frontiers | Frontiers in Water

TYPE Mini Review
PUBLISHED 12 September 2022
DOI 10.3389/frwa.2022.982605

OPEN ACCESS

EDITED BY
Liang Yuan,
China Three Gorges University, China

REVIEWED BY
Thomas Ramsey,
China Three Gorges University, China
Anamika Barua,
Indian Institute of Technology
Guwahati, India

*CORRESPONDENCE
Damon M. Hall
halldam@missouri.edu

SPECIALTY SECTION
This article was submitted to
Water Resource Management,
a section of the journal
Frontiers in Water

RECEIVED 30 June 2022
ACCEPTED 22 August 2022
PUBLISHED 12 September 2022

CITATION
Sarfaraz MU, Hall DM and Rotman RM
(2022) Data sharing in transboundary
water management.
Front. Water 4:982605.
doi: 10.3389/frwa.2022.982605

Data sharing in transboundary water management

M. Umer Sarfaraz[1], Damon M. Hall[1,2,3]* and Robin M. Rotman[1,3]

[1]School of Natural Resources, University of Missouri, Columbia, MO, United States, [2]Biomedical, Biological and Chemical Engineering, University of Missouri, Columbia, MO, United States, [3]The Missouri Water Center, University of Missouri, Columbia, MO, United States

Half the world's population resides within 310 transboundary lake and river basins shared among 151 riparian nations. Approximately 60% of these basins lack cooperative frameworks to share water. The complexities of sharing water necessitate identifying approaches for managing transboundary international freshwater resources. While much has been written about the histories, theory, and mechanisms of transboundary water management, conflict, and cooperation among riparian nations, we draw attention to scholarship written about what we believe is the central tool for cooperation: data and data sharing. The 1997 United Nations' Convention on the Law of the Non-Navigational Uses of International Watercourses (UN Watercourse Convention) recognizes sharing water resources data is vital to river basin cooperation. Data sharing builds trust between riparian states, aids in mitigating conflict, and improves environmental, economic, and social outcomes. Despite calls to increase data sharing in transboundary basins to support cooperative management, few papers review the role of data sharing in transboundary water management, including how often and what types of water resources data and information are shared. We synthesize the role of data in conflict and collaboration from peer-reviewed papers on transboundary water management from the year the UN Watercourse Convention went into force, 2014 to May 2022. We outline what scholars argue are the types of water-related data to be shared, the frequency of data sharing, and the mechanisms for sharing data for facilitating cooperation in transboundary waters.

KEYWORDS

data sharing, integrated water resource management (IWRM), water diplomacy, transboundary river basin management, water governance, transboundary water agreements, boundary object, boundary spanning

Introduction

By 2050, the world's population is projected to surpass 9 billion (Liu et al., 2018), and this increase has focused scholars' attention on the utilization, flow, and development of shared water resources (Gupta et al., 2020). Fifty percent of the world's population dwells in river basins shared by two or more nations (McCracken and Wolf, 2019). There are 310 of these transboundary lake and river basins containing freshwater resources in the form of rivers, lakes, and aquifers shared by 150 riparian nations worldwide

(McCracken and Wolf, 2019). Sharing water constitutes a unique affiliation between riparian states. These relationships are dynamic but often characterized as cooperative or conflicting depending on factors like economic development, long-term planning, and socio-economic status differences between riparian states.

Transboundary river scholarship has increasingly focused on understanding and enhancing cooperation concerning water management and allocation (Sadoff and Grey, 2002; UNECE, 2021). Studies must be updated to enable adaptations to climate change impacts on a changing hydroclimate and the accompanying shifts in patterns of precipitation that affect water availability and flood resilience management (Pörtner et al., 2022). In a changing hydroclimate, data for management are essential. How these data are shared, validated, and legitimated is an area of emerging interest made complicated by a history of international relations, technological advances, and changing quantities of water. Below, we briefly illustrate the spectrum of data sharing in two river basins: the Kabul and the Ganges River basins.

