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A Comparative Analysis of Water Governance, Water Management, and Environmental Performance in River Basins

Christian Knieper[1] · **Claudia Pahl-Wostl**[1]

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Abstract River ecosystems are facing a diversity of threats in many parts of the world. To restore and preserve riverine environments, human societies have established water governance and management responses. However, the means by which a satisfactory environmental state can be achieved in light of different regional contexts is still poorly understood. This article explores whether or not good environmental performance can be achieved through water governance and management in combination with further context factors. To this end, we applied fuzzy set Qualitative Comparative Analysis to examine data on water governance, water management, and environmental performance from a recent international study together with context data on per capita income, corruption, hydro-climate, and use pressure from other datasets. Results demonstrate that the combination of polycentric governance, high per capita income, and low levels of corruption is sufficient for achieving good water management practice. However, a good environmental state in river basins seems to primarily depend upon the overall level of pressure from human use rather than the quality of water management. This demonstrates that water governance and management should be seen as part of a broader societal transformation towards sustainability that focusses on a reduction of pressures in river basins instead of mitigating their impacts.

Keywords Polycentric water governance · Water management · Fuzzy set Qualitative Comparative Analysis (fsQCA) · River basins · Environmental state

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✉ Christian Knieper
cknieper@uos.de

[1] Institute of Environmental Systems Research, Osnabrück University, 49069 Osnabrück, Germany

1 Introduction

Rivers provide diverse benefits to humans. But whereas societies benefit from rivers immeasurably (Karr 1999), riverine ecosystems globally have been suffering from the growing intensity of human use. Excessive use of water resources has resulted in a significantly reduced capacity of freshwater ecosystems to sustain environmental services in many parts of the world (Vörösmarty et al. 2005). According to Naiman and Dudgeon (2011), freshwater ecosystems seem to be the most endangered ecosystems of the world. As pressures on water resources are likely to intensify in the near future, freshwater ecosystems are expected to face further deterioration at local and regional scales, with much of this being irreversible (Malmqvist and Rundle 2002).

In light of multiple threats to rivers, human societies have established water management provisions to protect water resources. Water management is an interdisciplinary, multi-sectorial field (Grigg 2015). It encompasses the "activities of analyzing and monitoring, developing and implementing measures to keep the state of a water resource within desirable bounds" (Pahl-Wostl et al. 2012: 25). This has led to improvements in some basins. For example, EEA (2015: 67) states that "Europe's waters are much cleaner than they were 25 years ago". Nevertheless, Vörösmarty et al. (2010) reveal that river biodiversity remains highly threatened and criticize wealthy countries for treating symptoms instead of addressing underlying causes. Gupta et al. (2013: 2) doubt that water management can be effective in isolation, emphasizing that "the drivers of water use and abuse are mostly external forces, over which water managers have little, if any, control, whereas the environment within which they operate is influenced by decisions that are made in other public, private, and civil sectors". To address this challenge, the concepts of Integrated Water Resources Management and the Water-Energy-Food Nexus demand a better integration of water management and other societal sectors (Benson et al. 2015).

The rules under which management operates are established by water governance (Pahl-Wostl et al. 2012), which "takes into account the different actors and networks that help formulate and implement water policy" (ibid.: 25). The Global Water Partnership defines water governance as "the range of political, social, economic and administrative systems that are in place to develop and manage water resources, and the delivery of water services, at different levels of society" (Rogers and Hall 2003: 16). Evidence suggests that certain water governance attributes, such as a polycentric architecture of the governance system, may contribute to the reconciliation of human and environmental water needs (Pahl-Wostl et al. 2013). Bucknall et al. (2006: 20) state that "good governance is an essential aspect of effective water resource management". Yet, previous research has provided little empirical evidence of the level of success of different resource governance strategies based on comparative analyses of sufficiently large, international samples of case studies (Kenward et al. 2011).

The European Twin2Go project has contributed to closing this research gap by performing a comparative analysis of 29 case studies to identify links between water governance, the societal and hydro-climatic context and measures of performance (Pahl-Wostl et al. 2012). The study found governance and context factors that are conducive to climate change adaptation and other performance measures, but it could not identify clear links between water governance characteristics and the state of the environment. In fact, it revealed that several river basins with a rather good environmental state are located in areas with poor governance. This observation was confirmed by the Transboundary Waters Assessment Programme (TWAP), which found that river basins with a good ecosystem state also tend to exhibit limited governance arrangements (de Sherbinin et al. forthcoming). This does not imply a causal link between poor water governance and a good state of the environment. Instead, it reflects the phenomenon that often both coincide in areas with few pressures on water resources. Consequently, any study of potential relationships between water governance and the environmental state of rivers requires an approach that is sensitive to the specific set of regional context factors.

In this paper, we present a study that builds on the Twin2Go dataset. It explores potential links between water governance and management and environmental performance in light of different context factors.[1] In doing so, we test two hypotheses:

1. Polycentric governance, in combination with further context factors, leads to good water management practice.
2. Good water management, in combination with further context factors, is associated with a good environmental state in river basins.

Drawing on an international dataset that is large enough for deriving general insights, our comparative analysis adds context factors not included in the Twin2Go study. It applies a methodological approach that allows identifying effects that only unfold if different factors combine. This represents a novel contribution to water governance research.

This article is structured as follows. Section 2 presents the study's methodology. Section 3 documents results of the analyses. In section 4, we discuss how far the hypotheses have been verified or contradicted, outline implications for water governance research and policy, and discuss one limitation of the analysis.

