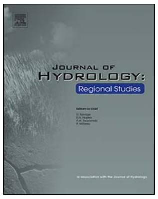
ARTICLE IN PRESS

Journal of Hydrology: Regional Studies xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

journal homepage: www.elsevier.com/locate/ejrh



Fifteen-year experiences of the internationally shared aquifer resources management initiative (ISARM) of UNESCO at the global scale

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ARTICLE INFO

Keywords:
Aquifer
Transboundary
Global
Cooperation
ISARM

ABSTRACT

Study region: Global scale.
Study focus: This paper highlights the main outputs and outcomes of the Internationally Shared Aquifer Resources Management Initiative (ISARM, 2000–2015) of UNESCO on the global scale. We discuss the lessons learned, what is still relevant in ISARM, and what we consider irrelevant and why. We follow with discussion on the looming scenarios and the next steps following the awareness on transboundary aquifers (TBAs) as identified by ISARM.
New insights for the region: This analysis emphasizes the need for more scientific data, widespread education and training, and a more clearly defined role for governments to manage groundwater at the international level. It describes the links, approach and relevance of studies on TBAs to the UN Law of Transboundary Aquifers and on how they might fit regional strategies to assess and manage TBAs. The study discusses an important lesson learned on whether groundwater science can solve transboundary issues alone. It has become clear that science should interact with policy makers and social entities to have meaningful impacts on TBAs. Bringing together science, society, law, policy making, and harmonising information, would be important drivers and the best guidance for further assessments. ISARM can still make contributions, but it could be redesigned to support resolving TBAs issues which, in addition to science (hydrogeology), require considering social, political, economic and environmental factors. ISARM can increase its international dimension in the continents that still lag behind the assessment and shared management of TBAs, such as Asia and Africa.

1. Introduction

Transboundary river basins have been extensively studied worldwide since the 1970s (Wolf et al., 1999). However, Transboundary Aquifers (TBAs) have received less attention despite their scientific, environmental, institutional and socio-economic importance. Since 2000, when the Internationally Shared Aquifer Resources Management Initiative (ISARM) was established by the International Hydrological Programme (IHP) of UNESCO, substantial efforts have been made to identify transboundary aquifers or aquifer systems (TBAs) in world regions, and to raise awareness of their societal and environmental importance (UNESCO, 2001). A few TBAs agreements that existed before ISARM, or were prepared following ISARM and/or the United Nations Resolution on TBAs (UN-A/RES/63/124) as they may be applied to TBAs, are summarised in the paper by Burchi, 2018.

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https://doi.org/10.1016/j.ejrh.2017.12.003
Received 23 October 2017; Received in revised form 11 December 2017; Accepted 12 December 2017

After the UNESCO-IHP Transboundary aquifer programme was launched (Puri and Aureli, 2005), a number of initiatives, contributions and programmes that focused on different aspects of this water resource, including agreements, have taken place on the global scale (Wada and Heinrich, 2013). Among the initiatives, the "Second assessment of Transboundary Rivers, Lakes and Groundwater" (UNECE, 2011); WHYMAP (2006), the "TWAP-Transboundary Aquifers of the World-Update 2012" (TWAP, 2012), or the "TAAP-Transboundary Aquifer Assessment Program, (TAAP, 2013) can be cited.

This contribution focuses on transboundary aquifers' *outputs,* on their management, and on policy and social issues worldwide after more than 15 years of experience. One important aspect covered herein refers to several aspects: *agreements* on TBAs as a result of ISARM, or existing agreements prior ISARM; whether they fit the ISARM philosophy and the UN Resolution on TBAs; where agreements are missing (Burchi, 2018). Existing legislation on groundwater and aquifers, whether transboundary or not, suggest how it may be applied (or not, and why not) to transboundary aquifers. A summary of perspectives and a discussion on the next steps per country, or per continent, and wherever common strategies exist (Americas, Europe,) is presented. Where they do not exist, we make a case of promoting them following international good practices. It is also worth mentioning the Sustainable Development Goals, towards the 2030 UN Agenda, where SDG6 is intended exclusively for water (to ensure availability and sustainable management of water and sanitation for all). However for SDG6 to be successful, it will require reliable management systems in be put in place, which may prove even more difficult to achieve when dealing with transboundary waters.

Our second aim is to synthesise the philosophy behind the management/assessment of TBAs per continent or large continental regions. The idea behind this approach is to assess the context, scope and perception of the ISARM methodology by different legislations and their associated issues and concerns. To that end, the paper presents real outputs and outcomes since ISARM was launched in 2000 by underlining the science, policy and social issues and what has been learned, what is still in (as per 2017), what is not working and what the next possible steps are.

2. ISARM outputs and outcomes

A number of important outputs and outcomes have emerged around the globe as a result of ISARM. The most important direct outputs across four continents are described below.

- Four regional ISARM networks of experts were created to identify, map and manage transboundary aquifers: ISARM-Europe, ISARM-Americas, ISARM-Asia, and ISARM-Africa.
- A global inventory and a global map of TBAs with 592 TBAs identified until 2015; of these, however, more than 50% are defined as 'groundwater bodies' (not necessarily TBAs as defined by ISARM) in EU Member States; this was decided to comply with their Water Framework Directive (2000/60/EC, 2000).
- World financial agencies (Global Environment Facility, or GEF, World Bank) supported ISARM activities, most notably on studies about some TBAs (e.g., Guarani, Nubian).
- Novel scientific practices to define transboundary groundwater resources availability (e.g., Milk River).
- Novel tools and instruments (e.g. GRACE) of the analysis to be done for large-scale transboundary aquifers (e.g., Northern Great Plains, Judith River, Edwards Trinity).
- The drafting of the adoption of the UN Draft articles on the Law of Transboundary aquifers.