Climatic variability and change will have a substantial influence on water flow patterns, especially in arid and semi-arid regions like the Kabul River Basin, which has recently experienced catastrophic droughts and flooding in Afghanistan and Pakistan (Akhtar et al., 2018). Despite the alarming nature of the problem, neither country has a data-sharing system. In the twentieth century, Afghanistan's glaciers declined by 50–70%, and fast snow and glacier melt caused landslides, river blockages, and downstream flooding (Vick, 2014). Located below the Hindu Kush Himalayas, Afghanistan and Pakistan are prone to flash flooding from annual rain-on-snow events (Taraky et al., 2021). By 2100, average surface temperature of the Hindukush-Karakorum-Himalayan area are expected to climb faster than the world average and annual precipitation in the Kabul River basin is likely to increase by 8–12% (Iqbal et al., 2018). Diplomatic tensions in the basin, such as the century-old dispute over the Durand line that establishes the border between the countries, contributed to hesitancies to exchange data about the water regime for water resource management. Like 60% of the world's internationally shared lake and river basins, there remains no framework for sharing water resources data.

For the Ganges River, Bangladesh and India's Joint River Commission posts water resources information online. Improved collaboration stems from a data-exchange platform, which has accelerated the process of conserving transboundary water resources (Tir and Stinnett, 2009). Because the availability of Ganges water at Farakka, India indicates water quantities within the basin, precipitation patterns and trends across various timescales are gathered and shared *via* the platform (Rahman et al., 2019). This collaboration improves management and international relations and continues to evolve.

Data sharing concerning water availability and patterns of water withdraws among upstream and downstream communities becomes essential for economic development, managing uncertainty for planning, and building trust among riparian states. In this paper, we review articles that characterize how data are shared, the mechanisms used, and the role of data in engendering cooperation or fueling conflict in transboundary river management. Our central question was: How are water resources data used in transboundary river conflict and cooperation? We examine articles from 2014 to 2022 that reveal the evolution of data sharing from the year the United Nation's (UN) Watercourse Convention went into force in 2014 to the rapid advances in computational technologies and spatial imagery of today. We use the Thompson Reuters' Web of Science to find articles published from January 2014 to May 2022 with the keyword combinations of "Transboundary water AND Data OR Information OR Sharing." A total of 277 articles were reviewed paying special attention to all mentions of the role of data in conflict or cooperation between nations. Five articles offered explicit examinations of our question.

Data sharing

Sharing data and information is widely regarded as essential in the history of cooperation (Gerlak et al., 2014) evident in every water treaty modified for water allocation between riparian governments. Currently, there are two multi-national conventions for transboundary water management: The 1992 United Nations Economic Commission for Europe's (UNECE) Convention on the Protection and Use of Transboundary Watercourses and International Lakes (UNECE, 1992) and the United Nations Convention on the Law of the Non-navigational uses of International Watercourses (UNWCC, 1997). These conventions obligate nations to engage in elaborating agreements to reduce the impacts of increasing demands and pollution on shared water resources.

The gathering, exchange, and sharing of water resources information is addressed in each. Article 9 of the UNWCC (1997) states "watercourse States shall on a regular basis exchange readily available data and information on the condition of the watercourse, in particular that of a hydrological, meteorological, hydrogeological and ecological nature and related to the water quality as well as related forecasts". Further, when data from a neighboring state is needed, article 13 of UNECE (1992) states "If a Riparian Party is requested by another Riparian Party to provide data or information that is not available, the former shall endeavor to comply with the request but may condition its compliance upon the payment, by the requesting Party, of reasonable charges for collecting and, where appropriate, processing such data or information." Beyond the above conventions, water resources data sharing has been a consistent subject within the last 50 years of international agreements which require riparian governments to regularly exchange data and statistics about their shared watercourses

(Plengsaeng et al., 2014). In 2015, UN member countries signed onto pursue the 17 Sustainable Development Goals (SDGs) by 2030. SDG Indicator 6.5 addresses transboundary water cooperation. Regular data sharing is one of the four determinants for operational transboundary water cooperation in SDG indicator 6.5.2, however, not all countries choose to participate or report progress on SDG target 6.5.

Although states have a latitude of discretion for which data and how frequently they are shared, the effects of sharing on planning capacity and inter-state trust are clear. The degree of transparency and openness with which riparian nations of international river basins share hydrometeorological data affects planning and decision-making capabilities of other riparian states (Kibler et al., 2014). Data sharing can establish trust among riparian states—as seen in the Okavango River Basin comprise of three riparian states of southern African States namely Angola, Botswana, and Namibia (Mogomotsi et al., 2020). After years of negotiation, transboundary states established the Permanent Okavango River Basin Water Commission (OKACOM) that requires contracting parties to exchange information needed to facilitate OKACOM's tasks and report any developments that could affect shared watercourses.

