Title: The Devil's in the Details: Data Exchange in Transboundary Waters

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*Abstract***:** Data exchange in transboundary waters is widely viewed as fundamental to advancing cooperative water management and now features in the Sustainable Development Goal (SDG) 6. Nonetheless, the degree to which data are practically shared in transboundary waters is not well-understood. To gauge levels of data sharing practice in international watercourses, an assessment framework was developed and applied in 25 international river basins. The framework captures the degree to which a set of data parameters (e.g. river flow, groundwater level, surface water abstraction, and water quality) are exchanged among countries. Results reveal that the proportion of surveyed basins that exchange at least some water data is reasonable. Nonetheless, the breadth of such data exchange is often limited with less than half of surveyed basins confirming exchange on presumably key parameters such as water quality, water abstraction and groundwater levels. Further, frequency of data exchange is not always regular; with key parameters often exchanged in an *ad hoc* fashion. Ultimately, this paper points to areas where data exchange can be improved, and provides guidance on how indicators utilized in global assessment frameworks such at the SDGs can enhance granularity in order to motivate this improvement.

Keywords: data exchange, transboundary basins, water data, SDG indicator 6.5.2

INTRODUCTION

Data exchange is central to equitable and sustainable management of transboundary watercourses. Article 9 of the 1997 UN *Convention on the Law of Non-Navigational Uses of International Watercourses* calls upon watercourse states to exchange data and information on a regular basis (UN, 1997), for example, and Article 6 and 9 of the 1992 UNECE *Convention on the Protection and Use of Transboundary Watercourses and International Lakes* obligates riparian parties to exchange data through joint bodies and establish joint monitoring and assessment programmes (UNECE, 1992)[1]. Similarly, the International Law Commission (ILC) stipulates 'the need for regular collection and exchange of a broad range of data and information relating to international watercourses' (ILC, 1994). Regional frameworks such as the 2000 Southern African Development

[1] Further, as part the UNECE Water Convention, considerable efforts are currently (2020-2022) being undertaken to encourage and capacitate basins to improve monitoring programmes and exchange water related data.

Community (SADC) *Revised Protocol on Shared Watercourses* and the 2000 European Union *Water Framework Directive*, equally embrace principles of data and information exchange in shared watercourses. More recently, data exchange in transboundary waters features in Sustainable Development Goal (SDG) indicator 6.5.2, which measures regular (at least yearly) exchange of data as one of the four determinants for 'operational' transboundary water cooperation (UN Water, 2018).

While skeptics may argue that data exchange in transboundary waters is a principle of international water law that may not always resonate in local contexts, integrating data from different countries in a shared watercourse can have real implications for disaster mitigation, water resources allocation and trust-building among countries (Timmerman & Langaas, 2005; Gerlak *et al*., 2011; Kibler *et al*., 2014; McCaffrey, 2019). Exchange of data undertaken regularly can indeed enable optimal decision-making based on the current state of a shared water system, maximizing benefits derived from water resources and ensuring their fair usage (WMO, 1999; Kibler *et al*., 2014; McCaffrey, 2019). The chronology of the River Rhine before vs. after data exchange (Bernauer & Moser, 1996), for example, highlights how water quality progressively improved, through a shared understanding and coordinated action facilitated by data exchange. Not surprisingly, data exchange typically features prominently in large development projects – supported by financiers and donors such as the World Bank, World Meteorological Organisation, United States Agency for International Development – focused on cooperation and water-sharing in transboundary basins (World Bank, 2014; USAID, 2015; World Bank, 2018).

Despite principled focus in international water law and practical relevance to shared watercourses, the abundance and frequency of data actually exchanged in transboundary waters has not been the subject of extensive investigation. Gerlak *et al*. (2011) investigated the degree to which the global corpus of transboundary water law contains reference to data exchange, but they did not examine whether data were actually exchanged. Chenoweth and Feitelson (2001) and Plengsaeng *et al*. (2014) highlighted the weaknesses of practical data exchange in the Mekong and speculated on the reasons behind it. Nishat and Shams (2013) reviewed how extensive networks of monitoring and data collection may exist in individual countries in the Ganges, but bottlenecks occur when it comes to data exchange across borders. Saruchera and Lautze (2015) applied data exchange and other indicators in three southern African basins, in order to assess their suitability for inclusion in the SDG process. Results of SDG indicator 6.5.2. application suggest data exchange in 70% of transboundary basins, though this figure should be considered in the context of relatively low thresholds applied on quantity and frequency of exchange (UN Water, 2018). A systematic examination of the breadth of, and variation in, data exchange in a set of transboundary watercourses has not been undertaken.

In this paper, we develop and apply a framework that captures the volume and frequency of data exchange in 25 shared watercourses. Through this effort, we seek to establish and understand practical heterogeneity in parameters that are exchanged, generate clues on meaningful benchmarks or data exchange performance, and begin to identify factors that promote exchange. The paper first reviews relevant literature as a means of identifying key parameters of data exchange, as a basis for formulation of a framework that measures the extent of data exchange in transboundary watercourses. This framework is then applied to the set of transboundary watercourses across Africa, the Americas, Asia and Europe.

