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ISARM2021

2nd International Conference

Transboundary Aquifers

Challenges and the way forward

06 – 09 December 2021 / UNESCO, Paris

Book of abstracts

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SHORT SUMMARY

Transboundary aquifers are not only a source of freshwater for human society, they also represent geographic, economic and geopolitical space

This book contains 152 abstracts selected by the Conference's Technical Programme Committee and Scientific Committee for presentations and posters at the International Shared Aquifer Resources Management conference ISARM2021.

The abstracts present the current status of knowledge, practice and progress on transboundary aquifers; they contain a rich variety of case studies related to all regions of the world.

38% of the authors are women, **21% of the abstract are presenting features related to the African countries**, and 15% of the authors are young scientists under 30 years old.

The content of the abstracts is related to all the five topics of the conference: "*Advances in the assessment and mapping of transboundary aquifer and hydrogeological methods*" which will highlight recent developments on the delineation and assessment of transboundary aquifers around the world; "*Governance of transboundary aquifers: strengthening cooperation*" where the available record will be explored, including the available legal frameworks at the global and aquifer-specific level; "*Science-Policy: focus on the management of transboundary aquifers*", which will highlight the importance of joint approaches, and greater degree of collaboration on a regular basis; "*Transboundary aquifers contributions to sustainable development goals and regional agendas*" and its critical role for human needs, for socio-economic development, and healthy ecosystems; and "*Education, Capacity Building and Raising Awareness*" to support the development of educational initiatives on transboundary water cooperation and develop sustainable practice and guidance tools on shared water resources management.

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"Since wars begin in the minds of men and women it is in the minds of men and women that the defences of peace must be constructed"

Preface

We present this book of abstracts with great pleasure, it constitutes the basis of the technical programme of the International Conference on 'Transboundary Aquifers: Challenges and new directions' (ISARM2021), organized by UNESCO and its partners as an online event on 6–9 December 2021.

The UNESCO International Shared Aquifer Resources Management (ISARM) Programme was launched in June 2000 at the 14th Session of the Intergovernmental Council of the UNESCO International Hydrological Programme (IHP). The first decade of the ISARM Programme culminated in a major international Conference in 2010 (ISARM2010 International Conference: "Transboundary Aquifers: Challenges and new directions", 6-8 December 2010). Ten years after that significant Conference, a second 'decadal Conference' is now being held in 2021.

This book of abstracts contains all the papers that were submitted by a significantly increased range of experts, compared to 2010, demonstrating that there is much wider interest in the topic of transboundary aquifers, complementing to some extent the very high level of interest in transboundary river basins and lakes. The scope of this interest encompasses the science and technology of these resources, their environmental and social value, and the required regulatory frameworks that ensure inter-country cooperation, as well as their sustainability.

The abstracts presented in this book somehow reflect the state of knowledge and shared management of transboundary aquifers at the global scale. They cover five important domains of study: Transboundary aquifer contributions to SDG goals and regional agendas; The Science/Policy interface: focus on the management of transboundary aquifers; Advances in the assessment and mapping of transboundary aquifers and hydrogeological methods; Governance of transboundary aquifers: strengthening cooperation; and Education, capacity development and awareness raising.

A selection of 30 technical papers, as well as a report of the discussions and the recommendations that will emerge from this Conference, will be published separately in 2022.

On behalf of our Conference's organisers, we wish to thank the co-conveners and partners of this second major international Conference on transboundary aquifers, as well as all the participants for their valuable contribution and their recommendations.

Alfonso Rivera,
Co-chair Scientific Committee

Alice Aureli,
Chair Organising Committee

Shammy Puri,
Co-chair Scientific Committee

Acknowledgements

This publication contains the abstracts of papers and posters received from countries across the world, that will be presented during the 2nd UNESCO International Conference on Transboundary Aquifers (ISARM2021). We would therefore like to acknowledge the work of the Technical programme Committee and the Scientific Committee for their initial remarks and recommendations on the selection of these conference papers. We also thank the Organization Committee and the Conference Secretariat. The abstracts were edited by Mahmoud Radwan and proofread by Marina Rubio, Ros Wright and Aya Ben Abdallah (UNESCO IHP).

We would like to express our gratitude to our partners, IAH and IW-LEARN for their continued support in the preparation of this Conference. In addition, to the many organizations that have also collaborated with UNESCO-IHP, including, amongst others, UNECE, UN-IGRAC, IWRA, CeReGAS, IWMI, the Texas Water Resources Institute and AIDA. Special thanks go to the Chairs and Rapporteurs of this event, for their time and commitment.

Finally, to all the speakers and their affiliated organizations, we gratefully acknowledge their technical input; without their expertise this Conference could not hope to achieve its full potential.

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TOPIC 1 :

Tba Contributions to Sustainable Development Goals and Regional Agendas

Transboundary groundwater in international law

Elena Quadri[1]

The strategic importance of groundwater is on the rise due to a variety of factors, notably the un-sustainable exploitation of the resource, pollution, and climate variability. Of the 592 aquifers that have been characterized as transboundary, including 226 "groundwater bodies" under EU Directive 2000/60/EC, only six are covered by a formal agreement concluded by the States concerned. After a technical analysis of water availability at a global scale, this research traces the steps that have led to the recognition of groundwater in the transboundary water agreements among States. The UN Draft Articles on the Law of Transboundary Aquifers (2008) will receive special attention in view of the importance of the Draft Articles as the chief legal instrument, albeit non-binding, concerning the management and protection of aquifers shared by two or more States The analysis of the UN Draft Articles will be complemented by the analysis of the few formal agreements on record regarding, respectively, the Genevese Aquifer (Swiss and French local authorities), the Nubian Sandstone Aquifer System (Egypt, Lybia, Sudan, Chad), the Northwestern Sahara Aquifer System (Algeria, Lybia, Tunisia), the Iullemeden Aquifer System (Niger, Nigeria, Mali) and the Iullemeden and Taoudeni/Tanezrouft Aquifer System (Algeria, Benin, Burkina Faso, Mali, Mauritania, Niger and Nigeria), the Guaranì Aquifer System (Argentina, Brazil, Paraguay, Uruguay), and the Al-Sag/Al-Disi Aquifer (Jordan, Saudi Arabia). A few informal agreements on record at the federal level will also be canvassed in the research, as well as global soft-law instruments, notably the UNECE Model Provisions on Transboundary Groundwaters (2012). The analysis bears out that State practice in the matter of transboundary groundwater is evolving, and that a binding agreement at the global level is highly desirable. In this connection, the UN Draft Articles provide an authoritative reference for States at the global scale.

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The evolution and success of ISARM, 2010-2020

Alfonso Rivera[1], Christina Fraser[2], Alice Aureli[3]

Abstract

The International Shared Aquifer Resources Management (ISARM) initiative was launched in 2000 at the 14th Session of the Council of the Intergovernmental Hydrological Programme (IHP) of the United Nations Educational, Scientific and Cultural Organization (UNESCO). Ten years later, on 6-8 December 2010, UNESCO organized the first International Conference "Transboundary Aquifers: Challenges and New Directions (ISARM2010").

Since then, the ISARM initiative has facilitated projects for the identification, mapping and assessment of transboundary aquifers (TBAs), carrying out regional studies and providing guidance for the cooperation of countries on TBAs.

In the framework of ISARM, UNESCO teamed up with donors such as the Global Environment Facility (GEF) and the Swiss Agency for Development and Cooperation (SDC).This paper presents some of the activities and projects implemented within that context.

ISARM has also provided a framework for the substantial advancement of the international law on transboundary aquifers . UNESCO-IHP assisted the United Nations International Law Commission (UNILC) in the preparation of a set of 19 Articles on "The Law of Transboundary Aquifers" considered in several resolutions of the UNGA. This paper examines the results of the monitoring of the Sustainable Development Goal Indicator 6.5.2 , before synthesizing the most important outputs and outcomes of the last 20 years of the ISARM initiative, drawing conclusions and reflections on the way forward for ISARM.

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Updating the ISARM- Balkans transboundary aquifer inventory: a tool for shared groundwater management

Charalampos Skoulikaris[1], Jacques Ganoulis[2]; Jean Fried[3]

The UNESCO's Intergovernmental Hydrological Programme (IHP) initiative "Internationally Shared Aquifer Resources Management" (ISARM) was inaugurated in the year 2000 and since then, it is considered as the keystone of Transboundary Aquifers (TBAs) management around the world. The UNESCO Chair and Network INWEB (International Network of Water-Environment Centers for the Balkans) has joined the UNESCO/ISARM programme since its beginning and has thoroughly contributed to the development of TBAs inventories for the South-Eastern Europe (SEE) region, broader known as the Balkans region. During the ISARM's initial Phase 2000-2008, INWEB organized in 2004 with the support of UNESCO/IHP and UNECE a workshop in Thessaloniki aiming at developing a preliminary TBAs assessment for the Balkans. National experts, scientists and policymakers representing all Balkan countries identified 47 TBAs; however, without delimitation of their hydrogeological boundaries. Thus, a follow-up second coordination meeting in Thessaloniki in 2007 resulted on acquiring increased information for 65 TBAs together with their approximate boundaries. In parallel, UNESCO initiated in 2006 a Training Program on TBAs, that was directed by two of the present article's co-authors and finalized in 2016 by the publication of a manual entitled "Transboundary Groundwater Resources: Sustainable Management and Conflict Resolution". This training program has been marked by two pilot courses, in 2008 in Thessaloniki and in 2010 at UNESCO in Paris. The INWEB's TBAs inventory for the Balkans is publicly available since 2008 by UNESCO (https://unesdoc.unesco.org/ark:/48223/pf0000188566), and within this assessment specific case studies were recommended for further development in the 2nd phase of ISARM, such as the Dinaric Karst Transboundary System (DIKTAS). The latter was initiated in 2010 as a GEF project under the coordination of the International Groundwater Resources Assessment Centre (IGRAC). In 2012, INWEB also contributed to preparing the UNESCO/GEF's global Transboundary Water Assessment Programme (TWAP). The object of the present research is the applicability assessment of the TWAP indicators methodology, i.e., the description of the conditions of the Balkans' TBA through a system of 10 quantitative indicators, based on the INWEB's inventory data of 2008. The majority of these TBAs have the peculiarity of being smaller than 5,000km2, and thus have not been investigated through the TWAP. However, in this region, local aquifers, including TBAs, even of moderate water potential have an increased importance since they are almost exclusive sources of drinking water for cities and human settlements and are subject to strong pressures especially in summer due to agricultural and touristic activities.

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Transboundary cooperation per aquifer under sustainable development goal target indicator 6.5.2

Christina Fraser[1], Neno Kukuric[2]

Under the United Nations 2030 Agenda for Sustainable Development, transboundary cooperation has been highlighted as a key contribution to Goal 6: Clean Water and Sanitation for All. Target 6.5 of Goal 6 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 of water resource management (indicator 6.5.2) calls for the percentage of a basin or aquifer under an operational agreement to be calculated. Countries are asked to report on the state of cooperation over their transboundary aquifers (TBAs) and to indicate if an operation agreement is in force. However, as results are presented per country it is difficult to get a sense of the level of cooperation occurring in each individual transboundary aquifer. Here, we utilize the Sustainable Development Goal (SDG) Target Indictor 6.5.2 data collected during 2018 and 2020 and present a current state of global cooperation per transboundary aquifer. Results are presented as a map with supporting tables and analysis. There are multiple benefits to presenting the state of cooperation per transboundary aquifer as opposed to per country. First, it allows for clear cooperation gaps between countries to be easily identified. These areas where TBAs are not covered by operational agreements can be targeted for more directed capacity building and assistance to develop their IWRM practices. Secondly, TBAs that exhibit operational agreements in all, but 1 country segment can be targeted to inform all riparian states of potential agreements that may have not been considered within the reporting but could be operational. This will assist in the achievement of the SDG target. Finally, countries with low levels of cooperation can look to others within the region who have achieved operational agreements over their TBAs for guidance of better practice.

1,2 IGRAC

Asian transboundary aquifer for sustainable development

Han Zaisheng[1]

Transboundary aquifers (TBAs) have served as vital sources of water upon which large number of people relies. Throughout the Asia, complex relationships occur between upstream recharge areas and downstream regions across the international borders, and the effective management of TBAs is of particular importance for the region. Despite the significance, TBAs have received less attention from policy makers, scientists, and the local communities due to their hidden, diverse nature and the difficulty in conducting the horological investigations across the international borders. The updated TBAs identified 129 shared aquifers in Asia. The total area of TBAs in Asia is approximately 9 million km2, covering about 20% of the entire region. According to the global TBAs inventory, total 38 countries in Asia are identified to have the internationally shared aquifer basins. In terms of number of TBAs, Central Asia includes most TBA basin with neighboring countries. Uzbekistan shares the most the TBA basin (total number: 31), followed by China (21), Russian (21), Tajikistan (15), Kyrgyzstan (14), Kazakhstan (14), Mongolia (14), Azerbaijan (13) and Iran (10). Groundwater quality of the TBAs in Asia showed varying characteristics depending on its climate, geological medium and human activities. Some TBAs showed serious groundwater quality problems. Similarly, most of countries in Asia also have shown substantial lacks water policies to deal with internationally shared groundwater resources. In Asia, several regional initiatives have been launched for promoting the establishment of the legal/institutional frameworks for TBA cooperation. With these efforts, many countries in Asia become to recognize the importance of their TBAs and the need to cooperate with their neighbors in dealing with the TBA governance. Several countries like China have endeavored to undertake international cooperation for the shared water resource management by establishing TBA institutes as well as creating mutual agreements with the neighbors, which is a significant milestone. Some developing countries do not have capacity to carry out the groundwater investigation and the proper groundwater management practices. Consequently, sustainable and equitable management of TBA resources in Asia requires increasing efforts from the intergovernmental agencies, policy makers, scientists, local communities to reach the mutual acceptance for effective cooperation. From the academic and technical perspectives, more attentions should be paid on establishing a link between hydrogeological knowledge to the groundwater management practices based on the improved understanding of the TBA basins and its impact on the water cycles.

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Contributions to agenda 2030 and to the climate change regime: a transboundary aquifers perspective

Raya Marina Stephan[1]

While groundwater might still be "out of sight, out of mind", it is now a well-known reality that it represents the most available source of freshwater on earth. In some regions of the world, it is often the only source of water. And most of it is locked up in transboundary aquifers spanning the territories of two or more States. Therefore, transboundary aquifers have a strong role to play to reaching the objectives set in various international agendas in which freshwater is a key element, such as the Sustainable Development Goals, or the Climate Change framework. This presentation will aim at analyzing the place of transboundary aquifers in the international development agendas including a close parallel and comparative analysis of the Draft Articles on the Law of Transboundary Aquifers (2008). The Sustainable Development Goals contain a specific goal related to water, goal 6. Under this goal one target relates to transboundary cooperation. However, the other targets related to the access and safe drinking water for all (i.e., achieving the right to water), improving water quality or increasing water-use efficiency, ensuring sustainable withdrawals and supply of freshwater in water scarce regions, and protect ecosystems, when depending on a transboundary aquifer cannot be properly achieved without an established cooperation among the riparian States. Furthermore, water appears as a transversal element in the SDGs, since it is closely linked to other goals such as goal 1 on ending poverty, goal 2 on food security, goal 3 on healthy lives, goal 15 on ecosystems and others… Regarding the climate change regime, while water is mentioned explicitly in the UNFCCC only when it relates to adaptation, it received an indirect recognition confirmed in the Paris Agreement with the specific attention given to ecosystems, food security as well to human rights (including the right to health and the right to development). The sustainable development of a transboundary aquifer is the over-all objective contributing to achieving the specific goals and targets under Agenda 2030, and under the climate change international regime. This sustainable development objective can only be reached through the overtaking of national interests and boundaries by the riparian States, and the consideration of the transboundary aquifer as a whole; with the establishment of a solid cooperation between the riparian States, based on international water law principles, and more specifically on the Draft Articles on the Law of Transboundary Aquifers (2008).

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Groundwater discharge to the river Niger from a large paleochannel estimated from subsurface geophysics in the Iullemeden basin

Abdou Mahaman Rabilou[1], Nazoumou Y.[2], Favreau G.[3], Issoufou Ousmane B.[4], Boucher M.[5], Taylor R.G.[6], Lawson F.M.A.[7], Abdou Babaye M.S.[8], Guero A.[9], Legchenko A.[10]

In drylands, groundwater is often the only perennial source of freshwater to sustain drinking-water supplies and irrigation. Knowledge of the pathways and dynamics of groundwater discharge and recharge is essential to the sustainable and rational management of available water resources. The lower valley of the Dallol Maouri in Niger represents a natural border with Nigeria and is a ~10-km large fossil tributary (i.e., paleochannel) of the Niger River which drains regional groundwaters from the transboundary Iullemmeden Basin through coarse-grained Quaternary sediments. The objective of this paper is to quantify groundwater discharge in the paleochannel. To achieve this, TDEM (Time Domain Electromagnetic) and MRS (Magnetic Resonance Sounding) geophysical soundings were carried out at 21 sites on 3 transects. Inversion of the TDEM soundings shows that the average thickness of the Quaternary infill varies between 11 m and 18 m. Evidence from MRS soundings reveals an average water content of 35% and hydraulic conductivity of up to 2 × 10-3 m/s in the paleochannel. Groundwater discharges evaluated at 3 sections with dense piezometric surveys range from 1000 to 2000 m3/day (dry season, i.e., minimum value). This study reveals that this paleochannel in the Dallol Maouri valley of Niger supports substantial groundwater flow that currently provides baseflow to the Niger River on the border between Niger and Nigeria. Development of groundwater resources from these paleochannels is desirable locally to increase access to water for drinking, livestock watering, and irrigation yet such potential withdrawals need also to recognize the contribution of baseflow to transboundary river discharge. Keywords : Semi arid area, environmental flow, alluvial aquifer

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The role of regional communities in transboundary groundwater cooperation

Jacques Ganoulis[1*], Jean Fried[2], Charalampos Skoulikaris[1]

The 17 SDGs (Sustainable Development Goals) and 169 Targets of the UN 2030 Agenda for Sustainable Development describe the indicators of progress to be made for ensuring a fair and secure world by 2030. Apart from SGD 6 that is dedicated to water, several other goals and targets are linked to water and its sustainable management. Target 6.5 through the indicators 6.5.1 and 6.5.2 focuses on water cooperation in transboundary basin areas, including Transboundary Aquifers (TBAs), and the degree of IWRM (Integrated Water Resources Management) implementation, respectively; nevertheless, either specific methodologies or roadmaps for achieving the target have been established. This is mainly due to the complexity of the interconnected technical, socio-economic and geo-political issues, especially in the case of TBAs, where limited data and slow progress of the International Law for Shared Aquifers has been registered.

The object of the research is to demonstrate, through two case studies, the role of regional administration and regional stakeholders concerning policies driven by national governments of riparian countries. The first example refers to the 2008 operational agreement for shared management of the Genevese TBA between the French Communities of the Greater Annemasse Region, Department of Haute-Savoie, France and the State Council of the Geneva Canton, Switzerland. The second case study illustrates the role of regional authorities concerning a common flood protection plan in the Maritsa/Evros transboundary river basin, shared between Bulgaria and Greece.

TBAs management and cooperation are mainly subject to the political will of national governments. Cooperation agreements, conventions and treaties between neighboring countries are negotiated at the governmental level, ratified by national assemblies and signed by the chiefs of state. Historical and geopolitical reasons of national sovereignty and socio-economic considerations are major obstacles for concluding interstate operational TBAs agreements. However, the process of preparing and developing them is complicated and influenced by regional and local authorities and stakeholders. Local groups of different interests from both sides of the political border may influence governmental decisions at the regional and state levels and play a major role in implementing cooperation agreements. The two case studies reported in this paper illustrate this process.

The main groups of social stakeholders at various administrative levels and in different political regimes at local, regional and national level, Figure 1, can have different names and different political attributes. Typical examples are: 1) National countries-states with people sharing a common language, culture and history, believing that their common interests should follow the same laws and regulations, 2) Federation of countries administered by associations of regions or states, dividing the power between a federal

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(national) government and many regional governments, such as the United States of America, the Federal Republic of Germany, and the Russian Federation, 3) Union of countries forming an economic or social union of independent nation-states, such as the European Union, the Republic of India, and the Union of American States.

Figure 1.
Main social groups of stakeholders at various levels and political regimes.

Administrative Level / Type of Stakeholders	Nation-State (Ex. France, Poland, Greece)			Federation of States (Ex. USA, Germany, Switzerland)			Union of States 'Ex. EU, India, South America Union)		
	National	Regional	Local	National	Regional	Local	National	Regional	Local
Decision Makers	• National Government • Ministries • National Deputies	• Region's President • Regional Council • Prefecture	• Cities • Mayors • Town Councils	• Federal Government • State Secretaries • Senators	• State Government • Counties • County Councils	• Local Government • Cities • Towns • Districts	• Union's Comm. • Commissioners • Elected Deputies	• State • Government • Local Gov.	• Local • Government • Cities • Towns • Districts
Knowledgee Generators	Universitu Staff, Researchers, Scientists			Universitu Staff, Researchers, Scientists			Universitu Staff, Researchers, Scientists		
Water Profesionnals	Consulting Firms and Construction Companies			Consulting Firms and Construction Companies			Consulting Firms and Construction Companies		
Civil Society	Worker Unions, Professional Associations, NGO's			Worker Unions, Professional Associations, NGO's			Worker Unions, Prof. Associations, NGO's		

Conflicts and associations of interests between these social groups at various levels and depending on the distribution of power in countries with different political structures strongly influence the accomplishment of TBAs cooperation agreements. Although the types of conflicts and cooperation opportunities differ on time and from country to country both in the interior of each country and the relationship between countries, we may underline some common patterns as follows:

1. Regional groups of stakeholders can develop easier cooperative structures of common interest with similar groups from the other side of the political border than with similar groups at the national level. This is because regional/local transboundary problems are related to activities different than those linked exclusively to water. In that case, water can play a catalytic role. For example, agricultural activities and exchange of agricultural goods between transboundary regions, transportation and touristic activities in transboundary areas can generate common benefits that facilitate the conclusion of TBAs agreements. This is the case of the transboundary Genovese Aquifer, where both parties have agreed to share the cost of the annual aquifer recharge from surface water that is used for irrigation in the summertime.
2. Local and regional groups of stakeholders can be opposed to national governmental authorities because they feel to be dominated by the central political power. Of course, this is not generally the case, but it was critical for the failure of developing a transboundary agreement between Bulgaria and Greece to establish a shared early warning system in case of major floods in the transboundary river Maritza/Evros. Local decision-makers in Greece have expressed their preference to directly link a flood information system with local authorities in opposition to the nationally centralized plan.

Integrated management of water from the cross-border aquifer of the Jordan valley: what role for hydrodiplomacy?

Bendriss Jilali[1], Ouatmane Mustapha[1]

Located in an arid zone strongly marked by persistent land and water conflicts, the groundwater of the aquifer considered, is subject to a use of "mining" logic marked by the exhausted race to pump groundwater. Sharing and access to aquifer water are dictated by the logic of power relations, water is a “hostage of politics” and “friend of the powerful” who can use it as a weapon. The real consequences of this mode of use are difficult to demonstrate once groundwater remains largely "invisible" for the managers of the resource. Therefore, the first challenge to take up is not that of improving knowledge of this mobile and fleeting resource. Experts believe that with the growth of needs, the diversification of uses, the multiplication of actors and the transformation of natural and anthropogenic conditions (global changes) in the use of the resource, water conflicts will intensify over time. risk of escalating in to armed conflict. Experts consider that integrated water management (IWRM), understood as the application of the principles of sustainable development to the water sector, is the appropriate solution for the equitable sharing of the Jordan aquifer. Our hypothesis is that hydro-diplomacy, conceived as “the concept of a new governance to achieve water peace” (Georges Comair, 2018), is an appropriate approach to “create a cross-border basin organization” capable of '' establish integrated water management. The question that arises at this level is how does hydro-diplomacy bring together the main states concerned (Israel and the Palestinian territories, Lebanon, Syria and Jordan) around a table to negotiate conditions for setting up IWRM in the shared aquifer? The object of our research is to assess the degree of validation of hydro diplomacy in the light of the experience of the areas where it has been verified (Oronte. F. G. Comair .2019)) and taking into account the fact that the Jordan Valley water(see Appendix)is "hostage to politics".

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Artificial recharge modeling of groundwater aquifer in arid regions

Mohammed Alfawzan[1], Ragab Rabeiy[1], Mudthir Bakri[1]

Saudi Arabia relies heavily on groundwater for its freshwater supply. Saq aquifer is a transboundary groundwater reservoir that spans the borders of Saudi Arabia and Jordan. The Saq aquifer stretches from southern Jordan to a significant portion of northern Saudi Arabia, with a depth of more than 1000 meters in Jordan and 500 meters in the research region, covering an area of about 160,000 km2 (Puri et al., 1999). The abstraction of groundwater has been increased significantly last two decades in Saudi Arabia and Jordan for irrigation and household purposes. Consequently, the amount of groundwater is depleted with negligible natural recharging due to the scarcity of rainfall (Ghazaw et al., 2014).

This research aimed to predict the artificial recharging of the Saq aquifer caused by urban storm drainage. Additionally, the research focused on determining the capacity of the ponds that would collect surface runoff and estimate the runoff's extreme levels for various return times and storm durations. The research was conducted in the Saudi Arabian city of Unaizah, in the Qassim Region. The Gumbel (EV1), Frechet and Weibull probability distributions were used to simulate extreme values of rainfall and runoff for return periods of 5, 10, 20, 25, 50, 75, 100 and 200 years (Millington et al., 2011). Additionally, the California method, Hazen's method, and Kimball's methods (Raghunath, 2006) were utilized to compare the findings of probability distribution models.

The results indicated that the average projected maximum rainfall for a week storm duration is 59 mm, 75 mm, 86 mm, 95 mm, and 100 mm for return periods of 10 years, 25 years, 50, 75, and 100 years, respectively. The study urban area is 46 km2 and was divided into four sub drainage areas according to the watershed analysis via the Global Mapper as presented in figure (1). The storm water drainage system should be built in agreement with the results of the watershed study shown in the figure.

The capacity of the storing ponds was estimated based on the quantity of runoff using the rational method, weekly extreme rainfall, return periods, and sub drainage areas while taking into account the urban rate of development. The total estimated runoff which is taken also as the capacity of required ponds are 6.24 Mm3 and 12.2 Mm3 for return periods 50, and 100 years respectively during a week-long storm.

The surface runoff carries a variety of contaminants among them are sand, hydrocarbons, and plastics. A circular sand filter with a 2.5 m inner radius was proposed to trap the contaminations. The filter is composed of 0.5 m of fine sand and 1.0 m of clean aggregate with hydraulic conductivities of 0.4 m/hr. and 20 m/hr., respectively. The filter is supported by 10 cm of perforated brick from both sides, as seen in figure (2).

The research showed that storm runoff collection protects urban areas from flash floods via storing the excessive rain in retention ponds and partly compensates for groundwater level decline caused by pumping water from the aquifer. Although the projected amount

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of water in the research region is small, the study is applicable to any metropolitan area that includes a transboundary aquifer. A feasibility assessment is needed to ascertain the environmental and economic impacts of such projects' adoption.

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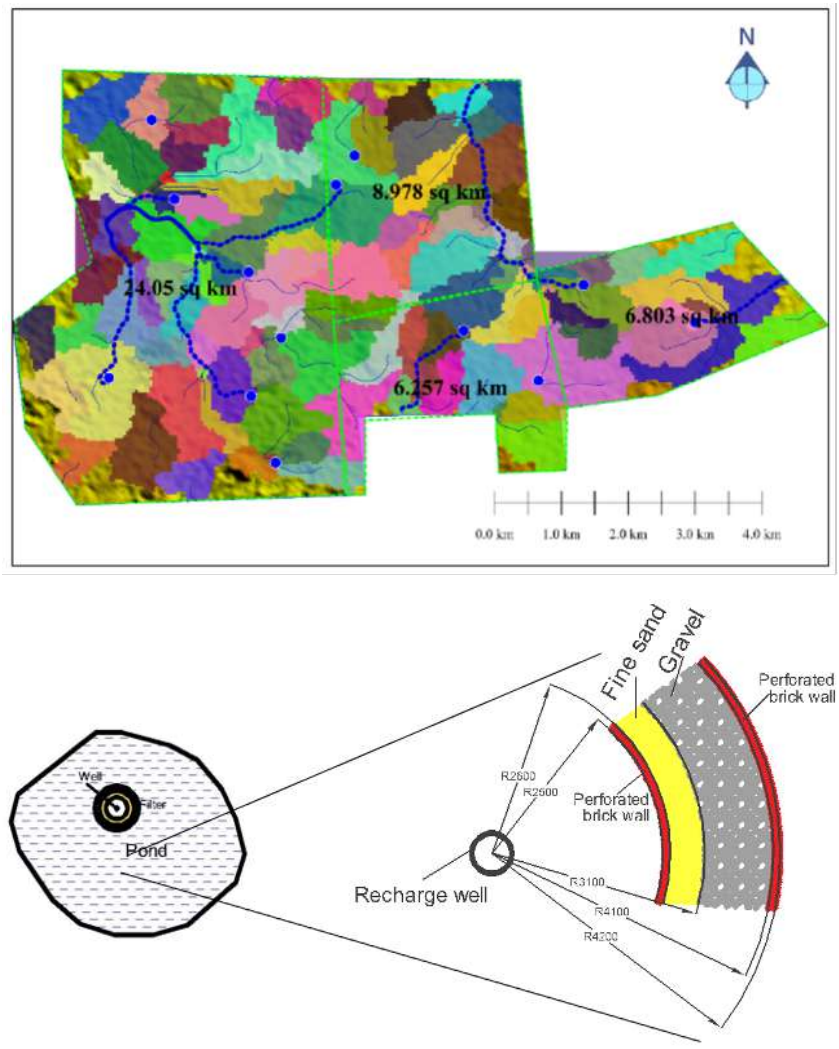
Figure 1.
Watershed analysis given drainage streams, and drainage areas



Source: Own Elaboration

Transboundary aquifer management on the island of Timor, Indonesia

Susilawati Cicilia Laurentia[1] and Bernadeta Tea[1]

Timor, a small island, consists of two land borders separating Indonesia and Timor-Leste. In the west, inside Indonesia's East Nusa Tenggara province, a 120 km curve creates an East Timorese enclave, Oecusse next to Kupang and North-Central-Timor (TTU) districts. While the eastern part is bordered by Belu and Malaka districts. The main challenge of aquifer management includes fulfillment of water need for domestic and agriculture purposes. The land and community could not rely on rainfall due to its erratic pattern. This has led to the study of integrated transboundary aquifer management on Timor Island. Literature study related to the hydrogeology of Timor Island is important to find strategies, specifically the policies for transboundary aquifer management in Timor Island. The Water Resources Council has submitted several recommendations to Nusatenggara II River Basin Authority (BWS NT II). This study employed a literature review and field survey in Indonesia's districts. Based on the concept of integrated water resource management that has been agreed on internationally, it can be concluded that the management of transboundary aquifers in Timor Island, especially in the border areas, needs special attention, in order to realize the SDGs, especially to streamline groundwater as an enabler for achieving the water-related SDGs.

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Contribution of transboundary aquifers between Nepal, India and Bangladesh for SDGs

Moti Lal Rijal[1]

Himalayan is considered as the water tower of Asia, which provides water for millions of people living in the downstream of the Himalaya. The rivers originating from the Himalaya provide water for various purposes such as household uses, irrigation, fisheries, power, and also for cultural activities. The rivers dynamics morphology shapes the landscape and ecosystems, which makes this region as the one of the major biodiversity hotspots of the world. As the reason main source of water is precipitation that happens within the three months from June to September, the surface water flow vastly deceases during dry and winter season, water sacra city of this region is becoming major issues and is rapidly increasing during recent years. Therefore, for the fulfilment of growing water demand during dry season, groundwater resource is used, and groundwater exploitation rate is skyrocketing during recent years. This has created enormous pressure as detail investigation on type and distribution of aquifer settings remains unexplored in many places. As Nepal, India, Bangladesh and Bhutan not only share river basins but also shares large part of groundwater systems. Out of many transboundary aquifers (TBA) in the world, the AS79 transboundary aquifer termed as the South of outer Himalaya's aquifer and the AS80, East Ganges River Plain aquifer are shared between Nepal and India, and India and Bangladesh. Since most of the population are distributed in the region where these TBAs are situated, groundwater is a major source for drinking water, water for irrigation and water for biodiversity conservation. Not only this, but this region is also the major food region, where irrigation water is fulfilled by groundwater extraction. Out of 17 The sustainable developments goals (SDGs), the aforementioned TBAs in this region can contribute mainly with SGD 1, 2, 6, 11 and 12, which respectively termed as no hunger, zero poverty, clean water and sanitation, sustainable cities and communities and responsible consumption and production. Similarly, building climate change resilience and implementing nature-based solutions can be addressed by managing these TBAs for fulfilling regional goals and contributing to global agendas.