The most relevant direct outcomes are:

- Some regional strategies to assess and manage TBAs have been prepared worldwide (Machard de Gramont et al., 2010; UNEP, 2011; WWAP, 2012; RIOB, 2013). When preparing their regional strategy of TBAs in the Americas (Rivera, ed., 2015), the ISARM-Americas network was inspired by the UN Draft Articles, namely in relation to adopting science-based norms for neighboring engagement, promoting knowledge, protecting groundwater resources in the optimal sustainable development context; establishing shared management practices; promoting international cooperation and good neighborliness, and encouraging the equitable and reasonable utilization of resources.
- Alliances among science, policy-making and society networks to build trust.
- Nine years after the Draft Articles were adopted by UNGA (2008), there has been no ratification or affirmative vote on the Draft Articles; there is a perception that there is *no political will* to establish international laws that may prove stronger than multilateral or bilateral agreements, and there are concerns about having to cede some riparian rights.

3. Lessons learned

Many important lessons were learned during the 15 years of ISARM in more than 130 countries (24 for the Americas, 27 for Europe, 38 for Asia and 45 for Africa) on four continents.

3.1. Information

One of the most important lessons learned overall was that background information on transboundary aquifers as a key obstacle was missing to establish clear and quantifiable objectives to monitor and manage the groundwater and aquifers that cross international boundaries (e.g., North American countries). A recurring theme throughout most transboundary water relationships is the reality and slow realization that we cannot separate waters: groundwater from surface water, raw from waste, quality from quantity, or shortage from adequate supply issues.

3.2. Communication

There are important lessons to be learned by hydrogeologists and water managers alike. The primary lesson is that, as long as hydrogeologists only “talk to themselves”, key elements of the natural and built environment will remain beyond decision makers’ understanding. In general, scientists and managers lack sufficient communication. A dissemination-communication strategy is generally lacking. Secondly, while good cooperation exists among the hydrogeologists who work across their own borders, this is insufficient, and it is only through relevant cross-disciplinary dialogue that essential water resources, and everything that follows on from them, can be managed for social, economic and environmental security. This is particularly true for transboundary aquifers.

3.3. Legal instruments

A key lesson that may be drawn from ISARM activities relates to the UN’s adoption of the Law of Transboundary Aquifers, which is also a direct outcome of the ISARM initiative. This is a clear outcome of how hydrogeological science transforms into a global legal instrument. This instrument was drafted with the direct involvement of hydrogeologists, who had to undertake significant intellectual efforts to establish a solid definition of the key hydrogeological terminology for it to be scientifically correct, but legally consistent, and to be made legally binding; i.e., direct, solid and very fruitful cooperation between hydrogeologists and lawyers. The result is a well-developed science-based legal tool to be used by the World UN Member States (Burchi, 2018). Since then, more work is being done to help and support Member States in adopting these guidelines. Some of these new activities involve hydrogeologists supported by the International Association of Hydrogeologists (IAH); other Member States are applying and undertaking the principles of the Law of Transboundary Aquifers independently. For more on this aspect, readers are referred to the paper by Burchi, 2018.

3.4. Non-legally binding regional treaties, protocols, conventions, agreements and strategies

As for agreements at the world level, the scope or meaning has different interpretations for the sharing countries in different regions (Europe, Africa and Asia). Some refer to the signed Water Directives in force (e.g. WFD-EU) or the signing of International conventions. There are very few TBAs for which signed agreements exist, and these generally take a bilateral form with institutions having quite variable scope and mandates. Given the concerns and fears of some countries to cede riparian rights, there have been many other multilateral or bilateral non-binding agreements for cooperation which, in some cases, are considered to have more strength than legally binding international laws (science cooperation between Canada and the USA, the USA and Mexico, Mali, Niger and Nigeria, and others; see Burchi, 2018).

The ISARM-Americas group has moved its activities a step further in designing a strategy for the American Hemisphere: “Regional Strategy for the Assessment and Management of the Transboundary Aquifer Systems in the Americas” (Rivera, ed., 2015). This Regional Strategy for the Americas is contained in the 4th Book of the ISARM-Americas Series; it is the result of more than 10 years of successful and fruitful collaboration of UNESCO-IHP and the Organization of American States (OAS) with members of 24 participating countries in the America hemisphere. The strategy adopted the *vision* of “Achieving improved sustainable management and protection of transboundary aquifer that goes beyond the boundaries of the participating countries,” and the *mission*: “to increase the generation and exchange of knowledge concerning the Transboundary Aquifers, developing communication pathways, cooperation and joint work between participating ISARM Americas countries.”

The strategy arises from the achievements made through the work by 24 countries within the ISARM Americas framework, which takes into account the information collected in the three previous publications of the ISARM-Americas network, where a total of 73 TBAs were inventoried (as per 2009, UNESCO, 2010). The strategy for the Americas was also inspired by the Draft Articles of the UN Resolution on the Law of Transboundary Aquifers.

3.5. Time-scale and space-scale factors

During the 15 years that ISARM activities took place, the sustainable management of transboundary aquifers concept has been extensively discussed. ISARM participants and stakeholders discussed various concepts in an effort to reach a consensus on the way forward. One of the most acceptable ideas was the “fair and equitable sharing of the groundwater resource” concept, which is also described in the UN Law of TBAs. But how effective may that concept be?

As previously mentioned, it is recommended that TBAs are used in a sustainable manner. However joint management can be complex, especially with large TBAs (e.g., Guarani, Milk River, Chad Basin). Thus as has been suggested in the TBAs assessment stage, the joint management of TBAs can also be oriented, in principle, to their portions of the international border in order to adopt a management plan which aims to prevent or mitigate cross-border conflicts.

A very complex aspect refers to the approach of distributing the available groundwater resources among the countries that share a TBA. When it comes to distributing a common good, it is natural to immediately think about fair equitable distribution. But how can one understand this concept when it comes to natural systems, which often present wide inequalities or asymmetries in all the involved factors?

