Official Journal of the World Water Council
Water Policy

Water Policy Vol 25 No 11, 1015 doi: 10.2166/wp.2023.026

Transboundary water cooperation under SDG indicator 6.5.2: disaggregating data to provide additional insights at the aquifer level

Christina May Fraser [a,*], Neno Kukurić[a], Tatiana Dmitrieva[b] and Aurélien Dumont[b]

[a] International Groundwater Resources Assessment Centre, Delft, The Netherlands
[b] United Nations Educational, Scientific and Cultural Organization-Intergovernmental Hydrological Programme, Paris, France
*Corresponding author. E-mail: cm-fraser@outlook.com

CMF, 0000-0003-0282-5770

ABSTRACT

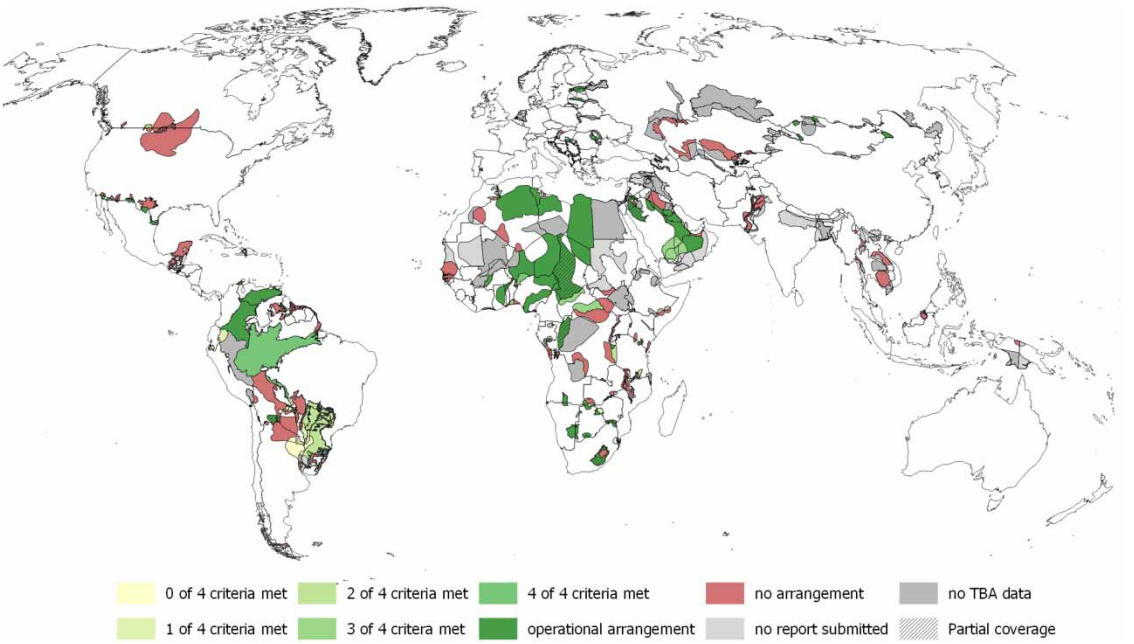
The acceleration of transboundary water cooperation is essential to support water security and ensure mutual benefits of sustainable development. The way existing Sustainable Development Goal (SDG) monitoring data is used to raise its importance further up political agendas and inform future reporting rounds is therefore crucial to acceleration. Using data extracted from national country reports of SDG indicator 6.5.2 on transboundary water cooperation, we showcase the level of cooperation, as reported, per aquifer to compliment the national approach currently followed by the official SDG framework. Our analysis uncovers a variety of insights and challenges to transboundary aquifer (TBA) cooperation that otherwise might be difficult to visualize through official national reports. Reported aquifer cooperation is often not harmonized across international borders. A lack of groundwater data and information is a major contributing factor to uncoordinated reporting, highlighting the importance of a sound scientific baseline. However, harmonization issues are also interlinked to a national-focused reporting process where Member States have the right to disagree over the status of their joint cooperation. These results can assist in improving future indicator coverage, both as an awareness raising tool for co-custodian agencies and by countries through direct interventions and coordination with neighbours.

Key words: aquifer, cooperation, groundwater, Integrated Water Resource Management (IWRM), Sustainable Development Goals (SDGs), transboundary

HIGHLIGHTS

- Disaggregating SDG data can provide additional insights into the status of water cooperation.
- Reported TBA cooperation is often not harmonized across international borders.
- Only 10 operational arrangements covering TBAs are reported consistently by all countries.
- A scientific baseline to support TBA cooperation is essential.
- Analysis can act as an awareness-raising tool to improve report coordination.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Around 60% of accessible water globally is transboundary and the majority of large aquifers that store groundwater are transboundary. Almost every nation-state shares a transboundary aquifer (TBA) and there are currently 468 known to exist (IGRAC, 2021a). Cooperation over these vital resources is therefore essential to ensure mutual benefits from sustainable development including poverty alleviation, food security, ecosystem protection and addressing the impacts of climate change alongside being a driver of peace and security in unstable regions (Ladel *et al.*, 2020; UNECE & UNESCO, 2021; World Economic Forum, 2023).

Under the United Nations 2030 Agenda for Sustainable Development, transboundary cooperation has been included as a contributor to the overall goal of 'Clean Water and Sanitation for All' (Goal 6). Target 6.5 specifically refers to transboundary water cooperation; 'by 2030, implement Integrated Water Resources Management (IWRM) at all levels, including through transboundary cooperation as appropriate' (UN Water, 2015). The target indicator dedicated to measuring transboundary cooperation over water resources (indicator 6.5.2) calls for the percentage of a basin or aquifer under an operational arrangement to be calculated (UN Water, 2017; UN Stats, 2022). Countries are asked to report on the state of cooperation over their *transboundary river and lake basins* and *transboundary aquifers* to indicate if an operational arrangement is in force. The reporting under indicator 6.5.2 is an opportunity to get data directly from Member States at the global level. The United Nations Educational, Scientific and Cultural Organization (UNESCO) and the United Nations Economic Commission for Europe (UNECE), co-custodian agencies of the indicator, support countries during the reporting process. But, as the SDG process is a national endeavor, data submitted ultimately reflects the national view regarding transboundary water cooperation.

The second official SDG progress report on transboundary water cooperation published in 2021 revealed that only 24 countries have operational arrangements covering all their transboundary basins (rivers, lakes and

aquifers) and that an additional 28 countries have operational arrangements for 90% or more of their transboundary basins. Regarding the aquifer component specifically, the numbers are even lower: 50 countries out of 145 that share groundwater resources reported that operational arrangements covered 30% or less of their aquifer areas (Figure S1, Supplementary Information) (UNESCO & UNECE, 2021).

The report ultimately showed that data on aquifers often remains a major obstacle for reporting countries and points to two key issues: one, the need to invest more in building capacity on groundwater resources and, two, the need to translate this knowledge by countries into concrete policy proposals and actions to improve their cooperation on TBAs (UNECE & UNESCO, 2018; Rieu-Clarke, 2020). However, these challenges are not only relevant to the target dedicated to water cooperation. Progress reports for almost all other water targets show that uptake is slow and the world is not on track to achieve SDG 6 (UN Water, 2021).

In response to this, in 2020, the SDG 6 Global Acceleration Framework was launched by the United National Secretary-General. The framework aims to deliver faster results at an increased rate for SDG 6 (UN Water, 2020b) and is driven through five accelerators: optimized financing, improved data and information, capacity development, innovation, and, governance (UN Water, 2020c). Within the context of TBA cooperation, this will need to include increased financing for TBA delineation and assessment, initiatives for cross-border data sharing and harmonization, and better monitoring practices (IGRAC, 2021b). However, it must also include increased capacity development and elevating TBA cooperation further up national political agendas. The way that SDG monitoring data is used to increase awareness and inform future monitoring rounds is, therefore, crucial to acceleration.

