies on water quantity and quality issues linked to domestic and industrial uses, which differ from "groundwater exploitation in agriculture" that solely focuses on the quantity of groundwater resources in relation to agricultural water uses. For instance, Mestre (1997) discusses river basin councils in the Lerma-Chapala Basin in Mexico. The basin experienced water scarcity and pollution exacerbated by population and industrial growth (Mestre 1997), which improved after the implementation of river basin councils. In another typical case within this problématique, Morris and Cabrera (2003) studied private sector involvement in water servicing and household water needs of the urban poor in the city of Aguascalientes, which experienced a lowering of groundwater supply due to escalating water uses for industrial, agricultural, and residential purposes.

Problématique 5: Hydropower vs. water ecology

Encompassing only 8% of all cases (n=13), "hydropower vs. water ecology" focuses on cases such as the Mekong basin, rivers in China, and the Em River Basin in south-eastern Sweden. These cases examine the ramifications of hydropower production on sustainability, with a particular focus on water quantity, aquatic biodiversity, and basin condition. All cases in this problématique relate to the issues of water quantity and aquatic biodiversity. Meanwhile, more than half of these cases also address the issue of basin condition. Unlike the "land and water systems sustainability" problématique, the main driver behind the state of aquatic biodiversity in surface water bodies is river developments. This problématique also incorporates cases addressing the issue of water-related ecosystem services, the fourth significant water-related sustainability issue category within this problématique. As one of the typical cases, Yang et al. (2016) analyze the river management system in China in light of river developments connected to hydropower generation and acquiring freshwater and other resources and the ecological impacts associated with such developments. Another case in this problématique discusses the practice of stakeholder participation in the Em River Basin, south-east Sweden, in addressing conflicts related to the different uses of the river, including negotiations with hydropower companies to ensure minimum water discharge and fish bypasses (Jönsson 2004).

Water-related problématiques across geographies

We also analyzed the association between water-related problématiques and global regions to unveil potential spatial patterns. Figure 4 presents the distribution of five water-related problématiques across different regions. Results show that certain problématiques have been more prominently studied in some regions than others. For instance, cases within "hydropower production and water ecology" are frequently observed in south-eastern Asia. In the case of the "surface water pollution" problématique, cases from the European and eastern Asia regions slightly dominate compared to other regions. Regarding the "land and water systems sustainability" problématique, North America holds a relatively higher number of cases, which is also similarly observed in the case of "groundwater exploitation in agriculture," along with the regions of Southern Asia and Europe. Finally, we also identified a significant association between water-related problématiques and geographical regions with a moderate effect size (Cramer's V= 0.3599, sig<0.001). To examine the relationship between our water-related problématiques and geographic regions, we conducted Fisher's exact test. We used this test because our contingency table had multiple expected frequencies that were less than five, which is a common requirement for this test (Kim 2017). We also calculated Cramer's *V* effect size to assess the strength of the relationship between the two variables. Cramer's *V* is a chi-squared measure used to assess the association between two nominal variables, where 0 denotes no relationship while one refers to a perfect association (Mair et al. 2012).

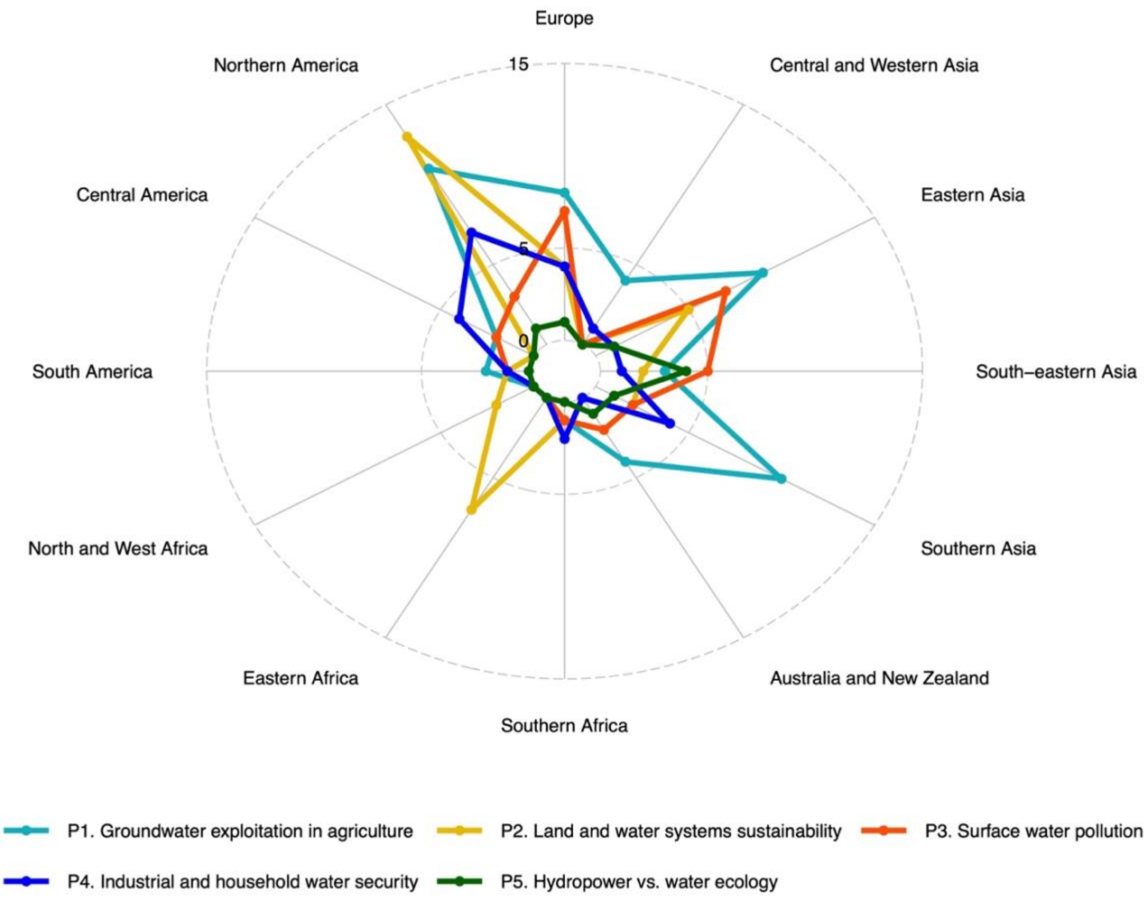


Figure 4 Distribution of cases within each water-related problématique across geographical regions. The geographical regions are defined under the Standard Country or Area Codes for Statistical Use (known as M49) of the United Nations Statistics Division.

DISCUSSION AND CONCLUSION

Archetype analysis of 160 empirical cases has unveiled five distinct water-related problématiques that are frequently the target of governance solutions: (1) "groundwater exploitation in agriculture"; (2) "land and water systems sustainability"; (3) "surface water pollution"; (4) "industrial and household water security"; and (5) "hydropower vs. water ecology." Each of these problématiques highlights distinctive challenges. "Groundwater exploitation in agriculture" problems are usually attributed to the difficulty in monitoring and managing highly invisible and movable resources like groundwater (Villamayor-Tomas et al. 2014), leading users to prioritize rent-seeking (i.e., overharvesting to reinvest gains in alternative income generating activities) over sustainability (Clark 1973, Acheson 2006). "Surface water pollution" and "industrial and household water security" problématiques can be understood in light of the cost and benefits of water pollution. The minimal cost of polluting, when compared to the gains for polluters (e.g., industries), or the ability to completely avoid pollution costs (e.g., upstream polluters), hampers cooperative efforts (Fleischman et al. 2014). The heterogeneity of interests and zero-sum situations can explain the "hydropower vs. water ecology" problématique, to the extent that hydropower developments negatively impact river health (Villamayor-Tomas et al. 2016). In both "industrial and household water security" and "land and water systems sustainability," urbanization emerges as a contributing factor to water-related issues. As argued by Anderson (1976, as cited in Clement 2010), the desire for profit expansion drives growth in society and environmental problems, urbanization being a paradigmatic symptom of it (Clement 2010). In the case of "land and water systems sustainability," it may also be explained by the speed and visibility of feedback between land use and water systems. At the landscape scale, the feedback is not very obvious and can be particularly slow, which may explain inaction or slow responses in changing land-use practices to address emerging water problems (Scheffer et al. 2003).

The water-related problématiques identified in this study exhibit parallels with three syndromes of water use, presented by Srinivasan et al. (2012): "groundwater depletion," "ecological destruction," and "water reallocation to nature." Our study shows that each syndrome shares common attributes with more than one problématique, offering a nuanced unpacking of the syndromes. For instance, "ecological destruction" aligns with four of our problématiques—"groundwater exploitation in agriculture," "industrial and household water security," "surface water pollution," and "hydropower vs. water ecology"—which also encompasses cases dealing with the state of water-related ecosystems linked to growing human water use, pollution, and hydropower generation. Examining these problématiques, rather than focusing on a broader syndrome, would enable a more comprehensive understanding of the problems, facilitating the design of targeted interventions. Furthermore, the syndromes identified by Srinivasan et al. (2012) do not fully capture the full spectrum of challenges arising from interactions between land and water systems, a gap tackled by the "land and water systems" problématique in our study.

Our study also informs about paradoxical situations regarding the state of the art around certain problématiques. While the OECD's assessment "Drying Wells, Rising Stakes: Towards Sustainable Agricultural Groundwater Use" (2015:15) suggests that groundwater is generally understudied and requires more in-depth analysis (Molle and Closas 2020), our research indicates that the use of groundwater in agriculture, in fact, one of the most extensively studied problématiques, at least among governance studies (see also Molle and Closas 2020, Petit et al. 2021). Still, the general lack of effective governance solutions to such an endemic problem suggests the need to direct even greater attention to this vital resource and its sustainability (Molle and Closas 2020). Also, our study shows that "hydropower vs. water ecology" encompasses only thirteen cases, revealing a significant gap in the literature concerning the impact of hydropower production on water resources and its governance. This is telling, despite the growing trend of dam construction worldwide for hydropower generation and its impacts on local communities (Castro-Diaz et al. 2023, García et al. 2021). The rapid increase in dam building, particularly in developing economies (Moran et al. 2018, Zarfl et al. 2015), indeed emphasizes the need for a comprehensive understanding of water governance within the context of hydropower development.

This study contributes to advancing the study of context in water governance systems and provides guidance for future research in several ways. Firstly, the problématiques and the exploration of their underlying causes contribute to the cumulation of knowledge within the realm of water governance research. Given the scarcity of shared governance frameworks, variables from isolated empirical studies and theories are unlikely to cumulate (Ostrom 2009). By synthesizing an array of contextual variables from 160 empirical studies, this study offers a stepping stone for accumulating knowledge about water-related problems. Future research may cross-check the results of our archetype analysis by extending our pool of cases.

Water-related problématiques can also contribute to the development of middle-range theories (Merton 1968, Stank et al. 2017, Oberlack et al. 2019). Middle-range theories offer contextual generalizations depicting the mechanisms that explain a relatively well-bounded set of phenomena, as well as the conditions that enable, trigger, or prevent those mechanisms (Meyfroidt 2016). Further research may develop such theories through comparative governance studies of cases addressing specific problématiques and integrating in that effort other socio-political, economic, and ecological contextual components.

Regarding policy implications, water-related problématiques can guide the development of a diagnostic approach to identify the underlying causes of each problem and explore potential policy responses to address them. Diagnostic approaches allow for the decomposition of environmental issues, by identifying key elements in each problem and determining governance responses that are best suited to address these elements (Young 2002). This involves posing system-related questions, where each subsequent question builds on the answers to previous ones and becomes more system-specific in nature (Frey and Cox 2015). The questions could then be asked to tease out the characteristics of each problématique as a way to understand their proximate causes and to analyze policy responses that would work in that specific context. Similarly to the development of middle-range theories, problématiques can also be used to assess the performance of policy interventions in specific contexts. The expectation is that successful policy solutions and lessons are particularly informative for cases that share a common problématique. Such insights can inform evidence-based policymaking, and the results can be discussed with stakeholders.

AUTHOR CONTRIBUTIONS

Shahana Bilalova: conceptualization, data curation, methodology, formal analysis, investigation, visualization, project administration, writing – original draft, writing – reviewing and editing. **Sergio Villamayor-Tomas:** conceptualization, methodology, investigation, writing–review & editing, supervision. **Jens Newig:** conceptualization, methodology, investigation, writing–review & editing, supervision.

ACKNOWLEDGEMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 861509 - NEWAVE.

DATA AVAILABILITY STATEMENT

The datasets generated and/or analyzed during the current study will be available after the paper published in the Leuphana University repository, https://doi.org/10.48548/pubdata-235.

LITERATURE CITED

Acheson, J. M. 2006. Institutional failure in resource management. *Annual Review of Anthropology* 35:117–134.

Aggarwal, R., and J. Anderies. 2023. Understanding how governance emerges in social-ecological systems: insights from archetype analysis. *Ecology and Society* 28(2):art2.

Armitage, D. 2008. Governance and the commons in a multi-level world. *International Journal of the Commons* 2:7–32.

Di Baldassarre, G., M. Kooy, J. S. Kemerink, and L. Brandimarte. 2013. Towards understanding the dynamic behaviour of floodplains as human-water systems. *Hydrology and Earth System Sciences* 17(8):3235–3244.

Bressers, H., and C. de Boer. 2013. Contextual Interaction Theory for assessing water governance, policy and knowledge transfer. *Water Governance, Policy and Knowledge Transfer: International Studies on Contextual Water Management*:36–54.

Castro-Diaz, L., M. A. García, S. Villamayor-Tomas, and M. C. Lopez. 2023. Impacts of hydropower development on locals' livelihoods in the Global South. *World Development* 169:106285.

Chang, H., P. Thiers, N. R. Netusil, J. A. Yeakley, G. Rollwagen-Bollens, S. M. Bollens, and S. Singh. 2014. Relationships between environmental governance and water quality in a growing metropolitan area of the Pacific Northwest, USA. *Hydrology and Earth System Sciences* 18(4):1383–1395.

Clark, C. W. 1973. The Economics of Overexploitation. *Science* 181(4100):630–634.

Clement, M. T. 2010. Urbanization and the Natural Environment: An Environmental Sociological Review and Synthesis. *Organization & Environment* 23(3):291–314.

Eisenack, K., C. Oberlack, and D. Sietz. 2021. Avenues of archetype analysis: roots, achievements, and next steps in sustainability research. *Ecology and Society* 26(2):art31.

Eisenack, K., S. Villamayor-Tomas, G. Epstein, C. Kimmich, N. Magliocca, D. Manuel-Navarrete, C. Oberlack, M. Roggero, and D. Sietz. 2019. Design and quality criteria for archetype analysis. *Ecology and Society* 24(3).

Fleischman, F. D., N. C. Ban, L. S. Evans, G. Epstein, S. Villamayor-Tomas, and G. Garcia-Lopez. 2014. Governing large-scale social-ecological systems: Lessons from five cases. *International Journal of the Commons* 8(2):428–456.

Frey, U. J., and M. Cox. 2015. Building a diagnostic ontology of social-ecological systems. *International Journal of the Commons* 9(2):595.

Frohlich, M. F., C. Jacobson, P. Fidelman, and T. F. Smith. 2018. The relationship between adaptive management of social-ecological systems and law: a systematic review. *Ecology and Society* 23(2):art23.

García, M. A., L. Castro-Díaz, S. Villamayor-Tomas, and M. C. Lopez. 2021. Are large-scale hydroelectric dams inherently undemocratic? *Global Environmental Change* 71:102395.

Garrick, D., M. A. Siebentritt, B. Aylward, C. J. Bauer, and A. Purkey. 2009. Water markets and freshwater ecosystem services: Policy reform and implementation in the Columbia and Murray-Darling Basins. *Ecological Economics* 69(2):366–379.

Gupta, J., C. Pahl-Wostl, and R. Zondervan. 2013, December. "Glocal" water governance: A

multi-level challenge in the anthropocene.
van der Heijden, P. G. M., and J. de Leeuw. 1989. Correspondence Analysis, with Special Attention to the Analysis of Panel Data and Event History Data. *Sociological Methodology* 19:43.
Hu, X. J., Y. C. Xiong, Y. J. Li, J. X. Wang, F. M. Li, H. Y. Wang, and L. L. Li. 2014. Integrated water resources management and water users' associations in the arid region of northwest China: A case study of farmers' perceptions. *Journal of Environmental Management* 145:162–169.
Husson, F., J. Josse, and P. Jerome. 2010. *Principal component methods - hierarchical clustering - partitional clustering: why would we need to choose for visualizing data?*
Ingram, H. 2011. Beyond universal remedies for good water governance: a political and contextual approach. Page 21 *in* A. Garrido and H. Ingram, editors. *Water for Food in a Changing World*. Routledge.
Ison, R. L., K. B. Collins, and P. J. Wallis. 2015. Institutionalising social learning: Towards systemic and adaptive governance. *Environmental Science and Policy* 53:105–117.
Jolliffe, I. T., and J. Cadima. 2016. Principal component analysis: a review and recent developments. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 374(2065):20150202.
Jönsson, B. L. 2004. Stakeholder participation as a tool for sustainable development in the Em River Basin. *International Journal of Water Resources Development* 20(3):345–352.
Kim, H.-Y. 2017. Statistical notes for clinical researchers: Chi-squared test and Fisher's exact test. *Restorative Dentistry & Endodontics* 42(2):152.
Kirschke, S., C. Franke, J. Newig, and D. Borchardt. 2019. Clusters of water governance problems and their effects on policy delivery. *Policy and Society* 38(2):255–277.
Knieper, C., and C. Pahl-Wostl. 2016. A Comparative Analysis of Water Governance, Water Management, and Environmental Performance in River Basins. *Water Resources Management* 30(7):2161–2177.
Lê, S., J. Josse, and F. Husson. 2008. FactoMineR : An R Package for Multivariate Analysis. *Journal of Statistical Software* 25(1).
Levers, C., D. Müller, K. Erb, H. Haberl, M. R. Jepsen, M. J. Metzger, P. Meyfroidt, T. Plieninger, C. Plutzar, J. Stürck, P. H. Verburg, P. J. Verkerk, and T. Kuemmerle. 2018. Archetypical patterns and trajectories of land systems in Europe. *Regional Environmental Change* 18(3):715–732.
Liu, J., T. Dietz, S. R. Carpenter, M. Alberti, C. Folke, E. Moran, A. N. Pell, P. Deadman, T. Kratz, J. Lubchenco, E. Ostrom, Z. Ouyang, W. Provencher, C. L. Redman, S. H. Schneider, and W. W. Taylor. 2007. Complexity of coupled human and natural systems. *Science* 317(5844):1513–1516.
Mair, J., J. Battilana, and J. Cardenas. 2012. Organizing for Society: A Typology of Social Entrepreneuring Models. *Journal of Business Ethics* 111(3):353–373.
McNeill, J. 2016. Scale Implications of Integrated Water Resource Management Politics: Lessons from New Zealand. *Environmental Policy and Governance* 26(4):306–319.
Meinzen-Dick, R. 2007. Beyond panaceas in water institutions. *Proceedings of the National Academy of Sciences of the United States of America* 104(39):15200–15205.
Merton, R. K. 1968. *Social Theory and Social Structure*. Simon & Schuster, New York.
Mestre, J. E. 1997. Integrated approach to river basin management: Lerma-chapala case study—attributions and experiences in water management in mexico. *Water International* 22(3):140–152.
Meyfroidt, P. 2016. Approaches and terminology for causal analysis in land systems science. *Journal of Land Use Science* 11(5):501–522.
Moher, D., A. Liberati, J. Tetzlaff, and D. G. Altman. 2009. Preferred Reporting Items for

Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Medicine* 6(7):e1000097.
Molle, F., and A. Closas. 2020. Why is state-centered groundwater governance largely ineffective? A review. *Wiley Interdisciplinary Reviews: Water* 7(1):1–17.
Moran, E. F., M. C. Lopez, N. Moore, N. Müller, and D. W. Hyndman. 2018. Sustainable hydropower in the 21st century. *Proceedings of the National Academy of Sciences* 115(47):11891–11898.
Morris, J. C., W. A. Gibson, W. M. Leavitt, and S. C. Jones. 2014. Collaborative federalism and the emerging role of local nonprofits in water quality implementation. *Publius* 44(3):499–518.
Morris, L., and L. F. G. Cabrera. 2003. The involvement of the private sector in water servicing: Effects on the urban poor in the case of Aguascalientes, Mexico. *Greener Management International*(42):35–46.
Namara, I., D. M. Hartono, Y. Latief, and S. S. Moersidik. 2018. Institution and legal aspect based river water quality management. *International Journal of Engineering and Technology(UAE)* 7(3):86–88.
Oberlack, C., and K. Eisenack. 2018. Archetypical barriers to adapting water governance in river basins to climate change. *Journal of Institutional Economics* 14(3):527–555.
Oberlack, C., D. Sietz, E. Bürgi Bonanomi, A. de Bremond, J. Dell'Angelo, K. Eisenack, E. C. Ellis, G. Epstein, M. Giger, A. Heinimann, C. Kimmich, M. T. Kok, D. Manuel-Navarrete, P. Messerli, P. Meyfroidt, T. Václavík, and S. Villamayor-Tomas. 2019. Archetype analysis in sustainability research: meanings, motivations, and evidence-based policy making. *Ecology and Society* 24(2):art26.
Ostrom, E. 2007. A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Sciences of the United States of America* 104(39):15181–15187.
Ostrom, E. 2009. A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science* 325(5939):419–422.
Pahl-Wostl, C., G. Holtz, B. Kastens, and C. Knieper. 2010. Analyzing complex water governance regimes: The Management and Transition Framework. *Environmental Science and Policy* 13(7):571–581.
Pahl-Wostl, C., and C. Knieper. 2014. The capacity of water governance to deal with the climate change adaptation challenge: Using fuzzy set Qualitative Comparative Analysis to distinguish between polycentric, fragmented and centralized regimes. *Global Environmental Change* 29:139–154.
Pahl-Wostl, C., L. Lebel, C. Knieper, and E. Nikitina. 2012. From applying panaceas to mastering complexity: Toward adaptive water governance in river basins. *Environmental Science and Policy* 23:24–34.
Petit, O., A. Dumont, S. Leyronas, Q. Ballin, S. Bouarfa, N. Faysse, M. Kuper, F. Molle, C. Alcazar, E. Durand, R. Ghoudi, A. Hubert, S. Le Visage, I. Messaoudi, M. Montginoul, S. Ndao, A. R. Ferroudji, J.-D. Rinaudo, J. Trottier, O. Aubriot, M. Elloumi, M. Boisson, R. Fofack-Garcia, F. Maurel, D. Rojat, B. Romagny, and E. Salgues. 2021. Learning from the past to build the future governance of groundwater use in agriculture. *Water International* 46(7–8):1037–1059.
Piemontese, L., R. Neudert, C. Oberlack, S. Pedde, M. Roggero, A. Buchadas, D. A. Martin, R. Orozco, K. Pellowe, A. C. Segnon, L. Zarbá, and D. Sietz. 2022. Validity and validation in archetype analysis: Practical assessment framework and guidelines. *Environmental Research Letters* 17(2).
R Core Team. 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.
Ratna Reddy, V., M. Srinivasa Reddy, and S. K. Rout. 2014. Groundwater governance: A tale

of three participatory models in Andhra Pradesh, India. *Water Alternatives* 7(2):275–297.

Rittel, H. W. J., and M. M. Webber. 1973. Dilemmas in a general theory of planning. *Policy Sciences* 4(2):155–169.

Scheffer, M., F. Westley, and W. Brock. 2003. Slow Response of Societies to New Problems: Causes and Costs. *Ecosystems* 6(5):493–502.

Sietz, D., J. C. Ordoñez, M. T. J. Kok, P. Janssen, H. B. M. Hilderink, P. Tittonell, and H. Van Dijk. 2017. Nested archetypes of vulnerability in African drylands: where lies potential for sustainable agricultural intensification? *Environmental Research Letters* 12(9):095006.

Sivapalan, M., H. H. G. Savenije, and G. Blöschl. 2012. Socio-hydrology: A new science of people and water. *Hydrological Processes* 26(8):1270–1276.

Srinivasan, V., E. F. Lambin, S. M. Gorelick, B. H. Thompson, and S. Rozelle. 2012. The nature and causes of the global water crisis: Syndromes from a meta-analysis of coupled human-water studies. *Water Resources Research* 48(10):1–16.

Stank, T. P., D. A. Pellathy, J. In, D. A. Mollenkopf, and J. E. Bell. 2017. New Frontiers in Logistics Research: Theorizing at the Middle Range. *Journal of Business Logistics* 38(1):6–17.

Václavík, T., S. Lautenbach, T. Kuemmerle, and R. Seppelt. 2013. Mapping global land system archetypes. *Global Environmental Change* 23(6):1637–1647.

Villamayor-Tomas, S., M. Avagyan, M. Firlus, G. Helbing, and M. Kabakova. 2016. Hydropower vs. fisheries conservation: A test of institutional design principles for common-pool resource management in the lower Mekong basin social-ecological system. *Ecology and Society* 21(1).

Villamayor-Tomas, S., F. D. Fleischman, I. Perez Ibarra, A. Thiel, and F. van Laerhoven. 2014. From Sandoz to Salmon: Conceptualizing resource and institutional dynamics in the Rhine watershed through the SES framework. *International Journal of the Commons* 8(2):361.

Villamayor-Tomas, S., I. Iniesta-Arandia, and M. Roggero. 2020. Are generic and specific adaptation institutions always relevant? An archetype analysis of drought adaptation in Spanish irrigation systems. *Ecology and Society* 25(1):art32.

Yang, X., X. Lu, and L. Ran. 2016. Sustaining China's large rivers: River development policy, impacts, institutional issues and strategies for future improvement. *Geoforum* 69:1–4.

Young, O. R. 2002. Environmental Change: Institutional Drivers, Institutional Responses. Pages 3–28 *The institutional dimensions of environmental change: Fit, Interplay, and scale*. The MIT Press.

Young, O. R., D. G. Webster, M. E. Cox, J. Raakjær, L. Ø. Blaxekjær, N. Einarsson, R. A. Virginia, J. Acheson, D. Bromley, E. Cardwell, C. Carothers, E. Eythórsson, R. B. Howarth, S. Jentoft, B. J. McCay, F. McCormack, G. Osherenko, E. Pinkerton, R. van Ginkel, J. A. Wilson, L. Rivers, and R. S. Wilson. 2018. Moving beyond panaceas in fisheries governance. *Proceedings of the National Academy of Sciences* 115(37):9065–9073.

Yu, H. 2016. Can water users' associations improve water governance in China? A tale of two villages in the Shiyang River basin. *Water International* 41(7):966–981.

Zarfl, C., A. E. Lumsdon, J. Berlekamp, L. Tydecks, and K. Tockner. 2015. A global boom in hydropower dam construction. *Aquatic Sciences* 77(1):161–170.

Supplementary material for: Water-related problématiques: five archetypical contexts of water governance

Appendix 1. Coding scheme

Criteria	**Type of information**	**Categories**	**Reference (where applicable)**
1. Bibliometric information			
1.1 Title of the publication	Text field		
1.2 Author(s)	Text field		
1.3 Publication year	Numbered field (four digits)		
2. Case, location, and scale (i.e., case-specific information – data will be coded for each case, which reports on the outcome, within a study separately)			
2.1 Name of the case	Text field		
2.2 Name(s) of country/countries, the case locates in	Dropdown	1. A dropdown list of countries (specifying particular sets of countries, e.g., OECD, EU, ASEAN, NAFTA, OPEC, ..., as a separate option) 2. Not (clearly) defined	
3. Characteristics of a water-related context (i.e., case-specific information – data will be coded for each case within a study, separately)			
3.1 Water source associated with the environmental/water-related sustainability issue	Checkboxes (check all that apply)	1. Surface water (e.g., rivers, lakes, ponds, wetlands, transitional water, etc.) 2. Groundwater 3. (Reclaimed) wastewater 4. Desalinized seawater and brackish water 5. Harvested rainfall-runoff water 6. Other non-conventional water sources	

		7. No clear water source targeted	
3.2 Water uses		1. Water for the living environment (sustaining flora and fauna) 2. Water for domestic use 3. Water for agricultural use (e.g., irrigation, drainage, livestock, etc.) 4. Water for industrial use, which means water used directly or indirectly for the production of economic goods and services (for instance, cooling as an indirect use or production of mineral water as a direct use) 5. Water for hydropower production (as a particular form of economic production) 6. Water resource as a medium for discharge of pollutants 7. Water as an infrastructure for tourism, leisure, recreation, sports, or medical use (e.g., bathing, swimming, skating, leisure navigation, sports fishing, windsurfing) 8. Water as an infrastructure for commercial navigation, fishing, gravel extraction, mining, or other commercial uses 9. Water as an infrastructure for land use (especially use of flood plains and basins for water storage, landscape development, urban development, settlement, etc.) 10. No clear water use indicated	Bressers and Kuks (2004)

3.3 Environmental/water-related sustainability issue studied/addressed in the paper (i.e., concerning the environmental health of freshwater systems)	Checkboxes (check all that apply)	1. Water quality (e.g., pollution level, sedimentation, eutrophication, treatment) 2. Water quantity (e.g., water use efficiency, water allocation, water stress, water flow, recycling and reusing, treatment) 3. Aquatic biodiversity (e.g., fish biomass, macroinvertebrates, status of freshwater biodiversity) 4. Basin condition (e.g., land cover, channel modification) 5. Water-related ecosystem services (i.e., the ability of water resources provisioning ecosystem services) 6. General (e.g., protection, conservation, adaptation, resilience, ecological integrity, environmental status, environmental sustainability) 7. Other (please specify)	

References

Bressers, H. and S. Kuks (2004) Governance of Water Resources, in *Integrated governance and water basin management: conditions for regime change and sustainability*, eds. H. Bressers and S. Kuks: Kluwer Academic Publishers: 265, page 11.

Appendix 2. Publications included for coding

1. Agovino, M., M. Cerciello, A. Garofalo, L. Landriani, and L. Lepore. 2021. Corporate governance and sustainability in water utilities. The effects of decorporatisation in the city of Naples, Italy. *Business Strategy and the Environment* 30(2):874–890.
2. Aminova, M., and I. Abdullayev. 2009. Water management in a state-centered environment: Water governance analysis of Uzbekistan. *Sustainability* 1(4):1240–1265.
3. Andersen, M. S. 1999. Governance by green taxes: implementing clean water policies in Europe 1970–1990. *Environmental Economics and Policy Studies* 2(1):39–63.
4. Asefa, T., A. Adams, and I. Kajtezovic-Blankenship. 2014. A tale of integrated regional water supply planning: Meshing socio-economic, policy, governance, and sustainability desires together. *Journal of Hydrology* 519(PC):2632–2641.
5. Asomani-Boateng, R. 2019. Urban Wetland Planning and Management in Ghana: a Disappointing Implementation. *Wetlands* 39(2):251–261.
6. Aubin, D., P. Cornut, and F. Varone. 2007. Access to water resources in Belgium: Strategies of public and private suppliers. *Water Policy* 9(6):615–630.
7. Barrios, J. E., J. A. RodríGuez-Pineda, and M. De La Maza Benignos. 2009. Integrated river basin management in the Conchos river basin, Mexico: A case study of freshwater climate change adaptation. *Climate and Development* 1(3):249–260.
8. Beierle, T. C., and D. M. Konisky. 2001. What are we gaining from stakeholder involvement? Observations from environmental planning in the Great Lakes. *Environment and Planning C: Government and Policy* 19(4):515–527.
9. Biddle, J. C. 2017. Improving the Effectiveness of Collaborative Governance Regimes: Lessons from Watershed Partnerships. *Journal of Water Resources Planning and Management* 143(9):04017048.
10. Biggs, H. C., J. K. Clifford-Holmes, S. Freitag, F. J. Venter, and J. Venter. 2017. Cross-scale governance and ecosystem service delivery: A case narrative from the Olifants River in north-eastern South Africa. *Ecosystem Services* 28:173–184.
11. Bitterman, P., and C. J. Koliba. 2020. Modeling Alternative Collaborative Governance Network Designs: An Agent-Based Model of Water Governance in the Lake Champlain Basin, Vermont. *Journal of Public Administration Research and Theory* 30(4):636–655.
12. Blumstein, S. 2017. Managing adaptation: international donors' influence on international river basin organizations in Southern Africa. *International Journal of River Basin Management* 15(4):461–473.
13. Boone, S., and S. Fragaszy. 2018. Emerging scarcity and emerging commons: Water management groups and groundwater governance in Aotearoa New Zealand. *Water Alternatives* 11(3):795–823.
14. Brillo, B. B. C., E. C. Quinones, and A. V. Lapitan. 2017. Restoration, development and governance of Dagatan Lake, San Antonio, Quezon, Philippines. *Taiwan Water Conservancy* 65(1):44–54.
15. Brombal, D., Y. Niu, L. Pizzol, A. Moriggi, J. Wang, A. Critto, X. Jiang, B. Liu, and A. Marcomini. 2018. A participatory sustainability assessment for integrated watershed management in urban China. *Environmental Science and Policy* 85:54–63.
16. Brubaker, E. 1998. Privatizing water supply and sewage treatment: How far should we go? . *Journal des Economistes et des Etudes Humaines* 8(4):441–454.
17. Chang, H., P. Thiers, N. R. Netusil, J. A. Yeakley, G. Rollwagen-Bollens, S. M. Bollens, and S. Singh. 2014. Relationships between environmental governance and

water quality in a growing metropolitan area of the Pacific Northwest, USA. *Hydrology and Earth System Sciences* 18(4):1383–1395.
18. Charlton, G., and B. Brunette. 2011. Sustainable development and water use in New Zealand: Water priority and allocation under section 5 of the resource management act 1991 and the national policy statement on freshwater management 2011. *WIT Transactions on Ecology and the Environment* 153:355–373.
19. Chattopadhyay, S., and K. Thiruvananthapuram. 2018. Challenges of water governance in the context of water quality problem: Comparative study of India, Indonesia and Germany. *Transactions of the Institute of Indian Geographers* 40(2):171–183.
20. Chaudhary, P., N. B. Chhetri, B. Dorman, T. Gegg, R. B. Rana, M. Shrestha, K. Thapa, K. Lamsal, and S. Thapa. 2015. Turning conflict into collaboration in managing commons: A case of Rupa lake watershed, Nepal. *International Journal of the Commons* 9(2):744–771.
21. Cobbing, J. E. 2008. Institutional linkages and acid mine drainage: The case of the Western Basin in South Africa. *International Journal of Water Resources Development* 24(3):451–462.
22. Conallin, J., E. Wilson, and J. Campbell. 2018. Implementation of Environmental Flows for Intermittent River Systems: Adaptive Management and Stakeholder Participation Facilitate Implementation. *Environmental Management* 61(3):497–505.
23. Cong, W., X. Li, Y. Qian, and L. Shi. 2021. Polycentric approach of wastewater governance in textile industrial parks: Case study of local governance innovation in China. *Journal of Environmental Management* 280.
24. Cookey, P. E., R. Darnsawasdi, and C. Ratanachai. 2016. Critical analysis of water governance challenges of Songkhla Lake Basin, Thailand. *Lakes and Reservoirs: Science, Policy and Management for Sustainable Use* 21(4):293–314.
25. Cookey, P. E., R. Darnswasdi, and C. Ratanachai. 2016. Local people's perceptions of Lake Basin water governance performance in Thailand. *Ocean and Coastal Management* 120:11–28.
26. Cuadrado-Quesada, G. 2014. Groundwater governance and spatial planning challenges: examining sustainability and participation on the ground. *Water International* 39(6):798–812.
27. Cui, C., and H. Yi. 2020. What drives the performance of collaboration networks: A qualitative comparative analysis of local water governance in China. *International Journal of Environmental Research and Public Health* 17(6).
28. Das, S., B. Behera, and A. Mishra. 2020. Property Rights and Institutional Arrangements of a Man-Made Wetland in Dryland Area of West Bengal, India. *Wetlands* 40(6):2553–2560.
29. Davies, P. J., and I. A. Wright. 2014. A review of policy, legal, land use and social change in the management of urban water resources in Sydney, Australia: A brief reflection of challenges and lessons from the last 200 years. *Land Use Policy* 36:450–460.
30. Delgado-Serrano, M. M., and M. M. Borrego-Marin. 2020. Drivers of innovation in groundwater governance. The links between the social and the ecological systems. *Land Use Policy* 91.
31. Dombrowsky, I. 2008. Institutional design and regime effectiveness in transboundary river management - The Elbe water quality regime. *Hydrology and Earth System Sciences* 12(1):223–238.

32. Drevno, A. 2018. From fragmented to joint responsibilities: Barriers and opportunities for adaptive water quality governance in California's urban-agricultural interface. *Resources* 7(1).
33. Eckerberg, K. 1997. Comparing the local use of environmental policy instruments in nordic and baltic countries - The issue of diffuse water pollution. *Environmental Politics* 6(2):24–47.
34. Emel, J., and R. Roberts. 1995. Institutional Form and Its Effect on Environmental Change: The Case of Groundwater in the Southern High Plains. *Annals of the Association of American Geographers* 85(4):664–683.
35. Enqvist, J., M. Tengö, and W. J. Boonstra. 2016. Against the current: rewiring rigidity trap dynamics in urban water governance through civic engagement. *Sustainability Science* 11(6):919–933.
36. Fischhendler, I. 2008. Institutional conditions for IWRM: The Israeli case. *Ground Water* 46(1):91–102.
37. Flores, C. C., V. Vikolainen, and H. Bressers. 2016. Water governance decentralisation and river basin management reforms in hierarchical systems: Do they work for water treatment policy in Mexico's Tlaxcala Atoyac sub-basin? *Water (Switzerland)* 8(5).
38. Furlong, K., and K. Bakker. 2011. Governance and sustainability at a municipal scale: The challenge of water conservation. *Canadian Public Policy* 37(2):219–237.
39. Furlong, K., and K. Bakker. 2010. The contradictions in "alternative" service delivery: Governance, business models, and sustainability in municipal water supply. *Environment and Planning C: Government and Policy* 28(2):349–368.
40. Garrick, D., and B. Aylward. 2012. Transaction costs and institutional performance in market-based environmental water allocation. *Land Economics* 88(3):536–560.
41. Gensemer, M. K., and M. Yamaguchi. 1985. Successful water quality planning: an areawide perspective (California). *Journal of Soil & Water Conservation* 40(1):76–78.
42. Graversgaard, M., B. H. Jacobsen, C. Kjeldsen, and T. Dalgaard. 2017. Stakeholder engagement and knowledge co-creation in water planning: Can public participation increase cost-effectiveness? *Water (Switzerland)* 9(3).
43. Grumbine, R. E., J. Dore, and J. Xu. 2012. Mekong hydropower: Drivers of change and governance challenges. *Frontiers in Ecology and the Environment* 10(2):91–98.
44. Guo, X. 2017. Application of Public Private Partnerships on urban river management in China: A case study of Chu River. *International Review for Spatial Planning and Sustainable Development* 5(4):32–41.
45. Gupta, A. D. 2001. Challenges and opportunities for water resources management in southeast Asia . *Hydrological Sciences Journal* 46(6):923–935.
46. Haregeweyn, N., A. Berhe, A. Tsunekawa, M. Tsubo, and D. T. Meshesha. 2012. Integrated watershed management as an effective approach to curb land degradation: A case study of the enabered watershed in northern Ethiopia. *Environmental Management* 50(6):1219–1233.
47. Harutyunyan, N. 2012. State versus private sector provision of water services in Armenia. *Frontiers of Environmental Science and Engineering in China* 6(5):620–630.
48. Hoornbeek, J., E. Hansen, E. Ringquist, and R. Carlson. 2013. Implementing Water Pollution Policy in the United States: Total Maximum Daily Loads and Collaborative Watershed Management. *Society and Natural Resources* 26(4):420–436.
49. Horinkova, V., and I. Abdullaev. 2003. Institutional aspects of water management in Central Asia: Water users associations. *Water International* 28(2):237–245.

50. Hu, X.-J., Y.-C. Xiong, Y.-J. Li, J.-X. Wang, F.-M. Li, H.-Y. Wang, and L.-L. Li. 2014. Integrated water resources management and water users' associations in the arid region of northwest China: A case study of farmers' perceptions. *Journal of Environmental Management* 145:162–169.
51. Iwasaki, S. 2013. Fishers-based watershed management in Lake Saroma, Japan. *Ocean and Coastal Management* 81:58–65.
52. Jahan, S., I. Islam, K. Takao, and H. Kanegae. 2008. Shrinkage of the wetlands of Dhaka: A study from an institutional perspective. *Studies in Regional Science* 38(4):861–875.
53. Jégou, A., and C. Sanchis-Ibor. 2019. The opaque lagoon. Water management and governance in L'albufera de València Wetland (Spain) . *Limnetica* 38(1):503–515.
54. Jetoo, S. 2018. Barriers to effective eutrophication governance: A comparison of the Baltic Sea and North American Great Lakes. *Water (Switzerland)* 10(4).
55. Jetoo, S., A. Thorn, K. Friedman, S. Gosman, and G. Krantzberg. 2015. Governance and geopolitics as drivers of change in the Great Lakes-St. Lawrence basin. *Journal of Great Lakes Research* 41(S1):108–118.
56. Jönsson, B. D. 2004. Stakeholder participation as a tool for sustainable development in the Em River Basin. *International Journal of Water Resources Development* 20(3):345–352.
57. Kajisa, K., and B. Dong. 2017. The effects of volumetric pricing policy on farmers' watermanagement institutions and their water use: The case of water user organization in an irrigation system in Hubei, China. *World Bank Economic Review* 31(1):220–240.
58. Kapembwa, S., A. Gardiner, and J. G. Pétursson. 2020. Governance assessment of small-scale inland fishing: The case of Lake Itezhi-Tezhi, Zambia. *Natural Resources Forum* 44(3):236–254.
59. Kaushik, R., B. K. Pattnaik, and B. Rath. 2019. Community participation in effective water resource management a comparative study in Alwar, Rajasthan. *Economic and Political Weekly* 54(35):53–58.
60. Kim, J. H., T. D. Keane, and E. A. Bernard. 2015. Fragmented local governance and water resource management outcomes. *Journal of Environmental Management* 150:378–386.
61. Kirk, N., A. Brower, and R. Duncan. 2017. New public management and collaboration in canterbury, New Zealand's freshwater management. *Land Use Policy* 65:53–61.
62. Knieper, C., and C. Pahl-Wostl. 2016. A Comparative Analysis of Water Governance, Water Management, and Environmental Performance in River Basins. *Water Resources Management* 30(7):2161–2177.
63. Knüppe, K., and C. Pahl-Wostl. 2013. Requirements for adaptive governance of groundwater ecosystem services: Insights from Sandveld (South Africa), Upper Guadiana (Spain) and Spree (Germany). *Regional Environmental Change* 13(1):53–66.
64. Koontz, T. M., and J. Newig. 2014. From Planning to Implementation: Top-Down and Bottom-Up Approaches for Collaborative Watershed Management. *Policy Studies Journal* 42(3):416–442.
65. Kundu, R., C. M. Aura, M. Muchiri, J. M. Njiru, and J. E. Ojuok. 2010. Difficulties of fishing at lake Naivasha, Kenya: Is community participation in management the solution? *Lakes and Reservoirs: Research and Management* 15(1):15–23.

66. Kunrong, S., and J. Gang. 2020. The Policy Effects of the Environmental Governance of Chinese Local Governments: A Study Based on the Progress of the River Chief System. *Social Sciences in China* 41(3):87–105.
67. Kurian, M., T. Dietz, and K. S. Murali. 2004. Public-private partnerships in watershed management - Evidence from the Himalayan foothills. *Water Policy* 6(2):131–152.
68. Kuzdas, C., B. P. Warner, A. Wiek, R. Vignola, M. Yglesias, and D. L. Childers. 2016. Sustainability assessment of water governance alternatives: the case of Guanacaste Costa Rica. *Sustainability Science* 11(2):231–247.
69. Kuzdas, C., A. Wiek, B. Warner, R. Vignola, and R. Morataya. 2014. Sustainability appraisal of water governance regimes: The case of Guanacaste, Costa Rica. *Environmental Management* 54(2):205–222.
70. Langridge, R., and C. Ansell. 2018. Comparative analysis of institutions to govern the groundwater commons in California. *Water Alternatives* 11(3):481–510.
71. Langridge, S. 2016. Social and biophysical context influences county-level support for collaborative watershed restoration: Case study of the Sacramento River, CA, USA. *Ecological Restoration* 34(4):285–296.
72. Larson, K. L., A. Wiek, and L. Withycombe Keeler. 2013. A comprehensive sustainability appraisal of water governance in Phoenix, AZ. *Journal of Environmental Management* 116:58–71.
73. Lee, S., and G. W. Choi. 2012. Governance in a River Restoration Project in South Korea: The Case of Incheon. *Water Resources Management* 26(5):1165–1182.
74. Leendertse, K., S. Mitchell, and J. Harlin. 2009. IWRM and the environment: A view on their interaction and examples where IWRM led to better environmental management in developing countries. *Water SA* 34(6):691–698.
75. Libanio, P. A. C. 2014. The use of goal-oriented strategies in the building of water governance in Brazil. *Water International* 39(4):401–416.
76. Lo, C. W., and S. -Y Tang. 1994. Institutional contexts of environmental management: Water pollution control in Guangzhou, China. *Public Administration and Development* 14(1):53–64.
77. Loftus, A. J., and D. A. Mcdonald. 2001. Of Liquid Dreams: A Political Ecology Of Water Privatization In Buenos Aires. *Environment & Urbanization* 13(2):179–199.
78. Lopez Porras, G., L. C. Stringer, and C. H. Quinn. 2019. Corruption and conflicts as barriers to adaptive governance: Water governance in dryland systems in the Rio del Carmen watershed. *Science of the Total Environment* 660:519–530.
79. Lopez-Gunn, E. 2003. The Role of Collective Action in Water Governance: A Comparative Study of Groundwater User Associations in La Mancha Aquifers in Spain. *Water International* 28(3):367–378.
80. Lu, Z., L. Zhao, and J. Dai. 2010. A study of water resource management in the Tarim Basin, Xinjiang. *International Journal of Environmental Studies* 67(2):245–255.
81. Mahanty, S., and T. D. Dang. 2013. Crafting Sustainability? The Potential and Limits of Institutional Design in Managing Water Pollution from Vietnam's Craft Villages. *Society and Natural Resources* 26(6):717–732.
82. Manda, A. K., and W. A. Klein. 2014. Rescuing degrading aquifers in the Central Coastal Plain of North Carolina (USA): Just process, effective groundwater management policy, and sustainable aquifers. *Water Resources Research* 50(7):5662–5677.
83. Mandarano, L., and K. Paulsenb. 2011. Governance capacity in collaborative watershed partnerships: Evidence from the Philadelphia region. *Journal of Environmental Planning and Management* 54(10):1293–1313.

84. Manou, D., and J. Papathanasiou. 2009. Exploring the potential failure of the regulatory framework and management tools which govern the conservation of biodiversity: The case of artificial lake kerkini in Greece. *Journal of Environmental Assessment Policy and Management* 11(2):213–243.
85. Marquardt, M., and S. Russell. 2007. Community governance for sustainability: Exploring benefits of community water schemes? *Local Environment* 12(4):437–445.
86. Marques, R. C. 2008. Comparing private and public performance of Portuguese water services. *Water Policy* 10(1):25–42.
87. Martinez, R., K. M. Green, and A. DeWan. 2013. Establishing reciprocal agreements for water and biodiversity conservation through a social marketing campaign in Quanda watershed, Peru. *Conservation Evidence* 10:42–47.
88. May, C. K. 2013. Power across scales and levels of fisheries governance: Explaining the active non-participation of fishers in Two Rivers, North Carolina. *Journal of Rural Studies* 32:26–37.
89. McNeill, J. 2016. Scale Implications of Integrated Water Resource Management Politics: Lessons from New Zealand. *Environmental Policy and Governance* 26(4):306–319.
90. Meijerink, S., and D. Huitema. 2017. The institutional design, politics, and effects of a bioregional approach: Observations and lessons from 11 case studies of river basin organizations. *Ecology and Society* 22(2).
91. Mekonnen, D. K., H. Channa, and C. Ringler. 2015. The impact of water users' associations on the productivity of irrigated agriculture in Pakistani Punjab. *Water International* 40(5–6):733–747.
92. Mestre, J. E. 1997. Integrated approach to river basin management: Lerma-chapala case study—attributions and experiences in water management in mexico. *Water International* 22(3):140–152.
93. Meyer, C., and A. Thiel. 2012. Institutional change in water management collaboration: Implementing the European Water Framework Directive in the German Odra river basin. *Water Policy* 14(4):625–646.
94. Meyer, S. M., and D. M. Konisky. 2007. Local institutions and environmental outcomes: Evidence from wetlands protection in Massachusetts. *Policy Studies Journal* 35(3):481–502.
95. Mirnezami, S. J., C. de Boer, and A. Bagheri. 2020. Groundwater governance and implementing the conservation policy: the case study of Rafsanjan Plain in Iran. *Environment, Development and Sustainability* 22(8):8183–8210.
96. Molle, F., and A. Mamanpoush. 2012. Scale, governance and the management of river basins: A case study from Central Iran. *Geoforum* 43(2):285–294.
97. Montero, S. G., E. S. Castellón, L. M. M. Rivera, S. G. Ruvalcaba, and J. J. Llamas. 2006. Collaborative governance for sustainable water resources management: The experience of the Inter-municipal Initiative for the Integrated Management of the Ayuquila River Basin, Mexico. *Environment and Urbanization* 18(2):297–313.
98. Morris, J. C., W. A. Gibson, W. M. Leavitt, and S. C. Jones. 2014. Collaborative federalism and the emerging role of local nonprofits in water quality implementation. *Publius* 44(3):499–518.
99. Morris, L., and L. F. G. Cabrera. 2003. The involvement of the private sector in water servicing: Effects on the urban poor in the case of Aguascalientes, Mexico. *Greener Management International*(42):35–46.
100. Mudliar, P. 2021. Polycentric to monocentric governance: Power dynamics in Lake Victoria's fisheries. *Environmental Policy and Governance* 31(4):302–315.

101. Nakamura, L., and S. M. Born. 1993. Substate institutional innovation for managing lakes and watersheds: a wisconsin case study. *JAWRA Journal of the American Water Resources Association* 29(5):807–821.
102. Namara, I., D. M. Hartono, Y. Latief, and S. S. Moersidik. 2018. Institution and legal aspect based river water quality management. *International Journal of Engineering and Technology(UAE)* 7(3):86–88.
103. Narayanan, N. C., and J.-P. Venot. 2009. Drivers of change in fragile environments: Challenges to governance in Indian wetlands. *Natural Resources Forum* 33(4):320–333.
104. Ngonyani, H., and K. A. Mourad. 2019. Role of water user associations on the restoration of the ecosystem in Tanzania. *Water (Switzerland)* 11(1).
105. Oledn, M. T. T. 2001. Challenges and opportunities in watershed management for Laguna de Bay (Philippines). *Lakes and Reservoirs: Science, Policy and Management for Sustainable Use* 6(3):243–246.
106. Ongley, E. D., and X. Wang. 2004. Transjurisdictional water pollution management in china: The legal and institutional framework. *Water International* 29(3):270–281.
107. Ouyang, J., K. Zhang, B. Wen, and Y. Lu. 2020. Top-down and bottom-up approaches to environmental governance in China: Evidence from the river chief system (RCS). *International Journal of Environmental Research and Public Health* 17(19):1–23.
108. Owens, K., and C. Zimmerman. 2013. Local Governance Versus Centralization: Connecticut Wetlands Governance as a Model. *Review of Policy Research* 30(6):629–656.
109. Özerol, G., and H. Bressers. 2015. Scalar alignment and sustainable water governance: The case of irrigated agriculture in Turkey. *Environmental Science and Policy* 45:1–10.
110. Özerol, G. 2013. Institutions of farmer participation and environmental sustainability: A multi-level analysis from irrigation management in Harran Plain, Turkey. *International Journal of the Commons* 7(1):73–91.
111. Pahl-Wostl, C., L. Lebel, C. Knieper, and E. Nikitina. 2012. From applying panaceas to mastering complexity: Toward adaptive water governance in river basins. *Environmental Science and Policy* 23:24–34.
112. Papalia, J. 1996. An initial assessment of coastal watershed management in new south wales, australia. *Coastal Management* 24(4):365–384.
113. Pereira, L. F. M., S. Barreto, and J. Pittock. 2009. Participatory river basin management in the São João River, Brazil: A basis for climate change adaptation? *Climate and Development* 1(3):261–268.
114. Piégay, H., P. Dupont, and J. A. Faby. 2002. Questions of water resources management. Feedback on the implementation of the french SAGE and SDAGE plans (1992-2001). *Water Policy* 4(3):239–262.
115. Qureshi, A. S. 2020. Groundwater governance in pakistan: From colossal development to neglected management. *Water (Switzerland)* 12(11):1–20.
116. Ratna Reddy, V., M. Srinivasa Reddy, and S. K. Rout. 2014. Groundwater governance: A tale of three participatory models in Andhra Pradesh, India. *Water Alternatives* 7(2):275–297.
117. Reymond, P., R. Chandragiri, and L. Ulrich. 2020. Governance Arrangements for the Scaling Up of Small-Scale Wastewater Treatment and Reuse Systems – Lessons From India. *Frontiers in Environmental Science* 8.

118. Rimmert, M., L. Baudoin, B. Cotta, E. Kochskämper, and J. Newig. 2020. Participation in river basin planning under the water framework directive-Has it benefitted good water status? *Water Alternatives* 13(3):484–512.
119. Rinaudo, J.-D., and G. Donoso. 2019. State, market or community failure? Untangling the determinants of groundwater depletion in Copiapó (Chile). *International Journal of Water Resources Development* 35(2):283–304.
120. Rouillard, J., and J. D. Rinaudo. 2020. From State to user-based water allocations: An empirical analysis of institutions developed by agricultural user associations in France. *Agricultural Water Management* 239.
121. Saldías, C., S. Speelman, B. van Koppen, and G. van Huylenbroeck. 2016. Institutional arrangements for the use of treated effluent in irrigation, Western Cape, South Africa. *International Journal of Water Resources Development* 32(2):203–218.
122. Salthouse, C. 2000. Making the most of the Mersey estuary: A partnership approach to catchment management. *International Journal of Urban Sciences* 4(2):129–138.
123. Saravanan, V. S. 2009. Decentralisation and water resources management in the indian himalayas: The contribution of new institutional theories. *Conservation and Society* 7(3):176–191.
124. Schleyer, R. G., and M. W. Rosegrant. 1996. Chilean water policy: The role of water rights, institutions and markets. *International Journal of Water Resources Development* 12(1):33–48.
125. Schulze, S., and S. Schmeier. 2012. Governing environmental change in international river basins: The role of river basin organizations. *International Journal of River Basin Management* 10(3):229–244.
126. She, Y., Y. Liu, L. Jiang, and H. Yuan. 2019. Is China's River Chief Policy effective? Evidence from a quasi-natural experiment in the Yangtze River Economic Belt, China. *Journal of Cleaner Production* 220:919–930.
127. Shiferaw, B., C. Bantilan, and S. Wani. 2008. Rethinking policy and institutional imperatives for integrated watershed management: Lessons and experiences from semi-arid India. *Journal of Food, Agriculture and Environment* 6(2):370–377.
128. Silveira, A., S. Junier, F. Hüesker, F. Qunfang, and A. Rondorf. 2016. Organizing cross-sectoral collaboration in river basin management: case studies from the Rhine and the Zhujiang (Pearl River) basins. *International Journal of River Basin Management* 14(3):299–315.
129. Sinclair, A. J., W. Kumnerdpet, and J. M. Moyer. 2013. Learning sustainable water practices through participatory irrigation management in Thailand. *Natural Resources Forum* 37(1):55–66.
130. Singh, C. 2018. Is participatory watershed development building local adaptive capacity? Findings from a case study in Rajasthan, India. *Environmental Development* 25:43–58.
131. Sithirith, M., J. Evers, and J. Gupta. 2016. Damming the Mekong tributaries: Water security and the MRC 1995 Agreement. *Water Policy* 18(6):1420–1435.
132. Sixt, G. N., L. Klerkx, J. D. Aiken, and T. S. Griffin. 2019. Nebraska's natural resource district system: Collaborative approaches to adaptive groundwater quality governance. *Water Alternatives* 12(2):676–698.
133. Snell, M., K. P. Bell, and J. Leahy. 2013. Local institutions and lake management. *Lakes and Reservoirs: Research and Management* 18(1):35–44.
134. Söderberg, C. 2016. Complex governance structures and incoherent policies: Implementing the EU water framework directive in Sweden. *Journal of Environmental Management* 183:90–97.

135. Sokhem, P., and K. Sunada. 2006. The governance of the Tonle Sap Lake, Cambodia: Integration of local, national and international levels. *International Journal of Water Resources Development* 22(3):399–416.
136. Somma, M. 1997. Institutions, ideology, and the tragedy of the commons: West Texas groundwater policy. *Publius: The Journal of Federalism* 27(1):1–11.
137. Steinebach, Y. 2019. Water quality and the effectiveness of European Union Policies. *Water (Switzerland)* 11(11).
138. Strauch, A. M., and A. M. Almedom. 2011. Traditional Water Resource Management and Water Quality in Rural Tanzania. *Human Ecology* 39(1):93–106.
139. Talukder, B., and K. W. Hipel. 2020. Diagnosis of sustainability of trans-boundary water governance in the Great Lakes basin. *World Development* 129.
140. Taylor, P. L., K. MacIlroy, R. Waskom, P. E. Cabot, M. Smith, A. Schempp, and B. Udall. 2019. Every ditch is different: Barriers and opportunities for collaboration for agricultural water conservation and security in the Colorado River Basin. *Journal of Soil and Water Conservation* 74(3):281–295.
141. Tevapitak, K., and A. H. J. (Bert) Helmsing. 2019. The interaction between local governments and stakeholders in environmental management: The case of water pollution by SMEs in Thailand. *Journal of Environmental Management* 247:840–848.
142. Tortajada, C., and Y. K. Joshi. 2014. Water quality management in Singapore: The role of institutions, laws and regulations . *Hydrological Sciences Journal* 59(9):1763–1774.
143. Ulibarri, N. 2015. Tracing Process to Performance of Collaborative Governance: A Comparative Case Study of Federal Hydropower Licensing. *Policy Studies Journal* 43(2):283–308.
144. van Leeuwen, C. J. 2017. Water governance and the quality of water services in the city of Melbourne. *Urban Water Journal* 14(3):247–254.
145. Varade, A. M., H. Wankhade, Y. K. Mawale, and H. Khandare. 2011. Watershed management as a tool for changing the Kaleidoscope of central India: A case study from Jhabua district of Madhya Pradesh, India. *Nature Environment and Pollution Technology* 10(4):589–594.
146. Venkatachalam, L. 2004. Sources of government failure and the environmental externality: Analysis of groundwater pollution in Tamil Nadu, India. *Water Policy* 6(5):413–426.
147. Villamayor-Tomas, S., M. Avagyan, M. Firlus, G. Helbing, and M. Kabakova. 2016. Hydropower vs. fisheries conservation: A test of institutional design principles for common-pool resource management in the lower Mekong basin social-ecological system. *Ecology and Society* 21(1).
148. Villeneuve, S., J. Painchaud, and C. Dugas. 2006. Targeted sustainable development: 15 years of government and community intervention on the St. Lawrence River. *Environmental Monitoring and Assessment* 113(1–3):285–301.
149. Vodden, K. 2015. Governing sustainable coastal development: The promise and challenge of collaborative governance in Canadian coastal watersheds. *Canadian Geographer* 59(2):167–180.
150. Wang, J., J. Huang, Q. Huang, and S. Rozelle. 2006. Privatization of tubewells in North China: Determinants and impacts on irrigated area, productivity and the water table. *Hydrogeology Journal* 14(3):275–285.
151. Wang, J., J. Huang, S. Rozelle, Q. Huang, and L. Zhang. 2009. Understanding the water crisis in Northern China: What the government and farmers are doing. *International Journal of Water Resources Development* 25(1):141–158.