METHODS

Background

To identify key aspects of data exchange in shared waters, literature on data requirements for effective basin management (Burton & Molden, 2005; Hooper, 2008; Hooper & Kranz, 2009; Bureau of Meteorology, 2017; Cantor *et al*., 2018), contents of transboundary data exchange protocols (e.g., MRC, 2001; ISRBC 2014; ZAMCOM, 2016) and literature related to SDG 6 (UN Water, 2018; UNECE, 2019) were reviewed. This led to identification of a range of parameters which can be broadly grouped into three areas:

- Types of water-related data that should be exchanged
- Frequency of exchange
- Modalities of exchange

Types of data identified for exchange were broadly consistent across international conventions, the SDGs, and basin protocols. The UNECE Water Convention (1992) and the UN Watercourses Convention (1997) require the sharing of available data on environmental conditions, hydrological, meteorological, ecological and water quality data and information. The SDG indicator

6.5.2 focuses on environmental conditions, research activities and application of best available techniques, emission monitoring data, planned measures taken to prevent, control or reduce transboundary impacts, point source pollution sources, diffuse pollution sources, existing hydro morphological alterations, flows or water levels (including groundwater), water abstractions, climatological information and future planned measures with transboundary impacts, such as infrastructure development (UNECE, 2019). The Mekong River Commission (MRC, 2001) lists a range of data exchange requirements for topography, natural resources including water, agriculture, navigation and transport, flood management and mitigation to infrastructure, urbanisation and industrialisation, administrative boundaries and socio-economic data.[2] Similarly, the Zambezi Watercourse Commission (ZAMCOM, 2016) requires the sharing of data on hydrology, meteorology, water quality, socio-economy, environment, policies; and more specifically exchange of data on water levels, discharge, rainfall, evaporation, temperature, sediment concentration and water quality. A synthesis of both the broad categories of data that can be exchanged, as well as the specific parameters within these categories, is shown below (Table 1).

Table 1: Data suggested for exchange in transboundary waters (Adapted from MRC, 2001; Burton & Molden, 2005; Bureau of Meteorology, 2017; ISRBC, 2014; UN Water, 2018)

Data category	**Parameters**
Hydrological (hydrometric)	River discharges, river water levels, river flood peak discharges, river base flows, river sediment load, river water quality, lake/reservoir water levels, lake/reservoir volumes, lake/reservoir water temperature, lake/reservoir surface evaporation, volume of water imported/exported to/from basin
Hydro morphological alterations	Dams, weirs
Future planned measures with transboundary impacts	Infrastructure development
Groundwater	Groundwater levels and pressure, quality, aquifer yields and quality, estimate annual groundwater recharge, aquifer thickness, permeability and storage capacity
Meteorological (and climatic)	Sunshine/radiation hours, wind speed, air temperature, humidity, evaporation, precipitation, precipitation intensity
Ecological (environmental)	Minimum flow requirements, critical flow periods and demands, protected areas and water demands, protected areas and water demands, required water quality standards

[2] The data here illustrate the range found in data exchange protocols. This article nonetheless limits its focus to water data – data relating to the quality and quantity of water

Data category	Parameters
Water Quality	Electrical conductivity, suspended sediment, nutrients, temperature, pH, oxygen
Water Pollutants	Concentrations of arsenic, bacteria, nitrogen, phosphorus, viruses, fertilizers, pesticides, algae, industrial waste, heavy metals
Water abstraction	Abstraction quantity (surface/groundwater), abstraction quality, return flow quality and quantity

A key point when considering types of data to exchange is the motivation or demand for particular data, which is often context-specific. Diverse priority issues may indeed drive different data that are collected in different watercourses (Cantor *et al*., 2018). In areas prone to flooding, for example, a dense network of rainfall monitoring networks might be expected (Bureau of Meteorology, 2017). In the case of the River Rhine, for example, one of the key drivers for cooperation was pollution, which resulted in the development of an extensive water quality monitoring network in the basin (Bernauer & Moser, 1996). The varied terrain in transboundary water cooperation can also impact on data exchange dynamics in specific watercourses (van der Zaag & Savenije, 2000).

Guidance on regularity of exchange is more discernable in basin-level protocols than international law. Article 9 of the UN Watercourse Convention (1997) calls for “regular” exchange of data, for example, but stops short of quantifying “regular”. The International Law Commission, in its commentary to Article 9 goes slightly further by suggesting that “regular” exchange requires an “ongoing and systematic process” rather than *ad hoc* exchange (ILC, 1994). Precise details on the frequency of data exchange will depend on the type of data being exchanged, and is more evident at the operational level in specific protocols (MRC, 2001; ISRBC, 2014; ZAMCOM, 2016). ZAMCOM (2016), for example, calls for exchange of flow data on a weekly basis and other data monthly. In the Sava Basin, water level, water temperature and river discharge are to be shared both annually and in real time (ISRBC, 2014). The SDG indicator 6.5.2 stipulates that data should be exchanged at least once per year for an arrangement to be considered operational (UN Water, 2018).