The UNWCC addresses the management of surface water, however, it does not elucidate the management of groundwater (Dellapenna, 2021). The International Law Commission has prepared language for aquifer management submitted to the UN general assembly as Draft Articles on the Law of Transboundary Aquifers in 2008, though it has not received the acceptance of the UNWCC (Dellapenna, 2021). Absent agreements, sharing groundwater level, pressure, storage, quality, and aquifer yield data—the amount released from an aquifer by pumping or drainage—is voluntary.

A conceptual framework for sharing water resources data focuses on three key elements: (1) types of water-related data to be shared, (2) frequency of data sharing, and (3) mechanisms for sharing data. This framework was developed based on an analysis of 25 transboundary watercourses in Africa, the Americas, Asia, and Europe (Mukuyu et al., 2020). Below, we consider each element.

Types of data shared

Both primary data (e.g., monitoring data collected in the field) and secondary data (e.g., outputs of computer models) about water can be shared (Milman et al., 2020). The specific data to be shared will depend on the intended use. The scope of data to be shared, and the format in which data is to be shared, should be agreed on by riparian states upon at the outset of any data-sharing arrangement (Jahanddideh-Tehrani et al., 2021). Data shared for one purpose—for example, master planning—may also be able to be used for subsequent purposes, such as water allocation (Burton and Molden, 2005; Thu and Wehn, 2016).

Among the array of technical barriers in improving water resource management, it has become increasingly challenging to extract value from the volumes of data collected in an acceptable amount of time to use (Ibrahim, 2020). Challenges to monitor and predict groundwater and surface water interfaces (Verma and Sharma, 2022), water withdraws (Abraha et al., 2022), and costs of monitoring within the basin (Lowry et al., 2019) are prevalent. Despite difficulties, the types of data recommended by researchers to foster transboundary cooperation are in Table 1 (Burton and Molden, 2005; Gerlak et al., 2014; Paisley and Henshaw, 2014; Thu and Wehn, 2016; Mukuyu et al., 2020; Jahanddideh-Tehrani et al., 2021).

Remote sensing data may offer advantages to data-sharing for nations not currently sharing data. Satellite imagery is impartial and can facilitate the incorporation of scientific data into decision-making. Remote sensing can aid in data collection, aggregation, organization, monitoring, and sharing for water resources management and decision making. Analysts can estimate ungauged catchment areas using remotely sensed data products to anticipate basin-wide river discharge (Kibler et al., 2014). Because remotely sensed data require calibration and validation with ground-based data, regional collaborations are needed. Sourcing these data from third party companies may be one method to overcome mistrust in constrained international relations.

In addition to assessment and monitoring of water resources, remote sensing can be used to predict natural and man-made disasters, schedule irrigations, regulate environmental contaminants, and assess effects of climate change (Ibrahim, 2020). In Bangladesh, a novel approach of forecasting based on remotely sensed atmospheric data, as opposed to direct observations, in the upper Ganges–Brahmaputra–Meghna (GBM) river basin has enabled the use of catchment-scale hydrologic modeling without relying on restricted ground-based observations (Kibler et al., 2014).

Frequency of data sharing

A collection and sharing program can be one-time, periodic, or continual in nature (Burton and Molden, 2005). Treaties often specify the agreed upon frequency of data sharing. For example, the Ganges River Treaty among Bangladesh and India specifies annual reporting requirements (Ganges, 1996, art-VI). Recommended frequencies for sharing various types of water data from peer-reviewed literature are depicted in Table 1.

Data sharing mechanisms

There are direct and indirect mechanisms for sharing data. Direct mechanisms consist of provisions in transboundary water treaties; the majority of transboundary water treaties feature a framework for exchanging data or information pertaining to

TABLE 1 Types of data scholars argue should be shared among riparian states to enhance cooperation and build trust.

