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Research

Water-related problématiques: five archetypical contexts of water governance

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ABSTRACT. It is necessary to consider the contextual factors surrounding water governance systems to understand their performance. We conducted a review of 165 empirical studies and 223 cases from the 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 the groundwater exploitation in agriculture problématique, contrary to arguments that groundwater is understudied, and the limited coverage of hydropower governance compared to other problématiques. Overall, our results enhance the understanding of contextual factors in water governance and suggest potential avenues for developing middle-range theories and advancing water governance diagnostics.

Key Words: *archetype; cluster analysis; context; water governance; water problems*

INTRODUCTION

Over the past decades, idealized approaches have been implemented in water governance, with success in some places and failure in others (Young et al. 2018). Scholars have criticized these idealized approaches, or "panaceas" (Meinzen-Dick 2007, Ingram 2011, Pahl-Wostl et al. 2012), and called for more systematic attention to contextual nuances (Ostrom 2007). In particular, decision-makers need to consider the respective problem context, what we call here "problématique," when designing or implementing water governance (Mayne et al. 2020). The fact that context matters (Armitage 2008, Ingram 2011, Gupta et al. 2013) becomes especially important when governance approaches are transferred across jurisdictions. Bressers and de Boer (2013) suggest considering both the sender's and receiver's governance contexts to avoid the unsuccessful transfers of blueprint approaches. To be successful, governance needs to be sensitive and adapted to (local) contexts (Aggarwal and Anderies 2023).

Some frameworks focusing on water governance do integrate contextual factors, including the management and transition framework (Pahl-Wostl et al. 2010), 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, Pahl-Wostl and Knieper 2014, Knieper and Pahl-Wostl 2016, Yu 2016). However, while these often small to medium-sized studies 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 (Liu et al. 2007, Sivapalan et al. 2012, Di Baldassarre et al. 2013). 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 variable. 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). There have been several efforts to develop archetypes in the field of water governance at different scales (Srinivasan et al. 2012, Oberlack and Eisenack 2018, Aggarwal and Anderies 2023). 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 archetypes, consolidated into 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). 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, neither of these attempts to develop archetypes address the problem context of water governance on a broader scale.

Here, we employ archetype analysis to examine problem contexts, which are characterized by the relationships between (1) water resources, (2) their uses, and (3) the associated issues representing the (un)sustainability of these resources with which the water governance systems engage. Specifically, we study explore the following research question: What are the prominent water-related problem contexts with which water governance systems

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engage? We specifically focus on water governance studies that provide information on water-related sustainability performance of governance systems. This research goes beyond existing efforts at clustering water governance problems in two respects: First, we take an explicitly global approach, including water governance settings from all continents. Thus, our identification of problématiques shows wider scope and applicability than earlier studies. Second, we explicitly recognize the problématique aspects of water governance contexts, as we will elaborate further.

The three contextual aspects are central to our analysis because 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 broad framing. Having a broad lens is important, especially considering how diverse water problems are. As posed by the SES framework, social-ecological outcomes emerge from the interactions among resource systems, the resource units produced by these systems, actor groups, and governance systems, which influence and are indirectly affected by these interactions (Ostrom 2007). 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. Analytically disentangling the problem context from the governance system creates an opportunity to take a closer look at the interactions between them, as well as to identify the configurations of governance characteristics that effectively address or aggravate different water-related problématiques. This approach does not imply an ontological position regarding the independent nature of governance and SESs. While we view governance as an inherent part of the broader SES, with continuous interaction between governance and its problem context (see, e.g., McGinnis and Ostrom 2014, Aggarwal and Anderies 2023), understanding and evaluating the effects of governance as a designed intervention within an SES (e.g., Olsson et al. 2004, Gunderson and Light 2006) requires analytical disentanglement of governance from the problem context.