However, as the specific purpose of the SDG indicator 6.5.2 methodology is to gain a national overview of transboundary water cooperation, it is often difficult to know which TBAs have operational arrangements governing them, which partially meet the four required criteria to be considered operational or if countries are reporting consistently within the same aquifer, without examining multiple individual country reports. Similarly, official indicator values do not provide insight into whether reported operational arrangements are part of a surface water agreement or if they are aquifer specific, which is significant in order to understand the type of water cooperation taking place and at what scale. It is therefore proposed that disaggregating data with a focus at the aquifer level may therefore capture a more in-depth view of transboundary cooperation that may not be as easily visible when presented as national-level data. This may prove useful in both supporting stakeholders to identify areas for future intervention to improve indicator 6.5.2 coverage and as an awareness-raising tool to highlight the current data gaps, challenges and methodology limitations that can be addressed moving forward in future reporting rounds by co-custodian agencies. In this paper, we therefore:

- Present the results of a global analysis in which we illustrate the state of global TBA cooperation, as reported under SDG indicator 6.5.2, *per aquifer*, to complement official national country reporting.
- Discuss the challenges of reporting under SDG indicator 6.5.2 that contribute to data harmonization and validation issues which result in low country indicator values.
- Highlight the value of disaggregating SDG indicator 6.5.2 data to complement official national reporting, both for awareness raising and as a tool and to identify direct interventions for improved coverage.

2. METHODS

Monitoring SDG indicator 6.5.2 can provide valuable insights into the state of TBA cooperation globally, shedding light on the challenges and opportunities in this crucial area. In this context, this subsection first introduces the official reporting procedure for SDG indicator 6.5.2, highlighting its procedure and data sources. The section

then showcases the approach taken in this paper that disaggregates SDG indicator 6.5.2 data to provide additional insights at the aquifer level.

2.1. SDG indicator 6.5.2 official reporting procedure

UNESCO and UNECE led the development of a methodology to calculate indicator 6.5.2 within a working group including other UN agencies and stakeholders. The methodology calls for the proportion of a transboundary basin/aquifer area with an 'operational arrangement' for water cooperation within the border of a state to be calculated (UN Water, 2020a) and results are presented by country as a percentage. An 'arrangement' is considered to be a bilateral or multilateral treaty, convention, agreement or other formal arrangement among riparian states that provides a framework for cooperation on transboundary water management. An arrangement is only 'operational' if the following four criteria are met (UN Water, 2020a):

(1) There is a joint body, joint mechanism or commission (e.g., a river basin organization) for transboundary cooperation.
(2) There are regular (at least once per year) formal communications between riparian countries in the form of meetings (either at the political or technical level).
(3) Joint objectives, a common strategy, a joint or coordinated management plan, or an action plan have been agreed upon by the riparian countries.
(4) There is a regular (at least once per year) exchange of data and information.

The overall SDG indicator 6.5.2 value is calculated from the combination of two components. The first is dedicated to 'transboundary river and lake basins' and the other to 'transboundary aquifers'. In this paper, we focus on the latter component, i.e. the proportion of TBA area within a country covered by an operational arrangement. In this specific case, the arrangement can be devoted specifically to a TBA (i.e. aquifer-specific), or the aquifer can be covered through another type of arrangement (e.g. bilateral agreements, river basin-related agreements).

Since the launch of the SDG agenda, two reporting rounds for SDG indicator 6.5.2 have been conducted, during 2017/2018 and 2020/2021. UNESCO and UNECE defined the list of 153 countries that share transboundary waters (rivers and lakes and aquifers) and reached out to them with a reporting template. Among 153 countries, 145 were identified as sharing TBAs and groundwater. A total of 127 countries responded during the reporting periods by sending an official report or an explanation letter. By combining data from 2017/2018 and 2020/2021, 94 country indicators for the TBA component are officially available (UNECE & UNESCO, 2021).

2.2. Data selection

The dataset used for this paper's analysis was created from the submitted 2020/21 national country progress reports of SDG indicator 6.5.2 (UNECE, n.d.). In the situation where no report was submitted in 2020/21 but was in 2017/2018, the 2017/2018 report was used as a replacement. The reporting template on SDG indicator 6.5.2 is organized into four sections: Section I – Calculation of SDG indicator 6.5.2; Section II – Information on each transboundary basin or group of basins; Section III – General information on transboundary water management at the national level; Section IV – Final questions. Sections I and II were used to extract TBA-specific data which encompassed: aquifer name; riparian countries; the presence (or lack thereof) of an arrangement for international cooperation; which of the four criteria required to be operational the arrangement met; if the arrangement is operational; if the arrangement is specific to the aquifer or not; it the arrangement covers the entire aquifer or only part of it. This dataset was complemented with validation and aquifer code data from separate IGRAC, UNESCO and UNECE databases (summarized in Table S1, Supplementary Information).

Upon submission, the country reports undergo a validation process by UNESCO and UNECE. This process involves checking that what is reported in Section I of the reporting template is consistent with the more detailed explanations in Section II. In circumstances where the entries do not match, the report is considered unvalidated and the data submitted is not used in the official overall indicator calculation unless, upon liaison with country coordinators, it can be clarified which entry is the correct one. Efforts are also made by the co-custodian agencies to check the accuracy of submissions, comparing to international inventories (e.g. IGRAC's Global TBA inventory and the Oregon State University International Freshwater Treaties Database) and other sources such as data from in-country geological departments. However, it is important to note that the validation process comes with a degree of trust in what countries are reporting is accurate. The co-custodian agencies therefore do not check every entry and only run validation if harmonization within a single report does not exist or an obvious mistake is present. Similarly, evidence of meeting each of the four criteria for an arrangement to be operational is not required to be submitted alongside national reports, although it is encouraged.

For this study, it was decided to include unvalidated data in the analysis. Therefore, in circumstances where data entry from Section I of a country report did not match Section II, data from Section II was used. The reasoning for this was multi-layered. First, the data submitted in the non-validated reports, although not usable for official country indicator values, are valuable to examine because they are a direct reflection of a country's current understanding of their TBA cooperation circumstances. Second, it is considered that data entry in Section II is likely to be more accurate than in Section I. It is more detailed and explains the criteria required to meet an operational arrangement in a more comprehensive format. Countries are therefore more likely to report correctly in Section II than in Section I. Finally, a significant portion of the reports submitted by countries were invalidated, particularly for the aquifer component. To exclude these would mean excluding a large portion of the dataset. In cases where a country report was unvalidated in 2020/2021 but was validated in 2017/2018, the 2017/2018 report was used if the TBA component was reported on.

In total, 118 country reports were included in the analysis, among which 81 were validated and 37 unvalidated reports. Eight reports were excluded from the analysis because they reported only on groundwater bodies under the EU Water Framework (further justification available in Section 2.3) and five reports were excluded because there was no TBA in the IGRAC database to correspond with. A summary of which reports included in the analysis were unvalidated, which were excluded from the analysis and which were from the 2017/2018 reporting round is provided in Supplementary Information (Tables S2–S5).

2.3. Spatial representation and analysis

QGIS was used to split TBA features from the Global TBA inventory (IGRAC & UNESCO-IHP, 2015) into separate country segments. The 2015 inventory was selected for this purpose over the 2021 update (IGRAC, 2021a) to reflect the resource that was available to countries during the reporting rounds in 2017/2018 and 2020/2021. The majority of countries reported were in line with IGRACs inventory; however, on occasion some countries chose to report using national datasets. In such cases, shapefile data was not submitted alongside reports and therefore these aquifers were excluded from the analysis. Countries also often used the same aquifer naming or code conventions as in IGRACs inventory when reporting over their TBAs and therefore in most cases it was possible to correlate reported aquifers with IGRAC inventory. However, it should be noted that when reported aquifer names were not exactly the same, a degree of margin was allowed when correlating with the IGRAC inventory and therefore countries may have not in fact considered the exact same aquifer from the database when reporting as has been selected in the analysis. In total, 342 TBA features were split into 793 country segments and included in the dataset. Extracted data from the SDG 6.5.2 country reports were added as feature attributes to each transboundary segment. In the situation that a progress report was submitted but a specific TBA

was not reported on, this was recorded. Twenty-two countries listed in the IGRAC database did not submit an official progress report in either reporting round, or only submitted a letter and therefore data was not available for those aquifer segments. Occasionally, TBAs were reported to be covered by both an aquifer specific and a non-specific arrangement. In these situations, the aquifer-specific arrangement was included in the dataset.