Data type	Example of indicators used in referenced articles	Frequency
Demographic	Population, age, socio-economic status	Yearly
Hydrometric	Measurement of river flow, river water level, flood peak discharge, base flow	Year, monthly
Social	Population dependent on the agriculture, Domestic dependence, Agriculture sector income, Human development index	Yearly, monthly
Economic	Unemployment in the basin, population living below poverty line, GDP per capita of the river basin in the country	Yearly, monthly
Hydrographic	Salinity, water tides, data regarding marine services, dams, weirs, and infrastructure development	Daily, weekly
Meteorological	Wind speed, air temperature, humidity, evaporation, precipitation intensity, precipitation	Daily, weekly
Climatic	Climate change forecasts, temperature, climate patterns, weather forecasts	Weekly, monthly
Ecological	Minimal flow of the river, flow of critical period, water demand, water quality demand	Monthly, weekly
Ground water	Ground water quality, ground water pressure, ground water level, aquifer yields, ground water recharge, ground water storage capacity	Yearly, monthly
Water pollution	Concentrations of bacteria, nitrogen, phosphorus, fertilizers, industrial wastes, emerging contaminants	Monthly, yearly
Water alternatives	Water stress index, GDP in the industrial sector, Irrigation efficiency	Yearly
Dependent on the river basin	Population dependent on the river, rate of population growth	Yearly
Water quality	Water quality index, electrical conductivity, suspended sediment, nutrients, temperature, dissolved oxygen	Yearly, monthly
Flood prediction	Flood prediction data, flood intensity data	Monthly, weekly
Spatial	Surface water ways, topographic surveys, terrain models, country boundaries, watershed boundaries.	Monthly, yearly
Agricultural	Crop types and acreage, maps of farmland, agriculture land usage, pesticide usage	Yearly, monthly
Water abstraction	Abstraction quantity, return flow quantity and quality	Monthly
Navigational	River discharges, river water levels, river channels and depths	Yearly, monthly
Industrial	Industrial growth rate, current industries in the basin, water withdraws	Yearly
Hydro electrical	Generation capacity, discharge requirement and timing, minimum discharge requirement, maximum discharge requirement	Monthly, weekly

Adapted from Burton and Molden (2005), Gerlak et al. (2014), Plengsaeng et al. (2014), Thu and Wehn (2016), Cantor et al. (2018), Mukuyu et al. (2020), and Jahanddideh-Tehrani et al. (2021).

water resources. Riparian nations also rely on indirect measures, such as prior notification and formalized communications to exchange data (Gerlak et al., 2014). In the absence of treaties, sharing data can strengthen trust between nations toward the development of treaties.

Regardless of the mechanism, any data system integration must include defined standards for data quality, documentation, and archiving. To facilitate data integration, protocols and strategies must be implemented to ensure that data are collected, managed, processed, utilized, and archived effectively across the entire data life cycle. Even for comparable situations, different decision-makers have distinct data and information requirements. Different forms and resolutions of data and information are necessary for different types of judgments, and a useful data exchange system must accommodate these requirements (Cantor et al., 2018).

Barriers to sharing data

However, anecdotal information reveals that data-sharing processes are trailing behind institutional and legal duties, not because of a lack of data, or technological challenges, but because of non-technical roadblocks (Plengsaeng et al., 2014). Political and cultural differences, vision asymmetries, national security concerns, and different approaches to economic development hinder data sharing. Even with treaties in place, history of mistrust poses formidable barriers for data exchange (Akhtar, 2010).

It is not easy to disentangle the relevance of shared waters in riparian state dynamics from other aggravating factors. Generally, conflict arises when data are used for political and economic gamesmanship to share information entirely, partially, or not at all (Thu and Wehn, 2016). Differences in the economic capacity and investments affect availability of data (e.g., poorly managed observing stations, a lack of technology and resources) of less wealthy nations impacts equity in negotiations (Vu et al., 2016). Countries may focus efforts to strengthen their data collection technology to gain competitive advantages in negotiations (Thu and Wehn, 2016). Resulting negotiations from asymmetrical positions increases conflict.

Conflicts over the sharing of water resources are the outcome of divergent government policies. This occurs more frequently when one country uses the groundwater (Giordano et al., 2002) or surface water resources without sharing the data (Vu et al., 2016).

Absence of institutional mechanisms

In transboundary relations, the most predictive variables for conflict are those that show a rapid or dramatic change in the amount or flow of the transboundary water body and the absence of an institutional mechanisms for sharing the data (De Stefano et al., 2017). Nearly 60% of basins lack cooperative frameworks to share water (IUCN, 2019). Institutional mechanisms—policies, practices, programs, and actions in economic, environmental, and social sectors that ensure effective implementation of policy—can mitigate effects of rapid changes in the basin (Jahanddideh-Tehrani et al., 2021).