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Transboundary aquifers, climate change and sustainable development

Jean-Louis Oliver[1]

Climate change has multiple and worrying effects, both quantitative and qualitative, on freshwater resources : decrease in river flows and pollution concentration, increase in the frequency, unpredictability and severity of extreme hydrometeorological events, floods and droughts, increase in water temperature, rise in ocean level leading to salinization of coastal aquifers and rise of marine water in estuaries and deltas, where populations are settled. Continental aquifers, renewable or fossil, transboundary or not, are not directly affected by these phenomena, and they will therefore have a more important role. It is essential to develop a joint and dynamic management of ground and surface waters : aquifers may be slightly overexploited during droughts and, during rainfall, wetlands, temporary storage of floods will be realized in order to recharge underlying aquifers. This joint water management is appropriate for transboundary aquifers : it will begin first at technical level, then at diplomatic level, with the support of international institutions and funding agencies. This concerted management of transboundary aquifers will respond to the challenges of increasing water needs related to population growth, urbanization, socio-economic development in the context of the Nexus "Water, Food, Energy and Biodiversity". This will contribute to the Sustainable Development Goals, to the 2030 Agenda, and to the international conventions on climate, biodiversity, desertification, disasters, ... It will calm and prevent tensions, crises, and even "water wars". agitative, on freshwater resources : decrease in river flows and concentration of their pollution, increase in the frequency, unpredictability and severity of extreme hydrometeorological phenomena, altering floods and droughts, increase in water temperature, rise in ocean level leading to salinization of coastal aquafers and uprising of marine water in estuaries and deltas , where population are located.

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Transboundary groundwater resources of Serbia - present status and future needs for sustainable management

Veljko Marinovic[1], Branislav Petrovic[1], Zoran Stevanovic[1]

Republic of Serbia is located at the crossroads of Southeast and Central Europe and belongs to the Central Balkans. With its 88,360 km2, Serbia is one of the larger countries of the Balkan Peninsula. It borders 8 countries and has at least one transboundary aquifer (TBA) with each of them. According to evaluation conducted for UNECE in 2008, Serbia has a total of 17 TBAs, out of which 15 are shared with one neighboring country, while two aquifers are shared with two or three neighboring countries. Concerning hydrogeological settings, Serbia has 5 karst TBAs, 5 intergranular TBAs, 4 fissure TBAs and 3 TBAs defined as a hydrogeological complex. The knowledge of hydrogeological characteristics of TBAs is diverse, especially when it comes to common hydrogeological research under cross-border cooperation and research. However, only two TBAs were studied in detail within the framework of joint research of specialists from neighboring countries. These are the intergranular TBA in the north of the country, which Serbia shares with Hungary, and the karst TBA in the southeast of the country, which Serbia shares with Bulgaria. Some studies have been conducted for the purpose of defining deep transboundary hydro geothermal systems within the Pannonian Basin shared by several countries of central and south Europe. The knowledge on current status of TBAs in Serbia is not at a satisfactory level. First and foremost, there is inaccurate delineation of TBAs, groundwater data are not harmonized with neighboring countries, common approach regarding sustainable groundwater exploitation has not been established yet, and there is absence of systematic groundwater monitoring. Although in recent years there has been achieved progress in the process of development of the groundwater monitoring network in Serbia, it is necessary to establish a joint water management body with the neighboring country(ies), which will sustainably manage transboundary groundwater resources. Support from the international commissions for protection of river Danube (ICPDR) and Sava (ISRBC) should help in creation of such body. Similarly, results from announced DIKTAS 2 projects would help to create a better platform for managing karst aquifers in the western part of country bordering with Montenegro and Bosnia & Herzegovina. As a prior step, is needed to: precisely delineate TBAs, establish proportional continuous groundwater monitoring along the borders, determine groundwater reserves in terms of sustainable exploitation, define water demands of local population and harmonize hydrogeological data of the countries that share groundwater.

Key words: transboundary aquifers, Serbia, groundwater monitoring, groundwater management

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Groundwater in the ipoly/ipeľ river transboundary region of Hungary and Slovakia: environmental state and sustainable management

Peter Malík[1], Teodóra Szocs2[2], György Tóth[2], Jozef Kordík[1], Igor Slaninka[1], Radovan Cernák[1], Juraj Michalko[1]

The 222 km long Ipoly/Ipel' river originates in the crystalline rocks of the Veporské vrchy mountains, but quickly reaches a sedimentary basin filled by Neogene and Paleogene deposits – clays, sands, Aleurites and rarely limestones. Neogene volcanic rocks are also present within its watershed. For 140 km, until reaching the Danube river, the Ipoly/Ipel' river forms the Slovak-Hungarian boundary. Due to the poor permeability of the pre-Quaternary sediments, the main aquifer exploited for drinking water supply is the 4 – 10 m thick Holocene alluvial fan and the surrounding Pleistocene terraces. Both Holocene and Pleistocene gravels and sands are usually covered by 1.5 – 4 m thick clayey flood sediments. The width of the river flood plain is about 1 – 2 km, but at some places only tens of meters. In order to fully understand both natural and anthropogenic processes acting in the whole watershed, the region was jointly evaluated by the Hungarian and Slovakian national geological surveys within the framework of the ENWAT project funded by the INTERREG III A Programme. The major risk posed to groundwater quality on both sides of the boundary comes from agricultural activities. Groundwater samples were taken and simultaneously evaluated by project teams from both countries. Poor groundwater quality is mostly characterized by high contents of nitrates, chlorides, ammonia, phosphates or specific organic parameters (PAH, COD), and occasionally also by pesticides. Due to the areal character of the contamination source, the uppermost groundwater horizons are the most polluted. Groundwater chemical compositions also reflect the variegated natural character of the whole watershed and this strong variability is characteristic for the whole region. The resulting maps showing the distribution of contaminants on both sides of the HU-SK border, but encompassing one watershed of the Ipoly/Ipel' river, these were created as mono-element and contamination index maps. Additionally, transboundary groundwater flow model was created here. The results of this joint effort are available in Hungarian, Slovak and also English versions of the maps and reports. The results support safe and healthy water supply of the studied regions, serve as environmental basis for decision-making processes involving major cross-border investments and provide information on quantitative and qualitative status of groundwater. It also filled the gap in our knowledge regarding organic contaminants by additional sampling and analyses. Based on the outcomes of this work the Ipoly/Ipel' transboundary aquifer was recognized as an important transboundary groundwater body on the ICPDR level.

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POSTER ABSTRACT

Investigation of the transboundary aquifer system in Prespa – Ohrid watershed using hydrogeological data and SWOT analysis

Emanuela Kiri[1], Konstantinos Voudouris[2], Hamza Reci[3], Elpida Kolokytha[2]

Great Prespa (shared between North Macedonia, Albania, and Greece) and Ohrid (between the southwestern part of North Macedonia and eastern part of Albania) lakes represent a common hydraulic system in the Balkan Peninsula (SE Europe). They are separated by Dry-Galichica Mountain chain with highest peak of 2288 m (a.s.l.). The elevation of Prespa Lake is about 153 m higher than that of Ohrid Lake. The lakes are very important wetlands, supported by Ramsar Convention, included in the European Network of Protected Areas NATURA 2000. Between the aforementioned lakes a transboundary aquifer is developed in karstified carbonate rocks (Triassic massive limestone). These rocks cover the western and southern edges of the valley, and a large part lie on the bottom of the Prespa Lake. This work describes the general characteristics of the transboundary aquifer using hydrogeological data and proposes indicators and measures for the sustainable water management performing SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis. The transboundary karstic system is a complex system which functions primarily as a hydro collector and hydro conductor, affecting the water balance of the lakes. The hydrogeological behavior of karst aquifer is controlled by tectonic deformation, which favors infiltration of meteoric water. The karstic rocks come out as a mixed porosity; the porosity of the rock blocks (matrix porosity), porosity of small and larger cracks, porosity of big faults and caverns and porosity of clastic material filling all rock discontinuities. Numerous crevices, sinkholes, and karstic fields, as surface forms, and also underground forms of the types such as: caves, canals, etc. are characteristics of the mountainous area. Groundwater recharge occurs via infiltration of rainfall and the groundwater flow direction is from Prespa to Ohrid Lake. In addition, the karst system discharges through many springs. The aquifer is also vulnerable to external pollution, as well as to climate changes affecting the lakes' ecosystems. It is pointed out that Prespa Lake is characterized by a continuous and prolonged decline of water level. This decline could be associated with hydrological parameters, anthropogenic activities and/or tectonic reasons. Based on results of SWOT analysis and use of indicators including water quality, groundwater level, level of lakes, discharge of springs, climatic data, land uses, water abstractions a water management action plan and a set of measures, is proposed for the sustainability of the transboundary aquifer and depended ecosystems under climatic change, and in favor of the socio-economic development of the wider area.

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POSTER ABSTRACT

Addressing the drying up of euphrates river using DAPSI(W)R(M)

Rasha Hassan[1], Richard Takyi[2], Badr El Mahrad[3]

The Euphrates river, which is the longest river in western Asia, provides valuable ecosystem services to approximately 30 million people. However, this transboundary river between Turkey, Syria and Iraq is drying up. A social-economic and environmental analysis using an integrated system methodology was carried out to illustrate this issue to decision makers and managers. DAPSI(W)R(M) framework was applied to analyze the issue. Its results identified the various Drivers (D) linked to each riparian state interests with climate change as indirect driver behind the drying-up then the human Activities (A) that led to Euphrates drying up, such as hydroengineering projects and irrigation. Thus, numerous Pressures (P) were generated such as negative changes in Euphrates quality and quantity. These have led to a State Change (S) including Euphrates environmental flows reduction. The resulting impacts (on human welfare) (I(W)) were assessed to evaluate the socio-economical aspects in order to suggest management Responses as Measures (R(M)) to mitigate the issue. Finally, this framework provides an analysis of the scientific knowledge-based needed for appropriate management. Transboundary cooperation is a pathway to restore and protect this important river, to achieve water security and foster regional development.

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TOPIC 2 :

Science/policy interface: focus on the management of transboundary aquifers

Drought management without boundaries

Doris E Wendt[1],David M Hannah[1], Joshua Larsen[1], John P Bloomfield[2]

Aquifers and droughts are transboundary across many administrative divides, including local, regional, and national. Severe drought events threaten sustainable groundwater use and water resource management, as groundwater use increases while water availability reduces, aggravating pressure on aquifers across boundaries. In near future, extreme droughts are likely to occur more frequently that stress the need for careful management of groundwater resources, particularly for transboundary aquifers (TBAs). Uncontrolled use of groundwater has resulted in heavily stressed aquifers, aquifer depletion and increased tension in transboundary aquifers. However, careful management of water resources has also proven effective to reduce or mitigate the impact of droughts by restricting water use, providing alternative sources of water supply, or introducing water transfers to alleviate pressure on groundwater systems. In TBAs, management practices can have contrasting impact on the overall groundwater availability, and it remains unknown if overarching international frameworks, such as the EU Water Framework Directive (WFD), result in structured drought response in TBAs. Under the WFD, drought policies have been introduced in 2000 to protect aquifers and dependent ecosystems, although implementation varies across EU member states and an assessment of current drought mitigation strategies to evaluate consistent drought response in TBAs is missing. In practice, it is therefore possible that variations in drought policies across many nested administrative divides can add additional stress on these TBAs. We present a tool, a socio-hydrological model, to assess the impact of drought mitigation strategies accounting for a range of hydrogeological conditions and thereby, we aim to review, comment and make suggestions on drought policies in these nested administrative frameworks, so that improvements for drought mitigation strategies can be more effective. In modelled scenarios, drought mitigation strategies were found sensitive to hydrogeological conditions and the overall pressure of groundwater use, demonstrating the importance of consistent drought mitigation strategies within TBAs. Model outcomes can therefore be used to evaluate drought policies in TBAs and highlight the importance of consistent drought response across country boundaries to advance sustainable groundwater management for TBAs.

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Source: Own Elaboration

Achieving water quality ambitions: experiences with local-regional governance approaches for more effective TBA management

Susanne Wuijts[1], Helena FMW van Rijswick[2] and Peter PJ Driessen[3]

Worldwide countries face challenges to restore and preserve water resources in accordance with UN SDG 6. These challenges come from both the ecological and hydro(geo)logical domain, societal and policy context and the role of legal frameworks. Transboundary aquifers and dependent ecosystems face yet another challenge in attaining SDG 6 due to issues related to coherence of legal and policy frameworks between neighboring countries. In Europe, the Water Framework Directive (2000/60/EC) offers an overarching framework to secure Europe's waters for future generations. As it uses a river basin approach, it holds a strong potential for effective transboundary management. The requirements set in the WFD regarding international cooperation show a strong resemblance to indicator 6.5.2 of SDG 6. Although the EU flagged the WFD as effective in terms of cooperation, water quality improvement seems to hamper to date (EU Fitness Check on Water Legislation, 2019). Studies so far, often focus on the effectiveness on the scale of a river basin. Here, we have studied how governance approaches at the local-regional scale support the attainment of water quality ambitions, using scientific literature and empirical material on water quality governance approaches in the Netherlands. Because of the hydrogeological nature of the Netherlands, a substantial part of the aquifers is transboundary. Several of the cases studied are directly influenced by transboundary challenges but more in general the analysis brings forward five areas for improvement of water quality governance approaches that are relevant to account for in the context of transboundary aquifers as well. These areas for improvement affect policy responses to both drivers, pressures, state and impacts on river basins and related aquifers. This means that the linkages between governance approaches, water system characteristics and the driving forces from other sectors that lead to water quality improvement are much more complex than described in literature so far and require a joint approach from different sectors and knowledge domains. The study presents the governance conditions needed to put these improvements into practice.

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Achieving cooperation in development of transboundary offshore aquifers by using science to define their boundaries and volume

Renee Martin-Nagle[1], Aaron Micallef[2]

Offshore aquifers containing vast quantities of freshened groundwater can be found between confining layers embedded in continental shelves around the globe. Given their ubiquity, some of these offshore aquifers will straddle international maritime boundaries. Sovereignty over marine natural resources has been addressed in a global treaty, the UN Law of the Sea Convention (LOSC), but the treaty is silent about governance of transboundary resources, leaving nations to find their own accommodations. Tapping offshore aquifers will require costly exploration, development and infrastructure, so one can assume that offshore freshwater resources will be tapped when the quantity and/or quality of land-based freshwater resources are scarce. In a time of such freshwater scarcity, conflicts over transboundary deposits of a critically and vitally important resource could easily arise. Thus, an ability to define the boundaries and volumes of offshore aquifers will support collaborative development of the resources. However, given their location in seabed geological formations that are submerged under meters of seawater, locating and measuring these freshwater deposits requires specialized equipment and techniques. Recent maritime expeditions have utilized specialized techniques for identifying and measuring offshore aquifers. These include non-invasive geophysical techniques such as seismic reflection profiling, which provides key information on sub-seafloor geology, and electromagnetic surveying, which can detect offshore freshwater. This information, particularly when combined with data from offshore boreholes, can be used to determine the extent and volume of offshore freshwater. Numerical modelling, on the other hand, is a cost-effective technique to estimate the volume of offshore freshwater and the processes that deposited it. Some offshore aquifers receive active recharge, but others are fossil aquifers whose water was emplaced thousands of years ago as the last glacial maximum was ending. Whether an offshore freshwater system is being actively recharged or not is an important constraint on whether the resource can be exploited in a sustainable way. This joint presentation will explain how scientists and policymakers can and must work together to achieve cooperative and sustainable development and utilization of transboundary offshore freshwater aquifers.

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Reaching groundwater agreement in the border between Mexico and the United States: science and policy Fundamental

Sharon B. Megdal[1], Stephen Mumme[2], Roberto F. Salmón[3], Rosario Sanchez[4], Elia M. Tapia-Villaseñor[5], Mary-Belle Cruz-Ayala and Oscar Ibañez[6]

This paper examines the prospects for reaching transboundary aquifer agreements on the Mexico-U.S. border. At least 30 transboundary aquifers are known to exist along this arid boundary, but to date groundwater is regulated in just one of these under a 1973 subsidiary agreement to the 1944 Mexico-U.S. Water Treaty. The prospects for other agreements may be improving, however, driven by advances in bilateral technical cooperation on aquifer assessment under the Transboundary Aquifer Assessment Program (TAAP) and other recent agreements strengthening bilateral cooperation on transboundary rivers. The accumulation of collaborative scientific practice and knowledge and the accrual of institutional experience and formal agreements under the authority of the International Boundary and Water Commission (IBWC) are now broadening the horizon for other joint endeavors supporting the sustainable use of groundwater resources. The paper first examines the institutional setting shaping bilateral engagement on groundwater, including the 1944 Water Treaty, the IBWC institutional mechanism for treaty implementation, the legal, institutional, and political governance context for groundwater diplomacy. We then look at recent advances in binational scientific-technical cooperation on the Colorado River, the Rio Bravo/Grande, and groundwater matters. We follow with a look at the diplomatic principles seen in successful agreements and the emerging binational practice of reaching framework agreements that accommodate varied solutions to particular problems within a certain domain, particularly groundwater. These recent agreements and other informal practices point to the importance of certain variables like binational oversight through the IBWC, joint effort and financing, equitable engagement, data sharing, incorporating local concerns and focusing on water quality protection as motive forces conducive to building support for binational groundwater initiatives. We conclude by charting a path forward for sustainable management of transboundary aquifers along the Mexico-U.S. border.

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Sustaining transboundary groundwater systems in sub-Saharan Africa: status, challenges and prospects

Callist Tindimugaya[1]

There is heavy reliance on groundwater in most of sub-Saharan Africa for rural and urban water supply due to its wide distribution and general good quality. Groundwater also enables communities across Africa to adapt to seasonal or perennial shortages in surface water. Groundwater is indispensable when managing water scarcity, a natural condition in 30 out of 53 African countries. Expanding irrigation to enhance food security is a growing necessity because per capita food consumption is largely inadequate. Groundwater is already playing a very important role in food production in the face of dwindling surface water resources due to climate change. Groundwater resources will therefore be under intense pressure due to increased demand as well as climate change, calling upon the African continent to institute measures to ensure sustainability of groundwater aquifers. Considering that groundwater aquifers in various parts of Africa are either transboundary and shared by a number of countries, or have transboundary significance there is need to put in place measures for their joint management if these aquifers are to be sustainably developed. Sustainability of transboundary groundwater aquifers however faces a number of challenges including hydrogeological diversity and complexity, inadequate scientific knowledge on characteristics of the aquifers, pollution, limited knowledge of the impacts of climate change and intensive abstraction on groundwater levels and storage, and limited capacity for transboundary aquifer management. A number of strategies are however under implementation in various parts of sub-Saharan Africa to improve transboundary groundwater management that include establishment of groundwater monitoring networks, instituting programs for characterization of transboundary groundwater resources, establishing regulatory and licensing systems for groundwater, integration of groundwater in basin management planning and implementation, capacity building in groundwater related fields at both national and river basin level, and participation and inclusion of water users in decision making. Prospects for sustaining transboundary groundwater systems in sub-Saharan Africa to support socio-economic development and achievement of national development plans are quite good but a lot still needs to be done to ensure that groundwater resources are sustainably developed and managed.

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What is the 'science' that policy makers want in order to address governance of transboundary aquifers?

Shammy Puri[1], Karen G. Villholth[2]

This paper starts by asking: "Is the science of transboundary aquifers (TBA) really so complex that it is nearly impossible to explain it to policy makers, so that they can implement governance?" If the answer to this is 'no', a natural next question is: 'What are the primary types of information that the policy makers need to understand, and in what degree of detail – and how to enhance the application of this knowledge for governance?' This paper attempts to draw lessons from existing cases to elucidate these questions. A significant amount of literature has been built up in the recent past on the linkage between science and policy. Policy makers routinely miss the significance of science-based conclusions, especially those that are couched in terms of risk envelopes. Although one may lay the blame on policy makers for their lack of understanding or willingness to policy-uptake, it is time to turn the tables around and ask: what is the science that policy makers need – and how can this best be co-developed and provided? In the case of aquifer systems, and more specifically transboundary groundwater resources, and their governance, it is worth investigating, whether the education, capacity building and awareness raising among the science community is "fit for purpose". Although the science of hydrogeology has made huge strides since the late '50's, and the study of TBAs has seen an exponential rise in the number of assessments since the early 2000s, arguably the scientists have been struggling to package and share their findings through understandable concepts for those who formulate policies at national and transboundary level. It may also be at international level, e.g., the UN General Assembly, where these issues, in particular the endorsement of the Draft Articles on the Law of Transboundary Aquifers, remains pending. This paper will discuss key scientific concepts in the governance of TBAs from eight case histories: the Geneva-Haute Savoie, the Stampriet, the Ramotswa, the Guaraní, the Rum-Saq, the Canadian-US, and the Mexico-US, and the Dinaric aquifers and analyze how ensuing policy relevant messages were presented and received by policy makers and the lessons learned. The measure of the success of science-to-policy effort were ascertained through analyzing statements made by policy makers once they had been engaged with the findings of scientists.

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Administrative, legal, and technical coordination over transboundary groundwaters

Anita Milman[1]

Sustainable management of transboundary groundwater resources will require substantial coordination, if not collaboration, across political boundaries. A variety of factors, ranging from the physical to the socio-economic and political, influence whether countries are willing to engage in efforts to coordinate over groundwaters. While political will is an essential ingredient for sustainable management of transboundary groundwater, coordination is a complex process that results not from a single action, but through negotiation across several concurrent action arenas. To fully understand the barriers and facilitators of transboundary action on groundwater, we need to recognize and address the details of how coordination is implemented more fully. This paper examines cross-border coordination in the development and implementation of groundwater sustainability plans in California in order to provide insights on the practical details of coordination. Specifically, we examine the processes employed, the challenges faced, and the solutions developed by 100 agencies located across 19 groundwater basins as they developed shared knowledge, set quantitative sustainability goals, and identified policies and projects for achieving sustainability at the groundwater basin-level. The number of agencies coordinating within each basin ranged between 1 and 24, and multiple sub-entities existed even in the basins with spanned by a single agency. While the empirical setting does not span international borders, due to the structure of California water law, the governmental entities coordinating sustainable management of the shared groundwater basin have many similarities with sovereign countries, and, due to the number of concurrent examples and the extensiveness to which the agencies coordinated, thus provides a useful lens for understanding the potential for coordination at the international level. Our findings indicate that, in addition to developing an institutional structure for coordination (equivalent developing an international river basin organization or treaty working group), agencies had to navigate the administrative, legal, and technical aspects of coordination. Administrative coordination entailed working through differences in agency-level decision-making, communication, approval, management, and financing requirements. Legal coordination entailed finding ways to traverse the laws, rules, and regulations each individual agency was bound to, many of which were unrelated to the groundwater responsibilities of the agency. Technical coordination involved not only addressing knowledge gaps and interoperability of data, but also either reaching consensus or demonstrating compatibility of differing methodological and analytical approaches to understanding groundwater. Examples of how agencies addressed each of these dimensions of coordination provide initial templates that can be used for transboundary groundwater management around the world.

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The control of hydrogeological data as an essential element in the governance and management of transboundary aquifers; the case of the Genevois aquifer (Switzerland-France)

Gabriel de los Cobos[1], Laurent Galeazzi[1]

The Franco-Geneva agreement on the drinking water resource of Geneva is among the first agreements in the world on the management and protection of cross-border aquifers. Signed in 1978, the application of this agreement has therefore been carried out for more than 40 years under the aegis of a Franco-Swiss commission, whose function is to check the pumping and recharge rates of the aquifer, the budgetary aspects linked to its exploitation, as well as everything related to the protection of the resource and the catchment area of the main tributary river. Facing pressures linked to climate changes and new contamination discovered in the aquifer in the recent years, the following has been observed. Despite good geological and hydrogeological knowledge of the groundwater body, certain situations in the past few years have raised many questions about the groundwater flow behavior as well as on the lateral limits of the aquifer, which could explain certain delicate situations regarding its protection: unsuspected supplies, connection with shallower unprotected water bodies, "geological windows" reducing the impermeability of the overlying protective formation, etc. Recently, a huge subsurface investigation work using geophysical methods, installation of observation boreholes, tracer measurement campaigns and water analysis was launched by the GESDEC in the framework of the Geneva development program for geothermal energy. Furthermore, the current establishment of a comprehensive geological database has led to the reinterpretation of thousands of existing boreholes across the Genevois aquifer area. This made it possible to improve subsurface knowledge, redraw geological and hydrogeological models, redefine more precisely the geometry of the aquifer and finally support the definition of new planning and protection tools. The production of specific maps therefore allowed a better understanding of the behavior of this aquifer, its extension and boundary conditions, as well as its protection needs. This work, in constant evolution and carried out in partnership with our French partners, demonstrates the importance of a robust and shared geological and hydrogeological knowledge in order to optimize the management of such a cross-border aquifer, since activities on a given side of the border can impact production wells on the other side. Such shared knowledge and knowhow are essential to implement a strategy for the protection and sustainable use of such a transboundary resource. To ensure its efficient governance, strong monitoring plans, adequate network of observation wells and robust flow models are proven to be essential.

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Towards a sustainable management of the groundwater resources of the north western Sahara aquifer system in the Adrar region

Johan Derouane[1], Ali Larbes[2], Faiza Bouchama[2], Nicolas Triolet[3]

The Algerian Sahara, and the Adrar region in particular, is experiencing increasing economic development in the agricultural and oil sectors. In this context, the region's water needs are constantly increasing and are at the origin of increased competition between the different water uses. The region is characterized by an extremely arid climate, and by the presence of a unique and non-renewable water resource, consisting of the transboundary Continental Intercalary aquifer. The increase in water abstraction nowadays constitutes a significant pressure on the transboundary aquifer which threatens its quantitative balance. On the environmental level, the increasing development of anthropic activities in this region, particularly in the agricultural and industrial sectors, constitutes an increased risk of degradation of the quality of this groundwater resource shared by Algeria, Tunisia and Libya. In particular, the Adrar region is experiencing considerable development of irrigated agriculture and is undergoing a profound change from traditional oasis agriculture, which it is trying to preserve, to modern agriculture. From a quantitative point of view, the abstractions from the Continental Intercalary aquifer and the increase in these over the years linked to the development of irrigated agriculture are causing a significant drop in the water table, which has resulted in particular in the drying up of the foggaras and the decline of the traditional oasis systems that depend on them. From a qualitative point of view, the transboundary aquifer of the Continental Intercalary presents in the region of Adrar significant and increasing contamination in areas with high density of irrigated agriculture, and near these areas, resulting on the one hand from the non-rational use of agricultural inputs and on the other hand from the salinization of the aquifer induced by often poorly controlled irrigation. Faced with these worrying observations, measures must be taken to improve the sustainable management and preservation of the only available groundwater resource, in harmony with the necessary socio-economic development of the three countries sharing this transboundary resource. It is in this context that the process of setting up the very first "Groundwater Agreement" in Algeria has been undertaken in the Adrar zone, which was signed in June 2019. It brings together, on a voluntary basis, all the stakeholders concerned by the management, exploitation and protection of this resource, around a collective action plan aimed at providing adequate responses to the problems encountered.

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Assessment, diagnostic analysis and mathematical modeling as a basis for the management of shared resources of the Pretashkent transboundary aquifer in Central Asia

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The Pretashkent transboundary aquifer (PTBA) is a unique source of deep fresh groundwater in Central Asia, located on the territory of Kazakhstan and Uzbekistan. The PTBA groundwater is widely used for drinking, SPA and bottling in Kazakhstan and Uzbekistan. And the PTBA is included as a case study to the GGRETA Project, funded by the Swiss Agency for Development Cooperation (SDC) and implemented by UNESCO-IHP Secretariat. The interdisciplinary assessment of the PTBA was carried out in accordance with the approach of GGRETA guidelines for transboundary aquifers assessment. It is based on the analysis of a set of collected information on physical, geographical and climatic indicators, for the aquifer, ecological, socio-economic and water management aspects. Since the main pressing factor on the PTBA in Kazakhstan is associated with its use for domestic and drinking needs, the constant growth of the population is the main impact on the PTBA. The diagnostic analysis of the main problems and risks for the Kazakhstani part of the PTBA was carried out in accordance with the methodology of the GGRETA project based on the DPSIR assessment. The assessment identified two main transboundary issues, both of which relate to the groundwater levels drawdown of the PTBA: 1. Storage depletion of the PTBA groundwater; 2. Potential deterioration in the quality of the PTBA groundwater. As a result of the diagnostic analysis, recommendations were prepared for optimizing the further exploitation of groundwater resources of the PTBA (Kazakhstani part). The results of the assessment and diagnostic analysis of the PTBA showed that the joint interstate governance and management of groundwater resources of the aquifer should be based on modern hydrogeological information and predictive estimates of the possibility of groundwater extraction. Such estimates can be given only on the basis of mathematical modeling in the environment of modern software. Harmonization of maps for the Kazakh and Uzbek parts of the PTBA and preparation of databases made it possible to create a numerical basis to fulfil mathematical simulation for the whole Pretashkent TBA. The generated model is in the calibration stage. The model is being developed in parallel by the Kazakh and Uzbek parties with the obligatory coordination of the results of each stage of modeling.

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Act locally but communicate globally – Guarani aquifer system transboundary cooperation

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The Guarani Aquifer System (GAS) of over 1.0 million km2 is one of the planet's largest aquifers, shared between Argentina, Brazil, Paraguay, and Uruguay. It underlies the social and economic development of more than 15 million people. A full inventory of production water wells of 2008 indicated that resource exploitation totaled 1.04 km3/yr., with 94% in Brazil (80% of which is in São Paulo State), 3% in Uruguay, 2% in Paraguay, and 1% in Argentina, predominantly for urban uses. The GAS comprises a sequence of weakly-cemented sandstones of Triassic-Jurassic age, deposited by the aeolic, fluvial, and lacustrine continental processes on a regional erosion surface (dated at 250 M years BP), overlain by equally extensive Cretaceous basalt flows (dated at 145-130 M years BP) exceeding 1,000 m thickness in some areas. The groundwater system is storage-dominated, with recharge amounting to only about 0.2% of the estimated 30,000 km3 held in storage, and slow flow rates were confirmed by radiometric dating (14C and 81Kr), with ages reaching 730,000 years BP in São Paulo State. The slow flow and large storage contrast sharply with the active flow systems located in the recharge zones, which cover only 10% of the total area. These characteristics mean that the problems of intense exploitation or serious contamination have only local reach, extending no more than a few kilometers from their origin and not affecting more than one country. The Guarani Aquifer Project, an initiative of the Global Environmental Facility in the 2000s, did not identify severe conflicts but did indicate the benefits of data exchange and technical dialogue. Although the transboundary aquifer agreement has taken time to ratify, the project has unequivocally demonstrated the value of collaboration between countries on understanding the aquifer's hydraulic functioning, management, and governance. Even without ties to their diplomatic services, the so-called "Guarani family" has shown the importance of transboundary personal relationships in furthering groundwater understanding and local management.

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Transboundary aquifer governance: a practitioners guide on putting science into policy

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A major hurdle to transboundary aquifers (TBA) governance is the lack of joint up rational between science and policy, largely due to excessively complex presentation of aquifer processes to the policy making community. In the draft strategic plan of the UNESCO/IHP IX, 2022-2029 it is stated that the program's mission includes support to Member States to: "b. Mobilize and disseminate effectively scientific and policy relevant expertise and knowledge for informed decisions in addressing water challenges". In the frame of the ISARM-2021 Conference, and with the knowledge and experience gained from the last 20 years, we propose to prepare a practical guide for practitioners in decision-making and policy adoption arenas, on how to appreciate the science, for effective drafting and implementing TBA policies, laws and regulations. Such a guide would mainly address topic 2 of the ISARM-2021 Conference, i.e.," The Science/Policy interface of TBA", and also indirectly themes 4 and 5. A tentative title of the guide could be: "A Practitioners Guide for effective Transboundary Aquifers Governance: Capturing the Science for Policy". Our aim is to compile and edit such a practical guide and invite experienced contributors from the scientific committee and elsewhere, to develop inputs for this guide, which would be presented at the ISARM 2021 Conference. Bearing in mind that the guide may not be finalized at the date of ISARM 2021, we will present the work in progress. The three editors will develop the scope of this guide in form of advice and guidance and will coordinate the final edition, based on consultation with experts. Here are some initial indications of the scope of the guide:

- Develop a step-by-step process for simplified but correct understanding of science of TARM (Transboundary Aquifer Resources Management) for policy makers
- Design the support for practitioners in policy making, to convert the scientific principles into nationally and internationally relevant negotiating documentation, for reaching mutually acceptable stances on cooperation over aquifers
- Formulate the essence of principles of hydro diplomacy as applied to aquifers in which resources are 'unseen' and time lag of impacts may be tens to hundreds of years
- Present several case histories from real world examples, where at present there is no aquifer systems included, even though a river basin agreement is in place
- Present a few real world examples of how the provisions of the UN ILC Draft Articles converge with the hydrogeology of selected transboundary articles
- Provide the practitioners with a guide to the relevance and scope of the current water and related global conventions on their applicability to shared aquifer resources We suggest that the final version of the guide be published under the joint sponsorship of UNESCO, IAH and IWRA.