An issue linked to frequency is latency of data exchange, defined as the time between measurement and use or sharing of data (EPA, 2015). The *Zambezi Basin Rules and Procedures for the Sharing of Data and Information* call for water level, discharge and rainfall for particular stations in the basin - to be shared at near real time frequency while other parameters like temperature, sediment concentration, evaporation and water quality are only to be shared quarterly (ZAMCOM, 2016). *The Mekong Procedures for Data and Information Exchange and Sharing* (PDIES) (MRC, 2001) fall short of giving practical detail and refer the intricacies of data exchange modalities to National Mekong Committees (NMCs). The Mekong PDIES nonetheless contain a clause calling for "timely" data exchange.

Finally, practical modalities of data exchange should not be overlooked. In the context of outlining attributes of successful river basin management, Hooper (2008) highlighted 'the use of a flexible and adaptive information exchange process' for which Hooper and Kranz (2009) developed a performance framework for data and information exchange with three main components: affordability of information exchange system, how integrated the information was into a single system, protocols for information management. Affordability – though not widely cited as key to effective data sharing – may in fact be a critical indicator to fostering sustainable data exchange particularly in resource-constrained contexts. Indeed, data collection can require costly instrumentation, maintenance and calibration and laboratory testing; thus exchange of data in a way that most effectively manages these costs may have the best chance for sustainability. Similarly, harmonized approaches are needed to ensure alignment in what is measured and how it is measured. Alternate formats of data can also constrain practical integration for effective use, so it is equally important to consider the degree to which disparately collected data can be harmonized.

Framework Development

Synthesizing pre-existing literature into a manageable framework for assessing the strength of data exchange in transboundary waters resulted in three categories for assessment. These categories are as follows: i) scope or extent of data exchange, ii) frequency of data exchange, and iii) modalities of data exchange (Table 2). In each category, a set of specific parameters was identified that gauge the strength of data exchange.

Table 2: Data Exchange Assessment Framework

Category	**Parameters**
Scope of exchange	*Class I* • Surface water parameters - River flow, dam storage • Groundwater parameters - Groundwater levels *Class II* • Water quality data - Electrical conductivity, suspended sediment, nitrates, pH, microbiological quality *Class III* • Water use – Surface water abstraction data
Frequency of exchange	• Real time • Daily • Monthly • Quarterly • Annually • Ad hoc
Modalities	• Existence of data exchange protocol • Means of transmitting exchanged data

The framework's first category is focused on the breadth in scope of data exchange. In the first class of parameters, which contains basics like water levels and river flow, a high exchange frequency may be expected to depict specific variation in cross border flows. In the second class of parameters, focused mainly on water quality, a somewhat lower frequency of exchange may be expected as the complexity of measurement increases and need to act on findings may be less urgent except in emergency situations. The scope of water quality parameters chosen covers conventional water quality indicators which are straightforward to measure, and which provide a snapshot of physico-chemical quality (UN Water, 2017). A third and final class of parameters, which include water abstraction, may be even less frequent as they are often used primarily in long term basin planning. The framework thus focuses on the exchange of water data rather than the exchange of information (i.e. processed data); the framework also excludes data related to planned measures, which may be subject to future investigation.

Frequency of data exchange is key to enable effective decision making, and as such is also considered. Importantly, exchanging data annually on some topics may hold value, whereas for other data parameters, hourly data may be important. Circumstances (such as risk of flooding, and pollution events) may also drive need for exchange, albeit at irregular frequencies.

Last, modalities of data exchange evidenced in a shared watercourse were considered. As such, focus was placed on two parameters to provide a foundation for the assessment conducted. First, the existence of a data exchange protocol was evaluated against levels of data exchange**.** Second, the influence of data exchange channels on data exchange abundance was assessed.

Data Collection

To enable measurement of data exchange in specific shared waters, it was necessary to select certain basins for assessment. On the assumption that transboundary data exchange is unlikely to occur without provision for data exchange in a transboundary water treaty, the world's 286 shared river basins (UN Water, 2018) were first filtered to those with reference to data and information exchange in an applicable transboundary water agreement (Gerlak et al., 2011).[3] To facilitate a manageable basin engagement process, focus was then placed on those basins with international River Basin Organizations (RBOs), estimated at 68 (Lautze et al., 2012) to 81 (Schmeier et al., 2015), and in particular those RBOs i) supported by a secretariat empowered to speak on basin's behalf, and ii) possessing a basin-wide mandate. Lautze et al (2012) determined the number of RBOs that met these criteria at 25, though this figure is believed to have now grown to approximately 37.[4]

These 37 basins were distributed as follows - Africa (18), Americas (4), Asia (5) and Europe (10). Ultimately, a set of 32 basins that met the criteria and with reliable email and phone contacts were selected for this analysis, though substantive replies were received from only 25.[5] RBO contact points for each basin were drawn from institutional networks of the author team. Each contact point was sent a questionnaire, the completion of which enabled population of the framework elaborated above. Questionnaires were sent, and responses received, between July and October 2019.