For example, a lack of institutional mechanisms for water sharing has plagued international relations in the Nile River (Wehling, 2021) and Kabul River Basins (Azizi and Akhtar, 2021). In the Kabul River basin, experts are still debating what kind of data should be shared and how it could be shared (Akhtar and Shah, 2020). In this basin where flow has decreased by 8.4% and changing monsoon patterns cause more severe floods in Afghanistan and Pakistan, the absence of a platform for data exchange threatens economies and endangers thousands of lives (Iqbal et al., 2018).

Shared water resources data can serve as boundary objects—tools useful for moving new understandings into deliberation capable of bridging disparate viewpoints or epistemologies (Cash et al., 2003; Leigh Star, 2010; Ward et al., 2017)—for improving communication and coordination among nations with tenuous relations over a shared resource. Data as a object around which to gather, build relations, and plan is evidenced in the mechanisms of the inter-governmental Mekong River Commission (Feng et al., 2019).

Conclusion

Water plays a substantial role in ongoing disputes throughout the world, particularly when climate variability and rapid changes in water quantities create high levels of perceived risks to national water security (Sadoff and Grey, 2002). The effects of a changing hydroclimate yields new uncertainties and hazards and offers new reasons to engage for riparian states in transboundary basins. Managing shared transboundary waters is equally a science of water resource management an art of navigating socio-political dynamics (Xie and Ibrahim, 2021).

In this rapidly advancing Information Age, a central socio-political and technical space for organizing cooperation is data and data sharing. Data and information are crucial for effective river basin administration and management, as these data are essential for making sound decisions in various water-related fields, including sectorial water management, integrated water sector planning, climate change adaptation, global and regional reporting, operational and emergency management, and more (Jahanddideh-Tehrani et al., 2021). Mechanisms and frameworks for data sharing constitute spaces for collaboration—boundary objects—between states with a history of constrained relations.

While it is possible to advocate for improved data exchange by promoting adherence to international conventions and declarations such as those mentioned at the beginning of this paper (e.g., the UN Watercourse Convention of 1997), the objectives of basin-specific cooperation may be equally or even more important. Nevertheless, the most effective institutionalized cooperation occurs when facts and information are shared (Gerlak et al., 2014). When nations' shared futures are bound to their shared natural resources, the available data for decision making is best shared too.

Author contributions

MS, DH, and RR conceptualized the study. MS conducted the literature review and wrote the original draft. DH and RR advised, revised, and edited the manuscript. All authors contributed to the article and approved the submitted version.

Funding

This research was supported by the United States-Afghanistan Fulbright Program and the United States Department of Agriculture, National Institute of Food and Agriculture, McIntire Stennis, Project 1021674 and Hatch project number is 00077267.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Abraha, T., Tibebu, A., and Ephrem, G. (2022). Rapid urbanization and the growing water risk challenges in Ethiopia: the need for water sensitive thinking. *Front. Water* 4, 890229. doi: 10.3389/frwa.2022.890229

Akhtar, D. S. (2010). Emerging challenges to Indus Waters Treaty. *Reg. Stud.* 28, 3–66.

Akhtar, F., Awan, U. K., Tischbein, B., and Liaqat, U. W. (2018). Assessment of irrigation performance in large river basins under data scarce environment-A case of Kabul river basin, Afghanistan. *Remot.Sens.* 10, 972. doi: 10.3390/rs10060972

Akhtar, F., and Shah, U. (2020). "Emerging water scarcity issues and challenges in Afghanistan," in *Water Issues in Himalayan South Asia: Internal Challenges, Disputes and Transboundary Tensions*, ed A. Ranjan (Singapore: Palgrave Macmillan), 1–28.

Azizi, A. H., and Akhtar, F. (2021). Analysis of spatiotemporal variation in the snow cover in Western Hindukush-Himalaya region. *Geocarto Int.* 1–23. doi: 10.1080/10106049.2021.1939442

Burton, M., and Molden, D. (2005). "Making sound decisions: Information needs for basin water management," in *Irrigation and River Basin Management: Options for Governance and Institutions*, ed M. Svendsen (Cambridge, MA: CABI Publishing), 51–74.

Cantor, A., Kiparsky, M., Kennedy, R., Hubbard, S., Bales, R., Pecharroman, L. C., et al. (2018). *Data for Water Decision Making: Informing the Implementation of California's Open and Transparent Water Data Act Through Research and Engagement*. Center for Law, Energy and the Environment. 56.

Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., et al. (2003). Knowledge systems for sustainable development. *Proc. Natl. Acad. Sci.* 100, 8086–8091. doi: 10.1073/pnas.1231332100

De Stefano, L., Petersen-Perlman, J. D., Sproles, E. A., Eynard, J., and Wolf, A. T. (2017). Assessment of transboundary river basins for potential hydro-political tensions. *Global Environ. Change* 45, 35–46 doi: 10.1016/j.gloenvcha.2017.04.008

Dellapenna, J. W. (2021). "The evolving international law of transnational aquifers," in *Management of Shared Groundwater Resources*, eds E. Feitelson and M. Haddad (Dordrecht: Springer), 209–257.

Feng, Y., Wang, W., Suman, D., Yu, S., and He, D. (2019). Water cooperation priorities in the Lancang-Mekong River basin based on cooperative events since the Mekong River Commission establishment. *Chin. Geogr. Sci.* 29, 58–69. doi: 10.1007/s11769-019-1016-4

Ganges. (1996). *Treaty Between the Government of the People's Republic of Bangladesh and the Government of the Republic of India on sharing of the Ganga/GangesWater at Farakka*.

Gerlak, A. K., Lautze, J., and Giordano, M. (2014). "Greater exchange, greater ambiguity: Water resources data and information exchange in transboundary water treaties," in *Global Water: Issues and Insights*, ed D. Allendes (Canberra, ACT: Australian National University), 57–63.

Giordano, M., Giordano, M., and Wolf, A. (2002). The geography of water conflict and cooperation: internal pressures and international manifestations. *Geogr. J.* 168, 293–312. doi: 10.1111/j.0016-7398.2002.00057.x

Gupta, J., Scholtens, J., Perch, L., Dankelman, I., Seager, J., Sánder, F., et al. (2020). Re-imagining the driver–pressure–state–impact–response framework from an equity and inclusive development perspective. *Sustain. Sci.* 15, 503–520. doi: 10.1007/s11625-019-00708-6

Ibrahim, I. A. (2020). Legal implications of the use of Big Data in the transboundary water context. *Water Resour. Manag.* 34, 1139–1153. doi: 10.1007/s11269-020-02491-x

Iqbal, M. S., Dahri, Z. H., Querner, E. P., Khan, A., and Hofstra, N. (2018). Impact of climate change on flood frequency and intensity in the Kabul River Basin. *Geosciences* 8, 114. doi: 10.3390/geosciences8040114

IUCN (2019). *International Union for Conservation of Nature. 2019. Water cooperation: Diplomacy From Source to Sea.* Available online at: www.iucn.org/news/water/201912/water-cooperation-diplomacy-source-sea (accessed June 28, 2022).

Jahanddideh-Tehrani, M., Bozorg-Haddad, O., and Daliakopoulos, I. N. (2021). "The role of water information and data bases in water resources management," in *Essential Tools for Water Resources Analysis, Planning, and Management*, ed O. Bozorg-Haddad (Singapore: Springer), 59–83.

Kibler, K. M., Biswas, R. K., and Juarez Lucas, A. M. (2014). Hydrologic data as a human right? Equitable access to information as a resource for disaster risk reduction in transboundary river basins. *Water Policy* 16, 36–58. doi: 10.2166/wp.2014.307

Leigh Star, S. (2010). This is not a boundary object: reflections on the origin of a concept. *Sci. Technol. Hum. Values* 35, 601–617. doi: 10.1177/0162243910377624

Liu, J., Hull, V., Godfray, H. C. J., Tilman, D., Gleick, P., Hoff, H., et al. (2018). Nexus approaches to global sustainable development. *Nat. Sustain.* 1, 466–476. doi: 10.1038/s41893-018-0135-8

Lowry, C. S., Fienen, M. N., Hall, D. M., and Stepenuck, K. F. (2019). Growing pains of crowdsourced stream stage monitoring using mobile phones: the development of CrowdHydrology. *Front. Earth Sci.* 7, 128. doi: 10.3389/feart.2019.00128

McCracken, M., and Wolf, A. T. (2019). Updating the register of international river basins of the world. *Int. J. Water Resour. Dev.* 35, 1572497. doi: 10.1080/07900627.2019.1572497