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Designing a transboundary groundwater monitoring network: The pilot case of the Skadar/Shkoder- Buna/Bojana transboundary aquifer

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Monitoring of the Sustainable Development Goal indicator 6.5.2 on transboundary water resources cooperation, reveals that only 22 countries have all their transboundary basins and aquifers covered by cooperation arrangements, showcasing that efforts are still needed to promote cooperation, particularly in the more than 300 major (> 5000 Km2) transboundary aquifers identified so far globally. The assumption is that transboundary cooperation on the shared water resource is a prerequisite for their sustainable management. The GEF/UNDP/GWP Med Project "Enabling transboundary cooperation and integrated water resources management in the extended Drin River Basin" aspires to promote joint management of the shared water resources of the transboundary Drin River Basin. To meet this objective, the Project includes, amongst others, the design of a monitoring network for the Skadar/Shkoder-Buna/Bojana transboundary aquifer system shared between Albania and Montenegro and located within the Drin Basin. As both countries are in an accession process to the European Union, the EU Water Directive (WFD) provides the framework for meeting management goals under a common data gathering program. Facilitating information sharing, should foster joint / harmonized policies to avoid water use conflicts and enhance cooperation. The methodology developed for the design of the transboundary groundwater monitoring network, while consistent with the WFD requirements, also draws from lessons learnt in transboundary aquifer management approaches used worldwide. Such methodology consists of three main steps: first, building a hydrogeological conceptual model including pressure and impact assessment on groundwater resources; second, producing a vulnerability analysis applying the ACVM method that considers the aquifer exposure to diffused and point pollution sources, flooding and seawater intrusion; and finally, designing a transboundary monitoring network proposal based on priority areas. The study led to the identification of priority monitoring areas and their targets. Establishing such priority areas rather than specific monitoring sites provides a starting point for both countries to recognize features of possible transboundary concern and harmonize monitoring efforts within the context of a common environmental vision. It also provides the necessary flexibility for the riparian states to reconcile regional and national interests in choosing specific locations that fulfil the objectives of the transboundary monitoring network.

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Environmental status assessment of transboundary groundwater bodies and ecological implications in riparian zones in Europe

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Groundwater is a very crucial natural resource providing water to economic sectors, as well as, sustaining healthy ecosystems. It's even more important in the cases of riparian nations where international cooperation can sufficiently link natural processes and functions among different administrational settings. Transboundary groundwater resources in the European Union have been assessed the last decade under the Water Framework Directive (WFD), where important attributes have been assessed in the framework of quantitative, chemical, and ecological characteristics of water bodies. This study attempts to bring upfront the relations of groundwater and surface water bodies, measurable improvements, as well as, exploring major drivers in transboundary regions via land cover accounting to measure surface disturbances from 2006 to 2018. Special focus has been given in those cases where a change in quantitative and chemical status has been occurred. Further exploring the interlinkages with the chemical and ecological status assessed in the same hydrogeological catchments for the surface water bodies via geospatial analysis. In total, 12 European Union countries have reported transboundary groundwater bodies in both WFD reporting cycles (2010 and 2016) covering a total area of 300,000 km2. In the transboundary regions under 2016 reporting, 83% of groundwater bodies were on good quantitative and chemical status while the rest 17% failed to achieve WFD targets either for quantitative or chemical reasons. Between the WFD reporting cycles of 2010 and 2016, a 7.7% and 3.8% of groundwater bodies presented quantitative and chemical status deterioration – from good to poor status - respectively. Additionally, 5.3% and 3.8% of groundwater bodies presented improvement – from poor to good – in quantitative and chemical status respectively. In 2016, intersected groundwater-surface water bodies presented a relative stable condition for moderate and above ecological status. For groundwater bodies failing to achieve good status, 33% of linked surface water bodies presented poor, bad or unknown ecological status. Chemical status presented slight improvements (from 35% in 2010 to 42% in 2016) for all surface water bodies in the transboundary zones. The expansion of monitoring networks in these transboundary regions proved to be a useful tool to further reduce the uncertainty on the assessment of the quantitative and chemical status in its impacts to the transboundary groundwater bodies.

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Towards an integrated management of the Colorado river lower basin

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The Colorado River Lower Basin aquifer is located in the border between Mexico and the United States. It comprises the states of California and Arizona, in the United States, and Baja California and Sonora, in Mexico. The population on this area is estimated in 200 000 inhabitants. Food production is the main activity and date is the most important product as it represents around 70% of the total annual production in the Mexican region and an extension of 1 432 hectares. The National Water Commission (CONAGUA, 2015) reports that the aquifer experience a low degree of natural recharge. The main flow comes from incidental recharge and horizontal inflow, both of them calculated in 520 Mm3/year. As for the extraction, 974 Mm3/year are pumped for agricultural purposes. Mexican regulation prohibits new extractions. The transboundary aquifer also experiences quality issues. Levels of salinity has increased over the last years due to leaching from agriculture drainages (1000-24000 ppm). As a result, both countries have experienced a reduction in the productive soil. In addition, high concentrations of heavy metals, such as iron and manganese, have been found in the north and northeast of the aquifer. Despite the arising issues regarding transboundary aquifers between the two countries, the 1944 Treaty between the United States of America and Mexico for the utilization of water of the Colorado and Tijuana rivers and of the Rio Grande does not regulate groundwater. The 242 Act was enacted to foster cooperation on groundwater management, nevertheless this agreement has not been considered enough to solve conflicts on water supply, salinity, sediments and environmental management. Both Mexico and the Unites States have dedicated extensive efforts to characterize and to understand the hydrodynamic of the aquifer, as well as surface water but an integrated management approach is still needed. The main goal of this work is to propose structural and non-structural measures to be implemented in different time frameworks to achieve an Integrated Surface and Ground Water Management. The plan will consider elements such as governance and food production. In order to achieve this objective, regulation of both countries will be analyzed.

1 Regional Center for Water Security under the auspices of UNESCO

Analysis of interlinkages between groundwater, land management, energy and ecosystems in the North Western Sahara Aquifer System

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Analysis of interlinkages between groundwater and land management, energy and ecosystems in the North Western Sahara Aquifer System as basis for integrated policy and technical responses (title). The North Western Sahara Aquifer System (NWSAS), shared by Algeria, Libya and Tunisia, is one of the biggest transboundary groundwater reserves of North Africa. Its water resources being largely non-renewable, and the socioeconomic development having led to steadily growing water abstraction, the countries are facing important challenges. Through a transboundary dialogue and application of various participatory techniques and analytical tools, the nexus assessment of the NWSAS allowed to identify key linkages among energy, water, land, and ecosystem resources, involving trade-offs and benefits, together with potential solutions for more sustainable management. This was the first application of the nexus assessment methodology developed as a collective multi-disciplinary effort under the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention) to a transboundary aquifer: The identified challenges can be clustered as related to the following: 1) management of water from the perspective of economic development and water security; 3) economic, social, and environmental sustainability of agriculture, including the oasis agro-systems; and 3) energy security and energy developments, particularly renewable energy and its potential to help transform water management and agriculture. The key to the interdependence of the sectors is reliance on common groundwater resources that are becoming scarcer. Policy responses are linked too, through indirect and often unintended impacts of measures such as energy subsidies, renewable energy deployment, or popularizing high-value crops. Selected management measures were analyzed quantitatively: An integrated model was developed to evaluate the competitiveness of off-grid solar pumping to supply future demands of the agricultural sector (irrigation and desalination), considering different costs of fuels and levels of subsidies. The results suggest that making photo voltaic solar power technology more affordable is an effective way to promote solar energy, even more than reducing subsidies. At the same time, without planning, solar energy may seriously aggravate groundwater depletion. The nexus package developed participatively includes 15 high-priority, implementable solutions (consisting of 65 actions) ranging from governance and cooperation, to economic and policy instruments, infrastructure and innovation. At a strategic level, coordinated implementation of solutions will also help achieve cross-sectoral goals like coherent planning for sustainable development, enhanced local resilience, and a circular economy, while still contributing to sectoral development, by minimizing intersectoral trade-offs and negative impacts, and maximizing synergies. This Nexus Assessment of the NWSAS was carried out as a cooperation between the United Nations Economic Commission for Europe the Global Water Partnership Mediterranean and the Sahara and Sahel Observatory.

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Modeling selection criteria for transboundary water projects under budget constraints

Kizito Paul Mubiru[1], Maureen Sempijja[1], Senfuka Christopher[2]

Transboundary water projects are vital for cities and towns around the world; supporting the lives and livelihoods of vast numbers of people. The scientific base of such projects supports its rapidly increasing use as a vital management tool in the sustainable use of the world's water resources. Although joint projects by global water partnership for regional development respond by preparing a transboundary, the projects are somehow hampered by the absence of a clear economic base for the investment to construct and operate such systems. The financial gap between cost of providing good water and sources of funding has raised greater public concern among policymakers worldwide; having long term budgetary implications. In most project selection problems of transboundary waters, a best subset of a larger set of possible alternatives may be chosen subject to an overall limited budget. Therefore, innovative financing options appropriate to particular projects are deemed vital as well as an analysis of appropriate roles of donors and national awareness as stakeholders. In this paper, we present a zero-one integer programming model to determine the optimum selection of transboundary water projects where project selection is made based on several time periods in the future. The objective is to determine whether to undertake a project or not such that the net present value of investment returns for transboundary water projects are maximized for optimal facilitation of water consumption to needy communities. A numerical example is presented for illustration; demonstrating the optimal selection of transboundary water projects. Considering the projects used in this study, the zero-one integer programming model solution provides feasible results; taking into consideration the competing nature of project funding for implementation. The proposed approach can be efficient as a project selection method for integrated water resource management projects where limited funds among competing projects serves as a basis for project selection criteria. The cooperation along transboundary waters often bring more benefits that expected; although frequently not fully perceived.

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Prioritizing and zoning transboundary aquifers in Africa for informed decision making

Christina Fraser[1], Arnaud Sterckx[1]

The management of transboundary aquifers (TBAs) is essential to ensure sustainable, equitable and reasonable development of the resource. To assist countries in their efforts towards this goal, IGRAC and UNESCO-IHP (2015) have already developed a methodology for joint scientific assessments of transboundary aquifers. During joint aquifer assessments and while cooperating to develop shared management tools, countries might find the need to identify priority-based actions that reflect key issues or concerns within TBAs that require immediate, future and/or additional attention for in depth studies or interventions. There are currently, however, no available guidelines that detail how to prioritize actions within TBAs to guide groundwater policy and decision making.

Building on the lessons learnt during the Transboundary Waters Assessment Programme (TWAP), IGRAC and UNESCO-IHP under the GGRETA 3 project have developed guidelines to identify priority areas and issues within transboundary aquifers in order to inform decision-making on the need/necessity for management intervention. Six transboundary aquifers across Africa were selected with which the guidelines were developed in cooperation with national experts: the SE Kalahari Karoo Basin/Stampriet Artesian Aquifer System, the Shire Valley Alluvial Aquifer, the Sudd Basin, the Keta/ Dahomey/Cotier Basin Aquifer, the Irhazer-Lullemeden Basin, and the Senegalo-Mauretanian Basin.

The guidelines are designed to be used by countries sharing TBAs after or while establishing an initial shared science-based understanding of the TBA. They assume that while working to develop shared management tools, countries agree that there is a need to prioritize actions and/or areas in the TBA to inform policy and decision-making. The guidelines take an 'expert analysis' approach where the knowledge and expertise of key national experts from the aquifer countries are engaged to identify key pressures and areas for concern within the aquifer, supported by available data. Stakeholders within the TBA are then consulted before recommendations for directed and priority-based actions are made to policy and decision makers. Although suitable to be used separately by countries sharing a TBA in order to undertake preliminary actions at the national level, the guidelines are designed to be applied in the framework of a joint transboundary aquifer assessment, and for countries to engage in a process of cooperation, dialogue and joint prioritization of management actions

The proposed guidelines delineate a 7-step process, summarized as follows and outlined in figure 1. The guidelines first seek to identify how the aquifer is being utilized and whether that usage is sustainable. Consideration is then directed to the main pressures and concerns within the transboundary aquifer with particular attention paid to over abstraction and reduced water quality. These pressures are first considered at a national

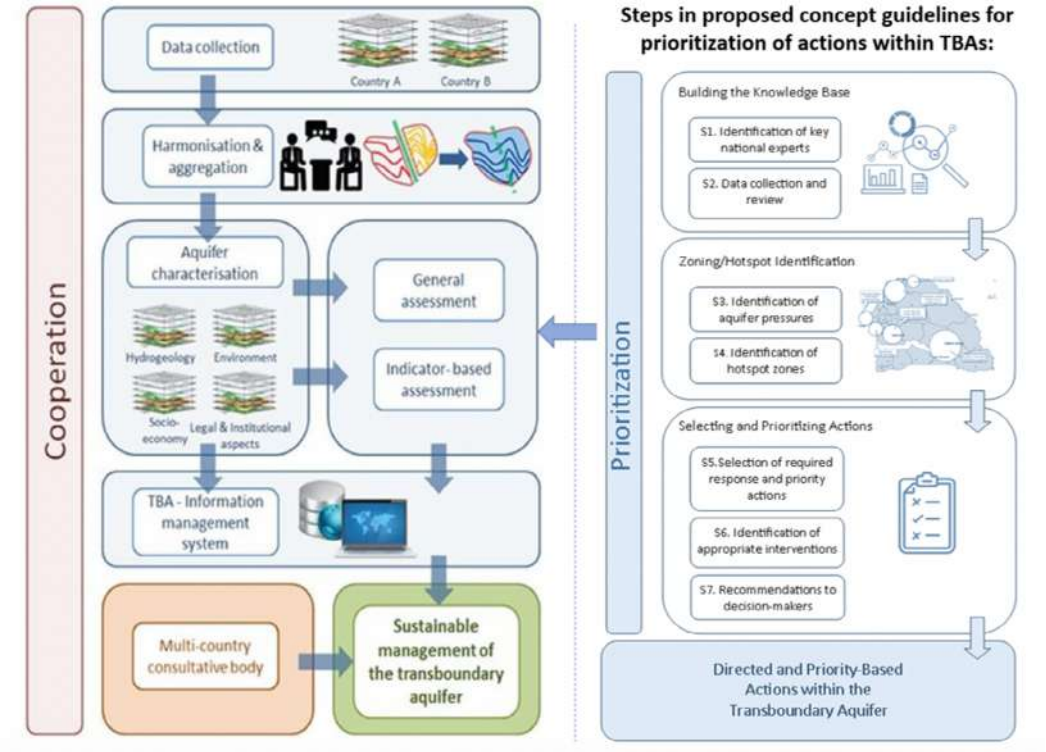
1 IGRAC: International Groundwater Resources Assessment Centre

level and then at a transboundary level, taking into account the potential for localized transboundary groundwater flow, transboundary surface water interactions and cross border impacts of over abstraction and contamination. Hydrogeological, socioeconomical and environmental data such as groundwater abstraction rates, water quality, population density, dependent ecosystems on groundwater, vulnerability to climate change, recharge capacity, provisions for IWRM and conjunctive water management, and the availability of institutional and legal frameworks will be utilized within the assessment.

The use of thematic maps is proposed within the guidelines to represent key transboundary pressures and stresses visually and spatially on the aquifer. Priority zones of key hotspot areas may also be identified within the aquifer if appropriate. The required response and potential actions moving forward are then considered, providing guidance over what type of response may be appropriate for a particular scenario alongside possible recommended actions and intervention practices to strengthen transboundary management. Finally, it is advisable that recommendations and next steps are proposed in consultation with stakeholders within the region before making recommendations to policy/decision-makers.

The development of guidelines to support decision making within transboundary aquifers is an essential step towards empowering nations to assess, prioritize and manage their transboundary aquifers effectively. These guidelines will also be an important instrument for policymakers and will bring more clarity about the importance of management of a TBAs, and, ultimately, improve cooperation within the TBAs.

Figure 1.
Modified schematic of the IGRAC and UNESCO-IHP, 2015 transboundary aquifer assessment methodology (left). The developed concept guidelines (right) can act as a standalone methodology or as an input to the overarching transboundary aquifer assessment methodology



source: Own elaboration

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IGRAC and UNESCO-IHP (2015). IGRAC and UNESCO-IHP. Guidelines for Multi-Disciplinary Assessment of Transboundary Aquifers - Draft version. IGRAC Publications, Delft.

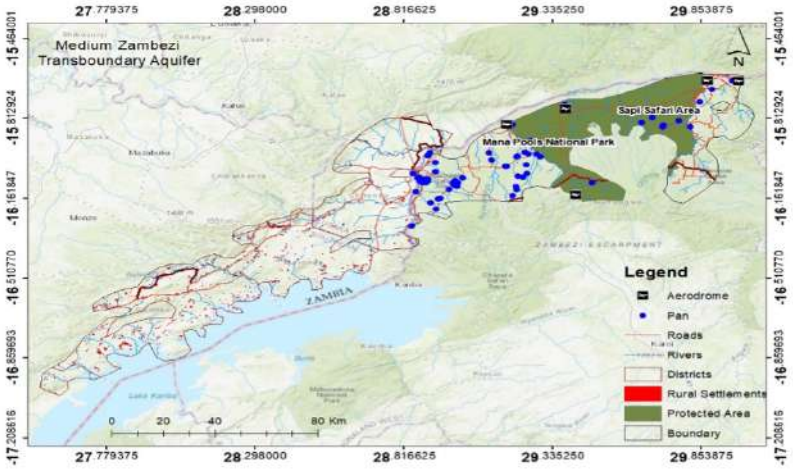
The interface between science and policy with respect to the governance of transboundary aquifers in Southern Africa

Edwin Nyamugadza[1], Percy Toriro[2] and Innocent Chirisa[3]

This article seeks to explore and discuss how the transboundary Aquifers (TBA) in different Southern African countries could be better managed for the benefit of local people amidst rising water abstraction used in agriculture and mining. In some of these TBAs there is a potential threat to overuse water leading to lowering of the underground water resource in these TBA. The Internationally Shared Aquifer Resources Management (ISARM) initiative aims to bring together countries that share aquifers along and across their international boundaries for joint cooperation and governance. The article argues that some of the shared TBAs already are in state of tension and there is potential future conflict between neighbouring countries due to lack of data that support the level of resource use of both countries that is compounded by lack of governance policy uniting countries.

This is very in common in TBA within the Southern African set up for example the Eastern Kalahari Karoo TBA between Zimbabwe and Botswana. As such what is missing in literature is an analysis of the extent of neighbouring countries water use or level of water abstraction given different human activities within the sharing countries. This means that, how much water each country is accessing from TBA is largely unknown. The study used Geographical Information System (GIS) to create TBA maps and remote sensing technology to analyse human activities occurring within the TBA boundaries. From the two case studies which were studied, created maps clearly showed that the majority of people living within the TBAs are subsistence farmers. This was clearly supported by the Medium Zambezi TBA which has its greater part in Zambia than it is in Zimbabwe in which a number of rural districts exist within this TBA in Zambia including Sinazongwe, Gwembe, Siavonga, Chirundu and Kafue. Sinazongwe, Gwembe and Siavonga which have altogether has a cumulative population of about 369,856 as of 2015.

Figure 1.
Medium Zambezi Transboundary Aquifer



source: Open Street Maps, Own elaboration

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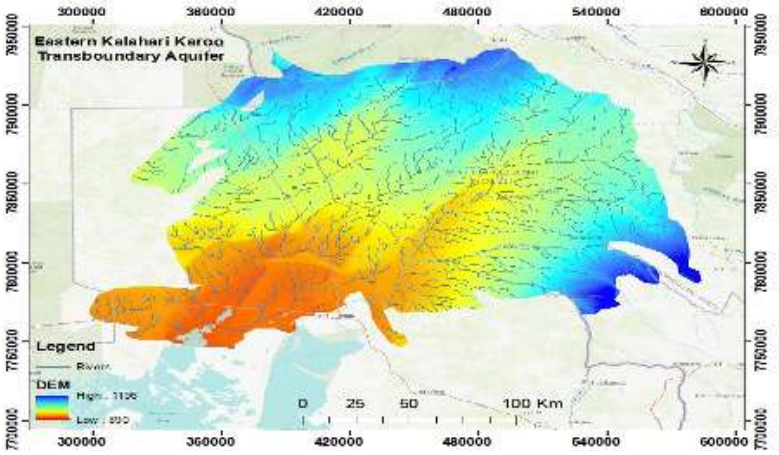
From the Eastern Kalahari Karoo TBA, Digital Elevation Model map results indicated that the TBA drains its waters from Gwai river basin in Zimbabwe towards Botswana. However interestingly, the area drained by the TBA supports population from about three districts with two districts of Tsholotsho and Bulilima districts consists of communal areas or villages where people use ground and borehole water as their only source of water.

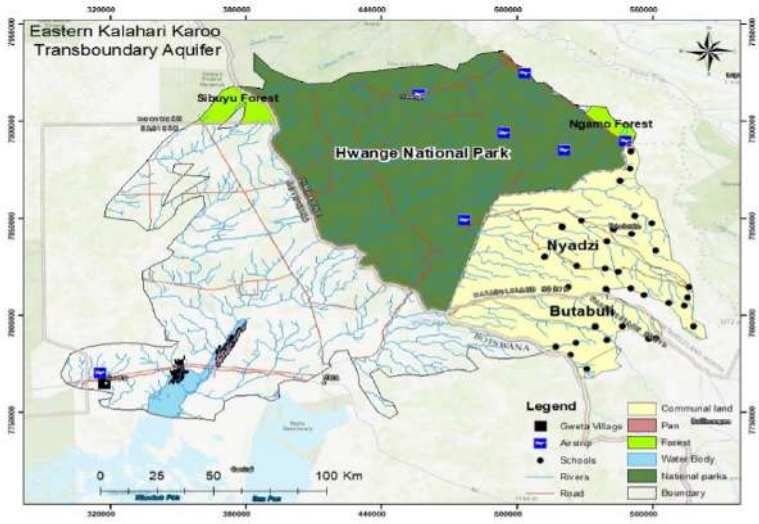
Figure 2.
Digital Elevation Model of the Eastern Kalahari TBA



source: Open Street Maps, Own elaboration

This only gives a clear indication of the level of demand for underground water within the TBA especially given the climatic conditions of and around the TBA. On the lower side of the TBA is Botswana which receives all the drained water from Zimbabwe through a number of major rivers. There is also however Gweta village in Botswana just closer to the edge of the TBA boundary who area also benefitting from underground water provided by the TBA though the level of water use may or may not surpass the way it is used in Zimbabwe based on the area that is being served by the TBA in Zimbabwe.

Figure 3.
The Eastern Kalahari Karoo TBA



source: Open Street Maps, Own elaboration

Results also indicate that that most TBA are under agricultural activities that results in unsustainable management of the water in communities within these TBAs hence attributing to high vulnerability of surface and underground water pollution due to unsustainable management practices within the TBAs. Despite the availability of the SADC Protocol on Shared Watercourses, a policy on shared water resources, there is need for bilateral agreements that foster equitable use of surface and underground water. Such a policy between Zimbabwe and Zambia and also Zimbabwe and Botswana are key and can to a greater extent help I sustainable use and management of the Kalahari Karoo and the Medium Zambezi TBAs. The research concludes that close monitoring of various human activities is necessary for sustainable use of underground water especially given the dramatic changes in climate change around the world. The study recommends policy measures that enforce and enhance proper governance and management of TBAs including research collaborations amongst member states. Research collaborations among member states are very key as they bring together policy makers, government and research personnel from all countries hence a guarantee of enhanced decisions for the survival of the TBA.

A review of regional groundwater flow model in Guarani Aquifer System outcrop region in Uruguay: consequences for integrated surface and groundwater management

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The Guarani Aquifer System (GAS) outcrop area in Uruguay develops as a N-NE strip of 165 km long and 30-55 km wide in the north-central region of the country. In this region, GAS is constituted by the Tacuarembó and Rivera formations (Upper Jurassic - Lower Cretaceous from Parana sedimentary basin), that encompass a succession of fine to medium siliciclastic sandstone strata, presenting good to the moderate selection, and good porosity. An extensive revision of the available wells data set (up to 1,100 wells) allowed a new interpretation of the GAS geometry and piezometry in the outcrop region in Uruguay. Based on the morpho-structural and stratigraphic features that it exhibits in the outcrop area, the GAS can be subdivided into 3 domains (South, Center, and North) and separated by strong NW lineaments: Arapey-Sopas-Tacuarembó Chico (ASTC) and Cuaró-Paguero-Isla Cristalina (CPIC), respectively. Despite these structures, GAS constituent units exhibit a homogeneous thickness about of 80-90 m.

Along the outcrop area GAS is a typical unconfined aquifer, despite some wells located in the western edge present basalts covering the sandstones, representing semi-confined conditions. According to the well depth two piezometric maps were constructed: one representing upper portions of the aquifer (well depth <70m), and another one for the lower aquifer (well depth >70m) (Figure 1).

Groundwater flow in the upper portion of GAS is directly related to the most outstanding relief and drainage features, associated with the main lineaments. Within the Northern Domain, the discharge occurs towards the depressed sector in the central portion of the outcropping area, represented by the Tacuarembó River, which develops in the NE direction. The groundwater flows to SE direction towards the Tacuarembó River in the Central Domain, strongly controlled by the morpho-structural features with NW direction, where the Tacuarembó Chico and Tres Cruces streams stand out. The Tacuarembó River initially runs under the NS direction to undergo a strong inflection under the NW direction. In the Southern Domain, the general discharge is towards the East, with a variation towards the SSE in the extreme south.

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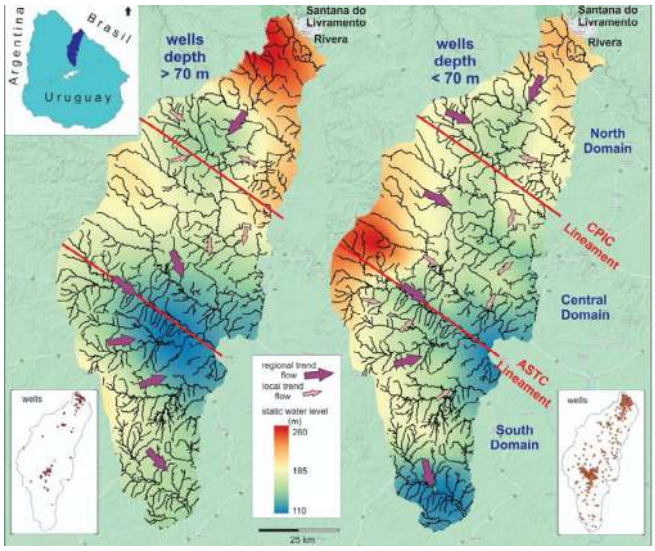
Despite the fewer deeper wells, it was possible construct a piezometric map for the lower portion of the GAS. In general way the regional directions are quite similar to the previous described, however some differences could be observed. Groundwater flow in the North Domain exhibits a SSW direction towards the Lunarejo Stream (PCIC Lineament) and its tributaries, while in the Central Domain the discharge and general flow direction is towards the SE, with the discharge being controlled by the Tacuarembó Chico River. In the Southern Domain, the regional discharge is towards the East with a slight variation towards the SE, observing that in this area the number of wells is very scarce.

Figure 1.
Left: Piezometric Map from the deep portion of GAS (>70m depth). Right: Piezometric Map from the shallow portion of GAS (<70m depth)



source: Open Street Maps, Own elaboration

The piezometric maps of the GAS outcrop area indicated a clear WE trend for the regional groundwater flow, strongly controlled by the relief elements, and the discharge is mainly directed towards the drainage network, which in turn, shows that morpho-structural features operate in its design. Despite the flow in the North Domain has a direction towards the SSW with a discharge towards the valley of the Tacuarembó River, in the other portion the flow is directed to the E, contributing to the baseflow of the Río Negro Basin. These findings are in opposite to the conceptual regional flow models for the GAS in Uruguay, that considers the outcrop area as a regional recharge area, and groundwater flows towards the West and Southwest.

The results presented, obtained using a geomorphological, geological, and hydrological database combined approach to evaluate the regional groundwater flow, open new perspectives for the water management in the GAS outcrop area, as well as opening the discussion about the recharge of GAS confined areas. Both the shallow and deep regional discharge of the GAS limits the original concept of considering the outcropping region as a natural recharge towards the W. At the transboundary level, the regional flow from north to south (from Brazil to Uruguay) remains in force, but the question remains about how the deepest area is recharged towards the Uruguay River (Argentina-Uruguay border). These aspects require that in both cross-border situations common criteria be adopted to evaluate and manage the resource, to propose actions for its coordinated management.

Groundwater levels simulation and forecasting using time series analysis (Case Study of Khour Abu-Simbel, Egypt)

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Simulation and forecasting of environmental and hydrological variables are useful approach in water resources management such a temperature, water consumption, water levels and water quality. Groundwater level forecasting models can help to enhance sustainable use of groundwater aquifers especially in shared aquifers as Nubian Sandstone Aquifer NSAS. This research simulates the groundwater levels using time series models for NSAS monitoring network in Khour Abu-Simbel in Aswan Governorate, south of Egypt. Where the main aquifer is the Nubian Sandstone Aquifer System (NSAS) which, is the largest transboundary aquifer in the world (2.2 million Km2) shared between, Chad, Egypt, Libya and Sudan. The main objective of this paper is to analysis and evaluate of the periodically monitored NSAS groundwater levels south Khour Tushka in Lake Nasser shore at Abu-Simbel, all over the year and during the Nile River flood seasons using Holt-Winters and ARIMA time series models to simulate and forecast the groundwater levels data which were collected recurrently by Research Institute for Groundwater (RIGW) form RIGW Experimental Station monitoring network in Abu-Simbel from (2001 to 2020) and to predict the local recharge of NSAS at Abu-Simbel area. The two models were compared its accuracy by using mean absolute percentage error (MAPE), root mean square error (RMSE), and R squared (R2). The analysis of Holt-Winters indicated that the optimum smoothing parameters a, ß, ? were calculated a = 0.83 to 0.99, ß = 0.02 to 0.03 and ? = 1.0 for the minimum error. The analysis of ARIMA model indicated that the best models for the eight observation wells are (9,1,9), (9,1,9), (9,1,9), (9,1,9), (12,1,12), (12,1,12), (14,1,14) and (13,1,13) respectively. The analysis showed that ARIMA model provided a reasonable forecasting tool for NSAS hydrodynamic status at the next five years (2021 to 2025).

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Multidisciplinary joint-force efforts towards science-based management in the Mediterranean region a particular focus on transboundary aquifers

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The Mediterranean Sea Region (MED) is unique in its human society, natural environment and climate variability. It is located in a transitional zone of atmospheric circulation regimes and is characterized by complex morphology with distinct landscapes including mountain chains, vast plains and contrasting land-sea interactions [1]. These unique features make the MED an attractive ground for diverse and culturally rich communities. The population of Middle East and North Africa has more than quadrupled between 1960 and 2020, and its degree of urbanization has risen from 35% to 66% during the same period [2]. This continuous increase in population and urbanization has resulted in increased water demand particularly for irrigation of agricultural crops and domestic consumption, ranking the MED as one of the world's most susceptible regions to water scarcity. The MED region has also become increasingly dependent on cereal imports over the past decades, which poses a serious threat to the food security of the region [3]. Furthermore, ongoing climate change in the MED region seem to exacerbate the situation. The average annual temperature is today about 1.5 °C higher than during the preindustrial period (1880-1899) and well above the mean global trends (+1.1°C) [4]. Also, for each degree increase of temperature, mean rainfall in the MED region is likely to reduce by about 4%, which is amongst the largest decreases in the world [1]. This situation is likely to result in a severe decline in groundwater recharge in the future by about 38% [5].

The MED includes numerous transboundary water bodies. For instance, 90% of South-Eastern Europe falls within transboundary rivers and lakes, while North-African transboundary aquifers comprise two-thirds of freshwater resources. The Sustainable Development Goal 6 of the United Nations (SDG 6) considers cooperation over transboundary water bodies as a critical

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priority to ensure equitable and sustainable water resources management. Its target 6.5.2 aims to reinforce the sharing of transboundary basins with an operational arrangement for water cooperation. Preliminary outcomes from SDG 6.5.2 showed that South Europe is one of the regions with the highest operational management levels. At the same time, North Africa is characterized by low to very low operational management levels in transboundary aquifers [6]. Thus, transboundary water bodies in the MED diverge from a source of cooperation in the South of Europe to a source of conflict in the North of Africa. Even though groundwater resources represent a strategic freshwater reserve in the MED and has played a crucial role in attenuating and buffering anthropogenic and climate-change associated impacts, its status is becoming increasingly uncertain. Data availability for the MED aquifers range from near absence in North Africa to high density in parts of Southern Europe, leading an uneven distribution of data availability. The scarcity of long-term and widespread monitoring data is a major constraint for management and vulnerability assessments [7].