Some countries in the EU chose to report on the status of their groundwater bodies, as defined under the EU Water Framework, instead of their TBAs. Groundwater bodies are not necessarily complete hydrologic units, but rather management units. In many cases, aquifers are subdivided into groundwater bodies while occasionally groundwater bodies may contain multiple aquifers (European Commission, 2004). Groundwater bodies are national units that meet at the border and are therefore not true transboundary entities. This means it is difficult to match them with corresponding neighboring units across international borders and thus to know which are covered by the same reported arrangements. For global consistency, it was decided to not include reported groundwater bodies in the analysis. In 2015, IGRAC included groundwater bodies in their inventory across Europe instead of TBAs. The number of aquifers available for Europe from the IGRAC 2015 dataset to cross reference with SDG reporting is therefore limited and spatial representation is difficult to characterize. This has repercussions for the amount of operational arrangements illustrated across Europe in our analysis. Future updates might want to consider expanding the dataset in this region.

Once the dataset was complete, it was spatially presented as a global map and also exported as a CSV file for additional analysis in Excel.

3. RESULTS AND DISCUSSION

3.1. Report coordination and data harmonization

Figure 1(a) illustrates the spatial representation of SDG indicator 6.5.2 reporting data disaggregated per aquifer. Theoretically, the reported status of cooperation over a single TBA should be matching for all riparian states. However, as is shown, this is often not the case. A lack of coordination between countries sharing aquifers is evident. In line with UNECE & UNESCO (2021), 12 countries reported having a total of eight aquifer-specific arrangements in place. Twenty countries share these aquifers, eight of which did not report on TBA arrangements mentioned by a neighboring country. However, aquifer-focused analysis reveals that only two of these eight aquifer-specific arrangements are reported by all riparian countries. Multiple TBAs that are known to have arrangements over them have not been reported by some riparian states (e.g. the Genevese Aquifer Agreement). Similarly, there are only eight additional TBAs that are reported by all countries to be covered by an arrangement not specific to the aquifer (e.g. bilateral agreement, river basin agreement). This accounts for only 10 operational arrangements globally that are reported consistently by all countries, a 3% coverage when compared to the number of TBAs available in the IGRAC inventory. These aquifers are presented in Table 1. One TBA is reported by all Member States to have a non-operational arrangement (Tulcán-Ipiales shared by Ecuador and Colombia). A further 38 TBAs are reported by all riparian countries to have no arrangement over them. In total, 49 TBAs are reported by all riparian countries consistently and 64 TBAs are not reported by any riparian country. This leaves 229 aquifers that have data harmonization issues, with at least one country disagreeing with neighbors over the cooperation status of an aquifer, meaning that 67% of the SDG 6.5.2 indicator data on aquifers is inconsistent.

The harmonization issues are linked to a lack of coordination between Member States when reporting over a single TBA and can be categorized into three groupings: (1) When an arrangement exists but countries report different levels of operationality; (2) When one or more country does not report on the TBA; and (3) When countries disagree over whether an arrangement exists. A short case study for each scenario has been selected

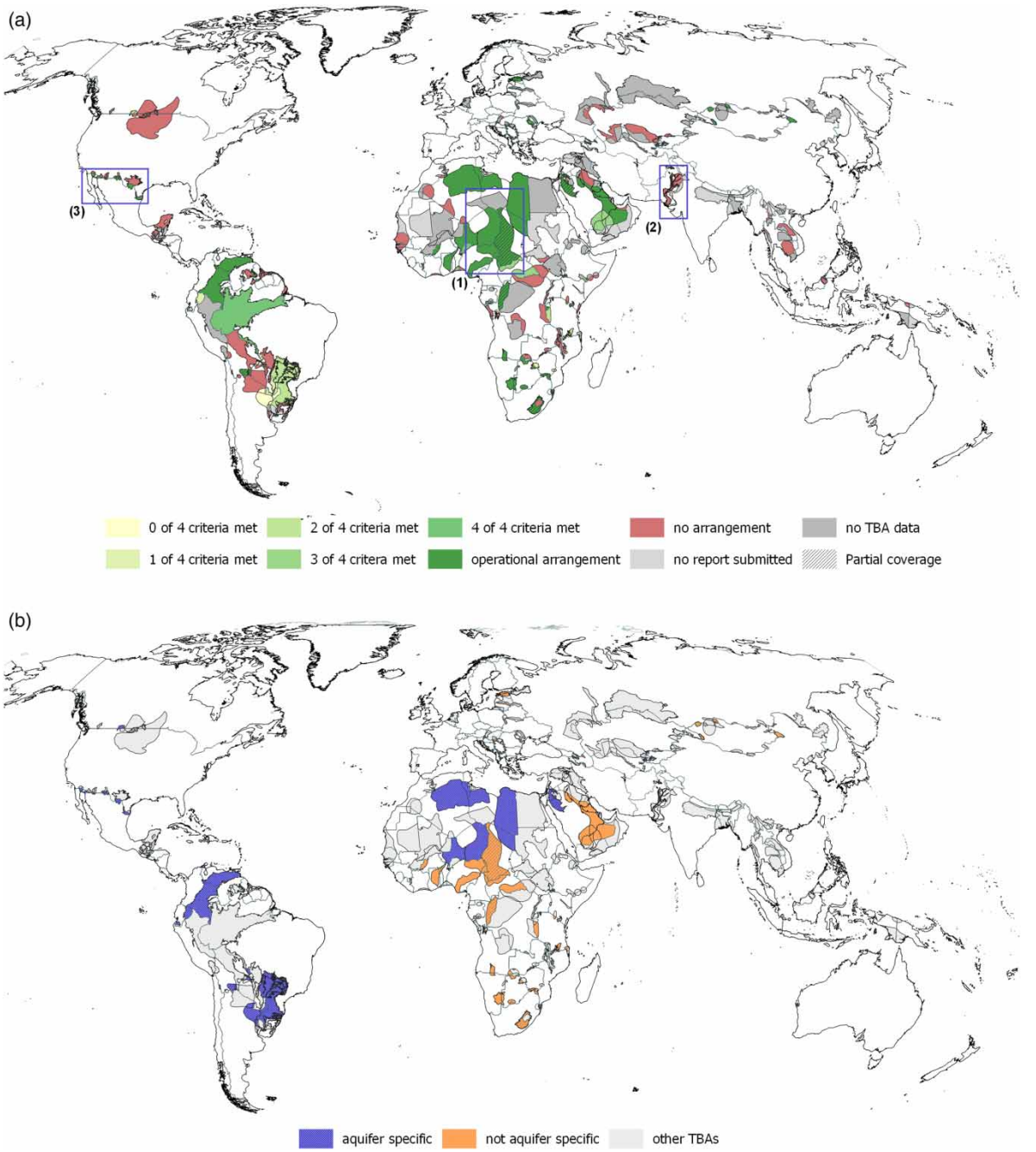


Fig. 1 | TBA cooperation, per aquifer. (a) Illustrates TBAs split into country segments illustrating the presence or lack of an operational arrangement. Also illustrated are situations where some of the four operational criteria are met but the arrangement is not operational or does not exist. The numbered inserts (1–3) link to the locations of transboundary aquifers discussed in 2. (b) Illustrates which reported arrangements are aquifer specific and which are not (e.g. part of a surface water arrangement).

Table 1 | Transboundary aquifers reported by all riparian states to have operational arrangements over them under SDG indicator 6.5.2.