Although there is no single answer to that question, the following aspects can be considered: the area of the TBA that corresponds to each country; each country's contribution to the total aquifer system recharge; the aquifer's hydrogeological characteristics; the magnitude of current and future water demands; the spatial distribution of their reserves (groundwater storage); the legal framework for water; parties and stakeholders' economic and technological ability, etc.

For example, can one of the countries that share the TBA claim a bigger fraction of the available water resources because it occupies a larger portion of the TBA, because their water needs are greater, because it began uptaking and using water before, because it brings a bigger recharge fraction? Although it may seem logical, the solution is not as simple as distributing the available volume equally, or proportionally, to the surface that corresponds to the TBA. Obviously no general distribution criterion exists which enables each case to be the subject of negotiations among the involved parties, which must necessarily rely on technical and scientific knowledge about the system.

In this context, extensive efforts to recognize and accommodate asymmetries in the underlying legal and regulatory frameworks for water management are essential to meet the objectives of the countries that share the aquifer. There have been a few cases in which binational research works have addressed institutional asymmetries and established the foundation of genuinely collaborative efforts to acquire, share and analyze data/information (Megdal and Scott, 2011).

This brings us to the importance of science, data, information, numerical tools and general scientific knowledge that transboundary aquifers must have for informed-based decision-making purposes. By way of example, we briefly discuss the case of the Milk River transboundary aquifer shared by Canada and the USA.

The Milk River Transboundary Aquifer (MRTA) forms part of the ISARM-Americas inventory with the official tag: ISARM#20N. The MRTA straddles southern Alberta (Canada) and northern Montana (USA) and lies in a semi-arid region with well-documented water shortages (Pétré et al., 2016). The MRTA is a confined sandstone aquifer that is a source for municipal water supply and agricultural uses on the Canadian side. It is also used for water supply to enhance the secondary oil recovery work on the US-side of the border. It is a transboundary aquifer shared by multi-stakeholders in six jurisdictions: Federal, State and Municipal (USA), and Federal, Provincial and Municipal (Canada).

Application of numerical models for aquifer management is not a new undertaking, but it is being increasingly applied to TBAs (Szöcs, this issue and Milk River TBA). Scientific studies of the MRTA have developed three models to better understand the nature, scales and hydrodynamics of groundwater fluxes of the transboundary aquifer: a geological 3D unified model (Pétré et al., 2015); a unified hydrogeological conceptual model (Pétré et al., 2016); and an integrated groundwater flow numerical model (Pétré et al., 2018).

These studies allowed a very detailed transboundary delineation of the aquifer with a continuous representation of its hydrostratigraphy across the Canada/US border, as well as a better understanding of the aquifer's regional transboundary dynamics. The conceptual model allowed a detailed quantitative understanding of the aquifer system and dynamics with detailed water balances, as well as the identification of areas with water deficits. Furthermore, clear regions for internationally shared management strategies were identified. As discussed above, not all the aquifer's areas have the same dynamics, nor the same interests or impacts; a map of the aquifer's space- and time-scale factors for the different MRTA stakeholders' interests is shown in Fig. 1.

The issue of scale is one of the reasons why some scientists are considering defining groundwater flow systems, rather than aquifers, as a future quantitative analysis to define groundwater availability, which was learned from the Guarani and the Milk River TBAs, among others (Rivera, 2017; Rivera et al., 2017).

3.6. *Global issues*

3.6.1. *North America*

Two drivers threaten most borderland-shared waters: the demographic momentum driven by migration and climate change. For instance, these drivers may increase further floods and more intense droughts to the US/Mexican border and Canada/US borders. The International Boundary and Water Commission (IBWC, US/Mexico) has already issued warnings about the eventual impacts of drought on water supplies. Moreover, the International Joint Commission (IJC, Canada/US) has issued its triennial assessment report that recommends activities to improve the understanding of groundwater and its connectivity to surface waters in the shared waters of the Great Lakes Basin (IJC, 2017).

The current binational efforts made between the U.S. and Mexico on transboundary aquifers have been limited to the aquifers designated as priority by the U.S. – Mexico Transboundary Aquifer Assessment Act (Public Law 109–448). Centers and institutes in both countries are working to develop joint strategic plans for future work based on lessons learned and relationships built (see Callegary et al., this Special Issue).

Inspired by the ISARM approach and the UN resolution on Law of Transboundary Aquifers, some of the TABs in these countries have strengthened cooperation along their borders. This has been critical to ensure cooperative mechanisms, such as new agreements and protocols for information exchange and data sharing, and to enhance the development of accurate water policies and water conservation plans for managing aquifers sustainably according to population requirements. These efforts establish the basis to apply international water law principles. The Cooperative Process for TBAs efforts along the US-MX border are well described in Callegary et al. (this issue). However, studies for some priority aquifers along the US-MX border did not form part of ISARM because they began after most ISARM-Americas efforts had been made. Thus in this regional case, one of the lessons that can be emphasized is the potential to learn from other studies beyond the ISARM process.