Key issues that pose obstacles in realizing good cooperation on the "invisible resource" include lack of adequate groundwater monitoring and detailed transboundary aquifer assessments at national and regional levels. This is due to the interplay of multiple complex factors such as geology, climate, human activities, absence of systematic monitoring and data-sharing policy, defragmented water policy and governance. The effects of these factors are further amplified by political and legal differences among neighboring countries. In this context, implementing science-based management solutions calls for transdisciplinary scientific knowledge based on co-production of in-situ evidence and benefiting from long-term and comprehensive information sharing on groundwater dynamics. To this end, an international and multidisciplinary team of scientists with complementary skills in hydrology, hydrogeology, agronomy, socioeconomics, environmental policy, governance and conflict mediation, modelling, climate change and remote sensing have joined efforts towards better groundwater management and governance in the MED. The objectives of this study are: (i) to assess the groundwater status in the MED, including the causal chain connecting drivers to impacts and response options, (ii) to identify regional groundwater depletion hotspots and, (iii) to elucidate pathways and recommendations towards sustainable and science-based management options of groundwater resources.

Examination of water policy of the MED region revealed an unbalanced situation. In South Europe, water policy is relatively complete, harmonized and straightforward mainly due to the legal basis and enforcement by the European Union through its different water and environmental directives. Conversely, in North Africa and Middle East, water policy was found complex, not regionalized and defragmented in various initiatives. The latter calls for a more sustainable regional governance structure to promote systematic monitoring, data sharing, awareness raising, and modelling of groundwater resources in Northern Africa and Middle East. Fostering scientific knowledge is crucial to identify scientifically based solutions and to define new environmental and ecological targets towards sustainable development and climate resilience in the MED region. Developing scientific knowledge from data-driven analysis requires extensive effort and time. Targeting detailed in-situ data at a fine time resolution and a large spatial scale is a long-term process. In a data-scarce region such as the MED, groundwater modelling at regional/global scale can offer further insights. However, it remains unclear to what extent those models can be used to support management decisions. Our study adopted an approach combining data-driven and modelling data, as an innovative method to assess better groundwater status and dynamics in the MED. A joint effort to collect groundwater level data was launched among partners of

two PRIMA funded projects (Sustain-COAST and InTheMED). So far, the gathered database contains more than 10.400 wells with historical time series of groundwater levels covering seven countries of the MED. To the best of our knowledge, this effort will result in the first long-term and, possibly, the most comprehensive groundwater-level database in the MED region connecting groundwater status to its drivers, pressures, impacts and responses. The first collected data were used to identify groundwater trends and their controlling factors in Portugal, Spain and France. The groundwater trend analysis will be extended to the whole MED. In parallel, regional modelling of steady-state groundwater head was operationalized using three global-gradient groundwater models for the entire MED region. Preliminary results indicated that regional models could represent the measured groundwater steady state of the Iberian Peninsula with a coefficient of determination R2 of ca. 0.70.

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source: Open Street Maps, Own elaboration

Procedure for the management of transboundary aquifers

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Based on Peru's experience in the management of basins that provide water to sanitation companies, a procedure is proposed for the management of transboundary aquifers. The procedure is about a set of elements that countries must develop for the sustainable management of transboundary aquifers. These elements are similar to those used by sanitation companies in Peru to manage their supply basins. The proposed procedure, after review and evaluation, could form part of the tools for Integrated Water Resources Management (IWRM). The elements that make it up are the following: 1. Establishment of agreements: in the agreements signed by the governments of the countries for the management of transboundary aquifers, it is a must to have minimum aspects established according to the elements that are part of the procedure proposed in this document. 2. Diagnosis of transboundary aquifers: studies are required to delimit transboundary aquifers and determine the problems they deal with. These studies will help to sustain the commitments that countries must fulfill in the framework of agreements for the management of transboundary aquifers. 3. Design for monitoring aquifers: it will be necessary to design a monitoring system for the transboundary aquifers delimited in the "Aquifer Diagnostics" to generate information that allows evaluating the evolution of transboundary aquifers and if the projects being executed are contributing to the handling them. 4. Platform for the Governance of Aquifers: in the platforms where the governments of the countries participate to establish commitments and carry out actions on water, a scheme that defines roles and functions within the framework of the proposed procedure must be incorporated. 5. Investment gap for sustainable management of transboundary aquifers: based on the "Diagnosis of transboundary aquifers" and other specific studies, an estimate of the investment gap that is required for the sustainable management of transboundary aquifers should be made. This will allow to define investment goals. 6. Development of projects and their financing: the projects that are formulated must form part of the commitments established in the agreements between the governments of the countries, which must be aligned with the closing of gaps for the sustainable management of transboundary aquifers. Given these elements, indicators can be developed for the Management of Transboundary Aquifers, which will allow to know their progress, identify bottlenecks, monitor compliance with agreements and for decision-making.

1 National Superintendency of Sanitation Services

Investigations of Seawater Intrusion in the Transboundary Aquifer System of Bir Guendouz - Boulanouar (Morocco-Mauritania)

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The Bir Guendouz-Boulanouar aquifer is a transboundary aquifer (TBA) that develops in the extreme southern Morocco, over an area of about 3,800 km², and extends southward to the northern Mauritania. The study area is characterized by a hyper-arid continental climate with very scarce surface water resources due its geographical location in the desert.

The rainfall regime is extremely irregular, typical of the Sahara and hyper arid regions, characterized in particular by maximum values which can represent several times the interannual average value. In contrast, extreme minimum rains can be near zero for one or more consecutive years. The rainy episodes are highly concentrated in time, generally in a few days in the year (13 days on average) leading to sporadic flows usually get lost in the sands of the desert or join the 'sebkhas' (isolated depression lands in the desert).

This TBA aquifer is composed of sand, sandstone and clay sandstone and exploited to supply the Bir Guendouz city in Morocco with drinking water and more importantly the large mining city of Nouadhibou and the neighboring centers in Mauritania with drinking water. Furthermore, the region, knows several socio-economic activities for its development on the Moroccan side at Bir Guendouz area, in addition to the increasing water demand relevant to the rural population and livestock of both areas located in Morocco and Mauritania.

The geophysical and hydrogeological investigations carried out in both sides of Morocco and Mauritania show that the aquifer hydrogeological knowledge has been improved and led to consider an aquifer system composed of two-layer aquifers: the upper unconfined layer with a thickness varying from 20 to 100 m and the greatest thicknesses (of the order of 80 to 100m) are observed in the center of the basin. The lower confined layer can exceed 300 m, and thicknesses ranging from 100m to 300m are observed over a large part of the basin (in a North-South and East-West directions). Its thickness increases from North to South. These aquifers are locally continuous and probably communicating by drainage. The aquifer reservoir is made up of sandy-clay formations from the Mio-Pliocene with intercalations of limestone. The groundwater wells are becoming artesian in the Dakhla-Bir Guendouz basin (Moroccan side). the whole aquifer system is exploited in three main well fields, 2 are located in the Moroccan side and an important well field captured in Boulanouar for supplying the city of Nouadhibou (Mauritania).

The aquifer piezometry varies from +40 m north-west to -5 m south-east, due to intensive pumping in the Boulanouar well field (Mauritania), and groundwater flow is generally directed from East to West, the natural recharge is low, and the mean transmissivity is estimated to 1.5 10-4 m2/s leading to a good well productivity with rates ranging between 5 and 40 l/s.

The chemical analysis of groundwater samples from observation wells in both sides of the

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two countries shows that salt concentration in groundwater varies from 0.5 g/l to more than 20 g/l (west of the Bir Guendouz area - Morocco). In the western part of Boulanouar area (Mauritania), chemical analyzes show also a high salinity (more than 24 g/l). The overall results from the geophysical prospecting investigations indicate that the saltwater intrusion extension is located 30 kilometers from the Atlantic coast to the east of the basin and can reach up to 40 km at Guerguerat region (Morocco - Mauritania borders). This situation has led to divide the aquifer system into two parts, a coastal part which is brackish covering almost a third of the area and the other which is relatively freshwater, where most of the wells are installed on either side of the borders. However, the risk of seawater intrusion cannot be avoided and will surely extend further into the aquifer system as we intensively increase groundwater pumping, which would reach the well fields in both countries and rendering groundwater unusable.

Hence, intensive exploitation of this TBA is expected to increase from both sides of the borders. In the Moroccan side, several socio-economic development activities are planned, such as tourism, industry in addition to local irrigation and water supply of urban and rural populations and a large livestock of camels. on the Mauritanian side, the largest city of Nouadhibou and the neighboring iron mining centers already present an overexploitation of the aquifer system, due to the increasing water demand. This will lead to more groundwater depletion and seawater intrusion advance. Technical collaboration and partnership between the two countries (Morocco and Mauritania) are essential for an integrated and sustainable water resources management of this TBA, and in particular more hydrogeological and geophysical investigations are required in both sides. this will improve and complete the hydrogeological knowledge acquired in order to build a good conceptual model on which a mathematical model for seawater intrusion will be designed, including the whole TBA aquifer. These models are very important tools to assist the decision-maker on the orientation measures of water management, planning and exploitation in both countries.

Transboundary aquifers – assessment and management – in the Pannonian Basin

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Multinational surveys of transboundary aquifers in the Pannonian Basin date back to the end of the 1980s and expanded after 2000. Starting with the DANREG project, cross-border cooperation continued through ENWAT, T-JAM, TRANSENERGY to the most recent DARLINGe project. The national geological surveys played an important and leading role in these cooperation.

Some of the achievements include:

- Harmonised mono-element and contamination index maps, and a joint transboundary groundwater flow model for three Hungarian-Slovakian transboundary aquifers were prepared within the ENWAT project;
- A joint transboundary aquifer management plan for the Hungarian-Slovenian porous intergranular thermal aquifer was prepared within the T-JAM project;
- Delineated transboundary geothermal aquifers, harmonized 3D transboundary hydrodynamic modelling, benchmarking indicators for thermal aquifer assessment and management and a white paper for a harmonised management strategy for the sustainable utilisation of thermal water and geothermal energy for Hungary-Slovenia-Austria-Slovakia within the TRANSENERGY project;
- Harmonised geoscientific data to identify and characterise potential geothermal reservoirs on a regional scale, assessed thermal water utilisation practice, a tool-box consisting of complementary methods for the sustainable management of geothermal resources and project development, an interactive web-site — the so-called Danube Region Geothermal Information Platform (https://www.darlinge.eu/) — where all the key findings of the project are accessible to the wider public. This project was carried out by partners from 6 countries, Hungary, Slovenia, Croatia, Serbia, Bosnia and Herzegovina, and Romania within the DARLINGe project. The investigated area covers 99,372 km2 situated in the Southern part of the Pannonian Basin. Within this large area, three transboundary aquifers were selected as pilot areas for more detailed studies. These are the Slovenian–Hungarian–Croatian, the Hungarian–Romanian–Serbian and the Bosnian-Herzegovinian–Serbian pilots, encompassing both intergranular and fractured thermal water aquifers (Nádor et al., 2019).

A benchmarking methodology refined within the DARLINGe project has been tested and evaluated using a unified and harmonised approach in the pilot areas, which is an easily comparable, informative tool for thermal water management, and additionally can support measures for a more efficient energy production.

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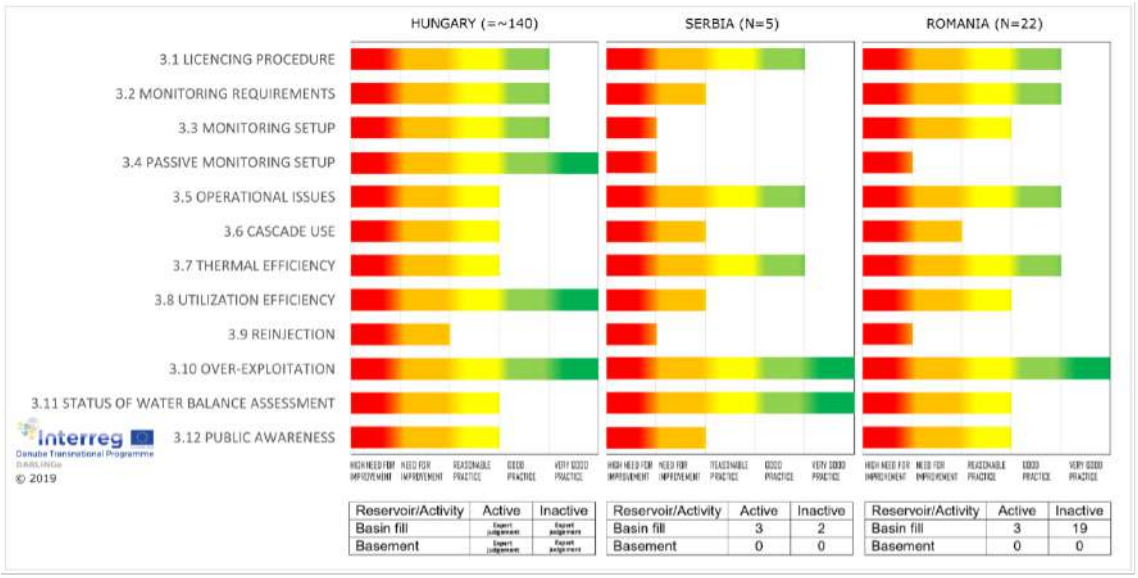
7 Geological Institute of Romania

Firstly the main stakeholder groups have been identified, including 1) management authorities and international organisations, 2) licencing authorities, 3) thermal water users, 4) investors in geothermal use and 5) research organisations and universities. Following that, relevant criteria for the benchmarking methodology were defined, such as transparent, harmonised, well-defined and understandable terminology and a methodology with worldwide applicability and which is not dependent on local geothermal exploitation characteristics. It also had to be informative, provide quantitative results and a clear delineation concerning the availability of information. In order to minimize the impact of potential data uncertainties, some key issues were identified, and special attention was paid to them during both data collection and evaluation. The availability and reliability of information was double checked and discussed between the partner country members, who reviewed reference dates, types of geothermal objects to be included and the weight assignment of the indicators was commonly defined. Four benchmarking indicator types have been defined and the required data collection and presentation/evaluation levels were also defined for each indicator. In total 12 benchmarking indicators were tested and evaluated (see Table and https://www.darlinge.eu/#/benchmarkingIntro).

Indicator type	Name of the indicator	Smallest data collection level	Smallest data presentation level
Management	Licencing procedure	Site/Country	Site or country
Management	Monitoring requirements	Site/Country	Site or country
Management	Monitoring setup	Object/Site	Site
Management	Passive monitoring	Aquifer/Region	Aquifer/Region
Technology & energy	Operational issues	Object	Site
Technology & energy	Cascade use	Site	Site
Technology & energy	Thermal efficiency	Object	Site
Technology & energy	Utilisation efficiency	Object	Site
Environment	Reinjection	Object/Site	Site
Environment	Over-exploitation	Site	Site
Environment	Status of water balance assessment	Object/Site	Site
Social	Public awareness	Site	Site

Results were grouped into the following five categories: „high need for improvement", which „need for improvement", „reasonable practice", „good practice" and „very good practice" based on these simple calculations. Results of the Hungarian-Serbian-Romanian pilot area are shown in the below figure (Nádor et al., 2019).



Although cooperation between scientists in the adjoining countries is good, and science based evidence has been presented to policy makers, with the exception of the Ipoly/Ipe' transboundary aquifer which was recognized as an important transboundary groundwater body on the ICPDR level based on these cooperation, transboundary thermal water aquifers of the Pannonian Basin are not yet legally recognised at a bilateral or international level.

Enhanced system understanding through water balance modeling in transboundary aquifers- case study from the Sokh Aquifer in Central Asia

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In Uzbekistan, groundwater has been of better quality than surface water and has thus been reserved for drinking water supply and strategic reserves in the country. Currently, around 69 cities, 335 rural settlements and 2902 villages are supplied with drinking water from groundwater. The intensive development of industry and agriculture over the past 40-50 years together with strong increases of groundwater abstraction in these sectors has however had a negative impact on fresh groundwater, which has led to an estimated decrease in their reserves by 35% and even caused the depletion of individual deposits. In oases with inadequate drainage and over-irrigation, shallow groundwater tables have risen to critical levels. They are causing soil salinization which render agricultural lands infertile and are threatening infrastructure. As most of Uzbekistan's freshwater resources are imported from upstream countries via river and groundwater discharge, these issues cannot solely be addressed at national levels but need to be tackled in a holistic way at watershed scales and through the inclusion of all sectors. Investments in groundwater resources assessments using modern technologies are needed in the region. They constitute the point of departure for the definition of sustainable and efficient management scenarios. Numerical groundwater models are in this regard state-of-the-art. These models are always a simplification of the real system and will thus be subject to the typical uncertainties. However, they can be extremely powerful tools to evaluate the impact of changes in infrastructure or management. They further allow the experts to improve their system understanding during the iterative modelling process and provide an objective tool for the joint exploration of management tradeoffs. The case study focuses on the Sokh aquifer region in the Fergana Valley. The Sokh aquifer is shared between upstream Kyrgyzstan and downstream Uzbekistan. It has seen severe water logging over the past 20 years in the downstream. To understand the causes of water logging and for the design of remedial measures, a robust conceptual water balance model was developed and implemented in Modflow. The model was calibrated against measured groundwater levels and fluxes and used to demonstrate the potential of numerical models to explore impacts of different management strategies. The present study is remarkable in that it brought together leading water resources experts from different Ministries/sectors to provide knowledge and data. It can be used as a template for other aquifers in the region.

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Depth-dependent groundwater response to climate variability and human influence in the transboundary aquifers of South Asia

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1. Introduction and background

The Indus-Ganges-Brahmaputra-Meghna (IGBM) river system of South Asia is one of the largest transboundary basin aquifer systems across the world[1,2]. This basin has one of the highest irrigation water demands and very high population density[3]. About 80% of total precipitation in India and Bangladesh occur through Indian Summer Monsoon4. Recent studies[1,5–9] disagree on the triggers for groundwater storage changes and recharge patterns across South Asia. While some studies[6] have argued that the precipitation patterns are the primary influencing factor for groundwater level (GWL) changes across the Indian subcontinent, other studies on this topic[7,10,11] suggest that even in areas demonstrating increased precipitation and primary/secondary recharge, enhanced depletion of groundwater storage are observed, which is potentially caused by intensive groundwater abstraction[12,13]. Furthermore, the groundwater regime may also be influenced by the seepage from natural surface water bodies[14], canals[1], irrigation return flows[8], and groundwater policy interventions[7]. Following the lack of agreement on the relative importance of drivers in previous studies and due to the limitation associated with regional groundwater flow models[15,16], Land surface models[16], GRACE, and global models[17], we revisited the subject-matter with a hypothesis-guided data-driven statistical approach involving a dense network of monitoring wells (n=6753). Our hypothesis is that while intuitive responses of groundwater to climate variability may be captured in the natural system without human interventions, pervasive human interference involving groundwater pumping may cause alteration in the natural dynamics leading to non-intuitive differential responses, depending on the abstraction pattern and hydro-stratigraphy. To evaluate our hypothesis, here we determine the influence of climate (via local-precipitation and global-climate cycles) on groundwater levels under the effect of groundwater abstraction with new information on the intake depths of the observation wells, in the parts of the IGBM basin and sub-basins for the last three decades (1985-2015). We used lag-correlation analysis, wavelet analysis, and multiple regression-based dominance analysis as our tools based on its wide uses by previous researchers[18–21] and rigorous statistical insights.

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2. Results, analysis, and discussion

We find Substantial variation in temporal phase lags between precipitation and GWLs linked to precipitation amount, sub-surface depth, and withdrawals. Higher phase lag for most exploited Indus basin, while lower phase lag in less exploited Brahmaputra basin is observed. The results from the wavelet analysis suggest, non-intuitive differential GWL response to global climate cycles in exploited parts, especially at greater depths. The findings from the dominance analysis are mostly in agreement with the lag and wavelet analysis; and suggests stronger dominance of abstraction, precipitation, ENSO, PDO in the study area. In general, groundwater abstraction (particularly from deeper depths) dominates in Indus and Meghna basin, while precipitation dominates in the Brahmaputra and Meghna basin. The influence of precipitation and abstraction are moderate for the Ganges basin. We also find that climate oscillations from the Pacific Ocean have a greater influence on groundwater than the oscillations from the Atlantic Ocean and the Indian Ocean. The results suggest irregular responses between GWLs and global climate patterns in areas where human interferences dominate over the natural recharge processes. Thus, the natural dynamics of the hydro-climatic cycle gets obscured when groundwater abstraction through pumping is introduced. Furthermore, irrigation return flow8, mass loading effects, and canal leakage1,22 which have a significant contribution to the groundwater recharge in the parts of the basin, may be partially accountable for modifying the natural linkage between climate and groundwater. The results presented here are sensitive to the spatio-temporal coverage of the existing data and the availability of data on other important drivers. Furthermore, additional information on groundwater use, canal leakage is required to truly isolate the anthropogenic effects and the climate effects on groundwater.

3. Conclusion

We surmise that groundwater pumping could provide an important role in modifying the link between hydroclimate and groundwater. This study emphasizes the climatic and the human-induced effects on different depths of the aquifer, particularly the adverse effects on greater depths due to increasing deep groundwater abstraction. Thus, efficient monitoring of deep groundwater abstraction is required to ensure its sustainability and usability in the present and future23. The findings may be helpful in constructing regional strategies and relevant policies related to prevailing high groundwater withdrawals in the region.

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The drinking water vulnerability of Sundarbans in present variable hydroclimatic conditions and unsustainable management practice

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The coastal aquifers of Sundarbans, an UNESCO world biodiversity heritage site, are highly vulnerable due to changing climatic conditions, intensification and increasing frequency of extreme climate events and uncontrolled abstraction of groundwater. The Sustainability and availability of fresh drinking water and the role of growing population are poorly understood in the Sundarbans. Thus, this study in aimed to understand the groundwater quality (Salinity) in variable hydraulic head conditions by considering the hydroclimatic variability (rainfall) and increasing population density. The rainfall amount and groundwater level of Sundarbans has a declining trend. Results revealed that salinity variability is observed between 1 and 4 ppT (at>100 meter below ground level depths), suggest mixing between chemically distinct water masses. The vertical transport of solute has been induced by declining groundwater level. However, human interferences, in terms of groundwater abstraction and land use-land cover change (e.g., brackish aquaculture) do have substantial impact on evolving groundwater response, thereby impacting resilience to drinking water option in this densely populated area. In this restricted condition of groundwater use, economic growth and urbanization would put further stress on future water availability. The surface water salinization and limitation of groundwater use led to restricting agricultural practices, leading to local people's migration and economic hardship. Due to the agricultural unproductivity and economic loss people are switching their agricultural land to brackish water aquaculture. The practices of brackish water aquaculture also have possible effects of shallow groundwater salinization. Most of the residents in this tide dominated delta front depend on groundwater for domestic use and irrigation of staple crops due to the unavailability of fresh surface water due to its vicinity to the Bay of Bengal. Groundwater sustainability of coastal aquifer needs proper management practices. Hence, it needs to address the maximum-optimum feasible pumping rates in a day and need to optimize the well locations to meet community needs. Thus, future planning and management strategies of sustainable supply of safe water in such ecologically sensitive groundwater systems immediately, otherwise depletion of rainfall amount with the unsustainable groundwater abstraction practices would create a potential threat to the available drinking water resources locally as well as regionally.

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Brazilian water policy law, goals, tools and state of the art

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Brazil shares 11 of the 29 existing transboundary aquifers in South America (ISARM, 2007), including 2 of the largest aquifers in the world, the Guarani, and the Amazon aquifer (UNESCO, 2015). The study of the water management policy and its implementation is essential for transboundary aquifers governance. The Constitution of 1988 profoundly altered the water resources domain in Brazil, making them a public good and subject to various legal, environmental, and administrative requirements. The Union centralizes much of the constitutional powers related to water, such as to plan and promote permanent defense against public calamities like droughts and floods; establish the national water resource management system, define the criteria for granting the rights of use, and provide guidelines for basic sanitation (article 21, item XVIII, XIX and XX). Through bibliographic and documentary research, this study aims to outline the current development of the national water resources policy, created in 1997, through Federal Law 9433/97- known as The Water Law - which, in addition to creating the National Water Resources Policy, established the National Water Resources Management System, providing the governance model where the basin is the mandatory territorial management unit and a key role to the National Water Agency (ANA). The aim is to verify the development progress of the different policy tools, crucial to the governance of transboundary groundwaters. Keywords: Water Policy; Governance; Tools.

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POSTER ABSTRACT

Investigation of the transboundary aquifer system in Prespa – Ohrid watershed using hydrogeological methods and SWOT analysis

Kiri, E.[1], Voudouris, K.[2*], Reci, H.[1],Kolokytha, E.[3,4]

Great Prespa (shared between North Macedonia, Albania, and Greece) and Ohrid (between the southwestern part of North Macedonia and eastern part of Albania) lakes represent a common hydraulic system in the Balkan Peninsula (SE Europe). They are separated by Dry-Galichica Mountain chain with highest peak of 2288 m (a.s.l.). The elevation of Prespa Lake is about 153 m higher than that of Ohrid Lake. The lakes are very important wetlands, supported by Ramsar Convention, included in the European Network of Protected Areas NATURA 2000. Between the aforementioned lakes a transboundary aquifer is developed in karstified carbonate rocks (Triassic massive limestone). These rocks cover the western and southern edges of the valley, and a large part lie on the bottom of the Prespa Lake. This work describes the general characteristics of the transboundary aquifer using hydrogeological data and proposes indicators and measures for the sustainable water management performing SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis. The transboundary karstic system is a complex system which functions primarily as a hydro collector and hydro conductor, affecting the water balance of the lakes. ?he hydrogeological behavior of karst aquifer is controlled by tectonic deformation, which favors infiltration of meteoric water. The karstic rocks come out as a mixed porosity; the porosity of the rock blocks (matrix porosity), porosity of small and larger cracks, porosity of big faults and caverns and porosity of clastic material filling all rock discontinuities. Numerous crevices, sinkholes, and karstic fields, as surface forms, and also underground forms of the types such as: caves, canals, etc. are characteristics of the mountainous area. Groundwater recharge occurs via infiltration of rainfall and the groundwater flow direction is from Prespa to Ohrid Lake. In addition, the karst system discharges through many springs. The aquifer is also vulnerable to external pollution, as well as to climate changes affecting the lakes' ecosystems. It is pointed out that Prespa Lake is characterized by a continuous and prolonged decline of water level. This decline could be associated with hydrological parameters, anthropogenic activities and/or tectonic reasons. Based on results of SWOT analysis and use of indicators including water quality, groundwater level, level of lakes, discharge of springs, climatic data, land uses, water abstractions a water management action plan and a set of measures, is proposed for the sustainability of the transboundary aquifer and depended ecosystems under climatic change, and in favor of the socio-economic development of the wider area.

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POSTER ABSTRACT

Challenges related with unforeseeable aspects of transboundary aquifer system management

Julio T. S. Kettelhut[1], Ana María C. Clerici[2]; Silvia Rafaelli[3]

The implementation of Transboundary Aquifer System (TAS) Management is a complex process that requires attention to several technical, environmental, economic, socio, cultural, administrative and political aspects. These details can make it difficult to succed, whether in achieving the expected objectives or in the delay of its execution. A significant part of these implementation challenges is predictable and measurable, such as those related to non-coincidence of basins and aquifer limits, areas of recharge and discharge of aquifers located in different countries, definition of a transboundary stripe of land where any water use intervention reflects in the neighboring country, differences among countries regarding their development levels, among others. In addition, there are externalities about some aspects -unforeseeable- of fundamental importance for medium and long-term strategic action implementation. During the process of formulating, executing and operating administrative systems for the TAS management, conjectural situations may occur in countries or among them, not initially foreseeable, which may compromise the achievement of expected results. These unforeseeable aspects are intrinsic/specific of each country, being more evident when related with economic, socio, cultural and political ones, in particular when referring to developing countries. They are difficult to solve, due to the complexity to equate and resolve them, however, the possibilities of their occurrences must be considered, identified and discussed, trying to establish mechanisms to avoid or mitigate them. These measures and their respective lessons learned can serve as a basis for more realistic assessment of the level of success of these transboundary regional enterprises, in particular by international donor agencies, to guide their future activities. This paper discussed challenges for integrated management of TAS considering particularly unforeseeable aspects that are of fundamental importance for the implementation of its medium and long-term action plans. Keywords: management, transboundary, aquifer, challenges, unforeseeable.

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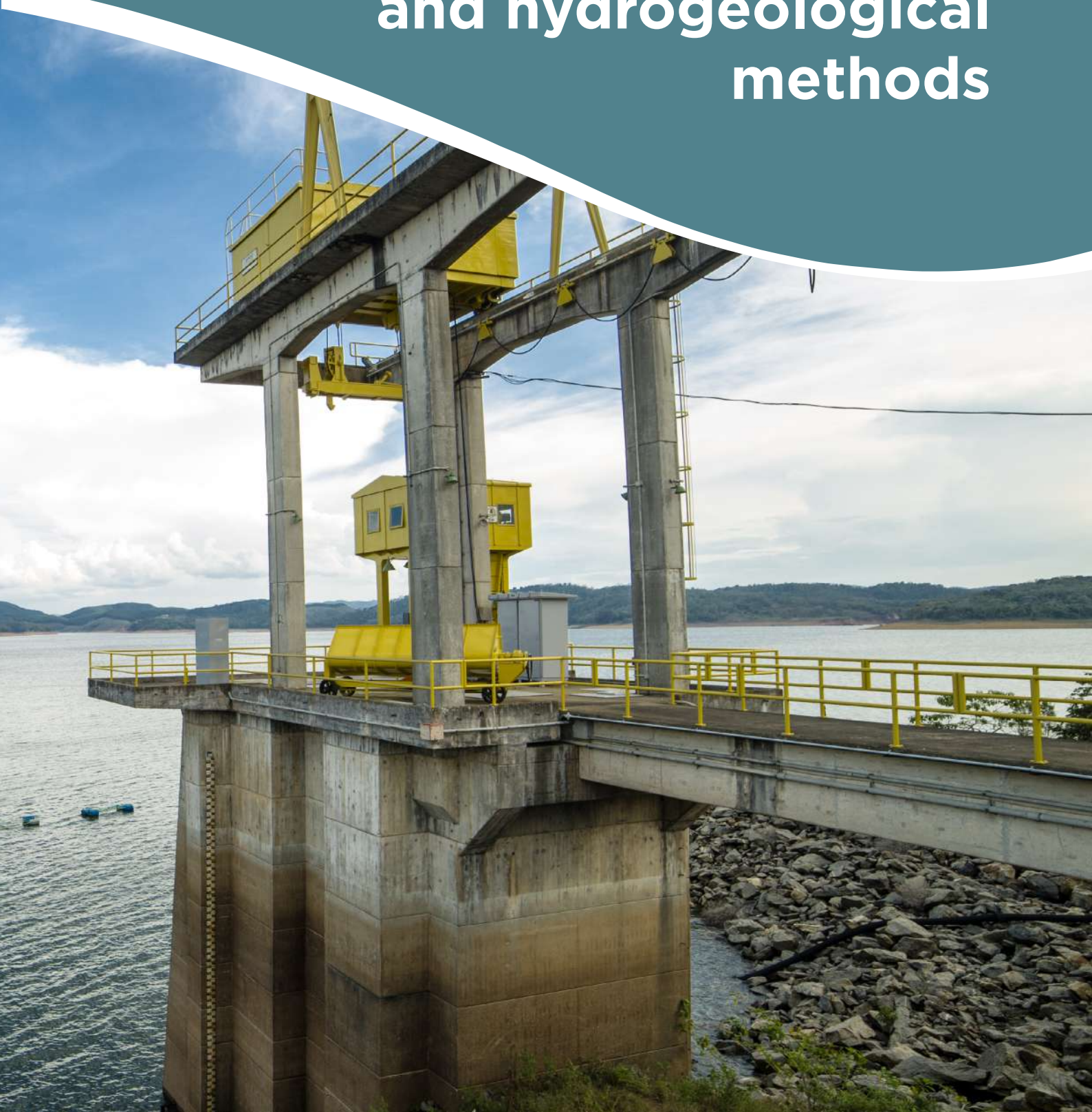
TOPIC 3 :

Advances in the assessment and mapping of transboundary aquifer and hydrogeological methods



Transboundary Aquifers between Mexico and the United States: the complete map

Rosario Sanchez[1], Laura Rodriguez[1]

Up until 2015, the number of transboundary aquifers reported between Mexico and the United States of America (U.S.) was 11. In 2016, new research indicated that there might be up to 36 aquifers traversing the border between the two countries. In 2018, a more detailed technical study showed that only between Mexico and Texas, there are 33 hydrogeological units (HGUs) identified in the border from which, 15 are considered transboundary aquifers with good to moderate aquifer potential, covering approximately 50 to 55% of the shareable area between Mexico and Texas.

In 2021, Sanchez & Rodriguez (2021) reported 39 HGUs between California, Arizona, New Mexico in the U.S., and Baja California, Sonora, and Chihuahua in Mexico. The latter manuscript reports what is considered the second edition of its predecessor Sanchez et al. (2018). It is based on the same methodology to assure consistency and robustness of the complete version of the border with its corresponding adaptations and data limitations. It identifies geological boundaries using surficial geology as the basis criteria for geological correlation and vertical geology for boundary delineation. Lithological and hydrogeological features were also used when available. Results from Sanchez & Rodriguez (2021) indicate the existence of additional 39 hydrogeological units (HGUs) between the remaining western areas of the border region, accounting for approximately 40% of shareable land with good aquifer potential. This publication has the purpose to present the first complete map of hydrogeological units across the border between Mexico and the U.S. The complete border area depicts approximately 72 HGUs shared between the two countries with an estimate of good aquifer potential and good to moderate water quality in approximately 45% of the shared land. What these results mean to the current state of knowledge is the increasingly strategic value of transboundary groundwater resources in the border region as a driver for binational insecurity that so far has been receiving limited attention on the binational agenda. Additionally, this study reflects two important realities: half of the area of the border region has good aquifer conditions; and second, those shared groundwater systems are indiscriminately used by both countries without any legal framework regulating its extraction and management.