152. Wang, Y., and X. Chen. 2020. River chief system as a collaborative water governance approach in China. *International Journal of Water Resources Development* 36(4):610–630.
153. Warner, A. T., L. B. Bach, and J. T. Hickey. 2014. Restoring environmental flows through adaptive reservoir management: Planning, science, and implementation through the Sustainable Rivers Project . *Hydrological Sciences Journal* 59(3–4):770–785.
154. White, I., M. Melville, B. Macdonald, R. Quirk, R. Hawken, M. Tunks, D. Buckley, R. Beattie, J. Williams, and L. Heath. 2007. From conflicts to wise practice agreement and national strategy: cooperative learning and coastal stewardship in estuarine floodplain management, Tweed River, eastern Australia. *Journal of Cleaner Production* 15(16):1545–1558.
155. Worte, C. 2017. Integrated watershed management and Ontario's conservation authorities. *International Journal of Water Resources Development* 33(3):360–374.
156. Xu, X., F. Wu, L. Zhang, and X. Gao. 2020. Assessing the effect of the Chinese river chief policy for water pollution control under uncertainty—using chaohu lake as a case. *International Journal of Environmental Research and Public Health* 17(9).
157. Yan, F., H. Daming, and B. Kinne. 2006. Water resources administration institution in China. *Water Policy* 8(4):291–301.
158. Yang, H., X. Zhang, and A. J. B. Zehnder. 2003. Water scarcity, pricing mechanism and institutional reform in northern China irrigated agriculture. *Agricultural Water Management* 61(2):143–161.
159. Yang, X., X. Lu, and L. Ran. 2016. Sustaining China's large rivers: River development policy, impacts, institutional issues and strategies for future improvement. *Geoforum* 69:1–4.
160. Yang, X., and X. X. Lu. 2013. Ten years of the Three Gorges Dam: A call for policy overhaul. *Environmental Research Letters* 8(4).
161. Yao, L., M. Zhao, and T. Xu. 2017. China's water-saving irrigation management system: Policy, implementation, and challenge. *Sustainability (Switzerland)* 9(12).
162. Yildirim, Y. E., and B. Çakmak. 2004. Participatory irrigation management in Turkey. *International Journal of Water Resources Development* 20(2):219–228.
163. Yu, Y., D.-G. Ohandja, and J. N. B. Bell. 2012. Institutional Capacity on Water Pollution Control of the Pearl River in Guangzhou, China. *International Journal of Water Resources Development* 28(2):313–324.
164. Zhang, L., N. Heerink, L. Dries, and X. Shi. 2013. Water users associations and irrigation water productivity in Northern China. *Ecological Economics* 95:128–136.
165. Zhang, Y., G. Fu, T. Yu, M. Shen, W. Meng, and E. D. Ongley. 2011. Trans-jurisdictional pollution control options within an integrated water resources management framework in water-scarce north-eastern China. *Water Policy* 13(5):624–644.

Appendix 3. Publications included in the archetype analysis

No.	Publication	No. of cases	Problématique
1	Andersen, M. S. 1999. Governance by green taxes: implementing clean water policies in Europe 1970–1990. *Environmental Economics and Policy Studies* 2(1):39–63.	3	P3
2	Asefa, T., A. Adams, and I. Kajtezovic-Blankenship. 2014. A tale of integrated regional water supply planning: Meshing socio-economic, policy, governance, and sustainability desires together. *Journal of Hydrology* 519(PC):2632–2641.	1	P1
3	Asomani-Boateng, R. 2019. Urban Wetland Planning and Management in Ghana: a Disappointing Implementation. *Wetlands* 39(2):251–261.	1	P2
4	Aubin, D., P. Cornut, and F. Varone. 2007. Access to water resources in Belgium: Strategies of public and private suppliers. *Water Policy* 9(6):615–630.	2	P4
5	Barrios, J. E., J. A. RodríGuez-Pineda, and M. De La Maza Benignos. 2009. Integrated river basin management in the Conchos river basin, Mexico: A case study of freshwater climate change adaptation. *Climate and Development* 1(3):249–260.	1	P1
6	Beierle, T. C., and D. M. Konisky. 2001. What are we gaining from stakeholder involvement? Observations from environmental planning in the Great Lakes. *Environment and Planning C: Government and Policy* 19(4):515–527.	1	P3
7	Biggs, H. C., J. K. Clifford-Holmes, S. Freitag, F. J. Venter, and J. Venter. 2017. Cross-scale governance and ecosystem service delivery: A case narrative from the Olifants River in north-eastern South Africa. *Ecosystem Services* 28:173–184.	2	P1; P3
8	Blumstein, S. 2017. Managing adaptation: international donors' influence on international river basin organizations in Southern Africa. *International Journal of River Basin Management* 15(4):461–473.	1	P4
9	Boone, S., and S. Fragaszy. 2018. Emerging scarcity and emerging commons: Water management groups and groundwater governance in Aotearoa New Zealand. *Water Alternatives* 11(3):795–823.	1	P1
10	Brillo, B. B. C., E. C. Quinones, and A. V. Lapitan. 2017. Restoration, development and governance of Dagatan Lake, San Antonio, Quezon, Philippines. *Taiwan Water Conservancy* 65(1):44–54.	1	P1

11	Brombal, D., Y. Niu, L. Pizzol, A. Moriggi, J. Wang, A. Critto, X. Jiang, B. Liu, and A. Marcomini. 2018. A participatory sustainability assessment for integrated watershed management in urban China. *Environmental Science and Policy* 85:54–63.	1	P2
12	Brubaker, E. 1998. Privatizing water supply and sewage treatment: how far should we go? *Journal des Économistes et des Études Humaines* 8(4):441–454.	2	P3
13	Chang, H., P. Thiers, N. R. Netusil, J. A. Yeakley, G. Rollwagen-Bollens, S. M. Bollens, and S. Singh. 2014. Relationships between environmental governance and water quality in a growing metropolitan area of the Pacific Northwest, USA. *Hydrology and Earth System Sciences* 18(4):1383–1395.	2	P2
14	Charlton, G., and B. Brunette. 2011. Sustainable development and water use in New Zealand: Water priority and allocation under section 5 of the resource management act 1991 and the national policy statement on freshwater management 2011. *WIT Transactions on Ecology and the Environment* 153:355–373.	1	P4
15	Chattopadhyay, S., and K. Thiruvananthapuram. 2018. Challenges of water governance in the context of water quality problem: Comparative study of India, Indonesia and Germany. *Transactions of the Institute of Indian Geographers* 40(2):171–183.	2	P3
16	Chaudhary, P., N. B. Chhetri, B. Dorman, T. Gegg, R. B. Rana, M. Shrestha, K. Thapa, K. Lamsal, and S. Thapa. 2015. Turning conflict into collaboration in managing commons: A case of Rupa lake watershed, Nepal. *International Journal of the Commons* 9(2):744–771.	2	P2; P5
17	Cobbing, J. E. 2008. Institutional linkages and acid mine drainage: The case of the Western Basin in South Africa. *International Journal of Water Resources Development* 24(3):451–462.	1	P2
18	Conallin, J., E. Wilson, and J. Campbell. 2018. Implementation of Environmental Flows for Intermittent River Systems: Adaptive Management and Stakeholder Participation Facilitate Implementation. *Environmental Management* 61(3):497–505.	1	P2
19	Cong, W., X. Li, Y. Qian, and L. Shi. 2020. Polycentric approach of wastewater governance in textile industrial parks: Case study of local governance innovation in China. *Journal of Environmental Management* 280.	1	P4
20	Cookey, P. E., R. Darnsawasdi, and C. Ratanachai. 2016. Critical analysis of water governance challenges of Songkhla Lake Basin, Thailand. *Lakes and Reservoirs: Research and Management* 21(4):293–314.	1	P2
21	Cookey, P. E., R. Darnswasdi, and C. Ratanachai. 2016. Local people's perceptions of Lake Basin water governance performance in Thailand. *Ocean and Coastal Management* 120:11–28.	1	P2
22	Cuadrado-Quesada, G. 2014. Groundwater governance and spatial planning challenges: examining sustainability and participation on the ground. *Water International* 39(6):798–812.	1	P1

23	Cui, C., and H. Yi. 2020. What drives the performance of collaboration networks: A qualitative comparative analysis of local water governance in China. *International Journal of Environmental Research and Public Health* 17(6).	1	P3
24	Das, S., B. Behera, and A. Mishra. 2020. Property Rights and Institutional Arrangements of a Man-Made Wetland in Dryland Area of West Bengal, India. *Wetlands* 40(6):2553–2560.	1	P2
25	Delgado-Serrano, M. M., and M. M. Borrego-Marin. 2020. Drivers of innovation in groundwater governance. The links between the social and the ecological systems. *Land Use Policy* 91.	3	P1
26	Dombrowsky, I. 2008. Institutional design and regime effectiveness in transboundary river management - The Elbe water quality regime. *Hydrology and Earth System Sciences* 12(1):223–238.	1	P2
27	Eckerberg, K. 1997. Comparing the local use of environmental policy instruments in nordic and baltic countries - The issue of diffuse water pollution. *Environmental Politics* 6(2):24–47.	1	P3
28	Emel, J., and R. Roberts. 1995. Institutional Form and Its Effect on Environmental Change: The Case of Groundwater in the Southern High Plains. *Annals of the Association of American Geographers* 85(4):664–683.	3	P1
29	Enqvist, J., M. Tengö, and W. J. Boonstra. 2016. Against the current: rewiring rigidity trap dynamics in urban water governance through civic engagement. *Sustainability Science* 11(6):919–933.	2	P4
30	Fischhendler, I. 2008. Institutional conditions for IWRM: The Israeli case. *Ground Water* 46(1):91–102.	1	P4
31	Flores, C. C., V. Vikolainen, and H. Bressers. 2016. Water governance decentralisation and river basin management reforms in hierarchical systems: Do they work for water treatment policy in Mexico's Tlaxcala Atoyac sub-basin? *Water (Switzerland)* 8(5).	1	P3
32	Garrick, D., and B. Aylward. 2012. Transaction costs and institutional performance in market-based environmental water allocation. *Land Economics* 88(3):536–560.	1	P1
33	GUPTA, A. DAS. 2001. Challenges and opportunities for water resources management in southeast Asia. *Hydrological Sciences Journal* 46(6):923–935.	1	P4
34	Haregeweyn, N., A. Berhe, A. Tsunekawa, M. Tsubo, and D. T. Meshesha. 2012. Integrated watershed management as an effective approach to curb land degradation: A case study of the enabered watershed in northern Ethiopia. *Environmental Management* 50(6):1219–1233.	1	P2
35	Horinkova, V., and I. Abdullaev. 2003. Institutional aspects of water management in Central Asia: Water users associations. *Water International* 28(2):237–245.	1	P1
36	Hu, X. J., Y. C. Xiong, Y. J. Li, J. X. Wang, F. M. Li, H. Y. Wang, and L. L. Li. 2014. Integrated water resources management and water users' associations in the arid region of northwest China: A case study of farmers' perceptions. *Journal of Environmental Management* 145:162–169.	1	P1

37	Iwasaki, S. 2013. Fishers-based watershed management in Lake Saroma, Japan. *Ocean and Coastal Management* 81:58–65.	1	P2
38	Jahan, S., I. Islam, K. Takao, and H. Kanegae. 2008. Shrinkage of the wetlands of Dhaka: A study from an institutional perspective. *Studies in Regional Science* 38(4):861–875.	1	P2
39	Jégou, A., and C. Sanchis-Ibor. 2019. The opaque lagoon. Water management and governance in L'albufera de València Wetland (Spain). *Limnetica* 38(1):503–515.	1	P3
40	Jönsson, B. L. 2004. Stakeholder participation as a tool for sustainable development in the Em River Basin. *International Journal of Water Resources Development* 20(3):345–352.	1	P5
41	Kajisa, K., and B. Dong. 2017. The effects of volumetric pricing policy on farmers' watermanagement institutions and their water use: The case of water user organization in an irrigation system in Hubei, China. *World Bank Economic Review* 31(1):220–240.	1	P1
42	Kapembwa, S., A. Gardiner, and J. G. Pétursson. 2020. Governance assessment of small-scale inland fishing: The case of Lake Itezhi-Tezhi, Zambia. *Natural Resources Forum* 44(3):236–254.	1	P2
43	Kaushik, R., B. K. Pattnaik, and B. Rath. 2019. Community participation in effective water resource management a comparative study in Alwar, Rajasthan. *Economic and Political Weekly* 54(35):53–58.	1	P1
44	Kim, J. H., T. D. Keane, and E. A. Bernard. 2015. Fragmented local governance and water resource management outcomes. *Journal of Environmental Management* 150:378–386.	1	P2
45	Kirk, N., A. Brower, and R. Duncan. 2017. New public management and collaboration in canterbury, New Zealand's freshwater management. *Land Use Policy* 65:53–61.	2	P1
46	Knüppe, K., and C. Pahl-Wostl. 2013. Requirements for adaptive governance of groundwater ecosystem services: Insights from Sandveld (South Africa), Upper Guadiana (Spain) and Spree (Germany). *Regional Environmental Change* 13(1):53–66.	3	P1
47	Kpéra, G. N., N. Aarts, A. Saïdou, R. C. Tossou, C. H. A. M. Eilers, G. A. Mensah, B. A. Sinsin, D. K. Kossou, and A. J. Van Der Zijpp. 2012. Management of agro-pastoral dams in Benin: Stakeholders, institutions and rehabilitation research. NJAS - Wageningen Journal of Life Sciences 60–63:79–90.	1	P5
48	Kundu, R., C. M. Aura, M. Muchiri, J. M. Njiru, and J. E. Ojuok. 2010. Difficulties of fishing at lake Naivasha, Kenya: Is community participation in management the solution? *Lakes and Reservoirs: Research and Management* 15(1):15–23.	1	P2
49	Kurian, M., T. Dietz, and K. S. Murali. 2004. Public-private partnerships in watershed management - Evidence from the Himalayan foothills. *Water Policy* 6(2):131–152.	1	P1
50	Kuzdas, C., A. Wiek, B. Warner, R. Vignola, and R. Morataya. 2014. Sustainability appraisal of water governance regimes: The case of Guanacaste, Costa Rica. *Environmental Management* 54(2):205–222.	1	P4

51	Kuzdas, C., B. P. Warner, A. Wiek, R. Vignola, M. Yglesias, and D. L. Childers. 2016. Sustainability assessment of water governance alternatives: the case of Guanacaste Costa Rica. *Sustainability Science* 11(2):231–247.	1	P4
52	Langridge, R., and C. Ansell. 2018. Comparative analysis of institutions to govern the groundwater commons in California. *Water Alternatives* 11(3):481–510.	2	P1; P4
53	Langridge, S. 2016. Social and biophysical context influences county-level support for collaborative watershed restoration: Case study of the Sacramento River, CA, USA. *Ecological Restoration* 34(4):285–296.	1	P4
54	Larson, K. L., A. Wiek, and L. Withycombe Keeler. 2013. A comprehensive sustainability appraisal of water governance in Phoenix, AZ. *Journal of Environmental Management* 116:58–71.	1	P4
55	Lee, S., and G. W. Choi. 2012. Governance in a River Restoration Project in South Korea: The Case of Incheon. *Water Resources Management* 26(5):1165–1182.	1	P3
56	Leendertse, K., S. Mitchell, and J. Harlin. 2009. IWRM and the environment: A view on their interaction and examples where IWRM led to better environmental management in developing countries. *Water SA* 34(6):691–698.	3	P2; P4
57	Lo, C. W., and S. -Y Tang. 1994. Institutional contexts of environmental management: Water pollution control in Guangzhou, China. *Public Administration and Development* 14(1):53–64.	1	P3
58	Loftus, A. j., and D. a. Mcdonald. 2001. Of Liquid Dreams: A Political Ecology Of Water Privatization In Buenos Aires. *Environment & Urbanization* 13(2):179–199.	1	P3
59	Lopez Porras, G., L. C. Stringer, and C. H. Quinn. 2019. Corruption and conflicts as barriers to adaptive governance: Water governance in dryland systems in the Rio del Carmen watershed. *Science of the Total Environment* 660:519–530.	1	P1
60	Lopez-Gunn, E. 2003. The Role of Collective Action in Water Governance: A Comparative Study of Groundwater User Associations in La Mancha Aquifers in Spain. *Water International* 28(3):367–378.	3	P1
61	Lu, Z., L. Zhao, and J. Dai. 2010. A study of water resource management in the Tarim Basin, Xinjiang. *International Journal of Environmental Studies* 67(2):245–255.	2	P2
62	Mahanty, S., and T. D. Dang. 2013. Crafting Sustainability? The Potential and Limits of Institutional Design in Managing Water Pollution from Vietnam’s Craft Villages. *Society and Natural Resources* 26(6):717–732.	1	P3
63	Manda, A. K., and W. A. Klein. 2014. Rescuing degrading aquifers in the Central Coastal Plain of North Carolina (USA): Just process, effective groundwater management policy, and sustainable aquifers. *Water Resources Research* 50(7):5662–5677.	1	P4

64	Mandarano, L., and K. Paulsenb. 2011. Governance capacity in collaborative watershed partnerships: Evidence from the Philadelphia region. *Journal of Environmental Planning and Management* 54(10):1293–1313.	1	P2
65	Manou, D., and J. Papathanasiou. 2009. Exploring the potential failure of the regulatory framework and management tools which govern the conservation of biodiversity: The case of artificial lake kerkini in Greece. *Journal of Environmental Assessment Policy and Management* 11(2):213–243.	1	P2
66	Marquardt, M., and S. Russell. 2007. Community governance for sustainability: Exploring benefits of community water schemes? *Local Environment* 12(4):437–445.	1	P1
67	May, C. K. 2013. Power across scales and levels of fisheries governance: Explaining the active non-participation of fishers in Two Rivers, North Carolina. *Journal of Rural Studies* 32:26–37.	1	P2
68	McNeill, J. 2016. Scale Implications of Integrated Water Resource Management Politics: Lessons from New Zealand. *Environmental Policy and Governance* 26(4):306–319.	1	P3
69	Meijerink, S., and D. Huitema. 2017. The institutional design, politics, and effects of a bioregional approach: Observations and lessons from 11 case studies of river basin organizations. *Ecology and Society* 22(2).	1	P1
70	Mekonnen, D. K., H. Channa, and C. Ringler. 2015. The impact of water users' associations on the productivity of irrigated agriculture in Pakistani Punjab. *Water International* 40(5–6):733–747.	1	P1
71	Mestre, J. E. 1997. Integrated approach to river basin management: Lerma-chapala case study—attributions and experiences in water management in mexico. *Water International* 22(3):140–152.	1	P4
72	Meyer, S. M., and D. M. Konisky. 2007. Local institutions and environmental outcomes: Evidence from wetlands protection in Massachusetts. *Policy Studies Journal* 35(3):481–502.	1	P2
73	Mirnezami, S. J., C. de Boer, and A. Bagheri. 2020. Groundwater governance and implementing the conservation policy: the case study of Rafsanjan Plain in Iran. *Environment, Development and Sustainability* 22(8):8183–8210.	1	P1
74	Molle, F., and A. Mamanpoush. 2012. Scale, governance and the management of river basins: A case study from Central Iran. *Geoforum* 43(2):285–294.	2	P1; P4
75	Montero, S. G., E. S. Castellón, L. M. M. Rivera, S. G. Ruvalcaba, and J. J. Llamas. 2006. Collaborative governance for sustainable water resources management: The experience of the Inter-municipal Initiative for the Integrated Management of the Ayuquila River Basin, Mexico. *Environment and Urbanization* 18(2):297–313.	1	P3
76	Morris, J. C., W. A. Gibson, W. M. Leavitt, and S. C. Jones. 2014. Collaborative federalism and the emerging role of local nonprofits in water quality implementation. *Publius* 44(3):499–518.	1	P2

77	Morris, L., and L. F. G. Cabrera. 2003. The involvement of the private sector in water servicing: Effects on the urban poor in the case of Aguascalientes, Mexico. *Greener Management International*(42):35–46.	1	P4
78	Mudliar, P. 2020. Polycentric to monocentric governance: Power dynamics in Lake Victoria's fisheries. *Environmental Policy and Governance*.	1	P2
79	Nakamura, L., and S. M. Born. 1993. Substate institutional innovation for managing lakes and watersheds: a wisconsin case study. *JAWRA Journal of the American Water Resources Association* 29(5):807–821.	1	P4
80	Namara, I., D. M. Hartono, Y. Latief, and S. S. Moersidik. 2018. Institution and legal aspect based river water quality management. *International Journal of Engineering and Technology(UAE)* 7(3):86–88.	1	P3
81	Narayanan, N. C., and J. P. Venot. 2009. Drivers of change in fragile environments: Challenges to governance in Indian wetlands. *Natural Resources Forum* 33(4):320–333.	1	P3
82	Ngonyani, H., and K. A. Mourad. 2019. Role of water user associations on the restoration of the ecosystem in Tanzania. *Water (Switzerland)* 11(1).	1	P2
83	Oledn, M. T. T. 2001. Challenges and opportunities in watershed management for Laguna de Bay (Philippines). *Lakes and Reservoirs: Research and Management* 6(3):243–246.	1	P3
84	Ongley, E. D., and X. Wang. 2004. Transjurisdictional water pollution management in china: The legal and institutional framework. *Water International* 29(3):270–281.	1	P3
85	Özerol, G. 2013. Institutions of farmer participation and environmental sustainability: A multi-level analysis from irrigation management in Harran Plain, Turkey. *International Journal of the Commons* 7(1):73–91.	1	P1
86	Özerol, G., and H. Bressers. 2015. Scalar alignment and sustainable water governance: The case of irrigated agriculture in Turkey. *Environmental Science and Policy* 45:1–10.	1	P1
87	Papalia, J. 1996. An initial assessment of coastal watershed management in new south wales, australia. *Coastal Management* 24(4):365–384.	1	P2
88	Pereira, L. F. M., S. Barreto, and J. Pittock. 2009. Participatory river basin management in the São João River, Brazil: A basis for climate change adaptation? *Climate and Development* 1(3):261–268.	1	P2
89	Piégay, H., P. Dupont, and J. A. Faby. 2002. Questions of water resources management. Feedback on the implementation of the french SAGE and SDAGE plans (1992-2001). *Water Policy* 4(3):239–262.	2	P1; P4
90	Qureshi, A. S. 2020. Groundwater governance in pakistan: From colossal development to neglected management. *Water (Switzerland)* 12(11):1–20.	1	P1
91	Ratna Reddy, V., M. Srinivasa Reddy, and S. K. Rout. 2014. Groundwater governance: A tale of three participatory models in Andhra Pradesh, India. *Water Alternatives* 7(2):275–297.	3	P1

92	Reymond, P., R. Chandragiri, and L. Ulrich. 2020. Governance Arrangements for the Scaling Up of Small-Scale Wastewater Treatment and Reuse Systems – Lessons From India. *Frontiers in Environmental Science* 8.	1	P4
93	Rinaudo, J. D., and G. Donoso. 2019. State, market or community failure? Untangling the determinants of groundwater depletion in Copiapó (Chile). *International Journal of Water Resources Development* 35(2):283–304.	1	P1
94	Rouillard, J., and J. D. Rinaudo. 2020. From State to user-based water allocations: An empirical analysis of institutions developed by agricultural user associations in France. *Agricultural Water Management* 239.	1	P1
95	Saldías, C., S. Speelman, B. van Koppen, and G. van Huylenbroeck. 2016. Institutional arrangements for the use of treated effluent in irrigation, Western Cape, South Africa. *International Journal of Water Resources Development* 32(2):203–218.	1	P4
96	Salthouse, C. 2000. Making the most of the Mersey estuary: A partnership approach to catchment management. *International Journal of Urban Sciences* 4(2):129–138.	1	P3
97	Schleyer, R. G., and M. W. Rosegrant. 1996. Chilean water policy: The role of water rights, institutions and markets. *International Journal of Water Resources Development* 12(1):33–48.	1	P1
98	Schulze, S., and S. Schmeier. 2012. Governing environmental change in international river basins: The role of river basin organizations. *International Journal of River Basin Management* 10(3):229–244.	1	P5
99	She, Y., Y. Liu, L. Jiang, and H. Yuan. 2019. Is China's River Chief Policy effective? Evidence from a quasi-natural experiment in the Yangtze River Economic Belt, China. *Journal of Cleaner Production* 220:919–930.	1	P3
100	Sinclair, A. J., W. Kumnerdpet, and J. M. Moyer. 2013. Learning sustainable water practices through participatory irrigation management in Thailand. *Natural Resources Forum* 37(1):55–66.	1	P1
101	Singh, C. 2018. Is participatory watershed development building local adaptive capacity? Findings from a case study in Rajasthan, India. *Environmental Development* 25:43–58.	1	P1
102	Sithirith, M., J. Evers, and J. Gupta. 2016. Damming the Mekong tributaries: Water security and the MRC 1995 Agreement. *Water Policy* 18(6):1420–1435.	1	P5
103	Snell, M., K. P. Bell, and J. Leahy. 2013. Local institutions and lake management. *Lakes and Reservoirs: Research and Management* 18(1):35–44.	1	P2
104	Sokhem, P., and K. Sunada. 2006. The governance of the Tonle Sap Lake, Cambodia: Integration of local, national and international levels. *International Journal of Water Resources Development* 22(3):399–416.	1	P5
105	Somma, M. 1997. Institutions, ideology, and the tragedy of the commons: West Texas groundwater policy. *Publius* 27(1):1–11.	1	P1

106	Strauch, A. M., and A. M. Almedom. 2011. Traditional Water Resource Management and Water Quality in Rural Tanzania. *Human Ecology* 39(1):93–106.	2	P2
107	Talukder, B., and K. W. Hipel. 2020. Diagnosis of sustainability of trans-boundary water governance in the Great Lakes basin. *World Development* 129.	1	P3
108	Taylor, P. L., K. MacIlroy, R. Waskom, P. E. Cabot, M. Smith, A. Schempp, and B. Udall. 2019. Every ditch is different: Barriers and opportunities for collaboration for agricultural water conservation and security in the Colorado River Basin. *Journal of Soil and Water Conservation* 74(3):281–295.	4	P1
109	Tortajada, C., and Y. K. Joshi. 2014. Water quality management in Singapore: the role of institutions, laws and regulations. *Hydrological Sciences Journal* 59(9):1763–1774.	1	P3
110	Ulibarri, N. 2015. Tracing Process to Performance of Collaborative Governance: A Comparative Case Study of Federal Hydropower Licensing. *Policy Studies Journal* 43(2):283–308.	3	P5
111	van Leeuwen, C. J. 2017. Water governance and the quality of water services in the city of Melbourne. *Urban Water Journal* 14(3):247–254.	1	P4
112	Villamayor-Tomas, S., M. Avagyan, M. Firlus, G. Helbing, and M. Kabakova. 2016. Hydropower vs. fisheries conservation: A test of institutional design principles for common-pool resource management in the lower Mekong basin social-ecological system. *Ecology and Society* 21(1).	1	P5
113	Villeneuve, S., J. Painchaud, and C. Dugas. 2006. Targeted sustainable development: 15 years of government and community intervention on the St. Lawrence River. *Environmental Monitoring and Assessment* 113(1–3):285–301.	1	P3
114	Vodden, K. 2015. Governing sustainable coastal development: The promise and challenge of collaborative governance in Canadian coastal watersheds. *Canadian Geographer* 59(2):167–180.	3	P2
115	Wang, J., J. Huang, Q. Huang, and S. Rozelle. 2006. Privatization of tubewells in North China: Determinants and impacts on irrigated area, productivity and the water table. *Hydrogeology Journal* 14(3):275–285.	1	P1
116	Wang, J., J. Huang, S. Rozelle, Q. Huang, and L. Zhang. 2009. Understanding the water crisis in Northern China: What the government and farmers are doing. *International Journal of Water Resources Development* 25(1):141–158.	1	P1
117	Warner, A. T., L. B. Bach, and J. T. Hickey. 2014. Restoring environmental flows through adaptive reservoir management: planning, science, and implementation through the Sustainable Rivers Project. *Hydrological Sciences Journal* 59(3–4):770–785.	1	P5
118	White, I., M. Melville, B. Macdonald, R. Quirk, R. Hawken, M. Tunks, D. Buckley, R. Beattie, J. Williams, and L. Heath. 2007. From conflicts to wise practice agreement and national strategy:	1	P2

	cooperative learning and coastal stewardship in estuarine floodplain management, Tweed River, eastern Australia. *Journal of Cleaner Production* 15(16):1545–1558.		
119	Worte, C. 2017. Integrated watershed management and Ontario's conservation authorities. *International Journal of Water Resources Development* 33(3):360–374.	1	P2
120	Yang, H., X. Zhang, and A. J. B. Zehnder. 2003. Water scarcity, pricing mechanism and institutional reform in northern China irrigated agriculture. *Agricultural Water Management* 61(2):143–161.	1	P1
121	Yang, X., X. Lu, and L. Ran. 2016. Sustaining China's large rivers: River development policy, impacts, institutional issues and strategies for future improvement. *Geoforum* 69:1–4.	1	P5
122	Yang, X., and X. X. Lu. 2013. Ten years of the Three Gorges Dam: A call for policy overhaul. *Environmental Research Letters* 8(4).	1	P5
123	Yao, L., M. Zhao, and T. Xu. 2017. China's water-saving irrigation management system: Policy, implementation, and challenge. *Sustainability (Switzerland)* 9(12).	1	P1
124	Yildirim, Y. E., and B. Çakmak. 2004. Participatory irrigation management in Turkey. *International Journal of Water Resources Development* 20(2):219–228.	1	P1
125	Yu, Y., D. G. Ohandja, and J. N. B. Bell. 2012. Institutional Capacity on Water Pollution Control of the Pearl River in Guangzhou, China. *International Journal of Water Resources Development* 28(2):313–324.	1	P3
126	Zhang, Y., G. Fu, T. Yu, M. Shen, W. Meng, and E. D. Ongley. 2011. Trans-jurisdictional pollution control options within an integrated water resources management framework in water-scarce north-eastern China. *Water Policy* 13(5):624–644.	1	P3

Appendix 4. Cluster analysis

The data used in the analysis were collected through the coding scheme presented in Appendix 1. As we could select multiple categories for all three variables, we transformed the raw data into binary categorical data using one-hot encoding to prepare it for the cluster analysis. Table A4.1 presents descriptive statistics of the data, used in the cluster analysis, on frequency and proportion.

Table A4.1 Description of the data used in the cluster analysis.

	Presence	Absence
Water resource		
Surface water	30 (18.8%)	130 (81.2%)
Groundwater	64 (40%)	96 (60%)
Reclaimed (wastewater)	9 (5.6%)	151 (94.4%)
Water use		
Water for agricultural use	82 (51.2%)	78 (48.8%)
Water resource as a medium for discharge of pollutants	48 (30%)	112 (70%)
Water for consumption and drinking water supply	47 (29.4%)	113 (70.6%)
Water resource as an infrastructure for land use	44 (27.5%)	116 (72.5%)
Water for the living environment	40 (25%)	120 (75%)
Water resource as an infrastructure for commercial uses	33 (20.6%)	127 (79.4%)
Water for industrial use	21 (13.1%)	139 (86.9%)
Water resource as infrastructure for tourism, leisure, recreation, sports or medical use	23 (14.4%)	137 (85.6%)
Water for hydropower production	14 (8.8%)	146 (91.2%)
Water-related environmental sustainability issue		
Water quality	92 (57.5%)	68 (42.5%)
Water quantity	97 (60.6%)	63 (39.4%)
Aquatic biodiversity	56 (35%)	104 (65%)
Basin condition	46 (28.7%)	114 (71.2%)
Water-related ecosystem services	17 (10.6%)	143 (89.4%)
General	30 (18.8%)	130 (81.2%)

Before conducting the cluster analysis, we performed multiple correspondence analysis (MCA). MCA can be considered a specialized form of Principal Component Analysis (PCA) tailored for handling categorical data, as mentioned by van der Heijden and de Leeuw (1989). MCA is a technique designed to handle categorical data, transforming it into a set of continuous variables known as principal components (Husson et al., 2010), enabling the use of the Ward clustering algorithm with the Euclidean metric. Following MCA, we conducted agglomerative hierarchical clustering using Euclidean distance and Ward's method on the components derived from MCA. We selected the first four dimensions from the Multiple Correspondence Analysis (MCA) results, as they collectively explain 53% of the variance (Figure A4.1). This choice was informed by the scree plot analysis, which indicates these dimensions capture significant variability in the dataset and are therefore suitable for clustering purposes.

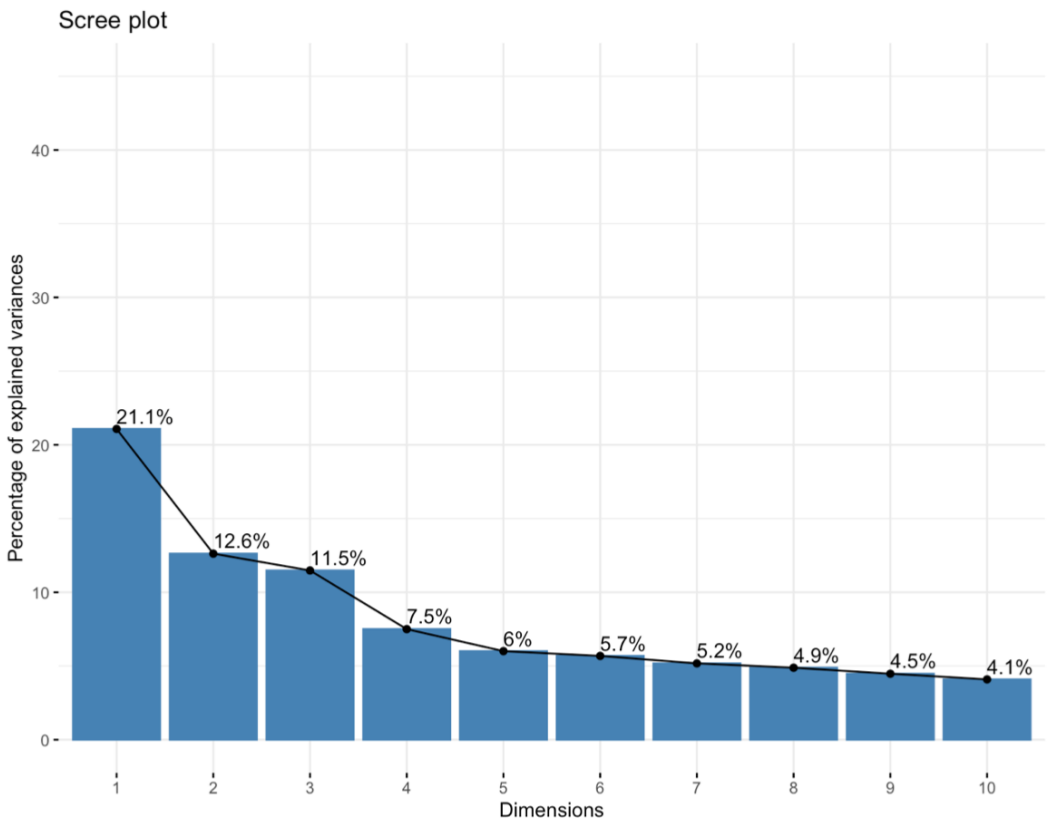


Figure A4. 1 Multiple correspondence analysis (MCA) screeplot

The number of clusters are chosen based on on the highest relative loss of within-group inertia. The within inertia serves as a measure of the homogeneity within a cluster (Charrad et al. 2014) and, a significant drop in this value suggests a natural division in the data. Figure A4.2 represents hierarchical clustering dendrogram, indexed by the within-inertia gain.

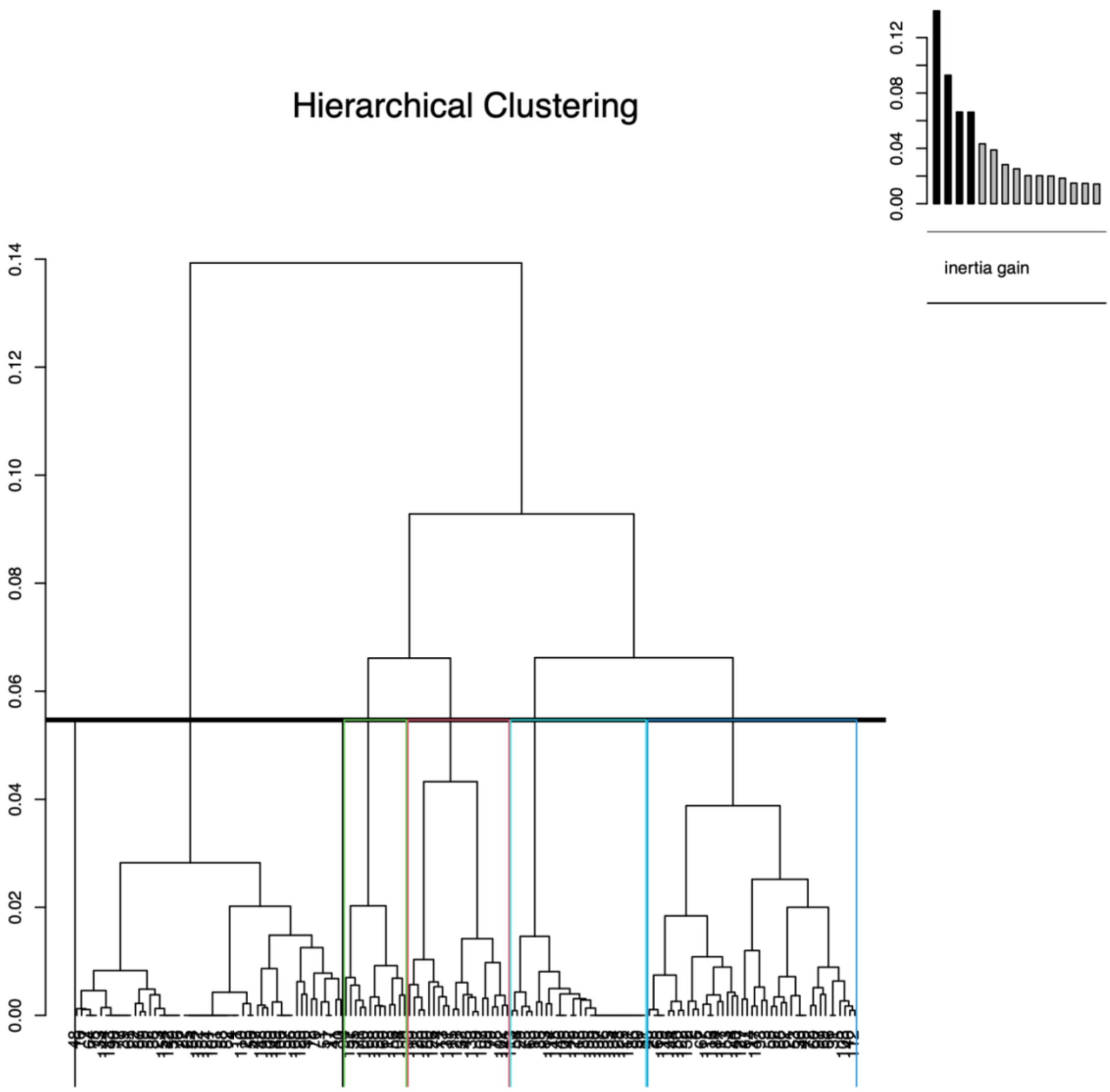


Figure A4.2 Hierarchical clustering (Ward's agglomerative criterion) illustrating the within-inertia gain.

The results of the cluster analysis are presented in Table A4.2. In Table A4.2, Cla/Mod represents the across-cluster membership, the share of cases across all problématiques that belong to a specific problématique for a given category, whereas Mod/Cla refers to the within-cluster membership, the share of cases within a specific problématique that have a particular category (Husson et al., 2010). The v.test values presented in the table indicate whether the mean of a category is significantly different from the overall mean (Husson et al., 2010). To this end, a v.test value greater than 1.96 indicates that the mean of the category is significantly greater than the overall mean. Conversely, if the v.test is less than -1.96, it signifies that the mean of the category is significantly lower than the overall mean.

Both MCA and cluster analyses were conducted using the FactoMineR package (Lê et al., 2008) in R (R Core Team, 2021).

Table A4.2 Overview of the description of water-related problématiques by categories based on the results from the hierarchical clustering on the dimensions acquired from Multiple Correspondence Analysis.

		P1. Groundwater for agriculture (56 cases - 35%)			P2. Land and water systems (38 cases - 24%)			P3. Surface water pollution (30 cases - 19%)			P4. Industrial and household water supply (23 cases - 14%)			P5. Hydropower and water ecology (13 cases - 8%)		
Variable	Category	Cla/Mod (%)	Mod/Cla (%)	v.test	Cla/Mod (%)	Mod/Cla (%)	v.test	Cla/Mod (%)	Mod/Cla (%)	v.test	Cla/Mod (%)	Mod/Cla (%)	v.test	Cla/Mod (%)	Mod/Cla (%)	v.test
Water resource	Surface water	23	51.8	-5.5	29.8	97.4	3.7	24.2	100.0	3.7				10.5	100	2.2
	Groundwater resources	68.8	78.6	7.3	4.7	7.9	-4.9	1.6	3.3	-4.9	25.0	69.6	3.0			
	Unconventional water resources										88.9	34.8	5.0			
Water use	Water for the living environment	15.0	10.7	-3.1	42.5	44.7	3.0									
	Water for consumption and drinking water supply	17.0	14.3	-3.1				6.4	10.0	-2.7	46.8	95.7	7.2			
	Water for agricultural use	62.2	91.1	7.7	9.8	21.1	-4.3	2.4	6.7	-5.7						
	Water for industrial use										76.2	69.6	7.1			
	Water for hydropower production													92.9	100.0	8.7
	Water resource as a medium for discharge of pollutants							62.5	100.0	9.2						
	Water resource as infrastructure for tourism, leisure, recreation, sports or medical use				43.5	26.3	2.2									
	Water resource as an infrastructure for commercial uses	15.2	8.9	-2.7	66.7	57.9	6.0	3.0	3.3	-2.8						
	Water resource as an infrastructure for land	2.3	1.8	-5.9	63.6	73.7	6.9									
Water-related sustainability issue	Water quality	12.0	19.6	-7.2				32.6	100.0	5.8	20.7	82.6	2.7			
	Water quantity	52.6	91.1	6.1	6.2	15.8	-6.4	5.2	16.7	-5.4	22.7	95.7	4.0	13.4	100.0	3.3
	Aquatic biodiversity	8.9	8.9	-5.3	42.9	63.2	4.0							23.2	100.0	5.1
	Basin condition	4.3	3.6	-5.6	60.9	73.7	6.7							17.4	61.5	2.5
	Water-related ecosystem services													23.5	30.8	2.1
	General															

References

Husson, F., J. Josse, and P. Jerome. 2010. *Principal component methods - hierarchical clustering - partitional clustering: why would we need to choose for visualizing data?*

van der Heijden, P. G. M., and J. de Leeuw. 1989. Correspondence Analysis, with Special Attention to the Analysis of Panel Data and Event History Data. *Sociological Methodology* 19:43.

Lê, S., J. Josse, and F. Husson. 2008. FactoMineR : An R Package for Multivariate Analysis. Journal of Statistical Software 25(1).

R Core Team. 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Article 3:

Successful governance pathways across problem contexts: a global QCA analysis

Abstract

It is widely acknowledged that the global water crisis is a governance crisis. Designing effective governance requires context-specific approaches tailored to the problems faced in different contexts. Our research aims to identify what types of governance pathways lead to successful sustainability performance, with a particular focus on the role of problem context. We use fuzzy set Qualitative Comparative Analysis (fsQCA) to examine water governance in 43 cases of surface water pollution and groundwater exploitation in agriculture. The analysis shows the link between problem context and successful governance pathways, emphasizing the need to understand the nature of the problem context when designing a governance response. The results also underscore the importance of governance capacity, as evidenced in all three solutions. Finally, the findings indicate that there is no easy solution to address water-related problems, as performance factors complement each other rather than being sufficient by themselves.

Successful governance pathways across problem contexts: a global QCA analysis

Paper submitted to Ecology and Society
Manuscript type: Research

Shahana Bilalova [1], Nicolas W. Jager [2], Jens Newig [1], Sergio Villamayor-Tomas [3]

[1] Faculty of Sustainability, Institute of Sustainability Governance (INSUGO), Research Group Governance, Participation and Sustainability, Leuphana University Lüneburg, Germany, [2] Public Administration and Policy Group, Wageningen University and Research, Wageningen, The Netherlands, [3] Institute of Environmental Science and Technology (ICTA-UAB), Autonomous University of Barcelona, Spain

ABSTRACT

It is widely acknowledged that the global water crisis is a governance crisis. Designing effective governance requires context-specific approaches tailored to the problems faced in different contexts. Our research aims to identify what types of governance pathways lead to successful sustainability performance, with a particular focus on the role of problem context. We use fuzzy set Qualitative Comparative Analysis (fsQCA) to examine water governance in 43 cases of surface water pollution and groundwater exploitation in agriculture. The analysis shows the link between problem context and successful governance pathways, emphasizing the need to understand the nature of the problem context when designing a governance response. The results also underscore the importance of governance capacity, as evidenced in all three solutions. Finally, the findings indicate that there is no easy solution to address water-related problems, as performance factors complement each other rather than being sufficient by themselves.

Keywords: water governance; sustainability performance; governance pathways; problem-specific pathways; QCA

INTRODUCTION

The global water crisis has been identified as a governance crisis (Taylor & Sonnenfeld, 2019). With an increasing emphasis on governance as a means to address water problems, there has been a notable rise in the promotion and application of a multitude of approaches (Tropp, 2007). Among these approaches, some have been promoted as universal remedies, or panaceas, receiving criticism from water governance scholars who argue that these approaches are proposed without a critical reflection on their appropriateness for the context in which they are applied (Ingram, 2011; Meinzen-Dick, 2007; Pahl-Wostl et al., 2012). Some examples of these approaches include privatization, integrated water resources management (IWRM), user-based management, or participatory models like water users associations (WUAs) and river basin management (Meinzen-Dick, 2007; Moss, 2012; Pahl-Wostl et al., 2012). Several studies have suggested that the implementation of these governance approaches varies significantly from one context to another, influenced by factors such as biophysical factors (Garrick et al., 2018), path dependency (Lukat et al., 2022; Sehring, 2009), diverse understandings and interpretations (Biswas, 2008; van Buuren et al., 2019), and their symbolic application to secure funding and gain greater acceptability (Biswas, 2008).

The ambiguity surrounding the effectiveness of these approaches calls for a shift away from promoting one-size-fits-all solutions to approaches tailored to the problems faced in different contexts. However, there is a gap in the literature regarding the relationship between problem context and water governance. While some studies have attempted to address this by examining the problem context (e.g., Srinivasan et al. 2012, Kirschke et al. 2019, Bilalova et al., *unpublished manuscript*) and determining the most appropriate governance approaches (e.g., Varady et al. 2016, Wuijts et al. 2018), most of them lack an explicit focus on the interaction between governance and problem context.

In this study, we systematically assess various water governance cases to identify the governance pathways that contribute to successful water-related environmental sustainability performance[1] in relation to the problems they address. Governance pathways encompass a constellation of several characteristics that shape the ways in which governance is structured and implemented, how decisions are made, and which actors are involved, as well as the interactions among them that collectively determine the effectiveness of governance in achieving desired outcomes. Specifically, we examine the role of problem context to understand whether successful governance pathways vary depending on the specific water-related problem they address and, if so, what the link is between the nature of the problem context and a successful governance pathway. Methodologically, the paper consists of a Qualitative Comparative Analysis (QCA) of 43 cases of water governance derived from a systematic literature review of 165 empirical water governance studies (Bilalova et al., 2024).

Following this introduction, we present the main concepts that guide our study, including the identification of governance characteristics that have been discussed as impacting governance performance. The "Methods" section briefly introduces our data and the QCA method. Subsequently, we present the findings of our analysis. Finally, we discuss the key results, explaining how they contribute to our understanding of water governance. The concluding part of this section reflects on our methodology and offers suggestions for further research.

---

[1] We will refer to "water-related environmental sustainability performance" simply as sustainability performance.

THEORETICAL FRAMEWORK

Within this section, we will specify and describe the main traits of problem contexts as well as the key governance characteristics assumed to determine the sustainability performance of given governance pathways. These traits and characteristics have been identified in various studies within the academic literature (e.g., Duit and Galaz 2008, Larson and Soto 2008, Moss and Newig 2010, Moss 2012, Jager et al. 2020, Hegga et al. 2020) and will form the conceptual basis for our empirical analysis.

Problem context

In designing effective governance measures, it is argued to be important to consider the attributes of the problem they aim to address (e.g., Peters 2005, Thomann et al. 2019, Kirschke et al. 2019). We follow Bilalova et al. (*unpublished manuscript*) and specifically understand problem contexts—"water-related problématiques"—as "recurring 'clusters' or 'ensembles' of water-related issues (or problems) in relation to water resources and the (un)sustainability of these resources connected to their use."

Peters (2005) identifies three core attributes of policy problems that influence the selection of measures. The first attribute determines whether a problem can have a finite and definable solution or if it tends to recur over time (Peters, 2005). Problems with high solubility can be easily addressed with one-time interventions, whereas those with ongoing recurrence require sustained efforts (Hoornbeek & Peters, 2017). Another crucial attribute is complexity, which encompasses factors such as the number of interests and actors involved, making negotiations challenging, the extent of technical expertise needed to understand the problem, and the existence of multiple and competing causal relations within it (Peters, 2005). Complex problems demand a shared understanding and expertise/research (Hoornbeek & Peters, 2017). Finally, scale refers to the magnitude of the problem and its range of effects (Peters, 2005). Some problems can be broken down into smaller components, allowing for more targeted interventions, while others necessitate comprehensive solutions (Thomann et al., 2019)

From this description, we assume that the problem contexts that present clear management questions (e.g., which issues should be targeted to address the problem) can be addressed with straightforward solutions (e.g., optimizing the wastewater plant) (DeFries & Nagendra, 2017; Head, 2022b; Kirschke et al., 2017). Such issues can be effectively managed through top-down regulatory measures (Homsy et al., 2019; Ruhl, 2005). Contrarily, addressing complex problems with inherent goal conflicts, boundary-spanning nature, and non-linearity requires strategies such as multisector decision-making, institutions enabling management across administrative boundaries, adaptive management, and stakeholder engagement (DeFries & Nagendra, 2017).

Institutional fit and interplay

Following previous works (Moss & Newig, 2010; Vatn & Vedeld, 2012; Young, 2002), we assume that a fit between the characteristics of governance and the biophysical system is essential for addressing environmental problems. Ensuring alignment between governance structure and the biophysical system is likely to result not only in better governance performance but also in resilient governance in relation to external shocks and disturbances (Vatn & Vedeld, 2012). Conversely, a misfit between governance solutions and environmental problems has been argued to cause the failure of governance blueprints in effectively addressing problems (Epstein et al., 2015; Young, 2002).

To capture the degree of fit, we rely on the literature, which mainly distinguishes between three types of fit: temporal (fit between the rate of environmental changes and the institutional capacity to respond), functional (fit between the functional linkages of the natural system), and spatial (fit between the geographic scopes of ecological issues and institutions) (Epstein et al., 2015; Vatn & Vedeld, 2012). We consider cases as misfit when institutional measures are either too localized or too broad to effectively address the problem (spatial misfit) or when governance results in a lag between biophysical processes and institutional responses, as well as a lag between the cause and symptoms of environmental problems (temporal misfit) (Epstein et al., 2015). Misfit can also occur when parts of the ecological system are managed independently, irrespective of interconnectedness and feedback mechanisms (functional misfit) (Epstein et al., 2015).

In line with Young (1999), we assume that the success of institutions depends not only on their own features but also on their interactions with each other. Interplay is characterized by interactions among institutions within a single societal level (horizontal interplay) as well as interactions between levels (vertical interplay) (Moss & Newig, 2010; Young, 2002). We assess the degree of interplay by examining both of these aspects. Institutional fit and interplay are not separate but rather interlinked. Since most resources have vertical links both upward and downward to systems of larger or smaller scales and horizontal effects on other resources at a similar spatial level (Brondizio et al., 2009), interplay becomes an important aspect of governing complex ecological systems. For example, it is argued that the effectiveness of institutions on a basin scale depends on good institutional interplay—coordination across levels and sectors (Moss, 2012). To this end, we hypothesize that having institutional fit without proper interplay may result in poor sustainability performance.

Governance capacity, structure, and stakeholder involvement

Capacity is argued to be an important factor for effective policy making and implementation within a water governance context (e.g., Hegga et al. 2020, Li et al. 2021, Yousefi et al. 2024). It can be understood as the ability of individuals, groups, or organizations to fulfill their responsibilities, determined by both capabilities and resources within a given framework (Franks, 1999). In this study, we assume a positive impact of capacity on the successful sustainability performance. We also expect capacity to play an important role in the effectiveness of the other characteristics, such as decentralization, participation, and adaptiveness, which will be explained below.

Decentralization has been heavily promoted as a blueprint by donor agencies, governments, and policymakers. For example, Integrated Water Resources Management (IWRM), integrated into the 2030 Agenda, highlights decentralization as one of its core principles. Decentralization refers to devolving power from higher levels to actors and institutions at lower levels within a political, administrative, and territorial hierarchy (Agrawal & Ribot, 1999). Centralized decision-making, which disregards local conditions, is argued to result in weak accountability and inadequate water resource management (Blomquist et al., 2005). In contrast, decentralization is theorized to enhance resource allocation, efficiency, accountability, and equity by aligning costs and benefits closely with local governments that understand local needs better than centralized governments (Larson & Soto, 2008). We capture decentralization by assessing the degree of decision-making power devolution to the lower levels of government.

Although it seems straightforward in theory, decentralization is a complex process that may not work as expected or may take longer than anticipated to yield benefits (Larson & Soto, 2008; Meijerink & Huitema, 2015). Once a decentralized system is in place, two major factors can significantly undermine its effectiveness. One of these factors is the lack of coordination, which can occur across levels and scales or among existing institutions (resulting from institutional bricolage and leading to the duplication of efforts) (Meijerink & Huitema, 2015). Another significant factor is poor capacity, which has been reported as a driving force behind the unsuccessful performance of decentralized governance. This occurs when roles and responsibilities are devolved to lower levels without providing them with adequate resources, such as financial and human resources, technical expertise, and knowledge (Hegga et al., 2020; Meijerink & Huitema, 2015). Building on the arguments of Meijerink and Huitema (2015), we refrain from hypothesizing any positive or negative impact of decentralization on sustainability performance, as the interplay and capacity within the system determines its effectiveness.

Granting decision-making power to not only the local state actors but also the non-state actors has been argued as key to better environmental outcomes (e.g., Koontz and Thomas 2006, Dietz and Stern 2008, Newig and Fritsch 2009, Jager et al. 2020). As opposed to top-down decision-making, participation allows for the integration of diverse values and sources of knowledge and is expected to result in more creative solutions, thus serving the common good rather than particular interests (Newig et al., 2023). Many scholars emphasize the importance of inclusivity in designing effective governance strategies for addressing complex problems, which enables enhanced knowledge, exploration of uncertainties, and accommodation of diverse values and perspectives (Head, 2022a). However, having participation in place does not guarantee success, as its design plays a decisive role. The recent study by Newig et al. (2023) concludes that the degree of power delegation—the extent to which participants can shape the decisions—strongly predicts better environmental outputs. To this end, we assume a positive impact of participation on sustainability performance and capture participation by assessing the degree of power delegation to non-state actors.

Granting decision-making power to local state actors and non-state actors has been argued as key to achieving better environmental outcomes (e.g., Koontz and Thomas 2006, Dietz and Stern 2008, Newig and Fritsch 2009, Jager et al. 2020). In contrast to top-down decision-making, participation allows for the integration of diverse values and sources of knowledge and is expected to result in more creative solutions, thus serving the common good rather than particular interests (Newig et al., 2023). Many scholars emphasize the importance of inclusivity in designing effective governance strategies for addressing complex problems, enabling enhanced knowledge exploration of uncertainties, and accommodating diverse values and perspectives (Head, 2022a). However, having participation in place does not guarantee success, as its design plays a decisive role. Consequently, we assume a positive impact of participation on sustainability performance and capture participation by assessing the degree of power delegation to non-state actors. We also expect to find capacity where we observe participation, as capacity is argued to be one of the factors playing a role in collaborative environmental management. Partnerships are more likely to form where institutions can cover the initial transaction costs associated with the process (Sabatier et al., 2005).

Adaptiveness/Knowledge integration

Following the existing literature (Akamani, 2016; Boyd & Folke, 2012; Clarvis et al., 2014; Duit & Galaz, 2008), we assume that addressing abrupt changes and uncertainties in complex water systems necessitates adaptive governance that is flexible and learning-based. Knowledge and learning play integral roles in adaptive governance (Karpouzoglou et al., 2016), which is essential for reorganization following changes and for designing strategies to navigate uncertainties and surprises (Folke et al., 2005). It is suggested that drawing from various knowledge sources—including local, traditional, scientific, and expert knowledge—relevant to the problem-solving process is important for managing and governance complex adaptive systems (Armitage et al., 2009; Folke, 2004; McLain & Lee, 1996). In line with the arguments above, we capture adaptiveness/knowledge integration by assessing (1) the degree of flexibility in decision-making, which is the ability of governing systems to adjust, revise, or change decisions in response to new information (i.e., monitoring of policy effects) and changing or unexpected conditions, (2) the use of the best available knowledge and evidence, and (3) the use of local or indigenous knowledge**.** We anticipate that adaptiveness/knowledge integration will positively impact sustainability performance, depending on the availability of the capacity required for adaptive management, as noted by DeFries and Nagendra (2017), who highlight the resource-intensive and time-consuming nature of monitoring systems.

METHODS

Data

This paper draws on cases identified in a systematic literature review of empirical water governance studies (Bilalova et al., 2024). From an original dataset of 223 cases, only 160 provided relevant information on the problem context, or "problématique," which is the central focus of this study. Initially, we conducted a case survey, coding cases falling within the "Groundwater exploitation for agriculture" and "Surface water pollution" problématiques (86 cases in total). The case survey method allowed for identifying and analyzing patterns across cases by converting qualitative narratives into quantified variables (Jensen & Rodgers, 2001). With a significant share of missing data points (36%) in our initial dataset and considering the limitations of Qualitative Comparative Analysis (QCA) in handling missing data, we selected the 20 most data-complete cases from each problématique. Missing data for these cases were filled in using expert surveys for 11 cases and additional case-based literature for the remaining 20, with one case still lacking data. This process addressed missing data for 30 cases, resulting in a total of 40 cases—a number deemed sufficient for conducting QCA within our current capacity and resources. Notably, three of these cases had mixed sustainability performance, where governance intervention succeeded in addressing one issue but failed in addressing another. Therefore, we coded each outcome as a separate case, following previous studies that employed a similar approach (Villamayor-Tomas, Oberlack, et al., 2020). In total, our final dataset included 43 cases stemming from five different continents and a variety of settings (see Table A1.1 in the Online Supplementary Material for more detail) (Bilalova et al., 2024).

Method

Following previous governance pathway studies (Knieper & Pahl-Wostl, 2016; Vallury et al., 2022; Villamayor-Tomas, Iniesta-Arandia, et al., 2020), we employed Qualitative Comparative Analysis (QCA) (Ragin, 2008) to identify associations between bundles of governance characteristics and successful sustainability performance. This analysis was conducted using the QCA (Duşa, 2019) and SetMethods (I. E. Oana & Schneider, 2018) packages in R. Grounded in Boolean algebra and its fuzzy set extension, QCA is a set-theoretic method that proves highly instrumental in investigating cause-effect relationships (Gary & Mahoney, 2012; I.-E. Oana et al., 2021). It enables the systematic comparison of cases, ranging from small to large N (Greckhamer et al. 2013, Oana et al. 2021). QCA allows for exploring causal complexities between conditions and outcomes, including equifinal, conjunctural, and asymmetric causality, which can be interpreted in terms of necessity and sufficiency (Oana et al. 2021). Necessary conditions are those that are always present for the outcome to occur (a superset of the outcome), while sufficient conditions are those present when the outcome occurs, but the outcome can also occur without them (a subset of the outcome) (I.-E. Oana et al., 2021; Schneider & Wagemann, 2010, 2012). The consideration of multi-causal pathways inherent within QCA aligns well with our research objective, as we assume the existence of diverse pathways leading to successful sustainability performance.

In this study, we utilize the fuzzy set version of QCA (fsQCA), which permits researchers to assign partial membership scores ranging from 0 (indicating non-membership) to 1 (representing full membership) (Ragin, 2008). These scores indicate the extent to which different cases belong to a set, with the crossover point (0.5) signifying maximum ambiguity or fuzziness in determining whether a case is more in or out of a set (Rihoux & Ragin, 2012). Establishing these qualitative anchors requires a robust foundation of theoretical and empirical knowledge (Rihoux & Ragin, 2012; Schneider & Wagemann, 2010). A critical analytical tool within QCA, the truth table, illustrates all logically possible configurations of conditions. Through minimization, the truth table facilitates identifying the shortest path sufficient for the outcome by eliminating irrelevant or redundant conditions (I.-E. Oana et al., 2021).