2 Methods

2.1 Methodological Approach

As the Twin2Go study has shown, a comparative analysis of potential relationships among water governance, water management, and environmental performance must consider the influence of context factors. In this respect, Qualitative Comparative Analysis (QCA)[2] is an appropriate methodological approach, because it addresses causal complexity. Causal complexity acknowledges three basic traits of many real-world phenomena: (1) conjunctural causation, i.e. the effect of a factor unfolds only in combination with other factors, (2) equifinality, i.e. different paths can be associated with the same outcome, and (3) asymmetric causation, i.e. the presence of a path leading to an outcome does not imply that the negated path is associated with the negated outcome (Schneider and Wagemann 2012). QCA addresses causal complexity by searching for conditions or combinations thereof that are necessary or sufficient for an outcome of interest (Berg-Schlosser et al. 2009). Necessity refers to a condition (set) that is always present when the outcome occurs, whereas sufficiency means

[1] In this paper, factors denote real-world phenomena that are supposed to influence other phenomena of interest. Indicators are measures describing such phenomena quantitatively or qualitatively. Conditions refer to indicators in an assessment based on Qualitative Comparative Analysis that have been calibrated (see section 2.3). An 'outcome' denotes a condition to be explained through Qualitative Comparative Analysis.
[2] Cf. Schneider and Wagemann (2012) for a comprehensive description of QCA.

that the outcome is always present when a specific condition (set) occurs (Rihoux and Ragin 2009).

QCA conceptualizes cases as combinations of conditions. In the original crisp-set variant, each condition may be either present or absent (represented by a value of 1 or 0, respectively). This study applies fuzzy set QCA (fsQCA), which allows conditions to be somewhere on a scale between fully absent and fully present (represented by values between 0 and 1). We chose fsQCA because many phenomena show gradual manifestations. An fsQCA-based analysis of necessity assesses to which degree the values associated with the cases for a particular condition are greater than or equal to the respective outcome value. In an fsQCA-based evaluation of sufficiency, all cases are first assigned to ideal-typical combinations, so-called configurations, by changing condition values lower than 0.5 to 0 and values larger than 0.5 to 1. Second, each configuration, the number of cases assigned to it, and consistency measures (see section 2.5) are documented in a so-called truth table. The researcher defines thresholds for consistency and the number of cases that determine whether each single configuration can be regarded as sufficient for the outcome. Third, all configurations fitting the criteria are merged into a solution term through logical minimization.[3]

Three kinds of solution terms exist in QCA: complex solution, most parsimonious solution, and intermediate solution. The former is derived from a truth table without making assumptions about configurations not reaching the minimum number of cases, so-called logical remainders (Schneider and Wagemann 2012). These are not included in logical minimization. To generate the most parsimonious solution, the outcome values (0 or 1) of logical remainders are determined in such a way that the resulting solution term comprises the lowest possible number of conditions and logical operators (Ragin 1987, cited by Schneider and Wagemann 2012). To produce the intermediate solution, logical remainders used to generate the most parsimonious solution are only considered in logical minimization if their inclusion does not lead to the loss of conditions assumed by the researcher as plausible contributions to the outcome (Ragin and Sonnett 2004, cited by Schneider and Wagemann 2012). In our study, we regard the complex solution as decisive because it builds only on those configurations with sufficient empirical evidence. Nevertheless, we also present the two other solution types to show how analysis results change if assumptions are made about the outcomes of logical remainders. To be treated as a logical remainder, a configuration must have no case with a membership value above 0.5.

2.2 Data

Our analysis builds on the dataset from the Twin2Go study (Pahl-Wostl et al. 2012), which comprises cases – domestic river basins and national parts of transboundary basins[4] – in Europe, Africa, Latin America, as well as Central, South, and Southeast Asia. Our analysis excludes one Twin2Go case, Paute (Ecuador), because of missing data on water management and environmental performance. The Rio Grande (USA) case was added using the Twin2Go

[3] For example, if the configurations"A AND B" and "A AND NOT B" are sufficient for an outcome, they will be merged into "A", because in order to achieve the outcome it is irrelevant whether condition A is combined with "B" or "NOT B".

[4] The spatial focus of the Brahmaputra case is on the Indian state of Assam.

questionnaire (cf. Pahl-Wostl and Lebel 2010, updated 2011). In total, the dataset consists of 29 cases.

To address the hypotheses, we adopted indicators from the Twin2Go dataset concerning water governance, water management, and environmental performance (see section 2.2.1). Furthermore, we adopted context indicators from further datasets after completion of a literature review (see section 2.2.2).

2.2.1 Indicators on Governance, Management, and Environmental Performance

The original governance analysis (Pahl-Wostl et al. 2012; Pahl-Wostl et al. 2011, updated 2012) focused particularly on polycentric water governance, i.e. the presence of "multiple centers of authority and distribution of power along with effective coordination structures" (Pahl-Wostl and Knieper 2014: 140). Polycentric governance is considered to be a requirement for integrated, adaptive water management (Pahl-Wostl 2007). Indeed, polycentricity proved to be central for explaining the high performance of governance systems in general and with respect to climate change adaptation in particular (Pahl-Wostl et al. 2012). We kept this governance focus in our study. The following list shows all indicators from the Twin2Go dataset that were adopted as conditions in our QCA analyses (numbers in parentheses reflect indicator numbers in the Twin2Go questionnaire).

1. Water governance: Polycentricity (Pahl-Wostl and Knieper 2014)
   - Integration of domestic water legislation (5)
   - Distribution of functions, responsibilities and authority (6)
   - Vertical coordination between government authorities (34)
   - Horizontal coordination between government authorities (35)
   - Involvement of local governments (36)
   - Degree of centralization (40)
   - Technical capacity and economies of scale (41)
2. Water management
   - Response to water pollution incidents (93)
   - Comprehensiveness of water quality monitoring (94)
   - Presence of sound hydro-meteorological monitoring (95)
   - Understanding of groundwater resources (96)
3. Environmental performance
   - Aquatic biodiversity (87)
   - Surface and groundwater quality (89)

2.2.2 Context Factors

We conducted a literature review to identify relevant context factors and operationalized these factors based on geographic information system (GIS) datasets and international data collections. Where such data sources contained data for several years, we adopted the values for 2010 because the Twin2Go data were collected in that year. We performed all GIS operations with ArcGIS 10. Cases were delineated based on spatial datasets covering river (sub-) basins ["HydroSHEDS" provided by USGS (2013), "HYDRO1k" provided by UNEP (2006a)] and administrative borders ["Administrative Boundaries - First Level (ESRI)" provided by UNEP (2006b)]. For the Raidak catchment, we adopted a shapefile from the European Brahmatwinn project, provided to Twin2Go. To receive more accurate spatial delineations, we made manual corrections where appropriate. In the case of the Inner Niger Delta, we delineated the whole case manually. GIS operations requiring equal-area property were performed using the sinusoidal projection.