RESULTS

[3] The list of treaties referencing data and information exchange in Gerlak et al (2011) was updated given the time gap between publication of that paper, and writing of the present one.
[4] A key issue when determining current number of RBOs is confirming their continued functionality or, conversely, establishing their dissolution. Such an exercise is not always straightforward.
[5] Responses were not received in a timely manner from the following seven basins: Congo, Drin, Gambia, Golok, Meuse, La Plata, Sixaola.

Responses were obtained from 25 basins, spanning five continents (Figure 1). This set of basins is believed to contain the vast majority of those with basin-wide secretariat-based RBOs. In Africa, 12 basins were assessed including the Nile, Volta and the Zambezi. The Danube, Rhine and Elbe basins were among the 7 basins assessed in Europe. Three basins were assessed in the Americas, namely Colorado, Tijuana and Lake Titicaca. In Asia, the Amu Darya, Mekong and Syr Darya were the three basins assessed.

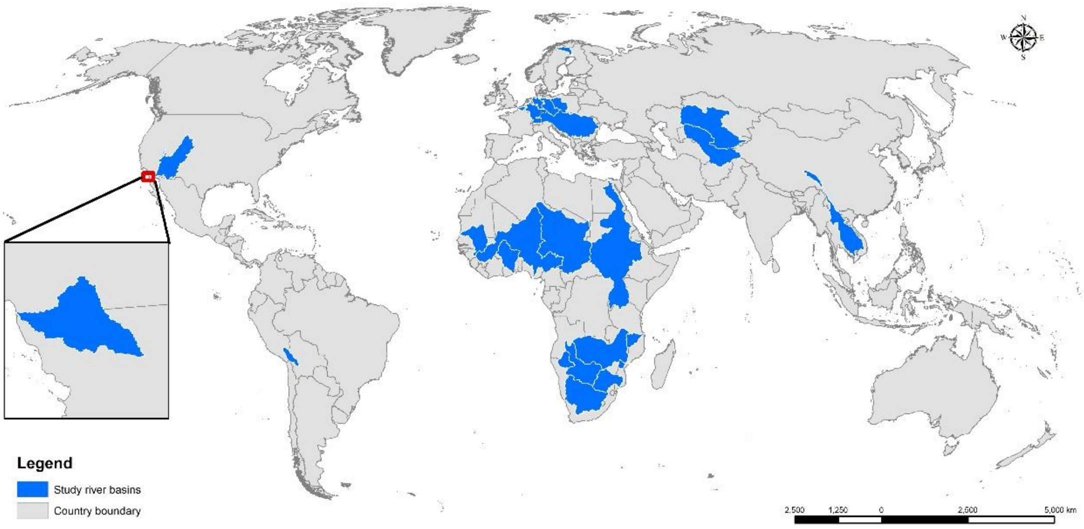

Figure 1: Basins of Focus

Over three-quarters of surveyed basins exchange river flow data. In total, 76% of basins share data on river flow (Figure 2). 40% of basins exchange river flow data at a daily frequency or higher (including real time and hourly). 24% of basins exchange river flow data at frequencies between monthly and annually[6]. 12% reported *ad hoc* exchanges. There was no reported exchange on river flow data in 24% of basins.

[6] There were no reported frequencies between daily and monthly (e.g. weekly)

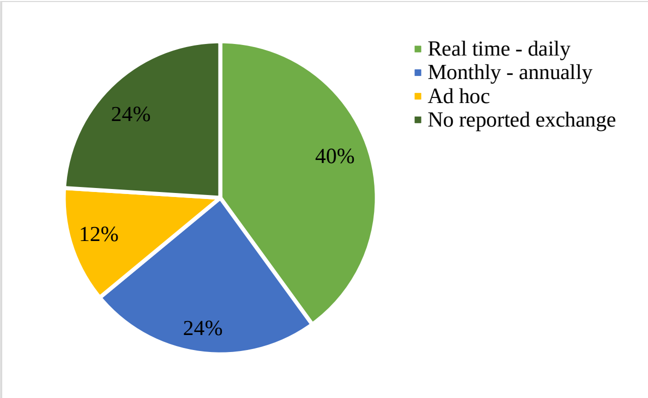

Figure 2: Frequency of exchange for river flow data[7]

Exchange of groundwater data is not high. Only 32% of basins exchange groundwater level data (Figure 3). Regular exchange on groundwater level data was reported in just 16% of basins, where data are exchanged between quarterly and annual frequencies. *Ad hoc* exchange[8] occurs in 16% of basins.