Outcome and conditions

The outcome was measured as either success (1) or failure (0). A case was deemed successful if the governance intervention improved the sustainable use of water resources and the well-being of freshwater ecosystems. One successful case is illustrated in the study by Montero et al. (2006), which outlines how an inter-municipal initiative addressed pollution in the Ayuquila River in Mexico, reducing pollution levels from industries and urban areas. In failure cases, governance interventions either failed to address the problem or exacerbated water-related environmental issues. For instance, Rinaudo and Donoso (2019) describe how governance contributed to groundwater depletion in the Copiapó Valley in Chile. Our dataset comprises 18 success cases, accounting for 42% of all cases.

Our selection of conditions aligns with the theoretical framework outlined above. Regarding problématiques, we rely on the study by Bilalova et al. (*unpublished manuscript*), which identified five water-related problématiques: “groundwater exploitation in agriculture,” “land and water systems sustainability,” “surface water pollution,” “industrial and household water security,” and “hydropower vs. water ecology” based on the archetype analysis of water resources, their uses, and related sustainability issues. In this study, we only focus on “groundwater exploitation” and “surface water pollution,” which encompass cases dealing with the water quantity aspects of agricultural groundwater withdrawal and cases addressing water quality issues resulting from the discharge of pollutants into surface water resources, respectively (Bilalova et al., *unpublished manuscript*). These problématiques were chosen for their representation of a significant number of cases and the diverse nature of problem contexts they encompass. Groundwater exploitation represents a hidden and complex issue, often requiring a longer timeframe to observe its impacts fully. Meanwhile, surface water pollution presents a multifaceted challenge varying in complexity and ease of resolution, influenced by factors such as the scale of pollution and the involvement of different actors with diverging interests.

Given that QCA suggests a range of three to seven conditions due to problems of theoretical interpretation and limited diversity (I.-E. Oana et al., 2021), we constructed compound variables for fit, interplay, and adaptiveness/knowledge integration, respectively. Fit comprised three variables: spatial, temporal, and functional fit; interplay consisted of two variables, vertical and horizontal interplay; and adaptiveness/knowledge integration included three variables: flexibility in decision-making, use of evidence, and knowledge integration. In line with Langhans et al. (2014), we aggregated the different components of these variables using an additive-minimum aggregation method, with equal weight from both the minimum and arithmetic aggregations. This method is useful as it combines the strengths of the two methods while ensuring that extreme values do not overly influence the aggregation. These conditions are measured on a scale from 0 to 1, where 0 indicates the absence of the condition, 1 signifies its complete presence, and values in between represent varying degrees of the condition (see Table A1.2 in Appendix 1). We primarily calibrated the raw data using direct calibration, employing a logistic function to align the raw data with three qualitative anchors (Schneider & Wagemann, 2012). We used indirect calibration for participation since the raw data corresponded to initial set-membership scores. Our anchor points were determined by examining the distribution of each variable to identify naturally occurring clusters and drawing on conceptual and empirical insights (Duşa, 2019). As part of calibration diagnostics (I.-E. Oana et al., 2021), we examined the calibrated sets for ambiguous cases (cases located at crossover points) and skewness (where less than 20 percent of the cases are either more "in" or more "out" than the calibrated set). For the analysis, we followed the standards of good practice suggested by Schneider and Wagemann (2010) and their protocol for the enhanced standard analysis (Schneider & Wagemann, 2013).

Following the robustness test protocol by Oana and Schneider (2024), we conducted a series of tests, including sensitivity ranges, fit-oriented assessments, and case-oriented robustness tests. These results are detailed in the Appendix 2, including the calibrated dataset.

RESULTS

The necessity analysis shows that capacity (CAP) is the only condition that comes close to the conventional consistency threshold of 0.9 (Schneider & Wagemann, 2012) with a value of 0.89 and a high RoN (0.852). None of the conditions are necessary for the negated outcome (failed sustainability performance). More details can be found in Appendix 2.

Regarding the sufficiency analysis, we focus on presenting and discussing the intermediate solution. This solution includes only simplifying assumptions that represent easy counterfactuals, aligning with the researcher's directional expectations on how the conditions contribute to the outcome (I.-E. Oana et al., 2021). Following the theoretical framework presented above, we set the anticipated impact for all governance-related conditions as positive, except for decentralization (DECEN), which may have positive or negative effects on the outcome (Table A1.2 in Appendix 1). The results of the conservative and most parsimonious solutions, along with the truth tables for both the outcome and the negated outcome, can be found in Appendix 2.

Table 2 presents the solutions leading to successful sustainability performance. The literature recommends 0.75-0.80 as the lower bound of consistency for sufficiency (I.-E. Oana et al., 2021; Ragin, 2008; Schneider & Wagemann, 2012). The findings reveal three solutions that result in successful sustainability performance, with an overall consistency of 0.97. The overall solution coverage is 0.59, suggesting that our solution explains the positive outcome for a large share of those cases that also display it. The solutions explain 12 out of the 18 cases with a positive outcome, while the remaining two did not meet the set threshold. This is not unusual, as some success cases may not align with the identified configurations, or other dynamics may be at play that are outside the focus of this study. Notably, we did not identify any fundamentally deviant cases, i.e., cases that contradict the sufficiency statement—being a member of the solution but not a member of the outcome (Nair & Gibbert, 2016).

Table 1 Intermediate solution for successful water-related sustainability performance (consistency threshold 0.80).

Solutions	Consistency	PRI	Raw cov.	Unique cov.	No. of cases[2]
(1) CAP*~DECEN*~P1	1.000	1.000	0.111	0.093	2
(2) CAP*INTER*PART*ADAPT/KNOW*~P1	1.000	1.000	0.241	0.038	5
(3) CAP*FIT*INTER*DECEN*PART* ADAPT/KNOW	0.965	0.965	0.442	0.257	9 (4 cases overlap with the second solution)
Overall solution consistency			0.974		
Overall solution coverage			0.591		
Overall PRI			0.974		

*Note: * denotes a logical AND, + a logical OR; ~ symbolizes the absence of the given condition.*

The analysis reveals two solutions specific to surface water pollution (~P1) and one generic solution covering both issues. None of the solutions are specific to groundwater exploitation in agriculture. One of the solutions specific to surface water pollution—solution 1 (CAP*~DECEN*~P1)—encompasses cases characterized by the absence or a lower degree of decentralization (~DECEN) and the presence of governance capacity (CAP), leading to successful sustainability performance (OUT) in cases of surface water pollution (~P1). Compared to the other two solutions, this solution has a lower coverage (0.11) and is observed in only two cases. One of the two cases with this solution is the case of Tlaxcala in Mexico, where water treatment policy reforms within a hierarchical governance system with enough financing and low municipal participation have proven successful in terms of the percentage of treated water (Flores et al., 2016).

Another solution that leads to successful sustainability performance in the case of surface water pollution is solution 2 (CAP*INTER*PART*ADAPT/KNOW*~P1). Similar to the previous path, the presence of capacity is one of the important conditions. In addition, cases in this solution are characterized by a high degree of interplay (INTER), participation (PART), and adaptation/knowledge integration (ADAPT/KNOW). One example of a typical case with this

[2] While the analysis primarily focuses on identifying configurations leading to successful sustainability performance, it also incorporates failure cases in calibrating conditions, constructing the truth table, and assessing the reliability of identified configuration.

solution is the St. Lawrence River Action Plan in Canada, which resulted in the cleanup of the river from pollutants and the protection of its ecosystem (Villeneuve et al., 2006). The case is characterized by a collaborative effort involving government actors across levels and sectors, as well as non-state actors, including communities (Villeneuve et al., 2006). The action plan had substantial financial and technical support, including for the community involved. Finally, in terms of adaptiveness, the decision-making involved both scientific (more prominent in Phase II) and local knowledge (especially in Phase III) and was flexible as the planning of the phases was shaped by reflections (Villeneuve et al., 2006).

The third solution (CAP*FIT*INTER*DECEN*PART*ADAPT/KNOW) is independent of any problématique and encompasses cases of both "groundwater exploitation for agriculture" and "surface water pollution." A closer examination of the cases within this solution reveals that those involving "groundwater exploitation for agriculture" and "surface water pollution" have almost an equal share, with a slight dominance of "groundwater exploitation for agriculture" (5 cases compared to 4). Successful sustainability performance within this solution results from the presence of governance capacity (CAP) and a higher degree of fit (FIT), interplay (INTER), decentralization (DECEN), and adaptation/knowledge integration (ADAPT/KNOW). This solution has comparatively lower consistency (0.97) but the highest coverage (0.44).

An example of a typical case within this solution is a pilot project in Tuppal Creek (an intermittent stream) in the Murray Darling Basin, Australia. The project was based on participatory decision-making involving stakeholders from government bodies (across levels and sectors) and non-state actors. It was initiated by the Tuppal Creek Landholder Group (TCLG) and the former Murray Catchment Management Authority. The project aimed to be adaptive with flexible management objectives, monitoring, research informing the process, and learning through implementation ("learning by doing"). Decision-making integrated both scientific and local knowledge. Finally, the project was designed in accordance with the ecological system of Tuppal Creek, aligning spatially, temporally, and functionally with its ecosystem (Conallin et al., 2018).

Finally, comparing the solutions for the outcome and negated outcome also provides some insights that can be relevant (see Table A2.9 in Appendix 2). First, the role of capacity has been observed among the solutions to failed sustainability performance, as its absence is noted in most solutions, except for the solution where the absence of fit and interplay with the decentralized system leads to groundwater depletion due to agricultural activities.

Taken together with its high prevalence in the solutions for the positive outcome and its high scores in the necessity tests, an overall picture emerges where capacities can be considered a necessary condition for achieving high sustainability performance. Examining the generic solutions applicable to both problématiques, we observe that capacity (CAP), fit (FIT), and interplay (INTER) are important conditions. Their presence, together with other conditions, leads to successful sustainability performance. Contrarily, their absence, coupled with decentralization being present or participation and adaptation/knowledge integration being absent, leads to failed sustainability performance.

DISCUSSION

Our results empirically contribute to the literature linking the nature of the problem with governance measures (e.g., Peters 2005, DeFries and Nagendra 2017, Hoornbeek and Peters

2017). Firstly, we identified two successful governance pathways specific to surface water pollution, and none specific to groundwater exploitation in agriculture. Groundwater systems are complex and multifaceted (Closas & Villholth, 2020), making it challenging to identify a governance pathway that consistently leads to successful sustainability performance. Groundwater-related problems involve multiple stakeholders with competing interests, making decision-making processes particularly convoluted (Barreteau et al., 2016). Additionally, the invisibility of groundwater makes it challenging to characterize, monitor, and understand the groundwater systems, often resulting in problems going unnoticed until it is too late to reverse the process (Barreteau et al., 2016; Hoogesteger, 2022). Moreover, actors may have diverging perspectives about the severity of problems and effective responses (Fallon et al., 2021).

Our analysis also shows notable differences between the two successful governance pathways specific to surface water pollution. While one governance pathway demonstrates a more straightforward approach with centralized governance and sufficient capacity, the other pathway is characterized by a more intricate combination of factors, including higher interplay, non-state actor participation, adaptation/knowledge integration, and adequate capacity. Qualitative analysis of the cases corresponding to each solution finds alignments with the characteristics of the pollution problem observed. In the case of the Tlaxcala Atoyac sub-basin, which corresponds to the first solution, the main problem targeted was municipal wastewater, which was addressed by building wastewater treatment plants (Flores et al., 2016). Contrarily, the pollution of the St. Lawrence River was linked to multiple sources (including industrial, municipal, and agricultural) concerning governments (Canada and Quebec) and impacted not only the river ecosystem but also wildlife and plant habitats, which required more nuanced and comprehensive intervention (Villeneuve et al., 2006).

Another consistent finding is the consistent presence of governance capacity across all three successful governance pathways. Capacity also stands out in the necessity analysis for successful sustainability performance, overall qualifying it as a necessary condition. These observations support the assumptions outlined in the theoretical framework regarding the important role of capacity and its positive impact on other conditions. Without adequate capacity, strategies effective in one context may not yield success in another (Hegga et al., 2020).

Finally, our study confirms that there is no easy solution or panacea to ensuring water-related sustainability (see Meinzen-Dick 2007, Ostrom 2007). Most conditions included in our study have been prescribed by international organizations and policymakers for effective water governance (Gupta & Pahl-Wostl, 2013; Huitema & Meijerink, 2017; Meijerink & Huitema, 2015; Woodhouse & Muller, 2017). Despite success stories, a substantial body of literature reports a variety of “failures” in various contexts (e.g., Benson et al. 2014, Meijerink and Huitema 2017, Hegga et al. 2020). Our findings suggest that success is not solely reliant on a single condition or governance paradigm (e.g., decentralization vs. adaptive capacity), but rather on the interplay and mutual reinforcement of various conditions. Each condition, as discussed in our theoretical framework, contributes to effective water governance, although none alone ensures success. For instance, capacity influences adaptiveness, decentralization, and participation, while interplay is crucial for achieving a successful fit. This underscores the importance of understanding the synergies and trade-offs among different governance characteristics. This emphasizes the need for a nuanced understanding of potential synergies and trade-offs among various governance characteristics.

Our study has some limitations that shall be addressed in future studies. One of the limitations is that we only look at two problem contexts—"groundwater extraction for agriculture" and "surface water pollution." Future research can expand this analysis to other problem contexts, such as "land and water systems," "household and industrial water security," and "hydropower vs. water ecology," to better understand the role of a problem context and to examine whether the results of this study are also observed in those problem contexts. Another limitation is that this study only presents the types of governance pathways for successful sustainability performance, without exploring their underlying causal interactions. More attention may be needed to the detailed causal interactions between conditions. Interactions within these successful governance pathways and between conditions and their causal link to successful performance could be further investigated in future studies by conducting in-depth analyses or process tracing.

CONCLUSION

This study aimed to examine water governance cases to identify the governance pathways that lead to successful sustainability performance in relation to the problem they address. Conducting fsQCA analysis on 43 water governance cases with the problem contexts of groundwater exploitation for agriculture and surface water pollution reveals three key findings. First, our results reveal the linkage between the nature of a problem context and successful water governance pathways. Second, governance capacity emerges as a determining factor for the effectiveness of the governance pathways and, ultimately, successful sustainability performance, as evidenced in the necessity analysis and all three solutions to successful sustainability performance. Finally, the findings substantiate that there is no easy solution to address water-related problems, as conditions reinforce each other rather than being sufficient by themselves.

Overall, these findings contribute to enhancing our understanding of successful water governance for water-related sustainability, including the nexus between problem context, governance design, and successful water-related sustainability performance. The results show that aligning problem context with the governance design can allow policymakers to enhance the effectiveness of their policies. Furthermore, the importance of capacity emphasizes the need for contextual considerations when transferring and implementing governance approaches. Finally, a governance structure that effectively addresses various problems comes with no easy solution, necessitating a holistic approach to crafting institutions. Designing effective governance pathways would benefit from considering how different governance characteristics interact with each other rather than focusing on particular aspects in isolation.

AUTHOR CONTRIBUTIONS

Shahana Bilalova: conceptualization, data curation, methodology, formal analysis, investigation, visualization, writing – original draft, writing – reviewing and editing. **Nicolas W. Jager:** methodology, investigation, writing – review & editing. **Jens Newig:** conceptualization, writing–review & editing, supervision. **Sergio Villamayor-Tomas:** conceptualization, writing–review & editing, supervision.

ACKNOWLEDGEMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 861509 - NEWAVE.

DATA AVAILABILITY STATEMENT

The datasets generated and/or analyzed during the current study will be available after the paper published in the Leuphana University repository, https://doi.org/10.48548/pubdata-236.

LITERATURE CITED

Agrawal, A., & Ribot, J. (1999). Accountability in Decentralization: A Framework with South Asian and West African Cases. *The Journal of Developing Areas*, *33*(4), 473–502. http://www.jstor.org/stable/4192885

Akamani, K. (2016). Adaptive Water Governance: Integrating the Human Dimensions into Water Resource Governance. *Journal of Contemporary Water Research & Education*, *158*(1), 2–18. https://doi.org/10.1111/j.1936-704X.2016.03215.x

Armitage, D. R., Plummer, R., Berkes, F., Arthur, R. I., Charles, A. T., Davidson-Hunt, I. J., Diduck, A. P., Doubleday, N. C., Johnson, D. S., Marschke, M., McConney, P., Pinkerton, E. W., & Wollenberg, E. K. (2009). Adaptive Co-Management for Social-Ecological Complexity. *Frontiers in Ecology and the Environment*, *7*(2), 95–102. http://www.jstor.org/stable/25595062

Barreteau, O., Caballero, Y., Hamilton, S., Jakeman, A. J., & Rinaudo, J.-D. (2016). Disentangling the Complexity of Groundwater Dependent Social-ecological Systems. In *Integrated Groundwater Management* (pp. 49–73). Springer International Publishing. https://doi.org/10.1007/978-3-319-23576-9_3

Benson, D., Fritsch, O., Cook, H., & Schmid, M. (2014). Evaluating participation in WFD river basin management in England and Wales: Processes, communities, outputs and outcomes. *Land Use Policy*, *38*, 213–222. https://doi.org/10.1016/j.landusepol.2013.11.004

Bilalova, S., Newig, J., & Villamayor-Tomas, S. (2024). *Water governance and sustainability outcomes: dataset from systematic review of 165 empirical water governance research articles*. https://doi.org/10.48548/pubdata-235

Biswas, A. K. (2008). Integrated water resources management: Is it working? *International Journal of Water Resources Development*, *24*(1), 5–22. https://doi.org/10.1080/07900620701871718

Blomquist, W., Diez, M., Dinar, A., Fru, W., Kemper, K., & Sine, G. (2005). *Decentralization Of River Basin Management : A Global Analysis*. The World Bank. https://doi.org/10.1596/1813-9450-3637

Boyd, E., & Folke, C. (2012). *Adapting Institutions: Governance, Complexity and Social Ecological Resilience*. Cambridge University Press.

Brondizio, E. S., Ostrom, E., & Young, O. R. (2009). Connectivity and the Governance of Multilevel Social-Ecological Systems: The Role of Social Capital. *Annual Review of Environment and Resources*, *34*(1), 253–278. https://doi.org/10.1146/annurev.environ.020708.100707

Clarvis, M. H., Fatichi, S., Allan, A., Fuhrer, J., Stoffel, M., Romerio, F., Gaudard, L., Burlando, P., Beniston, M., Xoplaki, E., & Toreti, A. (2014). Governing and managing

water resources under changing hydro-climatic contexts: The case of the upper Rhone basin. *Environmental Science & Policy*, *43*, 56–67. https://doi.org/10.1016/j.envsci.2013.11.005
Closas, A., & Villholth, K. G. (2020). Groundwater governance: Addressing core concepts and challenges. *WIREs Water*, *7*(1). https://doi.org/10.1002/wat2.1392
Conallin, J., Wilson, E., & Campbell, J. (2018). Implementation of Environmental Flows for Intermittent River Systems: Adaptive Management and Stakeholder Participation Facilitate Implementation. *Environmental Management*, *61*(3), 497–505. https://doi.org/10.1007/s00267-017-0922-4
DeFries, R., & Nagendra, H. (2017). Ecosystem management as a wicked problem. *Science*, *356*(6335), 265–270. https://doi.org/10.1126/science.aal1950
Dietz, T., & Stern, P. C. (2008). Public participation in environmental assessment and decision making. In T. Dietz & P. C. Stern (Eds.), *Public Participation in Environmental Assessment and Decision Making*. The National Academies Press. https://doi.org/10.17226/12434
Duit, A., & Galaz, V. (2008). Governance and Complexity—Emerging Issues for Governance Theory. *Governance*, *21*(3), 311–335. https://doi.org/10.1111/j.1468-0491.2008.00402.x
Duşa, A. (2019). *QCA with R*. Springer International Publishing. https://doi.org/10.1007/978-3-319-75668-4
Epstein, G., Pittman, J., Alexander, S. M., Berdej, S., Dyck, T., Kreitmair, U., Raithwell, K. J., Villamayor-Tomas, S., Vogt, J., & Armitage, D. (2015). Institutional fit and the sustainability of social-ecological systems. *Current Opinion in Environmental Sustainability*, *14*, 34–40. https://doi.org/10.1016/j.cosust.2015.03.005
Fallon, A. L., Lankford, B. A., & Weston, D. (2021). Navigating wicked water governance in the “solutionscape” of science, policy, practice, and participation. *Ecology and Society*, *26*(2). https://doi.org/10.5751/ES-12504-260237
Flores, C. C., Vikolainen, V., & Bressers, H. (2016). Water governance decentralisation and river basin management reforms in hierarchical systems: Do they work for water treatment policy in Mexico’s Tlaxcala Atoyac sub-basin? *Water (Switzerland)*, *8*(5). https://doi.org/10.3390/w8050210
Folke, C. (2004). Traditional knowledge in social–ecological systems. *Ecology and Society*, *9*(3).
Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). Adaptive governance of social-ecological systems. In *Annual Review of Environment and Resources* (Vol. 30, pp. 441–473). https://doi.org/10.1146/annurev.energy.30.050504.144511
Franks, T. (1999). Capacity building and institutional development: reflections on water. *Public Administration and Development*, *19*(1), 51–61. https://doi.org/10.1002/(SICI)1099-162X(199902)19:1<51::AID-PAD54>3.0.CO;2-N
Garrick, D. E., Schlager, E., De Stefano, L., & Villamayor-Tomas, S. (2018). Managing the Cascading Risks of Droughts: Institutional Adaptation in Transboundary River Basins. *Earth’s Future*, *6*(6), 809–827. https://doi.org/10.1002/2018EF000823
Gary, G., & Mahoney, J. (2012). A tale of two cultures: Qualitative and quantitative research in the social sciences. In *Cross Channel Currents: 100 Years of the Entente Cordiale*. Princeton University Press. https://doi.org/10.4018/jep.2013040104
Greckhamer, T., Misangyi, V. F., & Fiss, P. C. (2013). The Two QCAs: From a Small-N to a Large-N Set Theoretic Approach. In *Configurational Theory and Methods in Organizational Research* (pp. 49–75). https://doi.org/10.1108/S0733-558X(2013)0000038007
Gupta, J., & Pahl-Wostl, C. (2013). Global water governance in the context of global and

multilevel governance: Its need, form, and challenges. *Ecology and Society*, *18*(4). https://doi.org/10.5751/ES-05952-180453

Head, B. W. (2022a). Managing Environmental and Sustainability Challenges. In *Wicked Problems in Public Policy* (pp. 83–106). Springer International Publishing. https://doi.org/10.1007/978-3-030-94580-0_5

Head, B. W. (2022b). The Rise of 'Wicked Problems'—Uncertainty, Complexity and Divergence. In *Wicked Problems in Public Policy* (pp. 21–36). Springer International Publishing. https://doi.org/10.1007/978-3-030-94580-0_2

Hegga, S., Kunamwene, I., & Ziervogel, G. (2020). Local participation in decentralized water governance: insights from north-central Namibia. *Regional Environmental Change*, *20*(3), 105. https://doi.org/10.1007/s10113-020-01674-x

Homsy, G. C., Liu, Z., & Warner, M. E. (2019). Multilevel Governance: Framing the Integration of Top-Down and Bottom-Up Policymaking. *International Journal of Public Administration*, *42*(7), 572–582. https://doi.org/10.1080/01900692.2018.1491597

Hoogesteger, J. (2022). Regulating agricultural groundwater use in arid and semi-arid regions of the Global South: Challenges and socio-environmental impacts. *Current Opinion in Environmental Science & Health*, *27*, 100341. https://doi.org/10.1016/j.coesh.2022.100341

Hoornbeek, J. A., & Peters, B. G. (2017). Understanding policy problems: a refinement of past work. *Policy and Society*, *36*(3), 365–384. https://doi.org/10.1080/14494035.2017.1361631

Huitema, D., & Meijerink, S. (2017). The politics of river basin organizations: Institutional design choices, coalitions, and consequences. *Ecology and Society*, *22*(2). https://doi.org/10.5751/ES-09409-220242

Ingram, H. (2011). Beyond universal remedies for good water governance: a political and contextual approach. In A. Garrido & H. Ingram (Eds.), *Water for Food in a Changing World* (p. 21). Routledge. https://doi.org/10.4324/9780203828410

Jager, N. W., Newig, J., Challies, E., & Kochskämper, E. (2020). Pathways to Implementation: Evidence on How Participation in Environmental Governance Impacts on Environmental Outcomes. *Journal of Public Administration Research and Theory*, *30*(3), 383–399. https://doi.org/10.1093/jopart/muz034

Jensen, J. L., & Rodgers, R. (2001). Cumulating the Intellectual Gold of Case Study Research. *Public Administration Review*, *61*(2), 235–246. https://doi.org/10.1111/0033-3352.00025

Karpouzoglou, T., Dewulf, A., & Clark, J. (2016). Advancing adaptive governance of social-ecological systems through theoretical multiplicity. In *Environmental Science and Policy* (Vol. 57, pp. 1–9). Elsevier Ltd. https://doi.org/10.1016/j.envsci.2015.11.011

Kirschke, S., Franke, C., Newig, J., & Borchardt, D. (2019). Clusters of water governance problems and their effects on policy delivery. *Policy and Society*, *38*(2), 255–277. https://doi.org/10.1080/14494035.2019.1586081

Kirschke, S., Newig, J., Völker, J., & Borchardt, D. (2017). Does problem complexity matter for environmental policy delivery? How public authorities address problems of water governance. *Journal of Environmental Management*, *196*, 1–7. https://doi.org/10.1016/j.jenvman.2017.02.068

Knieper, C., & Pahl-Wostl, C. (2016). A Comparative Analysis of Water Governance, Water Management, and Environmental Performance in River Basins. *Water Resources Management*, *30*(7), 2161–2177. https://doi.org/10.1007/s11269-016-1276-z

Koontz, T. M., & Thomas, C. W. (2006). What Do We Know and Need to Know about the Environmental Outcomes of Collaborative Management? *Public Administration Review*, *66*(s1), 111–121. https://doi.org/10.1111/j.1540-6210.2006.00671.x

Langhans, S. D., Reichert, P., & Schuwirth, N. (2014). The method matters: A guide for indicator aggregation in ecological assessments. *Ecological Indicators*, *45*, 494–507. https://doi.org/10.1016/j.ecolind.2014.05.014
Larson, A. M., & Soto, F. (2008). Decentralization of Natural Resource Governance Regimes. *Annual Review of Environment and Resources*, *33*(1), 213–239. https://doi.org/10.1146/annurev.environ.33.020607.095522
Li, W., von Eiff, D., & An, A. K. (2021). Analyzing the effects of institutional capacity on sustainable water governance. *Sustainability Science*, *16*(1), 169–181. https://doi.org/10.1007/s11625-020-00842-6
Lukat, E., Schoderer, M., & Castro Salvador, S. (2022). When international blueprints hit local realities: Bricolage processes in implementing IWRM in South Africa, Mongolia, and Peru. *Water Alternatives*, *15*(2), 473–500.
McLain, R. J., & Lee, R. G. (1996). Adaptive management: Promises and pitfalls. *Environmental Management*, *20*(4), 437–448. https://doi.org/10.1007/BF01474647
Meijerink, S., & Huitema, D. (2017). The institutional design, politics, and effects of a bioregional approach: Observations and lessons from 11 case studies of river basin organizations. *Ecology and Society*, *22*(2). https://doi.org/10.5751/ES-09388-220241
Meijerink, S. V, & Huitema, D. (2015). The Challenges and Pitfalls of Decentralisation in Water Resources Management. *Water Governance*, *5*(Ivm), 16–21. https://go.exlibris.link/0jz8c44L
Meinzen-Dick, R. (2007). Beyond panaceas in water institutions. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(39), 15200–15205. https://doi.org/10.1073/pnas.0702296104
Montero, S. G., Castellón, E. S., Rivera, L. M. M., Ruvalcaba, S. G., & Llamas, J. J. (2006). Collaborative governance for sustainable water resources management: The experience of the Inter-municipal Initiative for the Integrated Management of the Ayuquila River Basin, Mexico. *Environment and Urbanization*, *18*(2), 297–313. https://doi.org/10.1177/0956247806069602
Moss, T. (2012). Spatial fit, from panacea to practice: Implementing the EU water framework directive. *Ecology and Society*, *17*(3). https://doi.org/10.5751/ES-04821-170302
Moss, T., & Newig, J. (2010). Multilevel water governance and problems of scale: Setting the stage for a broader debate. In *Environmental Management* (Vol. 46, Issue 1, pp. 1–6). https://doi.org/10.1007/s00267-010-9531-1
Nair, L. B., & Gibbert, M. (2016). Analyzing inconsistent cases in Management fsQCA studies: A methodological manifesto. *Journal of Business Research*, *69*(4), 1464–1470. https://doi.org/10.1016/j.jbusres.2015.10.126
Newig, J., & Fritsch, O. (2009). More Input – Better Output: Does Citizen Involvement Improve Environmental Governance? In *In Search of Legitimacy: Policy Making in Europe and the Challenge of Complexity* (pp. 205–224). Verlag Barbara Budrich. https://doi.org/10.2307/j.ctvhktkhn.15
Newig, J., Jager, N. W., Challies, E., & Kochskämper, E. (2023). Does stakeholder participation improve environmental governance? Evidence from a meta-analysis of 305 case studies. *Global Environmental Change*, *82*, 102705. https://doi.org/10.1016/j.gloenvcha.2023.102705
Oana, I.-E., & Schneider, C. Q. (2024). A Robustness Test Protocol for Applied QCA: Theory and R Software Application. *Sociological Methods & Research*, *53*(1), 57–88. https://doi.org/10.1177/00491241211036158
Oana, I.-E., Schneider, C. Q., & Thomann, E. (2021). *Qualitative Comparative Analysis Using R*. Cambridge University Press. https://doi.org/10.1017/9781009006781
Oana, I. E., & Schneider, C. Q. (2018). SetMethods: An add-on R package for advanced

QCA. *R Journal*, *10*(1), 507–533. https://doi.org/10.32614/rj-2018-031
Ostrom, E. (2007). A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(39), 15181–15187. https://doi.org/10.1073/pnas.0702288104
Pahl-Wostl, C., Lebel, L., Knieper, C., & Nikitina, E. (2012). From applying panaceas to mastering complexity: Toward adaptive water governance in river basins. *Environmental Science and Policy*, *23*, 24–34. https://doi.org/10.1016/j.envsci.2012.07.014
Peters, G. B. (2005). The Problem of Policy Problems. *Journal of Comparative Policy Analysis: Research and Practice*, *7*(4), 349–370. https://doi.org/10.1080/13876980500319204
Ragin, C. C. (2008). *Redesigning Social Inquiry: Fuzzy Sets and Beyond*. University of Chicago Press. https://doi.org/10.7208/chicago/9780226702797.001.0001
Rihoux, B., & Ragin, C. (2012). Configurational Comparative Methods: Qualitative Comparative Analysis (QCA) and Related Techniques. *Configurational Comparative Methods: Qualitative Comparative Analysis (QCA) and Related Techniques*. https://doi.org/10.4135/9781452226569
Rinaudo, J. D., & Donoso, G. (2019). State, market or community failure? Untangling the determinants of groundwater depletion in Copiapó (Chile). *International Journal of Water Resources Development*, *35*(2), 283–304. https://doi.org/10.1080/07900627.2017.1417116
Ruhl, J. B. (2005). Regulation by Adaptive Management - is it Possible? *Minnesota Journal of Law, Science & Technology*, *7*(2005), 21–57. http://papers.ssrn.com/abstract=719501
Sabatier, P. A., Leach, W. D., Lubell, M., & Pelkey, N. W. (2005). Theoretical Frameworks Explaining Partnership Success. In *Swimming Upstream* (pp. 173–200). The MIT Press. https://doi.org/10.7551/mitpress/6577.003.0012
Schneider, C. Q., & Wagemann, C. (2010). Standards of Good Practice in Qualitative Comparative Analysis (QCA) and Fuzzy-Sets. *Comparative Sociology*, *9*(3), 397–418. https://doi.org/10.1163/156913210X12493538729793
Schneider, C. Q., & Wagemann, C. (2012). *Set-Theoretic Methods for the Social Sciences*. Cambridge University Press. https://doi.org/10.1017/CBO9781139004244
Schneider, C. Q., & Wagemann, C. (2013). Doing justice to logical remainders in QCA: Moving beyond the standard analysis. *Political Research Quarterly*, *66*(1), 211–220. https://doi.org/10.1177/1065912912468269h
Sehring, J. (2009). Path dependencies and institutional bricolage in post-Soviet water governance. *Water Alternatives*, *2*(1), 61–81.
Srinivasan, V., Lambin, E. F., Gorelick, S. M., Thompson, B. H., & Rozelle, S. (2012). The nature and causes of the global water crisis: Syndromes from a meta-analysis of coupled human-water studies. *Water Resources Research*, *48*(10), 1–16. https://doi.org/10.1029/2011WR011087
Taylor, P. L., & Sonnenfeld, D. A. (2019). *Water crises and governance: Reinventing collaborative institutions in an era of uncertainty*. Routledge.
Thomann, E., Trein, P., & Maggetti, M. (2019). What's the Problem? Multilevel Governance and Problem-Solving. *European Policy Analysis*, *5*(1), 37–57. https://doi.org/10.1002/epa2.1062
Tropp, H. (2007). Water governance: trends and needs for new capacity development. *Water Policy*, *9*(S2), 19–30. https://doi.org/10.2166/wp.2007.137
Vallury, S., Shin, H. C., Janssen, M. A., Meinzen-Dick, R., Kandikuppa, S., Rao, K. R., & Chaturvedi, R. (2022). Assessing the institutional foundations of adaptive water governance in South India. *Ecology and Society*, *27*(1). https://doi.org/10.5751/ES-

12957-270118
van Buuren, A., van Meerkerk, I., & Tortajada, C. (2019). Understanding emergent participation practices in water governance. *International Journal of Water Resources Development*, *35*(3), 367–382. https://doi.org/10.1080/07900627.2019.1585764
Varady, R. G., Zuniga-Teran, A. A., Gerlak, A. K., & Megdal, S. B. (2016). Modes and approaches of groundwater governance: A survey of lessons learned from selected cases across the globe. *Water (Switzerland)*, *8*(10), 1–24. https://doi.org/10.3390/w8100417
Vatn, A., & Vedeld, P. (2012). Fit, interplay, and scale: A diagnosis. *Ecology and Society*, *17*(4). https://doi.org/10.5751/ES-05022-170412
Villamayor-Tomas, S., Iniesta-Arandia, I., & Roggero, M. (2020). Are generic and specific adaptation institutions always relevant? An archetype analysis of drought adaptation in Spanish irrigation systems. *Ecology and Society*, *25*(1), art32. https://doi.org/10.5751/ES-11329-250132
Villamayor-Tomas, S., Oberlack, C., Epstein, G., Partelow, S., Roggero, M., Kellner, E., Tschopp, M., & Cox, M. (2020). Using case study data to understand SES interactions: a model-centered meta-analysis of SES framework applications. *Current Opinion in Environmental Sustainability*, *44*, 48–57. https://doi.org/10.1016/j.cosust.2020.05.002
Villeneuve, S., Painchaud, J., & Dugas, C. (2006). Targeted sustainable development: 15 years of government and community intervention on the St. Lawrence River. *Environmental Monitoring and Assessment*, *113*(1–3), 285–301. https://doi.org/10.1007/s10661-005-9085-5
Woodhouse, P., & Muller, M. (2017). Water Governance—An Historical Perspective on Current Debates. In *World Development* (Vol. 92, pp. 225–241). Elsevier Ltd. https://doi.org/10.1016/j.worlddev.2016.11.014
Wuijts, S., Driessen, P., & Van Rijswick, H. (2018). Towards More Effective Water Quality Governance: A Review of Social-Economic, Legal and Ecological Perspectives and Their Interactions. *Sustainability*, *10*(4), 914. https://doi.org/10.3390/su10040914
Young, O. R. (1999). *Institutional Dimensions of Global Environmental Change*. Science Plan. IHDP Report No.9, IHDP.
Young, O. R. (2002). *The Institutional Dimensions of Environmental Change : Fit Interplay and Scale*. MIT Press.
Yousefi, A., Knieper, C., & Pahl-Wostl, C. (2024). State-centric water governance and ineffective coordination: developing a context-sensitive assessment in Iran's rentier state. *International Journal of Water Resources Development*, 1–26. https://doi.org/10.1080/07900627.2024.2310817

Supplementary material for: Successful governance pathways across problem contexts: a global QCA analysis

Appendix 1. Data and calibration

Information on the cases

The analysis encompasses 40 cases (Table A1.1). Three of these cases had mixed performance, where governance intervention succeeded in addressing one issue but failed in addressing another. One case study is the Tlaxcala Atoyac Sub-Basin in Mexico, where governance interventions resulted in improved treated wastewater, but water quality goals remain unmet (Flores et al. 2016). Another example is the Freshwater Management Regime in the Manawatu River Catchment, which successfully addresses point source pollution but struggles with long-term water quality (McNeill 2016). Finally, the Integrated River Basin Management (IRBM) Programme in the Conchos River shows mixed performance; while agricultural water use efficiency has improved, groundwater recharge has not seen similar progress (Barrios et al. 2009). These mixed cases were coded as separate instances, resulting in a final dataset of 43 cases. Among these cases, 21 address the problématique of "groundwater exploitation for agriculture," while the remaining cases focus on "surface water pollution." Overall, there are 18 cases of "success." Eight of these successful cases are related to groundwater exploitation for agriculture, while the rest pertain to surface water pollution. The cases cover a wide geographical distribution, covering Asia (China, India, Vietnam, Indonesia, Turkey), Europe (Estonia, Spain, UK), North America (USA, Canada), Latin America (Mexico, Chile), Africa (South Africa), Oceania (New Zealand, Australia), and the Middle East (Iran).

Table A1. 1 Overview of the cases.

Case name	**Country**	**Problématique**	**Water sustainability performance**	**Original source**
Transjurisdictional Water Pollution Management in China	China	Surface water pollution	Failure	Ongley, E. D., and X. Wang. 2004. Transjurisdictional water pollution management in china: The legal and institutional framework. *Water International* 29(3):270–281.
Zhangweinan River Basin	China	Surface water pollution	Failure	Zhang, Y., G. Fu, T. Yu, M. Shen, W. Meng, and E. D. Ongley. 2011. Trans-jurisdictional pollution control options within an integrated water resources management framework in water-scarce north-eastern China. *Water Policy* 13(5):624–644.
Water Pollution Control in Guangzhou, Pearl River	China	Surface water pollution	Failure	Yu, Y., D. G. Ohandja, and J. N. B. Bell. 2012. Institutional Capacity on Water Pollution Control of the Pearl River in Guangzhou, China. *International Journal of Water Resources Development* 28(2):313–324.
The Matsalu Bay	Estonia	Surface water pollution	Failure	Eckerberg, K. 1997. Comparing the local use of environmental policy instruments in nordic and baltic countries - The issue of diffuse water pollution. *Environmental Politics* 6(2):24–47.
Water Governance in Indonesia	Indonesia	Surface water pollution	Failure	Chattopadhyay, S., and K. Thiruvananthapuram. 2018. Challenges of water governance in the context of water quality problem: Comparative study of India, Indonesia and Germany. Transactions of the Institute of Indian Geographers 40(2):171–183.
Tlaxcala Atoyac Sub-Basin	Mexico	Surface water pollution	Success	Flores, C. C., V. Vikolainen, and H. Bressers. 2016. Water governance decentralisation and river basin management reforms in hierarchical systems: Do they work for water treatment policy in Mexico's Tlaxcala Atoyac sub-basin? *Water (Switzerland)* 8(5).
Tlaxcala Atoyac Sub-Basin	Mexico	Surface water pollution	Failure	Flores, C. C., V. Vikolainen, and H. Bressers. 2016. Water governance decentralisation and river basin management reforms in hierarchical systems: Do they work for water treatment policy in Mexico's Tlaxcala Atoyac sub-basin? *Water (Switzerland)* 8(5).

Olifants River (mid-1990s-2005/2006)	South Africa	Surface water pollution	Failure	Biggs, H. C., J. K. Clifford-Holmes, S. Freitag, F. J. Venter, and J. Venter. 2017. Cross-scale governance and ecosystem service delivery: A case narrative from the Olifants River in north-eastern South Africa. *Ecosystem Services* 28:173–184.
Institutional Design in Managing Water Pollution from Vietnam's Craft Villages in the Red River Delta Region of Vietnam	Vietnam	Surface water pollution	Failure	Mahanty, S., and T. D. Dang. 2013. Crafting Sustainability? The Potential and Limits of Institutional Design in Managing Water Pollution from Vietnam's Craft Villages. *Society and Natural Resources* 26(6):717–732.
Water Quality Management in Singapore	Singapore	Surface water pollution	Success	Tortajada, C., and Y. K. Joshi. 2014. Water quality management in Singapore: the role of institutions, laws and regulations. *Hydrological Sciences Journal* 59(9):1763–1774.
Cases of the Chilika, Kolleru and Vembanad Lakes	India	Surface water pollution	Failure	Narayanan, N. C., and J. P. Venot. 2009. Drivers of change in fragile environments: Challenges to governance in Indian wetlands. *Natural Resources Forum* 33(4):320–333.
Tuppal Creek system	Australia	Surface water pollution	Success	Conallin, J., E. Wilson, and J. Campbell. 2018. Implementation of Environmental Flows for Intermittent River Systems: Adaptive Management and Stakeholder Participation Facilitate Implementation. *Environmental Management* 61(3):497–505.
Government and Community Intervention on the St. Lawrence River	Canada	Surface water pollution	Success	Villeneuve, S., J. Painchaud, and C. Dugas. 2006. Targeted sustainable development: 15 years of government and community intervention on the St. Lawrence River. *Environmental Monitoring and Assessment* 113(1–3):285–301.
Environmental Planning in the Great Lakes (RAP)	Canada/United States	Surface water pollution	Failure	Beierle, T. C., and D. M. Konisky. 2001. What are we gaining from stakeholder involvement? Observations from environmental planning in the Great Lakes. *Environment and Planning C: Government and Policy* 19(4):515–527.
Trans-boundary Water Governance in the Great Lakes Basin	Canada/United States	Surface water pollution	Success	Talukder, B., and K. W. Hipel. 2020. Diagnosis of sustainability of trans-boundary water governance in the Great Lakes basin. *World Development* 129.

Inter-municipal Initiative for the Integrated Management	Mexico	Surface water pollution	Success	Montero, S. G., E. S. Castellón, L. M. M. Rivera, S. G. Ruvalcaba, and J. J. Llamas. 2006. Collaborative governance for sustainable water resources management: The experience of the Inter-municipal Initiative for the Integrated Management of the Ayuquila River Basin, Mexico. *Environment and Urbanization* 18(2):297–313.
Freshwater Management Regime in Manawatu River Catchment	New Zealand	Surface water pollution	Failure	McNeill, J. 2016. Scale Implications of Integrated Water Resource Management Politics: Lessons from New Zealand. *Environmental Policy and Governance* 26(4):306–319.
Freshwater Management Regime in Manawatu River Catchment	New Zealand	Surface water pollution	Success	McNeill, J. 2016. Scale Implications of Integrated Water Resource Management Politics: Lessons from New Zealand. *Environmental Policy and Governance* 26(4):306–319.
Watershed Management in Laguna de Bay	Philippine s	Surface water pollution	Success	Oledn, M. T. T. 2001. Challenges and opportunities in watershed management for Laguna de Bay (Philippines). *Lakes and Reservoirs: Research and Management* 6(3):243–246.
River Restoration Project in Incheon	South Korea	Surface water pollution	Success	Lee, S., and G. W. Choi. 2012. Governance in a River Restoration Project in South Korea: The Case of Incheon. *Water Resources Management* 26(5):1165–1182.
Water Management and Governance in l'Albufera de València Wetland	Spain	Surface water pollution	Failure	Jégou, A., and C. Sanchis-Ibor. 2019. The opaque lagoon. Water management and governance in L'albufera de València Wetland (Spain). *Limnetica* 38(1):503–515.
The Mersey Basin Campaign	United Kingdom	Surface water pollution	Success	Salthouse, C. 2000. Making the most of the Mersey estuary: A partnership approach to catchment management. *International Journal of Urban Sciences* 4(2):129–138.
Copiapó Valley	Chile	Groundwater exploitation for agriculture	Failure	Rinaudo, J. D., and G. Donoso. 2019. State, market or community failure? Untangling the determinants of groundwater depletion in Copiapó (Chile). *International Journal of Water Resources Development* 35(2):283–304.
The Minqin Oasis of Northwest China	China	Groundwater exploitation for agriculture	Failure	Hu, X. J., Y. C. Xiong, Y. J. Li, J. X. Wang, F. M. Li, H. Y. Wang, and L. L. Li. 2014. Integrated water resources management and water users' associations in the arid region of northwest China: A case study of farmers' perceptions. *Journal of Environmental Management* 145:162–169.

The Case of the Shiyang River Basin	China	Groundwater exploitation for agriculture	Success	Hu, X. J., Y. C. Xiong, Y. J. Li, J. X. Wang, F. M. Li, H. Y. Wang, and L. L. Li. 2014. Integrated water resources management and water users' associations in the arid region of northwest China: A case study of farmers' perceptions. *Journal of Environmental Management* 145:162–169.
The Groundwater System in the Rafsanjan Plain	Iran	Groundwater exploitation for agriculture	Failure	Mirnezami, S. J., C. de Boer, and A. Bagheri. 2020. Groundwater governance and implementing the conservation policy: the case study of Rafsanjan Plain in Iran. *Environment, Development and Sustainability* 22(8):8183–8210.
Water Governance in Dryland System in the Rio Del Carmen Wastershed	Mexico	Groundwater exploitation for agriculture	Failure	Lopez Porras, G., L. C. Stringer, and C. H. Quinn. 2019. Corruption and conflicts as barriers to adaptive governance: Water governance in dryland systems in the Rio del Carmen watershed. *Science of the Total Environment* 660:519–530.
Groundwater Governance in Pakistan	Pakistan	Groundwater exploitation for agriculture	Failure	Qureshi, A. S. 2020. Groundwater governance in pakistan: From colossal development to neglected management. *Water (Switzerland)* 12(11):1–20.
Upper Guadiana Basin, Castilla-La Mancha	Spain	Groundwater exploitation for agriculture	Failure	Knüppe, K., and C. Pahl-Wostl. 2013. Requirements for adaptive governance of groundwater ecosystem services: Insights from Sandveld (South Africa), Upper Guadiana (Spain) and Spree (Germany). *Regional Environmental Change* 13(1):53–66.
Irrigated Agriculture in Turkey	Turkey	Groundwater exploitation for agriculture	Failure	Özerol, G., and H. Bressers. 2015. Scalar alignment and sustainable water governance: The case of irrigated agriculture in Turkey. Environmental Science and Policy 45:1–10.
Farmer Participation and Irrigation Practices in Harran Plain	Turkey	Groundwater exploitation for agriculture	Failure	Özerol, G. 2013. Institutions of farmer participation and environmental sustainability: A multi-level analysis from irrigation management in Harran Plain, Turkey. *International Journal of the Commons* 7(1):73–91.
Tampa Bay Water	United States	Groundwater exploitation for agriculture	Success	Asefa, T., A. Adams, and I. Kajtezovic-Blankenship. 2014. A tale of integrated regional water supply planning: Meshing socio-economic, policy, governance, and sustainability desires together. *Journal of Hydrology* 519(PC):2632–2641.

Agricultural User Groups Created Across France	France	Groundwater exploitation for agriculture	Failure	Rouillard, J., and J. D. Rinaudo. 2020. From State to user-based water allocations: An empirical analysis of institutions developed by agricultural user associations in France. *Agricultural Water Management* 239.
WDP in Rajasthan, India	India	Groundwater exploitation for agriculture	Failure	Singh, C. 2018. Is participatory watershed development building local adaptive capacity? Findings from a case study in Rajasthan, India. *Environmental Development* 25:43–58.
Integrated River Basin Management (IRBM) Programme in the Conchos River	Mexico	Groundwater exploitation for agriculture	Success	Barrios, J. E., J. A. RodríGuez-Pineda, and M. De La Maza Benignos. 2009. Integrated river basin management in the Conchos river basin, Mexico: A case study of freshwater climate change adaptation. *Climate and Development* 1(3):249–260.
Integrated River Basin Management (IRBM) Programme in the Conchos River	Mexico	Groundwater exploitation for agriculture	Failure	Barrios, J. E., J. A. RodríGuez-Pineda, and M. De La Maza Benignos. 2009. Integrated river basin management in the Conchos river basin, Mexico: A case study of freshwater climate change adaptation. *Climate and Development* 1(3):249–260.
The Period 1999-2010: New Public Management and Collaboration in Canterbury	New Zealand	Groundwater exploitation for agriculture	Failure	Kirk, N., A. Brower, and R. Duncan. 2017. New public management and collaboration in canterbury, New Zealand's freshwater management. *Land Use Policy* 65:53–61.
Sandveld, Western Cape Province	South Africa	Groundwater exploitation for agriculture	Failure	Knüppe, K., and C. Pahl-Wostl. 2013. Requirements for adaptive governance of groundwater ecosystem services: Insights from Sandveld (South Africa), Upper Guadiana (Spain) and Spree (Germany). *Regional Environmental Change* 13(1):53–66.
Olifants River (2007-2016)	South Africa	Groundwater exploitation for agriculture	Success	Biggs, H. C., J. K. Clifford-Holmes, S. Freitag, F. J. Venter, and J. Venter. 2017. Cross-scale governance and ecosystem service delivery: A case narrative from the Olifants River in north-eastern South Africa. *Ecosystem Services* 28:173–184.
PIM activities at the Krasiew Reservoir	Thailand	Groundwater exploitation for agriculture	Success	Sinclair, A. J., W. Kumnerdpet, and J. M. Moyer. 2013. Learning sustainable water practices through participatory irrigation management in Thailand. *Natural Resources Forum* 37(1):55–66.

The SAGEs	France	Groundwater exploitation for agriculture	Success	Piégay, H., P. Dupont, and J. A. Faby. 2002. Questions of water resources management. Feedback on the implementation of the french SAGE and SDAGE plans (1992-2001). *Water Policy* 4(3):239–262.
The Ashburton Water User Group and Opuha Community Water Storage Dam	New Zealand	Groundwater exploitation for agriculture	Success	Kirk, N., A. Brower, and R. Duncan. 2017. New public management and collaboration in canterbury, New Zealand's freshwater management. *Land Use Policy* 65:53–61.
The Twyford Cooperative Company Ltd in Hawke's Bay and Central Plains Water Ltd	New Zealand	Groundwater exploitation for agriculture	Success	Boone, S., and S. Fragaszy. 2018. Emerging scarcity and emerging commons: Water management groups and groundwater governance in Aotearoa New Zealand. *Water Alternatives* 11(3):795–823.

Table A1.2 Conditions, outcome, and calibration decisions

Condition	Description	Original scale	Calibration			Expected impact on the outcome
			0	**0.5**	**1**	
Capacity (CAP)	Governance system has its capacity (financial, human, technical, knowledge, etc.)	No (0); To some extent (0.5); Yes (1)	0	0.75	1	+
Fit (FIT)	Does the institutional arrangement match with a problem scale? *(*Additive-minimum aggregation - *Following Langhans et al. (2014), we added the arithmetic mean and the minimum of related conditions and divided the sum by two).* *Spatial*: congruence between the geographical extents of an ecological problem and institutions *Temporal*: fit between institutional responses and the rate of biophysical processes *Functional*: The institutional design and responses consider functional linkages of natural system	No (0); To some extent (0.5); Yes (1)	0.1	0.45	0.7	+
Interplay (INTER)	Interplay (Additive-minimum aggregation) *Vertical*: There is a strong coordination among government bodies across administrative levels *Horizontal*: There is a strong cooperation among governance bodies across sectors	No (0); To some extent (0.5); Yes (1)	0.1	0.55	1	+
Decentralization (DEC)	Functions, responsibilities, and authority are delegated to very local levels of decision-making	No (0); To some extent (0.5); Yes (1)	0	0.4	1	-/+
Participation (PART)	Degree of engaging non-state actors into the decision-making	Not involving (0); consultation (0.33); collaborative decision-making (0.67); full	0	0.5	1	+

		decision-making power (1);				
Adaptiveness/knowledge integration(ADAPT/KNOW)	Degree of adaptiveness and knowledge integration (Additive-minimum aggregation) *Flexibility*: Governance is flexible and allows for adjustments when new information becomes available, especially in presence of high uncertainty *Use of evidence*: Using the best available knowledge and experimentation (i.e., policy and management as experiments and learning-by-doing) *Knowledge integration*: Scientific, indigenous as well as (co-produced) knowledge integration into decision-making	No (0); To some extent (0.5); Yes (1)	0.1	0.25	0.7	+
Problématique 1: Groundwater exploitation for agriculture (P1)	Problématique (i.e., problem context) of "groundwater exploitation for agriculture"	Absent (0); Present (1) Presence of the condition denotes to "groundwater exploitation for agriculture", while the absence refers to "surface water pollution"	0	0.5	1	
Successful water-related sustainability performance (OUT)	Water governance system/intervention resulted in positive changes in water-related environmental sustainability issue/water resources in terms of improvements	Failure (0); Success (1)	0	0.5	1	

Table A1. 3 Data description

Variable	n	min	max	mean	sd
Capacity	43	0	1	0.6	0.5
Fit	43	0	1	0.4	0.4
Interplay	43	0	1	0.4	0.4
Decentralization	43	0	1	0.6	0.4
Participation	43	0	1	0.4	0.4
Adaptiveness/knowledge integration	43	0	1	0.4	0.4
Problématique 1: Groundwater exploitation for agriculture	43	0	1	0.4	0.4
Water-related sustainability performance	43	0	1	0.4	0.5

Table A1. 4 Calibrated dataset

CASE	CAP	FIT	INTER	DECEN	PART	ADAPT/KNOW	P1	OUT
1	0	0.1	0	0	0	0	0	0
2	0	0	0	1	0	0	0	0
3	0	0	0	1	0	0	0	0
4	0	0	0	0	0	0.3	0	0
5	0	0.3	0	1	0	0.3	0	0
6	1	0.1	0.4	0	0	0	0	1
7	0	0.1	0.4	1	0	0	0	0
8	0	0	0	1	0	0.3	0	0
9	0	0	0	0	0	0	0	0
10	1	0.3	1	0	0.33	1	0	1
11	0	0	0	1	0.33	0	0	0
12	1	1	1	1	0.67	1	0	1

13	1	0.3	1	1	0.67	1	0	1
14	0	1	1	1	0.67	1	0	0
15	1	0.1	0.4	1	0.67	0.6	0	1
16	1	1	1	1	0.67	0.6	0	1
17	1	0.1	0	1	0.67	0.9	0	0
18	1	0.1	0	1	0.67	0.9	0	1
19	1	1	1	1	0.67	1	0	1
20	0	1	0.6	1	0.67	0.6	0	1
21	0	0	0	1	0.67	0.8	0	0
22	1	1	1	1	1	1	0	1
23	0	0	0	0	0	0.6	1	0
24	0	0.3	0	0	0	0.3	1	0
25	1	1	0	1	0	0.3	1	1
26	0	0	0	0	0	0	1	0
27	0	0	0	0	0	0	1	0
28	0	0	0	1	0	0	1	0
29	1	0.3	0.4	1	0	0.6	1	0
30	0	0.1	0	0	0	0	1	0
31	0	0	0	1	0.33	0	1	0
32	0	1	0.6	1	0.33	0.6	1	1
33	0	0.8	1	1	0.67	1	1	0
34	0	0.1	0	1	0.67	0.3	1	0
35	1	0.3	1	1	0.67	1	1	1
36	1	0.3	1	1	0.67	1	1	0
37	1	0	0	1	0.67	1	1	0
38	0	0.1	0	0	0.67	0	1	0
39	1	1	1	1	0.67	0.9	1	1
40	1	1	1	1	0.67	1	1	1

41	1	1	1	1	1	1	1	1
42	1	1	1	1	1	1	1	1
43	1	1	1	1	1	1	1	1

Table A1. 5 Results of the skewness analysis for the outcome and conditions after calibration.

Variable	**Cases > 0.5 / Total number of cases**
CAP	20 / 43 = 46.51 %
FIT	14 / 43 = 32.56 %
INTER	17 / 43 = 39.53 %
DECEN	19 / 43 = 44.19 %
PART	22 / 43 = 51.16 %
ADAPT/KNOW	24 / 43 = 55.81 %
P1	21 / 43 = 48.84 %
OUT	18 / 43 = 41.86 %

Appendix 2. Fuzzy-set Qualitative Comparative Analysis (fsQCA)

Table A2. 1 Analysis of necessity for the successful and unsuccessful water-related sustainability performance.

Conditions	Successful water-related sustainability performance (OUT)		Failed water-related sustainability performance (~OUT)	
	Cons.Nec	RoN	Cons.Nec	RoN
CAP	0.889	0.852	0.160	0.590
FIT	0.738	0.872	0.152	0.661
INTER	0.778	0.866	0.156	0.642
DECEN	0.889	0.407	0.640	0.407
PART	0.631	0.810	0.241	0.693
ADAPT/KNOW	0.796	0.705	0.338	0.585
P1	0.444	0.629	0.520	0.733

For a condition to be deemed necessary, the recommended consistency threshold is 0.9, indicating that the condition should be observed in at least 90% of the cases where the outcome is present (Schneider and Wagemann 2012). Upon examining our conditions, we observe that the consistency value is below this threshold for all seven conditions, for the negated outcome (failed water-related sustainability performance) (~OUT). In the case of the outcome (successful water-related sustainability performance) (OUT), there are two conditions with a very close consistency value, which are capacity (CAP) and decentralization (DECEN). However, having a closer look at the RoN (Relevance of Necessity), we observe that only capacity has RoN above the recommended value of 0.6 (see Oana et al. 2021). The RoN, or Relevance of Necessity, assesses whether a condition is non-trivial by comparing the sizes of the condition set to the outcome sets (Schneider and Wagemann 2012). When the outcome set and the condition set diverge significantly in size—either because the outcome is very small (very few cases are members) or because the condition set is very large (almost all cases are members)—a necessity claim becomes trivial (Oana et al. 2021).

Table A2. 2 Truth table for the presence of the outcome

	CAP	FIT	INTER	DECEN	PART	ADAPT/KNOW	P1	OUT	n	incl	PRI	cases
65	1	0	0	0	0	0	0	1	1	1	1	6
83	1	0	1	0	0	1	0	1	1	1	1	10
95	1	0	1	1	1	1	0	1	1	1	1	13
127	1	1	1	1	1	1	0	1	4	1	1	12,16,19,22
128	1	1	1	1	1	1	1	1	5	0.94	0.94	39,40,41,42,43
106	1	1	0	1	0	0	1	0	1	0.70	0.70	25
79	1	0	0	1	1	1	0	0	3	0.65	0.65	15,17,18
60	0	1	1	1	0	1	1	0	1	0.63	0.63	32
96	1	0	1	1	1	1	1	0	2	0.50	0.50	35,36
63	0	1	1	1	1	1	0	0	2	0.45	0.45	14,20
64	0	1	1	1	1	1	1	0	1	0.33	0.33	33
1	0	0	0	0	0	0	0	0	3	0	0	1,4,9
2	0	0	0	0	0	0	1	0	4	0	0	24,26,27,30
4	0	0	0	0	0	1	1	0	1	0	0	23
6	0	0	0	0	1	0	1	0	1	0	0	38
9	0	0	0	1	0	0	0	0	6	0	0	2,3,5,7,8,11
10	0	0	0	1	0	0	1	0	2	0	0	28,31
14	0	0	0	1	1	0	1	0	1	0	0	34
15	0	0	0	1	1	1	0	0	1	0	0	21
76	1	0	0	1	0	1	1	0	1	0	0	29
80	1	0	0	1	1	1	1	0	1	0	0	37

Note: If the row is sufficient for the outcome set, it is shown in the "OUT" column. The "n" column refers to the number of cases with each path. The "inclusion score," or consistency for path sufficiency, is displayed in the "incl" column. We set the consistency threshold at 0.8, and the paths that meet these criteria have been shown in light grey. These paths are included in the minimization.