Several meetings and workshops across North America have brought together water analysts and officials from the three countries to compare approaches to binational water cooperation. These meetings have proved quite useful in scientific water resources assessment, with a particular focus on transboundary aquifers on Canada-US and US-Mexico borders. Transboundary water resources

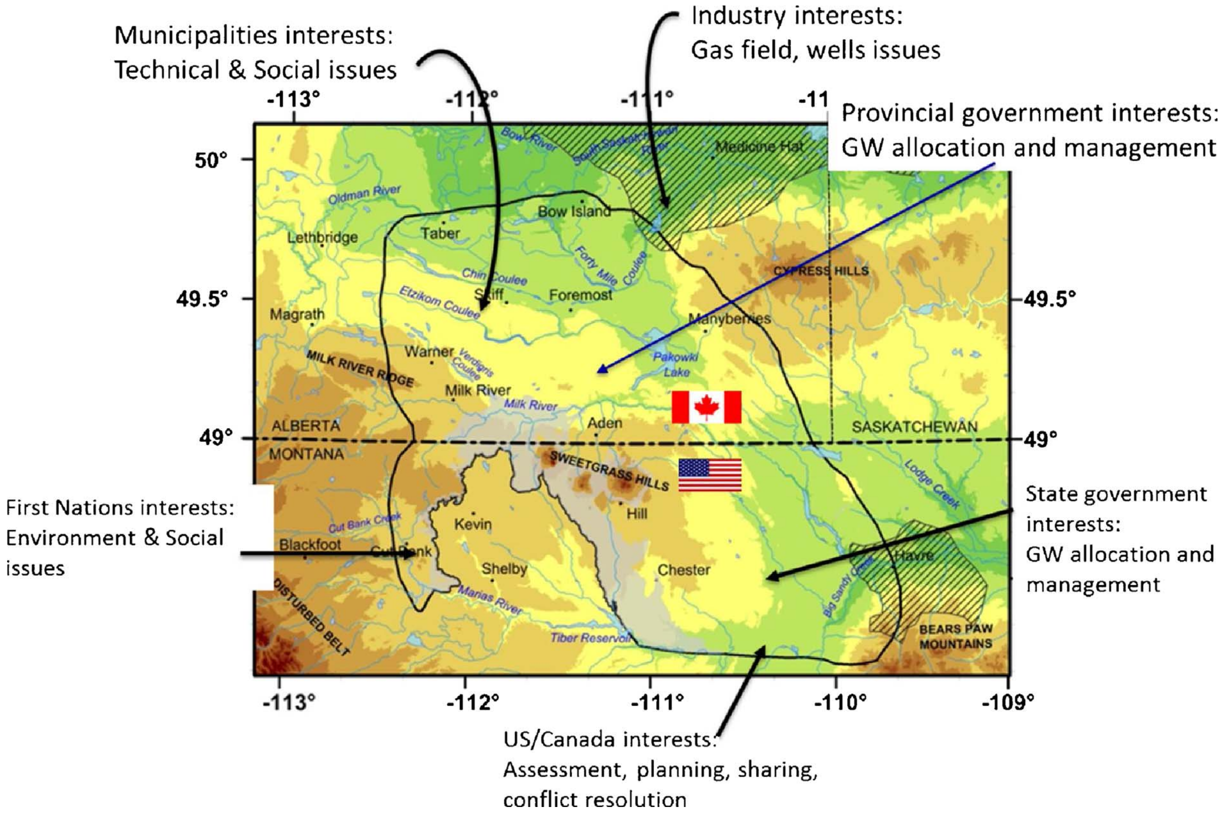

Fig. 1. Example of the space- and time-scale factors for the Milk River Transboundary Aquifer Canada/US stakeholders' different interests (Rivera, 2017).

policies, including legal frameworks, mechanisms for cooperation, and water rights administration, have also been discussed with less tangible outcomes. However, engaging high-level policy makers and government officials in discussions has proved most helpful as they provide a vision for future collaboration, including binational water management prospects (Minute 319, 2000; Rivera et al., 2017; TAAP, 2013). It should be noted, however, that the TBA assessment efforts along the US-MX border explicitly specify that the results of scientific studies do not imply anything about binational groundwater management.

3.6.2. South America

As in other areas of the world, two of the most important lessons learned in South America are related with space scales and socio-political issues. For instance, the large Guarani Aquifer system (ISARM#21S, shared by Brazil, Paraguay, Uruguay and Argentina), has undergone extensive hydrogeological assessments in more than a decade of intended shared management by the four countries sharing the same aquifer system. Being a world reference as to how to manage a TBA, the Guarani aquifer has passed from an inspiration and hope for other TBAs to a question mark due to the non-entry into force of the Guarani Aquifer Agreement (see Sindico et al., this issue). Indeed a management agreement for the Guarani Aquifer System was signed by the four presidents of those countries in 2010 as a: "Joint Declaration – San Juan, Argentina, August 2, 2010 Agreement on the Guarani Aquifer – Argentina, Brazil, Paraguay and Uruguay" (Acuerdo, 2010). For socio-political and other reasons explained in Sindico et al. (this issue), after 7 years this agreement has not been ratified by Brazil and Paraguay.

Nonetheless, management has continued in some specific areas of the aquifer system in past year despite the non-entry of the agreement into force. In particular, the cities located along the borders of the countries that share the aquifer have continued to jointly manage the natural resource. This also reflects the space issue of potential impacts closer to international borders.

Another issue is the precise delineation of a transboundary aquifer that is even larger than the Guarani, the Amazonas Transboundary Aquifer (ISARM#28S), which is shared by six countries and covers an estimated area of 3,950,000 km^2. Is this one transboundary aquifer, or is it an integration of several aquifers that are located mostly in Amazon plains? The ISARM Americas group defined it as a transboundary aquifer system based mostly on the geology of the central and eastern parts of Amazon plains and the Orinoco province with a unique ecosystem. However, no hydrogeological studies have been conducted to precisely define whether the whole system can be considered transboundary according to the ISARM definition and contex. So like other very large TBAs, the space scale likely is defined on whether or not these are indeed a one transboundary system.

3.6.3. Europe

In Europe, the extension and size of TBAs are generally limited compared to aquifer systems in other parts of the world. The complexity of the geology in the region means that some small aquifers have no hydraulic connection and fragmented information, which has led to previous inconsistent methodological approaches to map transboundary aquifers (UNESCO-IHP, 2011; DIKTAS, 2012; IGRAC, 2012; BGR-UNESCO, 2013). An added difficulty is information collection. Compiling available information is no easy task: most reports come in national languages and internationally available information is very limited.