In this section, the context factors identified and their operationalization are described.

Many authors regard agriculture, especially intensive agriculture, as a key factor placing pressure on water resources and related ecosystems (Vörösmarty et al. 2010; Revenga et al. 2000, 2005; UNEP 2006c; Harding et al. 1998). Wasson et al. (2010) state that various studies found relationships between the intensity of agriculture or the proportion of agricultural land in a river basin and biological indices. According to Allan (2004), many studies demonstrate that agricultural land use is associated with a decline in habitat, water quality, and biological assemblage, and some studies suggest that the impact of pasture farming is less than that of intensive cultivation. To represent intensive cultivation we made use of "Global Land Cover 2000" data (GVM and JRC 2004), a GIS dataset on land cover in 2000. We calculated the spatial proportion of the land cover class "Cultivated and managed areas" for all cases.

The concentration of human population represents another relevant context factor. Vörösmarty et al. (2010) find that aquatic biodiversity is particularly threatened in areas with high settlement density. Urban centers have a disproportionate impact on rivers (Paul and Meyer 2001, cited by Allan 2004). Based on a global analysis, Esty et al. (2005) conclude that low population density is a critical factor shaping environmental performance in a broader sense. To operationalize the concentration of human population, we derived population density values from a GIS dataset by CIESIN et al. (2005), which provides the projected population in 2010.

The pressure on ecosystems also depends on economic development. Morse (2006) finds that most pressure indicators underlying the Environmental Sustainability Index worsen with increasing per capita income. Lawford et al. (2013) observe that experts perceive regional and economic development as a main factor impacting water quality and quantity across various river basins. According to the impair-then-repair concept, the deterioration of aquatic ecosystems is a "byproduct of economic development" (Vörösmarty et al. 2013: 543). To operationalize economic development, we adopted the purchase-power-corrected Gross National Income per capita at the country-level in 2010 as provided by the World Bank (2014).

Modified flow regimes can severely impair river ecosystems. Allan and Johnson (1997: 110) point out that "altered hydrology is a particularly important and far-reaching indicator of human interference with natural ecosystem function". In a global assessment on transboundary water bodies, UNEP (2006c) concludes that the anthropogenic modification of flow regimes represents the most severe interference affecting freshwater ecosystems. Poff and Zimmerman (2010) demonstrate in their comprehensive review that ecosystem responses to various types of flow alteration are almost always negative. To operationalize flow regime modification, we built on the indicator "Environmental Stress induced by Flow Regime Alterations" (Flörke et al. forthcoming). It measures the modification of monthly flow magnitudes and their respective inter-annual variability during the period 1971–2000. For our study, the author of the indicator extended the original GIS dataset. This allowed us to calculate average flow modification values.

The hydro-climatic context matters as well. Grey and Sadoff (2007) point out that the natural hydrology – in terms of absolute water availability, temporal variability, and spatial distribution – is an outstanding factor for the achievement of water security for ecosystems and human beings. Threats to water quality tend to be particularly severe in water-scarce areas due to the lower capacity to dilute pollution (Revenga et al. 2000; Finlayson et al. 2005). To represent the hydro-climatic context, we made use of two GIS datasets. To assess the degree of aridity, we calculated average values of the Climate Moisture Index from a global GIS dataset provided by UNESCO (n.d.). Average flow variability was calculated based on another GIS [5]dataset: the coefficient of variation of annual flow for the period 1971–2000 (with each water year beginning October 1 and ending September 30) taking into account human water use and dam management. This dataset had been computed by the University of Kassel, using the global hydrological model WaterGAP 2.2 [cf. Müller Schmied et al. (2014) for a documentation of WaterGAP 2.2].

We also searched for factors with an indirect effect on environmental performance through their influence on the effectiveness of water management and governance. Morse (2006) finds a negative relationship between corruption and environmental governance and management response indicators. According to Welsch (2004), empirical evidence has suggested that corruption is a major cause of environmental decline, even though he points out that the total effect of corruption cannot be predicted. Esty et al. (2005) state that the absence of corruption is one of the critical factors shaping environmental performance. To operationalize the extent of corruption, we adopted country values of the Corruption Perceptions Index in 2010 from Transparency International (2010).

Governance and management effectiveness is also influenced by per capita income. Morse (2006) detects a positive relationship of average income with indicators for environmental governance and management response. Welsch (2004) points out that a range of studies show a negative relationship between income and pollution or an initial positive trend that turns into a negative relationship at a certain point. He states that this reduction of pollution is frequently interpreted as a response to requests by the population to improve the non-material standard of living, which occur after reaching a certain level of prosperity. Grey and Sadoff (2007) argue that a balance of investments in regulation and infrastructure is necessary for effective water management. Infrastructure requires funding, which is easier to provide in high-income countries. To operationalize income, we took the same dataset on Gross National Income per capita as for economic development.

Table A1 in the Online Resource shows all indicator values prior to data calibration, which is described in the following section.

2.3 Data Calibration

Data in an fsQCA-based assessment must be calibrated to fit in a data range from 0 to 1: For each indicator, the researcher defines non-membership and full membership and then decides how to assign values between these opposed states. Mathematical functions or classification rules serve to transform original values to fsQCA values. As cases with a value of 0.5 for one or more conditions cannot be assigned to a configuration (Ragin 2009), we ensured that this

[5] Although the calculation required equal-area property, we did not transform the GIS dataset to the sinusoidal projection because the dataset's projection (world cylindrical equal area) is an equal area projection as well.

value was not assigned for any case. The calibration rules applied in our study reflect our assessment of the degree to which the original values are closer to a completely favorable or completely unfavorable manifestation of an indicator (represented by fsQCA values of 1 and 0, respectively). Although we performed the calibration carefully, it is impossible to avoid some degree of arbitrariness (Skaaning 2011) in this step. We acknowledge this issue by documenting the calibration rules for governance, management, and performance indicators in Table A2 of the Online Resource and those for context indicators in Table A3. Table A4 lists the calibrated values for all conditions prior to aggregation, which we describe in the following section.