Table A2. 3 Truth table for the negated outcome

	CAP	FIT	INTER	DECEN	PART	ADAPT /KNOW	P1	~OUT	n	incl	PRI	cases
1	0	0	0	0	0	0	0	1	3	1	1	1,4,9
2	0	0	0	0	0	0	1	1	4	1	1	24,26, 27,30
4	0	0	0	0	0	1	1	1	1	1	1	23
6	0	0	0	0	1	0	1	1	1	1	1	38
9	0	0	0	1	0	0	0	1	6	1	1	2,3,5, 7,8,11
10	0	0	0	1	0	0	1	1	2	1	1	28,31
14	0	0	0	1	1	0	1	1	1	1	1	34
15	0	0	0	1	1	1	0	1	1	1	1	21
76	1	0	0	1	0	1	1	1	1	1	1	29

80	1	0	0	1	1	1	1	1	1	1	1	37
64	0	1	1	1	1	1	1	0	1	0.67	0.67	33
63	0	1	1	1	1	1	0	0	2	0.55	0.55	14,20
96	1	0	1	1	1	1	1	0	2	0.50	0.50	35,36
60	0	1	1	1	0	1	1	0	1	0.37	0.37	32
79	1	0	0	1	1	1	0	0	3	0.35	0.35	15,17, 18
106	1	1	0	1	0	0	1	0	1	0.30	0.30	25
128	1	1	1	1	1	1	1	0	5	0.06	0.06	39,40, 41,42, 43
65	1	0	0	0	0	0	0	0	1	0	0	6
83	1	0	1	0	0	1	0	0	1	0	0	10
95	1	0	1	1	1	1	0	0	1	0	0	13
127	1	1	1	1	1	1	0	0	4	0	0	12,16, 19,22

Prior to minimization, we checked the truth table to determine whether rows contain enough empirical evidence and for any contradictory truth table rows. Contradictory truth table rows are the rows that are sufficient for both the occurrence and non-occurrence of the outcome (Oana and Schneider 2024). Our truth table did not contain such rows.

Table A2. 4 Conservative solution for the outcome (OUT)

	inclS	**PRI**	**covS**	**covU**	**Cases**
CAP*FIT*INTER*DECEN*PART*ADAPT/KNOW	0.965	0.965	0.442	0.257	12,16,19,22; 39,40,41,42, 43
CAP*INTER*DECEN*PART*ADAPT/KNOW*~P1	1	1	0.223	0.038	13; 12,16, 19,22
CAP*~FIT*INTER*~DECEN*~PART*ADAPT/KNOW*~P1	1	1	0.037	0.037	10
CAP*~FIT*~INTER*~DECEN*~PART*~ADAPT/KNOW*~P1	1	1	0.031	0.031	6
M1	0.972	0.972	0.548		

Table A2. 5 Prime implicant chart for the conservative solution.

	65	**83**	**95**	**127**	**128**
CAP*FIT*INTER*DECEN*PART*ADAPT/KNOW	-	-	-	X	X
CAP*INTER*DECEN*PART*ADAPT/KNOW*~P1	-	-	X	X	-
CAP*~FIT*INTER*~DECEN*~PART*ADAPT/KNOW*~P1	-	X	-	-	-
CAP*~FIT*~INTER*~DECEN*~PART*~ADAPT/KNOW*~P1	X	-	-	-	-

Minimization in QCA is used to find the simplest solution and involves two steps using the Quine-McCluskey Algorithm: 1. Identifying prime implicants, and 2. Minimizing prime implicants by identifying and dropping logically redundant prime implicants. The Prime

Implicant Chart shows the link between prime implicants and primitive expressions, helping to distinguish between logically essential and redundant ones (i.e., primitive expressions are still covered after the prime implicant is dropped) (Oana and Schneider 2024).

Table A2. 6 Conservative solution for the negated outcome (~OUT)

	inclS	**PRI**	**covS**	**covU**	**cases**
~CAP*~FIT*~INTER*~PART*~ADAPT/KNOW	1	1	0.544	0.283	1,4,9; 24,26,27,30; 2,3,5,7,8,11; 28,31
~CAP*~FIT*~INTER*~ADAPT/KNOW*P1	1	1	0.3	0.048	24,26,27,30; 38; 28,31; 34
~CAP*~FIT*~INTER*~DECEN*~PART*P1	1	1	0.196	0.024	23
CAP*~FIT*~INTER*DECEN*ADAPT/KNOW*P1	1	1	0.062	0.062	29; 37
~CAP*~FIT*~INTER*DECEN*PART*ADAPT/KNOW*~P1	1	1	0.027	0.018	21
M1	1	1	0.696		

Table A2. 7 Prime implicants chart for the negated outcome (~OUT)

	1	2	4	6	9	10	14	15	76	80
~CAP*~FIT*~INTER*~PART*~ADAPT/KNOW	x	x	-	-	x	x	-	-	-	-
~CAP*~FIT*~INTER*~ADAPT/KNOW*P1	-	x	-	x	-	x	x	-	-	-
~CAP*~FIT*~INTER*~DECEN*~PART*P1	-	x	x	-	-	-	-	-	-	-
CAP*~FIT*~INTER*DECEN*ADAPT/KNOW*P1	-	-	-	-	-	-	-	-	x	x
~CAP*~FIT*~INTER*DECEN*PART*ADAPT/KNOW*~P1	-	-	-	-	-	-	-	x	-	-

M1: CAP*INTER*~P1 + (CAP*~DECEN + CAP*FIT*INTER) -> OUT
M2: CAP*INTER*~P1 + (CAP*~DECEN + CAP*FIT*PART) -> OUT
M3: CAP*INTER*~P1 + (CAP*~DECEN + CAP*FIT*ADAPT/KNOW) -> OUT
M4: CAP*INTER*~P1 + (CAP*FIT*INTER + CAP*~PART*~P1) -> OUT
M5: CAP*INTER*~P1 + (CAP*FIT*PART + CAP*~PART*~P1) -> OUT
M6: CAP*INTER*~P1 + (CAP*FIT*ADAPT/KNOW + CAP*~PART*~P1) -> OUT

		inclS	PRI	covS	covU	(M1)	(M2)	(M3)	(M4)	(M5)	(M6)
1	CAP*INTER*~P1	1.000	1.000	0.383	0.044	0.056	0.111	0.081	0.062	0.117	0.087
2	CAP*~DECEN	1.000	1.000	0.111	0.000	0.031	0.031	0.031			
3	CAP*FIT*INTER	0.947	0.947	0.563	0.006	0.294			0.294		
4	CAP*FIT*PART	0.952	0.952	0.472	0.000		0.265			0.257	
5	CAP*FIT*ADAPT/KNOW	0.933	0.933	0.551	0.019			0.314			0.306
6	CAP*~PART*~P1	0.917	0.917	0.203	0.010				0.049	0.041	0.041
	M1	0.957	0.957	0.707							
	M2	0.966	0.966	0.679							
	M3	0.948	0.948	0.728							
	M4	0.935	0.935	0.726							
	M5	0.953	0.953	0.689							
	M6	0.936	0.936	0.738							

		cases
1	CAP*INTER*~P1	10; 13; 12,16,19,22
2	CAP*~DECEN	6; 10
3	CAP*FIT*INTER	12,16,19,22; 39,40,41,42,43
4	CAP*FIT*PART	12,16,19,22; 39,40,41,42,43
5	CAP*FIT*ADAPT/KNOW	12,16,19,22; 39,40,41,42,43
6	CAP*~PART*~P1	6; 10

Figure A2. 1 Most parsimonious solution for the outcome (OUT)

```
M1: ~FIT*~INTER*P1 + (~CAP*~FIT) -> ~OUT
M2: ~FIT*~INTER*P1 + (~CAP*~INTER) -> ~OUT

                                        -------------------
                    inclS   PRI   covS   covU   (M1)   (M2)
-----------------------------------------------------------
1 ~FIT*~INTER*P1  1.000  1.000  0.394  0.062  0.062  0.062
-----------------------------------------------------------
2       ~CAP*~FIT  1.000  1.000  0.717  0.020  0.385
3     ~CAP*~INTER  0.954  0.954  0.742  0.046         0.411
-----------------------------------------------------------
               M1  1.000  1.000  0.779
               M2  0.958  0.958  0.804

                   cases
-----------------------
1  ~FIT*~INTER*P1  24,26,27,30; 23; 38; 28,31; 34; 29; 37
-----------------------
2       ~CAP*~FIT  1,4,9; 24,26,27,30; 23; 38; 2,3,5,7,8,11; 28,31; 34; 21
3     ~CAP*~INTER  1,4,9; 24,26,27,30; 23; 38; 2,3,5,7,8,11; 28,31; 34; 21
-----------------------
```

Figure A2. 2 Most parsimonious solution for the negation of the outcome (~OUT)

We also checked for the contradictory simplifying assumptions. When the same logical remainder row is included in the logical minimization for both the outcome's occurrence (Y) and non-occurrence (∼Y), this is known as a contradictory simplifying assumption (CSA) (Oana and Schneider 2024). We identified four rows (66, 68, 70, 72). To address CSA, we removed these rows from the logical minimization for the negated outcome and present the enhanced most parsimonious solution through Enhanced Standard Analysis (ESA).

```
M1: ~FIT*~INTER*DECEN*P1 + (~CAP*~FIT) -> ~OUT
M2: ~FIT*~INTER*DECEN*P1 + (~CAP*~INTER) -> ~OUT

                                             -------------------
                         inclS   PRI   covS   covU   (M1)   (M2)
-----------------------------------------------------------------
1 ~FIT*~INTER*DECEN*P1  1.000  1.000  0.177  0.062  0.062  0.062
-----------------------------------------------------------------
2            ~CAP*~FIT  1.000  1.000  0.717  0.020  0.602
3          ~CAP*~INTER  0.954  0.954  0.742  0.046         0.628
-----------------------------------------------------------------
                    M1  1.000  1.000  0.779
                    M2  0.958  0.958  0.804

                         cases
-----------------------------
1  ~FIT*~INTER*DECEN*P1  28,31; 34; 29; 37
-----------------------------
2            ~CAP*~FIT  1,4,9; 24,26,27,30; 23; 38; 2,3,5,7,8,11; 28,31; 34; 21
3          ~CAP*~INTER  1,4,9; 24,26,27,30; 23; 38; 2,3,5,7,8,11; 28,31; 34; 21
-----------------------------
```

Figure A2. 3 Enhanced most parsimonious solution for the negated outcome (OUT)

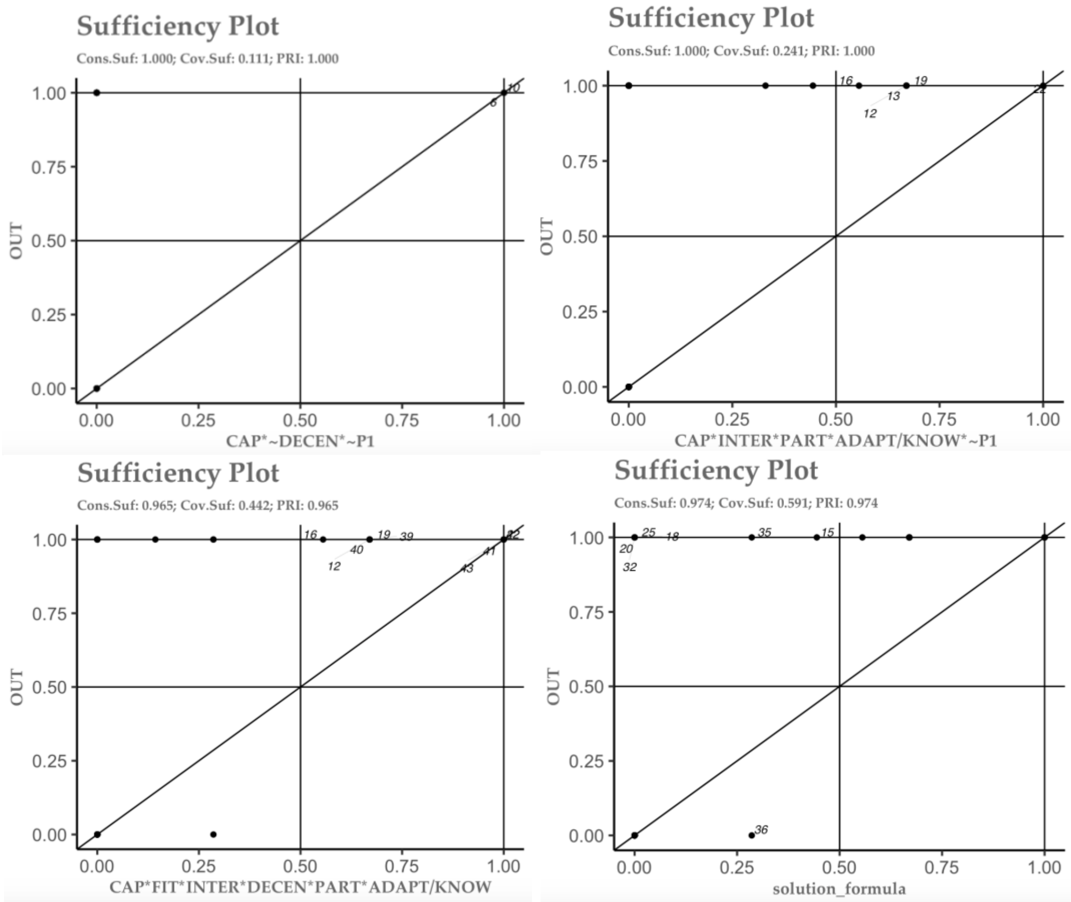


Figure A2. 4 Plot for the intermediate solution paths and the formula

Plotting the solution paths and formula for the outcome (Figures A2. 4), we observe no deviant case consistency in kind for any of the solution paths (lower right quadrant).

Table A2. 8 Easy counterfactuals, which are based on the researcher's directional expectations on the ways in which the conditions influence the result, used for the intermediate solution.

	CAP	FIT	INTER	DECEN	PART	ADAPT/KNOW	P1
67	1	0	0	0	0	1	0
69	1	0	0	0	1	0	0
71	1	0	0	0	1	1	0
81	1	0	1	0	0	0	0
85	1	0	1	0	1	0	0
87	1	0	1	0	1	1	0
97	1	1	0	0	0	0	0
99	1	1	0	0	0	1	0
101	1	1	0	0	1	0	0
103	1	1	0	0	1	1	0
113	1	1	1	0	0	0	0
115	1	1	1	0	0	1	0
117	1	1	1	0	1	0	0
119	1	1	1	0	1	1	0

Table A2. 9 Intermediate solution for the negation of the outcome.

	inclS	**PRI**	**covS**	**covU**	**cases**
~CAP*~FIT*~INTER*DECEN	1	1	0.365	0.06	2,3,5,7,8,11; 28,31; 34; 21
~FIT*~INTER*DECEN*P1	1	1	0.177	0.062	34; 29; 37
~CAP*~FIT*~INTER*~PART*~ADAPT/ KNOW	1	1	0.544	0.101	24,26,27,30; 2,3,5,7,8,11; 28,31
~CAP*~FIT*~INTER*~PART*P1	1	1	0.276	0.024	23; 28,31
~CAP*~FIT*~INTER*~ADAPT/KNOW *P1	1	1	0.3	0.021	38; 28,31; 34
M1	1	1	0.745		

We checked contradictory simplifying assumptions also for the intermediate solution and found none.

Robustness analysis for the intermediate solution for the outcome (OUT)

Following Oana et al. (2021), we conducted a three-step approach that includes sensitivity range (i.e., ranges that allow adjustments to be made to the frequency cutoff, raw consistency threshold, and calibration anchors, respectively, without changing the solution's Boolean expression), fit-oriented robustness (i.e., robustness of the solution to multiple and simultaneous changes), and case-oriented robustness (i.e., identifying various types of cases (robust cases, shaky cases, and possible cases) in the intersection between various alternative solutions created) evaluation.

Table A2. 10 Sensitivity ranges for calibration anchors for the conditions

		FIT	**INTER**	**ADAPT/KNOW**
	Lower bound	NA	NA	NA
Exclusion	Threshold	0.1	0.1	0.1
	Upper bound	0.1	NA	NA
	Lower bound	0.45	0.05	0.25
Crossover	Threshold	0.45	0.55	0.25
	Upper bound	0.45	0.55	0.75
	Lower bound	0.7	NA	NA
Inclusion	Threshold	0.7	1	0.7
	Upper bound	4.7	NA	NA

Note. We only ran the analysis for the conditions that underwent direct calibration.

Table A2. 11 Sensitvity ranges for raw consistency threshold and n.cut

	Raw Consistency Threshold	N.Cut
Lower bound	0.63	2
Threshold	0.8	2
Upper bound	0.91	2

For the fit-oriented robustness, we made the following changes to the test solution:

1. Adjusted the consistency to 0.75.
2. Modified the calibration for "FIT" by assigning anchor points of 0, 0.4, and 1.
3. Set the n.cut to 1.

Table A2. 12 Robustness parameters for the fit-oriented robustness analysis

	RF_cov	RF_cons	RF_SC
Robustness_Fit	0.898	0.993	0.893

We observe that RF_cov and RF_cons are both smaller than 1, indicating that the solution and the test solution do not perfectly overlap. However, the numbers are quite high, suggesting that the overlap is substantial.

```
                      RCR_typ RCR_dev SSR
Robustness_Case_Ratio     0.9     NaN   1

$CaseNames
Robust Typical Cases (IS*TS and Y > 0.5) :
-------------------

Boolean Expression: CAP*FIT*INTER + CAP*FIT*~DECEN

Cases in the intersection/Total number of cases: 9 / 43 = 20.93 %
Cases in the intersection/Total number of cases Y > 0.5:  9 / 18 = 50 %

Case Names:
12 16 19 22 39 40 41 42 43
-------------------

Robust Deviant Cases (IS*TS and Y < 0.5) :
-------------------

Boolean Expression: CAP*FIT*INTER + CAP*FIT*~DECEN

Cases in the intersection/Total number of cases: 0 / 43 = 0 %
Cases in the intersection/Total number of cases Y < 0.5:  0 / 25 = 0 %

Case Names:
No cases in this intersection
-------------------
```

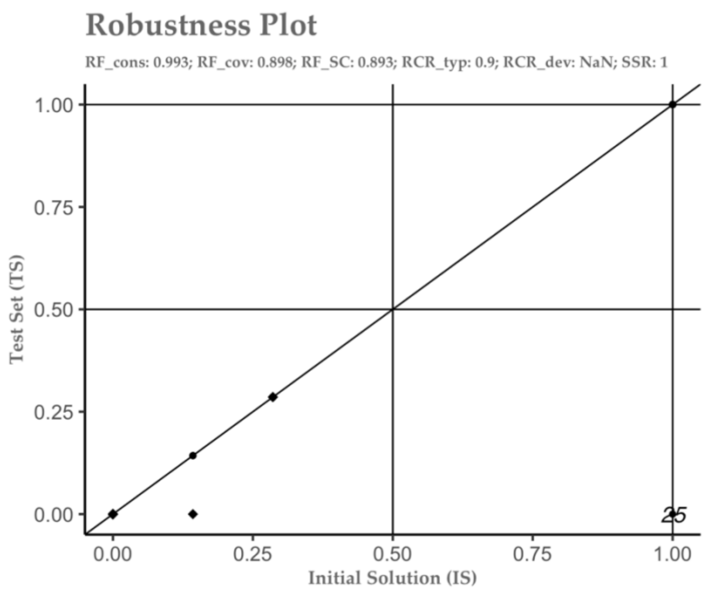


Figure A2. 5 Case-oriented robustness results

The case-oriented robustness analysis reveals that 90% of the typical cases are member of both initial solution and test solution. The plot does not show any case in the problematic upper-left quadrant.

Article 4:

Pathways to water sustainability? A global study assessing the benefits of integrated water resources management

Abstract

Integrated water resources management (IWRM) has been central to water governance and management worldwide since the 1990s. Recognizing the significance of an integrated approach to water management as a way to achieve the Sustainable Development Goals (SDGs), IWRM was formally incorporated as part of the SDG global indicator framework, thus committing the UN and its Member States to achieving high IWRM implementation by 2030 and measuring progress through SDG indicator 6.5.1. This paper examines the extent to which the implementation of IWRM improves the sustainable management of water and the health of water-related ecosystems—a first-of-its-kind in terms of quantitative analysis on a global scale. To achieve this objective, we conducted regression analyses between SDG 6.5.1 (both IWRM (total score) and the dimensions of SDG 6.5.1) and key water-related environmental sustainability indicators: SDG 6.2.1a (access to basic sanitation), 6.3.1 (treated wastewater), 6.4.1 (water-use efficiency), 6.4.2 (water stress), 6.6.1 (freshwater ecosystems, although here the trophic state and turbidity variables were used) and 6.3.2 (ambient water quality). Our analysis covers 124 countries for all these SDGs, with the exception of SDG 6.3.1 and SDG 6.3.2, which cover 112 and 85 countries, respectively. Results show that IWRM—to different degrees—is mainly associated with the good status of water-related sustainability indicators, with the exception of water stress, water quality, and turbidity. We observe a strong impact of control variables such as governance arrangements, economic situation and environmental and geographical conditions. Lagged effects and the scope of the framework may also explain some observed variations in the degree of association. Our study highlights the importance of further uncovering the interlinkages between IWRM implementation and the achievement of water-related environmental sustainability. Overall, the results suggest that although IWRM implementation is primarily linked to sustainable water management and the health of water systems, context-specific factors should be taken into account when evaluating its effectiveness, to enable policy- and decision-makers to make the necessary adjustments to optimize its outcomes.

Journal of Environmental Management 343 (2023) 118179

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Pathways to water sustainability? A global study assessing the benefits of integrated water resources management

Shahana Bilalova [a,*], Jens Newig [a], Laurent-Charles Tremblay-Lévesque [b,c], Julienne Roux [c], Colin Herron [c], Stuart Crane [d]

[a] Faculty of Sustainability, Institute of Sustainability Governance (INSUGO), Research Group Governance, Participation and Sustainability, Leuphana University Lüneburg, Universitätsallee 1, 21335, Lüneburg, Germany
[b] Sociology of Development and Change Group, Wageningen University, Droevendaalsesteeg 3/3a, P.O. Box 47, 6700, AA Wageningen, the Netherlands
[c] Global Water Partnership (GWP), Linnégatan 87D, PO Box 24177, 104 51, Stockholm Sweden
[d] United Nations Environment Programme, United Nations Avenue, P.O. Box 30552, 00100, Nairobi, Kenya

A R T I C L E I N F O

Keywords:
IWRM
Sustainable water systems
2030 agenda
Water-related ecosystems

A B S T R A C T

Integrated water resources management (IWRM) has been central to water governance and management worldwide since the 1990s. Recognizing the significance of an integrated approach to water management as a way to achieve the Sustainable Development Goals (SDGs), IWRM was formally incorporated as part of the SDG global indicator framework, thus committing the UN and its Member States to achieving high IWRM implementation by 2030 and measuring progress through SDG indicator 6.5.1. This paper examines the extent to which the implementation of IWRM improves the sustainable management of water and the health of water-related ecosystems—a first-of-its-kind in terms of quantitative analysis on a global scale. To achieve this objective, we conducted regression analyses between SDG 6.5.1 (both IWRM (total score) and the dimensions of SDG 6.5.1) and key water-related environmental sustainability indicators: SDG 6.2.1a (access to basic sanitation), 6.3.1 (treated wastewater), 6.4.1 (water-use efficiency), 6.4.2 (water stress), 6.6.1 (freshwater ecosystems, although here the trophic state and turbidity variables were used) and 6.3.2 (ambient water quality). Our analysis covers 124 countries for all these SDGs, with the exception of SDG 6.3.1 and SDG 6.3.2, which cover 112 and 85 countries, respectively. Results show that IWRM—to different degrees—is mainly associated with the good status of water-related sustainability indicators, with the exception of water stress, water quality, and turbidity. We observe a strong impact of control variables such as governance arrangements, economic situation and environmental and geographical conditions. Lagged effects and the scope of the framework may also explain some observed variations in the degree of association. Our study highlights the importance of further uncovering the interlinkages between IWRM implementation and the achievement of water-related environmental sustainability. Overall, the results suggest that although IWRM implementation is primarily linked to sustainable water management and the health of water systems, context-specific factors should be taken into account when evaluating its effectiveness, to enable policy- and decision-makers to make the necessary adjustments to optimize its outcomes.

1. Introduction

As the traditional command and control approach is widely argued as failing in relation to governing complex water systems, there has been a global paradigm shift toward more integrated and holistic approaches. Integrated water resources management (IWRM) is one of the prevailing paradigms and has played a central role in water governance and management in many countries since the 1990s (Challies and Newig, 2022). It is guided by the 1992 Dublin Principles, recognizing water as a finite resource with an economic value and calling for a participatory approach to water management and development, especially ensuring that women are involved in the process (Davis, 2007). The wide appropriation of the concept could be attributed to institutional and

* Corresponding author. Leuphana University Lüneburg Research Group Governance, Participation and Sustainability Universitätsallee 1, 21335, Lüneburg, Germany.

E-mail addresses: shahana.bilalova@leuphana.de (S. Bilalova), jens.newig@leuphana.de (J. Newig), laurentcharles.tremblaylevesque@gwp.org (L.-C. Tremblay-Lévesque), julienne.roux@gwp.org (J. Roux), colin.herron@gwp.org (C. Herron), stuart.crane@un.org (S. Crane).

https://doi.org/10.1016/j.jenvman.2023.118179
Received 23 February 2023; Received in revised form 2 May 2023; Accepted 13 May 2023
Available online 29 May 2023

Acronyms

EE	Enabling environment (IWRM dimension)
Fin	Financing (IWRM dimension)
GDP p.c.	Gross domestic product per capita
GWP	Global Water Partnership
IP	Institutions and participation (IWRM dimension)
IWRM	Integrated water resources management
MI	Management instruments (IWRM dimension)
NRI	National rainfall index
SDGs	Sustainable Development Goals
SDG 6.2.1a	Access to basic sanitation
SDG 6.3.1	Treated wastewater
SDG 6.3.2	Ambient water quality
SDG 6.4.1	Water-use efficiency
SDG 6.4.2	Water stress
SDG 6.5.1	IWRM total score and dimension scores
SDG 6.6.1	Freshwater ecosystems, although here we refer to trophic state and turbidity

ideological path dependency connected to a historical progression of integrated river basin management (Benson et al., 2015). Meanwhile, its current popularity as a dominant paradigm is mainly attributed to major political efforts, especially at the international level. The 2002 World Summit on Sustainable Development called for drafting IWRM and water efficiency strategies at the national level by 2005 (Allouche, 2017). Later, IWRM was also embedded in donor organization requirements for project proposals in developing countries (Lubell and Edelenbos, 2013). International organizations such as the Global Water Partnership (GWP) were also founded with the specific intention of supporting the implementation of IWRM around the world. Recognizing the significance of an integrated approach to water management as a way to achieve the Sustainable Development Goals (SDGs), Agenda 2030 incorporated IWRM into the SDG indicator framework and committed to measuring the progress of its implementation through indicator 6.5.1.

Within the scope of the broader research aim stated above, we explore the following key research questions.

1. To what extent does the degree of IWRM implementation (SDG 6.5.1 total score) correlate with the achievement of water-related environmental sustainability indicators as measured through SDG 6?
2. How much do the four dimensions used to evaluate IWRM implementation, namely, "Enabling environment," "Institutions and participation," "Management instruments," and "Financing," correlate with water-related environmental sustainability indicators as measured through SDG 6?

To address the aforementioned research questions, this paper uses regression analysis. The goal of regression analysis is to uncover the impact of one or more independent (predictor) variables on other dependent variables (response, outcome) (Sen and Srivastava, 1990). Regression analysis is used by scientists to investigate hypothesized (causal) mechanisms (Gordon, 2015). This aligns with our aim of investigating the extent to which the IWRM framework is empirically associated with the good status of other water-related SDG 6 indicators. As argued by Gordon (2015), regression analysis has a key benefit compared to other methods like bivariate t-tests or correlations in that it allows for the inclusion of more variables in the model to determine whether a relationship is genuine or spurious. This is particularly important for our study as it helps to control for the potential impact of contextual factors on the studied associations.

The central aim of this paper is to advance the debate on the effectiveness of IWRM as a top-down diffused governance paradigm, linking the Dublin Principles to national water policies (Lankford et al., 2007). As IWRM is promoted as a universal blueprint for solving water-related problems in different contexts with a diverse range of physical, socio-cultural, economic and legal conditions (Biswas, 2008), our study also aims to contribute to the literature by conceptualizing the linkage between IWRM implementation and water system health. Although the effectiveness of the IWRM framework has been widely discussed in literature (e.g., Biswas, 2004; Butterworth et al., 2010; Jeffrey and Gearey, 2006), few empirical studies exist that assess how IWRM implementation influences certain water-related sustainability issues such as water efficiency, demand management, climate change adaptation, water security and stress (Hidalgo and Peña, 2009; Jensen and Nair, 2019; Khadim et al., 2013; Mersha et al., 2018; Rouillard et al., 2014). Those that do exist are mostly single or small-N studies focusing on specific water-related sustainability issues, which limit their scope and ability to provide a comprehensive picture regarding the sustainability patterns of IWRM implementation at a global scale. Unlike those studies, this paper takes a more comprehensive approach by considering a broader range of water-related environmental sustainability issues and draws on country-level performance as reported through SDG 6 indicators, to provide a more complete picture. Our paper provides empirical evidence that may guide and assist policymakers and practitioners in their attempts to evaluate the effectiveness of the IWRM framework at national and global levels.

3. Background on integrated water resources management (IWRM)

IWRM is argued to be an ambiguous concept (Biswas, 2008). Despite the absence of a universal definition, international and national definitions of "IWRM" share similarities in terms of considering multiple objectives and addressing sustainability in a certain way (Davis, 2007). In this paper, we refer to a commonly used definition that was formulated by the Global Water Partnership (GWP) (2000):

IWRM is a process which promotes the coordinated development and management of water, land, and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

While the origin of IWRM is mainly associated with the Mar del Plata United Nations Conference of 1977, the Dublin Conference of 1992, and the creation of GWP in 1996, its basic tenets are argued to have been in existence for almost a century (Biswas, 2008; Butterworth et al., 2010; García, 2008; Giordano and Shah, 2014; Molle, 2008).

As reflected in the GWP definition, IWRM is promoted as a process that is not an end in itself but rather a means to achieve more balanced water resources development, thereby ensuring efficiency, equity, and environmental sustainability. As an agenda-setting boundary concept, IWRM has a strong discursive element through raising awareness, whilst also providing a learning backdrop by making examples of water management available to multiple actors in support of its prescriptive role (Gerlak and Mukhtarov, 2015). As a prescriptive concept with an instrumental logic, IWRM strives for holistic and comprehensive water management, integrating water with other policy objectives and human activities (Armitage et al., 2015). As a water-centric paradigm, IWRM perceives the river basin as the fundamental operational unit for governance (Benson et al., 2015; Foster and Ait-Kadi, 2012; Lukat et al., 2022b; Saravanan et al., 2009), and promotes multi-level, multi-actor, and decentralized decision-making as core components of good governance, in order to ensure transparency and accountability (Rouillard et al., 2014). Finally, IWRM mostly undertakes a “control and predict” approach to water systems by de-politicizing water allocation issues through optimization models (Gerlak and Mukhtarov, 2015).

IWRM operationalization requires actions in four interdependent dimensions, codified by SDG 6.5.1, which is used to evaluate progress on implementation (Fig. 1). Under (1) "Enabling environment," IWRM calls

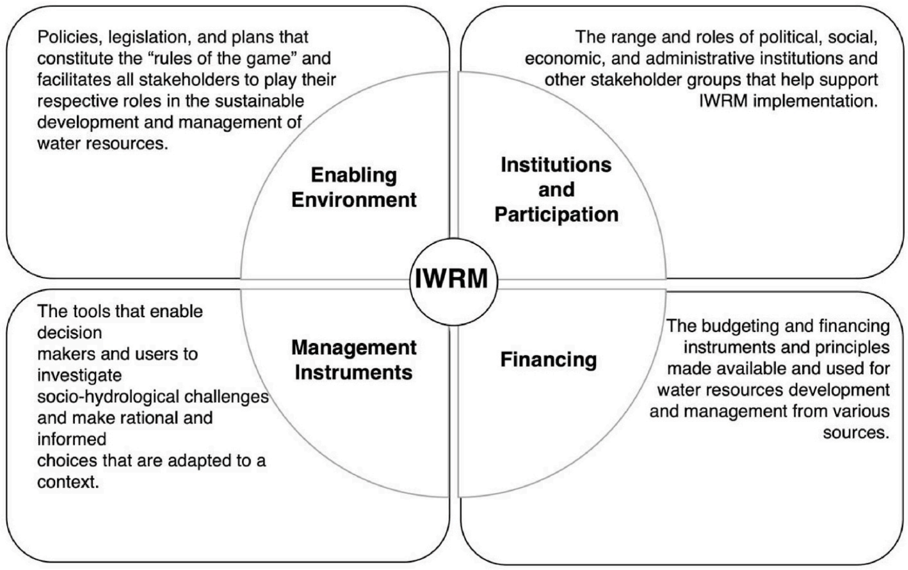


Fig. 1. Four dimensions of IWRM. Adapted from the GWP Toolbox: IWRM Action Hub: https://www.gwptoolbox.org/iwrm-explained.

for policies, legislative frameworks, and plans that set ground rules for the sustainable development and management of water resources. This is in line with research that advocates for effective regulatory regimes (Young, 2002) and well-designed and implemented policies (e.g., Kronvang et al., 2008; Reidsma et al., 2012; Steinebach, 2019, 2022) (Gollata and Newig, 2017; Knill et al., 2012) (Koutalakis et al., 2010; Steinebach, 2022). Under (2) "Institutions and participation," IWRM recognizes the significance of relevant political, socio-economic and administrative institutions as well as stakeholder coordination and alignment mechanisms being in place in such a way to support participatory water management. Strong institutions have been advocated for, both for understanding the major causes of biophysical changes and for responding to the underlying challenges (Young, 2002), including facilitating successful implementation (see, e.g. Lukat et al. (2022a) for an example of IWRM implementation in South Africa). Participatory and collaborative governance modes are advocated for by scholars and policymakers as a way to improve environmental outcomes of public decision-making by integrating local knowledge, representing environmental interests and increasing acceptability of decisions, leading to better compliance and implementation (Newig et al., 2018) (e.g., de Vente et al., 2016; Jager et al., 2020; Kochskämper et al., 2017). The next dimension of IWRM is (3) "Management instruments," which aims to equip decision-makers with the tools needed to make rational and informed choices and address water-related challenges based on a scientific understanding of socio-hydrological constraints. Finally, the (4) "Financing" dimension emphasizes the need for budgeting, financing instruments, principles and strategies to facilitate sustainable investments in water resources development and management across all levels. Governing the commons in a complex system requires capacities such as "providing information, dealing with conflict, inducing rule compliance, providing infrastructure, and being prepared for changes" (Dietz et al., 2003). In this regard, the latter two IWRM pillars contribute to the institutional capacity to design and maintain sustainable water resources management and development.

Notwithstanding its popularity, IWRM has also received broad criticism. Starting with the criticism of the overall paradigm, IWRM is argued to be quite a lofty and amorphous concept, which makes it difficult to establish a common understanding of what it means in operational terms, thus resulting in varying interpretations and implementation attempts (Biswas, 2004). To this end, there is a risk that many institutions and people continue to apply business-as-usual approaches under the framework (Biswas, 2008; Jewitt, 2002). IWRM as a "nirvana concept" is generally perceived as uncontroversial and desirable, while it can be turned into a discursive currency from which actors may cherry-pick in accordance with their interests and ideologies and then be used as a way to legitimize their own agendas (Molle, 2008). Thus, it is argued that more clarity and pragmatism are needed on the operationalization of IWRM to achieve balanced water management in terms of social, economic, and environmental outcomes (Foster and Ait-Kadi, 2012).

Despite the definition of IWRM as a "process," it is argued that it has become an end in itself by diverting focus away from real water problems to a goal of implementation, which makes it difficult for alternative thinking and solutions to thrive whilst at the same time possibly setting back the water reforms agenda (Giordano and Shah, 2014). To put it in other terms, it has been argued that the focus concerning IWRM has been mostly on the implementation of instruments rather than on the effects the whole approach yields (Lukat et al., 2022b). A growing focus on IWRM implementation as an end in itself also carries the risk of justifying business as usual through repackaging or masking other agendas (Giordano and Shah, 2014). As an international blueprint mainly shaped in the Global North, IWRM as a full package has been appropriated and implemented, regardless of the context, neglecting local peculiarities such as institutional legacies, sociocultural dynamics, and pre-existing inequalities (Butterworth et al., 2010; Lukat et al., 2022b). In this regard, its real impact in terms of improving water management has also been questioned (Biswas, 2004; Butterworth et al., 2010; Jeffrey and Gearey, 2006). Despite its popularity, the implementation of IWRM reforms has also faced conflicts and resistance in many developing countries due to a lack of contextuality and the perception of illegitimacy as a result of IWRM's inability to rally crucial stakeholders behind the integrated management idea (Al-Saidi, 2017).

Concerning the operationalization of its key features, major criticism has been levelled at the integrated and holistic approach to water management, coordination, the river basin as an operational unit, participatory decision-making and IWRM's ability to ensure the three Es, i.e., efficiency, equity, and environmental sustainability. As argued by Giordano and Shah (2014), holistic management is very costly and can be politically difficult. As far as the three Es are concerned, the goals are mostly in conflict, and making trade-offs is challenging, which leaves parties with relatively less power in a difficult position to achieve an optimal outcome (Molle, 2008). Furthermore, translating IWRM policy reforms on coordination across levels and scales does not necessarily ensure changes in policies or strategies on the ground, as political factors such as conflict, leadership, power, ideas and state capacity are argued to play decisive roles in this regard (Lukat et al., 2023). In addition, taking the river basin as the operational unit of IWRM is criticized as it legitimizes river basin master plans developed by consulting and construction companies, state agencies, or development banks (Molle, 2008).

Moreover, imposing institutionalization on a hydrological scale serves to encourage bureaucratic turf wars (Molle, 2008) and the legitimacy of these institutions faces challenges at a local level (Butterworth et al., 2010). Focusing on the basin scale has also been criticized as it results in certain limitations in water management, such as not resolving politically contested, complex and multi-scalar problems, where actors, institutions, and drivers are politically, temporarily or spatially far apart (de Loë and Patterson, 2017), the incorporation of groundwater resources (Foster and Ait-Kadi, 2012) and wetlands (Rebelo et al., 2013), and the management of water in rainfed agriculture (Rockström et al., 2010). Finally, as one of the core aspects of IWRM, the involvement of stakeholders in decision making has also drawn some criticism in literature, mainly regarding the degree of participation, stakeholder selection, weak mechanisms, and capacity in place to ensure participatory processes, as well as the risks of legitimizing existing access rights, marginalizing certain groups, reinforcing existing power structures and inequalities, and creating conflicts (Butterworth et al., 2010; Foster and Ait-Kadi, 2012; Lukat et al., 2022b; Saravanan, 2009; van Koppen et al., 2016).

Contrasting with these critical stances in literature, the benefits of IWRM are also acknowledged, including how its integration and participation features have played a significant role in improving the state of water resources around the world, how the concept brings multiple perceptions together through its focus on integration, as well as how it contributes to enhancing international legitimacy and acts as a premise for donors and funding agencies (Gerlak and Mukhtarov, 2015; Sauvage and Tremblay-Lévesque, 2021). Positive impacts of IWRM implementation have also been identified empirically despite evidence being extremely limited. For instance, Katusiime and Schütt (2020), in their study comparing the water resources governance aspects of two catchments in Uganda's Lake Albert basin, concluded that the performance of water resources governance was considerably better in the catchment as a result of IWRM practices. Considering the existing debate on the effectiveness of IWRM as a water governance paradigm, our study empirically explores the associations between IWRM implementation and water-related environmental sustainability indicators within SDG 6 at a global scale.

3. Methodology

To test the association between SDG 6.5.1 (both *IWRM (total score)* and the dimensions of SDG 6.5.1) (i.e., independent variables) and water-related environmental sustainability indicators within SDG 6 (i.e., dependent variables), we draw on open-source databases (see Table A1 in the Appendix). Data for IWRM (SDG 6.5.1) are extracted from the IWRM Data Portal (UNEP-DHI Centre on Water and Environment, 2020), which include the degree of overall IWRM implementation and that of its dimensions. SDG 6.5.1 is evaluated through a self-evaluation survey completed by UN Member States that includes 33 questions across the four aforementioned dimensions on a scale of 0–100 (UNEP-DHI Centre on Water and Environment, 2020). For water-related environmental sustainability indicators within SDG 6, we refer to SDG 6.2.1a (Access to basic sanitation), SDG 6.3.1 (Treated wastewater), SDG 6.3.2 (Water quality), SDG 6.4.1 (Water-use efficiency), SDG 6.4.2 (Water stress), and SDG 6.6.1 (Freshwater ecosystems, although we refer to two of the nine sub-indicators, namely Trophic state and Turbidity). The latter indicator relies on globally available datasets derived from both satellite observations and national-level in-situ monitoring (United Nations Environment Programme, 2020). We include the two aforementioned sub-indicators of SDG 6.6.1 in order to consider spatial and temporal data coverage and data reliability. Undertaking a complete case analysis, we select countries based on the availability of data for both these dependent and independent variables. While the sample for SDG 6.3.1 and SDG 6.3.2 includes 112 and 85 countries, respectively, data for the remaining SDG indicators covers 124 countries.

The control variables in our study are related to three broad categories, namely socio-political factors (i.e., regulatory quality, rule of law, government effectiveness, control of corruption, political stability and absence of violence or terrorism, voice and accountability, open data score, and population density), economic factors (GDP per capita), and environmental factors (i.e., relative forest area, average annual temperature change, national rainfall index (NRI) (mm/year), agricultural land area, and total harvested irrigated crop area).

We include governance-related variables (i.e., regulatory quality, rule of law, government effectiveness, control of corruption, political stability and absence of violence or terrorism, and voice and accountability) as control variables in our analysis, all sourced from the Worldwide Governance Indicators database (Kaufmann et al., 2010). These indicators have been extensively used in the prior literature exploring associations between governance and environmental performance (e.g., Dincă et al., 2022; Tan, 2006). For example, the study by Tan (2006) concluded that while the rule of law and government effectiveness are positively linked to improved air quality, on the other hand regulatory quality, the rule of law and voice and accountability positively effect improvements in water quality. Regarding the control of corruption, several previous studies have highlighted the negative association between corruption and environmental sustainability, in that an increase in corruption is linked to poorer environmental performance (Lisciandra and Migliardo, 2017; Lv and Gao, 2021; Sinha et al., 2019). A stable political environment is also associated with better environmental sustainability (Su et al., 2021; Sui et al., 2021). In their study, Su et al. (2021), focusing on Brazil, found that political stability was linked to reduced CO_2 emissions.

Finally, we also add the open data score as a proxy control variable for transparency. Transparency is believed to lead to enhanced accountability for environmental risks and harm, and it thereby forces actors to abide by regulatory goals, eventually linking to more sustainable performance (Clarkson et al., 2008; Halkos and Tzeremes, 2014). On the other hand, the study by Doan and Sassen (2020) identifies a weak and negative link between environmental performance and environmental reporting, indicating that poor environmental performers are more incentivized to enhance their disclosure levels compared to strong performers. Critics also argue that a transformative potential of transparency regarding substantive effects such as environmental improvements remains contested (Gupta et al., 2020; Haufler, 2010). Hereinafter, it is argued that there is a reverse causality between transparency and government outcomes, as the former follows advances in accountability and changes in environmental performance, rather than shaping them (Gupta, 2010). Despite these criticisms, we include the open data score as a control variable in our analysis, due to its significant correlation with our dependent variables. Along with governance-related factors, we also consider the role of economic factors and include GDP per capita as a proxy for wealth, facilitating provision of resources for public and private investments, which is claimed to be important for development (Norris, 2012). It can also be seen as an indicator for state capacity and hence the potential to put in place strong and effective policies.

The impacts on water-related sustainability of the remaining social and environmental factors—population density (Liyanage and Yamada, 2017; Tromboni et al., 2021), forest and agricultural land areas (e.g., Brogna et al., 2017; Liu et al., 2021; Tromboni et al., 2021), irrigation (e.g., Kammoun et al., 2021; Merchán et al., 2013), temperature (e.g., Huisman et al., 2018; Zhang et al., 2012), and rainfall (e.g., Sandoval et al., 2014; Shou et al., 2022)— have also been extensively studied in the prior literature. For example, the study by Tromboni et al. (2021), exploring land-use changes and its impact on the Lower Mekong Basin, concluded that deforestation, urbanization, and population density were associated with decreasing water quality in the area. For agricultural land area, the study by Liu et al. (2021), examining the association between landscape patterns and non-point source pollution distribution in Qixia County in China, indicates that cultivated land and orchards were mainly positively correlated with the water pollution level. In addition to agricultural land area, irrigation is also associated with changes in water resources, e.g., increases in the flow and amounts of salts and nitrates (Kammoun et al., 2021). Finally, it is argued that temperature and rainfall are linked to changes in both water quantity and quality, in that the sensitivity of hydrological processes to climatic changes in terms of temperature and rainfall has been emphasized previously (e.g., Chen et al., 2007; Legesse et al., 2003). Concerning water quality, while an increase in temperature is associated with the expansion of cyanobacterial blooms leading to eutrophication (Zhang et al., 2012), rainfall has been identified as a major predictor for non-point source pollution loads, according to Shou et al. (2022).

In order to explore the linkage between IWRM implementation and SDGs 6.2.1a (*Access to basic sanitation*) and 6.3.1 (*Treated wastewater*), we do not consider environmental factors due to their irrelevance, since improvements in both indicators are less dependent on environmental and more so on economic factors, as improvements to both sanitation services and wastewater treatment capacities require financing to be in place. Since some of the control variables have missing values, we use the MICE (Multivariate Imputation by Chained Equations) package in R for data imputation. All of the data were standardized before analysis.

We use multiple linear regression as the main method to estimate the association between IWRM-related variables (*IWRM (total score)* and the dimensions of SDG 6.5.1) and SDG 6 indicators related to water system health. For SDG 6.2.1a (*Access to basic sanitation*), we undertake ordinal logistic regression instead, as residuals are not normally distributed, even after transformation. The two other water quality-related indicators—SDG 6.3.2 (*Ambient water quality*) and SDG 6.6.1 (*Turbidity*)—do not show any significant association between any of the included variables; therefore, we exclude these two goals from our further analysis. We present the results for the ordinal logistic, linear, and elastic net linear regression models in Table A2 in the Appendix—with *IWRM (total score)* as an independent variable. In the Appendix (Table A3), we show models with all four IWRM dimensions as independent variables.

For each SDG 6 indicator related to water system health, we run several models, each investigating the effects of the control variables one by one. While model group 1 (i.e., models 1.1, 2.1, 3.1, etc.) explores only the association between independent and dependent variables, the remaining model groups also control for socio-political (model groups 2–9), economic (model group 10) and environmental (model groups 11–15) factors. While examining the variables, we observe that *Rule of law*, *Regulatory quality*, *Government effectiveness*, and *Control of corruption* are highly correlated. Therefore, we calculate an aggregated score (i.e., *Governance performance*) derived from the arithmetic average of these four scores and included as a control variable (model group 11 for SDG 6.2.1a (*Access to basic sanitation*) and SDG 6.3.1 (*Treated wastewater*), and model group 16 for the remaining SDGs). Where this score is significantly related to the dependent variable, we also include it in the last model. As controlling for all variables at once would lead to model overfitting, the last model group in all dependent variables controls for only significant variables. This model mainly serves our aim to explore whether the identified association between IWRM-related variables and dependent water-related environmental sustainability indicators would still hold when we accounted for all significant control variables. For analyses that had more than six control variables, we undertake elastic net linear regression, which is a regularized regression method that uses penalties from lasso and ridge techniques to regularize regression models and address the problem of overfitting (model group 17) (Zou and Hastie, 2005).

5. Results

5.1. IWRM implementation results

Comparing the reporting years of 2017 and 2020 for SDG 6.5.1 on the status of IWRM implementation (i.e., *IWRM (total score)*), we observe a 42% increase in the number of countries with medium-high, high, and very high implementation levels. Accordingly, countries with lower implementation levels decrease by 16% between the two years, accounting for 87 nations in 2020 in comparison to 104 in 2017. The global average SDG 6.5.1 indicator score also increases from 49 to 54%; however, 87 countries still have low or medium-low implementation levels. Furthermore, according to the Global Progress Report (UNEP, 2021), 107 countries, mainly in Latin America, the Caribbean, Oceania, Central and Southern Asia and sub-Saharan Africa, are not on track to achieve SDG target 6.5.1, with limited or moderate progress recorded between 2017 and 2020. Fig. 2 illustrates IWRM implementation (i.e., *IWRM (total score)*) levels by country for the year 2020. Concerning the SDG 6.5.1 scores for IWRM dimensions, the lowest average for the year 2020 is for *Financing* with a 46 score, while average scores for the remaining dimensions are all above 55. Respectively, the number of countries with very low, low and medium-low financing scores is reported to be 50% more than the number of countries with higher *Financing* scores. While for the remaining dimensions, the numbers of countries with a higher level of *Enabling environment*, *Institutions and participation*, and *Management instruments* are reported to be more than those with lower-level dimensions. The difference is more prominent in the case of *Institutions and participation* at 47%.

5.2. Regression analysis results and interpretation

All in all, the results of our regression analysis point toward a mostly positive association between IWRM-related variables and the good status of other water-related SDG 6 indicators. However, we observe a positive association with *Water stress* (SDG 6.4.2) and no significant association between the IWRM-related variables and two SDG 6 indicators, i.e., SDG 6.3.2 (*Water quality*) and SDG 6.6.1 (*Turbidity*). Across all models, relatively higher goodness-of-fits are in the models related to SDG 6.3.1 (*Treated wastewater*) and SDG 6.4.1 (*Water-use efficiency*) (i.e., models 2.2_MI and 2.4_MI with the highest adj. $R^2 = 0.61$), while the models with SDG 6.6.1 (*Trophic state*) as a dependent variable fall short in explaining a good deal of the variation (the highest adj. R^2 was 0.13 in all sub-models). Generally, adding control variables results in increased goodness-of-fit. However, we observe that some specific control variables have a dominant impact on the strength of association between certain water-related sustainability indicators of SDG 6 and IWRM-related variables: For SDG 6.2.1a (*Access to basic sanitation*), the significance for all IWRM-related variables disappears when controlling for *Government effectiveness* and *GDP per capita* (model groups 4 and 10). *GDP per capita* is also a dominant control variable in the case of SDG 6.4.1 (*Water-use efficiency*) and leads to the disappearance of significant effects for all IWRM-related variables (model group 10), with the exception of *Financing* (model 4.10_Fin). Finally, controlling for environmental factors such as *Forest* and *Temperature* results in insignificant association between SDG 6.4.2 (*Water stress*) and all IWRM-related variables, while the inclusion of *NRI* leads to the disappearance of any significant association with not only SDG 6.4.2 (*Water stress*) but also SDG 6.6.1 (*Trophic state*). The following sub-sections present the results for each SDG 6 indicator in more depth.

4.2.1. IWRM and access to basic sanitation

The regression shows that IWRM-related variables have a significant positive relationship with *Access to basic sanitation* (SDG 6.2.1a). However, this association only holds when we do not include any control variable while also controlling for *Voice and accountability* and *Population density*. In fact, the relationship disappears in model group 12,

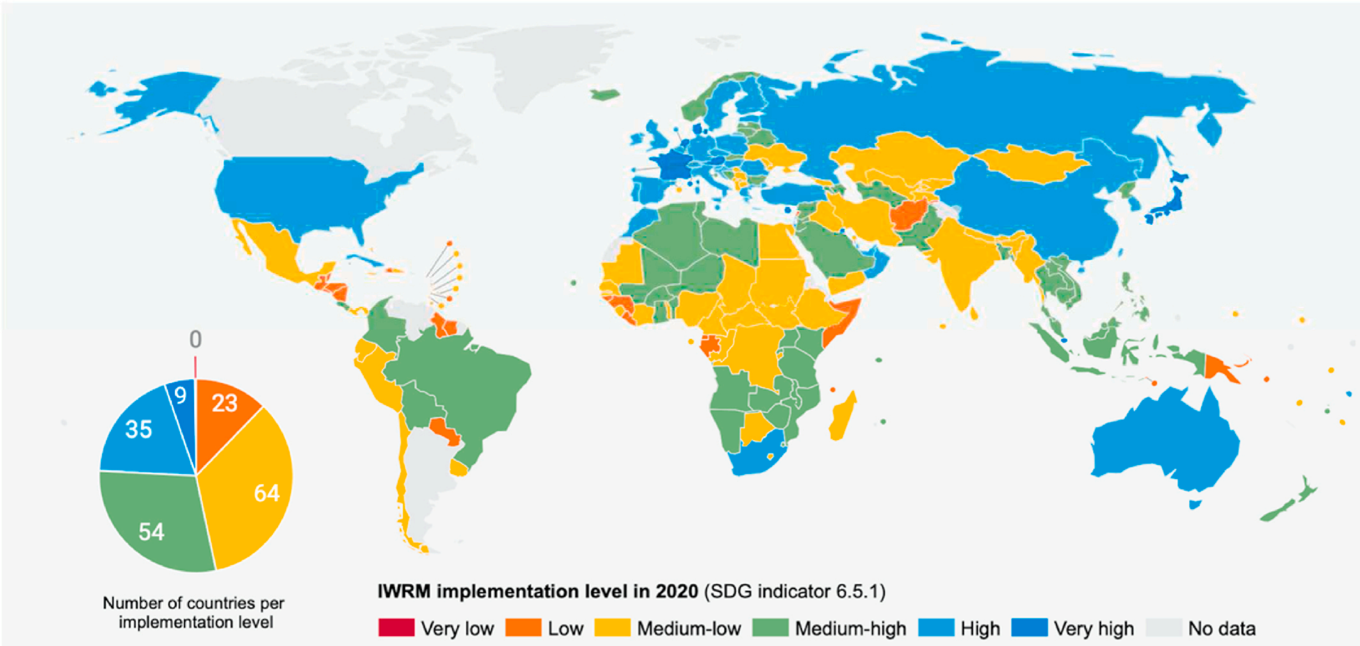


Fig. 2. IWRM implementation level in 2020. Source UNEP (2021).

controlling for all identified significant control variables at once, where *GDP per capita* is the strongest control variable for all IWRM-related variables. In addition, we observe that governance-related control variables in the model play an important role in terms of the association between all IWRM-related variables and SDG 6.2.1a; moreover, they lose their significance when controlling for *Government effectiveness* (model group 4). Controlling for *Regulatory quality* leads to the disappearance of significance in the cases of *IWRM (total score)*, *Enabling environment*, and *Institutions and participation* (models 1.2, 1.2_EE, 1.2_IP). Controlling for *Rule of law* and *Control of corruption* also makes *Financing* lose its significant relation in addition to IWRM-related variables mentioned previously (models 1.3_Fin and 1.5_Fin).

4.2.2. IWRM and treated wastewater

The regression results demonstrate a positive relationship between IWRM-related variables (*IWRM (total score)* and the dimensions of SDG 6.5.1) and *Treated wastewater* (SDG 6.3.1). Models with SDG 6.3.1 (*Treated wastewater*) as a dependent variable have the highest goodness-of-fit across all IWRM-related variables, in comparison with other dependent variables. The highest adj. R^2 (0.61) is in the case of *Management instruments* as a significant predictor of *Treated wastewater* ($ß_{MI} = 0.36^{***}$ and $ß_{MI} = 0.32^{***}$), controlling for the *Regulatory quality* ($ß_{Reg.qual} = 0.51^{***}$) (model 2.2_MI) and *Government effectiveness* ($ß_{Gov. Effect.} = 0.54^{***}$) (model 2.4_MI). All IWRM-related variables have significant positive effects in all models, as none of the control variables leads to the displacement of significant effects. Even controlling for all significant control variables at once, among which *Political stability* has comparatively more of an effect than other control variables, all IWRM-related variables still maintain their significant positive association with *Treated wastewater*, with the exception of *Enabling environment* (model 2.12_EE).

4.2.3. IWRM and water-use efficiency

The regression analysis results indicate that all IWRM-related variables are mainly positively associated with *Water-use efficiency* (SDG 6.4.1). Out of the SDG-related indicators we test for, SDG 6.4.1 (*Water-use efficiency*) has the second highest goodness-of-fit. We identify the highest adj. $R^2 = 0.57$ in the case of *Financing* ($ß_{Fin} = 0.12^{*}$) as an independent variable controlling for *GDP per capita* ($ß_{GDP.p.c.} = 0.42^{***}$) (model 4.10_Fin). Having an economy-oriented perspective, this indicator helps to measure to what extent countries' economic growth depends on the use of their water resources. In the models with individual control variables, all IWRM-related variables mostly have a significant and positive association with SDG 6.4.1. However, any significant association disappears when we include significant control variables (*GDP per capita* as the strongest one), with the exception of *Financing*, which is still identified as a significant and positive predictor of a change in *Water-use efficiency* over time (model 4.17_Fin). Across the models, we identify that governance-related control variables and *GDP per capita* play important roles in terms of associations between SDG 6.4.1 and independent variables. In this regard, while the inclusion of *Control of corruption* results in a loss of any significant effect for *Enabling environment* (model 4.5_EE), *Institutions and participation* (model 4.5_IP), and *Management instruments* (model 4.5_MI), controlling for *Rule of law*, *Government effectiveness*, and *GDP per capita* also leads to the displacement of a significant association for *IWRM (total score)* (models 4.3, 4.4, and 4.10) in addition to the aforementioned three dimensions (model groups 3, 4, and 10).

4.2.4. IWRM and water stress

Our regression analysis also points to the unexpected result that all IWRM-related variables are positively associated with *Water stress* (SDG 6.4.2). This suggests that this relationship might be due to a "reversed causality" in the sense that more water-stressed countries are inclined to place more emphasis on their IWRM implementation, especially on *Management instruments* and *Financing*. Supporting this assumption, model 5.11_MI with Management instruments ($ß_{ManInst} = 0.04^{***}$) and model 5.11_Fin with Financing ($ß_{Fin} = 0.04^{***}$) as independent variables controlling for *Forest* ($ß_{Forest} = -0.21^{***}$) are able to explain the highest percentage of variance in SDG 6.4.2 (adj. $R^2 = 0.22$). Unlike the previous dependent variables, for the case of SDG 6.4.2, environment-related control variables (*Forest, Temperature, NRI, Agricultural land area, and Irrigated crop area*) play more significant roles in the association between independent and dependent variables, leading to the disappearance of significant effects across all IWRM-related variables (model groups 11–15). As *Water stress* is more dependent on geographical and environmental factors, the strength of environment-related control variables in the models is as expected. In addition to environmental factors, the significance for all IWRM-related variables also disappears with the inclusion of *Population density*. Among the governance-related control variables, while the inclusion of *Government effectiveness* as a control variable results in the displacement of any significant association for *Enabling environment* (model 5.4_EE) and *Institutions and participation (*model 5.4_IP), controlling for *Open data score* leads to the displacement of a significant association for all IWRM-related variables (model group 8), with the exception of *Management instruments*. Similar to SDG 6.2.1a, all IWRM-related variables become insignificant when controlling for all significant control variables, where *Voice and accountability* has a higher coefficient compared to the other control variables (models 5.17, 5.17_EE, 5.17_IP, 5.17_MI, 5.17_Fin).

4.2.5. IWRM and trophic state

For SDG 6.6.1 (*Trophic state*), we identify mainly significant and negative associations with IWRM variables, indicating that IWRM implementation is associated with a better *Trophic state*. All models show very low goodness-of-fit, whilst among all models with *Trophic state* as a dependent variable, controlling for *Temperature* and *NRI* results in the highest adj. R^2 across all IWRM-related variables (0.13) (model groups 12 and 13). Similar to water stress, the inclusion of environment-related control variables—*Temperature* and *NRI*—leads to a loss of any significant association between all IWRM-related variables and *Trophic state*. In addition, the significance for all IWRM-related variables also disappears with the inclusion of *Open data score.* When we include all significant control variables (*Temperature* is the strongest control variable) in model group 17, we observe that the relationship between all IWRM-related variables and the *Trophic state* become insignificant.

7. Discussion

This study has provided insights into the effectiveness of the IWRM framework and whether it relates to better water-related environmental sustainability outcomes. In this section, we will discuss the results of this study, including how its findings fit with existing scholarly work.