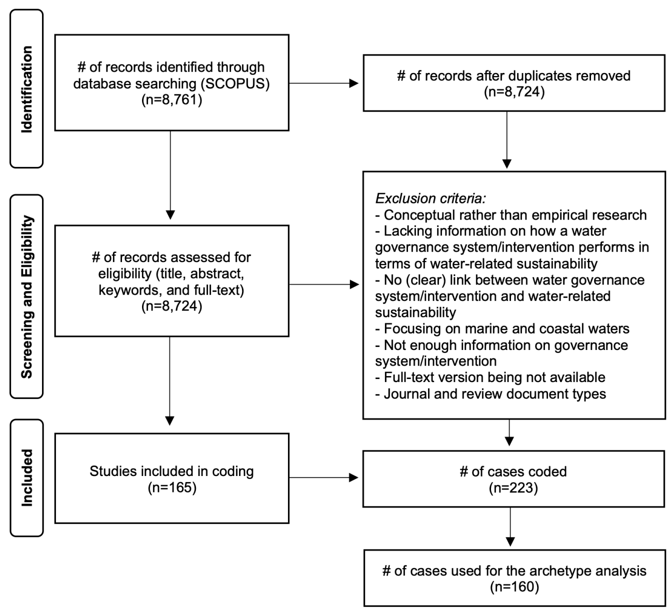
We introduce five distinct archetypes, which we term "water-related problématiques," in line with the overall terminology of the NEWAVE project (https://nextwatergovernance.net/about-newave), a European Union Horizon 2020-funded initiative aimed at advancing water governance research, in which this research 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). We define 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 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 a 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. This work contributes to a broad understanding of contextual factors in water governance research.

METHODS

Data collection

We relied on data collected through a systematic review of the empirical water governance literature reporting on water-related sustainability. The review was conducted following PRISMA guidelines (Fig. 1; Moher et al. 2009).

Fig. 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, and 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 governance and water-related terms to titles. Using the same search string without this limitation would have produced > 67,000 results, whereas our approach yielded 7909 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 search was conducted on 1 January 2020, yielding 8761 results.

Table 1. Search string stratified by the four aspects of the review question, which were connected with the "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*)

We included only papers that provided information on water governance performance in terms of water-related sustainability outcomes. We therefore excluded papers that lacked information on sustainability outcomes. For example, we excluded studies that merely proposed governance frameworks or analyzed them theoretically without providing information on their performance. Hypothetical or purely theoretical case scenarios were not considered because we were interested in real-world cases of water governance and their sustainability performance. However, we included cases in which the assessment of water governance performance was based on the authors' interpretations rather than on concrete empirical evidence.

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). Our study mainly draws on data concerning water-related context attributes such as case country, water resources, water uses, and environmental sustainability issues (hereafter referred to as sustainability issues). The term "water resources" refers to the origin of water, whether from natural sources such as surface water or groundwater, or from engineered sources such as reclaimed wastewater, desalinated seawater, brackish water, harvested rainfall-runoff water, or other nonconventional resources. Our focus is specifically on freshwater resources. "Water uses" describe the ways in which people use water such as for the living environment, domestic consumption, agriculture, industrial production, hydropower generation, discharge of pollutants, recreational activities, commercial purposes, or land development. Lastly, "sustainability issues" pertain to issues characterizing the (un) sustainability of the resources addressed or studied here in connection with the water resources and their respective uses. These issues primarily concern the environmental health of freshwater systems, including water quality problems resulting from pollutant discharge into surface water bodies; water quantity challenges related to 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 to 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. While coding for sustainability issues, we had an "other" category, but it did not result in finding a frequent occurrence of any other water-related sustainability issue (e.g., flooding) that would warrant a separate category.