2.4 Aggregation of Conditions

The number of conditions in a QCA analysis should be limited because a large number increases the probability that a given configuration of conditions is not represented by cases or cannot be interpreted meaningfully (Amenta and Poulsen 1994). We decided not to include more than four conditions in each single analysis of sufficiency other than the outcome. With four conditions and 29 cases all configurations can, at least theoretically, be represented by at least one case. To reduce conditions, we aggregated conditions referring to a common topic, such as water management. Aggregating conditions also increases the robustness with regard to the Twin2Go indicators (Pahl-Wostl et al. 2012).

We aggregated all underlying conditions for water management (MNGT), polycentric governance (POLY), environmental performance (ENV), use pressure (USE), and hydro-climatic context (HYDRO), respectively. Following Langhans et al. (2014), we added the arithmetic mean and the minimum of related conditions and divided the sum by two. The condition derived from Twin2Go indicator 93 received a double weight in the calculation of the arithmetic mean component of the MNGT aggregation because we regard the capacity to cope with pollution incidents as a particularly important aspect of water management. Regarding the POLY aggregation, we first calculated arithmetic means for the sub-dimensions distribution of power (based on the conditions derived from Twin2Go indicators 6, 40, and 41, with indicator 40 being double-weighted), vertical coordination (based on the conditions derived from indicators 34 and 36), and horizontal coordination (based on the conditions derived from indicators 5 and 35). This corresponds with the procedure applied by Pahl-Wostl and Knieper (2014). We then merged these sub-dimensions according to the procedure described above to calculate an overall POLY value. The interim step became necessary to avoid a dominance of low values for the POLY aggregation, which would otherwise have occurred since most of the cases have a value of 0 for at least one condition.

The values of all aggregations and the calibrated values for per capita income (GNI) and corruption (CORR) make up the dataset for the fsQCA assessment. Table A5 in the Online Resource documents the dataset.

2.5 Measures of Fit

To assess whether single conditions or combinations are necessary or sufficient for an outcome, we calculated measures of fit. Two types of measures exist. Consistency assesses the degree to which a condition (set) X is necessary or sufficient for an outcome Y. Coverage indicates the empirical relevance of a condition (set) identified as necessary or sufficient.

2.5.1 Necessity

An fsQCA assessment of necessity investigates the extent to which the membership in a condition X is larger or equal to the respective membership in the outcome Y across all cases. This can be calculated through the consistency measure for necessity (Ragin 2006):

$$Consistency\ (Y_i \leq X_i) = \sum(min(X_i, Y_i))/\sum(Y_i)$$

We followed Skaaning (2011), who recommends a high consistency threshold, such as 0.9, in the analysis of necessary conditions.

It may happen that a condition necessary for an outcome also tends to occur when the outcome is absent. According to Ragin (2006), such a necessary condition has little relevance. To determine the degree of relevance of a necessary condition, he proposes the following coverage measure:

$$Coverage(Y_i \leq X_i) = \sum(min(X_i,\ Y_i))/\sum(X_i)$$

2.5.2 Sufficiency

Regarding sufficiency, an fsQCA assessment investigates the extent to which the membership in a condition (set) X is smaller or equal to the respective membership in the outcome Y across all cases. This is evaluated through the consistency measure for sufficiency (Ragin 2006):

$$Consistency(X_i \leq Y_i) = \sum(min(X_i,\ Y_i))/\sum(X_i)$$

As a threshold value of 0.8 or higher is commonly recommended (Ragin 2009), we adopted 0.8 as consistency threshold for sufficiency.

Cooper and Glaesser (2011) point to a weakness of this consistency measure. Cases with low membership values can lead to the paradoxical situation that it indicates sufficiency both for the outcome Y and its negation ~Y. As an alternative measure, they suggest the Proportional Reduction of Inconsistency (PRI) consistency, which is calculated as follows (Schneider and Wagemann 2012):

$$PRI\ Consistency = \left[\sum(min(X_i, Y_i)) - \sum\left(min\left(X_i,\ Y_i, {}^{\sim}Y_i\right)\right)\right] \Big/ \left[\sum(X_i) - \sum\left(min\left(X_i,\ Y_i, {}^{\sim}Y_i\right)\right)\right]$$

No established PRI consistency threshold exists so far. We followed Pahl-Wostl and Knieper (2014), who apply a threshold of 0.7.

The empirical importance of a sufficient condition (set) can be assessed by expressing how much of the total outcome it covers (Schneider and Wagemann 2012). To this end, Ragin (2006) suggests the following coverage measure for sufficiency:

$$Coverage\,(X_i \leq Y_i) = \sum(min(X_i,\ Y_i))/\sum(Y_i)$$

Having documented the measures of fit, we now describe the models that will be tested to examine the hypotheses presented in the introduction.

2.6 Models to be Tested

We tested for each single condition and its negation whether it is necessary for the outcome. We also performed two analyses of sufficiency. First, we tested whether good management practice results from the interplay of income, corruption, polycentric water governance, and use pressure:

$$MNGT = f(GNI, CORR, POLY, USE)$$

We then addressed the question of whether water management in combination with use pressure and hydro-climatic context can account for good environmental conditions in river basins:

$$ENV = f(HYDRO, USE, MNGT)$$

We performed the analyses with the software fs/QCA 2.5 (Ragin et al. 2009).

3 Results

3.1 Good Water Management Practice

We first addressed the question of how good water management practice can be achieved. A test for necessity revealed that no condition or its negation passes the consistency threshold of 0.9, even though GNI and ~USE show relatively high values of 0.894 and 0.890, respectively (with coverages of 0.765 and 0.614). This indicates that areas with good water management practice also tend to exhibit high average income and use pressure, but we cannot regard those two conditions as necessary according to the strict threshold proposed by Skaaning (2011).