About 75% of the population depends on groundwater for water supply, but major industrial development takes place for geothermal exploitation purposes (TRANSENERGY project, Szőcs, this issue). Countries across the region experience water scarcities to varying degrees, mainly those in the dry and irrigation-intensive river basins in Southern Europe and hot spots around urban centers. Water scarcity often happens in areas with low rainfall, which opens a gap between demand and supply, particularly in areas with a high population density, tourist inflow, and intensive agriculture and water-demanding industries. Industrial development (large-scale mining, thermal exploitation) and groundwater pollution by agriculture may also deteriorate aquifer quality.

In terminology terms, in EU countries only the Water Framework Directive (WFD) of *Groundwater Bodies* applies (2000/60/EC, 2000). The WFD establishes a legal framework and harmonises other EU-related legislation. EU policy implementation foresees river basin management plans and the definition of groundwater bodies in the rivers district in line with integrated water resources management (IWRM). According to the EU definition, a groundwater body is a coherent subunit in the river basin (district) to which the environmental objectives of the Directive must apply. As part of the TWAP-GEF Groundwater component project, the European region was assessed for better harmonization in 2012 (UNESCO-IHP, 2011; IGRAC, 2012; WWAP, 2012).

In the 27 EU member countries, the WFD *Groundwater Bodies* have been mainly assessed. For EU Member States, Accession Countries (currently eight countries), or within EFTA (four countries), the WFD establishes a legal framework and harmonises other EU-related legislation. EU policy implementation foresees river basin management plans and the definition of groundwater bodies in the rivers district in line with the integrated water resources management approach (IWRM). To harmonise the implementation of the WFD between Member States and *Accession Countries*, the European Water Directors have developed a common implementation strategy. At the transboundary level, the WFD also contemplates establishing transboundary river basin commissions, like the International Commission for the Protection of the Rhine River (ICPDR), which also includes groundwater resources.

Governance and management of European TBAs are complicated by the fact that limited information on the scope of the agreements exists, and whether a common implementation strategy to cover the management plan and measures to be taken have been adopted, and if they are available.

As for agreements (33% of countries have reported ratified agreements), the scope or meaning has different interpretations for the countries that share TBAs, as reported information has indicated. Some refer to the signed Water Directives in force (e.g. WFD-EU TWAP) or the signing of international conventions. Very few TBAs have prepared, signed or ratified agreements. The few that exist are generally of a bilateral form (the management agreement for Upper Pannonian Thermal Aquifer EU24, Belgian-Dutch-German Lowland Aquifer).

3.6.4. *Africa*

Work on TBAs in Africa has proven to create an impetus for cooperation on groundwater-related activities of aquifer sharing countries, and can even be a driver for national groundwater management. In order to manage issues of transboundary impacts, very large units that comprise, for example, a complete sedimentary basin of more than 100,000 km^2 may, however, not be that useful. For management purposes, it is practical to define zones of (potential) transboundary impacts within the TBAs. Based on sound hydrogeological and scientific methods, such zoning (scale factor) will provide a focus to allocate limited resources for groundwater-related activities more efficiently.

Seventy-two transboundary aquifers have been mapped in Africa and are of much importance as they cover about 40% of the continent, and also because about 33% of the African population lives on top of these TBAs (see Nijsten et al., this issue). TBA Mapping in Africa has steadily progressed since the beginning of this century, but is far from conclusive. The same is true for assessments as information is fragmented and only about 11 TBAs have been assessed in detail. The joint monitoring and management of TBAs are still in their early stages. Notable exceptions include some six TBAs with formalised cooperation, mostly in North Africa. The recent Transboundary Waters Assessment Programme (TWAP, 2012) has compiled a lot of information that was not previously available nationally, which allows TBAs to be described in terms of indicators. However, discrepancies between reported governance arrangements and the formal status of such arrangements indicate that agreements may not be fully internalised.

Increased awareness and the activity of international organisations is noticeable, but remains challenging to convert international cooperation into positive impacts locally.

3.6.5. *Asia*

Lack of expertise, experience and institutional support in many parts of Asia has restricted the cooperation and sustainable management of shared aquifer resources.

Considerable progress has been made, but the level of understanding of the shared aquifer systems of Asia is limited. Reliable TBAs data are still lacking, particularly for developing countries, which suggests that continuous efforts are needed to improve knowledge about TBAs and to facilitate informant sharing and access to TBAs data.

Several countries, such as China, have endeavoured to cooperate internationally towards shared water resource management by establishing TBA institutes, as well as creating mutual agreements with neighboring countries. These are significant milestones and clear outcomes of ISARM. A more detailed description is provided in Lee et al. (this issue).

4. Legislation, governance and shared management

Currently there are two main frameworks, or guiding documents, that can be used for the shared management and governance of transboundary aquifers: the UN Draft Articles on the Law of Transboundary Aquifers (UNGA, 2008) and the UN Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention) completed in 1999 (UNWC, 2014). A detailed description of the development, application, relevance and comparison of the two frameworks is provided in Lipponen (this issue) and is not repeated here.

However, legislation is not enough for groundwater governance of transboundary aquifers. The application of legislation to TBAs is a very complex issue given the many stakeholders involved, the level of knowledge and the level of cooperation among stakeholders.

Transboundary water management presents many special challenges to politicians, planners, administrators and scientists. Problems that affect water management and water policy implementation include strong cooperation on data information about economic, political, cultural and social issues, and also on geographical issues. Joint efforts are needed to achieve a common implementation strategy to monitor networks' definition, standardised data collection, information exchange through networking activities, guidance documents to assist in implementation and technical reports at the transboundary level. Furthermore, for joint efforts to be practical and efficient, all types of data (e.g., socio-economic) need to be harmonised and joint databases have to be set up for joint information management.