The combined results of Sanchez et al. (2016), Sanchez et al. (2018), and Sanchez & Rodriguez (2021), are used in this paper as a compilation of findings to offer a sole reference to the overall border between Mexico and the U.S. The first section will cover main findings reported by Sanchez & Rodriguez (2021, forthcoming) and Sanchez et al. (2018) in terms of the number of HGUs, main aquifer unit in terms of aquifer potential and water quality, and proportions of shared land overall the border region and by state. The second part will present a Table (Table 1) which will arrange an updated list of transboundary aquifers that has the purpose to substitute the one published by Sanchez et al. (2016) and the map (Figure 1) that will also be the updated version of that published in 2016. The last section will address what the binational implications are in terms of current management conditions, and of course, binational water security concerns.

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Deciphering water sources and fluxes in the Iberá area: an isotope hydrological assessment

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The Guaraní Aquifer System (SAG) is one of the largest and the most important transboundary aquifer in Latin America. The Iberá area, which encompasses a large wetland zone and its surroundings, located above the southern portion of the SAG in Argentina, is the focus of this study. This work builds on recent hydrogeological results in the area. A revised hydrogeological conceptual model has been postulated, proposing a better-defined geometry of the aquifer units and revised groundwater flow patterns. Groundwater flow in this part of the SAG is complex and mainly controlled by regional faults, leading to difficulties in determining the main flow paths and potential admixtures. Identifying leakages and interconnections between different aquifer units is essential for water management since these processes affect groundwater's physicochemical characteristics and renewal time. Using a multi-tracer approach and End Member Mixing Analysis, we aimed to validate the hypothesis of a widespread occurrence of groundwater interconnections between various aquifer units. These models were used to better assess groundwater provenance, define mixing patterns in sampled wells and identify potential groundwater discharge areas into surface water bodies. A regional hydro chemical and isotopic study was conducted in lagoons, rivers and wells with the support of IAEA, Spain MICIN and IHLLA. End Member Mixing calculations clearly showed mixing between different aquifer units and the existence of two main mixing groups, one dominated by SAG water signature and another one dominated by Pre-SAG water. The geological structure controls, to a large extent, the distribution of both types of mixed waters. All surface water samples are poorly mineralized, and their chemical and isotopic properties are coherent with the signature of rainwater. 222Rn activities, used to identify groundwater discharge, do not suggest the existence of generalized groundwater discharge into surface water bodies, except at the S of the Iberá lagoon and in the Miriñay River, where the isotopic signature suggested shallow recent groundwater discharge.

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State of affairs of models and governance of transboundary aquifers along the Mexico-US border

Alfonso Rivera[1] and Randall T Hanson[1]

Where and how is there a water crisis along the Mexico-U.S.A. international border (MX/US)? Is this issue the combination of overexploitation of surface water and groundwater and a lack of governance that stewards the conjunctive use of transboundary water resources? Are these issues further exacerbated by a disconnect between governance and technical knowledge? The mismatch between scientific knowledge and governance is further complicated in transboundary regions by different frameworks of governance as well as different levels of monitoring and analysis. While it's not enough to know, the linkages between monitoring and analysis of natural resources and governance have generated potential conflicts at multiple levels with very little to no overarching management of resources across international and local jurisdictions. In many transboundary settings there is a disproportionate emphasis on surface-water resources and not enough scrutiny and related systematics needed to also manage groundwater resources as shared and alternate resources. We present an overview in an effort to provide some answers and issues related to these questions. There are numerous transboundary aquifers (TBA) along the MX/US border supporting water systems, socioeconomic development, and wellbeing of more than 10 million people in 30 cities along the 3145 km-long international border. The exact number of TBAs remains uncertain; ranging from 11 TBA (UNESCO, 2010) to 35 TBA (Sanchez et al., 2016). It has been known for decades that the intensive use of groundwater on both sides of the border is unsustainable, making it an issue of international water security. Is this only a perception, or is it real? Are there "secondary effects" that contribute to the degradation of water security, such as water quality, surface-water capture, land subsidence, groundwater-dependent ecosystems, and seawater intrusion? This overview, though not comprehensive, provides a path for discussion and a framework for shared TBA management using state-of-the art tools (integrated models and monitoring) for better analysis and informed groundwater governance between the two countries. A brief review of models (numerical and governance) on some specific aquifers along the borderlands, and from other regions of the world offer insights on the main principles and criteria that can be used successfully for water management purposes at transboundary level. Examples of state-of-the-art existing numerical models for TBA include the Lower Rio Grande of New Mexico, Texas, and Chihuahua. Regarding management models for TBA, unfortunately, the state of the art is rather poor, unpublished, or non-existent for the MX/US border.

1 IAH Transboundary Aquifers Commission

Advances in geological knowledge in the transboundary outcrop area of the Guarani Aquifer System, Artigas city and surroundings, Uruguay

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The Guarani Aquifer System (GAS) is one of the most important transboundary aquifer in the world. Its extension includes part of Argentina, Brazil, Paraguay and Uruguay, being used in those countries both for human consumption and for agricultural and recreational activities. Particularly in Uruguay, it is found in an unconfined or confined form (covered by the basalts of the Arapey Formation). In Uruguay, the GAS is constituted by the Mesozoic sandstones represented by the Tacuarembó and Rivera formations, found as an unconfined aquifer in two regions of the territory and, in a confined way, when covered by extensive eocretaceous basalts of the Arapey Formation. The purpose of this contribution is the stratigraphic and structural analysis of the GAS outcrop area located in the extreme east of the department of Artigas, an area in physical continuity and bordering Brazil, which places the cities of Artigas (Uy) and Quarai (Br) within the Cuareim Basin. Here, groundwater is used largely for human consumption (sometimes the only source of drinking water) and also contributes to the development of agricultural activities. The outcrop area of the GAS constitutes an elevated block controlled by a NW-oriented regional structure (Cuareim lineament), limited by normal faults in the NNE direction (showing continuity towards Brazilian territory), while towards the South, it exhibits control through of a zone of strike-slip faults almost EW oriented. This elevated block allowed erosion to subtract part of the basalt cover, exhuming the sandstones from the top of the GAS, thus giving rise to the so-called "Window of Artigas". On the other hand, surface and subsoil geological advances made it possible to define that, under this structural configuration, part of the sandstones belonging to the Arapey Formation (intertrapps) were considered, and therefore included in the geological maps, as part of the GAS. In this way, and with a clear impact on hydrogeology, the results obtained showed that the outcrops of the GAS in this region are significantly lower than that recorded in the cartographic antecedents. In summary, these defined stratigraphic and structural features made it possible to conceive a very different conceptual geological model that influences the understanding of GAS dynamics in this transboundary region and, therefore, the management and care of this groundwater.

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Conceptual model development for the assessment of transboundary groundwater resources in cross-border area (Estonia-Latvia)

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The conceptual model for the cross-border area (~9500 km2) between Estonia and Latvia was developed based on information about dominant pressures (e.g., water consumption, land use), hydro chemical composition and three-dimensional hydrogeological model. Both Estonia and Latvia have been EU Member States since 2004, thus are required to ensure joint assessment of transboundary groundwater resources and implement the requirements of Water Framework Directive (2000/60/EC). Study area is located in the North-East of Europe, on the coast of the Baltic Sea where sedimentary aquifers with dominant water bearing rocks being sandstones contain large freshwater resources and supply drinking water. The total thickness of sedimentary rocks containing freshwater in the study area is up to 135-352 m and calcium-magnesium bicarbonates is the prevailing water type with total dissolved solids less than 1 g/l. The borders of the transboundary area were selected based on surface watersheds which mainly covers Gauja/Koiva and Salaca/Salatsi transboundary river basins and we concentrate on the active water exchange zone. The land cover in the cross-border area is dominated by forests (63%) and followed by agricultural lands (32%) and wetlands (3%). The major processes responsible for formation of water chemical composition were identified using Multivariate Statistics (PCA and HCA). Semi analytical groundwater flow estimation method was developed to ease the assessment of transboundary resources. Finally, information included into the conceptual model was used to develop a transboundary groundwater monitoring program and identify gaps for future studies. The study was carried out within the project No.2018-1-0137 "EU-WATERRES: EU-integrated management system of cross-border groundwater resources and anthropogenic hazards" which benefits from a 2.447.761€ grant Iceland, Liechtenstein and Norway through the EEA and Norway Grants Fund for Regional Cooperation.

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The hydrogeological assessment of the Milk River Transboundary Aquifer (Alberta, Canada – Montana, USA): a basis towards joint management plans

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The Milk River Aquifer (ISARM #20N) is one of the ten transboundary aquifer systems identified along the Canada-USA border. This regional groundwater system (26,000 km2) has been exploited for over a century and constitutes a major groundwater resource for agricultural, municipal, and industrial use in southern Alberta (Canada) and northern Montana (United States). The aquifer is shared by multiple stakeholders spread out within six jurisdictions: Federal, State or Provincial and municipal. Concerns about the depletion of the groundwater resources have been raised since the mid-1950s, and the aquifer is still solicited on both sides of the international border in the absence of an agreement between the US and Canada on the use of this shared resource. This situation contrasts sharply with the surface water from the Milk River which has been apportioned by the Canada-US International Joint Commission since 1921. The transboundary management of the Milk River Aquifer is challenging due to the data and information fragmentation that led to gaps in the knowledge of the aquifer's hydrodynamics (previous studies were limited by the border; independent stratigraphic frameworks were developed). To expand the knowledge about the flow system, an integrated set of three cross-border models were developed: a three-dimensional geological model, a conceptual hydrogeological model and a three-dimensional numerical groundwater flow model. These models were based on the physical boundaries of the aquifer, instead of jurisdictional boundaries. For this purpose, geological, hydrogeological and isotopic data were combined and harmonized and focused field work was carried out on both sides of the border, with active involvement of stakeholders. Results include the first delineation of the transboundary extent of the Milk River Aquifer and the quantification of the transboundary groundwater fluxes from Montana into Alberta. The numerical model was used to define the conditions required for the sustainable exploitation of the aquifer and showed that the entire aquifer system was affected by groundwater withdrawals. While the extent of the Milk River Aquifer is larger than that of the Milk River watershed, the study revealed that transboundary groundwater management would be warranted in a localized area comprised between the recharge area in Montana and the southern reach of the Milk River in Alberta. This hydrogeological assessment of the Milk River Aquifer constitutes a common scientific basis for all jurisdictions on both sides of the border, which lays the foundation for future shared management of the aquifer. A few paths towards shared governance are proposed.

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Hydrogeological conditions on the border between Serbia and Bulgaria in order to assess the transboundary groundwater transfer

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Serbia and Bulgaria have a common state border of about 340 km. The aim of the present study is to analyze the boundary groundwater bodies in the two countries and to determine the probability of groundwater transfer. The groundwater bodies are defined separately in both countries - on the territory of Bulgaria they are 11, and on Serbia there are 5 included in UNECE evaluation made in 2008. The first step is to clarify the factors influencing the formation and movement of groundwater. Geological conditions predetermine the presence of different types of groundwater. Along the state border the most widespread are the fractured waters, formed mainly in the weathering zones of magmatic, metamorphic and sedimentary terrigenous and terrigenous-carbonate rocks - about 78% of the total length of the border. Different types of aquifer systems have been identified. The first type includes the alluvial deposits of the Timok River, which is the northernmost part of the state border (27.8 km). The second type are imposed outcrops of unbound Neogene sediments with limited extension. In places the border crossings the terraces of some smaller rivers with not very large, often interrupted terraces. The typical karst aquifers have a relatively small distribution along the surveyed border area. Some of them form parts of clearly defined karst basins, linearly extended in the east-west direction and having important hydrogeological significance. Such are the karst basins on the southern slopes of Balkan Mountains. Other types of karst collectors are isolated tectonic blocks with small areas bordered by non-karstic rocks. Sarmatian sediments form a layered complex, with well-defined aquifers in it, attached to sands and detrital limestones in the northernmost parts of the border. The analysis of the factors proves that during most of the border between Bulgaria and Serbia the probability of cross-border transmission is insignificant. This is due to the wide distribution of fractured aquifers groundwater in the weathering zone of the rocks, whose direction of movement coincides with the slope of the terrain and the fact that the most part (about 82%) of the state border passes along the watersheds. There is a possibility for such a transfer only for the karst basins and for the Sarmatian complex.

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Groundwater-surface water interaction in the Sava River basin

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Sava River has been identified as the main recharge source for the alluvial aquifers in its basin, especially in the upper part of the flow, in Slovenia and Croatia. However, there has not been a lot of research downstream of the Zagreb area, which could show the magnitude of influence of the Sava River on the groundwater resources. This is mostly related to the area of the Croatian and Bosnia and Herzegovina border, where in some parts the Sava River presents the border between two countries, but also in Serbia where more detailed investigations should be done.

The goals of this research are: to establish an international working group; to establish new GNIP (Global Network of Isotopes in Precipitation) and GNIR (Global Network of Isotopes in Rivers) monitoring points; to define groundwater-surface water interaction throughout the whole course of the Sava River, from Slovenia to Serbia; to identify areas in which the Sava River has relevant influence on groundwater resources; and to see if evaluation of historical and new data indicates the impact of climate change. All this will help to identify and implement measures for sustainable groundwater resource management in the Sava River basin and its related transboundary aquifers.

To realize the goals of this research, monitoring points will be established in Slovenia, Croatia, Bosnia and Herzegovina, and Serbia. At each monitoring point precipitation, river water and groundwater will be sampled. Water stable isotopes, as well as tritium, will be measured within the period of two years. The new monitoring program has started in the course of the year 2021.

Firstly, however, all available hydrological and meteorological data will be examined, and statistical analysis will be done. We present a first statistical analysis, based on the data (precipitation values, Sava River water levels, groundwater levels) from one location in each country (Ljubljana in Slovenia, Zagreb in Croatia, Orašje in Bosnia and Herzegovina, and Sremska Mitrovica in Serbia).

This research presents one of the case studies within the IAEA Regional Technical Cooperation Project RER7013, which goals are the development of new technical capacities and competencies in isotope hydrology, and the clarification of persisting issues in the region related to the sustainable management of transboundary water resources.

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Hydrogeological model of transboundary aquifers with significant groundwater exchange potential between Poland and Ukraine

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In the Polish-Ukrainian borderland, only the transboundary groundwater reservoir within the Bug River catchment area was qualified to the world list of transboundary aquifers published in 2015. As part of the international EU-WATERRES project, the assessment of transboundary groundwater flows and the identification of aquifers with significant potential for groundwater exchange between Poland and Ukraine were carried out. The overarching goal of this study was to create a numerical model of transboundary groundwater flows that will serve as a tool for joint management of groundwater resources between two countries for the sustainable use of resources and the maintenance of the good state of water-dependent ecosystems. The research included the analysis of hydrogeological data on both sides of the Polish-Ukrainian border in order to create the first cross-border conceptual model of the structure of the aquifer and the processes taking place in it, including contacts with the environment. The hydrogeological data compilation between Poland and Ukraine contributed to the continuity of transboundary aquifers. It has been assumed that the model area is limited to the area where significant transboundary flow in the usable aquifers occurs. For this purpose, minimum criteria were defined for aquifers conducting groundwater through the boundary line in terms of water conductivity (above 50 m2/24h) and the scale of spatial spread of the layer. The area identified this way covers approximately 7,150 km2 and, in the catchment division, it includes fragments of the catchment areas of the San and Bug rivers in their upper parts. The total thickness of sedimentary rocks containing fresh water in the study area is up to 382-529 m. In the zone of active water exchange, the transboundary flow occurs in the layers: 1) Quaternary with a unconfined groundwater table- in alluvia in the valleys of large rivers and in fluvioglacial sands - on postglacial plains, 2) Cretaceous with a partially confined groundwater table - in the Polesie and the Volyn Uplands, 3) Palaeogene-Neogene-Cretaceous with a confined groundwater table - in Roztocze and Carpathian Foredeep. This concept of the aquifer structure was the basis of the numerical three-dimensional model of groundwater flow and the assessment of transboundary flows. The study was carried out within the project No.2018-1-0137 "EU-WATERRES: EU-integrated management system of cross-border groundwater resources and anthropogenic hazards" which benefits from a € 2.447.761 grant Iceland, Liechtenstein and Norway through the EEA and Norway Grants Fund for Regional Cooperation.

Keywords: transboundary groundwater flow, hydrodynamic model, hydrogeological databases

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Multiscale and multidisciplinary approach for the mapping of surface and groundwater in the Lake Chad Basin

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The Lake Chad basin covers the 8% of the African continent. It is one of the widest transboundary African basin. It spans eight countries: Chad, Niger, Algeria, Nigeria, Cameroon, CAR, Sudan and Libya, hosting about 37 Million people, often living in critical conditions given the scarcity of water resources. In Chad for example, access to water has become a major concern and a source of inter-community conflicts. This critical situation is related to the climatic conditions, as well as to the lack of efficient water management policies and to the poor knowledge about water resources and their aquifer systems. Many studies were conducted in the Chadian part of the basin during the last years, but the resulting advances do not yet allow to fully address the critical issues of the availability and reliability of current and future resources. In order to fill these gaps and improve the management plans, the Chadian Government, in partnership with the Swiss Cooperation SDC, launched in 2012 the ResEau project. The objective of ResEau is to produce knowledge and to map the water resources, while building the capacities at a national level mainly through the creation of a higher-educational MSc program in Hydrogeology and GIS. Capacity building is also achieved through the creation of a Resource Center (Centre de Documentation et de l 'Information Géographique), aiming at providing services to the public and private sector. While the first phase of the ResEau project (2012-2016) focused on Eastern and Northern Chad, producing 30 hydrogeological maps at different scales, since 2019, the focus is on the Lake Chad Basin. The methodology developed for the mapping of surface and groundwater resources within this region is based on a multidisciplinary and multiscale approach. The multidisciplinary approach includes field hydrogeological measurements, advanced remote multi-sensor data processing (MSG, MODIS, LandSat-8, ASTER, PALSAR, Sentinel-1, Sentinel-2), machine learning techniques and knowledge-based analysis. The multiscale approach takes advantage of the top-down method allowing the analysis of large, often inaccessible, regions barely monitored from the hydrological and hydrogeological point of view. The aim of this work is to present the developed approach for mapping surface and groundwater resources in the Lake Chad Basin, both within the sedimentary and crystalline environments, in an area representative of the Sahelian region where water resources are affected by climate change.

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Sustainable transboundary groundwater management using groundwater modeling and hydro chemical and isotopic investigations

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Groundwater in the border regions of Sultanate of Oman and the United Arab Emirates (UAE), near Al-Buraimi and Al-Ain areas, has significant socioeconomic importance, both as a source of drinking water and as a factor of production in agriculture. In recent decades, substantial development of irrigated agriculture and city expansion has occurred, with enhanced exploitation of groundwater in this region. Given the increased stress on vital groundwater resources, it is critical to develop an integrated modeling and hydro chemical approaches to evaluate groundwater behavior of the region. In order to develop groundwater model a three-dimensional stratigraphic model representing the vertical and spatial extent of four principal hydrogeologic units was generated using data collected from hundreds drilled boreholes. Layer elevations and materials for four layers grid cells were taken from the generated stratigraphic model. This process led to accurate grid so that the developed groundwater conceptual model was mapped to simulate the groundwater flow and to estimate sustainable groundwater extraction for the October 1996 to September 2013 period. Results show that the long-term lateral groundwater flux ranging from 4.23 to 11.69 Mm3/year, with an average of 5.67 Mm3/year, drains from the fractured eastern ophiolite mountains into the alluvial zone. Moreover, the long-term regional groundwater sustainable groundwater extraction is 18.09 Mm3/year for 17 years, while it is, respectively, estimated as 14.51, 16.31, and 36.00 Mm3/year for dry, normal, and wet climate periods based on standardized precipitation index (SPI) climate condition. Groundwater samples collected from different geological units were analyzed for hydrochemistry and water isotopes, and subsets thereof were analyzed for 14C and 3H and 87Sr/86Sr. While the water-rock interaction is the dominant process controlling the groundwater chemistry, evaporation and groundwater mixing affect the hydrochemistry at the UAE borders. Therefore, groundwater evolves from carbonate-dominant in the NOM into sodium-chloride dominant close to the UAE borders. Groundwater dating (high pmc), homogeneous 87Sr/86Sr ratios and enriched d2H and d18O demonstrate the presence of modern recharge in the shallow zones of the ophiolites and alluvium. However, deep zones and areas at the UAE border contains older groundwater form during cooler and wetter climatic conditions as supported by the depleted d2H and d18O, and lower 87Sr/86Sr ratios and pmc. Furthermore, the data clearly showed that modern groundwater mixes with older groundwater along the flow path from the NOM into the UAE border. Modern recharge occurs as lateral recharge from NOM and direct recharge in the plain area.

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Science Role in the Sustainable Management of Transboundary Groundwater Basins in Sudan: Case of the Baggara Basin

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Sudan shares four of its main groundwater basins with other neighboring countries .These are: The Nubian Sandstone Basin (NSB) shared with Chad, Libya and Egypt; the Um Rawaba and Baggara basins shared with South Sudan; and the Gedarif Basin shared with Ethiopia. These basins represent an invaluable resource of strategic importance for the socioeconomic and agricultural developments leading to improved welfare and food security of the Sudan population. Sustainable management of these basins is a particularly challenging issue due to: limited understanding of their hydro-geologic characteristics and flow dynamics, lack of monitoring and adequate information base, limited understanding of recharge sources and quantities, lack of trans-boundary governance and legislative frameworks and lack of agreements between the riparian countries, in addition to political, institutional, socio-economic, cultural and other differences among the related countries. Some sort of cooperation has been progressing between the four countries sharing the NSB forming an existing committee in the hope that some knowledge base and capacity building could be improved through various projects funded by donors. However, a major challenge for the NSA is that groundwater is mostly non-renewable and often left to state practice in its utilization. The increased pressure in the utilization of these aquifers separately in individual countries, despite unclear knowledge of the trans-boundary impacts, represents a potential threat to a precious resource that if unchecked, could lead to irrational water use, deterioration of water quality with the potential to harm biodiversity, land degradation processes, or even lead to trans-boundary conflict. In this paper the authors focus, as an example, on the Baggara Basin shared between Sudan and South Sudan as a case study. Innovative scientific tools, namely, remote sensing, GIS and groundwater modeling, will be used to investigate the groundwater potential. Geology, lineaments, landforms, soil, land use/cover, rainfall, drainage density and slope drawn from satellite images will be used as indicators for the assessment. Based on existing water levels information, a groundwater model will be calibrated and used to investigate the consequences of different management scenarios for the aquifer with focus on the trans-boundary impacts. The results could be used as a basis for a trans-boundary agreement for win-win sustainable aquifer utilization between Sudan and South Sudan.

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Advancement in the Hydrogeological Knowledge of the Yrendá Toba Tarijeño Aquifer System

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The Yrendá Toba Tarijeño Aquifer System - YTTAS, refers to transboundary groundwater resources of South America, shared by the Plurinational State of Bolivia, the Argentine Republic and the Republic of Paraguay. During 2007, the Preliminary Evaluation of the document Transboundary Systems in the Americas, a shared initiative of UNESCO - through the International Hydrological Program and the Organization of American States - is presented, making the generalities of the System known, highlighting its nature as transboundary groundwater resources. However, it is through the implementation of the Framework Program for the Sustainable Management of the Water Resources of the La Plata Basin in relation to the effects of variability and climate change, (FP) carried out during the years 2011 - 2016, that progress is made in the hydrogeological knowledge of the YTTAS. With the ambitious objective of strengthening transboundary cooperation among the governments of Argentina, Bolivia, Brazil, Paraguay and Uruguay to ensure the management of the shared water resources of the Plata Basin in an integrated and sustainable manner, the FP contemplated, among other subjects, a specific activity to develop hydrogeological information of the YTTAS. With the coordination of the Intergovernmental Coordinating Committee of La Plata Basin (ICC), and through the National Coordinators, (NC) a working group was established, formed by the Organizations responsible for Groundwater in each country: The Hydrogeology Department of the National Service of Meteorology and Hydrology of Bolivia, the Secretariat of the Environment of Paraguay and the Geological Mining Service of Argentina. The studies carried out made it possible to recognize the YTTAS as one of the most important transboundary groundwater reserves in South America, underlining the following characteristics: i) It covers an area of approximately 410,000 km2, of which 200,000 km2 are developed in Argentina, 30,0000 km2 in Bolivia and 180,000 km2 in Paraguay. ii) It is a system formed by Tertiary and Quaternary aquifers with a regional flow Northwest – Southeast. iii) In the western foothill's regions, they have an excellent quality, presenting an increase in salinity towards the eastern plains. However, its waters can be exploited for certain uses in areas of water stress and deficit. iv) Isotopic analysis made it possible to identify the western foothills as the recharge area. v) The information, compiled in a Geographic Information System, allowed the integration of the different themes developed in each country. vi) The joint work made it possible to develop a conceptual hydrogeological model and to formulate the next steps to be followed in order to improve the knowledge of YTTAS.

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Transboundary aquifers of Lebanon: hydrogeological and dimensional assessment

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Located along the Eastern Mediterranean, Lebanon has an area of 10,452 km2, and there is about 74% of its border shared with the neighboring regions. The mountainous physiography makes Lebanon as a climatic barrier that capture cold air masses from the Mediterranean and condensate them as rainfall and snow. Thus, Lebanon encompasses 15 perennial watercourses and more than 2000 major springs. Moreover, there are a number of aquiferous formations and karstic galleries, which store considerable volume of groundwater. There are a number of aquiferous rock formations where carbonate rocks are the most dominant rock type, and they constitute more than 65% of the Lebanese territory. The largest part of these rock formations is extending beyond Lebanon; and hence sharing with Syria and the Occupied Palestinian Territories (OPT). As a result of the dominant rock structures and mainly beds inclination, a considerable amount of groundwater from Lebanon seeps along these rocks to the neighboring regions. Studies on transboundary water in Lebanon are still few, and more specifically those on groundwater where the hydrogeology and dimensional aspects of the transboundary aquifers are still undefined. This study has been achieved to investigate all transboundary aquifers of Lebanon which are represented mainly by the fractured and karstified limestone and dolomite rocks, and more specifically those attributed to the Upper Jurassic, Upper Cretaceous and Paleogene rocks. Therefore, a detailed hydrogeological assessments has been carried out using geological maps, satellite images and field surveys. This covered all existing aquiferous rock formations, and therefore, stratigraphic cross-sections and panel diagrams were established, and hence volumetric measures were integrated in order to apply the calculations required to estimate and allocate the volume of groundwater and its storage/flow mechanism between Lebanon and each of the neighboring regions. The results are considered as useful database which can be used for future negotiation on shared water resources in the region where international treaties and conventions are still inapplicable due to the lack of comprehensive hydrogeological data and information.

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Assessment of geochemical processes of the shared groundwater resources in the Iullemeden aquifer system (Sahel region)

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The Iullemeden Aquifer System (IAS) shared by Niger, Nigeria and Mali, with small parts in Algeria and Benin, constitutes the primary perennial source of water for sustainable development of the concerned countries. Considering the limited availability of surface waters in this part of the Sahel, the main sources of easily accessible freshwater in the region are the deep groundwaters of the Continental Intercalaire (CI) and Complex Terminal (CT) multi-layered aquifer system. These aquifer units constitute the largest aquifers in Niger and Nigeria, while the aquifer in the Kandi Precambrian formation is located in Benin. The local population is increasingly depending on groundwater as the critical source of water supply for all socio-economic activities. Consequently, the number of wells and irrigation systems is perceptibly and continuously increasing with no or inadequate regulation and institutional policy on groundwater abstraction. This inappropriate style of water governance has led to overexploitation, marked by the lowering of groundwater levels, which has led, in turn, to a subsequent decline in the availability of water. In this context, the study presented here, based on the combination of conventional hydrological techniques and environmental isotope methods, aims to improve the understanding of the hydrogeological functioning of the IAS, including, groundwater flow patterns, mechanisms and rates of recharge, residence time, vulnerability to pollution, as well as the interaction between surface waters and significant aquifers. The hydro chemical characterization of shallow groundwaters of IAS showed the predominance of good-quality groundwater, compared to the usual drinking water standards. Water rock interaction processes such as the dissolution of salts and cation exchange are the major processes that contribute to the observed groundwater mineralization in most aquifers. However, high nitrate concentrations are detected in some aquifers, reflecting the impact of point-source anthropogenic pollution (agricultural and domestic practices). Environmental isotopes (18O, 2H, 3H, 13C, 14C) have provided new insights to answer critical questions regarding the functioning of these transboundary aquifer units. The frequent presence of tritium and the similarity of the isotopic composition of precipitation and shallow groundwaters clearly illustrate the magnitude of present-day recharge in the IAS as well as its vulnerability to pollution. Palaeowaters have been identified and mapped using 14C activities for groundwater age dating and confirmed by isotopically depleted 18O and 2H contents, particularly in the CI aquifer. Most of these palaeowaters were recharged under distinctly different climatic conditions in the late Pleistocene and early Holocene.

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Analysis of the evolution of salinity and Hydrochemichal assessment of groundwater in the Massacre transboundary aquifer (Haiti)

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Groundwater is considered as the most important resource for water supply in both developed and developing countries. Indeed, the exploitation of groundwater is generally considered as the only realistic option to meet the dispersed demand for rural water. However, nowadays and all over the world, the quality of groundwater has deteriorated considerably. Several studies have generally focused on the salinization of groundwater in coastal aquifers, and particularly in island areas, a problem that poses a widespread threat to fresh groundwater resources and can be considered one of the most common global problems. significant pollution of groundwater. In Haiti, studies on Transboundary Massacre Aquifer (TMA - an aquifer shared by Haiti and the Dominican Republic) have showed that groundwater is threatened to salinization (PNUD, 1991). Within the framework of the activities of the UNESCO/OAS ISARM Americas Program, a research project has been started on the salinization of the TMA in the northeast department of Haiti. The aim of this actual study was: (i) to review the geophysical environment of the Massacre coastal aquifer system in order (ii) to assess the spatio-temporal evolution of salinity in groundwater of this aquifer, and (iii) to implement the hydro chemical assessment of groundwater from the TMA. The results of hydro chemical analysis indicate that the groundwater quality is highly variable. TDS concentrations ranging from 282 to 2640 were measured on boreholes fed by groundwater from this aquifer. This variability is due to the local hydrogeological conditions and other processes such as evaporation, anthropogenic activity and the interaction water-rock mixing. Based on the major ions contents in water samples, four main chemically water types were identified using the Piper diagram: Ca–Mg–HCO3, Ca–Mg–Cl–SO4, Na–K– HCO3 and Na –K –Cl–SO4. According to Wilcox diagram, water resources of the TMA are represented in five different water classes, such as Excellent, Good, Admissible, Mediocre and Bad. New studies, notably geochemical modeling, traces and isotopic elements will have to be carried out in order to deduce the physical and chemical processes governing the chemistry of these groundwater resources.

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Characteristics of Groundwater in the Hasbani River, Lebanon

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The Hasbani River in Lebanon is one major tributary of the transboundary Jordan River Basin. The Hasbani River derives most of its discharge from two springs in the south of Lebanon: the Wazzani and the Haqzbieh. The Hasbani runs for 40 km in Lebanon before crossing the frontier "Blue Line" at Ghajar and shortly after joining with the Banias and Dan Rivers to feed the Jordan River. For about 4 km downstream of Ghajar, the Hasbani forms the border between Lebanon and the Golan Heights. In the Hasbani area, groundwater is the main source for water for the Lebanese rural communities living in the south border's region for their agricultural needs as the Wazzani spring is the only continuous year-round flow into the Hasbani in Lebanon. After the withdrawal of Israeli forces from the area in 2000, and the international interventions, Lebanese government started to pump in October 2002 around 4.4 MCM/year (around 13% of its legal part allocated according to Johnston Plan in 1955) at the Wazzani spring to provide drinking and irrigation water to some 60 villages. Hence, the study of groundwater quality is an essential tool for better management of water resources in the region. The objective of this work is to study the hydrochemistry and geochemistry of the Hasbani basin aquifers. Three major aquifers: Jurassic, Cenomanian and Eocene are the main water sources in the basin. In Total 30 groundwater samples were collected from the 3 aquifers of the study area. Field parameters such as pH, temperature, Electric conductivity (EC) and Total Dissolved Solid (TDS) were measured on site, while major ions concentrations were analyzed in the laboratory. Results show that Ca2+, Mg2+, and HCO3- are the major ions of the Hasbani basin groundwater samples. The hydro-chemical facies of Hasbani basin's groundwater are Ca-Mg-HCO3. Rock-water interactions are the main geochemical processes that govern the formation of groundwater in the study area. Evaporation did not appear to impact the geochemical processes. Seemingly, pollution from human activities does not appear to be a main contributor to the water chemistry of the region's aquifer. Nevertheless, local contaminations exist, and further work is needed to investigate the full extent of groundwater pollution in the basin.