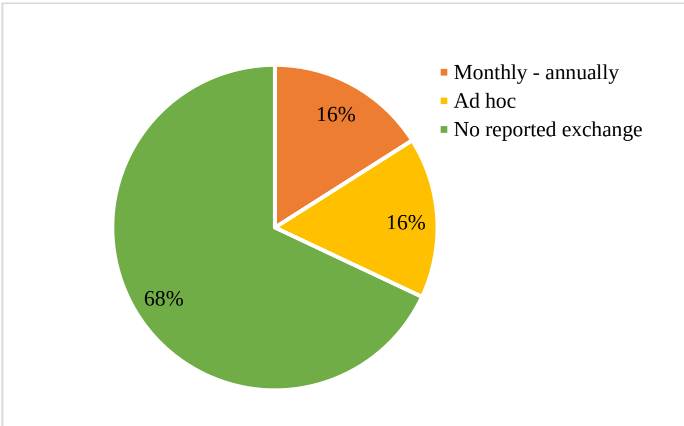

Figure 3: Frequency of data exchange, groundwater levels

Data on surface water abstraction are seldom exchanged. Only 28% of the basins exchange surface water abstraction data (Figure 4). Frequency of exchange is daily (12%) or between monthly and annually (16%). A large proportion of basins (72%) do not exchange surface water abstraction data.

[7] No data were exchanged between daily and monthly.
[8] This category includes an outlier basin that shares groundwater data every 6 years.

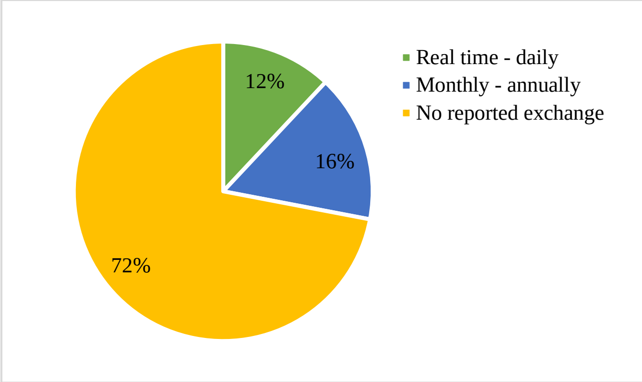

Figure 4: Frequency of data exchange, surface water abstraction data[9]

Less than half of basins share data on reservoir storage. 36% of basins share data on reservoir storage (Figure 5). 28% of basins share these data between real time and daily frequencies. In 8% of basins, dam storage data are shared at frequencies between monthly and annually. 64% of basins did not report on regular exchange of reservoirs' storage data.[10]

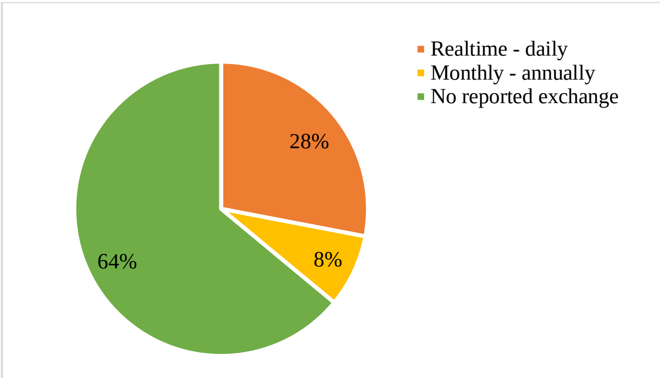

Figure 5: Frequency of data exchange, dam storage data[11]

Less than half of basins exchange data on water quality on a regular basis. pH and conductivity are the most exchanged water quality parameters; exchange of these parameters occurs in 44% of basins. Microbiological data is least shared; only 24% of basins share data on these parameters. Data on suspended solids, and nitrates are exchanged by just over one-third of basins (36%) (Figure 6).

[9] No surface water abstraction data is shared at frequencies between daily and monthly
[10] In one basin, absence of dam storage was explicitly reported and hence removed from this particular analysis.
[11] No reservoir storage data was reported between daily and monthly frequencies (e.g. weekly)

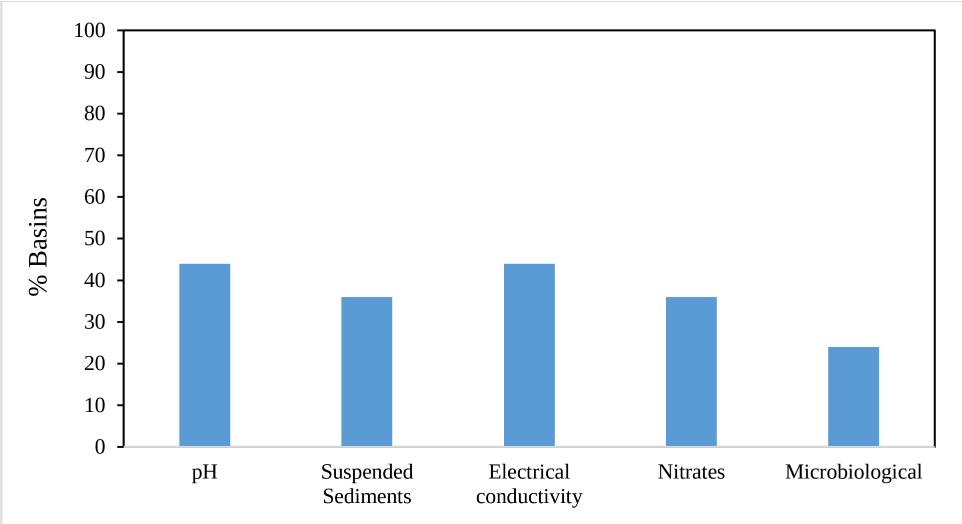

Figure 6: Proportion of basins exchanging water quality data

There is a mix of means used for river flow data exchange. Exchange via email is the most common channel of exchange and is utilised in 36% of basins. Online platforms only, were used in 16% of the exchanges. Telephone only was used in 8% of basins. 16% of basins use multiple channels of exchange. No exchange was reported in 24% of basins (Figure 7).