Aquifer name	Riparian countries	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Arrangement type	Operational arrangement?
(a)							
Northwest Sahara Aquifer System	Algeria, Libya	Yes	Yes	Yes	Yes	Specific	Yes
Saq-Ram Aquifer System (West)	Jordan, Saudi Arabia	Yes	Yes	Yes	Yes	Specific	Yes
(b)							
Middle Sarmantian Pontian Aquifer	Romania, Moldova, Ukraine	Yes	Yes	Yes	Yes	Not specific	Yes
Prespa and Ohrid Lake Aquifer	Albania, Greece, Macedonia	Yes	Yes	Yes	Yes	Not specific	Yes
Neretva	Bosnia and Herzegovina, Croatia	Yes	Yes	Yes	Yes	Not specific	Yes
Stampriet Aquifer System	Botswana, Namibia, South Africa	Yes	Yes	Yes	Yes	Not specific	Yes
Khakhea/Bray Dolomite	Botswana, South Africa	Yes	Yes	Yes	Yes	Not specific	Yes
Zeerust/Lobatse/Ramotswa Dolomite Basin Aquifer	Botswana, South Africa	Yes	Yes	Yes	Yes	Not specific	Yes
Cuvelai and Ethosa Basin/ Ohangwena Aquifer System	Angola, Namibia	Yes	Yes	Yes	Yes	Not specific	Yes
Tuli Karoo Sub-Basin	Botswana, South Africa, Zimbabwe	Yes	Yes	Yes	Yes	Not specific	Yes

Note: (a) Arrangements specific to the aquifer. (b) Arrangements not specific to the aquifer (e.g. surface water arrangements that encompass groundwater).

to showcase the additional insights and knowledge to be gained by presenting the state of transboundary cooperation per aquifer, as illustrated in Figure 2. Explanations as to why we see certain patterns in reporting are offered alongside proposed next steps for each scenario.

The Lake Chad Basin (Figure 2(1)) is an example of countries reporting different degrees of cooperation over the same aquifer. Cameroon and Niger report that operational arrangements exist, specifically the Convention establishing the Lake Chad Basin Commission and the Water Charter for the Lake Chad Basin (FAO, 2021). However, Niger reports that the arrangement is specific to the aquifer whereas Cameroon reports that it is not specific to the aquifer. Chad reports that although an operational arrangement does exist, the coverage is only partial and is non-specific to the aquifer. Nigeria reports that a non-specific operational arrangement covers the entire basin; however, this report is not validated. Central African Republic reports that only three of the criteria are met and therefore the arrangement is not operational; however, this report is also not validated. Algeria and Libya don't report on this TBA at all. Multiple countries reporting differently over their shared TBA indicates that there may be a misunderstanding of what constitutes an operational arrangement, or might suggest that the four criteria required for an operational arrangement are met in theory but not in practice (i.e. on the ground).

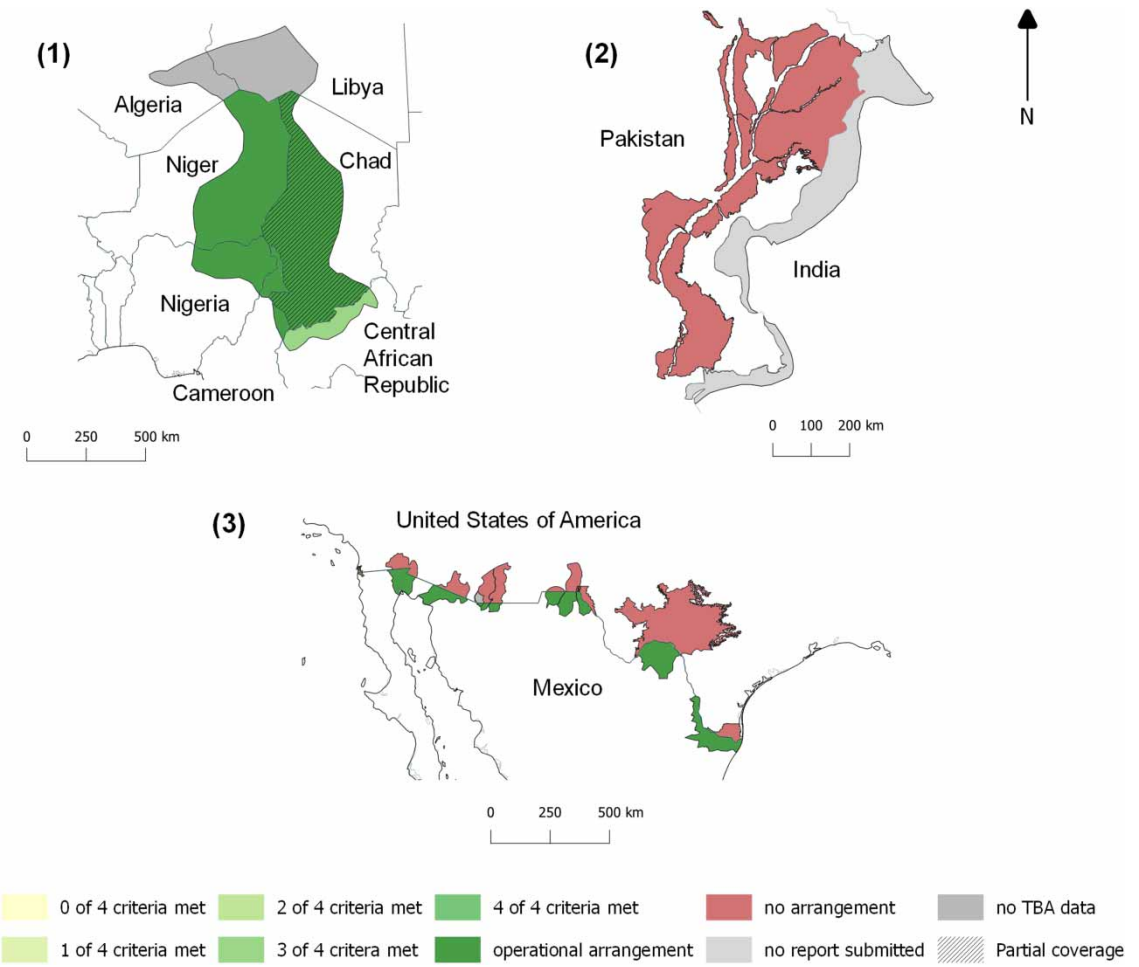


Fig. 2 | In focus examples of transboundary aquifer cooperation, per aquifer, as reported under SDG indicator 6.5.2. (1) Lake Chad Basin. (2) Indus River Plain Aquifer. (3) Mexico–United States of America border.

Countries might also disagree on the level of groundwater incorporation within the aforementioned arrangements. Therefore, although an arrangement for cooperation clearly exists, questions could be raised on whether or not it is truly operational. Additional questions may be raised about the data available within Libya and Algeria, the two countries that did not report on this aquifer or whether or not the aquifer is correctly delineated and extends as far north as is currently projected into these countries. Algeria and Libya may have no data to suggest it does and therefore subsequently consciously choose not to report it. The next steps in this scenario should be to clarify what the true status of cooperation within this aquifer is. This should include validation of the Central African Republic and Nigeria official reports, and then bridging of coordination gaps. Regional capacity development workshops may prove useful in this instance where this analysis could be used to highlight each country where inconsistencies in reporting have appeared in order to come to a general consensus.

The Indus River Plain aquifer (Figure 2(2)) showcases a scenario where only one riparian state reports over an aquifer. Pakistan, although unvalidated, reports that no arrangement exists for cooperation over the aquifer and India did not submit a report for SDG indicator 6.5.2. This information can guide more directed intervention including the collection of data and information related to groundwater or regional capacity development workshops to raise the political mandate for transboundary water cooperation. Research has shown that countries in the Indus Basin could reduce water stress and increase food production by cooperating over their water resources (Vinca *et al.*, 2021). Mobilization of resources and awareness raising is essential to achieve these. However, it should be noted that the absence of reporting does not necessarily mean that cooperation between riparian states is not taking place, the SDG process just may not be capturing it. However, for now, we are only left with Pakistan's interpretation of the situation.

The Mexico – United States of America (USA) border (Figure 2(3)) presents a case of direct conflicting reporting. Mexico reports that operational arrangements cover all their shared TBAs with the USA. However, the USA reports that no such arrangements exist. If operational arrangements do exist, this would be an easy gain for the USA to report on in the next round and increase their overall indicator value. Conversely, if such arrangements do not in fact exist, Mexico is overestimating its indicator value. In this scenario, validation of national reports is essential; the report from the USA is not validated and therefore may not be accurate. However, importantly, it reflects a viewpoint of the cooperative circumstances between the two countries which may be different on paper from the reality on the ground. Also important to highlight in this circumstance is the role of the person chosen to complete the official national 6.5.2 indicator report. Personal knowledge, political opinions, and whether they collaborate with other agencies and institutions to complete the report may influence reporting outcomes.