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Hydrogeology of the eastern Kalahari-Karoo transboundary basin aquifer system (EKK-TBA)

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Water insecurity in semi-arid regions of southern Africa provides a major challenge to socio-economic development. The Eastern Kalahari-Karoo Transboundary Basin Aquifer (EKK-TBA), straddling eastern Botswana and western Zimbabwe, faces similar water insecurity challenges. Groundwater constitutes the main source of water and hence requires proper assessment and effective and sustainable management. The Basin lies in a semi-arid region receiving mean annual rainfall of 625mm in the north-east to 325mm in the south. The EKK-TBA is generally flat, ranging from about 1 400 to 880m amsl towards the Makgadikgadi Pans in the southern part of the Basin. Perennial rivers in the eastern EKK-TBA drain towards the Zambezi River and few ephemeral rivers drain towards the Makgadikgadi Pans in the southwest. The EKK-TBA is home to about 600 000 people who, together with the mining sector, agriculture and biodiversity heavily rely on groundwater for their sustenance and yet there is limited data and information on the sustainability of the groundwater resources on a basin-wide scale. Most data and information is available from wellfields developed within the southeastern fringes of the EKK-TBA (Botswana: Orapa, Letlhakane, Dukwi and Maitengwe; Zimbabwe: Nyamandlovu). A detailed hydrogeological assessment of the EKK-TBA, including the development of a conceptual model, revealed that the main aquifers are the Kalahari Group deposits, Ntane/Forest Sandstone and the Mea Arkose/Wankie Sandstone. Faulting and fracturing have compartmentalized certain sections of the aquifers, whilst maintaining a regional discharge of groundwater into the Makgadikgadi Pans. Groundwater salinity increases towards the central portions of the Basin and with depth of the aquifers. A groundwater recharge map of the Basin was developed based on groundwater recharge studies in the region over the last four decades. Groundwater recharge is generally <3% of average annual rainfall and insignificant recharge is expected for annual rainfall <350mm. A sustainable abstraction map was subsequently developed as a first guide for groundwater development for areas where data and information are lacking. Current water demand is outstripping supply. Further increase in potable water demand, resulting from population growth, coupled with future expansion of groundwater irrigated agriculture under changing climatic conditions will exert additional pressure on the groundwater resources. This calls for innovative approaches to sustainably develop and utilize the limited groundwater resources of the Basin. Establishing and capacitating a Basin-wide management unit/organization and a groundwater monitoring network and simultaneously a groundwater model are paramount in balancing demand and supply.

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A new regional numerical groundwater flow model of the Guarani Aquifer System (SAG)

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Groundwater numerical simulation is a powerful tool to investigate the plausibility of different conceptual models of a hydrogeological system. In this sense, several groundwater flow numerical models of the SAG have been made according with the evolution of its knowledge. The first regional numerical model, made from few geological and hydrogeological data, covered 75 % of the SAG area and was run under steady state. In the framework of the Guarani Aquifer System Project, the model was improved to cover the whole SAG extension, and incorporate new piezometric data, but the SAG was supposed unconnected with the upper and bottom layers. This model just simulated steady state, but later it was implemented under transient state for a 40 years' period. This work shows the recent implementation of the numerical model based on an improved geological model of the SAG southwestern sector. It is a two-layer model that simulates the SAG interrelation with the shallowest post-SAG aquifer through the intermediate fractured basalts. Recharge on the outcropping SAG sandstones and, for the very first time, through the fractured basalts, is proposed. The plausibility of the model was numerically tested using the finite element code TRANSIN. The mean calculated permeability was 6.9 m/d, similar to the values proposed by other authors, between 3 and 15 m/d. The calculated average recharge, 17.7 mm/yr., amounts 1.22 % of the regional average precipitation, which equals to 1,450 mm/yr. Recharge on the SAG sandstones would be 3,844 hm^3 or 27.9 mm/yr., 1.9 % of the precipitation compared to the 0.8 or 2.5 % of previous model versions. The new recharge rate calculated is consistent with the values provided by on-site tests in outcrop areas. The calculated total outflow to the rivers is 87.7 m^3/s, a quarter of the minimum baseflow gauged in the Uruguay River. Consistent with the geological model, the largest discharge flows occur along the SAG's western and southern borders, recharge is higher than the outflow in the northeast quadrant and is lower in the southern half. Although it is a regional scale model, the improvements made allowed appreciating the effect of pumping on storage from 1991, when the volume of withdrawals was significant. The modelled levels declining rate for the last 30 years is 0.14 cm/yr., which is equivalent to a storage decrease of 15.74 km^3/yr. This work complements other contributions of the authors to this event on the SAG.

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New isotopic evidence of vertical flow exchange between superficial and the transboundary Maastrichtian aquifer in the Senegalo-Mauritanian Basin

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The deep Maastrichtian aquifer bears an important groundwater resources shared between Senegal, Gambia, Mauritania and Bissau Guinea. The aquifer is confined in most parts of these countries except in the center of Bissau Guinea and in the western part of Senegal (Diass Horst) were it outcrops. In Senegal, it is the main exploited aquifer with around 1,300 boreholes operating at 94.6 Mm3/year compared to the estimated value of recharge of 67 Mm3/year evidencing a negative water balance and mining of fossil groundwater. Many studies using isotopic data and conventional hydrogeological methods have been carried out and flow patterns mainly occurs from the south-east and north-west direction. The present paper is aimed at revisit the conceptual flow model using isotopic data collected from recent IAEA projects (RAF7011, RAF7019) focused on the northern part of the aquifer featured by a surrection of the Maastrichtian aquifer through a dome beneath a thin layers of Paleocene, Eocene and CT. In this region, 13 boreholes have been sampled for isotopic (18O,2H,13C,14C,3H) and chemical analyses. Results evidenced that groundwater in this part is salty in the west and low mineralized in the eastern part with stable isotopes values ranging from -6.33 to -5.02 ‰ for 18O and from -42.4 to -33.8 ‰ for 2H, respectively. All samples revealed non-Tritium content evidencing paleowaters in this part of the aquifer. However, the range of 14C data which is between 11.02 and 18.03 pmc as compared to very low values in the eastern part (below detective limit) reveal vertical flow exchange and mixing with the top aquifer. This is confirmed by geographical extend of saline water in this part of the aquifer together with high calcium and bromide values which reflect inflow of saline water derived from the top contaminated aquifer from ancient saline intrusion water. This new evidence allows to redefine groundwater flow patterns and saline evidence in the northern part of this shared aquifer.

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Application of Grace satellite data for groundwater flows in Indus Basin

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Groundwater is considered as the major supplier of domestic, agricultural and industrial sector. However, due to increased urbanization, climate change, expanding industrial and agricultural activities and domestic demand, scarcity of groundwater is occurring. Pakistan and India are sharing Indus basin aquifer. Since 1960, Indus basin groundwater is becoming the primary source for irrigation in Pakistan. Due to over exploitation and contamination, this aquifer is under stress. Therefore, quantification of aquifer flows across both countries must be assessed. The sparse piezometric network cannot provide sufficient data to assess groundwater changes spatio-temporally. Latest technologies e.g., Gravity Recovery and Climate Experiment (GRACE) can help us to estimate losses or gains in shared aquifers. Therefore, this study aims to make comparative analysis of satellite and piezometric data. Quantitative assessment of these changes will be made. Terrestrial water storage changes will be derived from GRACE measurements which will be compared with piezometer groundwater levels. Since, the monitoring of groundwater is limited so the results obtained from the comparative analysis of GRACE groundwater data and piezometer groundwater data will be helpful to estimate regional groundwater storage changes.

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Assessing the groundwater fluxes of the major transboundary aquifers, using a high-resolution global groundwater model

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Groundwater is an important resource for agricultural, domestic and industrial water users as well as for groundwater dependent ecosystems and river baseflows. The demand for sufficient groundwater with good quality at the right moment and the right place is expected to increase in decennia to come, as many stakeholders from governments to industries all over the world strive for water security in a changing climate. Transboundary aquifers (TBA) are not bounded by geopolitical borders, thus making them sensitive to transboundary effects of interferences like groundwater extractions. Awareness of such effects can be an important trigger for intensifying the cooperation on governance of these transboundary resources. The principles of transboundary interactions of groundwater resources over geopolitical borders are well-known and understood. However, a quantitative assessment of these interactions is, to our knowledge, not available, mainly because national groundwater models (if existing) often lack a good interaction with surrounding countries, e.g., due to different geological characterizations, lack of information or impediments on sharing the information between countries. During these last years, a high-resolution global groundwater model (GGM) has been developed, as part of the PCR-GLOBWB family of models having a 5 arcmin (~10*10km2 model cells) resolution. PCR-GLOBWB has been used over the last decade for different purposes such as quantifying environmental flows, global drought assessments and climate impacts on global water resources. Our current research focusses on updating the high-resolution GGM to 30 arcsec (~1*1km2 model cells) using high performance computing. Here, the high-resolution GGM is used to assess the magnitude of transboundary aquifer fluxes (TBAFs) of the major TBAs of Africa, Middle East and South-East Asia. Results show that though hydrogeological data like the geological conditions is often scarce, a rough order of magnitude as well as dynamics of the TBAFs can be assessed. To place these fluxes into perspective, they are compared with groundwater recharge fluxes on the scale of the TBA, with river and groundwater interaction fluxes, and with (future) estimated groundwater extractions. This analysis also stresses the importance of improving the (hydro)geological characterization of the larger TBAs and information on groundwater use.

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Transboundary groundwater recharge in a dryland environment: evidence from the River Goulbi de Maradi Basin in Niger and Nigeria

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The transboundary valley of the Goulbi de Maradi (GM) is shared between the Niger Republic and the Federal Republic of Nigeria and densely populated (~ 81 people/km^2). Located within the south-eastern Iullemmeden sedimentary basin, the flow of the ephemeral River GM runs from northern Nigeria northward into Niger and is influenced, in part, by dam releases in Nigeria, 5 km south of its border with Niger. This border region is underlain by weathered Precambrian granite-gneiss rocks that form a weak aquifer of low transmissivity and storage. Considerable dependence has thus developed upon a shallow alluvial aquifer along the River GM, which is of limited vertical (20 m) and lateral (2 km) extent, to provide drinking water as well as water for livestock and irrigation. Downstream of the border region, the alluvial aquifer rests on the regional Continental Hamadien (CH) sandstone aquifer. To better understand groundwater recharge and seasonal dynamics, high-frequency (hourly) monitoring of groundwater levels within the alluvium has been established along this transboundary alluvial aquifer. Hourly observations show strong responses related to the episodic flow of the River GM, indicating that groundwater recharge to the porous and permeable alluvium in Niger and Nigeria derives primarily from these surface flows. Additionally, dam releases in Nigeria are associated with dry-season recharge events in the alluvial aquifer. As focused recharge to the shallow alluvial aquifer in Niger downstream is also expected to replenish the underlying regional CH aquifer, these new observations highlight direct connections among dam operation, transboundary river discharge, and transboundary groundwater recharge. Optimal use of limited water resources in drylands requires recognition of these relationships and transboundary cooperation.

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Karavanke / Karawanken Transboundary Groundwater Body Between Republics of Austria and Slovenia

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Water in a broader sense has a unifying function and knows no boundaries. Scientific studies and management practices of water bodies can open up wide avenues of international communication and exchange, not the least of which are studies of aquifers. In the late 1980s, the Republic of Austria and the Republic of Slovenia, then part of Yugoslavia, began construction of an almost 8 km long road tunnel through the Karavanke/Karawanken border mountain ridge. During construction, several springs came to light and it was recognized that they could form important drinking water resources. At the same time, it was found that the recharge areas of these springs are located on both sides of the state border and cooperation will be needed to protect and manage the groundwater. The importance of tunnel water resources was also recognized by state and regional agencies, leading to a systematic hydrogeologic survey of the entire ridge. Over the next 15 years, the area was divided into several sectors, which were systematically studied using a plethora of hydrogeological methods (harmonization of geological maps, detailed hydrogeological mapping of all springs, simultaneous discharge measurements, sampling for chemistry and isotopic composition at important springs). Based on the information collected, transboundary groundwater flow was determined, and recharge areas of major springs were used for water supply. Many efforts were also directed toward recognition of groundwater management practices in both states. All activities were coordinated by the expert sub-commission for drinking water resources of the Karavanke within the bilateral Austrian Slovenian river basin water commission ''Drava water-management commission'', officially headed by the state ministries responsible for water. In 2004, the bilateral agreement between the Republic of Slovenia and the Republic of Austria on the joint transboundary groundwater body Karavanke/Karawanken was put into force. The body is defined according to the specifications of Water Framework Directive and extends along the area of the main border ridge. Within the area, five transboundary karst aquifers have been identified, which are now the subject of coordinated Austrian and Slovenian groundwater management.

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Isotope hydrology tools improve groundwater management within the transboundary aquifers of the Lake Chad Basin

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The Lake Chad Basin is one of the largest sedimentary groundwater basins in Africa extending over an area of about 2,381,000 km². Annual rainfall amount is strongly contrasted throughout the basin from Libya to Central African Republic varying between 1,500 mm/a in the south of the basin to less than 100 mm/a in the north. This phenomenon entails strong restrictions in the availability of water resources, which are unevenly distributed between the Northern, Central and Southern parts of the basin. However, groundwater can be found almost everywhere at various depths. Unfortunately, the extent and quality of theses groundwater resources is still poorly documented. Here, the lack of relevant hydrogeological information can be considered as a limiting factor for the socio-economic development of the Chad Basin region. The RAF/7/011 and RAF/7/019 projects lead by the International Atomic Energy Agency (IAEA) have brought new insight into the isotopic signature of surface, shallow and deep groundwater over the Lake Chad Basin with an important amount of sampling and associated data. Around 500 wells and boreholes have been analyzed for a selection of tools including the stable isotopes of the water molecule, tritium, radiocarbon and nitrogen-15 in order to gain new information on areas with knowledge gaps over Chad, Niger, Cameroon and the Central African Republic. Results highlight the major hydrogeological processes affecting the main aquifers of the Lake Chad basin. Amongst them, the intricate relationships between surface and groundwater, especially in the southern watershed between Cameroon, Central African Republic and Chad, where swamp areas are lying. These areas play a major ecological role for biodiversity heritage preservation and surface water/groundwater buffering. The southern boundary of the Lake Chad basin appears as the water feeder of all rivers and hence part of the groundwater resource within the Central basin. This project also underlined and confirmed the capacity of the regional aquifers to provide necessary amount of water. Shallow and deeper groundwaters are able to meet the human demand for drinking and agriculture uses and strengthen the resilience of the region to climate change impacts.

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Understanding the current and Future groundwater pressures for the transboundary Caplina/Concordia aquifer system (Peru/Chile)

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The 18 S Concordia/Escrito-Caplina transboundary coastal aquifer system, located in the Atacama Desert, is the primary source of water supply for human consumption and irrigation for the Concordia (Chile) and La Yarada (Peru) agriculture districts, and to a lesser extent, for Tacna city in Peru. Despite the desertic climate and the limited recharge fluxes from the Andean plateau, this aquifer has been heavily exploited since the 2000s. Drilling of new wells were prohibited starting in 2006 to mitigate the impacts of overexploitation of groundwater resources. However, the excessive extraction could not be reverted and caused blooming of illegal wells for agriculture. Currently, groundwater extraction is exceeding the aquifer recharge rate by three times. The impacts are depletion of groundwater reserves, advancement of seawater intrusion, and social a conflict between agricultural users and the Peruvian National Water Agency (ANA). Besides, the problem of water management in the study area is far from being an exclusive issue between Peru and Chile since Tacna city obtains water through an inter-basin water transfer from the upper part of the Mauri basin in the Andean mountains, located in the limits of Peru, Chile, and Bolivia. This water transfer, which includes groundwater from the Titicaca 14S transboundary aquifer system, has caused a conflict between the communities of the Andes, the Bolivian government, and different states of Peru. In order to analyze anthropogenic pressures caused by water management in the region, we developed a conceptual hydrogeological model for the Caplina-Concordia transboundary aquifer system based on the integration of official information from the three involved countries. First, a 3D geological model was built for the aquifer system using the LEAPFROG program. Based on this model, a 3D transient groundwater flow model with 12 layers was generated using the finite-element program FEFLOW, considering hydraulic data from the last two decades. Finally, different water resource management and climatic scenarios were evaluated considering the next 20 years. With the development of the model, it was possible to understand the transboundary aquifer system, its anthropogenic pressures, and hydrodynamic impacts between 2000 and 2020. The results show that the increase in the salt wedge and the average groundwater level drop at the observation points have been around 500 hm3 and 5 m, respectively, during the last two decades. Also, it is expected that the depletion trend will continue with groundwater level decreases between 3 m and 6 m in 20 years.

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Identifying groundwater and river water interconnections using hydrochemistry, stable isotopes and numerical modelling

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The hydrogeological basin of the Bay of Dahomey (Keta) shared by Ghana, Togo, Benin and Nigeria, hosting the biggest cities of the countries, is experiencing severe exploitation of groundwater resources in order to meet the growing demand for water. The Ouémé Delta (study area), which is an integral part of the Benin Coastal Sedimentary Basin (Beninese portion of the Keta Basin), has an abundant groundwater potential (probably the most exploited in the country) and a dense hydrographic network represented by the Ouémé River, the Sô River and Lake Nokoué (saltwater body), constitutes an important water exchange area between the two hydrological systems. However, a variety of factors can be enumerated, such as the uncontrolled occupation of land for agricultural activities, the areas of waste dumps (sources that can deteriorate the quality of the groundwater), the saltwater bodies that threaten the groundwater through surface water. This raises our attention to the effects of interactions for efficient management, optimizing the location of boreholes, the exploitation of the resource and the development of a judicious policy in agreement with the SDGs (Sustainable Development Goals). A study on the interactions between groundwater and surface water has been conducted, involving the Mio-Pliocene aquifer of South Benin and the hydrographic network of the Ouémé valley to understand the exchange processes between hydrological systems. This study, based on an approach using environmental isotopic tracers (18O and 2H) and numerical simulations, defined the preferential zones of water exchange between groundwater and surface water, the dynamics of interactions between groundwater and surface water, and the response to human interference. Isotopic separation of the hydrographs of the two main rivers showed a substantial contribution of groundwater to the flow of the Ouémé and Sô rivers.

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The conceptual model of the recharge of Transboundary Aquifers between Prut – Dniester rivers.

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The utilization of groundwaters for the agriculture and water supply in arid climate areas is important for water management purposes. The evaluation of the water reserve formation, including groundwater, is one of principal element of this activity. The territory between Prut and Dniester rivers of the Republic of Moldova is situated at the Moldavian artesian basin, which is part of the Black Sea artesian basin. According to its hydrodynamic properties, the Moldavian artesian basin can be considered as a separate basin, the borders of which are the Dniester, Prut rivers and the Black Sea in the south. This basin is connected to the Volyn-Podolsk artesian basin from Ukraine at the north by a narrow strip in the northwest and their interaction is limited. The principal aquifers are transboundary in this region between Romania, Ukraine and Republic of Moldova. The aim of this work is a creation of conceptual model for groundwater recharge evaluation. There are seven main stratigraphic rock groups, which form principal aquifer systems. The conceptual model of the groundwater system includes the seven aquifers. The water-bearing rocks are mainly limestone, sand, sandy loam, and sandstone. Between the aquifers and the complexes, there are no thick and regionally sustained low-permeability strata. The basin structure is a single hydrodynamic system, consisting of several aquifers and complexes interacting through weakly permeable sediments and hydraulically connected with surface waters. Regional waterproof layers are clays of middle Sarmatian, clays of Podolsky Formation of lower Baden. The local aquitards can be quaternary, alluvial clayey rocks. The principal information about studied transboundary aquifers can be obtained at site http://geologie.gov.md/ The aquifer recharge takes place directly on the territory of the basin due to the infiltration of atmospheric precipitation and river runoff. The groundwater discharge is river network, Black Sea, and water supply. The implementation of stable isotope technology for the evaluation of the water cycle (precipitation, river water, groundwater interaction) and groundwater reserve formation is proposed for the implementation in this work.

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Groundwater Potentiality Assessment in West Delta to Moghra, Egypt

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Groundwater in Egypt is an important non-conventional water resource. In Egypt there are many underground aquifers such as the Nubian Sandstone aquifer shared with Sudan, Libya and Chad, as well as non-shared aquifers such as Nile aquifer; Fissured Carbonate aquifer; Moghra aquifer; Coastal aquifer; and Fissured Hard-rock aquifer. To enhance the role of groundwater and to improve its management, a methodology for assessing groundwater potential is applied to many regions of Egypt with shared and non-shared aquifers. Groundwater potentiality refers to the amount of storage that exists in the aquifers. Groundwater potential is a dynamic term according to the rapid and continuous development of the reclamation and urbanization. Groundwater delineation, zonation maps and the updated groundwater potential map is important and imperative tool to express subsequent rapid changes in the hydrological conditions in easy way, and it helps decision makers for integrating the groundwater management. In this research the methodology was applied to the West Delta fringes up to El-dabaa road and Moghra region as a case study. Currently, in West Nile Delta fringes, the existing land reclamation projects depending on non-renewable groundwater faced various environmental management issues, as a result of the dynamic agricultural and urbanization process in the area such as decline in groundwater levels and deterioration of its quality. In the study, field investigations and GIS (geographic information system) were utilized to generate the main hydrogeological parameters; aquifer layers, lithology, extraction density, topography, slope, hydraulic conductivity, groundwater levels and groundwater quality. For accurate assessment for groundwater potential, study area delineated into equal unit cell and all analyses have been executed through geographical information system (GIS). The results show the updated groundwater potential map for the region, the groundwater potential assessment, groundwater bodies' delineation, and classification of potentiality.

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Hydrogeological synthesis of the transboundary Mio-Pliocene aquifer of Bir Guendouz (Morocco) - Boulanouar (Mauritania)

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Groundwater is essential to support socio-economic development of developing countries in particular. The Mio-Pliocene aquifer extents over a transboundary area of about 3,800 km² from the Bir Guendouz region (Southern Morocco) to Boulanouar (Northern Mauritania). The region is characterized by a hyper-arid continental climate where surface water resources are relatively scarce. This aquifer constitutes a vital water source as it is the only current source of drinking water supply for Beglamour and Nouadhibou city, the Mauritania economic capital. Conversely, in Morocco, the overall water needs of the rural population and livestock are increasing and future withdrawals for water bottling projects at Bir Gandouz are being considered. Therefore, the need for a joined aquifer water pumping strategy. On the basis of the geophysical and hydrogeological exploration work carried out in Bir Guendouz region, this study recognizes a two-layer aquifer geometry: an upper unconfined with a thickness varying from 20 to 100 m and a lower confined which can exceed 300 m of thickness. Our preliminary groundwater model indicates that recharge is low, mean transmissivity is around 1.5 10-4 m2/s and piezometric head varies between 40 m to the NE and-5 m to the SW. The delimitation of the freshwater table and the outline of the seawater is about 30 km away from the Atlantic coast and can reach up to 40 km in the Guerguerat region located on the Moroccan-Mauritanian border. Aquifer excessive exploitation could lead to lowering the groundwater table level. Hence, collaboration and partnership between the two countries (Morocco and Mauritania) are essential for an integrated water resources management towards the sustainability of this transboundary aquifer. Keywords: Transboundary aquifer; Morocco-Mauritania; Water management; Geophysical methods.

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Contribution to the understanding of the hydrodynamic behavior of aquifers of the Taoudéni sedimentary basin (South-Eastern part, Burkina Faso)

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This study aims at improving knowledge on the hydrogeology of shared aquifers of the Taoudéni sedimentary basin (Burkinabè part) for a better management of transboundary groundwater resources. The methodological approach adopted for this purpose, consisted first of all in the description of the lithological units in terms of extension and succession of different layers. Secondly, the study of the hydrodynamic behavior of these units by the analysis of the spatial and temporal variations of the piezometry was discussed. The data used are made up of 692 static level measurement points and 8 observation structures representatively located on the site and capturing five of the geological units described. For each of these observation structures, monthly chronicles of the piezometric levels are available and cover the period from 1989 to 2017. The temporal analysis of the piezometry, performed in comparison with the rainfall chronicles, revealed a general upward trend in the piezometric level over the entire basin. The reaction of the aquifers generally occurs with a delay of 1 to 2 months from the beginning of the rainy season. Indeed, the peaks of the piezometric level generally occur between September and October in reaction to the rainfall peaks that occur between July and August. Low groundwater levels are observed between May and July. This relatively slow reaction of the water table is observed in all the observation boreholes. The influence of the geological nature through the structure and hydrodynamic properties of the layers has been deduced. Notably, in fine pink sandstones, water table reacts slowly than in quartz granular sandstones (more porous). Spatial analysis reveals that the piezometric coastlines vary between 166 and 633 m with a rate indicating a flow that is generally from the Southwest to the Northeast, the feeding areas being located towards the Southwest and Northwest. There is a near concordance between the hydrogeological basins and the overlying hydrological basins, as well as the existence of a bimodal flow with a component following the topography and another major deeper component controlled by the SW-NE regional gradient. The latter component may present flows directed from the high relief towards the Nasso springs. In the area of the springs (Kou basin), the average maximum stock variation, calculated by the WTF method (Water Table Fluctuation), varies between 35 and 48.70 mm per year for the 2012-2014 period.

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Current knowledge and research prospects on priority management zones of internationally shared aquifers

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There seems to be a consensus in the latest literature that the joint management of Transboundary Aquifer Systems (TBAs) should focus on those parts of the aquifer that are prone to cause or receive cross-border impacts within a reasonable time frame. Current and potential cross-border effects can vary enormously within the aquifer boundaries due to the groundwater systems' inherent complexity. As groundwater flow velocity is generally slow and there is a usual fragmentation of groundwater into separate flow domains, not all parts of an aquifer have the same dynamics, nor are they subject to the same uses and impacts. Therefore, only some areas of TBAs may be relevant for controlling transboundary interactions. Although this idea differs from the more holistic paradigm of promoting integrated water management on the entire system, defining management priority zones within the aquifer's boundaries has been proposed as a more efficient and effective procedure. The "zoning" approach proposes dividing the aquifer into different zones, according to physical aspects (e.g., hydrogeological characteristics, flow directions, travel times) governance aspects (e.g., land use, water demand and water management time) and socio-economic aspects (e.g., population density, economic activities). The "scale factor" approach considers that groundwater fluxes rather than aquifers boundaries should be used to define groundwater availability. The "Effective Transboundary Aquifer Areas" approach proposes prioritizing aquifer productive zones based on the aquifer pumping patterns, regardless of the geological aquifer boundaries. But who has investigated these approaches and where? What specific methods have been used, and which subjects have been examined? Have one or more of these methods ever been applied to real TBA management cases? Have they been effective? What can we learn from them? This study presents a systematic quantitative literature review of research performed over the past decade on TBAs in different hydrogeological, climatic and societal contexts, thereby looking at the research goals, methods and prospects for defining priority management zones. We discuss trends in the field and provide recommendations for research and application to TBA management.

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Mapping transboundary aquifers in hyper-arid areas using orbital sounding radars: the Oasis mission concept

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The Orbiting Arid Subsurface and Ice Sheet Sounder (OASIS) mission concept is proposed to explore the signatures of climate change beneath the surface of two of the least well-understood arid regions of the Earth: the polar ice sheets and the hyper-arid deserts. With these first-of-a-kind measurements of land ice and shallow aquifers, OASIS has two well-defined science objectives. The first is to determine the thickness, inner structure, and basal boundary conditions of Earth's ice sheets to understand their dynamics and to improve models of current and future ice sheet response to climate change and, hence, to better constrain ice sheet contribution to sea level rise. The second objective is to perform detailed mapping of the spatial distribution of shallow (<100 m deep) aquifers in the most arid regions on Earth to understand groundwater hydrology, enhance groundwater flow models, and provide new insights into available water resources and paleoclimatic conditions. These two mission objectives, which align closely with two NASA Earth Science program objectives on climate and water cycle, are achieved using measurements made by a single, low-cost and proven-heritage instrument: a 45 MHz center frequency radar sounder with 10 MHz bandwidth. The OASIS radar is similar to instruments on two successful Mars missions, Mars Express and Mars Reconnaissance Orbiter, presently probing the Martian subsurface.

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Canada – USA Transboundary groundwater–surface water understanding: Refining approaches and knowledge

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Previous analysis of Canada–USA transboundary aquifers has emphasized the need for more scientific data, analysis, collaboration, and communication with more clearly defined roles that enable respective governments to improve joint management of groundwater at the international level. Although challenges remain, the past five years have seen progress in these areas and considering groundwater as both a resource and as a pathway to other ecosystem effects. Building on detailed studies at aquifer and watershed scales, joint work has allowed development of an approach that will consolidate into a framework knowledge of the integrated transboundary groundwater and surface water flows along the 8900 km Canada–USA boundary.

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Aquifer testing while drilling advances to characterize leaky shared systems

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Exploitation of shared aquifers can become a source of conflict between populations and/or Governments living on each side of a common administrative border, be it regional (within provinces or departments) or national. No doubt that climatic changes will exacerbate such conflicts as groundwater is becoming a vital strategic resource. In the majority of shared hydrogeological sedimentary basins, there is no coincidence between their 3D-boundary conditions and the limits of territories. Expected source of conflict evolves around the determination of long-term safe exploitation rates that would avoid flux and storage interferences across borders, while groundwater resources are being "mined" (usual very low rates of recharge). However, complexity of flow conditions around wells in "leaky aquifer systems" (a succession of aquifers separated by less permeable and, often fractured, aquitards) complicates this indispensable evaluation. Leakage factors between aquifers and through aquitards influence long-term drawdowns in the pumped unit and in the overlying and underlying aquifers. Safe exploitation rates should only be devised once degree of hydraulic connectivity between units is understood and quantified. This article proposes a methodology for aquifer testing while drilling deep reconnaissance wells (depths greater than 100 meters), using observation wells at suitable levels of aquifer and aquitard units. The data can be analyzed through specific sets of type-curves of two- or three-aquifers systems using semi-analytical modeling (Sauveplane, 1987), which can be corroborated via local numerical modeling. Hydraulic parameters of aquifers and aquitards are evaluated at ounce for several units. An example of a possible application of the proposed methodology is given for the Taoudéni basin shared between western Burkina Faso and Mali. The aquifer systems include 10 hydrogeological units (not always present) that are composed of more or less porous sandstones, argillites, siltstones and dolomitic carbonates. A reconnaissance drilling campaign will follow the current geophysical one (electric and seismic). It is expected that once the prognosis of the reconnaissance boreholes is known, the methodology proposed by this article will be applied using two drilling rigs working at the same time for pumped well and attached observation well. Exploitation wells already exist on the Burkinabè side, but hydrodynamic parameters are poorly understood (no observation wells were used) and pumping rates are classically not under scientific control.

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Use of digital tools in Africa for advancing transboundary aquifer management

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Groundwater is a resource of increasing prominence in Africa whose potential has still to be developed in full capacity. While it is clear that data gathering is of outmost importance to achieve a certain level of knowledge for many African aquifer systems, Information and Communication Technology may support and boost efficient data management. This way, more technically sound and even community-based decisions may be made. We performed a research for framing the state-of-the-art on the use of digital tools for supporting sustainable groundwater management in the African continent. By means of a comprehensive literature review and performing investigations via a structured questionnaire on ongoing practices at institutional/private sector level, the results allow a clear view on the present level of knowledge and on the diffusion of such tools. We focus the analyses of the results considering studies within the framework of the major African transboundary aquifers. At present the use of digital tools/groundwater numerical models is deemed to be an occasional activity, mostly applied for large engineering projects or basic modelling studies, rarely used for planning and management of the resource. All in all, their use in the period 2000-2020 can be considered low, with a clear difference between North Africa and Sub-Saharan African countries. Digital tools are recognized as needed tools by African institutions at national/regional level. However, skills and capacities are largely missing: the need for capacity building is (extremely) high. Commercial software solutions still dominate the market, while open-source ones appear in increasing trend of usage in the last years. Examples based on the use of groundwater modelling tools in transboundary aquifers are presented. The, main barriers in the use of digital tools are: i) scarcity of data, ii) inadequate resources (lack of computing resources), and iii) missing capacities (lack of computing skills). In addition to these, the lack of adequate and well-functioning Internet connection is considered one of the main bottleneck in favoring the spread of new technologies. Capacity building and knowledge transfer has then to be on top of the agenda for a digital groundwater governance in Africa.