One of the overarching findings of this study is that there is a mainly positive association between IWRM implementation and the good status of other SDG 6 indicators. To put it another way, results suggest that IWRM may be an effective approach to achieving the sustainable management of water resources and the good health of water systems and services. This finding is in line with previous empirical studies that show how introducing and applying an IWRM framework improves water management and the condition of water resources (Hidalgo and Peña, 2009; Katusiime and Schütt, 2020; Khadim et al., 2013; Leendertse et al., 2009). However, it should be acknowledged that in the presence of control variables, many identified effects of *IWRM (total score)* and the dimensions of SDG 6.5.1 on SDG 6 indicators become minor and statistically insignificant. In other words, there is a stronger impact of control variables on water-related environmental sustainability indicators, rather than by IWRM implementation. This observed pattern could support the assumption that SDG 6 indicator scores were shaped more by (a combination of) factors such as governance in place, economic strength, and environmental and geographical conditions rather than countries' progress in terms of IWRM implementation only.

Generally, the significance of context in water governance has been widely emphasized (Armitage et al., 2015; Ingram, 2011). As argued by Bressers and de Boer (2013), the successful transfer and implementation of a policy depends on the relationship between the context of its origin and the context of its application. Previous empirical studies are also in line with this argument and indicate that IWRM implementation might result in diverse impacts, while "success" goes beyond merely relying on IWRM features themselves (Jensen and Nair, 2019; Mersha et al., 2018; Rouillard et al., 2014). Considering the importance of contextual factors, which is also identified in our analysis, there is a need for a more comprehensive approach to water governance that places it within the wider social-ecological and political-economic contexts and dynamics (de Loë and Patterson, 2017).

The results also show that the degree of association between *IWRM (total score)* and the dimensions of SDG 6.5.1 and different water-related environmental SDG 6 indicators varies. Such variance may result from several factors. One of the explanations for this variance could be a lagged effect. This assumption might be especially relevant for indicators measuring water quality, such as SDGs 6.3.2 (*Water quality*), 6.6.1 (*Trophic state*), and 6.6.1 (*Turbidity*), as observing changes in water resources related to governance interventions would require a longer time to complete, compared to indicators such as SDG 6.3.1 (*Treated wastewater*). Generally, social-ecological challenges including the deterioration of water bodies are considered long-term policy problems, since the effects of policy measures might extend beyond one human generation (Underdal, 2010). The length of lag time may differ based on the pollutant and location, with a range of a few months to years for short-lived contaminants, several years to decades for excessive phosphorous levels, and decades or even longer for sediment accumulation in river systems or due to groundwater travel time (Meals et al., 2010). Therefore, it is usually a daunting task to assess the impact of governance interventions on pollutants over a short time span. Previous studies have also examined and discussed the lag time between management practices and changes in water quality (Ascott et al., 2021; Hamilton, 2012; McDowell et al., 2021; Mueller et al., 2015). The identified absence of a very weak association between IWRM implementation and water quality-related indicators in our analysis could serve as evidence to further these earlier discussions. Addressing such inevitable lagged effects would require the design of policy measures and monitoring programs that account for possible delays between policy or management interventions and the response of a water system (Ascott et al., 2021; Meals et al., 2010).

Connected to time lags between governance interventions and environmental changes, our results also show that indicators for which improvement is less dependent on environmental rather than socio-economic systems have stronger associations with IWRM-related variables. For instance, models depicting associations between the IWRM-related variables and SDGs 6.3.1 (*Treated wastewater*) and 6.4.1 (*Water-use efficiency*) have higher goodness-of-fit, explaining at least 18% of the variation, while the explanatory power of models in the case, for example, of SDGs 6.4.2 (*Water stress*) and 6.6.1 (*Trophic state*) is considerably lower. Our findings suggest that improvements in those indicators that tackle fewer complexities and uncertainties may be attained relatively more rapidly through effective policy interventions—as compared to other indicators that rely on more complex social-ecological interactions. This is also in line with earlier findings by Kirschke et al. (2017). Water-related challenges are multifaceted, complex, and intertwined, making it difficult to solve one issue in isolation with a linear, short-term approach, often leading to the emergence of new problems (Di Baldassarre et al., 2019). It is argued that the complexity of a problem, caused by various dimensions and sources, can impede problem-solving efforts, and even challenge the possibility of finding solutions, due to conflicting stakeholder interests and the interconnectedness of social, ecological and technical factors leading to delayed adverse side effects (Kirschke and Newig, 2021).

Finally, the varying degrees of association between IWRM-related variables and other SDG 6 indicators in this study could also be related to the scope of IWRM implementation. For instance, while SDG 6.2.1a (*Access to basic sanitation*) is included in our analysis to account for potential pollution from leaching linked to open defecation, this indicator is not explicitly covered by IWRM, unlike other indicators. As previously stated, most of the models exploring the relationship between IWRM-related variables and SDG 6.2.1a do not yield a significant association. Hence, the absence of a direct link between the scope of IWRM implementation and some of the other SDG 6 indicators (i.e., SDG 6.2.1a (*Access to basic sanitation*)) may serve as one of the explanations for variances in the degree of associations for this dependent variable.

8. Conclusion

Using regression analysis, the main question addressed in this paper is to what extent the IWRM framework, in interaction with contextual factors, is associated with the achievement of water-related environmental sustainability indicators within SDG 6. Our results reveal that the degree of IWRM implementation (both *IWRM (total score)* and the dimensions of SDG 6.5.1)—to different degrees—is mainly associated with the good status of water-related environmental sustainability indicators. We find associations between SDG 6.5.1 and SDG indicators 6.2.1a (*Access to basic sanitation*), 6.3.1 (*Treated wastewater*), 6.4.1 (*Water-use efficiency*), SDG 6.4.2 (*Water stress*), and 6.6.1 (*Trophic state*), but not with SDG 6.3.2 (*Water quality*) and SDG 6.6.1 (*Turbidity*). Results also show that there is a strong impact of control variables, such as governance in place, economic situation and environmental and geographical conditions, on the studied associations.

The findings of this study have to be seen in light of three major limitations that could be addressed in future research. First, this study provides insights by drawing on country-level performance across water-related SDG indicators (SDG 6.5.1 on IWRM implementation and various water-related environmental sustainability indicators measured under SDG 6). We acknowledge that making a statement regarding the causality between IWRM-related variables and other SDG 6 indicators should be treated carefully due to complexities embedded in socio-ecological systems, especially with an analysis on a global scale. Through our broad approach to analyzing the association between IWRM and its dimensions and other SDG 6 indicators at the national level, the results presented herein can serve as a proxy and guide further in-depth analyses. In this regard, causal pathways between IWRM implementation and water-related environmental sustainability indicators could be unpacked, for example by means of comparative in-depth case studies and drawing on qualitative methodologies, which would also address possible case-specific, socio-ecological complexities.

Secondly, this study has a limitation in its ability to account for potential lagged effects between IWRM implementation and actual changes in water systems connected to governance interventions. Accounting for possible lagged effects and studying changes over time would require the availability of datasets that contain observations over multiple time periods. However, such datasets are not currently available for both SDG 6.5.1 and most of the SDG 6 indicators on a global scale. Future research can identify the presence and magnitude of lagged effects, for example through longitudinal analyses and causal process tracing with a small sample size, and examine the relationship between IWRM-related variables and other SDG 6 indicators over time.

The final limitation in this study is related to data. We acknowledge that the data for our study needs to be treated with caution with respect to issues of data quality. Especially in the case of SDG 6.5.1, data collection is based on a self-assessment survey approach, which has certain limitations such as objectivity, transparency, and comparability of the results, according to Bertule et al. (2018). In this regard, Benson et al. (2020) argue that the current practice of assessing the Enabling Environment, Institutions and Participation, Management Tools and Financing for the IWRM framework is highly subjective, particularly considering the absence of the operationalization of the IWRM concept, while the survey can result in different meanings to different groups of stakeholders. While the SDG 6 IWRM Support Programme (https://www.gwp.org/en/sdg6support/) has managed to help 72 countries so far to self-report more accurately by convening multiple stakeholders to share their perspectives on the dimensions of IWRM, the majority have so far not been involved. To this end, while beyond the scope of this paper, future research may seek to validate the results presented herein and further unpack causality through small-N in-depth case studies.

Credit author statement

Shahana Bilalova: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Project administration. Jens Newig: Conceptualization, Methodology, Investigation, Writing – review & editing, Supervision. Laurent-Charles Tremblay-Lévesque: Conceptualization, Methodology, Writing – review & editing, Investigation, Supervision. Julienne Roux: Conceptualization, Methodology, Investigation, Writing – review & editing. Colin Herron: Conceptualization, Methodology, Investigation, Writing – review & editing. Stuart Crane: Conceptualization, Investigation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Laurent-Charles Tremblay-Levesque, Julienne Roux, Colin Herron report a relationship with Global Water Partnership that includes: employment. Stuart Crane reports a relationship with United Nations Environment Programme that includes: employment.

Data availability

The data that support the findings of this study were derived from the resources available online. Detailed information can be found in the supplementary material of this article.

Acknowledgements

The views and opinions expressed in this paper are those of the authors and do not necessarily reflect the views or positions of the institutions they represent. The authors acknowledge funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie Innovative Training Network NEWAVE – grant agreement no. 861509.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2023.118179.

References

Al-Saidi, M., 2017. Conflicts and security in integrated water resources management. Environ. Sci. Pol. 73, 38–44. https://doi.org/10.1016/j.envsci.2017.03.015.

Allouche, J., 2017. The birth and spread of IWRM - a case study of global policy diffusion and translation. Flows Pract. Polit. Integr. Water Resour. Manag. East. South. Africa 9, 30–56. https://doi.org/10.2307/j.ctvh8r2qk.5.

Armitage, D., De Loë, R.C., Morris, M., Edwards, T.W.D., Gerlak, A.K., Hall, R.I., Huitema, D., Ison, R., Livingstone, D., Macdonald, G., Mirumachi, N., Plummer, R., Wolfe, B.B., 2015. Royal Swedish Academy of Sciences Science-policy processes for transboundary water governance. Source: Ambio 44, 353–366. https://doi.org/10.1007/s13280-015-0644-x.

Ascott, M.J., Gooddy, D.C., Fenton, O., Vero, S., Ward, R.S., Basu, N.B., Worrall, F., Van Meter, K., Surridge, B.W.J., 2021. The need to integrate legacy nitrogen storage dynamics and time lags into policy and practice. Sci. Total Environ. 781, 146698 https://doi.org/10.1016/j.scitotenv.2021.146698.

Benson, D., Gain, A.K., Giupponi, C., 2020. Moving beyond water centricity? Conceptualizing integrated water resources management for implementing sustainable development goals. Sustain. Sci. 15, 671–681. https://doi.org/10.1007/s11625-019-00733-5.

Benson, D., Gain, A.K., Rouillard, J.J., 2015. Water governance in a comparative perspective: from IWRM to a "nexus" approach? Water Altern. (WaA) 8, 756–773.

Bertule, M., Glennie, P., Bjørnsen, P.K., Lloyd, G.J., Kjellen, M., Dalton, J., Rieu-Clarke, A., Romano, O., Tropp, H., Newton, J., Harlin, J., 2018. Monitoring water resources governance progress globally: experiences from monitoring SDG indicator 6.5.1 on integrated water resources management implementation. Water 10, 1744. https://doi.org/10.3390/w10121744.

Biswas, A.K., 2008. Integrated water resources management: is it working? Int. J. Water Resour. Dev. 24, 5–22. https://doi.org/10.1080/07900620701871718.

Biswas, A.K., 2004. Integrated water resources management: a reassessment: a water forum contribution. Water Int. 29, 248–256. https://doi.org/10.1080/02508060408691775.

Bressers, H., de Boer, C., 2013. Contextual Interaction Theory for assessing water governance, policy and knowledge transfer. Water Governance, Policy Knowl.

Transf. Int. Stud. Context. Water Manag. 36–54. https://doi.org/10.4324/9780203102992.

Brogna, D., Michez, A., Jacobs, S., Dufrêne, M., Vincke, C., Dendoncker, N., 2017. Linking forest cover to water quality: a multivariate analysis of large monitoring datasets. Water 9, 176. https://doi.org/10.3390/w9030176.

Butterworth, J., Warner, J., Moriarty, P., Smits, S., Batchelor, C., 2010. Finding practical approaches to integrated water resources management. Water Altern. (WaA) 3, 68–81.

Challies, E., Newig, J., 2022. Water, rivers and wetlands. In: Routledge Handbook of Global Environmental Politics. Routledge, London, pp. 512–525. https://doi.org/10.4324/9781003008873-43.

Chen, H., Guo, S., Xu, C., Singh, V.P., 2007. Historical temporal trends of hydro-climatic variables and runoff response to climate variability and their relevance in water resource management in the Hanjiang basin. J. Hydrol. 344, 171–184. https://doi.org/10.1016/j.jhydrol.2007.06.034.

Clarkson, P.M., Li, Y., Richardson, G.D., Vasvari, F.P., 2008. Revisiting the relation between environmental performance and environmental disclosure: an empirical analysis. Account. Org. Soc. 33, 303–327. https://doi.org/10.1016/j.aos.2007.05.003.

Davis, M.D., 2007. Integrated water resource management and water sharing (2007)133: 5(427). J. Water Resour. Plann. Manag. 133, 427–445. https://doi.org/10.1061/(ASCE)0733-9496(2007)133:5(427).

de Loë, R.C., Patterson, J.J., 2017. Rethinking water governance: moving beyond water-centric perspectives in a connected and changing world. Nat. Resour. J. 57, 75–99.

de Vente, J., Reed, M.S., Stringer, L.C., Valente, S., Newig, J., 2016. How does the context and design of participatory decision making processes affect their outcomes? Evidence from sustainable land management in global drylands. Ecol. Soc. 21, 24. https://doi.org/10.5751/ES-08053-210224.

Di Baldassarre, G., Sivapalan, M., Rusca, M., Cudennec, C., Garcia, M., Kreibich, H., Konar, M., Mondino, E., Mård, J., Pande, S., Sanderson, M.R., Tian, F., Viglione, A., Wei, J., Wei, Y., Yu, D.J., Srinivasan, V., Blöschl, G., 2019. Sociohydrology: scientific challenges in addressing the sustainable development goals. Water Resour. Res. 55, 6327–6355. https://doi.org/10.1029/2018WR023901.

Dietz, T., Ostrom, E., Stern, P.C., 2003. The struggle to govern the commons. Science 84 302, 1907–1912. https://doi.org/10.1126/science.1091015.

Dincă, G., Bărbuță, M., Negri, C., Dincă, D., Model, L.S., 2022. The impact of governance quality and educational level on environmental performance. Front. Environ. Sci. 10, 1–15. https://doi.org/10.3389/fenvs.2022.950683.

Doan, M.H., Sassen, R., 2020. The relationship between environmental performance and environmental disclosure: a meta-analysis. J. Ind. Ecol. 24, 1140–1157. https://doi.org/10.1111/jiec.13002.

Foster, S., Ait-Kadi, M., 2012. Integrated water resources management (IWRM): how does groundwater fit in? Hydrogeol. J. 20, 415–418. https://doi.org/10.1007/s10040-012-0831-9.

García, L.E., 2008. Integrated water resources management: a “small” step for conceptualists, a giant step for practitioners. Int. J. Water Resour. Dev. 24, 23–36. https://doi.org/10.1080/07900620701723141.

Gerlak, A.K., Mukhtarov, F., 2015. ‘Ways of knowing’ water: integrated water resources management and water security as complementary discourses. Int. Environ. Agreements Polit. Law Econ. 15, 257–272. https://doi.org/10.1007/s10784-015-9278-5.

Giordano, M., Shah, T., 2014. From IWRM back to integrated water resources management. Int. J. Water Resour. Dev. 30, 364–376. https://doi.org/10.1080/07900627.2013.851521.

Gollata, J.A.M., Newig, J., 2017. Policy implementation through multi-level governance: analysing practical implementation of EU air quality directives in Germany. J. Eur. Publ. Pol. 24, 1308–1327. https://doi.org/10.1080/13501763.2017.1314539.

Gordon, R.A., 2015. Examples of social science research using regression analysis. In: Regression Analysis for the Social Sciences. Routledge, pp. 4–28.

Gupta, A., 2010. Transparency in global environmental governance: a coming of age? Global Environ. Polit. 10, 1–9. https://doi.org/10.1162/GLEP_e_00011.

Gupta, A., Boas, I., Oosterveer, P., 2020. Transparency in global sustainability governance: to what effect? J. Environ. Pol. Plann. 22, 84–97. https://doi.org/10.1080/1523908X.2020.1709281.

Halkos, G.E., Tzeremes, N.G., 2014. Public sector transparency and countries' environmental performance: a nonparametric analysis. Resour. Energy Econ. 38, 19–37. https://doi.org/10.1016/j.reseneeco.2014.06.001.

Hamilton, S.K., 2012. Biogeochemical time lags may delay responses of streams to ecological restoration. Freshw. Biol. 57, 43–57. https://doi.org/10.1111/j.1365-2427.2011.02685.x.

Haufler, V., 2010. Disclosure as governance: the extractive industries transparency initiative and resource management in the developing world. Global Environ. Polit. 10, 53–73. https://doi.org/10.1162/GLEP_a_00014.

Hidalgo, J., Peña, H., 2009. Turning water stress into water management success: experiences in the lerma–chapala river basin. In: Lenton, R., Muller, M. (Eds.), Integrated Water Resources Management in Practice: Better Water Management for Development. Routledge, London, pp. 107–121.

Huisman, J., Codd, G.A., Paerl, H.W., Ibelings, B.W., Verspagen, J.M.H., Visser, P.M., 2018. Cyanobacterial blooms. Nat. Rev. Microbiol. 16, 471–483. https://doi.org/10.1038/s41579-018-0040-1.

Ingram, H., 2011. Beyond universal remedies for good water governance: a political and contextual approach. In: Garrido, A., Ingram, H. (Eds.), Water for Food in a Changing World. Routledge, p. 21. https://doi.org/10.4324/9780203828410.

Jager, N.W., Newig, J., Challies, E., Kochskämper, E., 2020. Pathways to implementation: evidence on how participation in environmental governance impacts on environmental outcomes. J. Publ. Adm. Res. Theor. 30, 383–399. https://doi.org/10.1093/jopart/muz034.

Jeffrey, P., Gearey, M., 2006. Integrated water resources management: lost on the road from ambition to realisation? Water Sci. Technol. 53, 1–8. https://doi.org/10.2166/wst.2006.001.

Jensen, O., Nair, S., 2019. Integrated Urban Water Management and Water Security: A Comparison of Singapore and Hong Kong. Water 11, 785. https://doi.org/10.3390/w11040785.

Jewitt, G., 2002. Can Integrated Water Resources Management sustain the provision of ecosystem goods and services? Phys. Chem. Earth 27, 887–895. https://doi.org/10.1016/S1474-7065(02)00091-8.

Kammoun, S., Trabelsi, R., Re, V., Zouari, K., 2021. Coastal aquifer salinization in semi-arid regions: the case of grombalia (Tunisia). Water 13, 129. https://doi.org/10.3390/w13020129.

Katusiime, J., Schütt, B., 2020. Integrated water resources management approaches to improve water resources governance. Water 12, 3424. https://doi.org/10.3390/w12123424.

Khadim, F.K., Kar, K.K., Halder, P.K., Rahman, M.A., Morshed, A.K.M.M., 2013. Integrated water resources management (IWRM) impacts in South west coastal zone of Bangladesh and fact-finding on tidal river management (TRM). J. Water Resour. Protect. 5, 953–961. https://doi.org/10.4236/jwarp.2013.510098.

Kirschke, S., Newig, J., 2021. Complexity in water management and governance. In: Handbook of Water Resources Management: Discourses, Concepts and Examples. Springer International Publishing, Cham, pp. 801–810. https://doi.org/10.1007/978-3-030-60147-8_25.

Kirschke, S., Newig, J., Völker, J., Borchardt, D., 2017. Does problem complexity matter for environmental policy delivery? How public authorities address problems of water governance. J. Environ. Manag. 196, 1–7. https://doi.org/10.1016/j.jenvman.2017.02.068.

Knill, C., Schulze, K., Tosun, J., 2012. Regulatory policy outputs and impacts: exploring a complex relationship. Regul. Gov. 6, 427–444. https://doi.org/10.1111/j.1748-5991.2012.01150.x.

Kochskämper, E., Jager, N.W., Newig, J., Challies, E., 2017. Impact of participation on sustainable water management planning. In: Participation for Effective Environmental Governance. Routledge, pp. 117–148. https://doi.org/10.4324/9781315193649-7.

Koutalakis, C., Buzogany, A., Börzel, T.A., 2010. When soft regulation is not enough: the integrated pollution prevention and control directive of the European Union. Regul. Gov. 4, 329–344. https://doi.org/10.1111/j.1748-5991.2010.01084.x.

Kronvang, B., Andersen, H.E., Børgesen, C., Dalgaard, T., Larsen, S.E., Bøgestrand, J., Blicher-Mathiasen, G., 2008. Effects of policy measures implemented in Denmark on nitrogen pollution of the aquatic environment. Environ. Sci. Pol. 11, 144–152. https://doi.org/10.1016/j.envsci.2007.10.007.

Lankford, B., Merrey, D., Cour, J., Hepworth, N., 2007. From integrated to expedient: an adaptive framework for river basin management in developing countrieas. In: IWMI Research Reports, H040223. International Water Management Institute.

Leendertse, K., Mitchell, S., Harlin, J., 2009. IWRM and the environment: a view on their interaction and examples where IWRM led to better environmental management in developing countries. WaterSA 34, 691–698. https://doi.org/10.4314/wsa.v34i6.183671.

Legesse, D., Vallet-Coulomb, C., Gasse, F., 2003. Hydrological response of a catchment to climate and land use changes in Tropical Africa: case study South Central Ethiopia. J. Hydrol. 275, 67–85. https://doi.org/10.1016/S0022-1694(03)00019-2.

Lisciandra, M., Migliardo, C., 2017. An empirical study of the impact of corruption on environmental performance: evidence from panel data. Environ. Resour. Econ. 68, 297–318. https://doi.org/10.1007/s10640-016-0019-1.

Liu, Y., Yang, C., Yu, X., Wang, M., Qi, W., 2021. Monitoring the landscape pattern and characteristics of non-point source pollution in a mountainous river basin. Int. J. Environ. Res. Publ. Health 18, 11032. https://doi.org/10.3390/ijerph182111032.

Liyanage, C., Yamada, K., 2017. Impact of population growth on the water quality of natural water bodies. Sustainability 9, 1405. https://doi.org/10.3390/su9081405.

Lubell, M., Edelenbos, J., 2013. Integrated water resources management: a comparative laboratory for water governance. Int. J. Water Gov. 1, 177–196. https://doi.org/10.7564/13-ijwg14.

Lukat, E., Lenschow, A., Dombrowsky, I., Meergans, F., Schütze, N., Stein, U., Pahl-Wostl, C., 2023. Governance towards coordination for integrated water resources management: the effect of governance modes. Unpubl. Manuscr. 141, 50–60. https://doi.org/10.1016/j.envsci.2022.12.016.

Lukat, E., Pahl-Wostl, C., Lenschow, A., 2022a. Deficits in implementing integrated water resources management in South Africa: the role of institutional interplay. Environ. Sci. Pol. 136, 304–313. https://doi.org/10.1016/j.envsci.2022.06.010.

Lukat, E., Schoderer, M., Castro Salvador, S., 2022b. When international blueprints hit local realities: bricolage processes in implementing IWRM in South Africa, Mongolia, and Peru. Water Altern. (WaA) 15, 473–500.

Lv, Z., Gao, Z., 2021. The effect of corruption on environmental performance: does spatial dependence play a role? Econ. Syst. 45, 100773 https://doi.org/10.1016/j.ecosys.2020.100773.

McDowell, R.W., Simpson, Z.P., Ausseil, A.G., Etheridge, Z., Law, R., 2021. The implications of lag times between nitrate leaching losses and riverine loads for water quality policy. Sci. Rep. 11, 1–14. https://doi.org/10.1038/s41598-021-95302-1.

Meals, D.W., Dressing, S.A., Davenport, T.E., 2010. Lag time in water quality response to best management practices: a review. J. Environ. Qual. 39, 85–96. https://doi.org/10.2134/jeq2009.0108.

Merchán, D., Causapé, J., Abrahão, R., 2013. Impact of irrigation implementation on hydrology and water quality in a small agricultural basin in Spain. Hydrol. Sci. J. 58, 1400–1413. https://doi.org/10.1080/02626667.2013.829576.

Mersha, A.N., Masih, I., de Fraiture, C., Wenninger, J., Alamirew, T., 2018. Evaluating the Impacts of IWRM Policy Actions on Demand Satisfaction and Downstream Water Availability in the Upper Awash Basin, Ethiopia. Water 10, 892. https://doi.org/10.3390/w10070892.

Molle, F., 2008. Nirvana concepts, narratives and policy models: insights from the water sector. Water Altern. (WaA) 1, 131–156.

Mueller, H., Hamilton, D.P., Doole, G.J., 2015. Response lags and environmental dynamics of restoration efforts for Lake Rotorua, New Zealand. Environ. Res. Lett. 10 https://doi.org/10.1088/1748-9326/10/7/074003.

Newig, J., Challies, E., Jager, N.W., Kochskaemper, E., Adzersen, A., 2018. The environmental performance of participatory and collaborative governance: a framework of causal mechanisms. Pol. Stud. J. 46, 269–297. https://doi.org/10.1111/psj.12209.

Norris, P., 2012. Welfare. In: Making Democratic Governance Work : How Regimes Shape Prosperity, Welfare, and Peace. Cambridge University Press, New York, pp. 135–163.

Rebelo, L.-M., Johnston, R., Hein, T., Weigelhofer, G., D'Haeyer, T., Kone, B., Cools, J., 2013. Challenges to the integration of wetlands into IWRM: the case of the inner Niger delta (Mali) and the lobau floodplain (Austria). Environ. Sci. Pol. 34, 58–68. https://doi.org/10.1016/j.envsci.2012.11.002.

Reidsma, P., Feng, S., van Loon, M., Luo, X., Kang, C., Lubbers, M., Kanellopoulos, A., Wolf, J., van Ittersum, M.K., Qu, F., 2012. Integrated assessment of agricultural land use policies on nutrient pollution and sustainable development in Taihu Basin, China. Environ. Sci. Pol. 18, 66–76. https://doi.org/10.1016/j.envsci.2012.01.003.

Rockström, J., Karlberg, L., Wani, S.P., Barron, J., Hatibu, N., Oweis, T., Bruggeman, A., Farahani, J., Qiang, Z., 2010. Managing water in rainfed agriculture—the need for a paradigm shift. Agric. Water Manag. 97, 543–550. https://doi.org/10.1016/j.agwat.2009.09.009.

Rouillard, J.J., Benson, D., Gain, A.K., 2014. Evaluating IWRM implementation success: are water policies in Bangladesh enhancing adaptive capacity to climate change impacts? Int. J. Water Resour. Dev. 30, 515–527. https://doi.org/10.1080/07900627.2014.910756.

Sandoval, S., Torres, A., Duarte, M., Velasco, A., 2014. Assessment of rainfall influence over water quality effluent of an urban catchment: a data driven approach. Urban Water J. 11, 116–126. https://doi.org/10.1080/1573062X.2013.765492.

Saravanan, V.S., 2009. Decentralisation and water resources management in the indian himalayas: the contribution of new institutional theories. Conserv. Soc. 7, 176–191. https://doi.org/10.4103/0972-4923.64735.

Saravanan, V.S., Mcdonald, G.T., Mollinga, P.P., 2009. Critical review of integrated water resources management: moving beyond polarised discourse. Nat. Resour. Forum 33, 76–86. https://doi.org/10.1111/j.1477-8947.2009.01210.x.

Sauvage, N.B., Tremblay-Lévesque, L.-C., 2021. Multi-Stakeholder Consultation Processes for SDG 6 Monitoring.

Sen, A., Srivastava, M., 1990. Introduction. In: Regression Analysis. Springer Texts in Statistics. Springer, New York, NY, pp. 1–27. https://doi.org/10.1007/978-1-4612-4470-7_1.

Shou, C.-Y., Tian, Y., Zhou, B., Fu, X.-J., Zhu, Y.-J., Yue, F.-J., 2022. The effect of rainfall on aquatic nitrogen and phosphorus in a semi-humid area catchment, northern China. Int. J. Environ. Res. Publ. Health 19, 10962. https://doi.org/10.3390/ijerph191710962.

Sinha, A., Gupta, M., Shahbaz, M., Sengupta, T., 2019. Impact of corruption in public sector on environmental quality: implications for sustainability in BRICS and next 11 countries. J. Clean. Prod. 232, 1379–1393. https://doi.org/10.1016/j.jclepro.2019.06.066.

Steinebach, Y., 2019. Water Quality and the Effectiveness of European Union Policies. Water 11, 2244. https://doi.org/10.3390/w11112244.

Steinebach, Y., 2022. Instrument choice, implementation structures, and the effectiveness of environmental policies: a cross-national analysis. Regul. Gov. 16, 225–242. https://doi.org/10.1111/rego.12297.

Su, Z.-W., Umar, M., Kirikkaleli, D., Adebayo, T.S., 2021. Role of political risk to achieve carbon neutrality: evidence from Brazil. J. Environ. Manag. 298, 113463 https://doi.org/10.1016/j.jenvman.2021.113463.

Sui, B., Chang, C.-P., Chu, Y., 2021. Political stability: an impetus for spatial environmental spillovers. Environ. Resour. Econ. 79, 387–415. https://doi.org/10.1007/s10640-021-00568-8.

Tan, X., 2006. Environment, governance and GDP: discovering their connections. Int. J. Sustain. Dev. 9, 311–335. https://doi.org/10.1504/IJSD.2006.014218.

Tromboni, F., Dilts, T.E., Null, S.E., Lohani, S., Ngor, P.B., Soum, S., Hogan, Z., Chandra, S., 2021. Changing land use and population density are degrading water quality in the lower Mekong Basin. Water 13, 1948. https://doi.org/10.3390/w13141948.

Underdal, A., 2010. Complexity and challenges of long-term environmental governance. Global Environ. Change 20, 386–393. https://doi.org/10.1016/j.gloenvcha.2010.02.005.

United Nations Environment Programme, 2020. Measuring Change in the Extent of Water-Related Ecosystems over Time: Sustainable Development Goal Monitoring Methodology Indicator 6, vol. 6, p. 1.

van Koppen, B., Tarimo, A., van Eeden, A., Manzungu, E., Sumuni, P., 2016. Winners and losers of IWRM in Tanzania. Water Altern. (WaA) 9, 588–607.

Young, O.R., 2002. Environmental change: institutional drivers, institutional responses. In: The Institutional Dimensions of Environmental Change: Fit, Interplay, and Scale. The MIT Press, pp. 3–28. https://doi.org/10.7551/mitpress/3807.001.0001.

Zhang, M., Duan, H., Shi, X., Yu, Y., Kong, F., 2012. Contributions of meteorology to the phenology of cyanobacterial blooms: implications for future climate change. Water Res. 46, 442–452. https://doi.org/10.1016/j.watres.2011.11.013.

Zou, H., Hastie, T., 2005. Regularization and variable selection via the elastic net. J. R. Stat. Soc. Ser. B (Statistical Methodol.) 67, 301–320.

Supplementary material for: Pathways to water sustainability? A global study assessing the benefits of integrated water resources management

Table A1 Description of variables used in a statistical analysis.

Variables	Definition	Source	Year
Independent variables			
(1) IWRM (total score)	IWRM total score: Degree of integrated water resources management implementation (0–100%), aggregated score	UNEP-DHI IWRM Data Portal	2020
(2) EE	IWRM sub-component: Enabling environment (laws, policies, and plans) (0–100%)	UNEP-DHI IWRM Data Portal	2020
(3) IP	IWRM sub-component: Institutions and participation (0–100%)	UNEP-DHI IWRM Data Portal	2020
(4) MI	IWRM sub-component: Management instruments (0–100%)	UNEP-DHI IWRM Data Portal	2020
(5) Fin	IWRM sub-component: Financing (0–100%)	UNEP-DHI IWRM Data Portal	2020
Dependent variables			
(6) Access to basic sanitation	SDG 6.2.1a: The proportion of the population using safely managed basic (improved facilities that are not shared with other households) sanitation services	WHO/UNICEF Joint Monitoring Programme (JMP)	2020
(7) Treated wastewater	SDG 6.3.1: The proportion of household wastewater flow safely treated (%)	WHO and UN-Habitat	2020
(8) Water quality	SDG 6.3.2: The proportion of bodies of water with good ambient water quality (%)	UNEP	2020
(8) Water-use efficiency	SDG 6.4.1: Change in water-use efficiency over time (United States dollars per cubic meter)	FAO	2018
(9) Water stress	SDG 6.4.2: freshwater withdrawal as a proportion of available freshwater resources (%)	FAO	2018
(10) Trophic state	SDG 6.6.1: High and extreme lake (for the lakes bigger than 300 m) water quality trophic state (%)	UNEP and Ramsar (sdg661.app)	2019
(11) Turbidity	SDG 6.6.1: High and extreme lake (for the lakes bigger than 300 m) water quality turbidity (%)	UNEP and Ramsar (sdg661.app)	2019
Control variables			
(12) Reg. qual	Regulatory quality: perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development (score)	World Bank (Worldwide Governance Indicators)	2018
(13) Rule of law	Rules of law: perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract	World Bank (Worldwide Governance Indicators)	2018

	enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence (score)		
(14) Gov. effect.	Government effectiveness: perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies (score)	World Bank (Worldwide Governance Indicators)	2018
(15) Cont. of corrup	Control of corruption: perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests (score)	World Bank (Worldwide Governance Indicators)	2018
(16) Pol. stabil.	Political stability and absence of violence/terrorism: perceptions of the likelihood of political instability and/or politically- motivated violence, including terrorism (score)	World Bank (Worldwide Governance Indicators)	2018
(17) Voice and account.	Voice and accountability: perceptions of the extent to which a country's citizens can participate in selecting their government, as well as freedom of expression, freedom of association, and free media (score)	World Bank (Worldwide Governance Indicators)	2018
(18) Open data score	Open data score: an indicator of how complete and open national statistical offices' environmental data offerings are	Open Data Watch	2018
(19) Pop. den.	Population density (people per sq. km of land area)	World Bank	2018
(20) GDP p. c.	Gross domestic product (GDP) per capita (current US$)	World Bank	2018
(21) Forest	Relative forest land: share of Forest Land with respect to the Total Land Area (%)	FAO	2018
(22) Temperature	Average annual temperature change	FAO	2018
(23) NRI	National rainfall index (NRI) (mm/yr.)	FAO	2018
(24) Agri. land area	Agricultural land area: share of agricultural land with respect to the land area (%)	FAO	2018
(25) Irrig. crop area	Total harvested irrigated crop area (full control irrigation)	FAO	2018

Table A2 Regression models exploring associations between IWRM and water-related environmental sustainability indicators within SDG 6, controlling for socio-political, economic, and environmental factors.

SDG 6.2.1a (Proportion of population using safely managed at least basic sanitation services)												
Model no.	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12
IWRM (total score)	0.91***	0.43'	0.28	-0.04	0.33	0.60**	0.70**	0.25	0.92***	0.01	0.20	-0.51
Reg. qual.		1.34***										
Rule of law			1.40***									
Gov. effect.				2.13***								
Cont. of corrup.					1.52***							
Pol. stabil.						0.80***						-0.30
Voice and account.							0.79***					-1.49***
Open data score								1.55***				0.94*
Pop. den.									-0.10			
GDP p. c.										7.69***		7.64***
Gov. per. (Comb.)											1.72***	1.65*
AIC	335	306	297	285	307	321	321	297	337	266	299	251

SDG 6.3.1 (Proportion of household wastewater flow safely treated)												
Model no.	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11	2.12
IWRM (total score)	0.65***	0.33***	0.34***	0.29***	0.35***	0.53***	0.52***	0.51***	0.64***	0.43***	0.31***	0.19*
Reg. qual.		0.53***										
Rule of law			0.50***									
Gov. effect.				0.56***								
Cont. of corrup.					0.49***							
Pol. stabil.						0.23**						0.65***
Voice and account.							0.27***					-0.19*
Open data score								0.25**				-0.18'
Pop. den.									0.03			
GDP p. c.										0.39***		0.10
Gov. per. (Comb.)											0.55***	0.31***
R2	0.42	0.60	0.58	0.61	0.58	0.46	0.48	0.46	0.42	0.52	0.60	0.67
Adj. R2	0.41	0.59	0.57	0.60	0.57	0.45	0.47	0.45	0.41	0.51	0.60	0.65
Model sign. (F-test). p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AIC	262	222	228	219	229	256	252	256	264	242	221	209

SDG 3.3.2 (Proportion of bodies of water with good ambient water quality) - log transformed																
Model no.	**3.1**	**3.2**	**3.3**	**3.4**	**3.5**	**3.6**	**3.7**	**3.8**	**3.9**	**3.10**	**3.11**	**3.12**	**3.13**	**3.14**	**3.15**	**3.16**
<u>IWRM (total score)</u>	-0.02	-0.02	-0.01	-0.01	0.00	-0.01	-0.03	-0.03	-0.01	-0.02	-0.02	-0.02	-0.01	-0.02	-0.02	-0.01
Reg. qual.		0.01														
Rule of law			-0.02													
Gov. effect.				-0.01												
Cont. of corrup.					-0.03											
Pol. stabil.						-0.01										
Voice and account.							0.02									
Open data score								0.02								
Pop. den.									-0.03							
GDP p. c.										0.00						
Forest											0.01					
Temperature												0.00				
NRI													0.02			
Agri. land area														0.00		
Irrig. crop area															0.05	
Gov. per. (Comb.)																-0.01
R2	0.01	0.01	0.01	0.01	0.03	0.01	0.02	0.02	0.03	-0.01	0.01	0.01	0.02	0.03	0.07	0.01
Adj. R2	0.00	-0.01	-0.01	-0.01	0.00	-0.01	0.00	-0.01	0.01	-0.01	-0.01	-0.01	0.00	0.00	0.05	-0.01
Model sign. (F-test). p-value	0.38	0.64	0.58	0.62	0.34	0.59	0.44	0.48	0.27	0.68	0.57	0.68	0.44	0.32	0.04	0.61
AIC	-35.6	-33.7	-33.9	-33.8	-35.0	-33.8	-34.5	-34.3	-35.5	-33.6	-33.9	-33.6	-34.5	-35.1	-39.3	-33.8

SDG 6.4.1 (Change in water-use efficiency over time) - log transformed																	
Model no.	**4.1**	**4.2**	**4.3**	**4.4**	**4.5**	**4.6**	**4.7**	**4.8**	**4.9**	**4.10**	**4.11**	**4.12**	**4.13**	**4.14**	**4.15**	**4.16**	**4.17**
<u>IWRM (total score)</u>	0.36***	0.15**	0.10'	0.11'	0.11*	0.24***	0.22***	0.24***	0.36***	0.09'	0.35***	0.33***	0.37***	0.35***	0.36***	0.10'	.
Reg. qual.		0.35***															
Rule of law			0.39***														
Gov. effect.				0.37***													
Cont. of corrup.					0.38***												
Pol. stabil.						0.24***											.
Voice and account.							0.30***										.
Open data score								0.20***									.
Pop. den.									-0.04								

GDP p. c.										0.44***							0.61
Forest											0.12***						.
Temperature												0.09					
NRI													0.06				
Agri. land area														-0.09'			
Irrig. crop area															-0.08***		.
Gov. per. (Comb.)																0.39***	.
R2	0.29	0.49	0.49	0.46	0.49	0.39	0.46	0.36	0.30	0.57	0.33	0.31	0.30	0.31	0.31	0.50	0.54
Adj. R2	0.29	0.48	0.48	0.46	0.49	0.38	0.45	0.35	0.29	0.57	0.32	0.30	0.29	0.30	0.30	0.49	
Model sign. (F-test). p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
AIC	210	173	171	177	170	193	178	199	211	149	205	209	210	209	209	169	

SDG 6.4.2 (Level of water stress: freshwater withdrawal as a proportion of available freshwater resources) - log transformed																	
Model no.	**5.1**	**5.2**	**5.3**	**5.4**	**5.5**	**5.6**	**5.7**	**5.8**	**5.9**	**5.10**	**5.11**	**5.12**	**5.13**	**5.14**	**5.15**	**5.16**	**5.17**
IWRM (total score)	0.03	0.14**	0.14*	0.13*	0.14*	0.14***	0.11**	0.08'	0.02	0.10'	0.03	0.01	-0.03	0.03	0.02	0.15*	0.07
Reg. qual.		-0.20***															
Rule of law			-0.17*														
Gov. effect.				-0.16*													
Cont. of corrup.					-0.17**												
Pol. stabil.						-0.22***											-0.13*
Voice and account.							-0.18***										-0.12
Open data score								-0.10									
Pop. den.									0.02								
GDP p. c.										-0.11*							
Forest											-0.21***						-0.10**
Temperature												0.04					
NRI													-0.20***				-0.10**
Agri. land area														0.02			
Irrig. crop area															0.06		
Gov. per. (Comb.)																-0.18*	0.09
R2	0.00	0.14	0.09	0.07	0.09	0.19	0.14	0.04	0.01	0.05	0.23	0.01	0.20	0.01	0.03	0.10	0.37
Adj. R2	0.00	0.13	0.07	0.06	0.08	0.18	0.13	0.02	-0.01	0.03	0.21	0.00	0.19	-0.01	0.01	0.09	0.33
Model sign. (F-test). p-value	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.69	0.06	0.00	0.48	0.00	0.66	0.21	0.00	0.00
AIC	153	136	144	146	143	129	136	150	154	149	123	154	128	154	152	142	107

SDG 6.6.1 (Percentage of high and extreme lake water trophic state) - log transformed																	
Model no.	**6.1**	**6.2**	**6.3**	**6.4**	**6.5**	**6.6**	**6.7**	**6.8**	**6.9**	**6.10**	**6.11**	**6.12**	**6.13**	**6.14**	**6.15**	**6.16**	**6.17**
IWRM (total score)	-0.24*	-0.26*	-0.27*	-0.27*	-0.30*	-0.28*	-0.25*	-0.22'	-0.24*	-0.29*	-0.24**	-0.12	-0.14	-0.24*	-0.24**	-0.28*	-0.11
Reg. qual.		0.05															
Rule of law			0.06														
Gov. effect.				0.06													
Cont. of corrup.					0.09												
Pol. stabil.						0.10											
Voice and account.							0.03										
Open data score								-0.03									
Pop. den.									-0.01								
GDP p. c.										0.08							
Forest											0.30**						0.19'
Temperature												-0.36***					-0.28**
NRI													0.35***				0.15
Agri. land area														-0.01			
Irrig. crop area															0.02		
Gov. per. (Comb.)																0.07	
R2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.13	0.14	0.15	0.05	0.05	0.05	0.21
Adj. R2	0.04	0.03	0.03	0.03	0.04	0.04	0.03	0.03	0.03	0.04	0.11	0.13	0.13	0.03	0.03	0.03	0.19
Model sign. (F-test). p-value	0.01	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.04	0.00	0.00	0.00	0.05	0.05	0.05	0.00
AIC	371	373	373	373	372	372	373	373	373	373	362	360	360	373	373	373	353

SDG 6.6.1 (Percentage of high and extreme lake water turbidity)																
Model no.	**7.1**	**7.2**	**7.3**	**7.4**	**7.5**	**7.6**	**7.7**	**7.8**	**7.9**	**7.10**	**7.11**	**7.12**	**7.13**	**7.14**	**7.15**	**7.16**
IWRM (total score)	0.07	0.04	0.02	0.03	-0.03	0.05	0.03	0.06	0.09	0.00	0.07	0.06	0.09	0.07	0.07	0.01
Reg. qual.		0.05														
Rule of law			0.08													
Gov. effect.				0.06												
Cont. of corrup.					0.16											
Pol. stabil.						0.05										
Voice and account.							0.09									
Open data score								0.03								
Pop. den.									-0.13							
GDP p. c.										0.12						

Forest											0.09					
Temperature												0.03				
NRI													0.05			
Agri. land area														-0.12		
Irrig. crop area															-0.02	
Gov. per. (Comb.)																0.09
R2	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.01
Adj. R2	0.00	-0.01	-0.01	-0.01	0.00	-0.01	0.00	-0.01	0.00	0.00	0.00	-0.01	-0.01	0.00	-0.01	-0.01
Model sign. (F-test). p-value	0.43	0.66	0.59	0.64	0.28	0.65	0.50	0.71	0.28	0.43	0.44	0.70	0.62	0.29	0.71	0.54
AIC	356	358	358	358	356	358	357	358	356	357	357	358	358	356	358	358

Note: Statistical significance is shown as '***' 0.001, '**' 0.01, '*' 0.05, '' 0.1. In the last model, which shows the results of elastic net linear regression, "." refers to removal of variables as a result of shrinkage of coefficients to 0.

Table A3. Regression models exploring association between IWRM sub-components and water-related environmental sustainability indicators within SDG 6 controlling for socio-political, economic, and environmental factors.

SDG 6.2.1a (Proportion of population using safely managed at least basic sanitation services) *												
Model no.	1.1_EE	1.2_EE	1.3_EE	1.4_EE	1.5_EE	1.6_EE	1.7_EE	1.8_EE	1.9_EE	1.10_EE	1.11_EE	1.12_EE
IWRM (Enabling environment)	0.60**	0.17	0.04	-0.18	0.10	0.32	.42*	-0.05	0.61***	-0.22	-0.01	-0.70
Reg. qual.		1.47***										
Rule of law			1.55***									
Gov. effect.				2.22***								
Cont. of corrup.					1.67***							
Pol. stabil.						0.94***						-0.28
Voice and account.							0.89***					-1.59***
Open data score								1.71***				1.03*
Pop. den.									-0.07			
GDP p. c.										7.94***		7.77***
Gov. per. (Comb.)											1.86***	1.69*
AIC	349	309	310	285	309	327	329	298	350	265	300	247

Model no.	1.1_IP	1.2_IP	1.3_IP	1.4_IP	1.5_IP	1.6_IP	1.7_IP	1.8_IP	1.9_IP	1.10_IP	1.11_IP	1.12_IP
IWRM (Institutions and participation)	0.73***	0.22	0.11	-0.13	0.17	0.43*	0.50*	0.08	0.74***	-0.15	0.05	-0.50
Reg. qual.		1.44***										
Rule of law			1.51***									
Gov. effect.				2.19***								
Cont. of corrup.					1.63***							
Pol. stabil.						0.88***						-0.31
Voice and account.							0.84***					-1.40**
Open data score								1.64***				.94*
Pop. den.									-0.09			
GDP p. c.										7.88***		7.66***
Gov. per. (Comb.)											1.82***	1.56*
AIC	343.33	308.84	310.25	285.04	308.66	325.13	327.16	298.33	344.98	265.13	300.10	249.89

Model no.	1.1_MI	1.2_MI	1.3_MI	1.4_MI	1.5_MI	1.6_MI	1.7_MI	1.8_MI	1.9_MI	1.10_MI	1.11_MI	1.12_MI

IWRM (Management instruments)	1.16***	0.72**	0.60*	0.28	0.62*	0.88***	0.96***	0.55*	1.18***	0.35	0.51*	-0.03
Reg. qual.		1.21***										
Rule of law			1.21***									
Gov. effect.				1.91***								
Cont. of corrup.					1.33***							
Pol. stabil.						0.68**						-0.33
Voice and account.							0.72**					-1.24**
Open data score								1.39***				0.88*
Pop. den.									-0.13			
GDP p. c.										7.24***		7.40***
Gov. per. (Comb.)											1.52***	1.30
AIC	322	300	304	272	302	313	312	293	323	264	296	254

Model no.	1.1_Fin	1.2_Fin	1.3_Fin	1.4_Fin	1.5_Fin	1.6_Fin	1.7_Fin	1.8_Fin	1.9_Fin	1.10_Fin	1.11_Fin	1.12_Fin
IWRM (Financing)	1.02***	0.55*	0.36	-0.03	0.41	0.70**	0.83***	0.45	1.03***	0.15	0.28	-0.38
Reg. qual.		1.30***										
Rule of law			1.35***									
Gov. effect.				2.12***								
Cont. of corrup.					1.47***							
Pol. stabil.						0.77***						-0.31
Voice and account.							0.79***					-1.46**
Open data score								1.47***				0.88*
Pop. den.									-0.10			
GDP p. c.										7.52***		7.55***
Gov. per. (Comb.)											1.67***	1.65*
AIC	331	304	308	285	306	319	317	295	332	265	299	252

	SDG 6.3.1 (Proportion of household wastewater flow safely treated)											
Model no.	2.1_EE	2.2_EE	2.3_EE	2.4_EE	2.5_EE	2.6_EE	2.7_EE	2.8_EE	2.9_EE	2.10_EE	2.11_EE	2.12_EE
IWRM (Enabling environment)	0.52***	0.20**	0.22**	0.19**	0.24**	0.37***	0.37***	0.33***	0.51***	0.30***	0.19**	0.11
Reg. qual.		0.62***										
Rule of law			0.60***									
Gov. effect.				0.65***								

Cont. of corrup.					0.59***							
Pol. stabil.						0.34***						0.69***
Voice and account.							0.35***					-0.19*
Open data score								0.36***				-0.21*
Pop. den.									0.07			
GDP p. c.										0.50***		0.13
Gov. per. (Comb.)											0.64***	0.35***
R2	0.27	0.56	0.54	0.58	0.54	0.36	0.37	0.36	0.28	0.47	0.57	0.66
Adj. R2	0.26	0.55	0.53	0.58	0.53	0.35	0.36	0.35	0.26	0.46	0.57	0.64
Model sign. (F-test). p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AIC	287	233	238	227	238	274	273	274	289	254	229	212

Model no.	2.1_IP	2.2_IP	2.3_IP	2.4_IP	2.5_IP	2.6_IP	2.7_IP	2.8_IP	2.9_IP	2.10_IP	2.11_IP	2.12_IP
IWRM (Institutions and participation)	0.60***	0.29***	0.30***	0.26***	0.31***	0.46***	0.47***	0.44***	0.59***	0.37***	0.27***	0.16*
Reg. qual.		0.57***										
Rule of law			0.55***									
Gov. effect.				0.60***								
Cont. of corrup.					0.54***							
Pol. stabil.						0.29***						0.66***
Voice and account.							0.32***					-0.18*
Open data score								0.31***				-0.19'
Pop. den.									0.06			
GDP p. c.										0.44***		0.12
Gov. per. (Comb.)											0.59***	0.33***
R2	0.36	0.59	0.56	0.60	0.56	0.42	0.44	0.42	0.36	0.50	0.60	0.67
Adj. R2	0.35	0.58	0.56	0.60	0.55	0.41	0.43	0.41	0.35	0.49	0.59	0.65
Model sign. (F-test). p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AIC	274	226	232	221	232	263	260	263	275	247	223	210

Model no.	2.1_MI	2.2_MI	2.3_MI	2.4_MI	2.5_MI	2.6_MI	2.7_MI	2.8_MI	2.9_MI	2.10_MI	2.11_MI	2.12_MI
IWRM (Management instruments)	0.67***	0.36***	0.37***	0.32***	0.38***	0.55***	0.55***	0.53***	0.66***	0.46***	0.33***	0.23**
Reg. qual.		0.51***										
Rule of law			0.48***									
Gov. effect.				0.54***								

Cont. of corrup.					0.48***							
Pol. stabil.						0.21*						0.63***
Voice and account.							0.27***					-0.20*
Open data score								0.23**				-0.15
Pop. den.									0.04			
GDP p. c.										0.38***		0.09
Gov. per. (Comb.)											0.53***	0.30***
R2	0.44	0.61	0.59	0.62	0.59	0.47	0.50	0.48	0.44	0.54	0.61	0.68
Adj. R2	0.44	0.61	0.58	0.61	0.58	0.47	0.49	0.47	0.43	0.53	0.61	0.66
Model sign. (F-test). p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AIC	257	218	225	218	226	253	247	252	259	237	218	207

Model no.	2.1_Fin	2.2_Fin	2.3_Fin	2.4_Fin	2.5_Fin	2.6_Fin	2.7_Fin	2.8_Fin	2.9_Fin	2.10_Fin	2.11_Fin	2.12_Fin
IWRM (Financing)	0.67***	0.36***	0.37***	0.31***	0.38***	0.56***	0.55***	0.54***	0.67***	0.46***	0.33***	0.19*
Reg. qual.		0.51***										
Rule of law			0.48***									
Gov. effect.				0.54***								
Cont. of corrup.					0.47***							
Pol. stabil.						0.20*						0.62***
Voice and account.							0.27***					-0.19
Open data score								0.26**				-0.16*
Pop. den.									0.01			0.13
GDP p. c.										0.35***		
Gov. per. (Comb.)											0.53***	0.31***
R^2	0.45	0.61	0.59	0.61	0.58	0.48	0.51	0.50	0.45	0.53	0.61	0.67
Adj. R^2	0.44	0.60	0.58	0.60	0.57	0.47	0.50	0.49	0.44	0.52	0.60	0.65
Model sign. (F-test). p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AIC	256	220	226	219	228	252	245	247	258	241	220	210

	SDG 3.3.2 (Proportion of bodies of water with good ambient water quality) - log transformed															
Model no.	3.1_EE	3.2_EE	3.3_EE	3.4_EE	3.5_EE	3.6_EE	3.7_EE	3.8_EE	3.9_EE	3.10_EE	3.11_EE	3.12_EE	3.13_EE	3.14_EE	3.15_EE	3.16_EE
IWRM (Enabling environment)	-0.01	-0.02	-0.01	-0.01	0.00	-0.01	-0.02	-0.02	-0.01	-0.01	-0.01	-0.01	0.00	-0.01	-0.02	-0.01
Reg. qual.		0.00														
Rule of law			-0.02													

Gov. effect.				-0.02												
Cont. of corrup.					-0.03											
Pol. stabil.						-0.02										
Voice and account.							0.02									
Open data score								0.02								
Pop. den.									-0.03							
GDP p. c.										-0.01						
Forest											0.01					
Temperature												0.00				
NRI													0.02			
Agri. land area														0.03		
Irrig. crop area															0.05	
Gov. per. (Comb.)																-0.02
R^2	0.01	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.02	0.03	0.07	0.01
Adj. R^2	-0.01	-0.02	-0.01	-0.01	0.00	-0.01	-0.01	-0.01	0.01	-0.02	-0.01	-0.02	-0.01	0.00	0.05	-0.01
Model sign. (F-test). p-value	0.48	0.78	0.59	0.64	0.34	0.62	0.60	0.66	0.29	0.75	0.65	0.78	0.47	0.33	0.05	0.63
AIC	-35.3	-33.3	-33.8	-33.7	-35.0	-33.7	-33.8	-33.6	-35.3	-33.4	-33.6	-33.3	-34.3	-35.0	-39.0	-33.7

Model no.	3.1_IP	3.2_IP	3.3_IP	3.4_IP	3.5_IP	3.6_IP	3.7_IP	3.8_IP	3.9_IP	3.10_IP	3.11_IP	3.12_IP	3.13_IP	3.14_IP	3.15_IP	3.16_IP
IWRM (Institutions and participation)	-0.02	-0.02	0.00	-0.01	0.00	-0.01	0.00	-0.03	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02	-0.01
Reg. qual.		0.00														
Rule of law			-0.02													
Gov. effect.				-0.02												
Cont. of corrup.					-0.03											
Pol. stabil.						-0.01										
Voice and account.							-0.02									
Open data score								0.02								
Pop. den.									-0.03							
GDP p. c.										-0.01						
Forest											0.01					
Temperature												0.00				
NRI													0.02			
Agri. land area														0.03		
Irrig. crop area															0.05*	
Gov. per. (Comb.)																-0.02

R^2	0.01	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.02	0.02	0.07	0.01
Adj. R^2	-0.01	-0.02	-0.01	-0.01	0.00	-0.01	-0.01	-0.01	0.01	-0.02	-0.01	-0.02	-0.01	0.00	0.05	-0.01
Model sign. (F-test). p-value	0.46	0.75	0.60	0.64	0.34	0.62	0.60	0.64	0.29	0.74	0.64	0.76	0.46	0.35	0.05	0.63
AIC	-35.3	-33.3	-33.8	-33.7	-35.0	-33.7	-33.8	-33.7	-35.4	-33.4	-33.7	-33.3	-34.4	-34.9	-38.9	-33.7

Model no.	3.1_MI	3.2_MI	3.3_MI	3.4_MI	3.5_MI	3.6_MI	3.7_MI	3.8_MI	3.9_MI	3.10_MI	3.11_MI	3.12_MI	3.13_MI	3.14_MI	3.15_MI	3.16_MI
IWRM (Management instruments)	-0.02	-0.03	-0.01	-0.01	0.00	-0.02	-0.01	-0.04	-0.01	-0.02	-0.02	-0.02	-0.01	-0.02	-0.03	-0.01
Reg. qual.		0.01														
Rule of law			-0.01													
Gov. effect.				-0.01												
Cont. of corrup.					-0.03											
Pol. stabil.						-0.01										
Voice and account.							-0.01									
Open data score								0.03								
Pop. den.									-0.03							
GDP p. c.										0.00						
Forest											0.01					
Temperature												0.00				
NRI													0.02			
Agri. land area														0.03		
Irrig. crop area															0.05*	
Gov. per. (Comb.)																-0.01
R^2	0.01	0.01	0.01	0.01	0.03	0.01	0.01	0.02	0.03	0.01	0.02	0.01	0.02	0.03	0.08	0.01
Adj. R^2	0.00	-0.01	-0.01	-0.01	0.00	-0.01	-0.01	0.00	0.01	-0.01	-0.01	-0.01	0.00	0.01	0.05	-0.01
Model sign. (F-test). p-value	0.32	0.55	0.55	0.58	0.34	0.56	0.55	0.39	0.25	0.61	0.51	0.61	0.42	0.29	0.04	0.57
AIC	-35.8	-34.0	-34.0	-33.9	-35.0	-34.0	-34.0	-34.7	-35.6	-33.8	-34.1	-33.8	-34.6	-35.3	-39.4	-33.9

Model no.	3.1_Fin	3.2_Fin	3.3_Fin	3.4_Fin	3.5_Fin	3.6_Fin	3.7_Fin	3.8_Fin	3.9_Fin	3.10_Fin	3.11_Fin	3.12_Fin	3.13_Fin	3.14_Fin	3.15_Fin	3.16_Fin
IWRM (Financing)	-0.02	-0.02	-0.01	-0.01	0.01	-0.01	-0.01	-0.03	-0.01	-0.02	-0.02	-0.02	-0.01	-0.01	-0.02	-0.01
Reg. qual.		0.01														
Rule of law			-0.02													
Gov. effect.				-0.01												
Cont. of corrup.					-0.03											
Pol. stabil.						-0.01										
Voice and account.							-0.02									

Open data score								0.02									
Pop. den.									-0.03								
GDP p. c.										0.00							
Forest											0.01						
Temperature												0.00					
NRI													0.02				
Agri. land area														0.03			
Irrig. crop area															0.05*		
Gov. per. (Comb.)																-0.01	
R^2	0.01	0.01	0.01	0.01	0.03	0.01	0.01	0.02	0.03	0.01	0.01	0.01	0.02	0.03	0.07	0.01	
Adj. R^2	0.00	-0.01	-0.01	-0.01	0.00	-0.01	-0.01	-0.01	0.01	-0.02	-0.01	-0.02	0.00	0.00	0.05	-0.01	
Model sign. (F-test). p-value	0.40	0.65	0.60	0.64	0.34	0.62	0.60	0.53	0.28	0.70	0.57	0.70	0.43	0.35	0.05	0.63	
AIC	-35.5	-33.7	-33.8	-33.7	-35.0	-33.8	-33.8	-34.1	-35.4	-33.5	-33.9	-33.5	-34.5	-34.9	-39.1	-33.7	

	SDG 6.4.1 (Change in water-use efficiency over time) - log transformed																
Model no.	4.1_EE	4.2_EE	4.3_EE	4.4_EE	4.5_EE	4.6_EE	4.7_EE	4.8_EE	4.9_EE	4.10_EE	4.11_EE	4.12_EE	4.13_EE	4.14_EE	4.15_EE	4.16_EE	4.17_EE
IWRM (Enabling environment)	0.29***	0.10*	0.05	0.06	0.07	0.17***	0.16**	0.16**	0.29***	0.07	0.28***	0.25***	0.30***	0.29***	0.29***	0.06	.
Reg. qual.		0.39***															
Rule of law			0.43***														
Gov. effect.				0.41***													
Cont. of corrup.					0.42***												
Pol. stabil.						0.29***											.
Voice and account.							0.34***										.
Open data score								0.26***									.
Pop. den.									-0.03								
GDP p. c.										0.46***							0.61
Forest											0.12*						.
Temperature												0.11'					
NRI													0.04				
Agri. land area														-0.10'			
Irrig. crop area															-0.70**		.
Gov. per. (Comb.)																0.43***	.
R^2	0.19	0.47	0.48	0.46	0.48	0.35	0.42	0.31	0.19	0.57	0.22	0.22	0.20	0.22	0.20	0.49	0.54
Adj. R^2	0.19	0.46	0.48	0.45	0.48	0.34	0.41	0.30	0.18	0.56	0.21	0.21	0.18	0.21	0.19	0.48	

Model sign. (F-test). p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AIC	226	177	173	179	173	201	186	208	228	150	223	224	228	224	227	171

Model no.	4.1_IP	4.2_IP	4.3_IP	4.4_IP	4.5_IP	4.6_IP	4.7_IP	4.8_IP	4.9_IP	4.10_IP	4.11_IP	4.12_IP	4.13_IP	4.14_IP	4.15_IP	4.16_IP	4.17_IP
IWRM (Institutions and participation)	0.32***	0.12*	0.07	0.08	0.08	0.20***	0.17***	0.20***	0.32***	0.07	0.31***	0.29***	0.32***	0.31***	0.32***	0.07	.
Reg. qual.		0.38***															
Rule of law			0.41***														
Gov. effect.				0.39***													
Cont. of corrup.					0.41***												
Pol. stabil.						0.27***											.
Voice and account.							0.32***										.
Open data score								0.24***									.
Pop. den.									-0.03								
GDP p. c.										0.46***							0.61
Forest											0.11*						.
Temperature												0.11'					
NRI													0.03				
Agri. land area														-0.08			
Irrig. crop area															-0.06*		.
Gov. per. (Comb.)																0.41***	.
R^2	0.23	0.47	0.49	0.46	0.49	0.37	0.43	0.33	0.24	0.57	0.27	0.26	0.24	0.25	0.24	0.49	0.54
Adj. R^2	0.23	0.46	0.48	0.45	0.48	0.36	0.42	0.32	0.22	0.56	0.25	0.25	0.22	0.24	0.23	0.48	
Model sign. (F-test). p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
AIC	220	176	172	178	172	197	185	204	221	151	217	217	221	219	220	171	

Model no.	4.1_MI	4.2_MI	4.3_MI	4.4_MI	4.5_MI	4.6_MI	4.7_MI	4.8_MI	4.9_MI	4.10_MI	4.11_MI	4.12_MI	4.13_MI	4.14_MI	4.15_MI	4.16_MI	4.17_MI
IWRM (Management instruments)	0.35***	0.14**	0.09	0.09	0.10'	0.23***	0.21***	0.24***	0.36***	0.07	0.35***	0.33***	0.37***	0.35***	0.37***	0.09	.
Reg. qual.		0.35***															
Rule of law			0.40***														
Gov. effect.				0.38***													
Cont. of corrup.					0.39***												
Pol. stabil.						0.23***											.
Voice and account.							0.30***										.
Open data score								0.20***									.