A test for sufficiency reveals that only the configuration GNI*CORR*POLY*~USE passes the thresholds for consistency and PRI consistency (cf. Table A6 in the Online Resource). The complex solution term[6] is therefore:

$$GNI{*}CORR{*}POLY{*}{\sim}USE \rightarrow MNGT$$

According to the solution term, polycentric governance in combination with high per capita income, little corruption, and high use pressure is sufficient for good management practice. The solution term's consistency (0.884) and PRI consistency (0.742) are high. Its mediocre coverage (0.672) indicates that it covers most of the outcome, but a distinct proportion cannot be explained with the conditions in this analysis. In total, six cases from Europe and North America have a membership value above 0.5 in the solution term: Rhine (Netherlands), Thames (UK), Rio Grande (USA), Norrström (Sweden), Upper Guadiana (Spain), and Elbe (Germany).

The presence of high use pressure in the solution term suggests that societies tend to establish water management as a response to existing threats. This supposition is supported by the fact that none of the eight cases in our sample with low use pressure also exhibits good water management practice. However, Fig. 1 demonstrates that all cases characterized by high per capita income, little corruption, and polycentric governance (GNI*CORR*POLY > 0.5) also exhibit high use pressure (USE < 0.5).

[6] In QCA, an asterisk (*) denotes a logical AND, a plus (+) a logical OR, and a tilde (~) a logical NOT. An arrow to the right (→) signifies "is/are sufficient for".

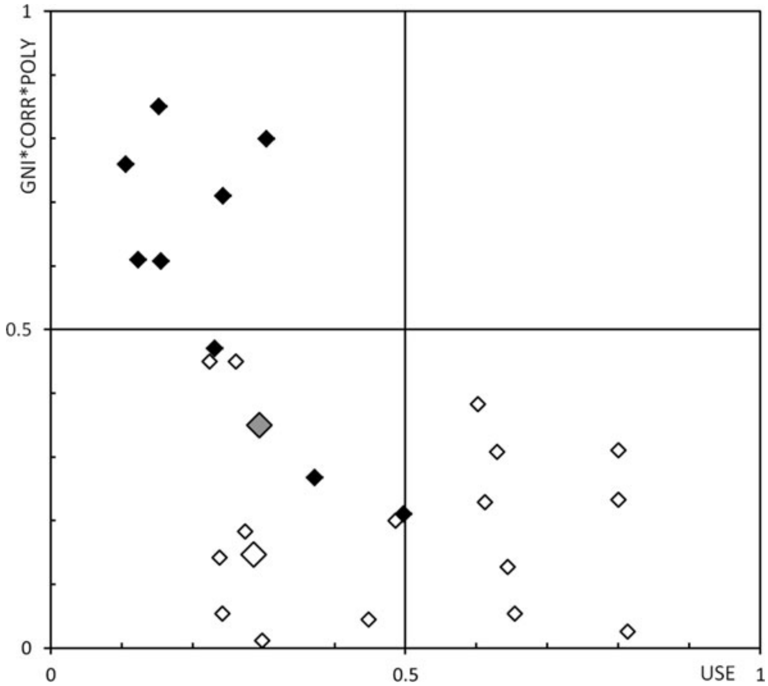

Fig. 1 Distribution of cases according to their values for USE and GNI*CORR*POLY. Please note that USE > 0.5 reflects rather low levels of use pressure. *Black squares* depict cases with MNGT > 0.5 (good water management). In the lower left quadrant, each of the two larger squares indicates two cases with almost identical positions. The grey *square* indicates a case with good and another one with poor management practice

So, the question arises whether high use pressure is really an essential component of the solution term. To answer this question, we repeated the test for sufficiency without the USE condition. Table A7 in the Online Resource is the corresponding truth table.

Only the configuration GNI*CORR*POLY passes the threshold both for consistency and PRI consistency (cf. Table A7). Consequently, the solution term is:

$$GNI{*}CORR{*}POLY \rightarrow MNGT$$

Consistency (0.884) and PRI consistency (0.742) of the simplified complex solution term correspond to those of the original term. This demonstrates that the simplified solution term without ~USE explains the outcome equally well. One should however keep in mind that high use pressure apparently represents an accompanying condition in cases with high average income, little corruption, and polycentric water governance. Coverage of the simplified solution (0.690) has slightly increased.

The intermediate solution, based on the assumptions that GNI, CORR, POLY, and ~USE contribute to MNGT, corresponds to the unsimplified complex solution. By contrast, the most parsimonious solution conforms to the simplified complex solution.[7] The fact that the

[7] Logical minimization allows an alternative most parsimonious solution, CORR*POLY*~USE. It results from the inclusion of the logical remainder ~ GNI*CORR *POLY* ~ USE instead of GNI*CORR*POLY*USE. However, the alternative solution does not pass the PRI consistency threshold and is therefore not considered here.

generation of the intermediate and the most parsimonious solution does not bring about a consistent, qualitatively different term supports the result that polycentric governance with high per capita income and little corruption is sufficient for good management practice and that this combination of conditions tends to be accompanied by high use pressure.

3.2 Good Environmental Performance

We now turn to the question how good environmental performance can be achieved. No condition or its negation passes the consistency threshold for necessity. Testing for sufficiency reveals that the configurations ~HYDRO*USE*~MNGT and HYDRO*USE*~MNGT pass the thresholds for consistency and PRI consistency (cf. Table A8 in the Online Resource). They are therefore included in logical minimization, resulting in the complex solution term:

$$USE^{*}{\sim}MNGT \rightarrow ENV$$

According to the solution term, low use pressure with poor management practice is sufficient for a good environmental state in river basins. Its consistency (0.894) and PRI consistency (0.756) are high. However, its mediocre coverage (0.594) indicates that a considerable part of the outcome remains unexplained on the basis of the conditions included in the analysis. Cases reflecting these characteristics are located in Latin America, Africa, and South Asia: Inner Niger Delta (Mali), Raidak (Bhutan), Okavango (Namibia), Catamayo/Chira (Ecuador), Lake Cocibolca (Nicaragua), Baker (Chile), Cuareim/Quarai (Brazil), and Cuareim/Quarai (Uruguay).