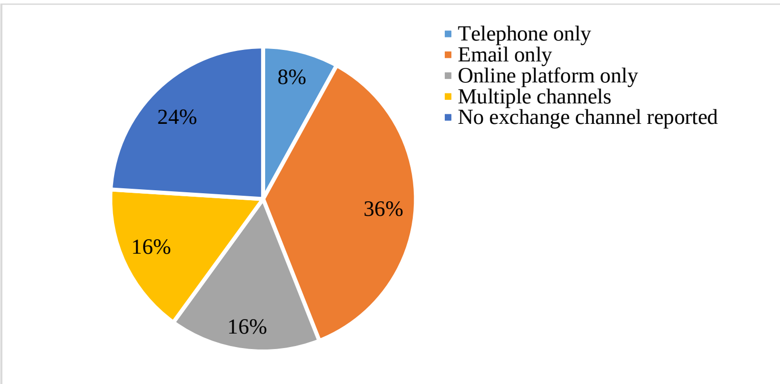

Figure 7: Channels used for data exchange

Basins with data exchange protocols do not exchange river flow data more frequently. More basins without a data exchange protocol (32%) share river flow data at a frequency of daily or higher than those which have a protocol (8%) (Figure 8a). More basins with a data exchange protocol (24%) share data at a frequency of monthly or less, as there is no reported exchange in basins without a data exchange protocol at this frequency. 12% of basins without a protocol reported no exchange, compared to 8% of basins which have a protocol.

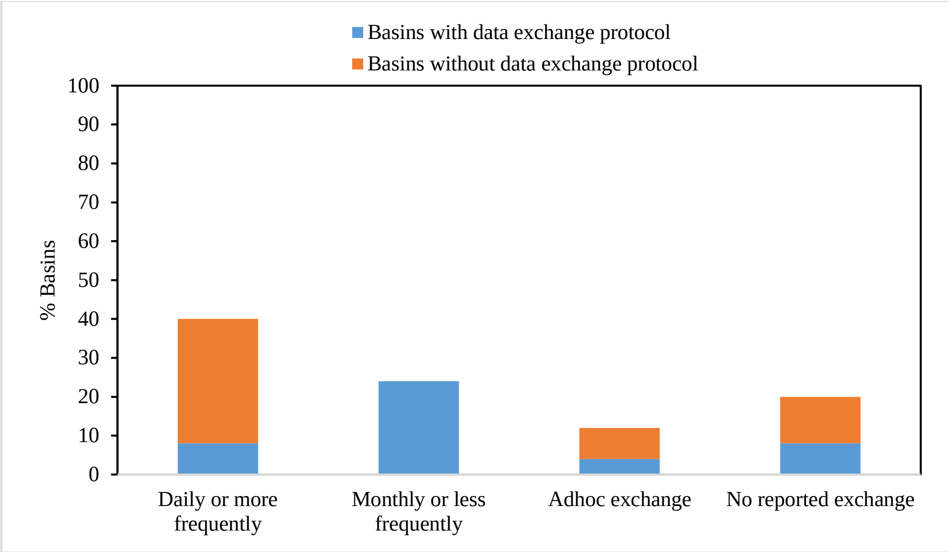

Figure 8a: Data exchange protocol and frequency of river flow data exchange.

There is greater exchange of water quality data among basins with a data exchange protocol (Figure 8b). 32% of basins with a data exchange protocol share water quality data compared with basins only 20% of those without a protocol. Reported exchange of water quality data was nonetheless generally low in both cases.

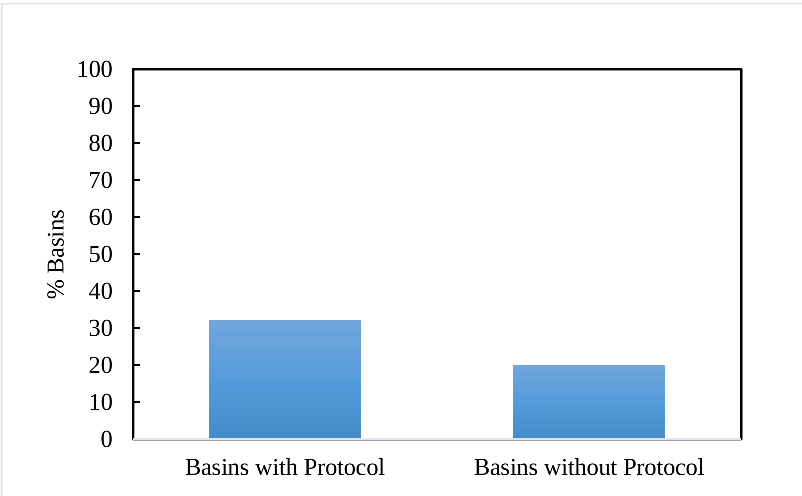

Figure 8b: Data exchange protocol and data exchange for water quality

Use of multiple exchange channels, as well as online platforms, promote more frequent exchange of river flow data. All basins which use telephone only as a channel of exchange, exchange river flow data at a daily or more frequency (Table 3a). Nearly half (45%) of basins using email only as a data transmission channel, exchange data at a monthly or more frequency. Of basins using multiple channels, 75% exchange data at a daily or higher frequency similar to basins which use online platforms only.