Pop. den.									-0.04								
GDP p. c.										0.45***							0.61
Forest											0.13*						.
Temperature												0.08					
NRI													0.06				
Agri. land area														-0.08			
Irrig. crop area															-0.10***		.
Gov. per. (Comb.)																0.40***	.
R^2	0.29	0.48	0.49	0.46	0.49	0.38	0.45	0.35	0.29	0.57	0.33	0.30	0.30	0.31	0.31	0.49	0.54
Adj. R^2	0.28	0.47	0.48	0.45	0.48	0.37	0.44	0.34	0.28	0.56	0.32	0.29	0.29	0.29	0.30	0.49	
Model sign. (F-test). p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
AIC	210	174	171	178	171	195	180	201	212	150	206	210	211	210	208	170	

Model no.	4.1_Fin	4.2_Fin	4.3_Fin	4.4_Fin	4.5_Fin	4.6_Fin	4.7_Fin	4.8_Fin	4.9_Fin	4.10_Fin	4.11_Fin	4.12_Fin	4.13_Fin	4.14_Fin	4.15_Fin	4.16_Fin	4.17_Fin
IWRM (Financing)	0.39***	0.20***	0.15*	0.16*	0.16**	0.28***	0.26***	0.29***	0.40***	0.12*	0.39***	0.36***	0.40***	0.38***	0.40***	0.15*	0.11
Reg. qual.		0.32***															
Rule of law			0.36***														
Gov. effect.				0.33***													
Cont. of corrup.					0.35***												
Pol. stabil.						0.21***											.
Voice and account.							0.28***										0.02
Open data score								0.18***									.
Pop. den.									-0.05								
GDP p. c.										0.42***							0.51
Forest											0.14**						0.04
Temperature												0.09'					
NRI													0.06				
Agri. land area														-0.08			
Irrig. crop area															-0.10***		-0.07
Gov. per. (Comb.)																0.36***	0.08
R^2	0.35	0.51	0.51	0.48	0.51	0.43	0.50	0.41	0.36	0.58	0.39	0.37	0.36	0.36	0.37	0.51	0.55
Adj. R^2	0.35	0.50	0.50	0.47	0.50	0.42	0.49	0.40	0.34	0.57	0.38	0.36	0.35	0.35	0.36	0.50	
Model sign. (F-test). p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
AIC	199	167	168	174	167	186	169	190	200	148	193	198	200	198	197	166	

	SDG 6.4.2 (Level of water stress: freshwater withdrawal as a proportion of available freshwater resources) - log transformed																
Model no.	**5.1_EE**	**5.2_EE**	**5.3_EE**	**5.4_EE**	**5.5_EE**	**5.6_EE**	**5.7_EE**	**5.8_EE**	**5.9_EE**	**5.10_EE**	**5.11_EE**	**5.12_EE**	**5.13_EE**	**5.14_EE**	**5.15_EE**	**5.16_EE**	**5.17_EE**
<u>IWRM (Enabling environment)</u>	0.02	0.01*	0.09*	0.08'	0.08*	0.01**	0.08*	0.06	0.02	0.06	0.03	0.00	-0.04	0.02	0.02	0.09*	0.03
Reg. qual.		-0.16***															
Rule of law			-0.12*														
Gov. effect.				-0.11'													
Cont. of corrup.					-0.13**												
Pol. stabil.						-0.19***											-0.13*
Voice and account.							-0.16***										-0.14*
Open data score								-0.08									
Pop. den.									0.02								
GDP p. c.										-0.08'							
Forest											-0.21***						-0.10**
Temperature												0.05					
NRI													-0.21***				-0.11**
Agri. land area														0.02			
Irrig. crop area															0.07		
Gov. per. (Comb.)																-0.14*	0.13'
R^2	0.00	0.11	0.06	0.04	0.06	0.16	0.12	0.03	0.00	0.03	0.23	0.01	0.20	0.00	0.02	0.07	0.36
Adj. R^2	-0.01	0.09	0.04	0.03	0.05	0.14	0.10	0.01	-0.01	0.01	0.21	-0.01	0.19	-0.01	0.01	0.05	0.32
Model sign. (F-test). p-value	0.65	0.00	0.03	0.06	0.02	0.00	0.00	0.17	0.78	0.18	0.00	0.50	0.00	0.77	0.23	0.01	0.00
AIC	153	141	148	149	147	134	140	152	155	152	123	154	127	155	152	146	108

Model no.	**5.1_IP**	**5.2_IP**	**5.3_IP**	**5.4_IP**	**5.5_IP**	**5.6_IP**	**5.7_IP**	**5.8_IP**	**5.9_IP**	**5.10_IP**	**5.11_IP**	**5.12_IP**	**5.13_IP**	**5.14_IP**	**5.15_IP**	**5.16_IP**	**5.17_IP**
<u>IWRM (Institutions and participation)</u>	0.01	0.10*	0.08	0.07	0.08'	0.09*	0.08*	0.05	0.00	0.05	0.02	-0.01	-0.04	0.01	0.01	0.09'	0.03
Reg. qual.		-0.17***															
Rule of law			-0.12'														
Gov. effect.				-0.11													
Cont. of corrup.					-0.13*												
Pol. stabil.						-0.19**											-0.13**
Voice and account.							-0.17**										-0.14*
Open data score								-0.08									

Pop. den.									0.02								
GDP p. c.										-0.08'							
Forest											-0.21***						-0.10**
Temperature												0.05					
NRI													-0.20***				-0.11**
Agri. land area														0.02			
Irrig. crop area															0.07'		
Gov. per. (Comb.)																-0.14*	0.13
R^2	0.00	0.11	0.05	0.04	0.06	0.15	0.12	0.02	0.00	0.03	0.22	0.01	0.20	0.00	0.02	0.07	0.36
Adj. R^2	-0.01	0.09	0.04	0.02	0.04	0.14	0.10	0.01	-0.01	0.01	0.21	0.00	0.19	-0.01	0.01	0.05	0.32
Model sign. (F-test). p-value	0.86	0.00	0.04	0.08	0.03	0.00	0.00	0.24	0.83	0.21	0.00	0.50	0.00	0.83	0.25	0.02	0.00
AIC	153	141	148	150	148	135	140	152	155	152	124	154	127	155	152	147	108

Model no.	5.1_MI	5.2_MI	5.3_MI	5.4_MI	5.5_MI	5.6_MI	5.7_MI	5.8_MI	5.9_MI	5.10_MI	5.11_MI	5.12_MI	5.13_MI	5.14_MI	5.15_MI	5.16_MI	5.17_MI
IWRM (Management instruments)	0.04	0.16***	0.16**	0.16*	0.16**	0.16***	0.13**	0.10*	0.03	0.12*	0.04	0.02	-0.02	0.04	0.03	0.17**	0.10'
Reg. qual.		-0.21***															
Rule of law			-0.18*														
Gov. effect.				-0.18*													
Cont. of corrup.					-0.18**												
Pol. stabil.						-0.24***											-0.14*
Voice and account.							-0.19***										-0.11
Open data score								-0.12'									
Pop. den.									0.02								
GDP p. c.										-0.13*							-0.02
Forest											-0.21***						-0.10**
Temperature												0.04					
NRI													-0.20***				-0.10**
Agri. land area														0.02			
Irrig. crop area															0.06		
Gov. per. (Comb.)																-0.20**	0.09
R^2	0.01	0.16	0.10	0.09	0.11	0.22	0.16	0.05	0.01	0.06	0.23	0.01	0.20	0.01	0.03	0.12	0.38
Adj. R^2	0.00	0.15	0.09	0.08	0.09	0.20	0.14	0.04	-0.01	0.04	0.22	0.00	0.18	-0.01	0.01	0.11	0.34
Model sign. (F-test). p-value	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.58	0.03	0.00	0.44	0.00	0.54	0.19	0.00	0.00
AIC	152	134	142	143	141	125	134	148	154	148	123	153	128	154	152	139	106

Model no.	5.1_Fin	5.2_Fin	5.3_Fin	5.4_Fin	5.5_Fin	5.6_Fin	5.7_Fin	5.8_Fin	5.9_Fin	5.10_Fin	5.11_Fin	5.12_Fin	5.13_Fin	5.14_Fin	5.15_Fin	5.16_Fin	5.17_Fin
IWRM (Financing)	0.04	0.17***	0.18*	0.18*	0.17**	0.17**	0.13**	0.10'	0.04	0.14**	0.04	0.03	-0.01	0.04	0.04	0.19***	0.11
Reg. qual.		-0.22***															
Rule of law			-0.20*														
Gov. effect.				-0.19*													
Cont. of corrup.					-0.20**												
Pol. stabil.						-0.24***											-0.13*
Voice and account.							-0.19***										-0.09
Open data score								-0.11'									
Pop. den.									0.02								
GDP p. c.										-0.14**							-0.03
Forest											-0.21***						-0.10**
Temperature												0.04					
NRI													-0.20***				-0.10**
Agri. land area														0.03			
Irrig. crop area															0.06		
Gov. per. (Comb.)																-0.21***	0.06
R^2	0.01	0.17	0.12	0.10	0.12	0.22	0.16	0.05	0.01	0.07	0.23	0.02	0.20	0.01	0.03	0.14	0.38
Adj. R^2	0.00	0.16	0.10	0.09	0.11	0.21	0.14	0.04	-0.01	0.06	0.22	0.00	0.18	0.00	0.01	0.12	0.34
Model sign. (F-test). p-value	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.51	0.01	0.00	0.38	0.00	0.46	0.17	0.00	0.00
AIC	152	132	140	141	139	124	134	148	154	146	123	153	128	154	151	137	106

	SDG 6.6.1 (Percentage of high and extreme lake water trophic state) - log transformed																
Model no.	6.1_EE	6.2_EE	6.3_EE	6.4_EE	6.5_EE	6.6_EE	6.7_EE	6.8_EE	6.9_EE	6.10_EE	6.11_EE	6.12_EE	6.13_EE	6.14_EE	6.15_EE	6.16_EE	6.17_EE
IWRM (Enabling environment)	-0.21 *	-0.21'	-0.21'	-0.20'	-0.22*	-0.24*	-0.21*	-0.18	-0.21*	-0.22'	-0.22*	-0.10	-0.11	-0.21*	-0.21*	-0.21'	-0.09
Reg. qual.		0.00															
Rule of law			-0.01														
Gov. effect.				-0.02													
Cont. of corrup.					0.02												
Pol. stabil.						0.05											
Voice and account.							0.00										
Open data score								-0.07									
Pop. den.									-0.02								
GDP p. c.										0.01							

Forest											0.31**						0.19'
Temperature												-0.36***					-0.28**
NRI													0.36***				0.15
Agri. land area														0.00			
Irrig. crop area															0.01		
Gov. per. (Comb.)																0.00	
R^2	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.12	0.14	0.14	0.04	0.04	0.04	0.21
Adj. R^2	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.10	0.13	0.13	0.02	0.02	0.02	0.18
Model sign. (F-test). p-value	0.03	0.09	0.09	0.09	0.09	0.08	0.09	0.08	0.09	0.09	0.00	0.00	0.00	0.09	0.09	0.09	0.00
AIC	372	374	374	374	374	374	374	374	374	374	363	360	360	374	374	374	354

Model no.	6.1_IP	6.2_IP	6.3_IP	6.4_IP	6.5_IP	6.6_IP	6.7_IP	6.8_IP	6.9_IP	6.10_IP	6.11_IP	6.12_IP	6.13_IP	6.14_IP	6.15_IP	6.16_IP	6.17_IP
IWRM (Institutions and participation)	-0.23*	-0.24*	-0.24*	-0.24'	-0.26*	-0.26*	-0.24*	-0.20'	-0.23*	-0.25*	-0.24**	-0.13	-0.15	-0.23*	-0.23*	-0.25*	-0.08
Reg. qual.		0.02															
Rule of law			0.02														
Gov. effect.				0.01													
Cont. of corrup.					0.06												
Pol. stabil.						0.06											
Voice and account.							0.02										
Open data score								-0.05									
Pop. den.									-0.02								
GDP p. c.										0.04							
Forest											0.31**						0.19'
Temperature												-0.36***					-0.28**
NRI													0.36***				0.16
Agri. land area														-0.02			
Irrig. crop area															0.01		
Gov. per. (Comb.)																0.03	
R^2	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.05	0.04	0.05	0.13	0.15	0.15	0.04	0.04	0.04	0.22
Adj. R^2	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.11	0.13	0.13	0.03	0.03	0.03	0.19
Model sign. (F-test). p-value	0.02	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.00	0.00	0.00	0.06	0.06	0.06	0.00
AIC	371	373	373	373	373	373	373	373	373	373	362	360	359	373	373	373	353

Model no.	6.1_MI	6.2_MI	6.3_MI	6.4_MI	6.5_MI	6.6_MI	6.7_MI	6.8_MI	6.9_MI	6.10_MI	6.11_MI	6.12_MI	6.13_MI	6.14_MI	6.15_MI	6.16_MI	6.17_MI

IWRM (Management instruments)	-0.23*	-0.25*	-0.26*	-0.26'	-0.29*	-0.28*	-0.24*	-0.21'	-0.22*	-0.27*	-0.23*	-0.10	-0.13	-0.23*	-0.23*	-0.27*	-0.13
Reg. qual.		0.04															
Rule of law			0.05														
Gov. effect.				0.05													
Cont. of corrup.					0.09												
Pol. stabil.						0.10											
Voice and account.							0.03										
Open data score								-0.03									
Pop. den.									-0.02								
GDP p. c.										0.08							
Forest											0.30**						0.19'
Temperature												-0.36***					-0.28**
NRI													0.36***				0.16
Agri. land area														-0.02			
Irrig. crop area															0.03		
Gov. per. (Comb.)																0.06	
R^2	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.05	0.12	0.14	0.14	0.04	0.04	0.05	0.21
Adj. R^2	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.11	0.13	0.13	0.03	0.03	0.03	0.18
Model sign. (F-test). p-value	0.02	0.06	0.06	0.06	0.05	0.05	0.07	0.07	0.07	0.06	0.00	0.00	0.00	0.07	0.06	0.06	0.00
AIC	372	373	373	373	373	373	373	373	374	373	363	360	360	374	373	373	354

Model no.	6.1_Fin	6.2_Fin	6.3_Fin	6.4_Fin	6.5_Fin	6.6_Fin	6.7_Fin	6.8_Fin	6.9_Fin	6.10_Fin	6.11_Fin	6.12_Fin	6.13_Fin	6.14_Fin	6.15_Fin	6.16_Fin	6.17_Fin
IWRM (Financing)	-0.23*	-0.26*	-0.27*	-0.28*	-0.30*	-0.28*	-0.24*	-0.21'	-0.23*	-0.29*	-0.23*	-0.12	-0.14	-0.23*	-0.23*	-0.01*	-0.11
Reg. qual.		0.04															
Rule of law			0.06														
Gov. effect.				0.07													
Cont. of corrup.					0.10												
Pol. stabil.						0.10											
Voice and account.							0.02										
Open data score								-0.05									
Pop. den.									-0.01								
GDP p. c.										0.10							
Forest											0.29**						0.19
Temperature												-0.36***					-0.28**
NRI													0.36***				0.15

Agri. land area														-0.02			
Irrig. crop area															0.03		
Gov. per. (Comb.)																0.05	
R^2	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.12	0.14	0.15	0.05	0.05	0.06	0.21
Adj. R^2	0.04	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.10	0.13	0.13	0.03	0.03	0.05	0.19
Model sign. (F-test). p-value	0.02	0.06	0.06	0.06	0.04	0.04	0.06	0.06	0.06	0.05	0.00	0.00	0.00	0.06	0.06	0.02	0.00
AIC	371	373	373	373	373	373	373	373	373	373	363	360	360	373	373	306	353

SDG 6.6.1 (Percentage of high and extreme lake water turbidity)																
Model no.	**7.1_EE**	**7.2_EE**	**7.3_EE**	**7.4_EE**	**7.5_EE**	**7.6_EE**	**7.7_EE**	**7.8_EE**	**7.9_EE**	**7.10_EE**	**7.11_EE**	**7.12_EE**	**7.13_EE**	**7.14_EE**	**7.15_EE**	**7.16_EE**
IWRM (Enabling environment)	0.06	0.03	0.01	0.02	-0.02	0.03	0.02	0.04	0.07	0.00	0.05	0.05	0.07	0.06	0.06	0.01
Reg. qual.		0.06														
Rule of law			0.09													
Gov. effect.				0.07												
Cont. of corrup.					0.15											
Pol. stabil.						0.06										
Voice and account.							0.10									
Open data score								0.04								
Pop. den.									-0.12							
GDP p. c.										0.12						
Forest											0.09					
Temperature												0.04				
NRI													0.05			
Agri. land area														-0.13		
Irrig. crop area															-0.02	
Gov. per. (Comb.)																0.10
R^2	0.00	0.01	0.01	0.01	0.02	0.01	0.01	0.00	0.02	0.01	0.01	0.00	0.01	0.02	0.00	0.01
Adj. R^2	0.00	-0.01	-0.01	-0.01	0.00	-0.01	-0.01	-0.01	0.00	0.00	0.00	-0.01	-0.01	0.00	-0.01	-0.01
Model sign. (F-test). p-value	0.52	0.68	0.60	0.65	0.29	0.67	0.51	0.75	0.33	0.43	0.49	0.76	0.70	0.30	0.79	0.54
AIC	356	358	358	358	356	358	358	358	357	357	357	358	358	356	358	358

Model no.	**7.1_IP**	**7.2_IP**	**7.3_IP**	**7.4_IP**	**7.5_IP**	**7.6_IP**	**7.7_IP**	**7.8_IP**	**7.9_IP**	**7.10_IP**	**7.11_IP**	**7.12_IP**	**7.13_IP**	**7.14_IP**	**7.15_IP**	**7.16_IP**
IWRM (Institutions and participation)	0.07	0.04	0.03	0.03	-0.02	0.05	0.03	0.06	0.09	0.01	0.07	0.06	0.08	0.06	0.07	0.02

Reg. qual.		0.05														
Rule of law			0.08													
Gov. effect.				0.06												
Cont. of corrup.					0.15											
Pol. stabil.						0.05										
Voice and account.							0.09									
Open data score								0.03								
Pop. den.									-0.12							
GDP p. c.										0.11						
Forest											0.09					
Temperature												0.03				
NRI													0.05			
Agri. land area														-0.12		
Irrig. crop area															-0.02	
Gov. per. (Comb.)																0.09
R^2	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.01
Adj. R^2	0.00	-0.01	-0.01	-0.01	0.00	-0.01	0.00	-0.01	0.00	0.00	0.00	-0.01	-0.01	0.00	-0.01	-0.01
Model sign. (F-test). p-value	0.43	0.65	0.59	0.63	0.29	0.64	0.50	0.71	0.29	0.43	0.45	0.69	0.64	0.29	0.72	0.54
AIC	356	358	358	358	356	358	357	358	356	357	357	358	358	356	358	358

Model no.	7.1_MI	7.2_MI	7.3_MI	7.4_MI	7.5_MI	7.6_MI	7.7_MI	7.8_MI	7.9_MI	7.10_MI	7.11_MI	7.12_MI	7.13_MI	7.14_MI	7.15_MI	7.16_MI
IWRM (Management instruments)	0.07	0.03	0.01	0.02	-0.05	0.04	0.02	0.05	0.08	-0.01	0.07	0.06	0.08	0.06	0.07	0.00
Reg. qual.		0.06														
Rule of law			0.09													
Gov. effect.				0.07												
Cont. of corrup.					0.17											
Pol. stabil.						0.06										
Voice and account.							0.09									
Open data score								0.03								
Pop. den.									-0.12							
GDP p. c.										0.13						
Forest											0.09					
Temperature												0.03				
NRI													0.05			
Agri. land area														-0.12		

Irrig. crop area															-0.03	
Gov. per. (Comb.)																0.10
R^2	0.00	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.01
Adj. R^2	0.00	-0.01	-0.01	-0.01	0.01	-0.01	-0.01	-0.01	0.00	0.00	0.00	-0.01	-0.01	0.00	-0.01	-0.01
Model sign. (F-test). p-value	0.46	0.68	0.60	0.65	0.27	0.67	0.51	0.74	0.30	0.43	0.45	0.73	0.65	0.31	0.73	0.54
AIC	356	358	358	358	356	358	358	358	356	357	357	358	358	356	358	358

Model no.	7.1_Fin	7.2_Fin	7.3_Fin	7.4_Fin	7.5_Fin	7.6_Fin	7.7_Fin	7.8_Fin	7.9_Fin	7.10_Fin	7.11_Fin	7.12_Fin	7.13_Fin	7.14_Fin	7.15_Fin	7.16_Fin
IWRM (Financing)	0.07	0.04	0.02	0.03	-0.04	0.05	0.03	0.06	0.09	-0.01	0.07	0.06	0.09	0.07	0.08	0.01
Reg. qual.		0.05														
Rule of law			0.08													
Gov. effect.				0.06												
Cont. of corrup.					0.17											
Pol. stabil.						0.05										
Voice and account.							0.09									
Open data score								0.03								
Pop. den.									-0.13							
GDP p. c.										0.12						
Forest											0.09					
Temperature												0.03				
NRI													0.05			
Agri. land area														-0.12		
Irrig. crop area															-0.03	
Gov. per. (Comb.)																0.09
R^2	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.01
Adj. R^2	0.00	-0.01	-0.01	-0.01	0.00	-0.01	0.00	-0.01	0.00	0.00	0.00	-0.01	-0.01	0.00	-0.01	-0.01
Model sign. (F-test). p-value	0.42	0.66	0.60	0.64	0.28	0.65	0.50	0.70	0.28	0.43	0.42	0.69	0.62	0.29	0.70	0.54
AIC	356	358	358	358	356	358	357	358	356	357	357	358	358	356	358	358

Note: Statistical significance is shown as '***' 0.001, '**' 0.01, '*' 0.05, '' 0.1. In the last model, which shows the results of elastic net linear regression, "." refers to removal of variables as a result of shrinkage of coefficients to 0.

Supplementary 1:

Now you see me, now you don't: the role and relevance of paradigms in water governance

Abstract

Current understandings of water governance rely on a multitude of paradigms, defined as normative ideas collectively held by actor groups. Reflecting on the role of paradigms in water governance enables a better understanding of the driving forces behind the implementation of certain water governance arrangements, their international spread, and what interests, politico-economic stakes or power dynamics are at play. This agenda-setting paper aims to unravel the intricacies of water governance paradigms, their roles, processes, and impacts on past and contemporary water governance. We aim to identify research gaps and shed light on issues that require attention. This paper explores why and how paradigms matter in water governance, as they fulfill specific functions, evolve over time and space, and drive or undergo power pressures from diverse groups of actors. Moreover, we identify ten agenda items that should be prioritized in a future research agenda on water governance paradigms. These agenda items serve to inspire research, critical reflection within research and praxis, and guidance for advancing more reflexive water governance practices.

Now you see me, now you don't: the role and relevance of paradigms in water governance

Paper submitted to Ecology and Society[1]
Manuscript type: Syntehsis

Shahana Bilalova [1], Nina Valin [2], Alejandra Burchard-Levine [2], Dona H. Geagea [2], Andrea K. Gerlak [3, 4], Nicolas W. Jager [5], Radhika Singh [6], Dave Huitema [5], Johanna K.L. Koehler [5], Jens Newig [1], Hannah Porada [7], Javier Rodríguez Ros [2, 8]

[1] Faculty of Sustainability, Institute of Sustainability Governance (INSUGO), Research Group Governance, Participation and Sustainability, Leuphana University Lüneburg, Germany, [2] Institute for Environmental Studies (IVM), Vrije Universiteit Amsterdam, The Netherlands, [3] School of Geography, Development & Environment, University of Arizona, [4] Udall Center for Studies in Public Policy, University of Arizona, [5] Public Administration and Policy Group, Wageningen University and Research, Wageningen, The Netherlands, [6] Faculty of Law, University of Nairobi, Kenya, [7] CEDLA Centre for Latin American Research and Documentation, University of Amsterdam, The Netherlands, [8] UMR G-EAU (IRD), Montpellier, France

ABSTRACT

Current understandings of water governance rely on a multitude of paradigms, defined as normative ideas collectively held by actor groups. Reflecting on the role of paradigms in water governance enables a better understanding of the driving forces behind the implementation of certain water governance arrangements, their international spread, and what interests, politico-economic stakes or power dynamics are at play. This agenda-setting paper aims to unravel the intricacies of water governance paradigms, their roles, processes, and impacts on past and contemporary water governance. We aim to identify research gaps and shed light on issues that require attention. This paper explores why and how paradigms matter in water governance, as they fulfill specific functions, evolve over time and space, and drive or undergo power pressures from diverse groups of actors. Moreover, we identify ten agenda items that should be prioritized in a future research agenda on water governance paradigms. These agenda items serve to inspire research, critical reflection within research and praxis, and guidance for advancing more reflexive water governance practices.

Keywords: paradigms; water governance; normative ideas; power dynamics; reflexivity; agenda-setting

[1] Received revisions for this paper, with both reviewers recognizing its importance.

INTRODUCTION

Given the persistent global water crisis, never in modern history has there been a more pressing demand for effective water governance (WG) (Woodhouse and Muller 2017, Ovink et al. 2023, United Nations 2023). To address this crisis, governance approaches are circulating rapidly, and it remains unclear which ones work best in which contexts. Consequently, there is no common understanding of how water governance 'works' or should work.

Water governance structures, approaches, and instruments do not emerge in isolation. Rather, they are coming from a collective and discursive identification of certain problems, which stimulates a need for action in the political agenda, potentially leading to specific governance choices. Such ideas on how to collectively govern water have merged into what we consider today as "major paradigms of water governance" (Challies and Newig 2022). These paradigms represent the ideational underpinnings of current approaches to water governance (NEWAVE proposal 2019). Paradigms perform a function in water governance in that they identify a society's water governance needs, objectives, and means.

Although researchers have helped conceptualize paradigms (Pahl-Wostl et al. 2006, Moss 2010, Baird et al. 2021) and study the implications and prescriptions of water governance paradigms (e.g., Harsha 2012, Chomba et al. 2017, Tantoh and Simatele 2017, Warner et al. 2017, Lebel et al. 2020), we are lacking a broader framework that would allow the appraisal and comparative assessment of the various, often implicit, paradigms. To this end, our paper provides a novel contribution by presenting a more holistic perspective on water governance paradigms, aiming to set the agenda for comprehensive future research. We argue that it is important to study the actors involved in creating, promoting, and implementing water governance paradigms, their spatial reach and temporal dynamics, as well as the power issues involved. This can allow a better understanding of the driving forces behind the implementation of certain water governance arrangements, their international spread, and what interests, politico-economic stakes or power dynamics are at play.

Drawing from the literature, we explore three analytical axes in this paper. First, we demonstrate why paradigms matter in water governance. Second, we examine how paradigms shape water governance. Finally, we identify what aspects should be paid more attention to in future water governance research. In doing so, we examine the following sub-questions: the first pertains to how we define water governance paradigms—how can we approach them at a conceptual level? The second question focuses on where, why, and how paradigms matter to the practices of governing water - and what is their importance in this sense? We also explore what the key dimensions of water governance paradigms are, and finally, we identify which issues could be prioritized in a future research agenda on water governance paradigms.

Uncovering the various dimensions of WG paradigms and making them accessible for comparative research could contribute to improved reflexivity amongst scholars, who would then have the language to make explicit the type and nature of the paradigms they are engaging with. By articulating the various aspects of water governance, we can better understand how the field of water governance has evolved in recent decades. This shift is particularly noticeable as it moves from a utilitarian view of water as a resource to be managed (e.g., to control or regulate water) to a more complex socio-ecological consideration of water as a resource that is governed (e.g., to involve stakeholders in decision-making on water and pay attention to relational dynamics) (Baldwin 2008).

The remainder of this paper is structured as follows: we begin in section 2 by defining water governance paradigms and briefly introduce examples of existing paradigms. In section 3, we discuss the functions that paradigms may play in shaping structures and processes of water governance. In sections 4 to 7, we discuss the role of actors, the spatial and temporal dimensions of water governance paradigms, and the power issues involved in creating, maintaining, implementing, and shifting paradigms. We conclude in section 8 by outlining proposed avenues for research on water governance that are mindful of the multiple facets and functions of paradigms.

DEFINING WATER GOVERNANCE PARADIGMS

The notion of "paradigm" can be traced back to Kuhn's (1962) work on scientific progress. Various analogous concepts have been used in academic literature to imply the same function of a paradigm and are thus at times employed interchangeably. Such terms include "ideas on steroids" (Baumgartner 2014, p.476), "policy ideas" (Daigneault 2014, p.482), "nirvana concepts" (Molle 2008), "trends" (Bréthaut and Schweizer 2018), or even "imaginaries" (Jasanoff and Kim 2015). Hall (1993, p.279) extends the concept to a "policy paradigm" and argues that policymakers work within "a framework of ideas and standards that specifies not only the goal of policy and the kind of instruments that can be used to attain them but also the very nature of the problems they are meant to be addressing.

Concerning water, Pahl-Wostl et al. (2006, p.6) have put forward a similar definition of "water management paradigms," referring to "a set of basic assumptions about the nature of the system to be managed, the goals of management and the ways in which these management goals can be achieved." The paradigm is held in common by an 'epistemic community,' or a group of actors involved in water management, and becomes visible through 'artifacts' ranging from infrastructure to planning approaches policies, and practices.

Drawing from this foundational work, we define a governance paradigm as a set of more or less coherent normative ideas intersubjectively held by groups of actors about the problématiques [2]that require public intervention, corresponding governance objectives, and appropriate means to achieve them. As such, paradigms involve (i) collectively held ideas about reality and the problems (cognitive frames, mental models, imaginaries, etc.), (ii) actors related to the problem and its resolution (state and non-state within governance networks), and (iii) objectives (the ends and means that aim to solve the identified water-related problématiques).

While paradigms serve as political agenda-setters on various scales (Challies and Newig 2022), they may also be used strategically by actor groups to benefit their interests or to sideline other groups' interests (Molle 2008). Their circulation can shape local policies beyond functional

[2] We understand problématiques as clusters of problems that arise from interdisciplinary understandings of hydrological and social governance challenges.

necessity (Blatter and Ingram 2000). Thus, governance paradigms refer to "the whole range of institutions and relationships involved in the process of governing" (Pierre and Peters 2020). This includes both formal institutions, such as laws, official policies, and organizational structures as well as informal institutions, and the power relations and practices that have developed and the rules that are followed in practice (Huitema et al. 2009).

As such, water governance paradigms encompass a wide range of cognitive-normative frameworks that influence water policy. Some of the popular paradigms that have been extensively addressed in the literature include integrated approaches to water management, like Integrated Water Resource Management and Integrated River Basin Management (e.g., García 2008), adaptive management (e.g., Pahl-Wostl 2008), hydraulic mission (e.g., Molle et al. 2009), and water security (e.g., Bakker and Morinville 2013). More recently, newer water governance paradigms have become prominent such as "rights for nature" (e.g., Harden-Davies et al. 2020) and "remunicipalisation" (e.g., Geagea et al. 2023), highlighting that paradigms become trends as to what is considered "good water governance", and solutions to tackle past governance discrepancies (Bréthaut and Schweizer 2018).

FUNCTIONALITY: PARADIGMS AS A 'SOURCE CODE'

Paradigms can be seen as the 'source code' of a system, a backbone determining a system's intent and identity leading to the emergence of rules, norms, values, and goals on which the system is based (Meadow 1999, Abson et al. 2017). In that sense, paradigms play a role in both problem-framing and providing solutions (Challies and Newig 2022). Interpretive frameworks embedded in paradigms guide decisions about appropriate policy goals respective to perceived problems and which instruments to implement to attain these goals (Hall 1993). Since paradigms also provide clear and distinct ideas about how to govern, they influence governance structures and practices on how formal institutions are set up and maintained, and the mandates they work towards (Kern et al. 2014).

To exemplify how paradigms are translated to political action in water governance, Table 1 presents the example of five paradigms including which problems they spotlight, preferred solutions, governance structures they envision, and their normative social, economic, and ecological goals. With select illustrative references, the table demonstrates that paradigms have different problem lenses, which also shape what solutions and governance structures they promote. For instance, the paradigm of the hydraulic mission aims at full control over water through large-scale water resource development planned and implemented by top-down and technocratic decision-making mechanisms (Molle et al. 2009). On the contrary, the adaptive water governance paradigm departs from the challenges of managing water resources under high uncertainty and inherent complexities, thus emphasizing learning-by-doing and experimentation in the management processes. Hence, it promotes polycentric and participatory governance on a bioregional scale, which would ensure enabling learning processes (Chaffin et al. 2014). Some paradigms overlap in the social, economic, and environmental goals they set. For example, equitable distribution is central for both paradigms of IWRM and water remunicipalization.

It is important to note that the functional aspects of a paradigm and the context in which it operates are intricately interconnected and co-evolve over time. When paradigms are adopted and translated, they have the potential to influence problem perceptions, transform governance structures, and determine which instruments are implemented. However, it is important to recognize that these functional aspects are not entirely context-free. The context in which a paradigm operates plays a significant role in shaping its development and application. Contextual factors such as cultural norms, socioeconomic conditions, and historical legacies influence how paradigms are formulated, interpreted, and adapted.

In fact, paradigms hardly appear in their pure form, but—through operationalization and interpretation in each context—form conglomerates of previous and current ideas that sediment particular governance structures, routines, or institutions. This might even lead to situations where paradigms are adapted merely symbolically; for example, Biswas (2008) argues that the operationalization of IWRM has been symbolic in several contexts as actors and institutions continue doing what they were doing previously, but under the umbrella of a popular paradigm to obtain both funding and greater acceptability and visibility. Therefore, to understand them in their context it appears pertinent to look beyond the mere names of paradigms and to uncover the attached actor structures, scalar dynamics, and power relations.

Table 1 Examples of paradigms with their main characteristics and rationales, drawn from existing literature.

Paradigm	**Problems addressed**	**Preferred solutions**	**Governance structure**	**Normative goals**		
				Social	**Economic**	**Ecological**
Integrated Water Resources Management (IWRM)	Competing uses of water when water quantity and/or quality issues arise result in an imbalance between water demand and supply (García 2008)	Demand management through an increase in water-use efficiency (Benson et al. 2015)	River basin as a fundamental operational unit for governance (Benson et al. 2015); Multi-level, multi-actor, and decentralized decision-making (Rouillard et al. 2014); Vertical and horizontal integration (Gerlak and Mukhtarov 2015); Holistic and comprehensive water management considering equity, efficiency, and the environment	Equitable access (GWP 2000)	Efficient allocation (GWP 2000)	Environmental and ecological sustainability (GWP 2000, Giordano and Shah 2014)

Water security	Water as a source of destruction, poverty, and dispute (Grey and Sadoff 2007)	Identifying, anticipating, and responding to risks (Bakker and Morinville 2013)	Linkages among sectors (Bakker and Morinville 2013); Multi-scalar linkages within and beyond watershed, which are not the sole unit of analysis and water management (Bakker and Morinville 2013); Recognition of inherent uncertainty in managing socio-ecological systems, therefore promoting an adaptive management paradigm (Bakker and Morinville 2013); Centrality of social power (Bakker and Morinville 2013)	An acceptable level of water-related risks to people; Availability of water of sufficient quantity and quality to support livelihoods, national security, and human health (Grey and Sadoff 2007)	An acceptable level of water-related risks to the economy; Availability of water of sufficient quantity and quality to support production and growth (Grey and Sadoff 2007)	An acceptable level of water-related risks to ecosystems; Availability of water of sufficient quantity and quality to support ecosystem services (Grey and Sadoff 2007)
Hydraulic mission	Supply enhancement and harnessing water for full control domination over nature (Molle et al. 2009)	Large-scale water resources development involving technology, mechanization, and large-scale centralized planning and production processes (Molle et al. 2009)	State-directed and top-down technocratic approach to decision-making (Molle et al. 2009); Centralized coordination and management (Benedikter 2014)	Contribution to welfare through flood control, food and energy generation, and water supply to urban areas (Molle et al. 2009)	Economic development and growth (Molle et al. 2009)	none

Adaptive water governance	Coordinating resource management in the face of the complexity and high uncertainty associated with abrupt changes (Chaffin et al. 2014)	Mainly focusing on a management process rather than an end goal, aims at increasing the adaptive capacity of a water system by putting in place learning processes and respective conditions for these processes to occur (Pahl-Wostl et al. 2007)	Promotes institutional prescriptions such as polycentric governance, public participation, experimentation, and a bioregional approach (Huitema et al. 2009); Adaptation of management strategies and goals in response to new information and quality of processes (Pahl-Wostl et al. 2007)	Desired social state (Chaffin et al. 2014)	none	Desired ecological state (Chaffin et al. 2014)
Remunicipalization	Lack of transparency in private management of water services. Kishimoto and Petitjean (2017) point out other issues: poor quality service provision and poor investment in upkeeping infrastructure; the monitoring and regulation of private contracts came at high costs; and a lack of trusted bidders for private contracts	Transparent, accountable, and socially just direct public management of water service, with civic participation and oversight(Bagué 2020, Geagea et al. 2023)	Full public and democratic governance at the municipal level with direct control of water services, in some cases, commons-inspired with mechanisms for direct civic participation (Bagué 2020)	Equitable access, right to a minimum vital amount per person, commons-inspired forms of direct democracy (Geagea et al. 2023)	Social tariff, non-commodification of water, not-for-profit model, 'reinvesting water back in water' (Geagea et al. 2023)	Circularity, resource sustainability for nature and future generations (Geagea et al. 2023)

Rights of nature	Existing laws do not ensure the protection of the natural world as they regulate rather than prevent its destruction (Chapron et al. 2019)	Granting legal personhood for nature (Rawson and Mansfield, 2018) and managing human activities to prevent the harm or destruction of nature (Harden-Davies et al. 2020)	Legal systems recognize nature as an entity with inherent rights, as opposed to viewing it as something possessed and governed by humans (Borràs 2016)	none	none	Maintain the ecological balance and prevent disturbances to the ecosystem (Harden-Davies et al. 2020)

WATCH ME, OR SEE ME NOT: THE ACTORS INVOLVED IN PARADIGMS

Paradigms do not emerge from nowhere, rather they are embedded in the situated knowledge (Haraway 1988) of human actors who create and circulate them. In this section, we explore the role of actors involved in the creation and diffusion of paradigms, the power struggles involved, as well as how (lacking) reflexivity influences these dynamics.

The first set of actors that play a role in the foundation and implementation of paradigms—often unwittingly—are academics. Most governance paradigms find their roots in academic thought. For example, market-oriented thinking hails from economics; much of the thought that emphasizes participation can be traced back to political science (boosted more recently by Elinor Ostrom's thinking on collective action); and paradigms that emphasize holistic or integrated thinking can be traced back to ecology (the same applies to resilience-based approaches or approaches such as nature-based solutions): as an example, the idea of integrated water management at the river basin scale was promoted by the EU Water Framework Directive with the intention to "[acknowledge] the ecological variability of European waters and treating the river basin, as one interconnected system" (Giakoumis and Voulvoulis 2018, p.822). The process through which these ideas find their way from the scientific community (often through empirical case studies) to policy and governance is long and winding (Voß and Simons 2018) and involves multiple iterations.

When paradigms first emerge, they are often connected to locally situated sites where novel practices of governance help to test, assess, and 'improve' (or reject) the paradigms. Often, it is academic researchers who conduct the initial empirical research and develop policy recommendations. Once these recommendations are regarded as a useful contribution to prevalent governance processes, certain epistemic communities—often collaborations of scientists, practitioners, and economic actors—form around the paradigm to facilitate its movement to other contexts (Pahl-Wostl et al. 2006). To promote the paradigm, they might resort to highlighting only the positive or successful experiences in adopting the paradigm and downplay negative experiences. These communities are also sometimes referred to as discourse coalitions (Hajer 1997), advocacy coalitions, or constituencies (Voß and Simons 2014). They tend to consist of actors from different fields and disciplines (politicians, bureaucrats, NGOs, international organizations) who operate collectively.

Within this process of promotion and implementation, the role of government actors has been well documented (e.g., Suhardiman et al. 2015, Allouche 2017, Lee et al. 2022). Yet, other actors also play a role, although they have received less attention in research, including civil society (e.g., Elfithri et al. 2019, Shields et al. 2021), international non-governmental organizations (e.g., Chikozho and Kujinga 2017), scientific communities (e.g., Pahl-Wostl 2020), citizens and residents (e.g., Chomba et al. 2017), multinational corporations (e.g., Pahl-Wostl 2019), and global private environmental consultancy firms (e.g., Bouteligier 2011).

Particularly, it is ‘policy entrepreneurs’ or ambassadors (Huitema and Meijerink 2009, De Oliveira 2021) who develop or attach themselves to new ideas, experiment with them to corroborate their value, sell them by linking them to existing problem frames, network and build coalitions, and identify venues from where they can propagate their approach. Such channels include transnational networks that form around a common paradigm—a common idea of water governance. These networks may gather in different paradigm arenas such as conferences where actors are involved in setting or breaking water governance agendas, or influential water reports that are used to reinforce paradigms or adjust the ‘branding’ of a paradigm (e.g., United Nations 2023; UN Water Conference 2023). Additionally, “venue shopping” refers to the fact that sometimes different levels of government (local, regional, national, supranational) are more receptive to the ideas of policy entrepreneurs, or to the fact that different branches of government, or sectors of society are more open to new ideas (e.g., the media) and are actively seeking them out (see also Huitema and Meijerink 2010).

The process of paradigm setting is often politically charged and influenced by power relations. In the literature on water governance, private actors are increasingly being seen as focal actors in the promotion and implementation of water governance paradigms (e.g., Mills-Novoa and Hermoza 2017). This may be seen as a result of entrenched neo-liberalism promoting techno-managerialism and public-private-partnership models; to the rise of austerity regimes impacting national and local policies for governments to facilitate the role of private sector involvement in water management (Geagea et al. 2023, Kaika et al. 2024). Private sector involvement does not mean only water companies, but also private consulting companies. For instance, Leitner et al. (2018, p.6) reveal how global consultancies like AECOM and Arup promote best-practice tools for assessing resilience, thereby “spreading an urban resilience gospel” that ultimately introduces a technical and managerial approach to urban resilience that privileges the private sector. Bakker (2010) argues that the promotion of private-sector paradigms was most concentrated (and contested) in large cities in the Global South countries, where the widespread lack of access to networked water supplies is seen as a global crisis.

International funding and donor organizations also play a crucial role in the circulation of paradigms. Huitema and Meijerink (2010) call attention to the role of these organizations that exert more influence on paradigm adoption in developing countries of the Global South than industrialized countries of the Global North. It has been documented that donor organizations, such as the World Bank, the International Monetary Fund, the Inter-American Development Bank, and the Asian Development Bank, played a crucial role in shaping water policy transitions in countries such as Indonesia, Mexico, Tanzania, Thailand and Turkey (Huitema et al. 2011). As a condition for obtaining financial support, these organizations call for fundamental changes in governance regimes and often, the adoption of certain paradigms such as privatization or decentralization. The authors emphasize the role of "shadow networks" that consist of actors operating on the peripheries or outside conventional power structures. They play a crucial role in paradigm development and demonstration of paradigm viability, although they depend on collaboration with formal policy networks to translate paradigms into tangible changes in governance.

Finally, our last point relates to the reflexivity of those involved in paradigm development, promotion, and implementation. Powerful place-based and transnational actor-networks mobilize 'universal' paradigms, like mining companies, depoliticize and naturalize certain approaches to govern water, which then stabilize the hydro-social order to serve their interest (Ahlers and Zwarteveen 2009) (Ahlers & Zwarteveen 2009). However, these can be promoted unintentionally. This happens especially where technical solutions play a major role and where main actors do not necessarily realize the political implications of adopting certain paradigms. Paying attention to and encouraging reflexivity among these powerful actor networks and the role they play in promoting, stabilizing, and naturalizing certain approaches, is one key entry point to re-politicizing water governance paradigms.

This section has reflected on the visible actors of water governance paradigms and others who are sometimes hiding in plain sight. In this sense, certain actors become involved in a 'labor of love,' exercise agency and a certain level of control over paradigms, while others are involved in this labor unintendedly, or without foreseeing the blind spots of these promoting these ideas without questioning their universality. For this reason, we next reflect on the role of intervention of water governance actors in distinct temporal and spatial scales.

TEMPORAL AND SPATIAL DIMENSIONS OF WATER GOVERNANCE PARADIGMS

There are interesting issues of spatial and temporal scalar dynamics around water governance paradigms (see Pahl-Wostl et al. 2021). While the issue of scales, at least spatial ones, is well acknowledged in water governance (e.g., Cook et al. 2013, Newig et al. 2016, Norman et al. 2016), it is rarely discussed in the context of water governance paradigms (e.g., Cohen and Davidson 2011). Against this backdrop, our writing has a more speculative character: 1) scales within paradigms: whether and how water governance paradigms explicitly address or problematize spatial or temporal dimensions; 2) paradigms within scales: whether and how water governance paradigms reflect the convictions and problems of particular times and places and are thus 'typical' for certain eras; and (relatedly); and 3) paradigms across scales: whether and how paradigms develop over time and spread across space.

Scales within paradigms: Do paradigms explicitly address space and time?

When it comes to the notion of space, water governance faces a particular issue in which hydrological systems rarely fit the political-administrative scales of states and regions. Paradigms treat this issue in varied ways. Integration-oriented paradigms (e.g., IWRM, river basin approach, transboundary water management, and to some extent also the debate on adaptive water governance) are most outspoken and make explicit prescriptions about scales: the scale at which problems emerge, is also the scale at which they must be addressed, and institutions must be adapted to this logic. As Schlager and Blomquist (2008, p.1) succinctly summarized: "For the last

25 years, prescriptions of the water policy literature have centered upon two themes. The first is that 'the watershed' is the appropriate scale for organizing water resource management. The second is that since watersheds are regions to which political jurisdictions almost never correspond, and watershed-scale decision-making structures do not usually exist, they should be created."

However, these ideas are not without critique: Molle (2009) shows quite clearly that the idea to align problem and solution scales is impossible to realize in practice, if only because water is a multidimensional resource and the scale at which one problem (e.g., related to fisheries) often does not match with the scale at which another issue (e.g., water quality) emerges. He also demonstrates how the river basin management is mainly a discursive ploy—and that those advancing it, tend to favor particular outcomes which they hope will be better served in new institutional settings. Schlager and Blomquist (2008) suggest the same but also argue that institutional engineering in the direction of river basin organizations breaks existing bonds between voters, citizens, and government, replacing visible and known government entities, for unknown new entities. Although these issues are well known (Huitema and Meijerink 2014), the lure of integration remains strong.

There are also subtler ways in which space plays a role in water governance paradigms. It is for instance clear that approaches such as collaborative, participatory governance, and community governance rely on a clear preference for local problem-solving. At this scale, actors involved can interact regularly and develop mutual understandings of each other's interests, levels of trust and solidarity can emerge, and there is a track record of preserving water resources in a sustainable way (Ostrom 1986).

Surprisingly enough, the issue of time is not integrated into many water governance paradigms, leaving hydrological time frames rather unaddressed (e.g., seasonal precipitation patterns, time—up to decades—that aquifers need to restore). WG paradigms revolving around adaptation (adaptive governance, resilience thinking) are premised on explicit notions of development over time (for instance in the form of the resilience cycle that suggests social-ecological systems go through loops in which management approaches—often based on simplified understandings of the system- do yield results for a while), are applied more intensively, but then break down, and need to be reorganized or transformed (Holling 1985). However, much of the thinking in these paradigms is about experimentation and learning to probe deeper into the dynamics of the social-ecological systems, thus allowing the parties involved to get ahead of potential collapse, or to experiment their way toward better approaches.

Are water governance paradigms 'typical' for certain periods or places?

It is not hard to see that water paradigms do reflect the time and places in which they have emerged, and certain attitudes and cultures of dealing with the environment (Franco-Torres 2021). The hydraulic paradigm, with its emphasis on taming water, appropriating it for human use, and on centralized decision-making, fits with the industrial age of the late 19th century, which was also a period of nation-state building, where large-scale water infrastructure was a source of national pride (Linton 2014). Other more localized and environmental interests were easily cast aside in the spirit of achieving societal progress, based on the elevation of poverty, the introduction of electricity, and the more predictable availability of water for agriculture (Molle et al. 2009).

This paradigm pervaded discussions about water around the globe for a long time but started to become more and more contested from the 1950s onwards when the first signs and later the full bloom of environmental concerns became visible, and democratization became a much more important concern. Initially, this mainly led to resistance and counter-reactions, but later this resulted in a more positive fight against pollution, the recognition of natural values, and a striving for sustainability—often carried in the form of formal state institutions such as environmental legislation (requiring permits), environmental impact assessments, and public participation rights. So, the state was still at bay but was now supposed to have a more balanced (or greener) approach.

When the critique of the state started swelling in the 1970s and 1980s, the state retreated, and an emphasis on markets and private parties to provide for water infrastructure on the one hand (privatization), and for markets to provide for environmental protection (market-based instruments, polluter pays principles) emerged (Bakker 2003). Various international organizations, such as the OECD and World Bank actively sought to insert such approaches and principles in water governance debates and were successful to a high degree in shaping water governance practices in various countries (commodification, privatization).

Finally, the realization that social-ecological systems are inherently complex and that many approaches to water governance or water resources (such as maximum sustainable yield for fisheries) were essentially based on dangerous simplifications, was brought home by the notion of global change, which transpired from the late 1980s onwards. In this context, paradigms such as adaptive governance, resilience thinking, and nature-based solutions could be seen.

Water governance paradigms did not and do not develop in isolation from the era and place in which they emerged. As we have discussed here, one can already glean that the societal goals and priorities have changed over time, that thinking about modes of governance (state, market, community) have also changed, and that greater insight into the complexities of water governance developed in accordance with broader societal developments. But paradigms are also marked by the place in which they have emerged. It has been argued in this context (Gupta 2009) that the global exchange of ideas on WG is a very titled process, where new paradigms are essentially developed, corroborated, and certified in the Global North, uploaded to global institutions such as the World Bank, and subsequently 'downloaded' (in highly unequal power settings) to the Global South, where they often sit awkwardly within existing institutional arrangements.

Up and down with paradigms: how do they develop over time and diffuse in space?

We do not have many credible conceptual models that can explain how policy paradigms develop over time. The best-known publication on policy paradigm change is the one by Hall (1993) who described how British economic and monetary policy went through a fundamental change in the 1970s. Hall suggested that policy change usually reflects ideational change and that such ideas are present in any policy subsystem at three levels: the level of overarching goals (paradigms), the level of instruments used, and the level of instrument settings. He emphasizes that policy-related learning is important in driving policy change, and that change at the levels of instruments is relatively frequent, but that paradigmatic policy change is rare.

Additionally, it is important to note that multiple paradigms are at times vying for influence over policy. Hall (1993, p.280) suggests that paradigms compete "because each paradigm contains its own account of how the world facing policymakers operate and each account is different, it is often impossible for the advocates of different paradigms to agree on a common body of data against which a technical judgment in favor of one paradigm over another might be made." He also indicates that it is difficult to objectively evaluate policy paradigms on scientific grounds alone because the movement from one paradigm to another will ultimately entail a set of judgments that is more political in tone, and the outcome will depend, not only on the arguments of competing factions, but on their positional advantages within a broader institutional framework (Hall 1993). This is also influenced by who is ultimately seen as a reliable expert, especially on matters of technical complexity. Finally, Hall suggests that failure of the existing paradigm helps transition to another one, involving experimentation with new policy shifting the center of authority, and reigniting competition between paradigms (Hall 1993).

Several critiques have been leveled at this model since, and especially the idea that paradigms are incommensurable with each other has drawn the ire of critics (Zittoun 2015). Indeed, if one looks at a paradigm such as IWRM, one sees a hodgepodge of ideas—including the notion that water governance should be at the river basin level, but also that it should be participatory, and that the polluter should pay. Sharpe et al. (2016), although not offering an analytical model, do suggest that paradigms can obtain a second life by taking over certain ideas from other paradigms, and it would seem that this has happened with IWRM (which was initially mainly a paradigm to do with integration), resulting in a more broadly aimed paradigm.

One might add that Hall's model is rather "policy-centric," meaning that in essence, he assumes that explanations for policy change are to be found in the world of policy and politics, although social-cultural and socio-economic developments also figure to some degree—for instance in the form of societal interests that start organizing around particular issues. This means that developments in socio-technical systems are not very explicitly considered, whereas it is quite clear that in the water management field, technical systems or infrastructural choices tend to heavily influence subsequent public decision-making (through sunk costs for instance, or through scale advantages and impacts on training and expertise) and societal perceptions and demand. Reflecting on these various comments, Groen et al. (2023) show that for German coastal management, it is very hard to switch from flood risk management through hard infrastructure (e.g., dams, dikes) to alternative approaches, such as those that would use natural dynamics (e.g., nature-based solutions) to potentially create similar safety levels. This realization would fit very well with insights from institutional change theory, which suggests that 'new institutions' tend to layer on top of already existing arrangements causing complex interaction patterns, rather than fully displace 'old' approaches (Streeck and Thelen 2005, Patterson 2021, Groen et al. 2023).

THE POWER OF PARADIGMS AND PARADIGMS OF POWER

In the previous sections, we have discussed different dimensions of water governance paradigms and have unpacked some of their complexity. We have, however, not yet drawn on critical scholarship (e.g., political ecology, feminist approaches) that studies how water governance is inherently political and how water governance research is often "more concerned with promoting particular politically inspired agendas of what water governance should be than with understanding what it actually is" (Zwarteveen et al. 2017, p.1). In this section, we engage with issues of power to unpack how particular interests are promoted through water governance paradigms (Wesselink et al. 2017).

Power of paradigms

The power of paradigms highlights the relation that exists between the features of crafting, diffusing, and implementing water governance paradigms and how they condition and shape the politics of human-water relations. We find potential in not only combining different interpretive and critical approaches to disentangle the universalizing, normative, and naturalizing dimensions of WG paradigms (Ingram 2011), but also to identify and understand tensions in their implementation and the multiple contestations that arise therein.

Looking into the power of paradigms allows us to nuance the academic debate around the 'successes' and 'failures' of water governance paradigms. Understandings of power, as produced by historically established social structures, have contributed to identifying the drive to scale up and universalize WG 'best practices' and general solutions for context-specific problems (Druijff and Kaika 2021, Lukat et al. 2022). In contrast, approaches of power as 'power to' (instrumental power, agency-based power, etc.) have been typically linked to highlight 'success stories' promoted by specific institutions, operationalizing and normalizing WG paradigms in accordance with their interest. These approaches give insight into the notion of 'success' as often defined by the beliefs of those who benefit the most from a paradigm's implementation. Exploring the agencies of different actors and their power to mobilize resources can also bring critical insights into the implementation of WG paradigms such as the IWRM (Harrison and Mdee 2017) or water privatization (Bieler 2018).

In addition, the trajectory of a paradigm (e.g., its formulation, adoption, implementation, etc.), as discussed earlier in section 4, is often embedded in complex and politically charged relationships between different actor groups. Some groups are particularly 'successful' in diffusing hegemonic views through knowledge production, as often argued in post-structuralist research (Gramsci 1971, Foucault 1980, Ekers and Loftus 2008). In other terms, specific discourses that aim to "conduct the conduct" of water uses, are conformed to socially shared perspectives and often naturalized through water governance paradigms (Vos and Boelens 2014). Besides consent production, we observe recurrent tensions in the implementation of WG paradigms and, particularly, in how the materialization of those imaginaries unfold through multiple forms of violence and coercion in particular contexts (Birkenholtz 2009, Marcatelli and Büscher 2019). Whether these are 'slow' (Nixon 2011) or explicit, violence and coercion can be rethought through the lens of radical geographies and decolonial and feminist epistemologies (Christian and Dowler 2019, Álvarez and Coolsaet 2020, Toro 2021), largely excluded from current academic understandings of power. These approaches additionally shed light on the emergence of resistance to certain WG paradigms: through counter-powers or counter-paradigms, and the capacity of the latter to build alternatives to dominant paradigms (Moffat et al. 1991, Miller 2013, Boelens 2022, p.19).

As discussed above, and from an ontological perspective, (ontology being defined as the "theory of how the world is—or is becoming (see Mol 2002, Barad 2007, Krueger and Alba 2022)), WG paradigms have the power to assert certain worlds while making others invisible. Engaging a plurality of ontological perspectives helps us to question the power some paradigms hold in identifying WG problems and universalizing particular solutions (Blaser 2009, Flaminio 2021). For example, some WG paradigms may be undergirded by a mechanistic ontology (what Krueger and Alba 2022 refer to as a "generalizing" tradition) that assumes the natural world can be understood through objective and quantifiable measurements. Other water governance paradigms may be grounded in a relational ontology (an interpretivist tradition), which assumes that the natural world is interconnected and our relationships with the environment are shaped by social, cultural, and historical factors. Questioning how one 'sees the world' plays a role in understanding how and why certain WG paradigms are valued above others, and thus hold more power in shaping reality. The consideration of plural ontological and epistemological perspectives also links with decolonization in WG and warns against approaches that try to recolonize indigenous knowledge into existing paradigmatic approaches to WG (Wilson and Inkster 2018, Viaene 2021, Brennan 2022).