Milman, A., Gerlak, A. K., Albrecht, T., Colosimo, M., Conca, K., Kittikhoun, A., et al. (2020). Addressing knowledge gaps for transboundary environmental governance. *Global Environ. Change* 64, 102162. doi: 10.1016/j.gloenvcha.2020.102162

Mogomotsi, G. E., Mogomotsi, P. K., and Mosepele, K. (2020). Legal aspects of transboundary water management: an analysis of the intergovernmental institutional arrangements in the Okavango River Basin. *Leiden J. Int. Law* 33, 391–408. doi: 10.1017/S0922156519000736

Mukuyu, P., Lautze, J., Rieu-Clarke, A., Saruchera, D., and McCartney, M. (2020). The devil's in the details: data exchange in transboundary waters. *Water Int.* 45, 1850026. doi: 10.1080/02508060.2020.1850026

Paisley, R. K., and Henshaw, T. W. (2014). If you can't measure it, you can't manage it: transboundary waters, good governance and data and information sharing and exchange. *Ind. Int'l. Comp. L. Rev.* 24, 203–247. doi: 10.18060/20963

Plengsaeng, B., Wehn, U., and Van Der Zaag, P. (2014). Data-sharing bottlenecks in transboundary integrated water resources management: a case study of the Mekong River Commission's procedures for data sharing in the Thai context. *Water Int.* 39, 933–951. doi: 10.1080/02508060.2015.981783

Poörtner, H. O., Roberts, D. C., Adams, H., Adler, C., Aldunce, P., Ali, E., et al. (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Wageningen: IPCC. Available online at: https://edepot.wur.nl/565644

Rahman, K. S., Islam, Z., Navera, U. K., and Ludwig, F. (2019). A critical review of the Ganges Water Sharing arrangement. *Water Policy* 21, 259–276. doi: 10.2166/wp.2019.164

Sadoff, C. W., and Grey, D. (2002). Beyond the river: the benefits of cooperation on international rivers. *Water Policy* 4, 389–403 doi: 10.1016/S1366-7017(02)00035-1

Taraky, Y. M., Liu, Y., McBean, E., Daggupati, P., and Gharabaghi, B. (2021). Flood risk management with transboundary conflict and cooperation dynamics in the Kabul river basin. *Water* 13, 1513. doi: 10.3390/w13111513

Thu, H. N., and Wehn, U. (2016). Data sharing in international transboundary contexts: the Vietnamese perspective on data sharing in the Lower Mekong Basin. *J. Hydrol.* 536, 351–364. doi: 10.1016/j.jhydrol.2016.02.035

Tir, J., and Stinnett, D. (2009). The institutionalization of river treaties. *International Negotiation* 14, 229–251. doi: 10.1163/157180609X.432815

UNECE (1992). *Convention on The Protection and Use of Transboundary Watercourses and International Lakes*. Geneva: UNECE.

UNECE (2021). *Handbook on Water Allocation in a Transboundary Context*. Geneva: UNECE.

UNWCC (1997). *Convention on the Law of the Non-navigational Uses of International Watercourses*. New York, NY: United Nations General Assembly.

Verma, A., and Sharma, P. (2022). Aquifer storage and recovery feasibility study with flowing fluid electrical conductivity logging in shallow aquifers of South Bihar, India. *Front. Water* 3, 802095. doi: 10.3389/frwa.2021.802095

Vick, M. J. (2014). Steps towards an Afghanistan–Pakistan water-sharing agreement. *Int. J. Water Resour. Dev.* 30, 224–229. doi: 10.1080/07900627.2014.886471

Vu, M., Raghavan, S., and Liong, S.-Y. (2016). Use of regional climate models for proxy data over transboundary regions. *J. Hydrol. Eng.* 21, 1342. doi: 10.1061/(ASCE)HE.1943-5584.0001342

Ward, L., Anderson, M. B., Gilbertz, S. J., McEvoy, J., and Hall, D. M. (2017). Public stealth and boundary objects: coping with integrated water resource management and the post-political condition in Montana's portion of the Yellowstone River watershed. *Geoforum* 8, 1–13. doi: 10.1016/j.geoforum.2017.04.017

Wehling, P. (2021). *Nile Water Rights An International Law Perspective*. Berlin: Springer.

Xie, L., and Ibrahim, I. A. (2021). Is the ecosystem approach effective in transboundary water systems: central Asia as a case study? *Wiley Interdiscip. Rev. Water* 8, e1542. doi: 10.1002/wat2.1542