3.2. SDG indicator 6.5.2 methodology constraints

Many have been critical of the SDG 6.5.2 indicator methodology approach, particularly related to legal limitations and the effective representation of global water cooperation as summarized by de Chaisemartin (2020) and reported on by Hussein *et al.*, (2018) and Yalew *et al.*, (2021). Examining the effectiveness of the indicator in representing transboundary cooperation at a global scale is outside the scope of this article. However, with regard to TBAs specifically, it is clear and agreeable among scholars and co-custodian agencies that the reporting and representativeness of complex and invisible shared groundwater systems continue to present a particularly challenging case (McCracken & Meyer, 2018; Rieu-Clarke *et al.*, 2022). The chosen indicator methodology could, however, provide insight into to why we see un-harmonized reporting among countries sharing the same TBA. First, custodian agencies state that the four criteria required to make a cooperative arrangement operational 'do not have to be embedded in the arrangement but should be happening in practice' (UN Water, 2020a). As highlighted by de Chaisemartin (2020), this flexibility means that it is difficult to assess and validate these criteria. Additionally, it leaves the interpretation of what is 'happening on the ground' to the riparian countries, which can, and has, led to conflicting reporting. In particular, there is a margin of interpretation linked to TBAs covered within non-aquifer-specific arrangements: while the official methodology suggests that only mentioning groundwater in an operational surface water arrangement or in an operational bilateral arrangement is enough to consider the concerned aquifers (i.e. institutions are in place to deal with the TBAs, regardless if work is done effectively), some countries prefer to apply the four criteria to each single aquifer on the ground. This flexibility, however, does encourage reporting and, although attempts are made to validate data, the reporting exercise is ultimately country-driven and a level of trust in what countries report is essential to the process (UNECE & UNESCO, 2021). Countries are encouraged to consult with other riparian countries when developing their national reports (UNECE & UNESCO, 2021), however, this analysis suggests that it is rarely done in

practice, and this constitutes a clear area of improvement for the next reporting exercises, which custodian agencies have identified the need to work on.

3.3. Additional insights into TBA cooperation

In addition to highlighting the challenges of reporting, the analysis per aquifer also provides insight into how close countries may be to achieving an operational arrangement over a TBA. There are 27 cases where a country reports that an arrangement exists but not all of the four operational criteria are met (e.g. Cameroon's reporting over the Aquifer Vallee de la Benoue states that criteria 3 and 4 are not met). Targeting those arrangements that are close to being operational should be a priority to improve coverage. Conversely, there are 10 cases where no arrangement exists, but a country reports that at least one of the criteria is not met (e.g. Kenya reports that the Mount Elgon Aquifer meets criteria 1–3 but not 4) and six cases where there is no formal arrangement, or the arrangement is not clearly defined, but all criteria are met (e.g. Brazil reporting over the Amazonas and Nigeria reporting over the Irhazer-Illuemeden Basin). Developing official arrangements for such cases may be low-hanging fruit to easily improve indicator values. Targeting those aquifers that are close to formal operational arrangements should be a priority to improve coverage.

These specific cases are highlighted in Table 2. Throughout the entire dataset, criteria 1 (joint body) is the most commonly achieved and criteria 3 (joint objectives) is the least likely to be met. This indicates that in some cases, joint bodies or commissions exist, but they have not yet agreed on a common strategy (for example, in the case of the Western Aquifer Basin and Coastal Aquifer Basin as reported by Palestine). Operationalizing arrangements by implementing the required additional criteria can also improve indicator values.

Visually, disaggregated data per aquifer also allows for the easy identification of which specific TBAs globally are included within a country's SDG 6.5.2 indicator calculation without having to access and read individual country reports, increasing its accessibility and the potential of how data can be used to inform future reporting rounds. It also allows for the visualization of the size and location of aquifers being represented in the indicator value; this is valuable because the indicator value is calculated based on area extent. It therefore removes the ambiguousness of the indicator value and places it into context. Noteworthy in Figure 1(a) are the number of TBAs reported to have operational arrangements but whose delineations are still uncertain. Represented as ellipses, these aquifers have been highlighted by IGRAC as requiring further assessment to confirm their location and extent. If the true extent of the aquifer is unknown, it cannot be expected that the resource is being monitored or managed effectively (e.g. South Africa reports that the Limpopo Basin Aquifer is covered by an operational arrangement but its exact extent is unknown). Under the SDG indicator 6.5.2 methodology, countries are invited to report on aquifers even if their delineation is uncertain, however, many choose not to unless delineations are officially approved. Countries may also be reluctant to identify and investigate new TBAs, as these would be covered by operational arrangements and thus reduce their overall SDG indicator 6.5.2 value.

Figure 1(a) also illustrates the regional variation of SDG 6.5.2 coverage. Coverage across Asia is low, primarily due to a lack of existing arrangements and limited national reporting. This could be linked to a lack of confirmed aquifer delineations in these regions, and reluctance to report on an unquantified resource. Many large aquifer systems across Africa have some form of cooperation reported by at least one riparian state, however, many of the smaller TBAs see low levels of operationalization of arrangements. Low coverage across Europe is likely due to many countries in this region reporting on groundwater bodies and these being excluded from the analysis. However, this exemplifies the river basin focused approach Europe has taken toward transboundary groundwater management facilitated through the EU Water Framework Directive.

Figure 1(a) likewise gives recognition to those countries who are making progress toward operational arrangements that do not yet meet all four of the required criteria, something not yet analyzed in detail by the

Table 2 | Additional insights into how close countries may be to achieving operational arrangements over their transboundary aquifers.

Aquifer Name	Aquifer Segment	Riparian Countries	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Operational Arrangement?
(a)							
Milk River	Canada	Canada, United States of America	Yes	No	No	Yes	Arrangement not operational
Châteauguay	Canada	Canada, United States of America	No	No	No	No	Arrangement not operational
Richelieu/Lake Champlain	Canada	Canada	No	No	No	No	Arrangement not operational
Basalt Aquifer System (West): Yarmouk Basin	Jordan	Jordan, Syria	No	No	No	No	Arrangement not operational
Táchira Pamplonita	Venezuela	Colombia, Venezuela	Yes	No	Yes	No	Arrangement not operational
Tulcán-Ipiales	Ecuador	Colombia, Ecuador	No	Yes	Yes	Yes	Arrangement not operational
Tulcán-Ipiales	Colombia	Colombia, Ecuador	Yes	Yes	Yes	No	Arrangement not operational
Choco-Darién	Colombia	Honduras, Colombia	Yes	Yes	Yes	No	Arrangement not operational
Aquifer Vallee de la Benoue	Cameroon	Nigeria, Cameroon	Yes	Yes	No	No	Arrangement not operational
Lake Chad Basin	Central African Republic	Chad, Niger, Nigeria, Cameroon, Central African republic, Algeria	Yes	Yes	Yes	No	Arrangement not operational
Wajid Aquifer System	Saudi Arabia	Saudi Arabia, Yemen	Yes	Yes	Yes	No	Arrangement not operational
Golok Aquifer	Malaysia	Thailand, Malaysia	No	No	No	No	Arrangement not operational
Puyango-Tumbes-Catamayo-Chira	Ecuador	Ecuador, Peru	Yes	Yes	No	No	Arrangement not operational
Zarumilla	Ecuador	Ecuador, Peru	Yes	Yes	No	No	Arrangement not operational
Pantanal	Bolivia	Bolivia, Brazil, Paraguay	Yes	No	No	No	Arrangement not operational
Karoo Sandstone Aquifer	Tanzania	Mozambique, Tanzania	Yes	No	Yes	No	Arrangement not operational
Coastal Sedimentary Basin III	Tanzania	Mozambique, Tanzania	Yes	No	Yes	No	Arrangement not operational
Kagera Aquifer	Rwanda	Tanzania, Rwanda, Uganda	Yes	Yes	Yes	No	Arrangement not operational