Paradigm of Power

Our critical inquiry leads us to also question the notion of governance itself as a paradigm of power. Drawing from prior scholarship that has scrutinized the powerful ideas inscribed into governance (e.g., Swyngedouw 2005, Priscoli and Wolf 2009, McGregor 2012, Zwarteveen et al. 2017, Nagendra et al. 2018, Sultana 2018, Micciarelli 2022, Querejazu 2022, Whaley 2022), we can problematize how governance is often understood as the 'natural' or 'normal' mode to address complex political issues (i.e., water problems). The normalization of governance implies the often unquestioned assumption that it (in contrast to government) allows for more democratic governing practices by involving multiple actors and levels in complex decision-making processes and drawing on pluralistic and inclusive principles of cooperation and polycentricity (Mayntz 2003, p.7; Shore 2011, p.288-289). At once, the ideological assumptions, norms, values, knowledge, and truths (i.e., humans must 'govern' water; belief in engineering solutions) that derive from the governance paradigm are made invisible (Shore 2011). Governance as 'governmentality' (Foucault 1991)—or 'conduct of conduct'—draws on technical knowledge systems, and neoliberal values, and produces truths about how subjects and objects are to be governed (Shore 2011). Instead of leading to more democratic practices, it results in a loss of political accountability (Shore 2011).

In Table 2, we propose an entry point to complicate and re-politicize water governance and water governance paradigms, providing relevant theoretical perspectives for examining power dynamics. For each theoretical perspective, we exemplify ways to analyze forms of power in WG. This approach is useful from an analytical perspective in hydrosocial studies, as it avoids a reductionist view of paradigms as power-neutral, instead highlighting them as tools and mechanisms for reproducing power dynamics in diverse forms.

Table 2 Potential of integrating diverse epistemological perspectives in the examination of power dynamics in WG paradigms.

Theoretical perspectives	**Relevance to understandings of water governance paradigms**
Structural power/power over	Despite the limitations of thinking in terms of 'power over' for its strict categorization and determinism (Göhler 2009), this structural power lens can be useful to understand social relations, where dominant actors influence others' interests through, for instance, the use of expert knowledge.
Power-to/instrumental power, or agency-based power	This analytical perspective can be useful to understand which and how 'success stories' are promoted by particular institutions as 'best practices' that aim to normalize certain approaches in WG. Nevertheless, we believe that analysis focused only on agency perspectives of power as a 'capacity' risk falling into assumptions of full rationality if we aim to analyze the pitfalls of particular implementations. We question the 'normative rationality' (Flyvbjerg 1998) that underpins WG paradigms to offer particular solutions with general applicability, based on specific contexts and resources of set actors.
Post-structuralist approaches to power	Unraveling the discursive dimension of power can help to delve into the assumptions and claims that often become naturalized in WG and underpin particular political orders. Despite its potential to understand the 'conduct of conduct,' these approaches could benefit from a complementary analysis that takes into account violence and coercion (Dell'Angelo et al. 2021, Pain and Cahill 2021, Dunlap 2023).
Decolonial and feminist epistemologies	Theoretical analysis of WG paradigms should not lose sight of the exploitations of the environment and the oppression they sometimes generate. In other words, coercion and violence are not only relevant in the physical and emotional dimensions but also in the production of consent and in the implications of marginalizing vulnerable groups in WG (see Sultana 2011, Harris 2015, Kaika 2017, Zaragocin and Caretta 2021, Kaika et al. 2024)

Counter-powers	While acknowledging the trap of falling into counter-paradigms as panaceas, it is key to identify that WG paradigms often unfold hindering local approaches (Immovilli et al. 2022). Recent work on the existence and production of water ontologies can contribute to new understandings of alternative and non-paradigmatic approaches to WG paradigms (Flaminio 2021). There is a need for the recognition of a 'pluriverse' of (political) ontologies (Escobar 2001) when analyzing movements of 'resistance.' From a standpoint in which "there are no relations of power without resistances" (Foucault 1980, p.142), we consider the analysis of power to be inseparable from the relations of resistance that emerge from the application of WG paradigms.

AGENDA FORWARD

Here we identify ten agenda items that should be prioritized in a future research agenda on water governance paradigms. These agenda items have been carefully curated based on our conceptual and empirical enquires in this paper to shed light on various dimensions and challenges within water governance. They are intended to help provide a more comprehensive understanding of water governance paradigms for researchers and practitioners in the field. Ultimately, these agenda items for future research serve to inspire research and promote critical reflection within research and praxis in the field of water governance. By outlining this agenda forward, we hope to contribute to the development of more reflexive water governance practices.

1. Paradigms act as a source code for decision-making processes and governance practices. A deeper understanding of water governance therefore necessitates research that identifies and examines what paradigms are underpinning and influencing the core norms, values, and goals of the broader system.

2. A comprehensive understanding of water governance paradigms necessitates an integrated examination of socio-economic, political, geographical, temporal, and cultural contexts. Researchers and practitioners must recognize the significance of these contextual factors, and more systematically study them, as they influence the development of paradigms, the implementation of governance practices, and the alignment with ecological time frames, thereby shaping governance approaches over time.

3. The notions of necessity and effectiveness of paradigms in enhancing water governance have been largely understudied, perhaps because of the complexity of this enterprise as highlighted in this paper. However, this topic requires further investigation, especially to avoid the pitfall of considering certain paradigms a "success" without acknowledging a success "of what" and "for whom"?

4. We are beginning to see how some actors are acting in the "backstage" of paradigms' trajectory, but it remains unclear who these actors are exactly. Further research should uncover the blind spots in literature around which types of actors have a role and assert levels of agency in the diffusion of water governance paradigms. Research is needed to

evaluate how well actors know the paradigm(s) within which they are operating, the paradigm(s) they are circulating, and the consequences of their actions.

5. It is important to identify which strategies are used to advance certain paradigms (e.g., windows of opportunity), and to acknowledge when these strategies result in the growing hegemony of a particular paradigm. When these paradigms are “locked in”, it is also important to identify which strategies can be used to maintain an open mind to new and possibly more relevant paradigms, to ensure that negative experiences are allowed to affect the debate and to acknowledge failure.

6. Greater attention is needed to subaltern actors, ‘alternative’ approaches to water governance, and plural ontologies of water (i.e., peasant groups, indigenous peoples, grassroots movements, and their non-paradigmatic human-water relations, water as a living entity, caring for water) without romanticizing and essentializing them nor recolonizing them into universal paradigms and panaceas for water management. This can help highlight gaps in the acknowledgment of certain actors' capacity and contribution in producing, translating, and absorbing paradigms.

7. It is important to acknowledge that paradigms emerge in particular periods and contexts. The development steps and the diffusion of water governance paradigms in space and time remain understudied, particularly in relation to advancing relevant water policies. Further study to connect paradigms to the broader spatial and temporal scale can shed light on these issues.

8. Acknowledging the limitations of a reductionist approach of power as “one” thing can inform us about the workings of water governance paradigms from a multifaceted power perspective (such as considerations of ‘power to’ and counter-powers). This awareness is necessary to re-politicize water governance paradigms and draw attention to the power dynamics that underlie them.

9. The normalization of water governance paradigms often leads to unquestioned governing practices, reinforcing their underlying ideological assumptions, norms, values, knowledge, and truths. To effectively challenge this normalization, research, and actions aimed at de-normalizing governance must recognize governance itself as a paradigm of power, as governmentality. Such reflexivity would allow researchers and practitioners to approach their work on and with paradigms with a deepened awareness, facilitating informed adjustments and responses.

10. Most dominant paradigms are generated in the Global North, which has implications for how water governance problems are defined and for the kinds of solutions that are presented in other contexts. We call for pluralizing epistemological and ontological perspectives on water governance, as a way to resist universalizing tendencies. Agency-based power, post-structuralist approaches to power, and counter-powers, along with decolonial and feminist epistemologies, among others, may offer new insights into future research agendas.

CONCLUSION

In this paper, we have emphasized the importance of understanding water governance paradigms and their role in shaping governance approaches. Paradigms serve as a source code for decision-making processes and practices, influencing the identification of water governance needs, goals, and means. However, paradigms are also often implicit, and actors who apply them may not be fully aware of which paradigms they are operating within or of the consequences of promoting these ideas. This calls for greater reflexivity among scholars and practitioners working with paradigms.

The agenda items presented in this paper contribute to missing pieces in understanding water governance paradigms and their research. They insist on acknowledging contextual factors, on nuancing the idea of 'effective paradigms' by carefully looking at the actors involved, including those that operate behind the scenes, and who might benefit from certain paradigms becoming a 'success.' Furthermore, the agenda highlights the power dynamics, transnational networks, and historical and cultural contexts that shape paradigms and their diffusion. It also emphasizes the importance of plural epistemic perspectives, the inclusion of subaltern actors, and the acknowledgment of plural ontologies to resist universalizing certain paradigms.

To advance our understanding of water governance paradigms, it is crucial to address these gaps in research, unpack the spatial and temporal considerations, and re-politicize paradigms by recognizing their power dynamics. Moreover, we must avoid the pitfall of recycling old ideas under different paradigm names and strive for reflexivity in our work. By embracing these agenda items, researchers and practitioners can facilitate more relevant policymaking and foster reflexive water management practices.

ACKNOWLEDGEMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 861509 - NEWAVE.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article because no data were analyzed in this study.

LITERATURE CITED

Abson, D. J., J. Fischer, J. Leventon, J. Newig, T. Schomerus, U. Vilsmaier, H. von Wehrden, P. Abernethy, C. D. Ives, N. W. Jager, and D. J. Lang. 2017. Leverage points for sustainability transformation. *Ambio* 46(1):30–39.

Ahlers, R., and M. Zwarteveen. 2009. The water question in feminism: Water control and gender inequities in a neo-liberal era. *Gender, Place and Culture* 16(4):409–426.

Allouche, J. 2017. The Birth and Spread of IWRM – A Case Study of Global Policy Diffusion

and Translation. Pages 30–56 *Flows and Practices*. Weaver Press.
Álvarez, L., and B. Coolsaet. 2020. Decolonizing Environmental Justice Studies: A Latin American Perspective. *Capitalism, Nature, Socialism* 31(2):50–69.
Bagué, E. 2020. La Remunicipalización del Agua en el marco de la Re-Definición de la Democracia. El Caso De Terrassa. *Clivatge* 8(8).
Baird, J., R. Plummer, G. Dale, B. Kapeller, A. Mallette, A. Feist, and Y. Kataoka. 2021. The emerging scientific water paradigm: Precursors, hallmarks, and trajectories. *Wiley Interdisciplinary Reviews: Water* 8(1):1.
Bakker, K. 2003. A Political Ecology of Water Privatization. *Studies in Political Economy* 70(1):35–58.
Bakker, K. 2010. *Governance failure and the world's urban water crisis*. Cornell University Press.
Bakker, K., and C. Morinville. 2013. The governance dimensions of water security: A review. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 371(2002):20130116.
Baldwin, C. 2008. Governance and Justice in Water - Introduction. *Social Alternatives* 27(3):3–7.
Barad, K. 2007. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Duke University Press, Durham.
Baumgartner, F. R. 2014. Ideas, paradigms and confusions. *Journal of European Public Policy* 21(3):475–480.
Benedikter, S. 2014. Extending the hydraulic paradigm: Reunification, state consolidation, and water control in the vietnamese mekong delta after 1975. *Southeast Asian Studies* 3(3):547–587.
Benson, D., A. K. Gain, and J. J. Rouillard. 2015. Water governance in a comparative perspective: From IWRM to a "nexus" approach? *Water Alternatives* 8(1):756–773.
Bieler, A. 2018. Agency and the Power Resources Approach: Asserting the Importance of the Structuring Conditions of the Capitalist Social Relations of Production. *Global Labour Journal* 9(2).
Birkenholtz, T. 2009. Groundwater governmentality: Hegemony and technologies of resistance in Rajasthan's (India) groundwater governance. *Geographical Journal* 175(3):208–220.
Biswas, A. K. 2008. Integrated water resources management: Is it working? *International Journal of Water Resources Development* 24(1):5–22.
Blaser, M. 2009. Political Ontology. *Cultural Studies* 23(5–6):873–896.
Blatter, J., and H. Ingram. 2000. States, markets and beyond: Governance of transboundary water resources. *Natural Resources Journal* 40(2):429–472.
Boelens, R. 2022. Rivers of Scarcity. Utopian water regimes and flows against the current. *Alternautas* 9(1):14–53.
Borràs, S. 2016. New Transitions from Human Rights to the Environment to the Rights of Nature. *Transnational Environmental Law* 5(1):113–143.
Bouteligier, S. 2011. Exploring the agency of global environmental consultancy firms in earth system governance. *International Environmental Agreements: Politics, Law and Economics* 11(1):43–61.
Brennan, R. 2022. Making space for plural ontologies in fisheries governance: Ireland's disobedient offshore islands. *Maritime Studies* 21(1):35–51.
Bréthaut, C., and R. Schweizer. 2018. *A Critical Approach to International Water Management Trends*. Page (C. Bréthaut and R. Schweizer, editors) *A Critical Approach to International*

Water Management Trends. Palgrave Macmillan London.
Chaffin, B. C., H. Gosnell, and B. A. Cosens. 2014. A decade of adaptive governance scholarship: synthesis and future directions. *Ecology and Society* 19(3):art56.
Challies, E., and J. Newig. 2022. Water, rivers and wetlands. Pages 512–525 *Routledge Handbook of Global Environmental Politics*. Routledge, London.
Chapron, G., Y. Epstein, and J. V. Lopez-Bao. 2019. Natural Systems From Destruction. *Science* 363(6434):1392–1393.
Chikozho, C., and K. Kujinga. 2017. Managing water supply systems using free-market economy approaches: A detailed review of the implications for developing countries. *Physics and Chemistry of the Earth* 100:363–370.
Chomba, M. J., T. Hill, B. A. Nkhata, and J. J. Förster. 2017. Paradigms for water allocation in river basins: A society-sciencepractice perspective from Southern Africa. *Water Policy* 19(4):637–649.
Christian, J. M., and L. Dowler. 2019. Slow and fast violence: A feminist critique of binaries. *Acme* 18(Spicialissue5):1066–1075.
Cohen, A., and S. Davidson. 2011. The watershed approach: Challenges, antecedents, and the transition from technical tool to governance unit. *Water Alternatives* 4(1):1–14.
Cook, B. R., M. Kesby, I. Fazey, and C. Spray. 2013. The persistence of 'normal' catchment management despite the participatory turn: Exploring the power effects of competing frames of reference. *Social Studies of Science* 43(5):754–779.
Daigneault, P. M. 2014. Reassessing the concept of policy paradigm: Aligning ontology and methodology in policy studies. *Journal of European Public Policy* 21(3):453–469.
Dell'Angelo, J., G. Navas, M. Witteman, G. D'Alisa, A. Scheidel, and L. Temper. 2021. Commons grabbing and agribusiness: Violence, resistance and social mobilization. *Ecological Economics* 184:107004.
Druijff, A., and M. Kaika. 2021. Upscaling without innovation: taking the edge off grassroot initiatives with scaling-up in Amsterdam's Anthropocene forest. *European Planning Studies* 29(12):2184–2208.
Dunlap, A. 2023. The green economy as counterinsurgency, or the ontological power affirming permanent ecological catastrophe. *Environmental Science & Policy* 139:39–50.
Ekers, M., and A. Loftus. 2008. The power of water: Developing dialogues between Foucault and Gramsci. *Environment and Planning D: Society and Space* 26(4):698–718.
Elfithri, R., M. Bin Mokhtar, and S. Zakaria. 2019. The need for awareness raising, advocacy, and capacity building in Integrated Water Resources Management toward sustainable development: A case study in Malaysia. *World Water Policy* 5(1):43–54.
Escobar, A. 2001. Culture sits in places: reflections on globalism and subaltern strategies of localization. *Political Geography* 20(2):139–174.
Flaminio, S. 2021. Modern and Nonmodern Waters: Sociotechnical Controversies, Successful Anti-Dam Movements and Water Ontologies. *Water Alternatives* 14(1):204–227.
Flyvbjerg, B. 1998. *Rationality and power: Democracy in practice*. University of Chicago Press.
Foucault, M. 1980. *Power/Knowledge: Selected Interviews and Other Writings*. Page (C. Gordon, editor). Pantheon, New York.
Foucault, M. 1991. Governmentality. Pages 87–104 *in* T. F. E. S. in Governmentality, editor. *G. Butchell, C. Gordon and P. Miller. Chicago: :* University of Chicago Press.
Franco-Torres, M. 2021. *The Path to the New Urban Water Paradigm – From Modernity to Metamodernism*. Page *Water Alternatives*.

García, L. E. 2008. Integrated water resources management: A “small” step for conceptualists, a giant step for practitioners. *International Journal of Water Resources Development* 24(1):23–36.
Geagea, D., M. Kaika, and J. Dell’Angelo. 2023. Recommoning water: Crossing thresholds under citizen-driven remunicipalisation. *Urban Studies* 60(16):3294–3311.
Gerlak, A. K., and F. Mukhtarov. 2015. ‘Ways of knowing’ water: integrated water resources management and water security as complementary discourses. *International Environmental Agreements: Politics, Law and Economics* 15(3):257–272.
Giakoumis, T., and N. Voulvoulis. 2018. A participatory ecosystems services approach for pressure prioritisation in support of the Water Framework Directive. *Ecosystem Services* 34:126–135.
Giordano, M., and T. Shah. 2014. From IWRM back to integrated water resources management. *International Journal of Water Resources Development* 30(3):364–376.
Göhler, G. 2009. ‘Power to’ and ‘power over.’ Pages 27–39 *in* A. Gramsci, editor. *The SAGE Handbook of Power*. SAGE.
Gramsci, A. 1971. *Selections from the Prison Notebooks*. International Publishers, New York.
Grey, D., and C. W. Sadoff. 2007. Sink or Swim? Water security for growth and development. *Water Policy* 9(6):545–571.
Groen, L., M. Alexander, J. P. King, N. W. Jager, and D. Huitema. 2023. Re-examining policy stability in climate adaptation through a lock-in perspective. *Journal of European Public Policy* 30(3):488–512.
Gupta, J. 2009. Driving Forces Around Global Fresh Water Governance. Pages 37–57 *in* D. Huitema and S. Meijerink, editors. *Water Policy entrepreneurs. A Research Companion to the Water Transitions around the Globe*. Edward Elgar.
GWP. 2000. *Towards Water Security : A Framework for Action Foreword*. Stockholm.
Hajer, M. A. 1997. *The Politics of Environmental Discourse*. Page *The Politics of Environmental Discourse*. Oxford University PressOxford, Oxford.
Hall, P. A. 1993. Policy Paradigms, Social Learning, and the State: The Case of Economic Policymaking in. *Comparative Politics* 25(3):275–296.
Haraway, D. 1988. Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective. *Feminist Studies* 14(3):575.
Harden-Davies, H., F. Humphries, M. Maloney, G. Wright, K. Gjerde, and M. Vierros. 2020. Rights of Nature: Perspectives for Global Ocean Stewardship. *Marine Policy* 122.
Harris, L. M. 2015. Hegemonic Waters and Rethinking Natures Otherwise. Pages 157–181 *Practising Feminist Political Ecologies*. Zed Books Ltd.
Harrison, E., and A. Mdee. 2017. Successful small-scale irrigation or environmental destruction? The political ecology of competing claims on water in the Uluguru Mountains, Tanzania. *Journal of Political Ecology* 24(1):406–424.
Harsha, J. 2012. IWRM and IRBM concepts envisioned in Indian water policies. *Current Science* 102(7):986–990.
Holling, C. S. 1985. Resilience of ecosystems: local surprise and global change. Pages 228–269 *in* J. G. Roederer and T. F. Malone, editors. *Global Change*. Cambridge University Press, Cambridge.
Huitema, D., L. Lebel, and S. Meijerink. 2011. The strategies of policy entrepreneurs in water transitions around the world. *Water Policy* 13(5):717–733.
Huitema, D., and S. Meijerink. 2009. *Water policy entrepreneurs: A Research companion to*

water transitions around the globe. Page (D. Huitema and S. Meijerink, editors) *Water Policy Entrepreneurs: A Research Companion to Water Transitions around the Globe*. Edward Elgar, Cheltenham.
Huitema, D., and S. Meijerink. 2010. Realizing water transitions: The role of policy entrepreneurs in water policy change. *Ecology and Society* 15(2):3.
Huitema, D., and S. Meijerink. 2014. *The politics of river basin organizations: institutional design choices, coalitions and consequences*. Edward Elgar Publishing, Cheltenham, UK.
Huitema, D., E. Mostert, W. Egas, S. Moellenkamp, C. Pahl-Wostl, and R. Yalcin. 2009. Adaptive water governance: Assessing the institutional prescriptions of adaptive (co-)management from a governance perspective and defining a research agenda. *Ecology and Society* 14(1).
Immovilli, M., S. Reitsma, R. Roncucci, E. Dueholm Rasch, and D. Roth. 2022. Exploring contestation in Rights of River approaches: Comparing Colombia, India and New Zealand. *Water Alternatives* 15(3):574–591.
Ingram, H. 2011. Beyond Universal remedies for good water governance. Pages 241–261 *in* A. Garrido and H. Ingram, editors. *Water for Food in a Changing World*. Routledge, London.
Jasanoff, S., and S.-H. Kim. 2015. *Dreamscapes of modernity: Sociotechnical imaginaries and the fabrication of power*. University of Chicago Press.
Kaika, M. 2017. Between compassion and racism: how the biopolitics of neoliberal welfare turns citizens into affective 'idiots.' *European Planning Studies* 25(8):1275–1291.
Kaika, M., R. Calvario, and G. Velegrakis. 2024. Austerity: An environmentally dangerous idea. *Journal of Political Ecology* 31(1):67–81.
Kern, F., C. Kuzemko, and C. Mitchell. 2014. Measuring and explaining policy paradigm change: The case of UK energy policy. *Policy and Politics* 42(4):513–530.
Kishimoto, S., and O. Petitjean. 2017. *Reclaiming Public Services: How cities and citizens are turning back privatization*. Amsterdam: Transnational Institute.
Krueger, T., and R. Alba. 2022. Ontological and epistemological commitments in interdisciplinary water research: Uncertainty as an entry point for reflexion. *Frontiers in Water* 4.
Lebel, L., A. Haefner, C. Pahl-Wostl, and A. Baduri. 2020. Governance of the water-energy-food nexus: insights from four infrastructure projects in the Lower Mekong Basin. *Sustainability Science* 15(3):885–900.
Lee, M., H. Kim, J. Y. Lee, J. E. Yang, and C. Lim. 2022. A Shift Towards Integrated and Adaptive Water Management in South Korea: Building Resilience Against Climate Change. *Water Resources Management* 36(5):1611–1625.
Leitner, H., E. Sheppard, S. Webber, and E. Colven. 2018. Globalizing urban resilience. *Urban Geography* 39(8):1276–1284.
Linton, J. 2014. Modern water and its discontents: a history of hydrosocial renewal. *Wiley Interdisciplinary Reviews: Water* 1(1):111–120.
Lukat, E. C. G., M. Schoderer, and S. C. Salvador. 2022. When International Blueprints Hit Local Realities: Bricolage Processes in Implementing IWRM in South Africa, Mongolia and Peru. *Water Alternatives* 15(2):473–500.
Marcatelli, M., and B. Büscher. 2019. Liquid violence: The politics of water responsibilisation and dispossession in South Africa. *Water Alternatives* 12(2):760–773.
Mayntz, R. 2003. *New challenges to governance theory*. Page *Governance as social and political communication*. Jean Monnet Chair Papers, Florence.

McGregor, D. 2012. Traditional knowledge: Considerations for protecting water in Ontario. *International Indigenous Policy Journal* 3(3):3.
Meadow, D. 1999. *Leverage points: places to intervene in a system*. The Sustainability Institute, Hartland.
Micciarelli, G. 2022. Hacking the legal: The commons between the governance paradigm and inspirations drawn from the "living history" of collective land use. Pages 112–126 *in* F. Savini, A. Ferreira, and K. C, editors. *Post-Growth Planning: Cities Beyond the Market Economy*. Routledge, von Schönfeld: : 14.
Miller, B. 2013. *Spaces of Contention: Spatialities and Social Movements*. Routledge, London.
Mills-Novoa, M., and R. T. Hermoza. 2017. Coexistence and conflict: IWRM and large-scale water infrastructure development in Piura, Peru. *Water Alternatives* 10(2):370–394.
Moffat, L. Y., A. Geadah, and R. Stuart. 1991. *Two halves make a whole: balancing gender relations in development*. CCIC, Ottawa.
Mol, A. 2002. *The Body Multiple: Ontology in Medical Practice*. Duke University Press, Durham.
Molle, F. 2008. Nirvana concepts, narratives and policy models: Insights from the water sector. *Water Alternatives* 1(1):131–156.
Molle, F. 2009. Water, politics and river basin governance: Repoliticizing approaches to river basin management. *Water International* 34(1):62–70.
Molle, F., P. P. Mollinga, and P. Wester. 2009. Hydraulic bureaucracies and the hydraulic mission: Flows of water, flows of power. *Water Alternatives* 2(3):328–349.
Moss, T. 2010. Managing water beyond IWRM – from paradigm to pragmatism. *Water* 1st Water(July):13–14.
Nagendra, H., X. Bai, E. S. Brondizio, and S. Lwasa. 2018. The urban south and the predicament of global sustainability. *Nature Sustainability* 1(7):341–349.
Newig, J., D. Schulz, and N. W. Jager. 2016. Disentangling Puzzles of Spatial Scales and Participation in Environmental Governance—The Case of Governance Re-scaling Through the European Water Framework Directive. *Environmental Management* 58(6):998–1014.
Nixon, R. 2011. *Slow Violence and the Environmentalism of the Poor*. Harvard University Press.
Norman, E. S., C. Cook, and A. Cohen. 2016. Negotiating Water Governance: Why the Politics of Scale Matter. *Negotiating Water Governance: Why the Politics of Scale Matter*:1–318.
De Oliveira, O. P. 2021. A prelude to policy transfer research. Pages 1–24 *Handbook of Policy Transfer, Diffusion and Circulation*. Edward Elgar.
Ostrom, E. 1986. An agenda for the study of institutions. *Public Choice* 48(1).
Ovink, H., S. Rahimzoda, J. Cullman, and A. J. Imperiale. 2023. The UN 2023 Water Conference and pathways towards sustainability transformation for a water-secure world. *Nature Water* 1(3):212–215.
Pahl-Wostl, C. 2019. Governance of the water-energy-food security nexus: A multi-level coordination challenge. *Environmental Science and Policy* 92:356–367.
Pahl-Wostl, C. 2020. Adaptive and sustainable water management: from improved conceptual foundations to transformative change. *International Journal of Water Resources Development* 36(2–3):397–415.
Pahl-Wostl, C., P. Gorris, N. Jager, L. Koch, L. Lebel, C. Stein, S. Venghaus, and S. Withanachchi. 2021. Scale-related governance challenges in the water–energy–food nexus: toward a diagnostic approach. *Sustainability Science* 16(2):615–629.
Pahl-Wostl, C., N. Isendahl, S. Möllenkamp, M. Brugnach, P. Jeffrey, W. Medema, and T. Tessa

de Vries. 2006. Paradigms in Water. *NeWater Project Deliverable Nr.* 1:39.
Pahl-Wostl, C., J. Sendzimir, P. Jeffrey, J. Aerts, G. Berkamp, and K. Cross. 2007. Managing change toward adaptive water management through social learning. *Ecology and Society* 12(2):2.
Pain, R., and C. Cahill. 2021. Critical political geographies of slow violence and resistance. *Environment and Planning C: Politics and Space*:239965442110520.
Patterson, J. J. 2021. *Remaking Political Institutions: Climate Change and Beyond*. Cambridge University Press.
Pierre, J., and B. G. Peters. 2020. *Governance, politics and the state*. Bloomsbury Publishing.
Priscoli, J. D., and A. T. Wolf. 2009. *Managing and transforming water conflicts*. Page *Managing and Transforming Water Conflicts*. Cambridge University Press, Cambridge.
Querejazu, A. 2022. Water governance. *New Perspectives* 30(2):180–188.
Rouillard, J. J., D. Benson, and A. K. Gain. 2014. Evaluating IWRM implementation success: are water policies in Bangladesh enhancing adaptive capacity to climate change impacts? *International Journal of Water Resources Development* 30(3):515–527.
Schlager, E., and W. Blomquist. 2008. *Embracing watershed politics*. Page *Embracing Watershed Politics*. University Press of Colorado.
Sharpe, B., A. Hodgson, G. Leicester, A. Lyon, and I. Fazey. 2016. Three horizons: A pathways practice for transformation. *Ecology and Society* 21(2).
Shields, K. F., M. Moffa, N. L. Behnke, E. Kelly, T. Klug, K. Lee, R. Cronk, and J. Bartram. 2021. Community management does not equate to participation: Fostering community participation in rural water supplies. *Journal of Water Sanitation and Hygiene for Development* 11(6):937–947.
Shore, C. 2011. 'European Governance' or Governmentality? The European Commission and the Future of Democratic Government. *European Law Journal* 17(3):287–303.
Streeck, W., and K. Thelen. 2005. *Beyond Continuity: Institutional Change in Advanced Political Economies*. Oxford University Press.
Suhardiman, D., F. Clement, and L. Bharati. 2015. Integrated water resources management in Nepal: key stakeholders' perceptions and lessons learned. Pages 284–300 *International Journal of Water Resources Development*. ' International Journal of Water Resources Development 31 (2.
Sultana, F. 2011. Suffering for water, suffering from water: Emotional geographies of resource access, control and conflict. *Geoforum* 42(2):163–172.
Sultana, F. 2018. Water justice: why it matters and how to achieve it. *Water International* 43(4):483–493.
Swyngedouw, E. 2005. Governance innovation and the citizen: The Janus face of governance-beyond-the-state. *Urban Studies* 42(11):1991–2006.
Tantoh, H. B., and D. Simatele. 2017. Community-based water resource management in North-west Cameroon: the role of potable water supply in community development. *South African Geographical Journal* 99(2):166–183.
Toro, F. J. 2021. Stateless Environmentalism. *ACME: An International Journal for Critical Geographies* 20(2):189–205.
United Nations. 2023. *The United Nations World Water Development Report 2023: Partnerships and Cooperation for Water*. Paris.
Viaene, L. 2021. Indigenous water ontologies, hydro-development and the human/more-than-human right to water: A call for critical engagement with plurilegal water realities. *Water*

(Switzerland) 13(12):12.
Vos, J., and R. Boelens. 2014. Sustainability standards and the water question. *Development and Change* 45(2):205–230.
Voß, J.-P., and A. Simons. 2018. A novel understanding of experimentation in governance: co-producing innovations between "lab" and "field." *Policy Sciences* 51(2):213–229.
Voß, J. P., and A. Simons. 2014. Instrument constituencies and the supply side of policy innovation: the social life of emissions trading. *Environmental Politics* 23(5):735–754.
Warner, J. F., J. Hoogesteger, and J. P. Hidalgo. 2017. Old wine in new bottles: The adaptive capacity of the hydraulic mission in Ecuador. *Water Alternatives* 10(2):322–340.
Wesselink, A., M. Kooy, and J. Warner. 2017. Socio-hydrology and hydrosocial analysis: toward dialogues across disciplines. *WIREs Water* 4(2).
Whaley, L. 2022. Water Governance Research in a Messy World: A Review. *Water Alternatives* 15(2):218–250.
Wilson, N. J., and J. Inkster. 2018. Respecting water: Indigenous water governance, ontologies, and the politics of kinship on the ground. *Environment and Planning E: Nature and Space* 1(4):516–538.
Woodhouse, P., and M. Muller. 2017, April 1. Water Governance—An Historical Perspective on Current Debates. Elsevier Ltd.
Zaragocin, S., and M. A. Caretta. 2021. Cuerpo-Territorio: A Decolonial Feminist Geographical Method for the Study of Embodiment. *Annals of the American Association of Geographers* 111(5):1503–1518.
Zittoun, P. 2015. From Policy Paradigm to Policy Statement: A New Way to Grasp the Role of Knowledge in the Policymaking Process. Pages 117–140 *in* P. Paradigms, editor. *Policy Paradigms in Theory and Practice*. Palgrave Macmillan UK, London.
Zwarteveen, M., J. S. Kemerink-Seyoum, M. Kooy, J. Evers, T. A. Guerrero, B. Batubara, A. Biza, A. Boakye-Ansah, S. Faber, A. C. Flamini, G. Cuadrado-Quesada, E. Fantini, J. Gupta, S. Hasan, R. Ter Horst, H. Jamali, F. Jaspers, P. Obani, K. Schwartz, Z. Shubber, H. Smit, P. Torio, M. Tutusaus, and A. Wesselink. 2017. Engaging with the politics of water governance. *Wiley Interdisciplinary Reviews: Water* 4(6):1–9.

Supplementary 2:

Paradigms of water governance: a systematic review

Abstract

Water resources face critical challenges globally, and the current water crisis is often seen as a crisis of governance, which means that ideas about water governance matter a lot. In fact, we argue that the so-called water governance paradigms play a crucial role in shaping policy agendas, influencing decision-making processes, and ultimately determining the success or failure of water management strategies. But why, how, and where policy paradigms matter is unclear at present. To address this research gap, this article presents a systematic review of studies that focus on water governance paradigms, examining (1) the characteristics of this literature and (2) how and which aspects of water governance paradigms are studied. Analysis of 93 pertinent studies reveals that the "integrated approach to govern/manage water" paradigm is a central concern in the academic literature, as is the role of governmental actors in promoting and implementing paradigms and the existence of imbalances in water governance debates. The studies we analyze also highlight a discrepancy between promoted paradigms and contextual realities, compounded by the problem of institutional layering, which means that older paradigms linger and affect the actual levels of change. Finally, our results show that, while many studies adopt a critical perspective, few provide evidence for the effects of the paradigms in their studies, and there is an absence of common terminology. Overall, this review emphasizes the importance of problematizing water governance paradigms as they serve as a "source code" for governance arrangements and considering contextual nuances when working with paradigms.

Paradigms of water governance: a systematic review

Paper submitted to Ecology and Society
Manuscript type: Research

Shahana Bilalova [1], Nicolas W. Jager [2], Jens Newig [1], Dave Huitema [2], Johanna K.L. Koehler [2]

[1] Faculty of Sustainability, Institute of Sustainability Governance (INSUGO), Research Group Governance, Participation and Sustainability, Leuphana University Lüneburg, Germany, [2] Public Administration and Policy Group, Wageningen University and Research, Wageningen, The Netherlands

ABSTRACT

Water resources face critical challenges globally, and the current water crisis is often seen as a crisis of governance, which means that ideas about water governance matter a lot. In fact, we argue that the so-called water governance paradigms play a crucial role in shaping policy agendas, influencing decision-making processes, and ultimately determining the success or failure of water management strategies. But why, how, and where policy paradigms matter is unclear at present. To address this research gap, this article presents a systematic review of studies that focus on water governance paradigms, examining (1) the characteristics of this literature and (2) how and which aspects of water governance paradigms are studied. Analysis of 93 pertinent studies reveals that the "integrated approach to govern/manage water" paradigm is a central concern in the academic literature, as is the role of governmental actors in promoting and implementing paradigms and the existence of imbalances in water governance debates. The studies we analyze also highlight a discrepancy between promoted paradigms and contextual realities, compounded by the problem of institutional layering, which means that older paradigms linger and affect the actual levels of change. Finally, our results show that, while many studies adopt a critical perspective, few provide evidence for the effects of the paradigms in their studies, and there is an absence of common terminology. Overall, this review emphasizes the importance of problematizing water governance paradigms as they serve as a "source code" for governance arrangements and considering contextual nuances when working with paradigms.

Keywords: normative ideas; paradigms; systematic literature review; water governanc

INTRODUCTION

Water resources worldwide face critical challenges due to climate change, environmental degradation, competing human activities, and ongoing global trends such as urbanization and globalization (Cosgrove and Loucks 2015). Contrary to the perception that scarcity results from a physical lack of water (Biswas and Tortajada 2023), the global water crisis is increasingly recognized as a governance crisis (Global Water Partnership 2000, Gupta et al. 2013b, Taylor and Sonnenfeld 2017, Katusiime and Schütt 2020). Understanding this crisis and designing effective management practices require delving into the underlying paradigms shaping the governance of water resources. If the water crisis is a governance crisis, then the paradigms underlying water governance regimes require closer inspection and scrutiny.

We argue that paradigms play a crucial role as a "source code" in water governance systems. They act as a foundation, shaping the rules, norms, values, and goals that form the entire system (Abson et al. 2017). In this sense, understanding them is crucial when considering systemic transformations for robust and effective water governance. Focusing on paradigms is likely to be a promising strategy for understanding how policy actions are structured or limited, why certain actors are involved in the process, and the strategies they pursue (Hogan and Howlett 2015).

Several existing publications have explicitly focused on water governance paradigms (e.g., Molle et al. 2009, Del Moral et al. 2014, Bréthaut and Schweizer 2018, Challies and Newig 2022) or examined certain paradigms empirically (e.g., Lopez-Gunn 2009, Chomba et al. 2017, Warner et al. 2017, Lebel et al. 2020). These offer indications that paradigms matter a lot in water governance. However, to date, the study of paradigms remains a relatively fragmented field with scattered ideas about what paradigms are, which ones exist, and what they do. No systematic overview exists, to our knowledge, that offers a structured inventory of this extant literature, discusses the patterns that exist in the way paradigms are examined, or offers a clear overview of the findings embedded in this literature, thus leaving uncertainty about the relevance and impacts of paradigms. We do not know which paradigms are studied, how they have been examined, and what aspects are studied. But we also do not know what we can learn from the literature about who promotes certain paradigms and how, or about how in the application of paradigms context is taken into account, or which effects are typically achieved (or not achieved) in such instances. Hence, our primary objective, through a systematic literature review, is to take stock of what can be known from the literature about water governance paradigms, through an exploration of how they are analyzed in the academic literature. In doing so, this paper aims to provide core insights that not only deepen our understanding of water governance paradigms but also provide a foundation for further advancements in the scholarly exploration of this domain.

WATER GOVERNANCE PARADIGMS

The term "paradigm" originates from Kuhn's (1962) seminal work, "The Structure of Scientific Revolutions," where it was used in the context of the development of scientific knowledge. Drawing on Kuhnian scientific paradigms, in 1993, Peter Hall introduced the notion of paradigms into the field of policy analysis when he attempted to make sense of fundamental changes in British economic policy that occurred in the 1970s and 1980s. Introducing the concept of a policy paradigm, he argued that "… policymakers customarily work within a framework of ideas and standards that specifies not only the goals of policy and the kind of instruments that can be used to attain them but also the very nature of the problems they are meant to be addressing" (Hall 1993, p.279). In the context of water, Pahl-Wostl et al. (2006, p. 6) proposed the definition of “water management paradigms,” defining them as "a set of basic assumptions about the nature of the system to be managed, the goals of management and the ways in which these management goals can be achieved."

Building on these works, we understand *governance paradigm* as “a set of more or less coherent normative ideas intersubjectively held by groups of actors about the problématiques that require public intervention, corresponding governance objectives, and appropriate means to achieve them” (Bilalova et al., *unpublished manuscript*). The literature on water governance has witnessed the emergence and implementation of many paradigms. Integrated water resources management (IWRM) (Benson et al. 2020), adaptive water governance (Chaffin et al. 2014), hydraulic mission (Molle et al. 2009), river basin management (Molle 2009), and water security (Bakker and Morinville 2013), are among the popular ones.

Paradigms can be seen as part of the “ideational turn” that policy science has taken in recent decades, as they constitute the framework of "normative-cognitive ideas" that shape problem perception, policy goals concerning these problems, and a set of instruments to achieve them (Hall 1993, Challies and Newig 2022). As such, they exert influence on policy choices, ranging from the design of formal institutions to the mandates they pursue (Kern et al. 2014). Just as an example, the paradigm of the “hydraulic mission” is said to focus the attention of policymakers and water managers on the enhancement of the supply and the acquisition of complete control over water resources, implying a large-scale development infrastructure of water resources, often in combination with a state-centric and technocratic approach to water management (Molle et al. 2009). Paradigms serve as significant agenda setters for political action at various scales and may provide better explanations for the enactment of certain policies than functional necessity or strategic actions by involved actors (Challies and Newig 2022). At the same time, paradigms are said to be functional in determining which policy options are prioritized, overlooked, or dismissed, and it is indicated that they help identify which actors shall be empowered or marginalized (Molle, 2008). The notion of “counter-paradigms” has also emerged and refers to the fact that paradigms often have limitations or inefficiencies, which triggers the need to offer alternative approaches and narratives as a means to challenge them.

Actors play an important role in the emergence, promotion, and implementation of paradigms. Government actors are widely recognized in the literature on water governance for their roles in advocating and implementing various paradigms (e.g., Allouche 2017, Mancilla García et al. 2019). Furthermore, international organizations (e.g., Allouche 2017), funding agencies (e.g., Meijerink and Huitema 2010), experts (e.g., Valin and Huitema 2023), private actors (e.g., Vatn 2018), and NGOs (e.g., Tyagi 2019) are also recognized as significant players.

Although paradigms possess the potential to transform governance structures toward the realization of a collective vision (Molle 2006), new policies may not always replace existing ones or be fully implemented, as many adoptions of new paradigms tend to not reach that stage (Meijerink and Huitema 2010). Symbolic implementation of paradigms is also observed; for instance, Biswas (2008) argues that IWRM has been implemented in a “symbolic” way by actors in several contexts to obtain funding and greater acceptability and visibility.

METHODS

Search and study selection

We conducted our systematic review following the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher et al. 2009). The stages of the review are illustrated in Figure 1.

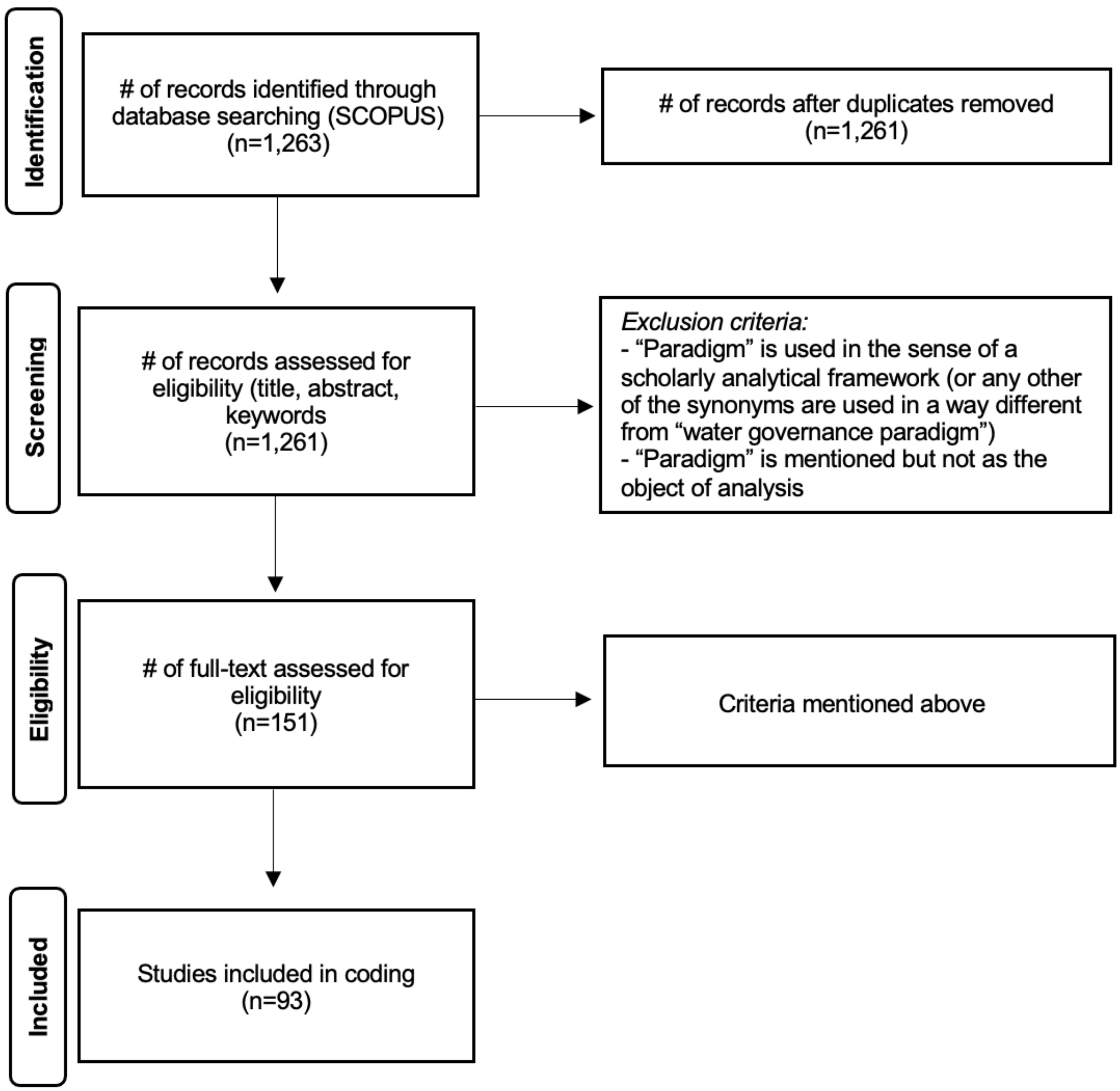


Figure 1 PRISMA flow diagram for the systematic review of the literature.

We developed our search string through an iterative process, engaging in discussions with water governance scholars and examining sample key papers on water governance paradigms (e.g., Molle 2008, Gerlak and Mukhtarov 2015, Franco-Torres 2021). The search string consists of two main components: The first part targets the literature on water policy and governance, while the second part includes terms related to paradigms. This design aimed to retrieve publications discussing paradigms within the context of water policy and governance (C#1 AND C#2):

C#1: water* W/3 (policy* OR govern*)
C#2: paradigm* OR idea* OR discourse* OR discursi* OR narrative* OR imaginar*

Our search was carried out across titles, abstracts, and keywords of documents and was limited to journal articles, editorials, and conference proceedings available on SCOPUS (the last run was conducted in May 2022). Although Scopus does not cover all publications, it is widely considered one of the most suitable databases for conducting systematic reviews (Gusenbauer and Haddaway 2020) and provides comprehensive coverage across the environmental and social sciences (Frohlich et al. 2018).

Given our global interest, we limited our search to English-language articles. To trace the literature from its inception to the latest contributions, we intentionally refrained from restricting our search to a specific time period.

Executing our search string yielded 1,261 results after removing duplicates. The resulting publication records (including titles, abstracts, and keywords) were manually selected for suitability. To be included in the dataset, the use of the paradigm(s) had to align with the concept of a water governance paradigm and the (empirical) analysis had to focus on the water governance paradigm(s). Records were excluded when “paradigm” as a term was employed in the sense of a scholarly analytical framework (or any other synonym used differently from “water governance paradigm”), or when paradigms were mentioned but not as the object of analysis. Following the screening process, we retained 93 articles covering the years 1997–2022 for subsequent coding and analysis (see Appendix 1).

Coding process and data analysis

To systematically retrieve information from publications, we developed a structured coding scheme (see Appendix 2). The coding scheme consisted of three main sections: bibliographic information, general characteristics of the publication, and the treatment of water governance paradigms. Although some elements were text fields, many were defined on a three-point scale, where 0 meant the absence of a certain factor, 1 denoted its presence, and 0.5 indicated its partial presence.

We did two rounds of test coding involving all coauthors; each publication was independently coded by two coders. This test phase was crucial to removing any small differences in the interpretation of the coding items, ensuring consistency and reliability in the coding process. It resulted in a high intercoder reliability of $r_{WG}=0.93$ (as per James et al. 1984). To mitigate the risk of reviewer bias and potential errors, all authors took trial steps at each stage of the review process, ensuring a shared understanding of exclusion criteria and the coding scheme had been established.

RESULTS

Socio-bibliometric analysis

Seen in relation to the wide field of water governance, the number of papers addressing paradigms remains rather small. We observe only a gradual increase with fluctuations in the number of papers over time, with notable peaks in 2016 (10%; n=9), 2017 (11%; n=10), and 2019 (15%; n=14), but also high fluctuations in numbers (Figure 2). As our last search was conducted in May 2022, it is important to note that the publications from that year do not provide a comprehensive overview of the entire year's observations.

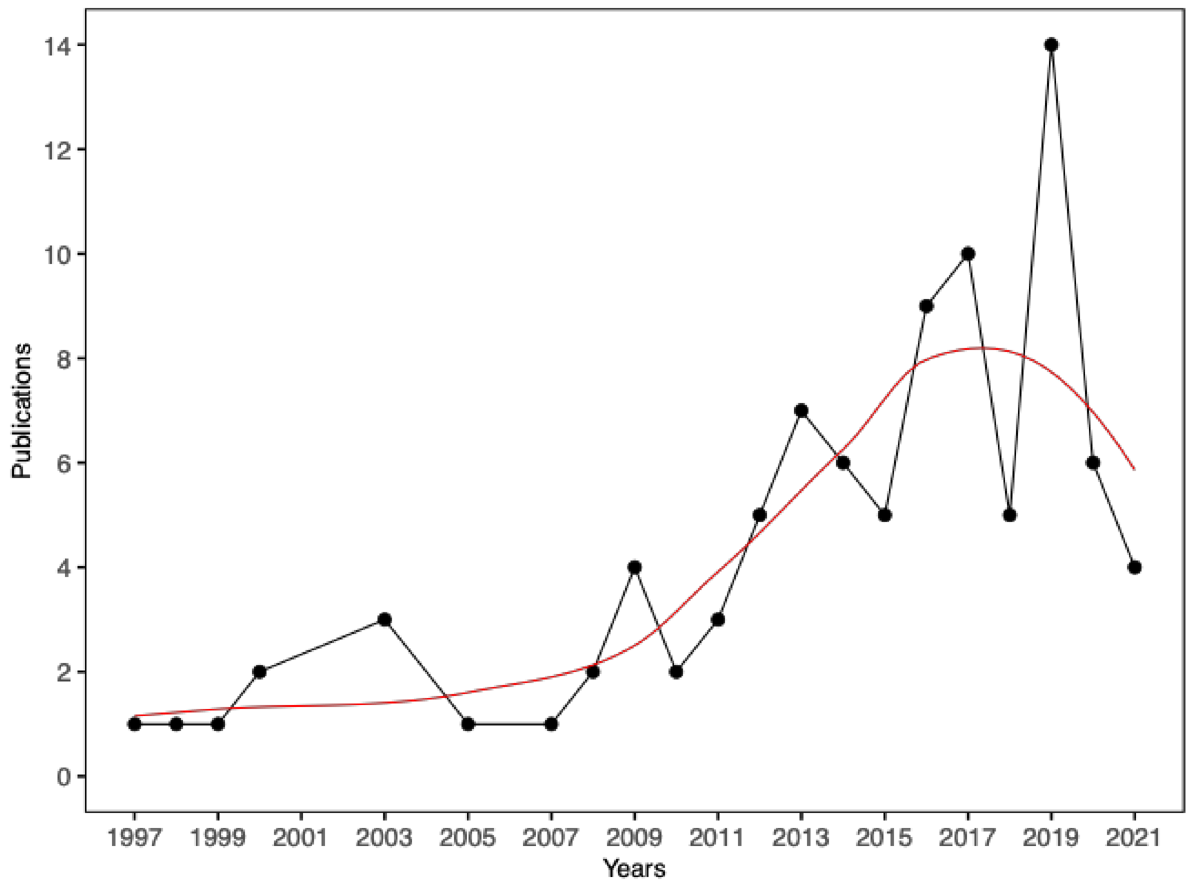


Figure 2 Number of publications over the years.

The studies included in the review were published in 46 different individual outlets, 3 of which were conference proceedings. 38% of these outlets are directly related to water (n=18), accounting for more than half of the publications (53%; n=49). The three most observed sources are "International Journal of Water Resources Development" (10%; n=9), "Water Alternatives" (10%; n=9), and "Water Policy" (9%; n=8). “Environmental Science and Policy” (6%; n=6), “Ecology and Society” (4%; n=4), and “Global Environmental Change” (3%; n=3) are the most frequent outlets with a larger focus on environmental issues.

We observe a slight dominance of male first authors, constituting 59% (n=55), whereas female authors led 41% of the studies (n=38). In particular, the majority of studies are led by authors from the Global North, with 69 out of 93 cases (74%). This trend persists when examining the countries of all authors' institutions, with 130 out of 196 institutions (66%) situated in the Global North.

Nature of research

In terms of research methodology, our analysis reveals a predominance of empirical research. Specifically, 71% of the publications are classified as at least partially empirical research, with 18% of them falling under a partially empirical classification (n=12), i.e. being primarily conceptual with some empirical illustration. In terms of epistemology, 91% of all included studies are classified as adopting a positivist approach (n=85), while only 9% (n=8) identified as at least partially constructivist approach.

Furthermore, our observations indicate a notable portion of publications classified as at least partially reviews (38%, n=35) or theory development and operationalization (24%, n=22). Conversely, there are relatively fewer studies identified as at least partially critique (12%, n=11) or theory testing/confirmation/disconfirmation (11%, n=10) (Table 1).

Table 1 Nature of research among the included studies.

Nature of research	Yes	To some extent	No
Empirical research	54 (58%)	12 (13%)	27 (29%)
Review	20 (22%)	15 (16%)	58 (62%)
Theory development and operationalization	11 (12%)	11 (12%)	71 (76%)
Critique	5 (5%)	6 (6%)	82 (88%)
Theory testing/confirmation/disconfirmation	4 (4%)	6 (6%)	83 (89%)

The included studies cover various research topics. The majority of publications examine the implementation of paradigms and their implications within one or more cases. For example, Tantoh & Simatele (2017) discuss community-based water management in Cameroon, highlighting how such processes are sustained by specific actors but challenged by centralized decision-making and cooptation by local elites, thereby exploring the fit of this paradigm within the local institutional and cultural context. Several other studies investigate certain paradigms in relation to the context in which they are implemented, focusing on applicability, enabling or hindering factors, as well as interaction with existing paradigms. For example, Harsha (2012) studies Indian water policy and existing challenges in the successful implementation of IWRM and IRBM principles. We also observed a considerable number of studies that focus on the political aspects of paradigms. One of the examples is the study by Molle (2009), which examines the concept of a river basin and how it is used by certain actors to legitimize their agenda. Finally, there are also a considerable number of papers that study paradigmatic transitions (e.g., Shapiro and Summers 2015, Lee et al. 2022), examine paradigms on a conceptual level (e.g., Mukhtarov and Gerlak 2014, Woodhouse and Muller 2017), or discuss the transformative power of paradigms (e.g., Muskatirovic 1997, Furlong et al. 2016).

Treatment of water governance paradigms in the literature

Our search string included paradigm-related terms, such as “paradigm,” “discourse,” “idea,” “narrative,” and “discursive.” In addition to these, a variety of other descriptors are identified in the literature. While nearly 20 different terms are used to denote paradigms in the examined literature, the most frequently used terms include the term "paradigm" itself (81%; n=75). Other terms used to denote what we understand as paradigms are “approach” (52%; n=48), and “concept” (and its derivatives) (43%; n=40). Additionally, terms such as “process,” “framework,” “model,” “discourse,” “idea,” and “tool” are also used in more than one study to discuss paradigms.

In exploring the various paradigms discussed in the publications we examined, an interesting question emerges: Which paradigms are studied the most? The results show that the “integrated approach to governing/managing water” (i.e., Integrated Water Resources Management (IWRM), Integrated River Basin Management (IRBM), Integrated Lake Basin Management (ILBM), Integrated Coastal Zone Management (ICZM), Integrated Flood Management (IFM), etc) emerges as the paradigm that receives the most significant level of attention since it appeared in more than three-quarters of all studies (76%; n=71), followed by publications on “adaptive governance/management” (24%; n=22) and “controlling nature” (24%; n=22) (Figure 3). Examining the paradigms in all publications, we also observed that most studies (72%; n=67) talk about more than one paradigm. For instance, 16 out of 71 papers talking about “integrated approach to governing/managing water” also talk about the paradigms of “controlling nature” and “adaptive governance/management.” The paradigms were coded according to how the authors identified them, but we grouped them based on their conceptual similarities.

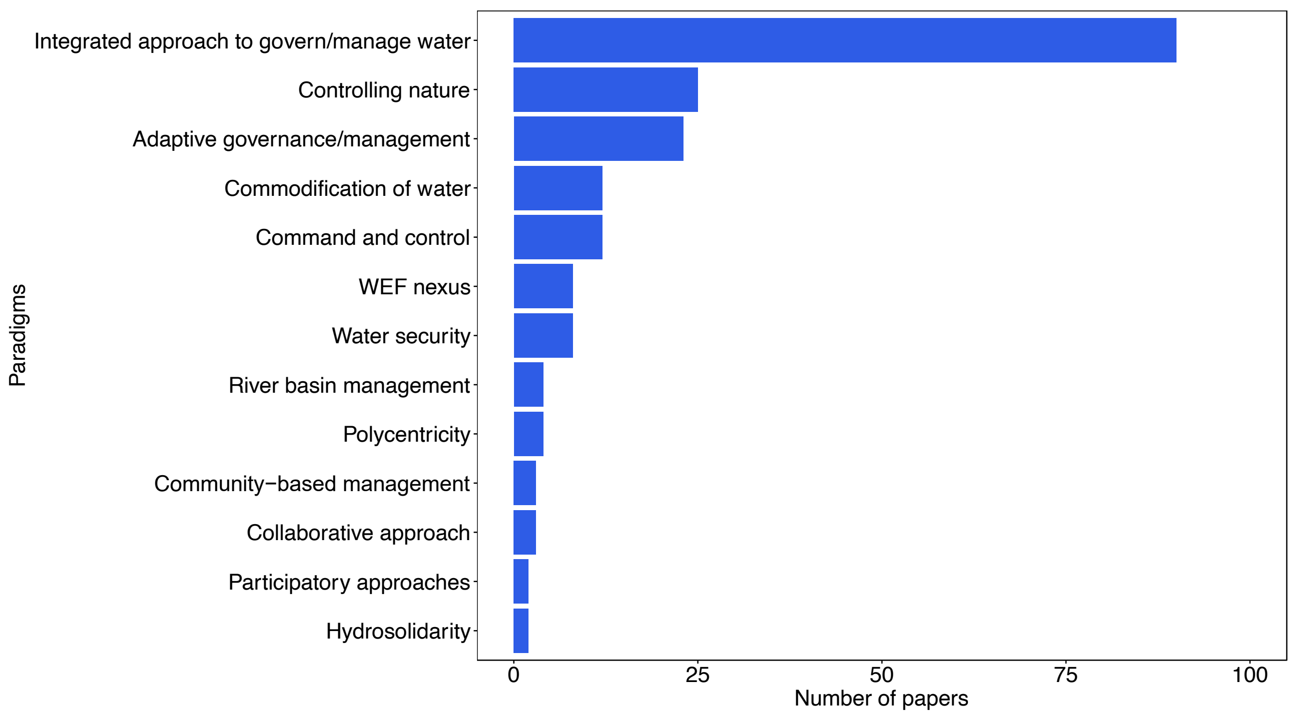


Figure 3 Paradigms across the included studies.

Regarding “counter-paradigms,” 23% (n=21) of the publications study these to some extent. Some examples of counter-paradigms observed in the reviewed literature include the rise of Buen Vivir as a counter-paradigm in Ecuador, emphasizing respect for Mother Earth as an alternative to exploitative Western practices (Warner et al. 2017), the emergence of integrated and collaborative approaches to traditional natural resources management (Harrington 2017), and the suggestion of environmental stewardship model as an alternative to market failure paradigm in the western United States (Supalla 2003).

Furthermore, 85% of the studies adopt an empirical focus, with geographically diverse cases. However, the cases from the Global South are almost two times those from the Global North (57 compared to 34). This presents an intriguing contrast to the origin of the studies, the majority of which are led by authors from the Global North, as mentioned above. Among the cases, the United States (n=9) emerges as the most studied, followed by South Africa (n=6) and Australia (n=5). Geographically, the cases are diverse, with the majority addressing sub-national (39%, n=31), local (38%, n=30), and national (19%, n=15) levels. Interestingly, higher geographical levels, such as transboundary (10%; n=9), global (8%; n=7), international (6%; n=6), and continental (1%; n=1), are comparatively less explored.