The units of analysis in the 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 data set contained 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-the-ground realities. Moreover, the existing state of knowledge within the field, revealed through systematic review, serves as a reflection of the general understanding and provides a foundation upon which we can develop further 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 SESs (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). We used archetypes as types of cases (Oberlack et al. 2019), following studies that have taken a similar approach

(Václavík et al. 2013, Sietz et al. 2017, Levers et al. 2018, Villamayor-Tomas et al. 2020). With this approach, we strove 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 was 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 in which 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 (Appendix 4; Husson et al. 2010). We focused solely on cases with complete data for this analysis, which comprised 160 of 223 cases. Prior to conducting the cluster analysis, we performed 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 that is designed specifically for categorical data (van der Heijden and de Leeuw 1989). Principal component analysis is a technique that reduces the dimensionality of a large data set while retaining as much variation as possible (Jolliffe and Cadima 2016). Following MCA, we identified clusters and examined "typical" cases, i.e., those situated near the center of 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). Our analysis meets the conceptual validity criterion because 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 variables used in the analysis is informed by the interaction between the SES's components, 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 ensures transparency and replicability. We have also measured within-archetype variation (Appendix 4) and evaluated cluster quality through an assessment of case sets within each cluster.

After deriving archetypes, we also examined the relationship between water-related problématiques and geographic regions. For this analysis, we conducted Fisher's exact test because the contingency table had multiple expected frequencies of < 5, 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, and 1 refers to a perfect association (Mair et al. 2012).

RESULTS

We begin by outlining our findings concerning water resources, water uses, and sustainability issues across all 223 reviewed cases. We then 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

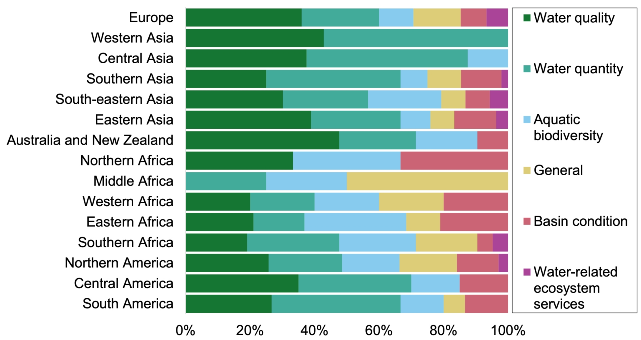
The majority of cases (70%; N = 155) focus on a single resource. Of the remaining cases, 19% (N = 43) address two resources, and only three cases simultaneously examine three resources. Surface and groundwater are the resources that appear together most frequently (N = 42). Surface water is a dominant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

Most cases report on water uses (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 uses. In 64% of the cases reporting on water uses (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, i.e., 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 uses (N = 112). In contrast, 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 uses (N = 40), with just two cases referring exclusively to water use for the 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 the living environment (N = 1) and domestic purposes (N = 1).

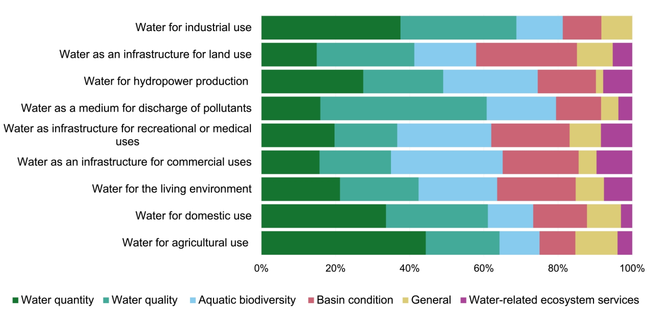
Regarding sustainability issues, we observe that these issues often appear together rather than being addressed in isolation. Water quality (N = 130) and quantity (N = 115) are most frequently addressed (84% of cases) and have a diverse geographic distribution (Fig. 2). Other sustainability issues covered 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 (N = 48) have general coverage of sustainability issues.

Fig. 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 (Fig. 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. Water quantity is primarily tied to agricultural (68%; $N = 78$) and domestic (38%; $N = 44$) uses. The primary uses associated with aquatic biodiversity are water for commercial activities (42%; $N = 25$) and the living environment (42%; $N = 25$). The main use associated with basin condition is water for land uses (62%; $N = 31$). Finally, water-related ecosystem service issues mainly appear together with water use for the living environment (53%; $N = 9$), commercial purposes (47%; $N = 8$), and land (35%; $N = 6$).