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Recent advances with the integrated hydrological model of the Stampriet Transboundary Aquifer System (STAS)

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The STAS is a very large transboundary aquifer system (100 000 km2) shared between Botswana, Namibia, and South Africa. It provides the only water resource in this otherwise arid region. As part of the GGRETA project, the UNESCO and local stakeholders have been promoting the development of a groundwater model for the assessment and the sustainable management of this shared resource. In this communication, we retrace recent progress and lessons learnt from this modelling endeavor. First, a detailed hydro stratigraphic study allowed us to refine the geometry of the STAS and in particular the position of its boundaries. This study also highlighted links between the STAS and the neighboring Central Kalahari Basin. To the south, a large complex of salt pans was identified as the regional outlet for the basin (Hakskeen, Koppieskraal, Uitsak pans). Second, although the isotope data for the basin were compiled in phase 1 of the GGRETA project, they have, to date, never been used as information for the STAS numerical model. Integration of environmental tracer data allowed the identification of key hydrological recharge, discharge, and aquifer exchange processes. In particular, the hydro chemical and isotopic synthesis highlighted the importance of surface and groundwater interaction, even in this arid environment. In turn, this led us to select an integrated hydrological model capable of simulating interaction between land surface (UZF) and groundwater (MODFLOW). A feasibility study showed there would be great benefits moving from a stand-alone model, which requires manual updating, to a state-of-the-art modelling platform that can be shared by all stakeholders and updated automatically with remote sensing data.

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Deciphering of recharge possibility to complex terminal (2nd member of North -Western Sahara Aquifers System) using conventional and non-conventional Techniques

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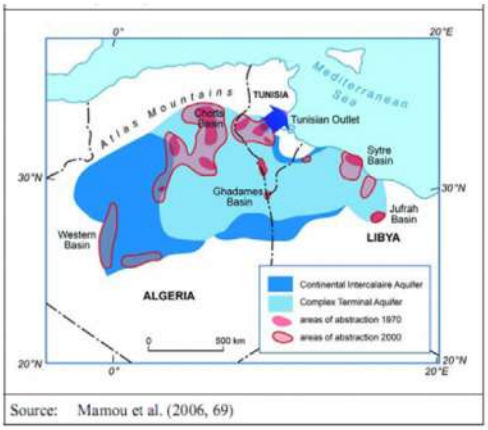
Complex Terminal is the 2nd upper member of the major transboundary aquifer known as North -Western Sahara Aquifer System(NWSAS) shared by Algeria,Tunisia and Libya.Complex Terminal aquifer is of upper Cretaceous to lower Miocene age and its facies changes from sandy farcies at the top layer to limestone facies at the bottom layer of aquifer member. The multi-layer nature of the Complex Terminal aquifer causes the geometry of its aquifer reservoir (sands and limestone) to be still insufficiently known in several zones. Recent recharge to this aquifer is subject to considerable uncertainties under the overall aridity conditions and climate change of the region. Furthermore the description of Complex Terminal as devoid of any meaningful recharge, a rather stagnant water body, disconnected from any surface water body would therefore be misleading and represents one of the most obvious inaccuracy as well. Accordingly the present study is aiming at revealing a more realistic approach to the recharge of this aquifer.

1. Introduction

1.1. Geologic Setting

The multi-layer nature of the Complex Terminal aquifer causes the geometry of its aquifer reservoir (sands and limestone) (Fig.1) to be still insufficiently known in several zones, of which in particular the Tolga aquifer (at the level of Biskra) and, more generally, outside of the exploitation zones.

Figure 1.
Location map for Complex Terminal.



ALGERIA	TUNSIA	LIBYA
Impermeable top	Impermeable top	Impermeable top
Sands aquifer	Sands aquifer (Djérid)	Lower Miocene sands and limestone aquifer (coastal zone)
Complexe Terminal aquifers		
Limestone aquifer	Limestone aquifer (Nefzaoua)	Limestone aquifer (Mizdah
Semi-permeable	Semi-permeable	Semi-permeable
Turonian aquifer	Turonian aquifer	Turonian aquifer
Semi-permeable	Semi-permeable	Semi-permeable
Continental Intercalaire Aquifer		
Lower Cretaceous Jurassic - Trias	Lower Cretaceous Upper Jurassic	Lower Cretaceous Upper Jurassic / L. Cretaceous (Kiklah) – Upper Jurassic -Trias

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Complex Terminal displays a mostly porous and fissured / fractured structure (Struckmeier / Richts 2006). Among its different layers, two have to be distinguished as being of major size and importance. The so-called Complex Terminal (CT) is of upper Cretaceous to lower Miocene age and its facies changes from sandy facies at the top layer to limestone facieses the bottom layer of aquifer member (Fig.2).

2. Evidence supporting renewability of Complex Terminal

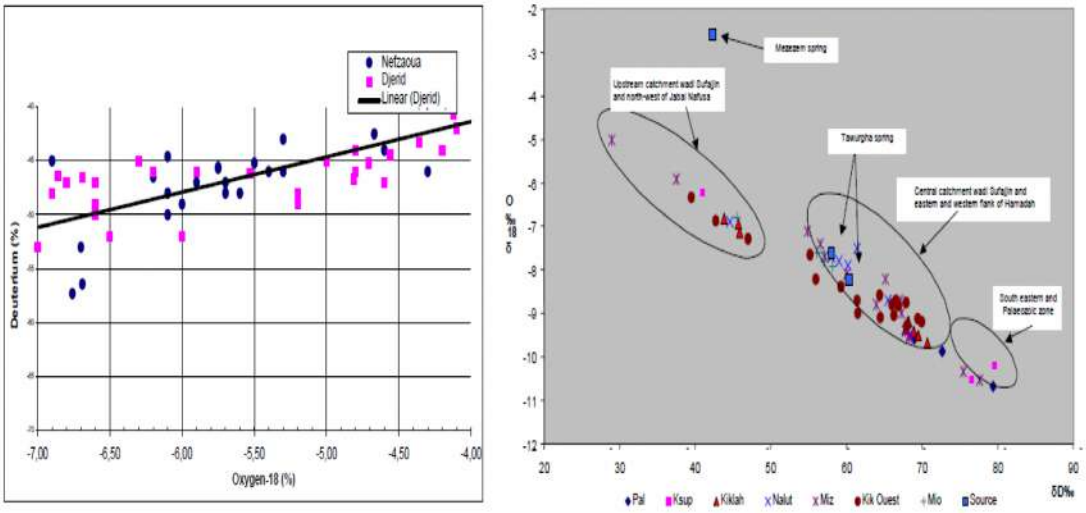
2.1.Hydrologic Criteria

The recharge rate estimation based on the groundwater flows at velocities between 0.1m/day and 1m/year estimated by different authors ((Foster/ Margat / Droubi 2006; Mamou et al. 2006) represents a real mismatch. Another formula based on the speed of underground flow as deduced from the carbon-14 activities(Aranyossi& Mamou, 1985) yielded a recharge flow that do not exceed, at best, 190 l/s. Evaluation of recharge rate by "Etude des Ressources en Eau du Sahara Septentrional" – ERESS, (2009) by current infiltration on the Dahar (Q : 2m3/s) is overestimated and does not exceed, at best, 250 l/s. Accordingly, the situation thus represented is that which recharge is closest to the initial state of the system. The foregoing recharge rates would take recharge water which entered the NWSAS on its western border, nearly 2 million years to reach its eastern border and 900,000 years to travel from the south to the north and would therefore, contradicts the fact of having frequent data of pmc up to 60 ‰ and Tritium data up to 16 T.U., which corresponds to an age resolution of about ± 16000 to ± 40,000 years. Even at a speed of 1 m/day, a full turn –over of the present water stock will therefore never occur within human lifetime dimensions.

2.2.Isotopic evidence

The isotopic compositions of Complex Terminal at Hamada El Hamra in Libya show mix of recent meteoric waters with ancient waters stored in the aquifers (Fig.3). The waters with a very low stable isotopes content correspond to the waters of the Palaeozoic aquifers of the south of the Saharan basin and to those of the Upper Cretaceous (Mizdah) in direct relation with the Cambro-Ordovician aquifer. Carbon 14 yields, for these waters, ages of more than 25 000 years. The intermediate waters group comprises almost all the waters of the Cretaceous aquifers (Kikla, Nalut, Mizdah), originating from the central zone, between parallels 30° and 31°30', on both sides of Hamadah al Hamra(Fig.3). It is worth noting, however, that the Kiklah waters originating from the eastern flank of the Hamadah have a stable isotopes composition that is very close to that of the Palaeozoic waters. While complex terminal in Tunisia (Nefzaoua and Djerid localities) modern water of Pleistocene age is mixed with Palaeozoic water in a clear cut relationship (Fig.3)

Figure 3.
Stable isotopes composition of the Complex Terminal waters of Southern Tunisia (Nefzaoua and Djerid localities) and in Libya (El Hamada El Hamra)



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3.Conclusions

Recharge rates to Complex Terminal using different techniques would take recharge water , nearly 2 million years to reach its eastern border and 900,000 years to travel from the south to the north and would therefore, contradicts the fact of having frequent data of pmc up to 60 and Tritium data up to 16 T.U., which corresponds to an age resolution of about ± 16000 to ± 40,000 years. Even at a speed of 1 m/day, a full turn –over of the present water stock will therefore never occur within human life time dimensions. The data provided by the foregoing authors deviate from the actual possible situation and represents a real mismatch. Furthermore, a significant, present-day recharge of the Pliocetocene aquifer system to the complex terminal has to be taken into consideration.

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The Permo-Carboniferous Aquifer between Brazil and Uruguay: In search of the transboundary link

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The Permo-Carboniferous Aquifer System (PCAS) is located on the Brazil and Uruguay border and is one of the sixty-eight shared aquifers that are located in South America and identified during the UNESCO/OAS ISARM Americas Programme. Within the PCAS, Rio Bonito/Tres Islas Aquifer (RBTI) has a different hydrogeological behavior than the other formations that compose it and significantly increased the water supply of many municipalities of both countries. Location is fundamental to define the aquifer as a transboundary one; however, there is a lack of detailed technical information about this aquifer (e.g., geometry, flow, productivity, water quality, and recharge zones), and differences in the legal and constitutional aspects to manage this kind of water resources in each country. . From the analysis of the available data, the present work lighting hydrogeological and legal aspects and gives possible next steps to future studies to aim the transboundary management of the RBTI and raise the importance of this water resource to the region, which presents a lack of water availability.

The sequences of the Rio Bonito and Palermo Formations (Brazil) are relatively coeval, in the early Permian age, to the Tres Islas and Fraile Muerto Formations (Uruguay), as figure 1 shows. The RBTI is an aquifer system that varies from unconfined to confined, whereas the pelitic sediments of the Palermo/Fraile Muerto Formation and other overlapping units (Kettelhut et. al., 2007; Capeci, 2013) act as aquitards the average thickness is approximately 60m and the average depth of the wells is about 65m, yielding up to 12m³/h. The majority of the wells have discharge rates varying from 1 to 6m³/h. Capeci (2013) concluded that the RBTI shows higher productivity on the Brazilian side and that it decreases towards the Uruguayan border. New wells were drilled near the border, tapping confined units at 200m depth, whose discharges reached 50m³/h (CeReGAS), demonstrating the RBTI potential, especially under specific depths and confining circumstances. Recharge dynamics is also being re-evaluated then new data are indicating that effective recharge is also occurring in both sides of the border and is not restricted to the Brazilian side, as supposed.

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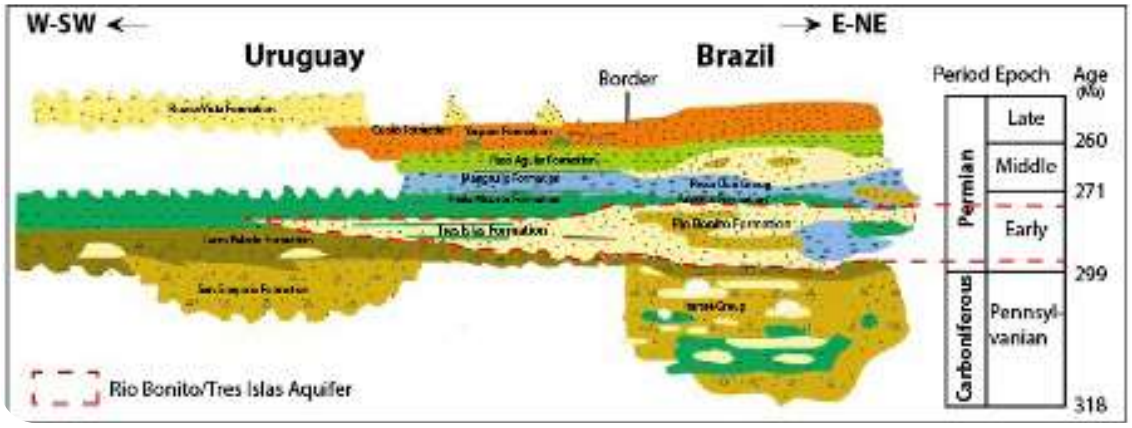
Figure 1.
Stratigraphic correlation between formations that composed the PCAS in Uruguay and Brazil. Modified from Capeci (2013).



With regard to legal and institutional aspects, it was clear that there are convergences that allow joint actions. At the national level, for instance, both countries do have similar legal provisions. However, there are differences with regard to the instruments related to the practical effectiveness of the policies. In Uruguay the main provision (Water Code14.859/78) establishes the responsibility of the executive for the water management throughout agencies directly linked to the Ministry of Environment. Brazil, on the other hand, assumes a state jurisdiction for the groundwater management. It's important to mention the existence of Binational Commissions (BC), which were established to conflict prevention and establishing bridges for sharing relevant scientific-technical information concerning the Guarani Aquifer System.

This work discussed technical and legal aspects around the cross-border Rio Bonito/Tres Islas Aquifer. Technical data on both sides of the border are insufficient for the precise characterization of each aquifer in order to maximize the use of this water resource in a sustainable way. New studies should focus on the correlation of the aquifer in the region and across borders, as well as raising more data on the distribution of productivity and recharge zones. The increase in technical knowledge, linked with the binational commissions' experiences in progress, will contribute to a cooperation project between Brazil and Uruguay for the management of the transboundary aquifer Rio Bonito/Tres Islas, avoid running out of water in the region.

A revision of the geological model of the Guaraní Aquifer System (SAG) in the Corrientes Province, Argentina

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The Guaraní Aquifer System (SAG), a mega-aquifer of South America, extends for some 1.2 million km² covering vast areas of Argentina, Brazil, Paraguay, and Uruguay. This groundwater reservoir provides water to more than 90 million inhabitants. From the 1990´s, it suffers a growing extractive pressure, with many management strategies implications due to its transboundary character. However, the geologic structure of its southern sector within Corrientes Province, Argentina, was scarcely known due to lack of outcropping areas, a flat geomorphology, and the reduced number of deep geological and geophysical data. Most of the wells barely tap 100 m of the stratigraphic column due to the abundance of surface water sources, sufficient to supply water demands. Average precipitation in the area ranges from 1,100 to 1,500 mm/year.

Recent investigations allowed posing a new geological model of the SAG in Corrientes Province. The interpretation of new well-logging and magnetotelluric data, along with previous geological information, contributed to advance knowledge on the deep geology of Corrientes, and hence, to revisit the location of the SW boundary of SAG. Besides, the tectonic framework of the study area with the prevalence of the NW-SE trend associated to the Asunción-Rio Grande Arch, the SAG thinning confirmed in boreholes, and the virtual disappearance of the aquifer sandstones westward of the Mercedes Plateau, helped redefining the mapped SW boundary of SAG, displacing it towards the center of Corrientes Province. The proposed boundary is conditioned by tectonic structures such as the Mercedes High and the Curuzú and Corrientes grabens, with N145 and N35 preferential directions, respectively. The boundary displacement supposes a 6.4 % reduction of the currently accepted surface area of SAG estimated by the PSAG Project.

Relying on a thorough geologic model and a correct location of the SW boundary is relevant for the hydrogeologic conceptual model, for which it is proposed that SAG water would discharge to adjacent formations, mixing with more saline waters. This hypothesis is consistent with the presence of high salinity groundwater locations identified near the SAG boundary. Also, the SW-W boundary would constitute a transition zone between SAG and the transboundary Yrenda-Toma-Tarijeno aquifer.

New studies are needed to define the boundary with finer precision, focusing on the role of tectonic structures on the geometry and groundwater flow patterns of the aquifer. This work complements other contributions on the SAG presented on this event developed by the authors over the past 10 years.

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Groundwater flow patterns in the southwestern sector of the Guaraní Aquifer System using hydro chemical, isotope and age modeling

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Extending beneath parts of Brazil, Paraguay, Argentina and Uruguay, the Guarani Aquifer System (SAG) is one of the world's largest transboundary aquifers. It constitutes a major source of water for around 90 million people. The unprecedented increase in water demand in the last twenty years, has raised concerns about the sustainability of groundwater quantity and quality. Characterizing groundwater chemistry and tracing its origin is essential for proper water quality and quantity management. Groundwater chemical characteristics and the derived quality are controlled by its origin and flow paths, but in the SW portion of the SAG flow patterns and the origin of abstracted groundwater were highly uncertain till some years ago. Geological, geophysical, hydrodynamic, hydro chemical, isotope, and modelling tools have been applied by the authors since 2007 with the support of IAEA, MICINN (Spanish Ministry of Science and Innovation), and IHLLA, allowing defining revised geological and hydrogeological conceptual models for this sector of the SAG. Hadrochemical and isotope data have contributed significantly to the development of the revised models, which have improved the understanding of the origin of groundwater's chemical composition. Most studied groundwaters are mixtures of waters from different depths and geological formations. Stable isotopes combined with hydrochemistry showed two mixing trends involving recent and two old groundwater endmembers, one corresponding to the SAG and the other to Pre-SAG groundwater. Noble gas isotopes dissolved in groundwater (4He and 81Kr/Kr) provided residence times ranging from recent recharge up to 770 ± 130 ka. The regional distribution of both clusters of mixed waters seems controlled by geological and hydrogeological features: existence of multiple deep faults, shallow depth of SAG due to tectonic elevation, thinning of the SAG formations and hydrodynamic conditions favorable to deep upward flows in most of the area. Groundwater age modelling confirmed the role of the geological structures in controlling groundwater flow. This work is part of a series of contributions presented by the authors on the SW portion of the SAG.

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The role of the groundwater divide in transboundary aquifers

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The role of the groundwater divide in transboundary aquifers Although the transboundary regional aquifer extends over more than one country, its detailed hydrogeology may hide many of the characteristics that will have a role in setting up the strategy for groundwater exploitation from these aquifers among the riparian countries. One of these characteristics is the "groundwater divides", which are the lines that separate the areas where groundwater moves in different directions. Within one aquifer we may find several lines that divide the groundwater. The importance of the groundwater divides lies in the fact that the volume of extracted water from the aquifer in countries on one of its sides will not affect other countries on the other side, unless it affects the groundwater divide itself. In this paper, we will briefly the clarify of the hydrogeological concept of the groundwater divide and the necessary data to determine its path and the ways of using computer methods in drawing and delineating the groundwater divide, indicating the geological and hydrogeological role in this, especially the idea of compatibility of the surface water basin and the groundwater basin. We will then move on to present case studies on groundwater divides in Arab region. At the moment, I propose the groundwater divide between Syria and Lebanon along the Anti-Lebanon mountain range and the groundwater divide in the Nubian sandstone Aquifer between Chad, Sudan, Egypt and Libya. In each case study we will briefly review the general natural conditions in the region and the aquifer itself, especially its geological and hydrogeological characteristics, then we will contour lines of groundwater levels, define the path of groundwater divide and explain its hydrogeological role in each case. We will then review the hydrogeological methods used to assess the impact of groundwater exploitation on groundwater divides, especially groundwater modeling method, and explain its role in predicting potential changes of the position and path of groundwater divides. Finally, we will present the measures that must be taken by the riparian states around the aquifer to monitor and find the groundwater divides and to use this feature (groundwater divide) in solving issues between these countries.

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Recent contributions of combined 81Kr and 4He chronometers to characterize groundwater flow patterns in the transboundary Guarani System

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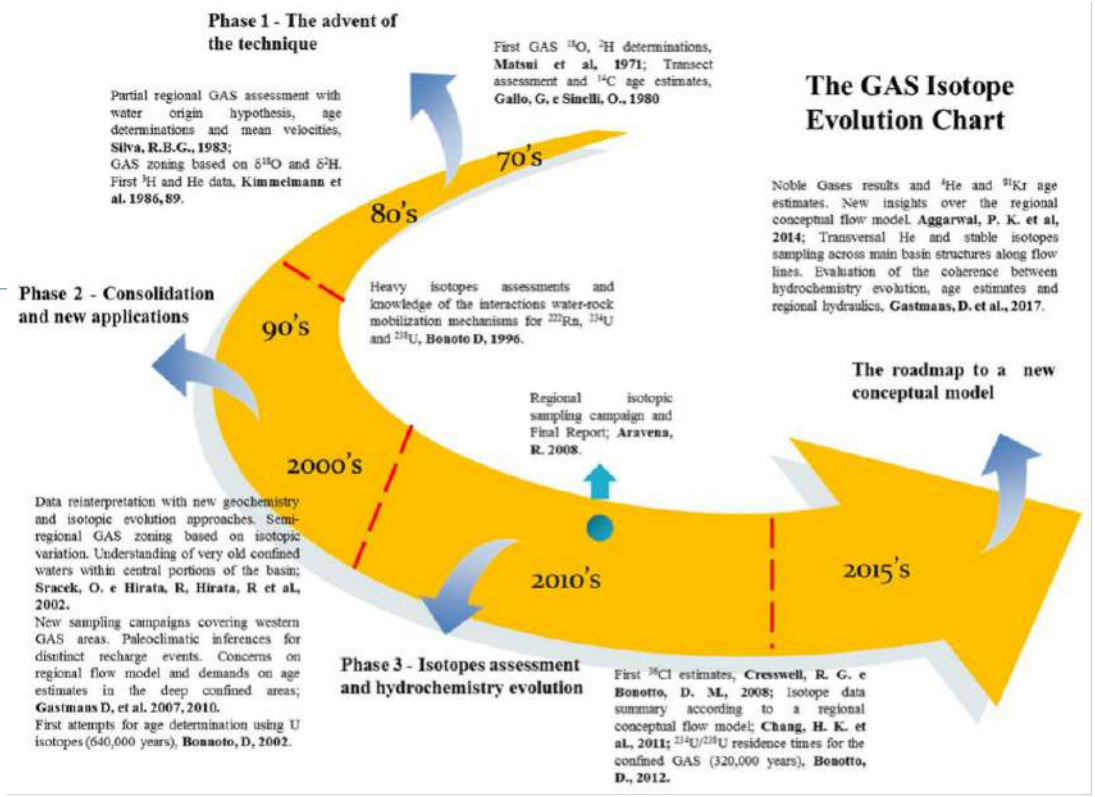
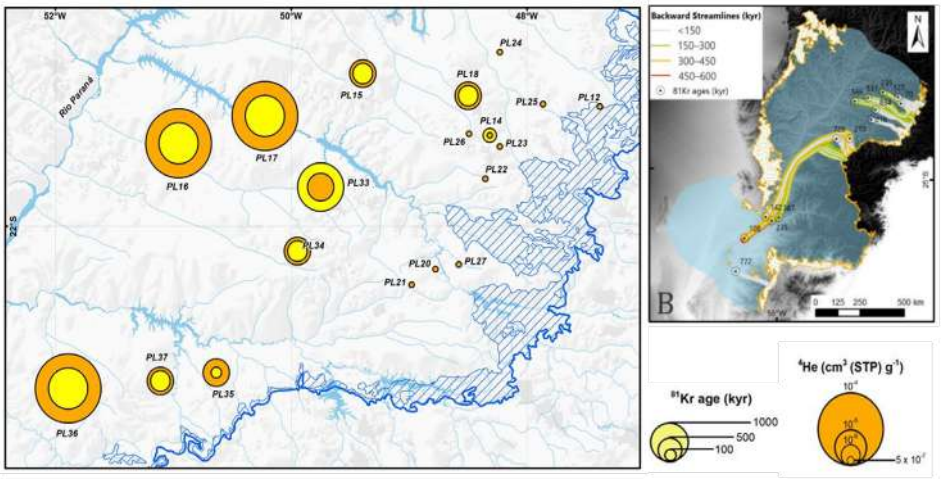
The Guarani Aquifer System (GAS) extends for 1,088,000 km2 and covers considerable areas of Brazil (8%), Argentina (8%), Paraguay (21%), and Uruguay (21%). It is the most important aquifer within the South American continent and one of the largest transboundary aquifers in the world. The hydrogeology of the GAS has been studied since the 1970s, a time frame that coincides with the wider use of isotope hydrology tools in South America. Stable and radiogenic isotope applications in hydrology were consolidated during the 1980s, with the support of the IAEA, when new applications based on stable isotopes and dating approaches using with radiogenic isotopes were introduced. The conceptual model describing the hydrological functioning of the GAS has evolved from a large homogeneous aquifer to a segmented and heterogeneous groundwater system, where regional fluxes are controlled by its compartmentalization and geological structures.

Figure 1.
Evolution of the isotope knowledge applied to the GAS (Kirchheim et al., 2019.



Recent analytical efforts coordinated by IAEA, focused on the use of dissolved noble gas led to new findings on the GAS regional groundwater flow patterns and hydro chemical evolution. Samples collected from deep confined areas allowed the application of combined 81Kr and 4He chronometers. Groundwater samples collected for 4He analysis along different flow lines, depths and distances from recharge areas revealed heterogeneities and cross-formational groundwater mixing with overlying and underlying units. Groundwater age dating using 4He and long-lived radionuclides offered additional constraints for the conceptual groundwater flow model.

Figure 2.
^{81}Kr-^{4}He GAS age determination (Modified from Aggarwal et al., 2014) calibrating regional flow model (Extracted from Gonçalves et al., 2021).



As a result, lower groundwater recharge rates for the GAS have been estimated to be at least one order of magnitude lower than previously considered. In 2010, the four countries signed the Guarani Aquifer Treaty, an essential move to foster international cooperation on groundwater. The new modeled age distribution, therefore, is a huge step towards the sound management of this common transboundary aquifer.

Needs related to sustainable transboundary water management of the sensitive and complex karst aquifer system of the Prespa-Ohri

Zoran Stevanović[1], Romeo Eftimi[2], Vasko Stojov[3]

Lakes Prespa and Ohrid, which are among the largest in the Balkan Peninsula, are situated in the border area of Albania, North Macedonia and Greece (Fig.1). UNESCO has acknowledged the ecological importance of Lake Ohrid in 1979, when it was included in the World Heritage list. The high mountain chain of Mali Thate-Galichitsa, consists mainly of thick bedded and massive limestone of Upper Triassic-Lower Jurassic age whose thickness reaches 550 m (Arsovski 1997). The limestones are highly karstified, separate the two lakes at the surface, but they are connected by a system of underground channels so that water lost from the Prespa Lake drains at the springs along the shore of Lake Ohrid (Cvijic 1906, Anovski et al. 1991, Eftimi and Zoto 1997). The connection between main ponor (swallow hole) Zaver and the two major springs Tushemisht in Albania and St. Naum in North Macedonia has been proven by tracer test conducted in September 2002. Injected tracer Sulphorhodamine G appeared in just 6 hours at main outlet channel of the Tushemisht spring, which resulted with an extremely high apparent velocity of 0.81 m/s (Amataj et al, 2007).

Figure 1.
Transboundary karst aquifer system Mali Thate-Galichitsa between connected Prespa and Ohrid lakes (blue dots are major springs, arrows show groundwater directions)

Source: Open Street Maps, own elaboration

The total area of outcrop of karstic rocks is about 810 km2. The total average discharge of all the springs and the sub lacustrine flow in Ohrid Lake is estimated at about 14.6 m3/s. The effective infiltration in karst massif is thus calculated to be about 55-62% of the precipitation, whose annual amount is 505-570 mm (Popovska and Bonacci 2007, Eftimi 2010). Although the water level of the Prespa Lake has been mostly stable from the 1950s until 1985, successive considerable decrease of the water level has been observed since then. It is currently 7 metres below its initial level (Fig. 2) with the extreme amplitude more than 9 m (Stojov 2020).

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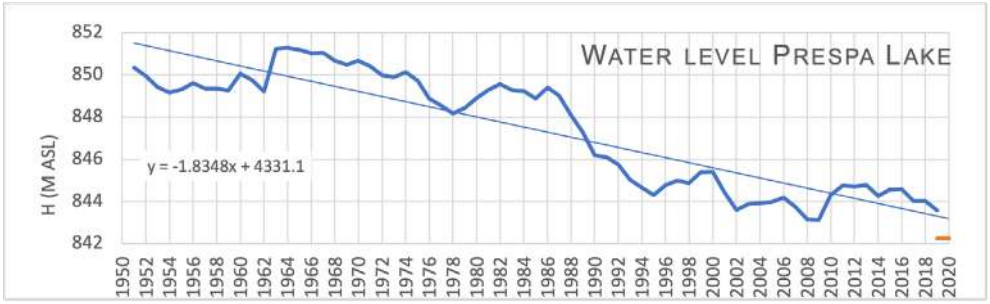
Figure 2.
Water level of the Prespa Lake during period 1950-2020 and decrease tendency since 1985 (after HMS N. Macedonia)



Source: Own elaboration

The lowering of the level of the lake has exposed the old dam-like construction which was built from stone blocks around the Zaver ponor. This construction probably dates back to the Roman times, and proves that, in the past, the level of the lake also used to be lower for certain periods of time, probably due to the cyclical character of the hottest climate conditions. The deficit of the water inflow to the Prespa Lake can be roughly calculated that is 1.7 m3/s.

There are various hypotheses for the current decline of the lake. Out of the three possible causes: geological, anthropological and climatic, it seems that climate variations and non-effective management of the water resources could be the main reasons. As a rising trend of air temperature and evaporation, and an insignificant lowering trend of precipitation have been confirmed, what is missing is, systematic observation of the pumping rate of lake water and groundwater used for irrigation in the three countries. It is thus necessary to establish a joint consultative water management body and an international water monitoring network. A proper monitoring of lake water and groundwater and exchange of essential information should be therefore included in the national water plans as a high priority.

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On the current movement of the intertropical convergence zone (ITCZ) in response to climate change and its impact on the management of transboundary aquifer systems (TBAS) in the Arabian Peninsula

Yusuf Al-Mooji[1]

The ITCZ is intimately connected to seasonal monsoon circulations and any response of the ITCZ to climate change will have implications for tropical regions (Byrne et al., 2018). During the early Holocene (11 000-8 000 yrs. B.P), there was a substantial increase of rainfall in the southwestern part of the Peninsula due to a northward displacement in the mean latitudinal position of the summer ITCZ and the associated summer monsoon rainfall belts. New evidence of an ongoing robust northward shift of the ITCZ over Africa and the Indian Ocean as a result of the current climate change, has been reported (Mamalakis et al., 2020). This new shift of the ITCZ is expected to impact significantly on the availability and management of freshwater resources in the Peninsula, particularly the TBAS.

Changes in the position of the ITCZ are presently going along with variations in rainfall intensity, and Byrne et al., 2018 summarized projections for future changes in ITCZ location, width, and strength using 32 state-of-the-art climate models from the Coupled Model Inter-comparison Project Phase 5 (CMIP5). Their analysis showed an overall northward shift with substantial zonal and seasonal heterogeneity. A new study using projections from 27 CMIP6 has also documented a robust zonally-opposing response of the ITCZ, with a northward shift over eastern Africa and the Indian Ocean and a southward shift in the eastern Pacific and Atlantic Oceans by 2100 (Mamalakis et al., 2020). These changes appear to be the result of zonally-opposing imbalances in the hemispheric atmospheric heating over the two sectors.

A northward shift of the ITCZ will affect both the NE winter and the SW summer monsoon seasons in Southern Arabia. In the summer, more monsoonal rains would fall over the Peninsula as it is swept by the ITCZ during its migration northward. During winter, the NE continental monsoon winds, which take up moisture while passing over the warm Arabian Sea and bring the largest annual winter rains will extend to the mainland as the ITCZ approaches the coastal areas of Oman and Yemen bringing monsoon rains and tropical storms from northern Indian Ocean. When the ITCZ continues to retreat southward during autumn, it's southernmost position in January would be further north than it is today. Hence precipitation over the Peninsula during the NE winter monsoon season would increase.

Rainfall increase across the Peninsula in recent years has been reported by several Saudi researchers and it is projected that the northward migration of the ITCZ will bring more rains into the area. This increase in rainfall is expected to have both positive and negative

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aspects from the groundwater management point of view. On the positive side, extensive TBAS spreading across the central part of the Peninsula will receive more recharge. On the negative side, there will be a significant increase in destructive heavy flash floods that can cause considerable damage and heavy losses of human lives. These floods descend from the highlands covering most of the southern part of the Peninsula onto the surrounding lowlands. A growing number of unprecedented and unusually heavy flash floods have been recently observed in major cities along coastal plains like Jeddah and Aden as well as hyper-arid desert areas such as Wadi Hadhramout in Yemen.

Hence it is recommended that a water resources management strategy for enhancing recharge of the TBAS across the Peninsula while minimizing the damaging effect of the flash floods at the same time has to be adopted through building recharge dams and flood conveyance systems. These structures are to be concentrated near the outcrop areas of the aquifer system in the catchment zones.