Groundwater governance presents challenges that require many different sets of skills from different fields: hydrogeologists, lawyers, economists, water managers, anthropologists, just to name a few. All of these speak very different languages in their own way and often do not make the necessary effort to communicate among others. Some of these challenges are discussed in the FAO "Global Framework for Action" (FAO, 2015a). It has been found that groundwater governance almost everywhere is insufficient, with the various key deficiencies as identified in the Global Diagnostic on groundwater governance (FAO, 2015b).

To achieve the Shared Vision 2030 goals, the Framework for Action describes in detail the main urgent actions needed, which are: (1) creating an adequate basis for governance; (2) building effective institutions; (3) making essential linkages; (4) redirecting finances; (5) starting the planning and management process. These are described in detail in the Global Framework for Action document (FAO 2015a).

In all EU regions, legal agreements on cooperation in transboundary water issues have been concluded and operational components in the form of joint commissions have been established, while some other agreements are still being prepared. The Geneva Aquifer (de los Cobos, this issue) is an example of a full governance and management agreement, while a more specific agreement that focuses mainly on geothermal aspects of the TBA is the objective of the Upper Pannonian transboundary aquifer (Szöcs, this issue).

Although the legal basis for cooperation in managing transboundary waters in the pan-European region is well developed, most existing agreements do not explicitly refer to groundwater, or their application to groundwater remains limited. Thus it is necessary to improve legal frameworks for cooperation and to strengthen institutions for the management and protection of groundwater.

Establishing shared transboundary resource management should imply defining common approaches for data collection and information requirements. Requirements should focus on meeting the proposed objectives towards a common implementation strategy.

5. Sustainable development goal #6, towards the 2030 UN agenda

The UN seeks to transform the World with the 2030 Agenda for Sustainable Development. The adopted 17 Sustainable Development Goals and 169 targets will stimulate action over the next 15 years in areas of critical importance for humanity and the planet.

Of the 17 sustainable development goals of the UN for 2030, the sixth Sustainable Development Goal (SDG6: Ensure availability and sustainable management of water and sanitation for all) is exclusively designed for water, and covers a 15-year time span to achieve and maintain universal access to water. However, reliable management systems need to be put into place for SDG6 to be successful. An SDG subcategory, SDG6.5, may even be more difficult to achieve as it deals with transboundary waters. While ISARM has been underway for 15 years, TBA-related institutions that work on managing transboundary aquifers have been even scarcer than any other water-related institutions.

In the next 15 years, SDGs are expected to act as a major target for the efforts of the practitioners who deal with transboundary waters and national aquifers. It is anticipated that some consultation mechanisms will become operational, and will provide a new paradigm for bi- and multi-lateral engagement between countries, whose outcome would improve socio-economic development, and, if not a reversal of aquifer degradation, then at least a stabilization.

The goal on water and sanitation for the 2030 Agenda has recognized that the sector at large would require a coherent monitoring framework with improved data collection and analysis to cover the whole water cycle. To meet this need, seven UN agencies joined forces under the UN-Water umbrella to develop the Integrated Monitoring of Water and Sanitation Related SDG Targets initiative.

By integrating and extending existing monitoring efforts, draft methodologies for all the global SDG 6 indicators have been developed. Starting in April 2016, methodologies were introduced into six countries for in-depth pilot testing purposes.

Based on learning from pilot testing and the broader review, the methodologies were revised by the end of 2016, and will follow a global implementation that started in 2017. By 2018, a global baseline for SDG 6, target 6.5, indicator 6.5.2, should be available; this indicator is designed by UNESCO-IHP for transboundary aquifers (UNECE and UNESCO, 2017).

6. Summary and conclusions: what is next?

This paper synthesizes more than 15 years of experiences of the Internationally Shared Aquifer Resources Management Initiative (ISARM, from 2000 to 2015) outputs and outcomes. We discuss the lessons learned from ISARM, as well as the status and perspectives for the future. The conclusions and recommendations are based mainly on the chapters on the special issue, but themes (issues) are laid out from other stories of transboundary aquifers (TBAs) in the world that are not presented in the special issue.

Many analyses have indicated a future of the *institutionalized* transboundary aquifer cooperation distilled from analyzing experience so far, as also indicated by some of the other contributions made to this Special Issue. Bringing together science, society, law and policy making, and harmonising information, important drivers and impacts, will act as guidance for further TBAs assessments.

Sharing a common groundwater resource requires all the parties involved to collaborate in a coordinated and excellent way to ensure the sustainable use and protection of the resource. The best way to protect and manage transboundary aquifers is through close international cooperation among all the countries involved in TBAs by bringing together all interests.

One of the most important lessons learned with TBAs is that related with the *scale issue*. As a result of assessing some of the largest transboundary aquifers (Guarani, Milk River), some scientists are considering parsing out *groundwater flow systems* rather than aquifers boundaries as a future quantitative analysis to define groundwater availability along the borderlines of TBAs. This is a very important outcome of ISARM; it is a matter of scales to accommodate TBA-related issues, other than *only* science. TBAs require social, political, economic and environmental factors *in* addition to science (hydrogeology).