Table 3a: Data exchange channels, river flow data

Channel for exchanging data	Daily or more frequent (%)	Monthly or less frequent (%)	*Ad hoc* (%)	Total (%)
Telephone exchange (only)	100	0	0	100
Email exchange (only)	22	45	33	100
Online Platform exchange (only)	75	25	0	100
Multiple channels of exchange (Telephone+ Email + Online Platform)	75	25	0	100

Email is the most common means of transmitting water quality data. Of basins exchanging water quality data, 54% used email as a channel of exchange. Only 8% of basins exchanging water quality data used the telephone. 23% of basins used other channels of exchange such as reports and presentations at meetings, as well as publications (Table 3b).

Table 3b: Data exchange channels, water quality data

Channel for exchanging data	% Basins sharing water quality data (%)
Telephone exchange (only)	8
Email exchange (only)	54
Online platform exchange (only)	15
Other: Publications, meeting reports and presentations	23
Total	100

DISCUSSION

This paper designed and applied a data exchange assessment framework to 25 international watercourses. Widely regarded as a central foundation for effective management of shared waters, data and information exchange had not been thoroughly assessed across a set of transboundary basins. This paper is thus believed to be the first to measure breadth and depth of data exchange – as judged by RBO representatives – across a diverse set of transboundary watercourses. It is hoped that this work clarifies important gaps between aspirational principles of data exchange contained in international conventions on the one hand, and mixed practice of basin-level realities on the other. Perhaps more importantly, it is hoped that this paper will support a constructive conversation on how to move practice toward principles of data exchange.

The paper generated five key findings. First, there are encouraging levels of data exchange on one core parameter: river flow. Second, the scope of data exchanged is limited; groundwater levels and abstraction data, for example, are seldom exchanged. Third, the importance of formalized data exchange protocols – hypothesized as being important to structure data exchange – was not apparent. Fourth, related, there is evidence that adoption of online platforms promotes data exchange. Finally, lack of benchmarks on *breadth* of data exchange in the current SDG indicator framework may result in a low, easily-met threshold; this may in turn contribute to the checkered realities evidenced.

The paper's first finding – reasonable exchange of river flow data – is broadly consistent with other evidence. The SDG reporting process found more than 70% of basins share data on environmental conditions, which one may assume to include river flow data (UN Water, 2018). Similarly, evidence from the Mekong indicated that data were exchanged mostly on 'water resource related data' (Thu & Wehn, 2016). Nonetheless, the reality that river flow data are not exchanged in about one-quarter of surveyed basins, which have their cooperation institutionalized in an RBO, also raises questions. While an exhaustive set of factors deterring exchange remain to be established, varying incentives, risk perceptions, and simply inertia may undoubtedly constrain actual data exchange to varying degrees (van der Zaag & Savenije, 2000; Nishat & Shams, 2013; Thu & Wehn, 2016).

The paper's second finding – limited breadth and depth of data exchange – highlights that the devil is in the details. In other words, more robust assessment of data exchange begins to unearth the challenges characterized in case study analyses (e.g., Nishat & Shams, 2013; Plengsaeng *et al*., 2014; Thu & Wehn, 2016). At least four key data parameters – namely, water quality data (pH, electrical conductivity, suspended sediments, nitrates, microbiological data), groundwater levels, surface water abstraction and dam storage – are exchanged in less than half the basins. These findings drive home realities in which some level of data exchange occurs, yet challenges or bottlenecks simultaneously persist.

Review of challenges, barriers and incentive-vacuums provide clues that may explain the data exchange realities observed. In the Mekong, barriers of a perceived loss of control over shared data, uncertainty of associated benefits, political interference and technical capacity are said to constrain data exchange (Plengsaeng *et al*., 2014). In the Ganges, disjointed bilateral exchanges detract from basin wide data exchange (Nishat & Shams, 2013). Another, broader issue is that upstream countries may not always have incentive to generate and share water quality and quantity data, when downstream countries may have more to benefit. In the case of early warning data in the Ganges, for example, considerable gaps and inefficiencies exist in data being made available to downstream Bangladesh which constrain timely implementation of necessary interventions (Kibler *et al*., 2014).