Agua Dulce	Bolivia	Bolivia, Paraguay	No	No	No	No	Arrangement not operational
Amazonas	Ecuador	Bolivia, Brazil, Colombia, Ecuador, Peru, Venezuela	yes	no	no	no	Arrangement not operational
Sistema Aquífero Guaraní	Argentina	Argentina, Brazil, Paraguay, Uruguay	No	No	No	No	Arrangement not operational
Sistema Aquífero Guaraní	Brazil	Argentina, Brazil, Paraguay, Uruguay	No	No	Yes	Yes	Arrangement not operational
Karoo-Carbonate	Central African Republic	Central African Republic, Congo, South Sudan	Yes	Yes	Yes	No	Arrangement not operational
Tanganyika	Tanzania	Burundi, Democratic Republic of the Congo, Tanzania	Yes	No	Yes	No	Arrangement not operational
Aquifere du Rift	Rwanda	Democratic Republic of the Congo, South Sudan, Uganda	Yes	Yes	Yes	No	Arrangement not operational
Western Aquifer Basin	Palestinian Territory	Egypt, Israel, Palestinian Territory	Yes	Yes	No	No	Arrangement not operational
La Guajira	Venezuela	Colombia, Venezuela	Yes	No	Yes	No	Arrangement not operational
(b)							
Debet Aquifer	Armenia	Azerbaijan, Armenia, Georgia	No	No	Yes	No	No arrangement
Keta/Dahomey/Cotier Basin Aquifer	Benin	Ghana, Togo, Benin, Nigeria	Yes	Yes	Yes	No	No arrangement
Merti Aquifer	Kenya	Kenya, Somalia	No	Yes	No	No	No arrangement
Mount Elgon Aquifer	Kenya	Uganda, Kenya	Yes	Yes	Yes	No	No arrangement
Dawa	Kenya	Ethiopia, Kenya, Somalia	No	Yes	Yes	No	No arrangement
Eastern Kalahari Karoo Basin	Zimbabwe	Botswana, Zimbabwe	No	Yes	No	No	No arrangement
Save Aluvial	Zimbabwe	Mozambique, Zimbabwe	No	Yes	No	No	No arrangement
Sistema Aquífero Guaraní	Paraguay		No	No	Yes	No	No arrangement

(*Continued.*)

Table 2 | Continued

Aquifer Name	Aquifer Segment	Riparian Countries	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Operational Arrangement?
		Argentina, Brazil, Paraguay, Uruguay					
Aquifers in Quaternary deposits; Oxfordian-Cenomanian Carbonate-Terrigenous Aquifer; Mazursko-Podlashi Aquifer; Upper Cretaceous Aquifer	Lithuania	Belarus, Lithuania, Poland, Russia	Yes	No	No	No	No arrangement
Coastal Aquifer Basin	Palestinian Territory	Egypt, Israel, Palestinian Territory	Yes	Yes	No	No	No arrangement
(c)							
Irhazer-Illuemeden Basin	Nigeria	Algeria, Benin, Mali, Niger, Nigeria	Yes	Yes	Yes	Yes	No arrangement
Coastal Sedimentary Basin VI/Coastal Plain Sedimentary Basin Aquifer	Mozambique	Mozambique, South Africa	Yes	Yes	Yes	Yes	No arrangement
Rhyolite-Breccia Aquifer	Mozambique	South Africa, Swaziland, Mozambique	Yes	Yes	Yes	Yes	No arrangement
Boa Vista-Serra do Tucano-North Savanna	Guyana	Brazil, Guyana	Yes	Yes	Yes	Yes	No arrangement
Grupo Roraima	Guyana	Brazil, Guyana, Venezuela	Yes	Yes	Yes	Yes	No arrangement
Amazonas	Brazil	Bolivia, Brazil, Colombia, Ecuador, Peru, Venezuela	Yes	Yes	Yes	Yes	No arrangement

Note: (a) Arrangements that exist but where not all operational criteria are met. (b) Where no arrangement exists, least 1 of the criteria is met but not all are. (c) No arrangement exists but all operational criteria are met.

co-custodian agencies (UNECE & UNESCO, 2021). This might help raise the mandate of transboundary cooperation within governments and provide an incentive to operationalize existing arrangements, particularly when neighboring countries in the region are seen to have comparatively high levels of indicator coverage. It also provides a more in-depth insight into how many of the four operational criteria are met within a TBA, alleviating some of the binary issues with the indicator and indicating different levels of operationality (McCracken, 2017), which can not only assist co-custodian agencies with where to direct capacity development but also provide guidance to international organizations and governments on where direct interventions need to be made. The dataset used to develop the map can also be used to identify which of the four criteria are met (available to download, see Data Availability Statement). For example, data exchange is seen to be fundamental in the facilitation of transboundary water management, however, the degree to which data is shared globally is not well understood (Mukuyu *et al.*, 2020). This dataset allows us to see where transboundary data is currently being exchanged globally. There are in fact multiple cases where data is exchanged without an arrangement in place, suggesting that at the technical level, TBA cooperation may be more easily facilitated (e.g. Guyana reports that data is shared over the Boa Vista-Serra do Tucano-North Savanna aquifer but that no arrangement exists; Mozambique reports that data is exchanged over the Coastal Sedimentary Basin VI/Coastal Plain Sedimentary Basin aquifer but that no arrangement exists). Finally, the map can act as a tool for countries with low levels of cooperation to easily identify others within the region who have achieved operational arrangements over their TBAs for the guidance of better practice.

3.4. Reporting under surface water arrangements

During reporting, countries are asked to specify whether or not the arrangement they are reporting is specific to the aquifer. In Figure 1(b), reported arrangements (both operational and non-operational) are split by type. The majority of arrangements over TBAs are not specific to the aquifer itself. Instead, TBAs tend to be included in broader surface water arrangements, where groundwater is hydraulically connected to surface water. In these cases, aquifer management is often nested within river and lake basin organizations (R/LBO). This reflects the reality that there are very few cases worldwide of interstate agreements regarding TBAs that are in force (Burchi, 2018; Sindico, 2020). However, it is often not clear to what extent groundwater is incorporated into these surface water arrangements. For example, regular meetings may occur to discuss surface water issues, but it is unclear if groundwater issues are also included. Notwithstanding limitations, the important role that river and lake basin organizations have in facilitating transboundary groundwater cooperation cannot be understated, so much so, that in 2007 the African Ministers' Council on Water (AMCOW) recommended that river and lake basin organizations act at the center point for TBA management across the continent of Africa (Braune & Xu, 2011 in Altchenko & Villholth, 2013). In line with this, UNECE & UNESCO (2021) highlight that progress in cooperation over aquifers can be made by incorporating groundwater into the activities of existing river basin commissions or river basin management plans. The Stampriet Aquifer System (STAS) is an example of an operational arrangement (reported consistently by all Member States) nested in the structure of an RBO, the Orange-Senqu River Commission (ORASECOM) (UNESCO, 2016). Across the Southern African Development Community (SADC) region this could be a model for how to incorporate groundwater into river basin arrangements. However, this form of cooperation is only effective when an aquifer lies entirely within one RBO and often the areal extents of surface water basins do not align with the underlying groundwater systems. For some aquifers, no R/LBO exists, such is the case in some arid regions where there are limited perennial surface water bodies. In addition, RBOs often do not have the groundwater-specific technical capacity, financing or mandate required to develop such arrangements. When they are incorporated, there is a risk that groundwater is included only as an

afterthought and that provisions dedicated to the management of surface water are ineffectively extended to also encompass groundwater (Altchenko & Villholth, 2013).