Whereas low use pressure seems obvious for the explanation of good environmental performance, the combination with poor management practice is astonishing at first sight. But again, one has to consider the distribution of cases: All cases in the sample with low use pressure also exhibit rather poor management practice. Figure 2 shows the distribution of cases according to their USE and MNGT values. Whereas all cases but one in the lower right quadrant representing USE*~MNGT are associated with good environmental performance, the quadrant representing USE*MNGT is empty. The diagram also shows that several cases with good performance are located in the left quadrants representing ~USE. This is consistent with the mediocre coverage value of the solution term, which indicates that several cases exhibit good environmental performance even though they do not follow the path USE*~MNGT.

To verify our supposition that use pressure is the decisive condition in the solution term above, we tested whether USE on its own is sufficient for good environmental performance. As only USE passes both thresholds (cf. Table A9 in the Online Resource), the solution term is:

$$USE \rightarrow ENV$$

The simplified complex solution's consistency (0.891) and PRI consistency (0.738) are only slightly below those of the original solution term. Its coverage increases to 0.670. The higher but still mediocre value shows that a considerable part of the outcome needs to be explained through further conditions not included in this analysis.

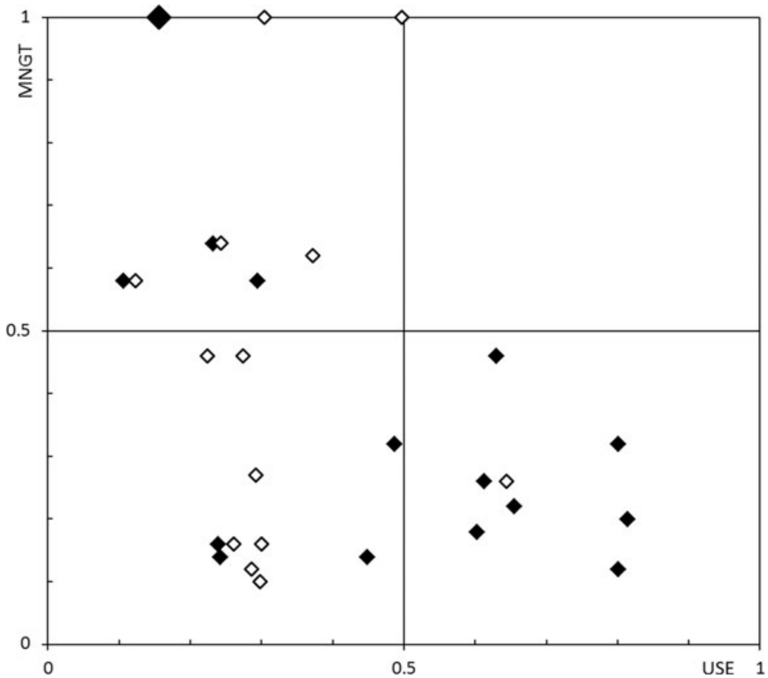

Fig. 2 Distribution of cases according to their USE and MNGT values. *Black squares* depict cases with ENV > 0.5 (good environmental state). The *larger square* in the upper left quadrant marks two cases with almost identical positions

The test confirms our supposition that the solution term USE*~MNGT → ENV can be simplified to USE → ENV. Low use pressure alone is sufficient for good environmental performance, even though it tends to be accompanied by poor water management practice. But one should refrain from regarding the latter as a causal condition.

Both the intermediate solution, based on the assumption that HYDRO, USE, and MNGT contribute to ENV, and the most parsimonious solution consist of the USE condition only. This supports the result that low use pressure in itself is sufficient for good environmental performance.

4 Discussion and Conclusions

What do the results imply with respect to our hypotheses? Regarding the first hypothesis, our analyses confirm that polycentric governance in combination with further context factors (viz. high per capita income and little corruption) leads to good water management practice. But is good water management in combination with further context factors associated with a good environmental state, as the second hypothesis suggests? According to our analyses, this is not automatically the case. As can be seen from the Norrström, Volga, Upper Guadiana, Rio Grande, and Bang Pakong cases, rather good management practice (as indicated by values above 0.5) does not have to go hand in hand with high environmental performance (cf. Table A5). Instead, our analyses show that a low level of use pressure is sufficient for a good state of the riverine environment. This is particularly evident in the Okavango, Inner Niger Delta, and Raidak cases. Here, water management practice exhibits low values, but the environmental state is rather good in light of low use pressure. A couple of Latin American cases, viz. Catamayo/Chira (Ecuador), Cuareim/Quarai (both Brazil and Uruguay), and Baker, show this pattern as well, even though use pressure is not as low as in the three former cases.

It is a significant result of the analysis that low use pressure plays a decisive role for achieving a good environmental state. This supports a TWAP finding according to which most river basins facing little degradation are characterized by a low level of human pressures (de Sherbinin et al. forthcoming). Contrary to our expectation, good water management – on its own or with further conditions – does not automatically bring about a good overall state of the river environment. However, water management is not futile. As mentioned in the introduction, "Europe's waters are much cleaner than they were 25 years ago" (EEA 2015: 67). However, only 53 % of all surface water bodies are expected to reach good ecological status by 2015 as demanded by the European Water Framework Directive (EEA 2015). For comparative analyses of water governance and management, this implies that environmental performance should be defined in a relative manner, i.e. as the degree of improvement or deterioration of the environmental state, along with adequate consideration of pressures. Otherwise, there is a risk of disregarding the successes of water management efforts.

For water policy, the significant role of use pressure implies that reaching a good state of rivers is a long-term process that needs to be part of a wider societal transformation that involves addressing pressures and their sources instead of merely treating symptoms. In light of historical legacies, such as morphologic modification of rivers and unsustainable patterns in agricultural or other economic sectors, this is a tremendous challenge. Therefore, one needs to acknowledge that a certain level of pressure will remain in the longer term, especially in populous regions. Defining achievable environmental targets will require compromises among diverse interests, which need to be negotiated with the involvement of a range of water users. Regarding rivers with a rather good environmental state, our study suggests that preventing the growth of pressures will be more effective than creating sophisticated management responses. This insight is in particular relevant for developing countries and emerging economies where some river basins are still in a relatively good environmental state, but increasing pressure is expected due to population growth or economic development.