Other relevant conclusions, open questions, and recommendations are:

- In the Pan-European region, a long-standing history of inventories and documentation of evolution demonstrates the gradual refinement of information, and also the interplay of scientific knowledge advancement and fluctuating political recognition on TBAs.
- Should we re-direct ISARM driven by policy, social, environmental economic issues?
- What can science do? Can groundwater science do it alone? How can science interact with policy makers and social impacts? How should a science-policy interface be implemented? Is ISARM still needed? These and many other similar questions were asked from stakeholders around the world during the ISARM continental surveys. Clearly, a paradigm shift is emerging from the “science for science sake” towards more integrated, issue-driven, science-based socio-political partnerships.
- Groundwater science and technology for TBAs should be embedded in a larger socio-economic and political system for international stability.
- *Trust* among the countries that share TBAs is essential to promote effective cooperation and to exchange information for shared management. In this sense, the process developed by ISARM Americas for over 15 years has successfully obtained tangible results: four books, plus a strong network of national experts.
- The international legal instruments in the Americas are still incipient. The only agreement on integrated transboundary aquifers in South America is about the management of the Guarani Aquifer System: “Joint Declaration – San Juan, Argentina, August 2, 2010 Agreement on the Guarani Aquifer – Argentina, Brazil, Paraguay and Uruguay” (Acuerdo, 2010).
- The ISARM process is slow and difficult, but stakeholders across continents are reducing and balancing the cooperative gap among science, society and policy making.
- A very positive, and perhaps a model to follow, is the Genevese transboundary aquifer (Switzerland-France) of 40 years of peaceful and successful shared management.
- The UNESCO-IHP ISARM remains one of the key dedicated global drivers for the continued understanding, assessment and strengthening of inter country collaboration of transboundary aquifers. Acknowledgement of their efforts is mentioned in Puri and Aureli’s paper (this Special Issue).
- As discussed in detailed by Puri and Aureli and by Burchi, 2018, the most critical part of the whole equation is the *institutionalization* of the process. This part remains a conundrum since there is no ideal single format for such a body and their design has to be adopted on a case-by-case basis.
- Nine years after adopting the first Draft Articles, there is a perception that there is *no will* to establish international laws that may have be stronger than multilateral or bilateral agreements, and there are concerns about having to cede some riparian rights. Recently during the adoption of the third round of discussions on the Law of TBAs at the United Nations General Assembly (UNGA, 2016), a speaker told the Sixth Committee that “While Management of Transboundary Aquifers is critical for the success of the UN 2030 Agenda, the Draft Articles must be tailored to each state”.
- Detailed studies of TBAs have high costs. Most developing countries face other basic priorities as their society have bare any public investment capacity.
- In general, there are no conflicts among the countries that share TBAs. However, some conflicts have arisen, which could increase in the TBAs of North America where *competition* for groundwater resources is much more obvious and prominent (e.g., Mexico-U.S.). Knowledge cooperation and exchange has been crucial to prevent conflicts.
- Regular TBAs assessments are needed; building a sustainable coalition within regions may require building a community platform to establish links among the researchers, practitioners, policy makers and stakeholders involved with TBAs initiatives.
- Regular assessments will ensure up-to-date aquifer information, which is implied by the concept of integrated water resources management at the transboundary level and the assessments of possible trends and the definition of new information needs by taking into account the needs of the interest groups involved in the process. Building a participatory infrastructure is considered a very important condition for successful future assessments.

- Policy responses reflect times of global change and uncertainties, which depend on: a) good information; b) a good information dissemination; c) a good understanding of that information.
- Political (legal) agreements are issue-driven, and environmental concerns are low down in political agendas, but *social pressures* and *science-push* are changing this scenario.
- The Draft Articles on the Law of transboundary aquifers have become a reference for TBAs and are still relevant, but are perceived *only* as guidelines and for influence.
- As a final remark, we should wonder why we continue to pay attention to transboundary aquifers. Fifteen years of ISARM clearly show that this is mainly to build trust and to avoid conflict- *any* conflict: social, political, economic, environmental, even human confrontations.

Conflicts of interest

None.

Acknowledgements

The authors would like to acknowledge the ongoing support of UNESCO and the corresponding ISARM teams from the Americas and Europe. The Geological Survey of Canada and the Technical University of Catalonia-UPC, Spain, provided technical support.

This is a Lands and Minerals Sector contribution 20170318 for the first author and Ministerio de Economía y Competitividad of Spain (CGL2013-48802-C3-3-R) for the second author. This paper has benefited from the generous comments of three anonymous reviewers.