As outlined in the definition, paradigms typically highlight a problem and propose means to address it. Consistent with this, our analysis reveals that in most studies paradigms articulate an understanding of water-related problems and their underlying causes and suggest governance solutions to address these issues. Specifically, in 77% of the included studies (n=72), paradigms address water-related problems and their causes at least to some extent. Regarding governance solutions, 54% of the publications (n=50) discuss governance solutions to address these problems, at least to some extent.

In terms of the impact of paradigms on governance, more than half of the articles (67%; n=62) focus, at least to some extent, on concrete changes in governance structures and practices under the influence of paradigms. Majority study certain governance mode in the context of paradigm (86%, n=80). Among these articles, most study centralized governance modes (70%; n=56), at least to some extent, while only slightly fewer publications study decentralized modes (60%; n=48), at least to some extent. In contrast, interactive governance, public-private governance, and self-governance modes are identified in only a smaller proportion of studies (Figure 4). When we examine the most dominant paradigm we identified in the included studies, “integrated approach to govern/manage water,” we observe an almost equal share of the centralized (41%; n=9) and decentralized governance (50%; n=11) modes that are being practiced, at least to some extent.

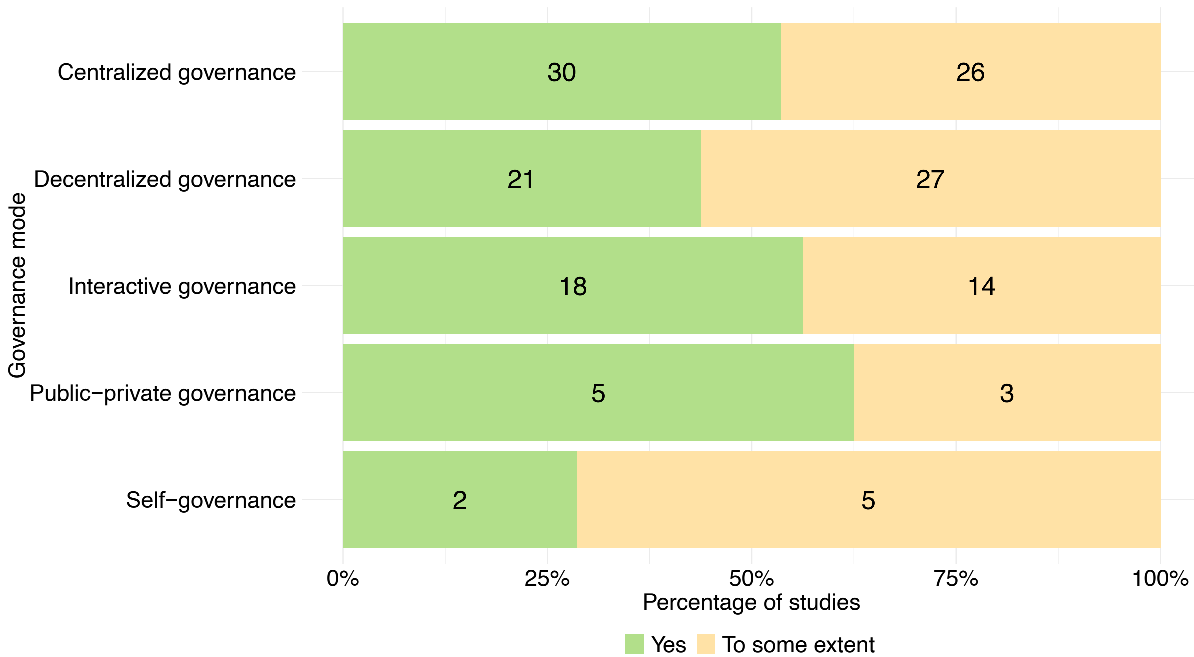


Figure 4 Studied governance modes across the papers (n=80).

In terms of the "lifecycle of paradigms," the literature provides relatively comprehensive coverage of the origin, implementation, and shifts from one paradigm to another (Table 3). In contrast, the spread or diffusion of paradigms and significant changes within paradigms are identified in only 27% (n=25) and 18% (n=17) of the publications, respectively, addressing them at least to some extent. This indicates that paradigms are predominantly treated as closed ideational blocks rather than work-in-progress.

Table 3 Coverage of the "lifecycle" of paradigms in the included studies.

	Yes	**To some extent**	**No**
Paper studies the origins of the studied paradigms	39 (42%)	13 (14%)	41 (44%)
Paper studies the spread or diffusion of the studied paradigms	19 (20%)	6 (6%)	68 (73%)
Paper studies the implementation of the studied paradigms	66 (71%)	17 (18%)	10 (11%)
Paper studies shift from one paradigm to another (in the given empirical context)	38 (41%)	9 (10%)	46 (49%)
Paper studies significant changes within paradigms	12 (13%)	5 (5%)	76 (82%)

When it comes to the question of which actors are involved in governance, government actors (84%; n=67) and administration (64%; n=51) are focal in more than half of the included studies, followed by private actors (35%; n=28), civil society (34%; n=27), community and citizens (31%; n=25), and international organizations (14%; n=11) (see Table A3.1 in Appendix 3). Actor groups such as science, international nongovernmental organizations (INGOs), and indigenous people are the focus of less than 15% of studies that report on governance modes (n=10). This prevalence of government actors could be observed across virtually all paradigms, highlighting the central role of the state. Administration has a considerable presence in centralized, decentralized, and self-governance modes. For public-private governance and interactive governance modes, the second most observed actor groups are private actors and community and citizens, respectively (Table A3.1).

In particular, 73% (n=68) of the included studies analyze the activities of actors promoting specific paradigms, at least to some extent. Actors who promote certain paradigms tend to be the "usual suspects" in the sense that they are the same actors who participate in water governance processes in general. Government actors and administration are identified as focal actors in more than 63% of papers that analyzed actors promoting paradigms, at least to some extent (n=43). Interestingly, in this context, the second largest focal actor is international organizations, identified in 44% of studies that analyze actors who promote paradigms to some extent (n=30) (Figure 5).

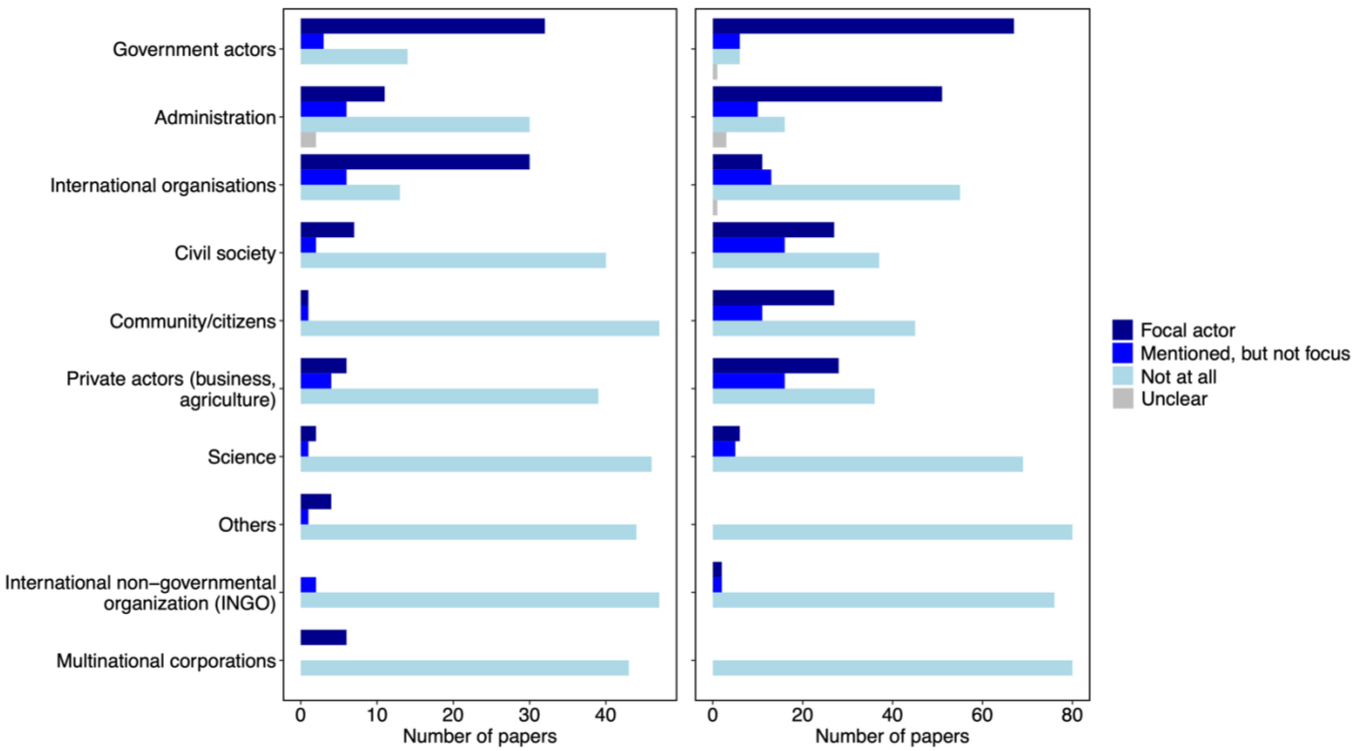


Figure 5 Actor groups involved in the promotion (left side) and governance (right side) of paradigms.

We also explored the extent to which authors critically engage with paradigms, e.g. by providing norm-informed commentary. In this context, we observe that more than half of the studies provide a critical account of water governance paradigms and consider power imbalances. Specifically, 61% of the included studies (n=57) offer a critical assessment of water governance paradigms, at least to some extent. Regarding power imbalances, 53% of the studies (n=49) consider them, at least to some extent. Only 12% of the publications (n=11) address the issue of paradigms being used in a symbolic sense, at least to some extent.

Despite a considerable share of studies that critically engage with paradigms, we identify ambiguity in all studies regarding whether paradigms are considered a "success" or "failure." Only 17% of the included studies (n=16) present a "success story" of water governance, at least to some extent. A similar observation is made for the "failure story," since only 33% of the studies (n=31) address whether the paradigm is considered a failure, at least to some extent. Among these studies, 65% (n=28) provide policy recommendations, at least to some extent. This implies a relatively balanced perspective in the overall discourse.

Finally, we observe that most studies use evaluative criteria of effectiveness, encompassing environmental sustainability or other dimensions, which are not paradigm-specific. Although most studies evaluated the effectiveness, we observe a very small share of studies that focus on the effectiveness of paradigms, including their effects. More than half of the included publications do not examine the social, economic, or ecological effects associated with the introduction of paradigms in practice (Table 4). However, this number is relatively smaller in the case of social effects, as 45% of the publications (n=42) study the social aspects of paradigms, at least to some extent. Despite the ambiguity over the performance of paradigms and their effects, most studies (54 out of 93) provide policy recommendations, at least to some extent.

Table 4 Effects and evaluative criteria.

	Yes	To some extent	No
Effects of paradigms			
Social effect	25 (27%)	17 (18%)	51 (55%)
Environmental effect	17 (18%)	7 (8%)	69 (74%)
Economic effect	14 (15%)	11 (12%)	68 (73%)
Evaluative criteria (general)			
Effectiveness (excluding environmental or sustainability aspects)	45 (48%)	13 (14%)	35 (82%)
Effectiveness (as regards environmental or sustainability aspects)	35 (38%)	13 (14%)	45 (48%)
Efficiency/ cost-effectiveness	29 (31%)	11 (12%)	53 (57%)
Policy coherence	17 (18%)	15 (16%)	61 (66%)
Justice	17 (18%)	8 (9%)	68 (73%)
Other	14 (15%)	14 (15%)	65 (70%)
Acceptance	15 (16%)	10 (11%)	68 (73%)
Accountability	19 (20%)	1 (1%)	73 (78%)
Adaptability / adaptive capacity	14 (15%)	10 (11%)	69 (74%)
Legitimacy	11 (12%)	9 (10%)	73 (78%)
Resilience/robustness	5 (5%)	4 (15%)	84 (90%)

DISCUSSION

In this section, we will discuss some key issues emerging from our results. More specifically, we will discuss the dominance of certain paradigms in the literature, informing about the imbalances in the research focus, the pivotal role of specific actors in promoting and implementing paradigms, the challenges encountered in translating paradigms into practical governance approaches, as well as the extent to which existing literature problematizes paradigms. We will conclude with the limitations of our study and future research areas.

Imbalances in the research focus

The review reveals imbalances in the research focus across the literature on the paradigm of water governance. The results show the dominance of the "integrated approach to govern/manage water" paradigm, identified in almost all studies while being the most relevant paradigm in half of the publications. Contrarily, paradigms such as the "collaborative approach," the "community-based (natural resource) management," the "polycentricity," and the "hydrosolidarity" are observed in only 5% of these studies.

The large number of studies on the paradigm of "integrated approach to govern/manage water" may result from its hegemonic nature in governance practice. This paradigm, widely promoted by governments and international development discourses, including its incorporation into global development strategies such as the SDG indicator framework under Agenda 2030 (Benson et al. 2015), has gained substantial empirical attention (with 51 studies primarily focused on it). Integrated Water Resources Management (IWRM) has been heavily promoted by governments and international development discourses and incorporated into international development strategies, including the SDG indicator framework as part of Agenda 2030. However, the governance implications derived from the concept vary considerably; studies focusing on this paradigm describe almost as equally often how this paradigm was translated into a decentralized as a centralized governance mode, highlighting the amenability and opaqueness of central paradigms.

Although the abundance of research on IWRM offers opportunities for thorough cross-case comparisons and deeper insights into this particular paradigm, such a heavy focus also introduces the risk of overshadowing alternative ontologies. As paradigms usually envision certain societal realities to aspire towards (Molle 2008), they invisiblize or destabilize alternative paradigms (Yates et al. 2017). Therefore, engaging with a diverse range of paradigms becomes important. By acknowledging these imbalances and recognizing the overshadowing effect of dominant paradigms, we emphasize the importance of fostering diversity in the discourse surrounding water governance. Engaging with the plurality of paradigms and even putting them in dialogue helps us to reflect on how different paradigms frame water governance problems and what kind of solutions are suggested to address them. Bringing in alternatives also pluralizes our understanding of water and ideas of what water management and governance entail (Yates et al. 2017). Thus, promoting diversity in the discourse ensures a more inclusive and comprehensive approach to addressing water governance challenges.

The central role of specific actors in the promotion and implementation of paradigms

Policy changes can be initiated by both governmental actors—whether politicians, bureaucrats, or officials at various levels—and nongovernmental entities such as NGOs, academics, or individual citizens (Huitema and Meijerink 2010). Although actors, such as private actors, civil society, and international organizations, are involved to varying degrees in the governance process, our review reveals the significant influence of government actors in both promoting and implementing paradigms. In this, our review highlights that despite the multitude of actors involved in water governance, state actors (government and administration) still serve as the focal point for studying paradigms and their reification in water governance actions.

Alongside governmental actors, we observed that international organizations play a crucial role, particularly in the promotion of paradigms. As emphasized by Meijerink & Huitema (2010), international donor organizations such as the World Bank, the International Monetary Fund, and others have been instrumental in shaping water policy transitions, particularly in developing countries. These organizations not only offer financial assistance but also impose conditions on national governments, thereby influencing policy directions and implementation strategies (Meijerink and Huitema 2010). The literature acknowledges the roles of national governments and international organizations in promoting paradigms, particularly integrated water resources management (IWRM) (e.g., Benson et al. 2015, Allouche 2017, Lee et al. 2022).

Paradigms hitting the ground

Our results highlight the predominance of integrated approaches, while also observing an almost equal share of centralized and decentralized governance modes among the studies solely focusing on this paradigm. This discrepancy hints at the difference between what paradigms call for and what happens on the ground. This phenomenon has also been previously discussed in the literature on water governance literature (e.g., Lukat et al. 2022, Rowbottom et al. 2022). For example, the study by Meijerink & Huitema (2010) shows that the adoption of new water policies in 16 case studies did not result in their full implementation or replacement of existing policies. The main reason for such a discrepancy, as also discussed in some of the reviewed studies, is a strong connection between the paradigm and the context in which it is situated. The importance of context in water governance has been widely acknowledged (Armitage 2008, Ingram 2011, Gupta et al. 2013a). As argued by Bressers and de Boer (2013), the effective adoption and implementation of a certain policy is significantly dependent on the connection between its original context and the environment in which it is applied. One way the context can impact how paradigms are translated is through a layering effect, where the new institutional elements are attached to the old ones (Streeck and Thelen 2005), due to the legacy effect (path-dependency) that makes the change difficult (Rowbottom et al. 2022). An example of such a case could be water governance in Tajikistan and Kazakhstan, as water reforms in both countries face challenges due to the traditional and Soviet path dependency, and newly introduced institutions are undermined by old informal ones (Sehring 2009).

At the beginning of this article, we frame paradigms as the source code of water governance. Our review shows that when attempts are made to introduce new paradigms in water governance systems, for instance, because the desire is to create more sustainable water governance outcomes, this can usually be quite difficult since existing institutions (often inspired by an older paradigm) may not relent that easily. Although we also examined whether studies assess the actual outcomes arising from the introduction of new paradigms, we did not identify many instances where this is found in the literature. This might be related to the difficulties associated with implementing the approaches associated with a new paradigm in the first place.

Problematizing paradigms in the water governance research

The results of our review reveal that most studies take a critical perspective on water governance paradigms, evident in the number of articles offering a critical analysis of these paradigms or addressing power imbalances. In addition, a small percentage of studies that present paradigms as "success" or "failure" stories suggest that the discussion might not be entirely biased in favor of or against paradigms. This implies a relatively balanced perspective in the overall discourse.

However, we observe that only a limited number of studies consider the implications of adopting specific paradigms, as evidenced by the limited number of publications studying the effects of paradigms. Furthermore, we identify the absence of a common term to indicate a “paradigm,” in contrast to the multitude of terms used. Many publications studying paradigms do not appear in our search results because they do not use any specific term for the studied paradigm. Addressing these issues would help advance paradigm problematization and provide a more comprehensive understanding of their real-world impacts and potential alternatives.

Limitations and future research

One limitation of this study is the language limitations and the restrictive focus on articles. We acknowledge that exploring regional debates in various languages, including those of the Global South, as well as incorporating different forms of literature, such as books, book chapters, and gray literature, would be valuable. However, this goes beyond the scope of our study. This exclusion may affect the representation of certain paradigms and the frequency with which they are discussed in the literature. Focusing solely on academic literature also limits our ability to delve into aspects such as financial flows and deeper power imbalances that influence the emergence and decline of these paradigms. We see potentials for future studies to expand beyond our current scope, allowing a more comprehensive view of water governance paradigms that may not have received adequate attention in the existing literature.

It is important to note that our study primarily focused on papers that analyze paradigms as the unit of analysis, rather than directly examining the paradigms themselves. Although this approach allowed us to gain insight into the literature on paradigms, it may not fully capture the nuances inherent in the actual paradigms. Therefore, future research may directly investigate the paradigms discussed in these papers, possibly through comparative studies, to gain a more comprehensive understanding of their characteristics and implications. Our review establishes a repository that holds significant potential for researchers looking to conduct more in-depth investigations into specific paradigms or aspects of paradigms (e.g., specific stages of the lifecycle of paradigms, their effects, etc). In addition, it provides a valuable platform for comparative analysis of various paradigms and facilitates the exploration of nuanced aspects that require further examination.

CONCLUSION

In conclusion, this systematic review examines what we currently know about water governance paradigms and how they are studied in the literature. Reviewing 93 studies reveals multiple paradigms discussed in the literature, with “integrated approach to governing water” emerging as the most prevalent, followed by paradigms centered on “controlling nature” and “adaptive governance/management.” This dominance raises questions about the plurality of perspectives in the literature and the overshadowing of alternative ontologies.

The promotion and implementation of water governance paradigms are primarily driven by governmental actors, along with international organizations that also play an important role in promotion. However, our review hints at the discrepancy between promoted paradigms and contextual realities. Paradigms often may disregard the local context in which they are implemented, leading to challenges in effective implementation exacerbated by the problem of layering.

Furthermore, our review reveals areas for advancing the problematization of paradigms within the water governance discourse. Although many studies take a critical view of paradigms, few examine their effects. Furthermore, the lack of a common terminology to indicate paradigms poses a challenge for comprehensive literature reviews.

Moving forward, future research should expand beyond language and publication limitations to explore regional debates and incorporate diverse forms of literature. Furthermore, a direct examination of the paradigms themselves is necessary to gain a comprehensive understanding of their characteristics and implications, thus contributing to a more nuanced discourse on water governance. We hope that this review will contribute to an improved understanding of water governance paradigms and will serve as a catalyst for further research in this field, fostering increased scholarly engagement, and facilitating additional work on this crucial topic.

AUTHOR CONTRIBUTIONS

Shahana Bilalova: conceptualization, data curation, methodology, formal analysis, investigation, visualization, writing – original draft, writing – reviewing and editing. **Nicolas W. Jager**: conceptualization, methodology, formal analysis, investigation, visualization, writing – original draft, writing – reviewing and editing. **Jens Newig:** conceptualization, data curation, methodology, investigation, writing – reviewing and editing. **Dave Huitema:** conceptualization, investigation, writing – original draft, writing – reviewing and editing. **Johanna Koehler**: conceptualization, investigation, writing – reviewing and editing.

ACKNOWLEDGEMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 861509 - NEWAVE.

DATA AVAILABILITY STATEMENT

The data and code that support the findings of this study are available on request from the corresponding author.

LITERATURE CITED

Abson, D. J., J. Fischer, J. Leventon, J. Newig, T. Schomerus, U. Vilsmaier, H. von Wehrden, P. Abernethy, C. D. Ives, N. W. Jager, and D. J. Lang. 2017. Leverage points for sustainability transformation. *Ambio* 46(1):30–39.

Allouche, J. 2017. The birth and spread of IWRM - A case study of global policy diffusion and translation. *Flows and Practices: The Politics of Integrated Water Resources Management in Eastern and Southern Africa* 9(3):30–56.

Armitage, D. 2008. Governance and the commons in a multi-level world. *International Journal of the Commons* 2:7–32.

Bakker, K., and C. Morinville. 2013. The governance dimensions of water security: a review.

Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 371(2002):20130116.
Benson, D., A. K. Gain, and C. Giupponi. 2020. Moving beyond water centricity? Conceptualizing integrated water resources management for implementing sustainable development goals. *Sustainability Science* 15(2):671–681.
Benson, D., A. K. Gain, and J. J. Rouillard. 2015. Water governance in a comparative perspective: From IWRM to a "nexus" approach? *Water Alternatives* 8(1):756–773.
Biswas, A. K. 2008. Integrated water resources management: Is it working? *International Journal of Water Resources Development* 24(1):5–22.
Biswas, A. K., and C. Tortajada. 2023. Global crisis in water management: Can a second UN Water Conference help? *River* 2(2):143–148.
Bressers, H., and C. de Boer. 2013. Contextual Interaction Theory for assessing water governance, policy and knowledge transfer. *Water Governance, Policy and Knowledge Transfer: International Studies on Contextual Water Management*:36–54.
Bréthaut, C., and R. Schweizer. 2018. *A Critical Approach to International Water Management Trends*. Page (C. Bréthaut and R. Schweizer, editors) *A Critical Approach to International Water Management Trends*. Palgrave Macmillan London.
Chaffin, B. C., H. Gosnell, and B. A. Cosens. 2014. A decade of adaptive governance scholarship: Synthesis and future directions. *Ecology and Society* 19(3).
Challies, E., and J. Newig. 2022. Water, rivers and wetlands. Pages 512–525 *Routledge Handbook of Global Environmental Politics*. Routledge, London.
Chomba, M. J., T. Hill, B. A. Nkhata, and J. J. Förster. 2017. Paradigms for water allocation in river basins: a society-science-practice perspective from Southern Africa. *Water Policy* 19(4):637–649.
Cosgrove, W. J., and D. P. Loucks. 2015. Water management: Current and future challenges and research directions. *Water Resources Research* 51(6):4823–4839.
Franco-Torres, M. 2021. *The Path to the New Urban Water Paradigm – From Modernity to Metamodernism*. Page *Water Alternatives*.
Frohlich, M. F., C. Jacobson, P. Fidelman, and T. F. Smith. 2018. The relationship between adaptive management of social-ecological systems and law: a systematic review. *Ecology and Society* 23(2):art23.
Furlong, C., K. Gan, and S. De Silva. 2016. Governance of Integrated Urban Water Management in Melbourne, Australia. *Utilities Policy* 43:48–58.
Gerlak, A. K., and F. Mukhtarov. 2015. 'Ways of knowing' water: integrated water resources management and water security as complementary discourses. *International Environmental Agreements: Politics, Law and Economics* 15(3):257–272.
Global Water Partnership. 2000. *Towards water security: Framework for Action*. Page *Global Water Partnership*. GWP: Stockholm, Stockholm.
Gupta, J., A. Akhmouch, W. Cosgrove, Z. Hurwitz, J. Maestu, and O. Ünver. 2013a. Policymakers' reflections on water governance issues. *Ecology and Society* 18(1).
Gupta, J., C. Pahl-Wostl, and R. Zondervan. 2013b, December. "Glocal" water governance: A multi-level challenge in the anthropocene.
Gusenbauer, M., and N. R. Haddaway. 2020. Which academic search systems are suitable for systematic reviews or meta-analyses? Evaluating retrieval qualities of Google Scholar, PubMed, and 26 other resources. *Research Synthesis Methods* 11(2):181–217.
Hall, P. A. 1993. Policy Paradigms, Social Learning, and the State: The Case of Economic Policymaking in. *Comparative Politics* 25(3):275–296.
Harrington, C. 2017. The political ontology of collaborative water governance. *Water*

International 42(3):254–270.
Harsha, J. 2012. IWRM and IRBM concepts envisioned in Indian water policies. *Current Science* 102(7):986–990.
Hogan, J., and M. Howlett. 2015. Reflections on Our Understanding of Policy Paradigms and Policy Change. Pages 3–18 *Policy Paradigms in Theory and Practice*. Palgrave Macmillan UK, London.
Huitema, D., and S. Meijerink. 2010. Realizing water transitions: The role of policy entrepreneurs in water policy change. *Ecology and Society* 15(2):3.
Ingram, H. 2011. Beyond universal remedies for good water governance: a political and contextual approach. Page 21 *in* A. Garrido and H. Ingram, editors. *Water for Food in a Changing World*. Routledge.
James, L. R., R. G. Demaree, and G. Wolf. 1984. Estimating within-group interrater reliability with and without response bias. *Journal of Applied Psychology* 69(1):85–98.
Katusiime, J., and B. Schütt. 2020. Integrated Water Resources Management Approaches to Improve Water Resources Governance. *Water* 12(12):3424.
Kern, F., C. Kuzemko, and C. Mitchell. 2014. Measuring and explaining policy paradigm change: The case of UK energy policy. *Policy and Politics* 42(4):513–530.
Lebel, L., A. Haefner, C. Pahl-Wostl, and A. Baduri. 2020. Governance of the water-energy-food nexus: insights from four infrastructure projects in the Lower Mekong Basin. *Sustainability Science* 15(3):885–900.
Lee, M., H. Kim, J. Y. Lee, J. E. Yang, and C. Lim. 2022. A Shift Towards Integrated and Adaptive Water Management in South Korea: Building Resilience Against Climate Change. *Water Resources Management* 36(5):1611–1625.
Lopez-Gunn, E. 2009. Agua para todos: A new regionalist hydraulic paradigm in Spain. *Water Alternatives* 2(3):370–394.
Lukat, E., M. Schoderer, and S. Castro Salvador. 2022. When international blueprints hit local realities: Bricolage processes in implementing IWRM in South Africa, Mongolia, and Peru. *Water Alternatives* 15(2):473–500.
Mancilla García, M., J. Hileman, Ö. Bodin, A. Nilsson, and P. R. Jacobi. 2019. The unique role of municipalities in integrated watershed governance arrangements: a new research frontier. *Ecology and Society* 24(1):art28.
Meijerink, S., and D. Huitema. 2010. Policy entrepreneurs and change strategies: Lessons from sixteen case studies of water transitions around the globe. *Ecology and Society* 15(2):17.
Moher, D., A. Liberati, J. Tetzlaff, and D. G. Altman. 2009. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Medicine* 6(7):e1000097.
Molle, F. 2008. Nirvana concepts, narratives and policy models: Insights from the water sector. *Water Alternatives* 1(1):131–156.
Molle, F. 2009. River-basin planning and management: The social life of a concept. *Geoforum* 40(3):484–494.
Molle, F., P. P. Mollinga, and P. Wester. 2009. Hydraulic Bureaucracies and the Hydraulic Mission: Flows of Water, Flows of Power Introduction: The Prophets of Irrigation. *Water Alternatives* 2(3):23.
Del Moral, L., M. F. Pita, B. Pedregal, N. Hernández-Mora, and N. Limones. 2014. Current paradigms in the management of water: Resulting information needs. *Publicationes Instituti Geographici Universitatis Tartuensis* 110:21–31.
Mukhtarov, F., and A. K. Gerlak. 2014. Epistemic forms of integrated water resources management: towards knowledge versatility. *Policy Sciences* 47(2):101–120.

Muskatirovic, J. 1997. International river basin management - imperative for sustainable water development. Pages 363–368 *Proceedings, Congress of the International Association of Hydraulic Research, IAHR*.

Rowbottom, J., M. Graversgaard, I. Wright, K. Dudman, S. Klages, C. Heidecke, N. Surdyk, L. Gourcy, I. A. Leitão, A. D. Ferreira, S. Wuijts, S. Boekhold, D. G. Doody, M. Glavan, R. Cvejić, and G. Velthof. 2022. Water governance diversity across Europe: Does legacy generate sticking points in implementing multi-level governance? *Journal of Environmental Management* 319(July 2021).

Sehring, J. 2009. Path dependencies and institutional bricolage in post-Soviet water governance. *Water Alternatives* 2(1):61–81.

Shapiro, A., and R. Summers. 2015. The evolution of water management in Alberta, Canada: the influence of global management paradigms and path dependency. *International Journal of Water Resources Development* 31(4):732–749.

Streeck, W., and K. Thelen. 2005. *Beyond Continuity: Institutional Change in Advanced Political Economies*. Oxford University Press.

Supalla, R. J. 2003. Institutional arrangements to improve water quality in irrigated agriculture. *International Journal of Water Resources Development* 19(1):89–99.

Tantoh, H. B., and D. Simatele. 2017. Community-based water resource management in North-west Cameroon: the role of potable water supply in community development. *South African Geographical Journal* 99(2):166–183.

Taylor, P. L., and D. A. Sonnenfeld. 2017. Water Crises and Institutions: Inventing and Reinventing Governance in an Era of Uncertainty. *Society & Natural Resources* 30(4):395–403.

Tyagi, A. C. 2019. Civil Society in the Water Sector. Pages 303–311 *in* A. Singh, D. Saha, and A. C. Tyagi, editors. *Water Governance: Challenges and Prospects*. Springer, Singapore.

Valin, N., and D. Huitema. 2023. Experts as policy entrepreneurs: How knowledge can lead to radical environmental change. *Environmental Science & Policy* 142:21–28.

Vatn, A. 2018. Environmental Governance – From Public to Private? *Ecological Economics* 148:170–177.

Warner, J. F., J. Hoogesteger, and J. P. Hidalgo. 2017. Old wine in new bottles: The adaptive capacity of the hydraulic mission in Ecuador. *Water Alternatives* 10(2):322–340.

Woodhouse, P., and M. Muller. 2017, April 1. Water Governance—An Historical Perspective on Current Debates. Elsevier Ltd.

Yates, J. S., L. M. Harris, and N. J. Wilson. 2017. Multiple ontologies of water: Politics, conflict and implications for governance. *Environment and Planning D: Society and Space* 35(5):797–815.

Supplementary material for: Paradigms of water governance: a systematic review

Appendix 1. List of included publications

1. Abdullaev, I., and S. Rakhmatullaev. 2015. Transformation of water management in Central Asia: from State-centric, hydraulic mission to socio-political control. *Environmental Earth Sciences* 73(2):849–861.
2. Acheamponga, E. N., M. Swilling, and K. Urama. 2016. Developing a framework for supporting the implementation of integrated water resource management (IWRM) with a decoupling strategy. *Water Policy* 18(6):1317–1333.
3. Agyenim, J. B., and J. Gupta. 2013. Water management in Ghana: between the idea and the implementation. *Journal of Natural Resources Policy Research* 5(1):35–48.
4. Akhmadiyeva, Z., and I. Abdullaev. 2019. Water management paradigm shifts in the Caspian Sea region: Review and outlook. *Journal of Hydrology* 568:997–1006.
5. Al-Masri, R. A., J. Chenoweth, and R. J. Murphy. 2019. Exploring the Status Quo of Water-Energy Nexus Policies and Governance in Jordan. *Environmental Science and Policy* 100:192–204.
6. Al-Saidi, M. 2017. Conflicts and security in integrated water resources management. *Environmental Science and Policy* 73:38–44.
7. Allan, C., J. Xia, and C. Pahl-Wostl. 2013. Climate change and water security: Challenges for adaptive water management. *Current Opinion in Environmental Sustainability* 5(6):625–632.
8. Allan, J. A. 2003. *Integrated water resources management is more a political than a technical challenge*. Page *Developments in Water Science*.
9. Allouche, J. 2017. The birth and spread of IWRM - A case study of global policy diffusion and translation. *Flows and Practices: The Politics of Integrated Water Resources Management in Eastern and Southern Africa* 9(3):30–56.
10. Ammon, K., T. Strowd, and J. Obeysekera. 2007. Integrated Water Resources Management - South Florida's experience. Page *Restoring Our Natural Habitat - Proceedings of the 2007 World Environmental and Water Resources Congress*.
11. Arfan, M., K. Ansari, A. Ullah, D. Hassan, A. A. Siyal, and S. Jia. 2020. Agenda setting in water and IWRM: Discourse analysis of water policy debate in Pakistan. *Water (Switzerland)* 12(6).
12. Bell, E. V., A. D. Henry, and G. Pivo. 2020. Assessing sectoral heterogeneity and leadership in urban water management networks. *Water Policy* 22(5):867–886.
13. Bellaubi, F., and R. Bustamante. 2018. Towards a new paradigm in water management: Cochabamba's water agenda from an ethical approach. *Geosciences (Switzerland)* 8(5).
14. Belmar, Y. N., K. E. McNamara, and T. H. Morrison. 2016. Water security in small island developing states: the limited utility of evolving governance paradigms. *Wiley Interdisciplinary Reviews: Water* 3(2):181–193.
15. Bjornlund, H. 2005. Irrigators and the new policy paradigm - An Australian case study. *Water Policy* 7(6):581–595.
16. Blanco, D. V. 2019. Urban domestic water governance in the Philippines: Paradigms and capacities. *Philippine Political Science Journal* 40(1–2):69–99.
17. Booher, D. E., and J. E. Innes. 2010. Governance for Resilience: CALFED as a complex adaptive network for resource management. *Ecology and Society* 15(3).
18. Bouckaert, F. W., V. V. Vasconcelos, Y. Wei, V. L. Empinotti, K. A. Daniell, and J. Pittock. 2020. A diagnostic framework to assess the governance of the São Francisco River Basin Committee, Brazil. *World Water Policy* 6(1):8–37.

19. Cashman, A. C. 2012. Water policy development and governance in the Caribbean: An overview of regional progress. *Water Policy* 14(1):14–30.
20. Chen, S., J. C. Pernetta, and A. M. Duda. 2013. Towards a new paradigm for transboundary water governance: Implementing regional frameworks through local actions. *Ocean and Coastal Management* 85:244–256.
21. Cherlet, J., and J. P. Venot. 2013. Structure and agency: Understanding water policy changes in West Africa. *Water Policy* 15(3):479–495.
22. Chikozho, C., and K. Kujinga. 2017. Managing water supply systems using free-market economy approaches: A detailed review of the implications for developing countries. *Physics and Chemistry of the Earth* 100:363–370.
23. Ching, L., and M. Mukherjee. 2015. Managing the socio-ecology of very large rivers: Collective choice rules in IWRM narratives. *Global Environmental Change* 34:172–184.
24. Chomba, M. J., T. Hill, B. A. Nkhata, and J. J. Förster. 2017. Paradigms for water allocation in river basins: A society-sciencepractice perspective from Southern Africa. *Water Policy* 19(4):637–649.
25. Clement, F., D. Suhardiman, and L. Bharati. 2017. IWRM discourses, institutional holy grail and water justice in Nepal. *Water Alternatives* 10(3):870–887.
26. Connick, S., and J. E. Innes. 2003. Outcomes of collaborative water policy making: Applying complexity thinking to evaluation. *Journal of Environmental Planning and Management* 46(2):177–197.
27. Cook, C., and K. Bakker. 2012. Water security: Debating an emerging paradigm. *Global Environmental Change* 22(1):94–102.
28. Cossío, V., and J. Wilk. 2017. A paradigm confronting reality: The river basin approach and local water management spaces in the Pucara Basin, Bolivia. *Water Alternatives* 10(1):181–194.
29. de Boer, C. 2013. Adaptive implementation for river restorations in Canada and the Netherlands. *Environmental Engineering and Management Journal* 12(8):1619–1628.
30. De Carvalho, K. M. 2019. The global water security: An approach for multilevel governance on hydric resources. *International Journal of Innovation and Sustainable Development* 13(1):57–78.
31. Del Moral Ituarte, L., and C. Giansante. 2000. Constraints to drought contingency planning in Spain: The hydraulic paradigm and the case of Seville. *Journal of Contingencies and Crisis Management* 8(2):93–102.
32. Elfithri, R., M. Bin Mokhtar, and S. Zakaria. 2019. The need for awareness raising, advocacy, and capacity building in Integrated Water Resources Management toward sustainable development: A case study in Malaysia. *World Water Policy* 5(1):43–54.
33. Engle, N. L., O. R. Johns, M. C. Lemos, and D. R. Nelson. 2011. Integrated and adaptive management of water resources: Tensions, legacies, and the next best thing. *Ecology and Society* 16(1).
34. Fornés, J. M., E. López-Gunn, and F. Villarroya. 2021. Water in Spain: paradigm changes in water policy. *Hydrological Sciences Journal* 66(7):1113–1123.
35. Förster, J. J., L. Downsborough, and M. J. Chomba. 2017. When Policy Hits Practice: Structure, Agency, and Power in South African Water Governance. *Society and Natural Resources* 30(4):521–536.
36. Fritsch, O. 2019. Participatory water governance and organisational change: Implementing thewater framework directive in England and Wales. *Water (Switzerland)* 11(5).
37. Fritsch, O., and D. Benson. 2020. Mutual learning and policy transfer in integrated water resources management: A research agenda. *Water (Switzerland)* 12(1).

38. Furlong, C., K. Gan, and S. De Silva. 2016. Governance of Integrated Urban Water Management in Melbourne, Australia. *Utilities Policy* 43:48–58.
39. Gallego-Ayala, J., and D. Juízo. 2011. Strategic implementation of integrated water resources management in Mozambique: An A'WOT analysis. *Physics and Chemistry of the Earth* 36(14–15):1103–1111.
40. Gerlak, A. K., and F. Mukhtarov. 2015. 'Ways of knowing' water: integrated water resources management and water security as complementary discourses. *International Environmental Agreements: Politics, Law and Economics* 15(3):257–272.
41. Gerlak, A. K., R. G. Varady, and A. C. Haverland. 2009. Hydrosolidarity and international water governance. *International Negotiation* 14(2):311–328.
42. Giakoumis, T., and N. Voulvoulis. 2018. The Transition of EU Water Policy Towards the Water Framework Directive's Integrated River Basin Management Paradigm. *Environmental Management* 62(5):819–831.
43. Giordano, M., and T. Shah. 2014. From IWRM back to integrated water resources management. *International Journal of Water Resources Development* 30(3):364–376.
44. Gleick, P. H. 2000. A look at twenty-first century water resources development. *Water International* 25(1):127–138.
45. Godinez-Madrigal, J., N. Van Cauwenbergh, and P. van der Zaag. 2019. Production of competing water knowledge in the face of water crises: Revisiting the IWRM success story of the Lerma-Chapala Basin, Mexico. *Geoforum* 103:3–15.
46. Grigg, N. S. 2014. Integrated water resources management: unified process or debate forum? *International Journal of Water Resources Development* 30(3):409–422.
47. Grillos, T., A. Zarychta, and J. Nelson Nuñez. 2021. Water scarcity & procedural justice in Honduras: Community-based management meets market-based policy. *World Development* 142.
48. Harrington, C. 2017. The political ontology of collaborative water governance. *Water International* 42(3):254–270.
49. Harsha, J. 2012. IWRM and IRBM concepts envisioned in Indian water policies. *Current Science* 102(7):986–990.
50. Kramer, A., and C. Pahl-Wostl. 2014. The global policy network behind integrated water resources management: Is it an effective norm diffusor? *Ecology and Society* 19(4).
51. Lebel, L., A. Haefner, C. Pahl-Wostl, and A. Baduri. 2020. Governance of the water-energy-food nexus: insights from four infrastructure projects in the Lower Mekong Basin. *Sustainability Science* 15(3):885–900.
52. Lee, M., H. Kim, J. Y. Lee, J. E. Yang, and C. Lim. 2022. A Shift Towards Integrated and Adaptive Water Management in South Korea: Building Resilience Against Climate Change. *Water Resources Management* 36(5):1611–1625.
53. Lopez-Gunn, E. 2009. Agua para todos: A new regionalist hydraulic paradigm in Spain. *Water Alternatives* 2(3):370–394.
54. Malisa, R., E. Schwella, and M. Kidd. 2019. From 'government' to 'governance': A quantitative transition analysis of urban wastewater management principles in Stellenbosch Municipality. *Science of the Total Environment* 674:494–511.
55. Mang, G. 2009. Moving blindly towards integrated water resources management? Challenges and constraints facing Cambodia's new water law. *Asia Pacific Journal of Environmental Law* 12(1):21–49.
56. Mehta, L., R. Alba, A. Bolding, K. Denby, B. Derman, T. Hove, E. Manzungu, S. Movik, P. Prabhakaran, and B. van Koppen. 2014. The politics of IWRM in Southern Africa. *International Journal of Water Resources Development* 30(3):528–542.

57. Mehta, L., B. Derman, and E. Manzungu. 2017. Flows and practices: The politics of integrated water resources management in Eastern and Southern Africa. *Flows and Practices: The Politics of Integrated Water Resources Management in Eastern and Southern Africa* 9(3):1–366.
58. Menahem, G. 1998. Policy paradigms, policy networks and water policy in Israel. *Journal of Public Policy* 18(3):283–310.
59. Mensah, F. A. 2010. Integrated water resources management in Ghana: Past, present, and the future. Pages 2026–2037 *World Environmental and Water Resources Congress 2010: Challenges of Change - Proceedings of the World Environmental and Water Resources Congress 2010*.
60. Mersha, A. N., C. De Fraiture, A. Mehari, I. Masih, and T. Alamirew. 2016. Integrated Water Resources Management: Contrasting principles, policy, and practice, Awash River Basin, Ethiopia. *Water Policy* 18(2):335–354.
61. Mills-Novoa, M. 2020. Making agro-export entrepreneurs out of Campesinos: the role of water policy reform, agricultural development initiatives, and the specter of climate change in reshaping agricultural systems in Piura, Peru. *Agriculture and Human Values* 37(3):667–682.
62. Mills-Novoa, M., and R. T. Hermoza. 2017. Coexistence and conflict: IWRM and large-scale water infrastructure development in Piura, Peru. *Water Alternatives* 10(2):370–394.
63. Molenveld, A., and A. van Buuren. 2019. Flood risk and resilience in the Netherlands: In search of an adaptive governance approach. *Water (Switzerland)* 11(12).
64. Molle, F. 2009. River-basin planning and management: The social life of a concept. *Geoforum* 40(3):484–494.
65. Molle, F. 2008. Nirvana concepts, narratives and policy models: Insights from the water sector. *Water Alternatives* 1(1):131–156.
66. Mukhtarov, F., and A. K. Gerlak. 2014. Epistemic forms of integrated water resources management: towards knowledge versatility. *Policy Sciences* 47(2):101–120.
67. Muskatirovic, J. 1997. International river basin management - imperative for sustainable water development. Pages 363–368 *Proceedings, Congress of the International Association of Hydraulic Research, IAHR*.
68. Pahl-Wostl, C. 2020. Adaptive and sustainable water management: from improved conceptual foundations to transformative change. *International Journal of Water Resources Development* 36(2–3):397–415.
69. Pahl-Wostl, C. 2019. Governance of the water-energy-food security nexus: A multi-level coordination challenge. *Environmental Science and Policy* 92:356–367.
70. Rouillard, J. J., K. V. Heal, T. Ball, and A. D. Reeves. 2013. Policy integration for adaptive water governance: Learning from Scotland's experience. *Environmental Science and Policy* 33:378–387.
71. Rusca, M., and K. Schwartz. 2012. From passive recipient to empowered client? The changing role of water consumers. *Environmental Engineering and Management Journal* 11(5):991–997.
72. Schmidt, J. J. 2013. Integrating Water Management in the Anthropocene. *Society and Natural Resources* 26(1):105–112.
73. Schoeman, J., C. Allan, and C. M. Finlayson. 2014. A new paradigm for water? A comparative review of integrated, adaptive and ecosystem-based water management in the Anthropocene. *International Journal of Water Resources Development* 30(3):377–390.
74. Schröder, N. J. S. 2019. IWRM through WFD implementation? Drivers for integration in polycentric water governance systems. *Water (Switzerland)* 11(5).

75. Shapiro, A., and R. Summers. 2015. The evolution of water management in Alberta, Canada: the influence of global management paradigms and path dependency. *International Journal of Water Resources Development* 31(4):732–749.
76. Shields, K. F., M. Moffa, N. L. Behnke, E. Kelly, T. Klug, K. Lee, R. Cronk, and J. Bartram. 2021. Community management does not equate to participation: Fostering community participation in rural water supplies. *Journal of Water Sanitation and Hygiene for Development* 11(6):937–947.
77. Suhardiman, D., F. Clement, and L. Bharati. 2015. Integrated water resources management in Nepal: key stakeholders' perceptions and lessons learned. *International Journal of Water Resources Development* 31(2):284–300.
78. Supalla, R. J. 2003. Institutional arrangements to improve water quality in irrigated agriculture. *International Journal of Water Resources Development* 19(1):89–99.
79. Tantoh, H. B., and D. Simatele. 2017. Community-based water resource management in North-west Cameroon: the role of potable water supply in community development. *South African Geographical Journal* 99(2):166–183.
80. Tran, T. A., J. Pittock, and D. D. Tran. 2020. Adaptive flood governance in the Vietnamese Mekong Delta: A policy innovation of the North Vam Nao scheme, An Giang Province. *Environmental Science and Policy* 108:45–55.
81. Tundisi, J. G., and T. M. Tundisi. 2016. Integrating ecohydrology, water management, and watershed economy: Case studies from Brazil. *Ecohydrology and Hydrobiology* 16(2):83–91.
82. Van Ast, J. A. 1999. Trends towards interactive water management; developments in international river basin management. *Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere* 24(6):597–602.
83. van Buuren, A., E. H. Klijn, and J. Edelenbos. 2012. Democratic Legitimacy of New Forms of Water Management in the Netherlands. *International Journal of Water Resources Development* 28(4):629–645.
84. Van Cauwenbergh, N., A. Ballester Ciuró, and R. Ahlers. 2018. Participatory processes and support tools for planning in complex dynamic environments: A case study on web-GIS based participatory water resources planning in Almeria, Spain. *Ecology and Society* 23(2).
85. Van de Meene, S. J., R. R. Brown, and M. A. Farrelly. 2011. Towards understanding governance for sustainable urban water management. *Global Environmental Change* 21(3):1117–1127.
86. Varady, R. G., A. A. Zuniga-Teran, G. M. Garfin, F. Martín, and S. Vicuña. 2016. Adaptive management and water security in a global context: definitions, concepts, and examples. *Current Opinion in Environmental Sustainability* 21:70–77.
87. Vij, S., E. Moors, K. Kujawa-Roeleveld, R. E. F. Lindeboom, T. Singh, and M. K. de Kreuk. 2021. From pea soup to water factories: wastewater paradigms in India and the Netherlands. *Environmental Science and Policy* 115:16–25.
88. Warner, J., P. Wester, and A. Bolding. 2008. Going with the flow: River basins as the natural units for water management? *Water Policy* 10(SUPPL. 2):121–138.
89. Warner, J. F., J. Hoogesteger, and J. P. Hidalgo. 2017. Old wine in new bottles: The adaptive capacity of the hydraulic mission in Ecuador. *Water Alternatives* 10(2):322–340.
90. Williams, J. 2018. Diversification or loading order? Divergent water-energy politics and the contradictions of desalination in Southern California. *Water Alternatives* 11(3):847–865.
91. Withanachchi, S. S., G. Ghambashidze, I. Kunchulia, T. Urushadze, and A. Ploeger. 2018. A paradigm shift in water quality governance in a transitional context: A critical

study about the empowerment of local governance in Georgia. *Water (Switzerland)* 10(2).
92. Woodhouse, P., and M. Muller. 2017. Water Governance—An Historical Perspective on Current Debates. *World Development* 92:225–241.
93. Workman, C. L. 2019. Ebbs and flows of authority: Decentralization, development and the hydrosocial cycle in Lesotho. *Water (Switzerland)* 11(2).

Appendix 2. Coding scheme

Bibliographical information

1. Title
2. Authors
3. Sex of first author (m / f / neither or unclear)
4. Country of first author affiliation
5. Institution of the first author
6. Year
7. Type (journal article, book, book chapter)
8. Source title (e.g. journal name)
9. Funding (if applicable): Funding organization, project title and grant no.

General characteristics of publication

10. Nature of research (0, .5, 1): theory development and operationalization; theory testing/confirmation/disconfirmation; empirical research; review; critique; other.
11. Epistemological stance: positivist (0...1), constructivist (0...1)
12. Major conceptual basis, if any (e.g. "power dynamics", "post-colonialism", "policy diffusion", "collaborative governance", etc. multiple possible): text field
13. Research aim / question: text field (as succinct as possible. If possible, copy-paste from publication, otherwise paraphrase)
14. Identified need(s) for further research: text field (as succinct as possible)

Water governance paradigm(s)

15. Names of all paradigms addressed in the paper (sorted by relevance, starting with most relevant): text field
16. Term(s) used for treating paradigms (e.g. paradigm, narrative, imaginary, idea, discourse): text field
17. Does the empirical study have a geographical focus relevant to the studied paradigm(s)? yes/no.
18. If the empirical study has a geographical focus, name the relevant geographical scale(s): Local, sub-national, national, transboundary, continental, international, global
19. World regions (governance) (main focus): Select all that apply. For country classification according to World Bank regions, see https://datahelpdesk.worldbank.org/knowledgebase/articles/906519:
    a. Europe and Central Asia
    b. North America
    c. Latin America and Caribbean
    d. Middle East and North Africa
    e. Sub-Saharan Africa
    f. East Asia and Pacific
    g. South Asia
20. Do the studied paradigms, in the light of the publication, clearly mention water-related problems and their causes? 0 = no; 0.5 = to some extent; 1 = yes, clearly mentioned.
21. Do the studied paradigms, in the light of the publication, clearly mention governance solutions? 0 = no; 0.5 = to some extent; 1 = yes, clearly mentioned.

22. Does the paper analyze actors promoting certain paradigms? 0 = no; 0.5 = to some extent; 1 = yes, clearly mentioned.
23. If yes, to what extent does the paper focus on the following actor groups who are promoting paradigms:
    Government actors (0= not at all, 0.5= mentioned, but not focus, 1= focal actor, I do not know /Unclear):
    administration; international organisations; INGOs; civil society; community/citizens; private actors (business, agriculture); multinational corporations; science; others
24. Timeframe of empirical study (begin year; end year); Text field
25. Does the paper study the origins of the studied paradigms? 0 = no; 0.5 = to some extent; 1 = yes, with details.
26. Does the paper study the spread or diffusion of the studied paradigms? 0 = no; 0.5 = to some extent; 1 = yes, with details.
27. Does the paper study shifts of one paradigm to another (in the given empirical context)? 0 = no; 0.5 = to some extent; 1 = yes, with details.
28. Does the paper study significant changes within paradigms? 0 = no; 0.5 = to some extent; 1 = yes, with details.
29. Does the paper explicitly address the issue that a paradigm is only 'used' in a hollow, merely symbolic sense? (0, 0.5, 1)
30. Does the paper study 'counter-paradigms' in the sense that is designed in opposition to another one? 0 = no; 0.5 = to some extent; 1 = yes, with details.
31. Does the paper study how paradigms change concrete governance structures and practices? 0 = no; 0.5 = to some extent; 1 = yes, with details.
32. To what extent are the following governance modes studied? (as defined in Driessen et al. 2012): Centralized governance (0 = no; 0.5 = to some extent; 1 = yes, with details); Decentralized governance; Public-private governance; Interactive governance; Self-governance
33. With regards to these governance modes, to what extent does the paper focus on the following actor groups:
    Government actors (0= not at all, 0.5= mentioned, but not focus, 1= focal actor):
    administration; international organisations; INGOs; civil society; community/citizens; private actors (business, agriculture); multinational corporations; science; Indigenous; extra-terrestrial
34. Does the paper study social effects of paradigms? 0 = no; 0.5 = to some extent; 1 = yes, with details (which ones, e.g. social justice, equal access,..); Text field
35. Does the paper study environmental effects of paradigms? 0 = no; 0.5 = to some extent; 1 = yes, with details; Text field
36. Does the paper study economic effects of paradigms? 0 = no; 0.5 = to some extent; 1 = yes, with details; Text field
37. Does the paper tell a 'success story' of wg paradigms? 0 = no; 0.5 = to some extent; 1 = yes, with details.
38. Does the paper tell a 'failure story' of wg paradigms? 0 = no; 0.5 = to some extent; 1 = yes, with details.
39. Is the paper a critical account of wg paradigms? 0 = no; 0.5 = to some extent; 1 = yes, with details.
40. Does the paper consider power imbalances? 0 = no; 0.5 = to some extent; 1 = yes, with details.
41. Were any of the following evaluative criteria used (0 = no; 0.5 = to some extent; 1 = yes, with details; I do not know/Unclear): effectiveness (as regards environmental or sustainability aspects); effectiveness in a different sense; efficiency/ cost

effectiveness; justice; legitimacy; accountability; acceptance; policy coherence; adaptability / adaptive capacity; resilience / robustness; other

42. Does the paper give policy recommendations? 0 = no; 0.5 = to some extent; 1 = yes, with details.

References

Driessen, P. P. J., C. Dieperink, F. van Laerhoven, H. A. C. Runhaar, and W. J. V. Vermeulen. 2012. Towards a Conceptual Framework for The Study of Shifts in Modes of Environmental Governance – Experiences From The Netherlands. *Environmental Policy and Governance* 22(3):143–160.

Appendix 3. Additional figures and tables

Table A3.1 Actor's distribution across governance modes.

	Focal actor	Mentioned, but not focus	Not at all	I do not know/Unclear
Government actors	67	6	6	1
Administration	51	10	16	3
International organisations	11	13	55	1
Civil society	27	16	37	0
Community/citizens	25	10	45	0
Private actors (business, agriculture)	28	16	36	0
Science	6	5	69	0
Indigenous	2	1	77	0
Extra-terrestrial	0	0	80	0
International non-governmental organization (INGO)	2	2	76	0
Multinational corporations	0	0	80	0

Overview of articles included in this cumulative dissertation

(in accordance with the guideline for cumulative dissertations in Sustainability Science [January 2012], in the following termed “the guideline”)

[1] **Bilalova, S.,** Newig, J., & Villamayor-Tomas, S. 2024. Toward sustainable water governance? Taking stock of paradigms, practices, and sustainability outcomes. WIREs Water e1762. https://doi.org/10.1002/wat2.1762.

[2] **Bilalova, S.,** Villamayor-Tomas, S., & Newig, J. Water-related problématiques: five archetypical contexts of water governance.” Submitted to Ecology & Society.

[3] **Bilalova, S.,** Jager, N. W., Newig, J., & Villamayor-Tomas, S. Successful governance pathways across problem contexts: a global QCA analysis. Submitted to Ecology & Society.

[4] **Bilalova, S.,** Newig, J., Tremblay-Lévesque, L.-C., Roux, J., Herron, C., & Crane, S. 2023. Pathways to water sustainability? A global study assessing the benefits of integrated water resources management. Journal of Environmental Management 343(October):118179. https://doi.org/10.1016/j.jenvman.2023.118179.

Authors' contributions to the articles and articles publication status (according to §16 of the guideline):

Article #	Title	CRediT author statement	Author status	Weighting factor	Publication status	Conference contributions
1	Toward sustainable water governance? Taking stock of paradigms, practices, and sustainability outcomes.	SB: Data curation, Formal analysis, Visualization, Project administration, Writing – original draft SB, JN, SVT: Conceptualization, Methodology, Investigation, Writing – reviewing and editing JN, SVT: Supervision	Co-author with predominant contribution	1.0	Published in *WIREs Water* (JIF: 6.8)[5]	ECPR 2021*, ICPP5*, ESG 2022*
2	Water-related problématiques: Five archetypical contexts of water governance.	SB, JN, SVT: Conceptualization, Methodology, Investigation, Writing – reviewing and editing SB: Data curation, Formal analysis, Visualization, Project administration, Writing – original draft JN, SVT: Supervision	Co-author with predominant contribution	1.0	Revised and resubmitted to *Ecology & Society* (JIF: 3.6)	
3	Successful governance pathways across problem contexts: a global QCA analysis.	SB: Data curation, Formal analysis, Writing – original draft SB, NWJ: Methodology, Investigation SB, NWJ, JN, SVT: Writing – reviewing and editing SB, JN, SVT: Conceptualization JN, SVT: Supervision	Co-author with predominant contribution	1.0	Submitted to *Ecology & Society* (JIF: 3.6)	ESG 2023*
4	Pathways to water sustainability? A global study assessing the	SB: Formal analysis, Writing – original draft, Visualization, Project administration	Co-author with predominant contribution	1.0	Published in *Journal of Environmental*	ESG 2022*

[5] This article was under review when the cumulative dissertation was submitted and was published afterwards.

	benefits of integrated water resources management.	SB, JN, LCTL, JR, CH, SC: Conceptualization, Investigation SB, JN, LCTL, JR, CH: Methodology, Writing – review & editing JN, LCTL: Supervision			*Management* (JIF: 8.0)	

Explanations

Specific contributions of all authors

CH: Colin Herron, JN: Jens Newig, JR: Julienne Roux, LCTL: Laurent-Charles Tremblay-Lévesque, NWJ: Nicolas Wilhelm Jager, SVT: Sergio Villamayor-Tomas, SB: Shahana Bilalova, SC: Stuart Crane.

Author status

according to §12b of the guideline:

Single author [Allein-Autorenschaft] = Own contribution amounts to 100%.

Co-author with predominant contribution [Überwiegender Anteil] = Own contribution is greater than the individual share of all other co-authors and is at least 35%.

Co-author with equal contribution [Gleicher Anteil] = (1) own contribution is as high as the share of other co-authors, (2) no other co-author has a contribution higher than the own contribution, and (3) the own contribution is at least 25%.

Co-author with important contribution [Wichtiger Anteil] = own contribution is at least 25%, but is insufficient to qualify as single authorship, predominant or equal contribution.

Co-author with small contribution [Geringer Anteil] = own contribution is less than 20%.

Weighting factor according to §14 of the guideline:

Single author [Allein-Autorenschaft]	1.0
Co-author with predominant contribution [Überwiegender Anteil]	1.0
Co-author with equal contribution [Gleicher Anteil]	1.0
Co-author with important contribution [Wichtiger Anteil]	0.5
Co-author with small contribution [Geringer Anteil]	0

Publication status

JIF: 2023 Web of Science Journal Impact Factor

Conference contributions (acronym, society, date, venue, website)

ECPR 2021, European Consortium for Political Research (ECPR), 30 August-3 September, 2021, online, https://ecpr.eu/Events/151.

ICPP 2021, The International Public Policy Association, June 5-9, 2021, Barcelona, Spain, https://www.ippapublicpolicy.org/conference/icpp5-barcelona-2021/13#:~:text=The%205th%20International%20Conference%20on,%2C%20Ciutadella%20Campus%2C%20and%20online.

ESG 2022, Earth System Governance, October 20-24, 2021, Toronto, Canada, https://www.earthsystemgovernance.org/2022toronto/.

ESG 2023, Earth System Governance, October 22-27, 2023, Nijmegen, The Netherlands, https://www.earthsystemgovernance.org/2023radboud/.

* Paper presented by first author

Declaration (according to §16 of the guideline)

I avouch that all information given in this appendix is true in each instance and overall.