A limitation of our analyses of sufficiency is that significant proportions of the outcomes cannot be explained with the few conditions in this study, as indicated by the coverage values. Regarding water management, the Upper Cauca, Bang Pakong, Volga, and Tisza cases show rather good practice although they do not follow the solution path identified. With respect to the environmental state, the situation is even more pronounced: Nine cases show rather good environmental performance even though they deviate from the solution term. Among these cases, the Rhine, Elbe, and Thames cases are remarkable since they face very high use pressure. Perhaps their relatively high environmental performance is facilitated through advanced water management activities. But if so, it remains unclear why the Norrström, Bang Pakong and Volga cases reveal lower environmental performance, although they are similar in terms of use pressure and management practice. Future studies may lead to more differentiated insights into additional successful paths towards good water management and good environmental performance on the basis of further indicators. It may be instructive to compare a small sub-set of those cases in qualitative in-depth analyses that are similar in the values of their conditions but different regarding management or environmental performance.

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Compliance With Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

References

Allan JD (2004) Landscapes and riverscapes: the influence of land use on stream ecosystems. Annu Rev Ecol Evol Syst 35:257–284

Allan JD, Johnson LB (1997) Catchment-scale analysis of aquatic ecosystems. Freshw Biol 37(1):107–111

Amenta E, Poulsen JD (1994) Where to begin: a survey of five approaches to selecting independent variables for qualitative comparative analysis. Sociol Methods Res 23(1):22–53

Benson D, Gain AK, Rouillard JJ (2015) Water governance in a comparative perspective: from IWRM to a 'nexus' approach? Water Alternatives 8(1):756–773

Berg-Schlosser D, De Meur G, Rihoux B, Ragin CC (2009) Qualitative comparative analysis (QCA) as an approach. In: Rihoux B, Ragin CC (eds) Configurational comparative methods. Qualitative Comparative Analysis (QCA) and related techniques. SAGE Publications, Thousand Oaks, pp 1–18

Bucknall J, Damania R, Rao H (2006) Good governance for good water management. In: Evans JW, Roshchupkin VP, Sanhueza A et al (eds) Environment matters at the World Bank: 2006 Annual Review. Washington, DC, pp 20–23, http://siteresources.worldbank.org/INTENVMAT/64199955-1162240805462/21127276/8GoodGovernance.pdf. Accessed 4 March 2015

Center for International Earth Science Information Network - Columbia University (CIESIN), FAO, Centro Internacional de Agricultura Tropical (CIAT) (2005) Gridded population of the world, version 3 (GPWv3): population count grid. Future Estimates NASA Socioeconomic Data and Applications Center (SEDAC), Palisades, NY. doi:10.7927/H42B8VZZ, Accessed 27 May 2014

Cooper B, Glaesser J (2011) Paradoxes and pitfalls in using fuzzy set QCA: illustrations from a critical review of a study of educational inequality. Sociol Res Online 16(3):8

de Sherbinin A, Mara V, Bertule M et al. (forthcoming) Integrated Indicator Analysis. In: UNEP, UNEP-DHI (eds). Transboundary River Basins: Status and Trends. UNEP, Nairobi, pp 135–165

Esty DC, Levy M, Srebotnjak T, de Sherbinin A (2005) Environmental Sustainability Index: benchmarking national environmental stewardship. Yale Center for Environmental Law & Policy, New Haven, http://www.yale.edu/esi/. Accessed 2 June 2015

European Environment Agency (EEA) (2015) The European Environment. State and Outlook 2015. Synthesis Report. Copenhagen. http://www.eea.europa.eu/soer-2015/synthesis/report. Accessed 24 April 2015

Finlayson CM, D'Cruz R et al (2005) Inland water systems. In: Hassan R, Scholes R, Ash N (eds) Ecosystems and human well-being: current state and trends, vol 1, Island Press. Washington, DC, pp 551–583, http://www.unep.org/maweb/en/Condition.aspx. Accessed 9 October 2013

Flörke M, Schneider C, Green P, Vörösmarty C (forthcoming) Water Quantity. In: UNEP, UNEP-DHI (eds). Transboundary River Basins: Status and Trends. UNEP, Nairobi, pp 46–70

Global Vegetation Monitoring (GVM), Joint Research Centre (JRC) (2004) The Global Land Cover Map for the Year 2000. GLC2000 database. http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php. Accessed 14 June 2013

Grey D, Sadoff CW (2007) Sink or swim? Water security for growth and development. Water Policy 9(6):545–571

Grigg NS (2015) Problem archetypes as common ground for water resources management education. Water Resour Manag 29(10):3535–3550

Gupta J, Akhmouch A, Cosgrove W et al (2013) Policymakers' reflections on water governance issues. Ecol Soc 18(1):35

Harding JS, Benfield EF, Bolstad PV et al (1998) Stream biodiversity: the ghost of land use past. PNAS 95(25): 14843–14847