3.5. Groundwater data and information availability

The analysis and representation of SDG 6.5.2 indicator data per aquifer highlights limitations related to groundwater data and information availability. The global assessment of TBAs is decades behind that of surface waters (Eckstein & Sindico, 2014). Regional inventories of delineated TBAs only started in 1999 and it is recognized that much progress still needs to be made (IGRAC, 2021a; Rivera *et al.*, 2022). Although most of the world's largest TBAs are identified, many are still not validated or recognized by riparian states and even more do not have detailed assessments past the initial delineation stage. There is also likely a significant number of smaller, locally important TBAs still to be identified, particularly across South America, Africa and Asia (Fraser *et al.*, 2018). Without this data, transboundary cooperation and management of aquifer systems is limited and reliable calculation of the SDG indicator 6.5.2 is impossible (McCracken, 2017; McCracken & Meyer, 2018). A lack of transboundary data and information is therefore a major challenge in not just the development of operational arrangements and the ultimate achievement of the target 6.5 and related indicator 6.5.2 (Rieu-Clarke *et al.*, 2022) but also TBA cooperation more generally. This is reflected in the reporting exercise which showed significant gaps in spatial data and a lack of knowledge pertaining to the physical characteristics of TBAs needed to calculate the indicator accurately (UNECE & UNESCO, 2018; Rieu-Clarke, 2020). Additionally, many countries chose not to report on their transboundary component at all, citing reluctance to report on an unquantified resource. Others did not recognize that they shared TBA resources, alluding to the political nature of this indicator. This is also exacerbated in some regions more than others. Many countries across Sub-Saharan Africa and Asia reported having difficulties in obtaining the requisite aquifer data. Several countries in Europe (e.g. Germany and Netherlands) do not provide figures for the spatial extent of their TBAs, raising questions regarding the level of knowledge of TBAs within the region (UNECE & UNESCO, 2021). During both reporting rounds a number of countries did not report on their TBAs with reference to IGRAC's global inventory (IGRAC, 2021a) but instead used national sources such as hydrogeological maps, as the SDG 6.5.2 indicator methodology invites countries to preferentially use their own sources of information or consider global datasets as not an absolute reference due to the inherent assumptions in delineating aquifers (UN Water, 2020a). However, very few countries submitted maps or shapefiles alongside reports that detailed the delineations of these aquifers, making it difficult to validate these and correlate them with neighboring riparian reports. Moving forward, these TBAs should be investigated further for future validation and inclusion in IGRAC's inventory.

Another important consideration relating to TBA data availability is the fourth criterion that the indicator 6.5.2 methodology stipulates must be met for an arrangement to be operational; the regular (at least once per year) exchange of data and information. Many TBAs are reported to be covered by surface water operational arrangements. In these instances, it is often unclear if this criterion is always met for both surface and groundwater. It is unlikely, due to the data limitations already mentioned above, that groundwater data is regularly collected and exchanged in many of these river basins. The indicator methodology makes no distinction as to what specific data must be exchanged between riparian states for the arrangement to be operational and subsequently, TBA data exchange risks being significantly overlooked for surface water data that is often more accessible and easier to collect. This raises questions over the quality of operational river basin arrangements that also claim to encompass groundwater within their scope. It may also explain why we see inconsistencies in the reporting of data exchange between countries sharing the same aquifer. Ultimately, it could be argued that the infancy of TBA assessment, lack of groundwater monitoring globally and the complexity of groundwater systems are not accounted for in the SDG 6.5.2 indicator methodology and reporting template.

Despite the limited availability of data and information for TBAs globally, it should be recognized that significant efforts are still being made to map and assess these aquifers in more detail. In 2020 the TBAs shared between Malawi and neighbors were remapped and in 2021 the TBA delineation along the USA-Mexico border was completed (Fraser *et al*., 2020; Sanchez & Rodriguez, 2021). Even more recently, ministers from Gambia, Guinea Bissau, Mauritania and Senegal agreed to establish a legal and institutional framework for cooperation on the Senegal-Mauritanian Aquifer Basin (SMAB), a shared groundwater reserve on which 80% of their populations depend (IGRAC, n.d.). This agreement was underpinned by a significant preliminary transboundary assessment of groundwater resources, groundwater data and information, as well as capacity-building needs. Moving forward it will be essential to ensure that this knowledge is captured and reflected in the reporting of SDG indicator 6.5.2 process. Capacity development in particular will be essential to ensure validation and recognition of this progress by national experts. However, information on the extent of aquifer systems alone is not enough. Progress in the assessment of these systems should include conceptual hydrogeological models, groundwater flow regimes, abstraction quality and monitoring data to fully understand their vulnerability to the possible impacts of development (Lipponen & Chilton, 2018).

A positive insight gained from past indicator reporting rounds is that the number of countries providing sufficient data to calculate the aquifer component increased from 65 in 2017/18 to 94 in 2020/21, suggesting that countries have sought to deepen the knowledge of their TBA systems (UNECE & UNESCO, 2021; Rieu-Clarke *et al*., 2022). Countries have also reported that the SDG indicator 6.5.2 monitoring exercise triggered new internal and binational dialogues on transboundary water cooperation (UNECE & UNESCO, 2021). Finally, it is hoped that the analysis in this paper will contribute to further data and information acquisition by highlighting the underlying importance of groundwater data and information to TBA cooperation in a new and insightful way but also by allowing for the visualizing of data gaps spatially.

4. CONCLUSIONS AND THE WAY FORWARD

The way that previous rounds of SDG indicator 6.5.2 monitoring data are used to spread awareness and inform future reporting rounds is crucial to target acceleration. The presentation of SDG indicator 6.5.2 reporting data per aquifer captures a more in-depth and complimentary view of transboundary cooperation that is not easily visible with national-level data. Results show that reported cooperation is often not consistent across borders with only 10 operational arrangements globally covering TBAs that are reported on by all countries. A lack of groundwater data and information has been highlighted as a key barrier to cooperation, providing critical impetus to the necessity for improved TBA assessment. Such assessment must not only take place at a regional or global level (as has been the case in the past with initiatives such as the International Shared Aquifer Resources Management (ISARM) network and the Transboundary Waters Assessment Program (TWAP) setting the global baseline for TBA understanding) but moving forward it will be essential that countries take ownership over their own transboundary assessments and invest more in data collection and monitoring. As a starting point, some countries reported on TBAs that were not recorded in the IGRAC inventory. The process of establishing the delineation of these aquifers should begin with the intention of adding them to the next published edition of the global inventory.

Moving forward, it is proposed that the results presented in this paper may support future reporting rounds and help improve coverage of SGD indicator 6.5.2. The dataset developed may also act as an awareness-raising tool for custodian agencies (to utilize in workshops) and for countries who wish to improve their indicator value through direct interventions and improved report coordination with neighboring states. R/LBOs may also find it used to better consider the inclusion of TBAs within the scope of their mandate. Finally, the potential of the data collected under the SDG agenda should not be underestimated. This study is just one example of utilizing

such data to provide additional insights into an otherwise rigid official reporting process. Scholars and researchers alike should use this opportunity to investigate new ways of understanding and using SDG data to help improve target achievement. Such innovative approaches and alternative viewpoints will be crucial to help achieve SDG 6.

ACKNOWLEDGEMENTS

The research for this paper has been supported by the Water and Development Partnership Programme (project number 110688) with funding from the Ministry of Foreign Affairs of the Netherlands. The authors would also like to thank Claudia Ruz Vargas, Arnaud Sterckx, Stefan Siepman, Alexandra Urgilez Vinueza and Elisabeth Lictevout for their support and review of the manuscript.

DATA AVAILABILITY STATEMENT

All relevant data are available from an online repository or repositories: http://doi.org/10.58154/2R9F-P278.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Altchenko, Y. & Villholth, K. (2013). TBA mapping and management in Africa: A harmonised approach. *Hydrogeology Journal*. Springer Verlag *21*(7), 1497–1517. ff10.1007/s10040-013-1002-3ff. ffhal-02328461f.

Braune, E. & Xu, Y. (2011). TBA utilization and management in Southern Africa: water – a shared responsibility. *ISARM-SADC*, Position paper for the UNESCO Cluster Office, Harare, Zimbabwe, p. 53.

Burchi, S. (2018). Legal frameworks for the governance of international TBAs: Pre- and post-ISARM experience. *Journal of Hydrology: Regional Studies 20*, 15–20.

de Chaisemartin, M. (2020). Measuring transboundary water cooperation within the framework of Agenda 2030: A proposal for a revision of SDG Indicator 6.5.2. *Water International 45*(1), 60–78. doi:10.1080/02508060.2019.1708659.

Eckstein, G. E. & Sindico, F. (2014). The law of TBAs: many ways of going forward, but only one way of standing still. *Review of European Community & International Environmental Law. 23*(1), 2014. ISSN 2050-0386.