References

2000/60/EC, 2000. Directive 2000/60/EC of the European Parliament and of the Council Establishing a Framework for the Community Action in the Field of Water Policy.
Acuerdo, 2010. Acuerdo sobre el Acuífero Guaraní (Argentina, Brasil, Paraguay y Uruguay); en San Juan, Argentina, 2 de agosto de 2010.
BGR-UNESCO, 2013. IHME1500: International Hydrogeological Map of Europe. www.bgr.bund.de/ihme1500/.
Burchi, S., 2018. Agreements on Transboundary Aquifers: Pre- and Post-ISARM Experience. (This issue).
DIKTAS, 2012. Protection and Sustainable Use of the Dinaric Karst Transboundary Aquifer System. National Report Bosnia and Herzegovina. . http://diktas.iwlearn.org.
FAO, 2015a. A Global Framework for Action – to Achieve the Vision on Groundwater Governance. www.groundwatergovernance.org.
FAO, 2015b. Global Diagnostic on Groundwater Governance. www.groundwatergovernance.org.
IGRAC, 2012. Transboundary Aquifers of the World: Update 2012. Special Edition for 6thWorldWater Forum, Marseille, France, March 2012. http://www.un-igrac.org/publications/456.
International Joint Commission-IJC, 2017. First Triennial Assessment of Progress On~ Great Lakes Water Quality Prepared by the International Joint Commission Pursuant to Article 7 (1) (k) of the 2012 Great Lakes Water Quality Agreement January 2017 Draft Report for Purposes of Public Consultation. January, 2017.
Lee, E., Jayakumar, R., Shrestha, S., Zaisheng, H., 2018. Assessment of Transboundary Aquifer Resources in Asia: Status and Progress towards Sustainable Groundwater Management (this issue).
Machard de Gramont, H., Noel, C., Oliver, J.L., Pennequin, D., Rama, M., et Stephan, R.M., 2010. Vers une gestion concertée des systèmes aquifères transfrontaliers: guide méthodologique. AFD, Paris.
Megdal, S.B., Scott, C.A., 2011. The importance of institutional asymmetries to the development of binational aquifer assessment programs: the Arizona-Sonora experience. Water 3, 949–963. http://dx.doi.org/10.3390/w3030949.
Minute 319, 2012. International Boundary and Water Commission United States and Mexico. Interim International Cooperative Measures in the ColoradoRiver Basin Through 2017 and Extension of Minute 318Cooperative Measures to Address the Continued Effects of the April 2010 Earthquake in The Mexicali Valley, Baja California. Minute 319, Mexico (November 20, 2012).
Pétré, M.A., Rivera, A., Lefebvre, R., 2015. Three-dimensional unified geological model of the milk river transboundary aquifer (Alberta, Canada –Montana, USA). Can. J. Earth Sci. 52, 96–111. http://dx.doi.org/10.1139/cjes-2014-0079.
Pétré, M.A., Rivera, A., Lefebvre, R., Hendry, J., Folnagy, A., 2016. A unified hydrogeological conceptual model of the Milk River transboundary aquifer, traversing Alberta (Canada) and Montana (USA). Hydrol. J. 2016 (24), 1847. http://dx.doi.org/10.1007/s10040-016-1433-8.
Pétré, M.A., Rivera, A., Lefebvre, R., 2018. Steady-state regional groundwater flow model of the milk river transboundary aquifer (Alberta, Canada- Montana, USA). J. Hydrol (in review).
Puri, S., Aureli, A., 2005. Tranboundary aquifers: a global program to assess, evaluate, and develop policy. Groundwater 43 (5), 661–668.
RIOB, 2013. Manuel de la Gestion Intégrée des Ressources en Eau dans les Bassins des Fleuves, des Lacs et des Aquifères Transfrontaliers. Réseau International des Organismes de Bassin, Partenariat Mondial de l'eau. Office International de l'Eau. http://www.riob.org/riob/information-et-publications/article/manuel-de-la-gestion-integree-des.
Rivera, A., (ed.), 2015. Regional Strategy for the Assessment and Management of the Transboundary Aquifer Systems in the Americas – a UNESCO publication: http://unesdoc.unesco.org/images/0023/002353/235394s.pdf. Serie ISARM Américas, No 4 ISBN 978-92-9089-196-3.
Rivera, A., 2017. International Course on Regional Strategies for the Management of Transboundary Aquifers. UNAM, Mexico City (August 2017).
Rivera, A., Megdal, S., Tracy, J., Van Schoik, R., Fernald, S., Milanés-Murcia, M., 2017. Shared Water of North America, Special Session of the XVI World Water Congress, Cancun, May, 2017. http://www.worldwatercongress.com/; http://wwc2017. iwra.org/agenda.php.
TAAP, 2013. Five-Year Interim Report of the United States –Mexico Transboundary Aquifer Assessment Program (TAAP): 2007–2012 Open-File Report 2013–1059. U.S. Department of the Interior U.S. Geological Survey.
TRANSENERGY-Project, 2017. Transboundary Geothermal Energy Resources of Slovenia, Austria. Hungary and Slovakia, TRANSENERGY-Project. http://transenergy-eu.geologie.ac.at/.
TWAP, 2012. Rransboundary Aquifers (TWAP Project). https://www.un-igrac.org/ggis/transboundary-aquifers-twap-project.
UNECE, UNESCO, 2017. Step-by-Step Monitoring Guide: Indicator 6.5.2. (Available from: http://www.sdg6monitoring.org/news/indicators/652).
UNECE, 2011. Second Assessment of Transboundary Rivers, Lakes and Groundwaters. Economic Commission for Europe. Convention on the Protection and Use of Transboundary Watercourses and International Lakes. ECE/MP.WAT/33. www.unece.org/?id=26343.
UNEP, 2011. Methodology for the GEF transboundary waters assessment programme. In: In: Jeftic, L., Glennie, P., Talaue-McManus, L., Thornton, J.A. (Eds.), Methodology for the Assessment of Transboundary Aquifers, Lake Basins, River Basins, Large Marine Ecosystems, and the Open Ocean Vol. 1 UNEP (x+60 pp).
UNESCO, 2001. Internationally Shared (Transboundary) Aquifer Resources Management. Their Significance and Sustainable Management. A Framework Document.

on Serial Document SC-2001/WS/40. (74 pp).
UNESCO, 2010. Aspectos socioeconómicos, ambientales y climáticos de los sistemas acuíferos transfronterizos de las américas. Book no 3 PHI-VII/series ISARM Américas no 3.
UNESCO-IHP, 2011. Methodology for the GEF Transboundary Waters Assessment Programme. Volume 2. Methodology for the Assessment of Transboundary Aquifers. UNEP vi + 113 pp.
UNGA, United Nations General Assembly Resolution on the Law of Transboundary Aquifers: A/RES/63/124, December 2008; A/RES/66/104, December 2011; A/RES/68/118, December 2013; and A/RES/71/150, December 2016, 2008.
UNWC, 2014. Convention on the Law of the Non-navigational Uses of International Watercourses 1997. (http://legal.un.org/ilc/texts/instruments/english/conventions/8_3_1997.pdf).
WHYMAP, 2006. Groundwater Resources of the World: Transboundary Aquifer Systems. BGR and UNESCO. http://www.whymap.org/whymap/EN/Downloads/Global_maps/.
WWAP, 2012. The of the World Water Development Report (WWDR4), 'Managing Water Under Uncertainty and Risk' A UNESCO Publication. fourth edition. . http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/wwdr4-2012/.
Wada, Y., Heinrich, L., 2013. Assessment of transboundary aquifers of the world#xp#vulnerability arising from human water use. Environ. Res. Lett. 8 (number 2). http://dx.doi.org/10.1088/1748-9326/8/2/024003.
Wolf, A.T., Natharius, J.A., Danielson, J.J., Ward, B.S., Pender, J.K., 1999. International river basins of the world Int. J. Water Resour. D 15, 387–427.