Karr JR (1999) Defining and measuring river health. Freshw Biol 41(2):221–234

Kenward RE, Whittingham MJ, Arampatzis S et al (2011) Identifying governance strategies that effectively support ecosystem services, resource sustainability, and biodiversity. PNAS 108(3):5308–5312
Langhans SD, Reichert P, Schuwirth N (2014) The method matters: a guide for indicator aggregation in ecological assessments. Ecol Indic 45:494–507
Lawford R, Bogardi J, Marx S et al (2013) Basin perspectives on the Water-Energy-Food Security Nexus. Curr Opin Environ Sustain 5(6):607–616
Malmqvist B, Rundle S (2002) Threats to the running water ecosystems of the world. Environ Conserv 29(2): 134–153
Morse S (2006) Is corruption bad for environmental sustainability? A cross-national analysis. Ecol Soc 11(1):22
Müller Schmied H, Eisner S, Franz D et al (2014) Sensitivity of simulated global-scale freshwater fluxes and storages to input data, hydrological model structure, human water use and calibration. Hydrol Earth Syst Sci 18:3511–3538
Naiman RJ, Dudgeon D (2011) Global alteration of freshwaters: influences on human and environmental well-being. Ecol Res 26(5):865–873
Pahl-Wostl C (2007) Transitions towards adaptive management of water facing climate and global change. Water Resour Manag 21(1):49–62
Pahl-Wostl C, Knieper C (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. Glob Environ Chang 29:139–154
Pahl-Wostl C, Lebel L (2010, updated 2011) Methods for Comparative Analysis. http://www.twin2go.uos.de/downloads/deliverables/167-d1-3-comparative-methods-v2
Pahl-Wostl C, Lebel L, Knieper C, D'Haeyer T (eds.) (2011, updated 2012) Synthesis Report. Context-Sensitive Comparative Analysis of Associations between Water Governance Properties and Performance in Water Management. http://www.twin2go.uos.de/downloads/deliverables/170-d2-3-synthesis-report-v2
Pahl-Wostl C, Lebel L, Knieper C, Nikitina E (2012) From applying panaceas to mastering complexity: toward adaptive water governance in river basins. Environ Sci Pol 23:24–34
Pahl-Wostl C, Palmer M, Richards K (2013) Enhancing water security for the benefits of humans and nature - the role of governance. Curr Opin Environ Sustain 5(6):676–684
Paul MJ, Meyer JL (2001) Streams in the urban landscape. Annu Rev Ecol Syst 32:333–365
Poff NL, Zimmerman JKH (2010) Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. Freshw Biol 55:194–205
Ragin CC (1987) The comparative method: moving beyond qualitative and quantitative strategies. University of California Press, Berkeley
Ragin CC (2006) Set relations in social research: evaluating their consistency and coverage. Polit Anal 14(3):291–310
Ragin CC (2009) Qualitative Comparative Analysis using fuzzy sets (fsQCA). In: Rihoux B, Ragin CC (eds) Configurational comparative methods. Qualitative Comparative Analysis (QCA) and related techniques. SAGE Publications, Thousand Oaks, pp 87–121
Ragin CC, Sonnett J (2004) Between complexity and parsimony: limited diversity, counterfactual cases and comparative analysis. In: Kropp S, Minkenberg M (eds) Vergleichen in der Politikwissenschaft. VS Verlag für Sozialwissenschaften, Wiesbaden, pp 180–197
Ragin CC, Drass KA, Davey S (2009) Fuzzy-Set/Qualitative Comparative Analysis 2.5. Department of Sociology, University of Arizona, Tucson. http://www.u.arizona.edu/~cragin/fsQCA/software.shtml. Accessed 21 May 2012
Revenga C, Brunner J, Henninger N et al. (2000) Pilot Analysis of Global Ecosystems. Freshwater Systems. http://pdf.wri.org/page_freshwater.pdf. Accessed 10 May 2013
Revenga C, Campbell I, Abell R et al (2005) Prospects for monitoring freshwater ecosystems towards the 2010 targets. Philos T Roy Soc B 360:397–413
Rihoux B, Ragin CC (eds.) (2009) Configurational Comparative Methods. Qualitative Comparative Analysis (QCA) and Related Techniques. SAGE Publications, Thousand Oaks
Rogers P, Hall AW (2003) Effective Water Governance. Elanders Novum, Sweden. http://www.tnmckc.org/upload/document/bdp/2/2.7/GWP/TEC-7.pdf. Accessed 12 March 2014
Schneider C, Wagemann C (2012) Set-theoretic methods for the social sciences: a guide to Qualitative Comparative Analysis. Cambridge University Press, Cambridge
Skaaning SE (2011) Assessing the robustness of crisp-set and fuzzy-set QCA results. Sociol Methods Res 40(2):391–408
Transparency International (2010) Corruption Perceptions Index 2010. http://files.transparency.org/content/download/132/531/2010_CPI_EN.pdf. Accessed 17 October 2014
U.S. Geological Survey (USGS) (2013) HydroSHEDS. 30 sec SHAPE: Drainage Basins (Beta). http://hydrosheds.cr.usgs.gov/datadownload.php?reqdata=30bass. Accessed 27 May 2013
UNEP (2006a) Environmental Data Explorer. Watershed Boundaries Level 2 - HYDRO1k. http://geodata.grid.unep.ch/. Accessed 27 May 2013

UNEP (2006b) Environmental Data Explorer. Administrative Boundaries - First Level (ESRI). http://geodata.grid.unep.ch/options.php?selectedID=290&selectedDatasettype=16. Accessed 27 May 2013

UNEP (2006c) Challenges to International Waters - Regional Assessments in a Global Perspective. UNEP, Nairobi, Kenya

UNESCO (n.d.) WWDRII Data Download Page. http://wwdrii.sr.unh.edu/download.html. Accessed 29 May 2013

Vörösmarty CJ, Lévêque C, Revenga C et al (2005) Fresh water. In: Hassan R, Scholes R, Ash N (eds) Ecosystems and human well-being: current state and trends, volume 1. Island Press, Washington, pp 165–207, http://www.unep.org/maweb/en/Condition.aspx

Vörösmarty CJ, McIntyre PB, Gessner MO et al (2010) Global threats to human water security and river biodiversity. Nature 467:555–561

Vörösmarty CJ, Pahl-Wostl C, Bunn SE, Lawford R (2013) Global water, the anthropocene and the transformation of a science. Curr Opin Environ Sustain 5(6):539–550

Wasson J-G, Villeneuve B, Iital A et al (2010) Large-scale relationships between basin and riparian land cover and the ecological status of European rivers. Freshw Biol 55:1465–1482

Welsch H (2004) Corruption, growth, and the environment: a cross-country analysis. Environ Dev Econ 9:663–693

World Bank (2014) World DataBank. World Development Indicators. http://data.worldbank.org/indicator/NY.GNP.PCAP.PP.KD. Accessed 17 October 2014