European Commission. (2004). *Common Implementation Strategy for the Water Framework Directive (2000/60/EC)*. Groundwater body characterisation. Technical report on groundwater body characterisation issues as discussed at the workshop of 13th October 2003. Office for Official Publications of the European Communities, Luxembourg.

FAO. (2021). *FAOLEX Database: Water Charter of the Lake Chad Basin (Version of 2011)*. Available at: https://www.fao.org/faolex/results/details/en/c/LEX-FAOC203691/#:~:text=The%20Water%20Charter%20constitutes%20a,shared%20water%20resources%20and%20environment (accessed 20/01/2023).

Fraser, C. M., Kalin, R. M., Rivett, M. O., Nkhata, M. & Kanjaye, M. (2018). A national approach to systematic TBA assessment and conceptualisation at relevant scales: A Malawi case study. *Journal of Hydrology: Regional Studies 20*, 35–48. Special Issue on International Shared Aquifer Resources Assessment and Management.

Fraser, C. M., Kalin, R. M., Kanjaye, M. & Uka, Z. (2020). A national border-based assessment of Malawi's TBA units: towards achieving sustainable development goal 6.5.2. *Journal of Hydrology: Regional Studies 31*, 100726. https://doi.org/10.1016/j.ejrh.2020.100726.

Hussein, H., Menga, F. & Greco, F. (2018). Monitoring transboundary water cooperation in SDG 6.5.2: How a critical hydropolitics approach can spot inequitable outcomes. *Sustainability 10*(10), 3640. https://doi.org/10.3390/su10103640.

IGRAC (n. d.). Advances in Transboundary Cooperation in the Senegalo-Mauritanian Aquifer Basin (SMAB). Available at: https://www.un-igrac.org/sites/default/files/resources/files/Flyer%20WWF%20-%20SMAB%20-%20English%20-%20web.pdf (accessed 20/01/2023).

IGRAC and UNESCO-IHP (2015). *TBAs of the World*. Edition 2015. Scale 1: 50 000 000. IGRAC Publications, Delft, Netherlands.

IGRAC (International Groundwater Resources Assessment Centre) (2021a). *TBAs of the World [map]*. Edition 2021. Scale 1:50 000 000. IGRAC, Delft, Netherlands.

IGRAC (International Groundwater Resources Assessment Centre) (2021b). *TBAs, A Global Outline 2021*. Brochure. IGRAC, Delft, Netherlands.

Ladel, J., Mehta, M., Gulemvuga, G. & Namayanga, L. (2020). Water policy on SDG6.5 implementation: progress in integrated & transboundary water resources management implementation. *World Water Policy 00*, 1–19. https://doi.org/10.1002/wwp2.12025.

Lipponen, A. & Chilton, J. (2018). Development of cooperation on managing transboundary groundwaters in the pan-European region: the role of international frameworks and joint assessments. *Journal of Hydrology: Regional Studies 20*, 145–157. https://doi.org/10.1016/j.ejrh.2018.05.001.

McCracken, M. (2017). *Measuring Transboundary Water Cooperation: Options for Sustainable Development Goal Target 6.5 (TEC Background Paper No. 23)*. Global Water Partnership Technical Committee.

McCracken, M. & Meyer, C. (2018). Monitoring of transboundary water cooperation: Review of sustainable development goal indicator 6.5.2 methodology. *Journal of Hydrology 563*, 1–2. https://doi.org/10.1016/j.jhydrol.2018.05.013.

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

Rieu-Clarke, A. (2020). Can reporting enhance transboundary water cooperation? Early insights from the Water Convention and the Sustainable Development Goals reporting exercise. *RECIEL 29*, 361–371. https://doi.org/10.1111/reel.12344.

Rieu-Clarke, A., Bernardini, F., Tiefenauer-Linardon, S. & Aureli, A. (2022). Advances in monitoring transboundary water cooperation? Reflecting on the development and implementation of SDG indicator 6.5.2. *Water International* doi:10.1080/02508060.2022.2025556.

Rivera, A., Pétré, M. A., Fraser, C., Petersen-Perlman, J. D., Sanchez, R., Movilla, L. & Pietersen, K. (2022). Why do we need to care about TBAs and how do we solve their issues? *Hydrogeology Journal*. https://doi.org/10.1007/s10040-022-02552-y.

Sanchez, R. & Rodriguez, L. (2021). TBAs between Baja California, Sonora and Chihuahua, Mexico, and California, Arizona and New Mexico, United States: Identification and categorization. *Water 2021*(13), 2878.

Sindico, F. (2020). *International Law and TBAs*. Edward Elgar.

UNECE (n. d.). National Country Reports on SDG Indicator 6.5.2. Available at: https://unece.org/national-country-reports-sdg-indicator-652 (accessed 20/01/2023).

UNECE and UNESCO (2018). *Progress on Transboundary Water Cooperation – Global Baseline for SDG Indicator 6.5.2*. Available at: https://www.unwater.org/publications/progress-on-transboundary-watercooperation-652.UN-Water (accessed 20/01/2023).

UNECE and UNESCO (2021). *Progress on Transboundary Water Cooperation: Global Status of SDG Indicator 6.5.2 and Acceleration Needs 2021*. UNESCO, Paris. Available at: unesdoc.unesco.org/ark:/48223/pf0000378914?posInSet=1&queryId=957ce00a-0462-4bab-8d10-8c5307999dee (accessed 20/01/2023).

UNESCO. (2016). *Stampriet TBA System Assessment Governance of Groundwater Resources in TBAs (GGRETA) - Phase 1*. Technical Report. 2016/SC/HYD/GGRETA-3.

UN Stats (2022). *Tier Classification for Global SDG Indicators*. as of 30 November 2022. Available at: https://unstats.un.org/sdgs/iaeg-sdgs/tier-classification/ (accessed 31/01/2023).

UN Water (2015). *Water in the 2030 Agenda for Sustainable Development*. Available at: http://www.unwater.org/sdgs/a-dedicated-water-goal/en/ (accessed 20/01/2023).

UN Water (2017). *Integrated Monitoring Guide for Sustainable Development Goal 6 on Water and Sanitation Targets and Global Indicators*. Geneva, Switzerland.

UN Water (2020a). *Step-by-Step Monitoring Methodology for SDG Indicator 6.5.2*. Available at: https://www.unwater.org/sites/default/files/app/uploads/2020/02/SDG_652_Step-by-step_methodology_2020_ENG.pdf (accessed 20/01/2023).

UN Water (2020b). *Delivering the Promise: Safe Water and Sanitation for all by 2030. The SDG 6 Global Acceleration Framework*. In brief. Geneva, Switzerland.

UN Water (2020c). *The Sustainable Development Goal 6 Global Acceleration Framework*. Geneva. Available at: https://www.unwater.org/publications/the-sdg-6-global-accelerationframework/ (accessed 20/01/2023).

UN Water (2021) Summary Progress. Update 2021 – SDG 6 – water and sanitation for all. Version: July 2021. Geneva, Switzerland.

Vinca, A., Parkinson, S., Riahi, K., Byers, E., Siddiqi, A., Muhammad, A., IIyas, A., Yougswaran, N., Willaarts, B., Magnuszewski., Awais, M., Rowe, A. & Djilali, N. (2021). Transboundary cooperation a potential route to sustainable development in the Indus basin. *Nat Sustain 4*, 331–339. https://doi.org/10.1038/s41893-020-00654-7.

Wada, Y. & Heinrich, L. (2013). Assessment of TBAs of the world – vulnerability arising from human water use. *Environmental Research Letters 8*(2), 24003.

World Economic Forum. (2023). *Global Risks Report 2023*, 18th edn. Insight Report. WEF, Geneva. ISBN-13: 978-2-940631-36-0

Yalew, S. G., Kwakkel, J. & Doorn, N. (2021). Distributive justice and sustainability goals in transboundary rivers: Case of the Nile Basin. Front. *Environ. Sci. 8*, 590954. doi:10.3389/fenvs.2020.590954.

First received 31 January 2023; accepted in revised form 4 November 2023. Available online 11 November 2023