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



Water-related problématiques

Cluster analysis yielded five distinct water-related problématiques, which we labeled as: (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” (Table A4.2 in Appendix 4). When we refer to “exploitation” in one cluster and “sustainability” in another, we do not imply better water governance or better status of waters in the latter; rather, we point to the respective issues at stake. We next describe the individual water-related problématiques in more detail.

Problématique 1: groundwater exploitation in agriculture

Groundwater exploitation in agriculture is the largest cluster, constituting 56 (35%) cases. Cases predominantly address the water quantity aspects of agricultural groundwater withdrawal. A typical case is presented in Ratna Reddy et al.’s (2014) study, 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 and the factors underpinning the ineffectiveness of water users’ associations in the Minqin Oasis. This oasis, situated in northwestern 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 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 ($N = 2$) resources quantity, linked to commercial ($N = 1$) or domestic water uses ($N = 1$) as well as water use for the 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

Land and water systems sustainability is the second largest cluster, representing 24% of cases ($N = 38$). 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, USA, 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-off. 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, USA and Johnson Creek in Portland, USA. 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 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, medical, and commercial purposes, as well as water for the living environment and agriculture.

Problématique 3: surface water pollution
Surface water pollution, accounting for 19% of cases ($N = 30$), 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, Indonesia. This watershed, a major source of 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 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 insufficiently 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
The industrial and household water security problématique, consisting of 23 cases, is the most diverse of all problématiques. 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, in contrast to the groundwater exploitation in the agriculture problématique, which focuses solely on the quantity of groundwater resources in relation to agricultural water use. 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, Mexico, which experienced a lowering of groundwater supply due to escalating water uses for industrial, agricultural, and residential purposes.

Problématique 5: hydropower vs. water ecology
The hydropower vs. water ecology problématique encompasses only 8% of all cases ($N = 13$) and focuses on places such as the Mekong basin, rivers in China, and the Em River basin in southeastern Sweden. These cases examine the ramifications of hydropower production on sustainability, with particular focus on water quantity, aquatic biodiversity, and basin condition. All cases in this problématique relate to issues of water quantity and aquatic biodiversity. 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 a typical case, 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 discusses the practice of stakeholder participation in the Em River basin, southeastern Sweden, in addressing conflicts related to 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 the five water-related problématiques and global regions to unveil potential spatial patterns (Fig. 4). Certain problématiques have been more prominently studied in some regions than in others. For instance, cases within hydropower production vs. water ecology are frequently observed in southeastern Asia. In the surface water pollution problématique, cases from Europe and eastern Asia 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 similarly observed in the case of groundwater exploitation in agriculture, along with southern Asia and Europe. Finally, we identified a significant association between water-related problématiques and geographical regions with a moderate effect size (Cramer's $V = 0.3599$, $P < 0.001$).

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 of monitoring and managing highly invisible and movable resources such as 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 costs 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 affect 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

Fig. 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.

growth in society and environmental problems, and urbanization is 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 here 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.

Our study also informs us about paradoxical situations regarding the state of the art around certain problématiques. While the Organisation for Economic Co-operation and Development's assessment *Drying Wells, Rising Stakes: Towards Sustainable Agricultural Groundwater Use* (2015) 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 is, 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 13 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 (García et al. 2021, Castro-Diaz et al. 2023). The rapid increase in dam building, particularly in developing economies (Zarfl et al. 2015, Moran et al. 2018), emphasizes the need for a comprehensive understanding of water governance within the context of hydropower development.

Our study contributes to advancing the study of context in water governance systems and provides guidance for future research in several ways. The problématiques and exploration of their underlying causes contribute to knowledge gain 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, our results offer 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. Finally, building on the identified problématiques, future research can examine how the problem contexts and governance systems interact. Exploring the dynamic interactions between these two components allows for a nuanced understanding of how governance systems either facilitate or hinder problem-solving efforts, and how problem contexts, in turn, shape governance.