The paper's third finding – questionable value-addition of data exchange protocols – was at odds with existing knowledge. Substantial investment has been placed in protocol development in major basins such as the Mekong, Sava and Zambezi (MRC, 2001; ISRBC 2014; ZAMCOM, 2016)), for example, on the assumption that protocols enhance data exchange across borders. One possible explanation for this confounding finding is that protocols may be developed where pre-existing data exchange challenges exist, which a protocol may not necessarily address, as suggested by Plengsaeng *et al*. (2014). Protocol formulation may also explain these findings. The Nile Basin *Data and Information Sharing and Exchange Interim Procedures*, for example, may not necessarily promote regular data exchange since it prescribes data to be shared only on a project need basis and not regularly (NBI, 2009).

A fourth finding may support a proliferation in the use of online data platforms in transboundary waters. While skeptics may point to reservations in the provision of high-tech instruments in low-tech contexts, evidence emerging from this paper underlines the utility of such tools. Coupled with the preceding finding on limitations on protocols, the positive association between online platforms and data exchange may call for prioritization on investment in levers that directly enable exchange, such as platforms that transmit data, potentially at the expense of investment to establish processes for exchange.

A final finding calls for more nuance in the formulation and application on the indicator applied in the SDG 6.5.2 reporting process. Indeed, it may be time to partially close a seemingly anomalous reality gap whereby more than 70% of countries report exchanging data on environmental conditions (UN Water, 2018), yet broader investigation reveals substantial limitation on the range of data exchanged. Notwithstanding the additional legwork required to populate a more data-intensive indicator, it may be prudent to elevate the threshold in the SDG reporting process from its current standard in which exchange of any water data suffices. It may be advisable, for example, to compel data exchange in *at least* three key categories in order to achieve an optimal data exchange threshold. Such categories could be: (i) water quantity data, e.g., flow (ii) water quality according to locally relevant quality parameters and (iii) water use data. While data needs undoubtedly vary across basins, exchange of data in these three categories of data, inform decision-making related to fairly common aims of water allocation, flood management and satisfaction of ecosystem services.

CONCLUSION

To achieve effective basin management and efficient progress toward global development targets, a substantial augmentation in the volume and frequency of data exchange is needed. This paper assessed 25 basins – among those with more advanced levels of cooperation and data exchange – and found that outside of one core parameter (river flow), their current levels of data exchange are often insufficient to enable for effective water allocation, flood management and ecosystem services satisfaction. Should the assessment be extended to include basins without RBOs or without codified cooperation entirely, these results would assuredly appear even more concerning. Ultimately, this paper's findings confirm that challenges described in case studies are not isolated, and indeed suggest context-specific assertions about barriers to data exchange in shared waters may be pervasive.

While one may advocate for improving data exchange by promoting adherence to international conventions and declarations such as those stipulated at the outset of the paper (e.g., 1997 UN Watercourse Convention), the aims of basin-specific cooperation may be equally if not more relevant. Nonetheless, transboundary basin-specific cooperation is undertaken with an increasingly common set of goals including equitable and sustainable use, sustainable development, environmental conservation and disaster risk reduction. While the precise importance associated with each goal undoubtedly varies by basin, the fact remains that progress toward realization of these goals typically benefits from exchange of data.

A limitation of this paper is that it focused mainly on measuring the current state of data exchange in shared waters, and not extensively on factors driving and constraining exchange. We view this effort as a valuable first step to establish current conditions, on which investigation into actual catalysts and deterrents for exchange can build. In this context, at least two areas may merit specific focus. First, it may be worthwhile to conduct a demand assessment that identifies data exchange needs of riparian countries; it may very well be that if countries in a basin want to share data, they will – regardless of formal provisions or channels of exchange. Second, the role of joint monitoring systems and associated online platforms as catalysts for exchange, merits deeper investigation.

Related in some ways to platforms of exchange are methods of data collection. The potential for enhanced earth observation data to satisfy riparian data exchange obligations has indeed begun to receive focus (Leb, 2020). At present, data in shared waters is generally collected directly via, for example, flow gauging stations. Approaches based on monitoring networks no doubt currently face practical limitations, such as insufficient maintenance leading to high proportions of non-functional stations (Houghton-Carr *et al*., 2006). Nonetheless direct measurement – particularly if undertaken as part of a joint program – may provide soft benefits through trust and relationship-building. Further, direct measurement may be needed to calibrate and validate data derived from remote sensing. In either case, an issue that may merit greater focus is the role of affordability and ensuring sustainable financing.

Ultimately, this paper set out to capture practical heterogeneity in the breadth of data exchange in shared waters, generate clues on meaningful data exchange benchmarks, and identify factors that promote exchange. On the first point, we found relatively high exchange of river flow data but far less exchange on a suite of other key parameters. On the second aim, findings point to value in a broader-based and gradational set of thresholds to measure diversity and frequency of data exchanged in shared waters *vis-a-vis* those currently used in the SDGs. Nonetheless, there is a need to balance the strength of an updated indicator framework with its ease-of-application. On the third aim, there is evidence that online platforms promote data exchange whereas data protocols do not. While deeper investigation can certainly be directed toward both findings, this evidence supports calls for greater use of online platforms in shared waters.

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