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Research article

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

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

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

A R T I C L E I N F O

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A B S T R A C T

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

1. Introduction

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

* Corresponding author. Leuphana University Lüneburg Research Group Governance, Participation and Sustainability Universitätsallee 1, 21335, Lüneburg, Germany.
E-mail addresses: shahana.bilalova@leuphana.de (S. Bilalova), jens.newig@leuphana.de (J. Newig), laurentcharles.tremblaylevesque@gwp.org (L.-C. Tremblay-Lévesque), julienne.roux@gwp.org (J. Roux), colin.herron@gwp.org (C. Herron), stuart.crane@un.org (S. Crane).

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Acronyms

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

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

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

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

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

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

3. Background on integrated water resources management (IWRM)

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

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

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

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

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

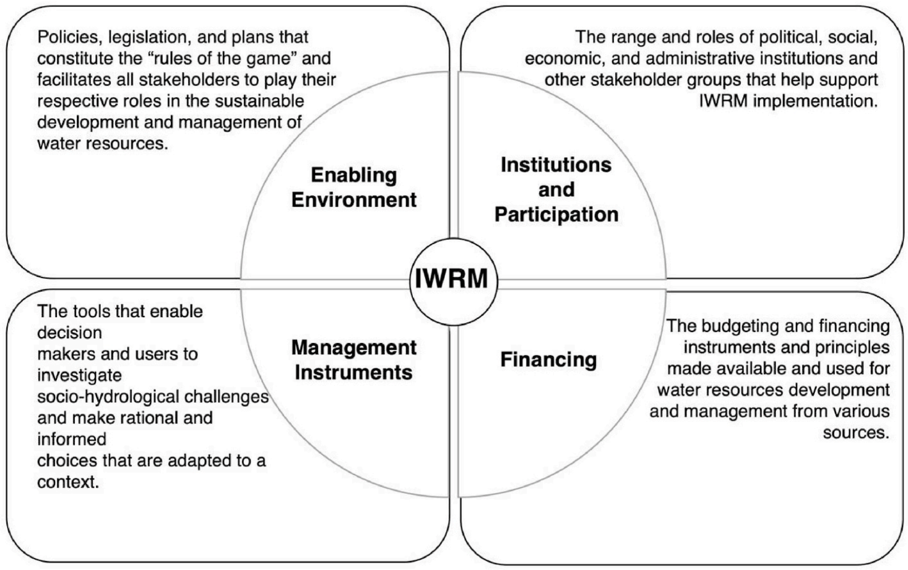

Fig. 1. Four dimensions of IWRM. Adapted from the GWP Toolbox: IWRM Action Hub: https://www.gwptoolbox.org/iwrm-explained.

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

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

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

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

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

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

3. Methodology

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

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

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

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

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

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

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

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

5. Results

5.1. IWRM implementation results

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

5.2. Regression analysis results and interpretation

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

4.2.1. IWRM and access to basic sanitation

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

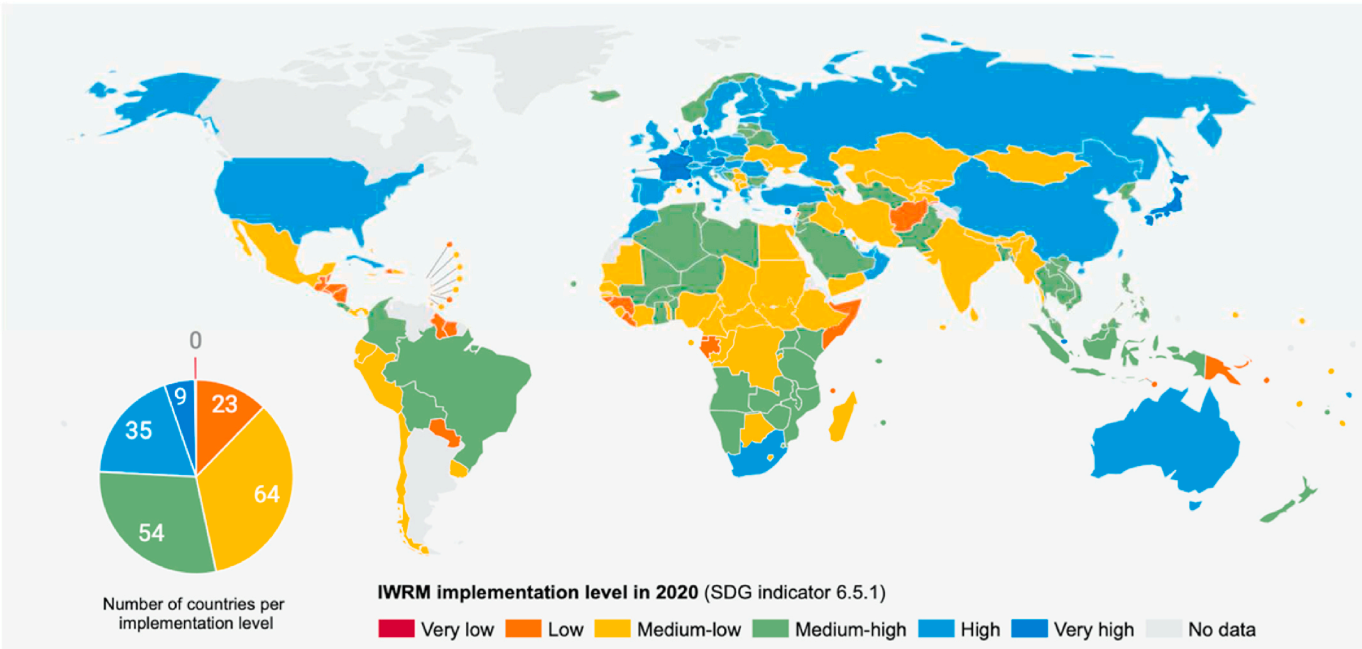

Fig. 2. IWRM implementation level in 2020. Source UNEP (2021).

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

4.2.2. IWRM and treated wastewater

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

4.2.3. IWRM and water-use efficiency

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

4.2.4. IWRM and water stress

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

4.2.5. IWRM and trophic state

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

7. Discussion

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

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

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

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

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

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

8. Conclusion

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

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

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

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

Credit author statement

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

Declaration of competing interest

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

Data availability

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

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Appendix A. Supplementary data

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