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 those elements (Young 2002). This process involves posing system-related questions, wherein 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:

S. Bilalova: conceptualization, data curation, methodology, formal analysis, investigation, visualization, project administration, writing – original draft, writing – reviewing and editing. S. Villamayor-Tomas: conceptualization, methodology, investigation, writing – reviewing and editing, supervision. J. Newig: conceptualization, methodology, investigation, writing – reviewing and editing, supervision.

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Data Availability:

The data that support the findings of this study are available on request from the corresponding author.

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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 resources associated with the environmental/water-related sustainability issues	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	(Bressers and Kuks 2004)

		water storage, landscape development, urban development, settlement, etc.) 10. No clear water use indicated	
3.3 Environmental/water-related sustainability issues 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)	

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Appendix 2. Publications included for coding

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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.
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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.
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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.
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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

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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.

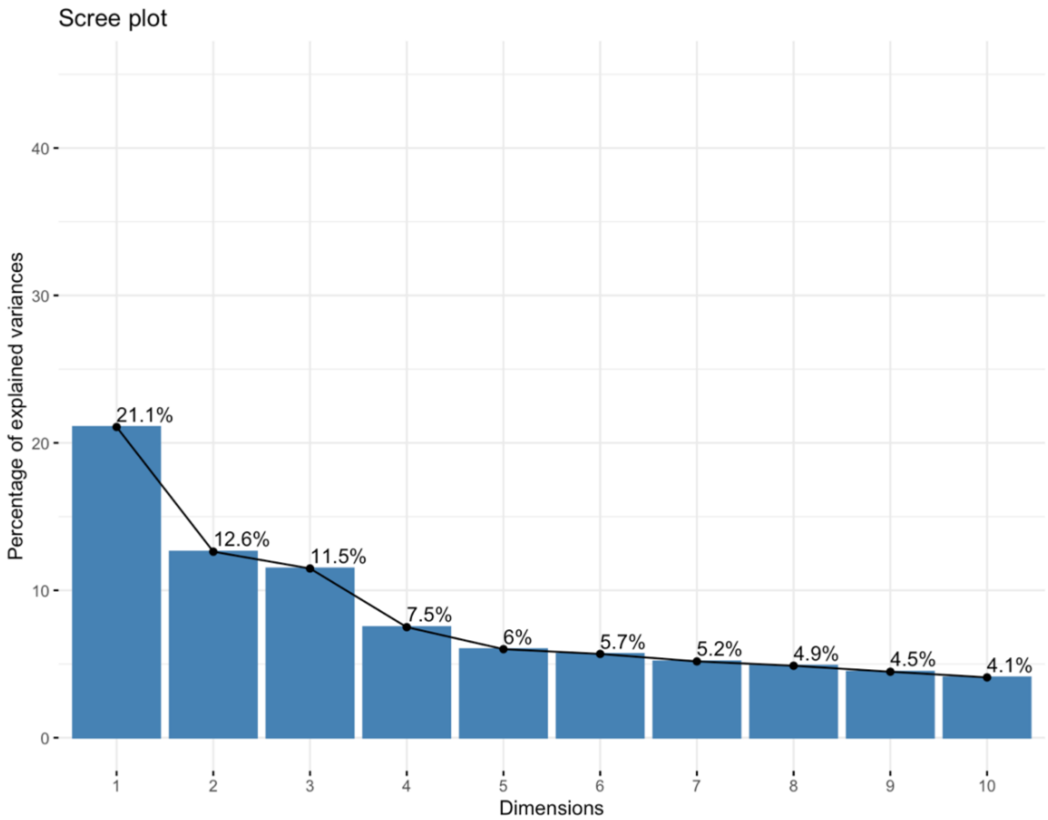

Figure A4. 1 Multiple correspondence analysis (MCA) screeplot

The number of clusters are chosen based on on the highest relative loss of within-cluster inertia. The within-cluster 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. The y-axis of the dendrogram in Figure A4.2 represents the gain in within-cluster inertia at each level of the hierarchical clustering process. The higher values on the y-axis indicates greater dissimilarity between the merged clusters, while a smaller values suggest more natural groupings. The barplot on the upper right corner represents the within-cluster inertia gain at each level of hierarchical clustering process.

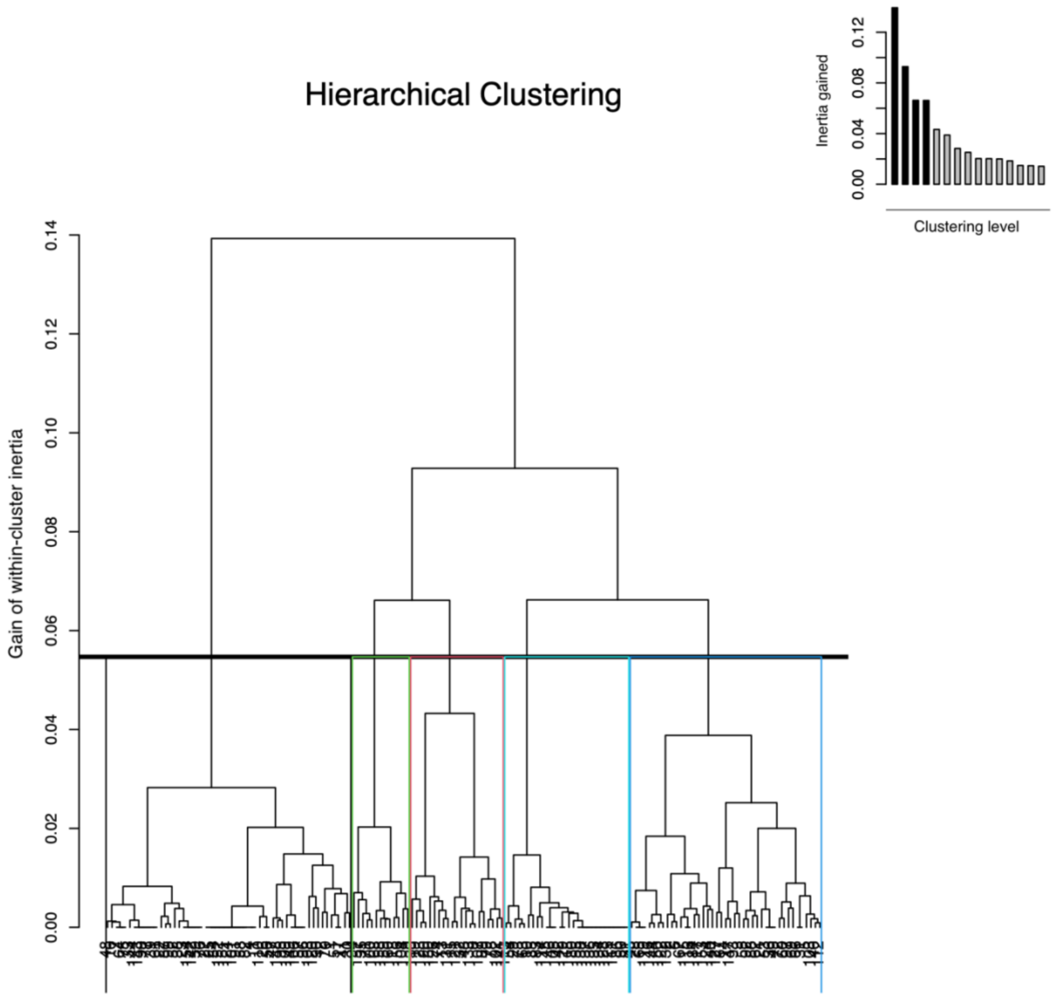

Figure A4.2 Hierarchical clustering (Ward's agglomerative criterion) indexed by the gain of within-cluster inertia.

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															

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