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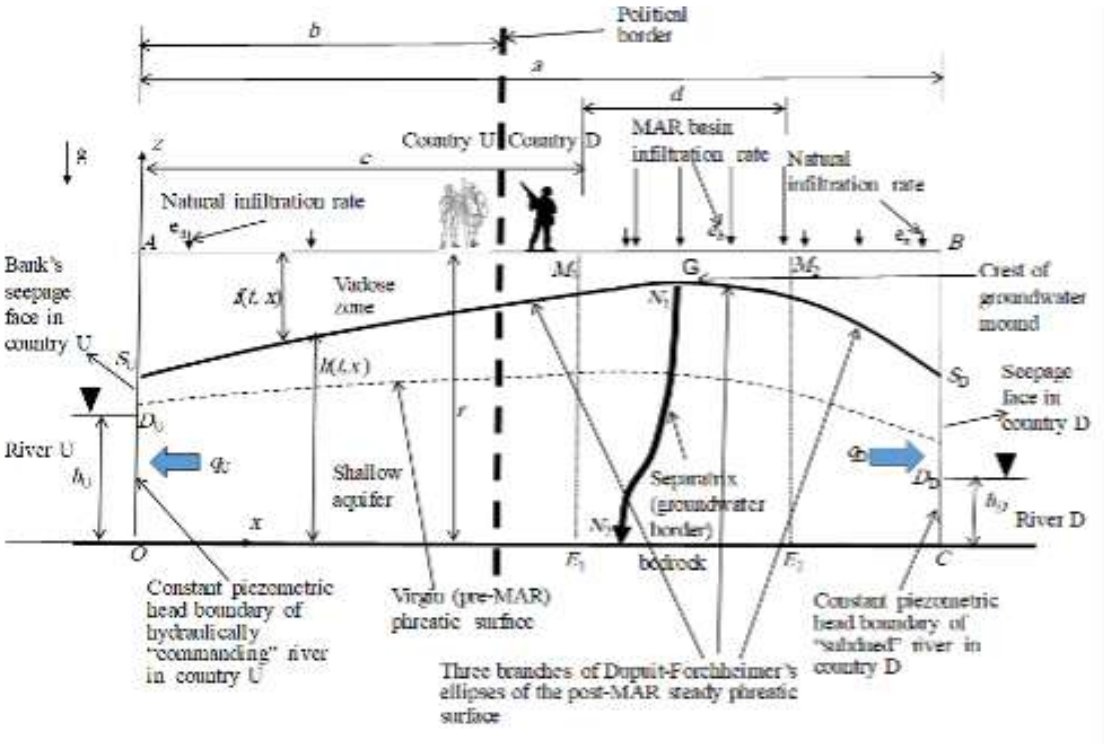
Optimization of MAR and demarcation of disputed groundwater storage/fluxes in a transboundary unconfined aquifer with natural accretion and smartly located infiltration basin

Anvar Kacimov[1], Jirka Šimunek[2]

Hydro-geopolitics is a new branch of hydrology, which revisits the legacy of VanDam, Haushofer, Brzezinski (among others) in applications to regional conflicts/litigations on sharing water resources (Eckstein, 2017). Below, a hydro-litigation game between Country U (hydraulically upstream River U) and Country D (downstream River D, parallel to U) is played using two models for Darcian seepage in an unconfined aquifer, which is based on a horizontal bedrock and sandwiched between the rivers.

Figure 1.



Cartesian coordinates are Ozx (Fig. 1), the distances between the rivers and demarcated surface border are a [m] and b [m], respectively. In the pre-MAR conditions, the rivers' piezometric heads are hU [m] and hD [m]. The water table elevation is h(t,x) [m] (a dashed line). The natural recharge from the vadose zone is en [m/year]. A porous medium (of thickness r=h(t,x)+f(t,x) [m]) is characterized by the pentad of van Genuchten's (VG) hydraulic parameters $(\theta_r, \theta_s, \alpha[1/m], n, K_s[\text{m/year}])$., 2018).

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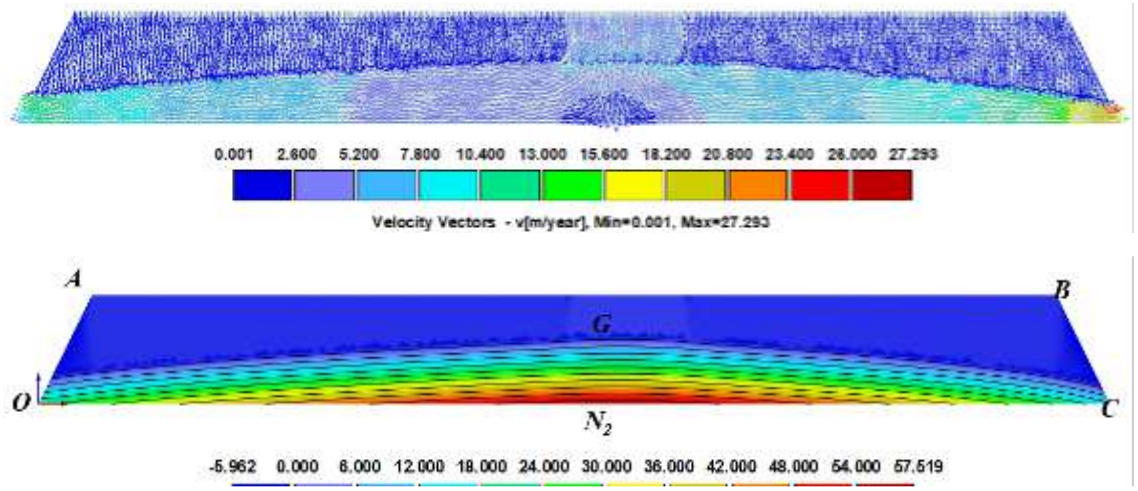
Both countries maximize the groundwater storage (quantified by the areas S1(t) and S2(t) [m2] under the "national" segments of the phreatic surface) and groundwater fluxes qU(t) and

qD(t) into their rivers. Let Country D construct a MAR infiltration basin located distance c [m] from rival's river. Basin's width is d=a-c [m], and a constant recharge rate is eb. The separatrix N1N2 is a streamline, which demarcates groundwater flow bifurcating to U and D. N1N2 is a curvilinear "dynamic hydrological border" between two subdomains of essentially 2-D seepage.

Figure 2.
illustrates the vector field of Darcian velocities, V(t,x,z), and pressure heads p(t,x,z), computed at t=50 years (HYDRUS-2D simulations conducted for 0<t<50) and the following decade of VG parameters:



= (1000 m, 100 m , 400 m , 0.2 m/y, 22.7 m, 13.6 m, 0.43-0.078, 3.6 m-1, 1.56, 91.1 m/y). At t=25 years (prior to MAR), the crest of the water table, G, and the stagnation point, N2, have coordinates (276 m, 22.5 m), and (230 m, 0), respectively. The infiltration basin M1M2 (Fig. 1) ads the triad (400 m, 100 m, 5 m/y). At t=50 years coordinates of G and N2 dramatically changed: (556.5 m, 57.5 m) and (540 m, 0).

Analytically, we used Dupuit-Forchheimer's model of a steady seepage, i.e., we formulated a boundary-value problem for the following ODE:

$$\frac{d^2F_s(x)}{dx^2}=\begin{cases}e_n/K_s, & 0\le x\le c,\ c+d\le x\le a,\\ e_b/K_s, & c<x_c\le c+d,\end{cases}$$

$$F_s(x)=\frac{h^2}{2},\quad q(x)=-K_s h\frac{dh}{dx}=-K_s\frac{dF_s}{dx},\quad F_s(0)=\frac{h_U^2}{2},\quad F_s(a)=\frac{h_D^2}{2}$$

where Fs is the Strack (1989) potential, and q is the comprehensive discharge. An explicit solution to (1) is used to find and optimize S1(50) and S2(50), compare them with HYDRUS results, and give recommendations for hydro-wars.

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Transboundary unconfined alluvial aquifers (Slovenia – Croatia)

Patricia Buškulić[1], Jelena Parlov[1], Zoran Kovač[1], Nina Rman[2]

Transboundary groundwater resources are very important sources of water for different uses and represent a significant role in some region, although monitoring and management are an major issue (Ganoulis, 2007). The Bregana – Obrežje (Slovenia) / Sava – Samobor (Croatia) aquifers were identified by the International Network of Water-Environment Centres for the Balkans (INWEB) inventory as transboundary aquifers. The Bregana – Obrežje aquifer is in hydraulic connection with upstream Krško and Čatež aquifers (Slovenia) and they extend along the Sava River from Krško to the Slovenia – Croatia national border. Sava – Samobor aquifer (or Samobor – Zaprešić aquifer) stretches from the national border till the Zagreb aquifer. Bregana – Obrežje aquifer covers an area of 4 square kilometers whereas Sava – Samobor aquifer covers 54 square kilometers. Those aquifers form a single hydraulic system, i.e. a transboundary unconfined alluvial aquifer system that spreads along the Sava River. These areas were formed in the same geological period by the same deposition mechanisms and they $(a,r,b,e_n,h_U,h_D,\theta_s-\theta_r,\alpha,n,K_s)$ are hydraulically connected by groundwater and surface water flows. Aquifers consist of Quaternary sediments mainly composed of sand and gravels with a very thin surface deposits. Sediments were deposited during the Middle and Upper Pleistocene (lacustrine-marshy deposits) and Holocene (alluvial deposits) (Velic and Saftic, 1991; Velic and Durn, 1993). Hydraulic conductivity of the aquifers varies from 0.002 to 0.043 m/s. Saturation thickness at low waters ranges from 2 to 10 m in the Slovenian part and from 4 to 42 m in the Croatian part, while during high waters it is 2 to 12 m in the Slovenian part and 4 to 46 m in the Croatian part. Sava River is in direct hydraulic connection with the aquifers and represents the main source of recharge. Fluctuations in the Sava River water levels dominantly influence the changes in groundwater levels. During high waters, the Sava River gives water to the aquifers, while during low and medium waters it drains the aquifers in some parts (Posavec, 2006). The exception is the northwestern area between Krško and the Nuclear power plant Krško, where the Krško aquifer discharges into the Sava River most of the year (Barešic et al., 2020). The general groundwater flow direction is from west to east or south-east, which coincides with the Sava River flow direction. Groundwater flow velocities vary from 8 to 28 m/day (conservative approach with an effective porosity value of 10%). The lateral boundary conditions of the aquifer system are inflow boundary in the north near Krško, no flow (impermeable) boundaries in the northeast and southwest, and outflow boundary near Podsused. Groundwater inflows, along the national border, fluctuate significantly and depend on hydrological conditions. The hydraulic connection between these aquifers exists during the lowest waters and it is never disturbed. Different problems arising in transboundary groundwater resources monitoring and management, such as lack of common monitoring systems, limited data sharing between neighboring countries, data interpretation, data modelling and a lack of political willingness for collaboration (Ganoulis, 2007). The significant detected problem is changes in groundwater levels

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in Zagreb and Samobor – Zaprešic aquifer. One of the major cause of lowering of groundwater levels is deepening of the Sava riverbed, influenced by construction of hydroelectric power plants on the Sava River upstream from the city of Zagreb, river regulation and gravel exploitation. The main goal is to set up a cooperative framework so that institutions from both sides can effectively work together and ensure effective monitoring and management of transboundary aquifers (Ganoulis, 2007).

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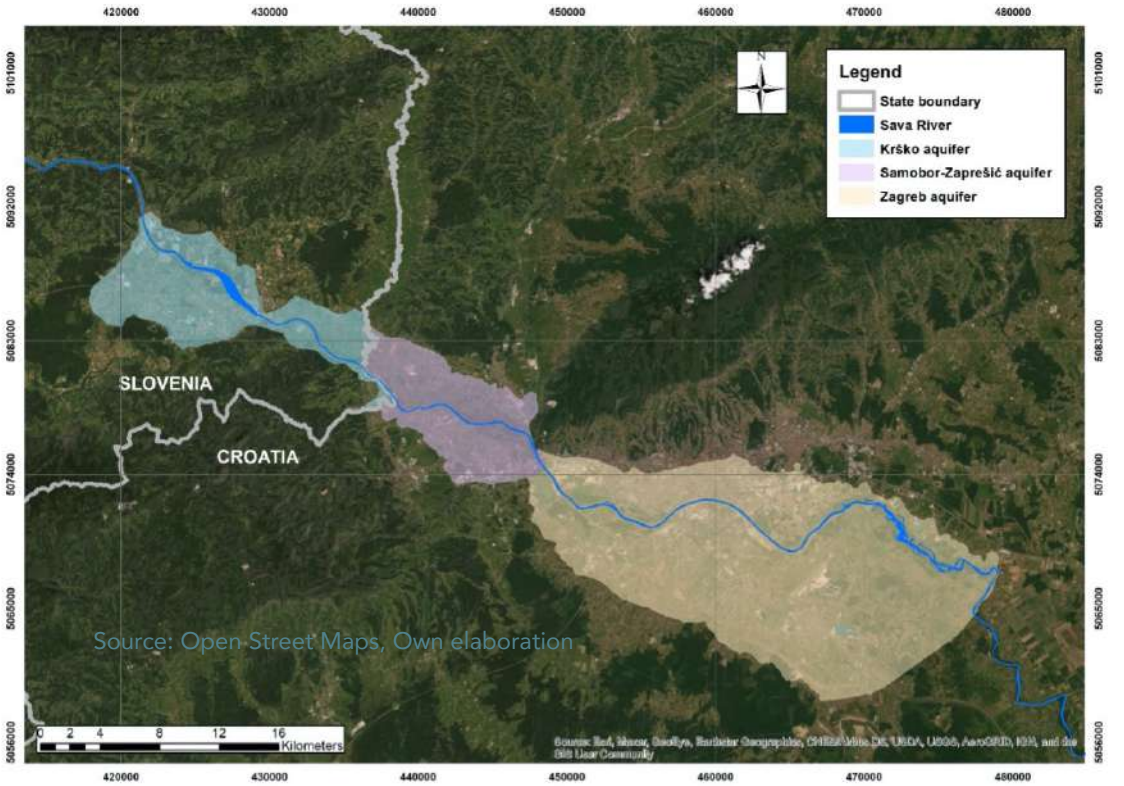
Figure 1.
The geographical position of the transboundary aquifers (Slovenia – Croatia)



Source: Open Street Maps, Own elaboration

Hydrogeological GIS-Mapping as a basis for information support of transboundary groundwater resources management

Oleg Podolny[1], Alexander Kuchin[1]

Groundwater resources of transboundary aquifers in Kazakhstan are part of the water resources of the water basin as an object of their management and protection. Such management is based on modern and constantly updated information support in the GIS environment. The basis of the GIS-system for the management of groundwater resources is a hydrogeological GIS-map.

There are many hydrogeological maps in Kazakhstan, including the Hydrogeological map of Kazakhstan in scale of 1:1,000,000. However, the use of these maps for subsoil and groundwater use management goals is difficult even for expert hydrogeologists for a number of reasons. The use of GIS in hydrogeological mapping enables expanding the possibilities of information supply for groundwater body management.

Such a map should provide a groundwater use specialist with information support of subsoil and water use management related to the groundwaters. This is achieved by filling the internal attributive database and the ability to connect to external databases and information systems upon requests.

For such purposes, the standard legend for hydrogeological GIS-map contains the following sections:

1. Hydrogeological units and their distribution over the area;
2. Hydrogeological zoning;
3. Groundwater well-fields, its exploitable resources, and their use purposes;
4. Water exchange characteristics;
5. Natural and technical groundwater objects (springs, water-wells, etc.);
6. Groundwater salinity and chemical compositions;
7. Schemes of hydrodynamic conditions of the transboundary groundwater flow

The basis of such a GIS map is a hydrogeological map, which is compiled on the basis of combining sheets of the state hydrogeological map on a scale of 1: 200000.

The main hydrogeological attributes - criteria for allocation of hydrogeological units – are as follows:

1. The type of permeability of an aquifer;
2. The value of hydraulic conductivity
3. The content of gravitational water in an aquifer;
4. Spatial variability of water-permeability and water content in rocks.

The main hydrogeological units of mapping on a scale of 1: 500,000 are aquifers, aquifer complexes, fractured aquifers, and aquitards. Sub-complexes and hydrogeological storeys can also be mapped in hydrogeological systems. The volume of the hydrogeological unit may correspond to the volume of the stratigraphic one, be part of it or cover several stratigraphic units. The boundary of the hydrogeological units may either coincide or not

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coincide with the boundary of the corresponding stratigraphic one.

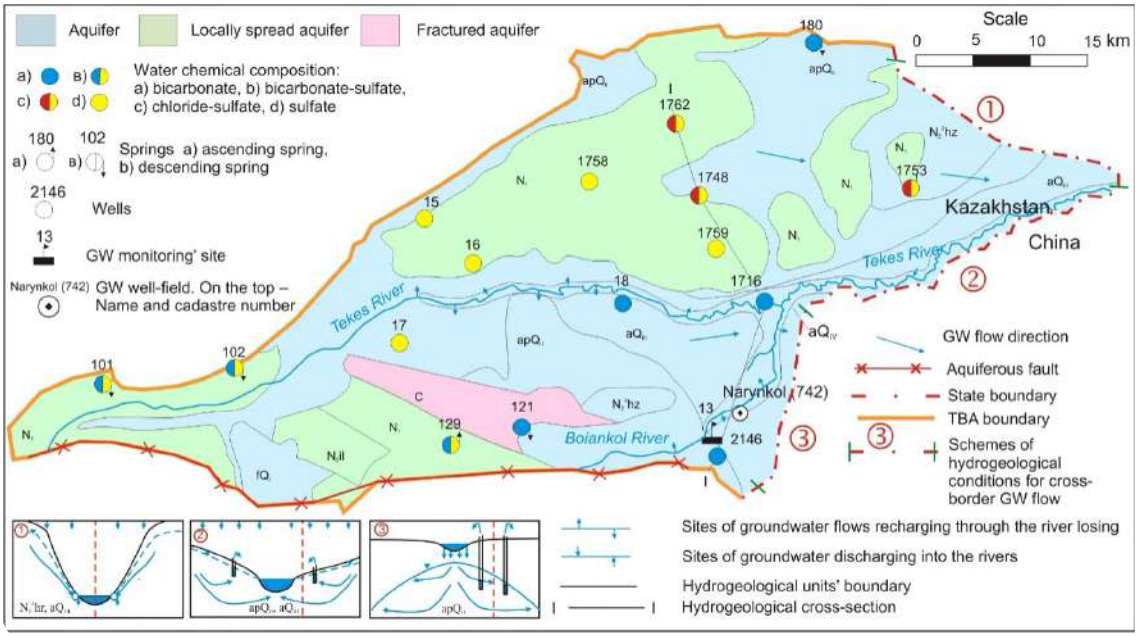
Hydrogeological units (aquifers, aquifer complexes, and aquitards) are shown with the solid colours or with the hachure of the specific form in accordance with the type of permeability and an aquifer conductivity rank.

The features of GIS-map compilation and functioning are illustrated with the example of the GIS-map of the transboundary aquifer in Kazakhstan (figure 1).

On the map legend 3 schemes show the conditions of the transboundary groundwater flow:

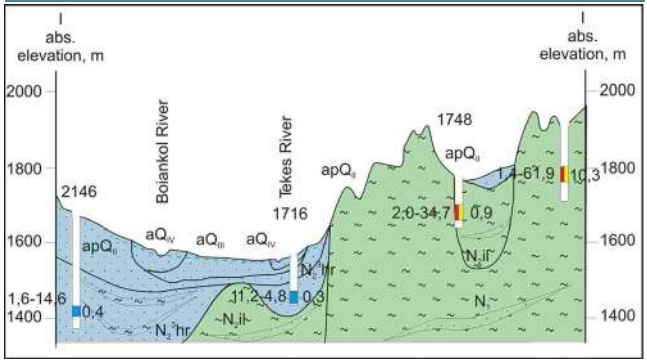
1. There is no transboundary groundwater flow.
2. The transboundary groundwater flow is directed towards the border from the river side. Polluted groundwater can reach a downstream neighbouring country.
3. The transboundary groundwater flow is directed towards the border from the main river valley. A groundwater abstraction will lead to a reduction of the groundwater flow. Removal of river runoff from the riverbed can lead to a reduction of groundwater recharge and transboundary groundwater flow through the state boundary

Figure 1.
Hydrogeological map of the Tekes TBA



Source: Open Street Maps, Own elaboration

Figure 2.
Hydrogeological cross-section I – I



Source: Own elaboration

Besides, the GIS-map enables displaying the hydrogeological cross-section in a separate window (figure 2).

Additional information necessary for managing groundwater resources in real time is displayed in pop-up windows by clicking a point of interest on the map.

Each point of the map contains information about a hydrogeological section. When clicking the hydrogeological unit of interest, the information about this unit becomes available. Such information will characterize only a part of the hydrogeological unit within a separate closed contour. That is, the information may be various in different parts of the spreading area of the hydrogeological unit. More complete textual attributive information about the hydrogeological unit is available in the "Geolink" option.

Groundwater well-fields are displayed by a sign in accordance with the designations of the State Groundwater Monitoring (SGWM) Data Base and placed at the point with the coordinates of the geographic center of gravity of the well-field. The well-field objects are created in the corresponding layer of the GIS-map as areal sites. Information about the well-fields is available in the "Information" window by clicking the corresponding line in the pop-up window.

Brief details about water points are available by clicking the conventional water point symbol in the "Information" pop-up window. Full information about hydrogeological wells (hydrogeological and technical sections of wells in .JPEG format) becomes available on the GIS-map by clicking the symbol of the well in the "Geolink" option. It is assumed that such a database of hydrogeological wells should contain complete information about all of them.

The offered map shall be a new useful tool for provision of a transboundary groundwater resources management at the basin level.

Groundwater quality in transboundary aquifers and the world water quality assessment

Neno Kukuric[1], Ralf Klingbeil[2]

In the last two decades, substantial progress has been made in the delineation and description of many transboundary aquifers (TBAs) across the world. Preliminary estimations of change of groundwater storage in some TBAs have been made as well. However, much less information has been collected and much less has been learned about the quality of groundwater in TBAs. The Transboundary Waters Assessment Programme (TWAP, 2012-2016), included an indicator-based baseline assessment of status and trends in almost 200 TBAs worldwide. Two indicators dedicated to Groundwater Quality (GWQ), namely Groundwater Natural Background Quality and Groundwater Pollution could not be sufficiently assessed due to lack of data, covering only 30 and 10 percent of TBA national segments, respectively. Yet, the TWAP has illuminated some processes, e.g. that a very low background GWQ is often the result of high impact from irrigation return flows in densely populated areas with low to medium natural recharge, such as the Nubian Sandstone and Indus TBAs. Apart from TWAP, there are very few studies dedicated to GWQ of TBAs, to mention a salinity mapping in Middle East (UN-ESCWA and BGR, 2013) and a nitrate issue analysis in the Abbotsford aquifer, shared between Canada and USA (Kidd 2002, Norman & Melious, 2004). GWQ assessment at the aquifer scale of a TBA is challenging for many reasons, starting with upscaling of point findings to an aquifer level. Further, GWQ usually changes not only with depth, but also with time. Accordingly, a possible travel time to the border between two aquifer states needs to be included in the TBA assessment. Differences in national legislations and in monitoring/sampling procedures make the assessment of the qualitative state of a TBA even more complex. The Friends of Groundwater (FoG), a network of about 30 global groundwater experts representing 20 institutions and organizations, prepared a perspective paper "Assessing Groundwater Quality: A Global Perspective. Importance, Methods and Potential Data Sources". The paper is prepared in the framework of the World Water Quality Assessment (WWQA) initiative led by UN Environment (UNEP). This baseline document for the global assessment also addresses specifics of TBAs, in particular comparable standards for the aquifers, data sharing and joint capacity development programmes. Some progress has been made in standardization within the European Union, although the European concept of Groundwater Bodies does not provide much guidance on possible transboundary impacts. Moreover, the priorities regarding transboundary GWQ assessment could differ per region. Therefore, the work of the FoG https://groundwater-quality.org/ within the WWQA initiative should be allied with activities of ISARM programme and the IAH Commissions on Transboundary Aquifers and on Groundwater Quality.

1 IGRAC
2 IAH

The complex Yarmouk transboundary water resources

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The Yarmouk River is the primary tributary to the Jordan River and a strategic transboundary freshwater resource of Syria, Jordan, and Israel. In the past decades, the Yarmouk watershed has been extensively exploited by the riparian with the construction of dams including the Al-Wehda and Adassiyeh dams, situated along the Jordan border and intended for agricultural purposes. The operation of the dams is guided by international water agreements between Jordan and Israel and Jordan and Syria and control the flux of the Yarmouk River. Repeated sampling over 16 years revealed variable flow paths towards certain wells over time as documented by variable REE-pattern and ?18O, ?D and 87Sr/86Sr signatures of groundwater and lead to new insight with respect to sources of groundwater, their flow patterns and salinization in the Yarmouk basin. The conjoint interpretation water table fluctuations indicate unexpected interactions of the river with the major groundwater resources of the entire region. 2D transient numerical simulations of coupled fluid flow and heat transport processes are used to investigate the impact of (i) a zone of hydraulic anisotropy and (ii) abstraction on hydraulic heads and temperature profiles in the shallow aquifers. The models successfully reproduce hydraulic head distribution pre- and post-groundwater abstraction and it shows the dominance of conductive and advective heat transport processes. The models further support the existence of a structural feature along the principal axis of the gorge, which hydraulically connects groundwaters in both flanks, while cross flow of groundwaters is prevented. That implies a subsurface anisotropic zone, which lets the gorge act as a complex conduit-barrier system where adjacent N-S and S-N flow-fields confluence and get drained towards the Jordan Rift. The present numerical investigations support the hypothesis that, most likely, structural features that represent physical anisotropies control the hydrothermal system of the LYG. Furthermore, the study provides an example of numerical investigation of a complex transboundary aquifer system, with emphasis on existent anisotropies, structural ambivalence and restricted field accessibility. Optimization of both dams and groundwater pumping operation has the high potential to increase the availability of freshwater in the area for many years.

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Trend analysis applied to the Guarani aquifer water storage variability using satellite and ground-based observations

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Guarani is a transboundary aquifer is one of the world's largest aquifer systems, located beneath the surface of Brazil, Paraguay, Argentina and Uruguay, encompassing 1,182,000 km2. Since 2010, the Brazilian portion of the aquifer has been monitored at 39 wells by Brazil's Integrated Groundwater Monitoring Network (RIMAS), partially characterizing the aquifer's recharge zone. On the other hand, numerous studies show that terrestrial water storage (TWS) variability derived from the Gravity Recovery and Climate Experiment1 space mission (GRACE/NASA) can be an important source of information to characterize transboundary aquifers worldwide. The objective of this study is to integrate RIMAS, GRACE and Global Precipitation Measurement2 (GPM/NASA) rainfall data to characterize Guarani's spatiotemporal groundwater level variability.

The methodological approach includes the application of the following statistical tests to the Guarani aquifer specially highlighting the 2010–2020-time span: Mann-Kendall; Sen and Pettitt. The Mann-Kendall3 statistical test used to assess the significance of trends in the time series under study, being very appropriate for analyzing possible changes in time series. The test indicates whether the data series has an increasing, decreasing trend or not. Sen's4 statistical test used to estimate the magnitudes of the trends observed in the data sets. Finally, the Pettitt5 test is used, based on classification and used to detect points of change present in data series.

The results shows Sen-RIMAS and Sen-GRACE are well related, with slope RIMAS -0.35 to 0.86, GRACE -0.67 to 0.42 and GPM -1.0 to 1.8, showing a delay in the wells' responses when compared to TWS. This delay is expected since TWS signals also include "faster" water storages (i.e., surface water storage and soil moisture). The Mann-Kendall test identifies differences in spatial and temporal relationships among RIMAS, GPM and GRACE data, with greater proximity between RIMAS and GRACE, also indicating a delay in terms of groundwater level results. The Pettitt results show a TWS discontinuity in 2010 over the central part of the aquifer, as well as a trend change, from no trend to a positive trend regime, reflecting a TWS increase in the region. A positive trend is also observed in RIMAS measurements. However, wells located near urban areas show decreasing tendencies, which could be explained by groundwater exploitation. It is noteworthy to mention that this is the first ever effort made to jointly evaluate consisted RIMAS data with gravimetric and rainfall satellite datasets in Brazil. Figure 1 show the results.

The three datasets used, RIMAS, GRACE and GPM indicate the variability of water storage in the study region. As a limitation of the work the non-use of surface water data (faster GRACE storage) stands out, which can lead to different storage responses not being detected by the in-situ monitoring points concentrated in the aquifer recharge areas.

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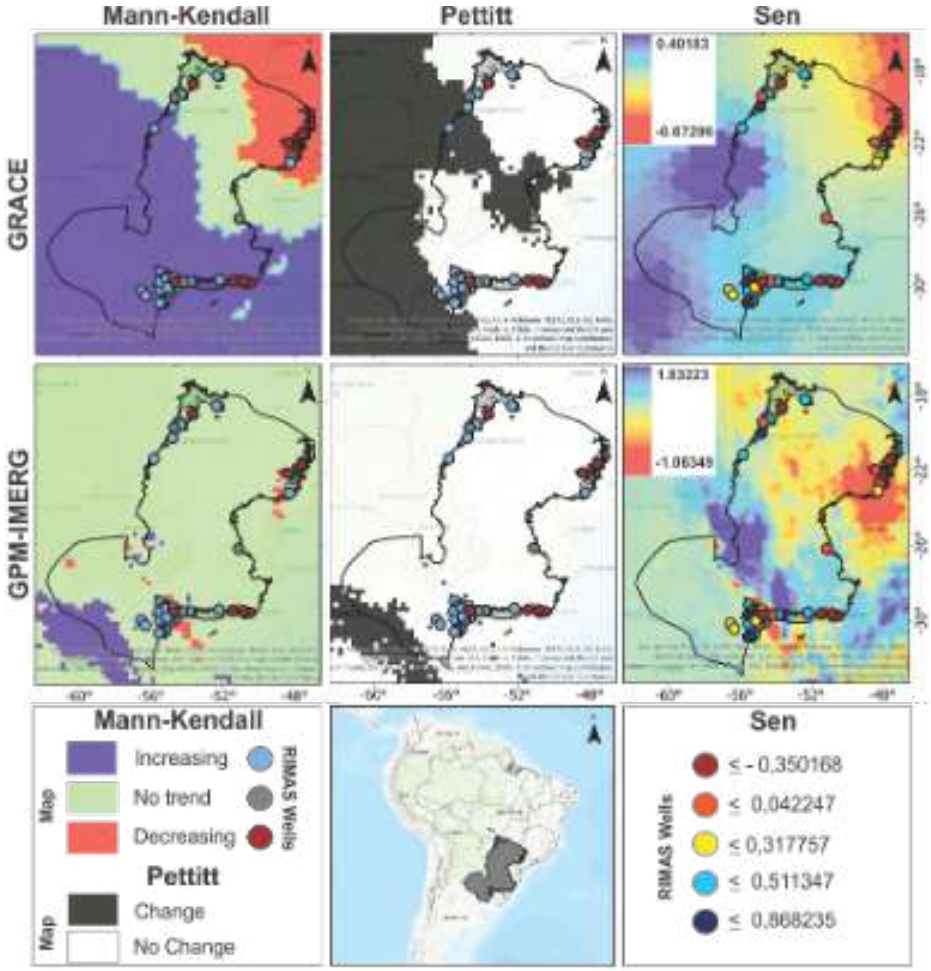
The work shows that the aquifer recharge areas can indicate the behavior of the confined area, however, the existence of other reservoirs on the Guarani aquifer should be taken into account, such as the Bauru-Caiuá aquifer that covers the north-central part of the study area. For future work, integrated groundwater and surface water studies and static level measurement analysis of confined areas of the Guarani aquifer are recommended.

Figure 1.
The Guarani aquifer. Results of statistic tests Mann-Kendall, Pettitt and Sen for RIMAS, GRACE and GPM data. In central figure the RIMAS wells shows Mann-Kendall results.



Source: Open Street Maps, Own elaboration

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Impacts of anthropogenic activities on groundwater quality in the Ouémé River Delta (Southern Benin)

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The study area is the Ouémé River Delta located in the south of Benin's coastal sedimentary basin. This hydrogeological basin is part of the Keta Basin which covers Ghana, Togo, Benin and Nigeria. The economic development of the study area is essentially based on agriculture, fishing and livestock farming, which constitute the potential sources of groundwater degradation. In addition, the expansion of industrialization and urbanization is noted, especially in the large cities (Cotonou, Porto-Novo, Sèmè-Kpodji and Abomey-Calavi) in the Delta. Indeed, population growth and the development of urban areas, cultivated land and industrial units have led to a deterioration of groundwater quality, which represents the resource used for water supply to the populations of the Ouémé River Delta. The study of the physico-chemical characteristics of groundwater through wells and boreholes in the Ouémé Delta, which are subject to various anthropogenic activities, shows that the quality of its water is variable and depends on a number of factors such as population density, land use and the location of water catchment facilities relative to wastewater discharge points, waste dumps and agricultural activities. The interpretation of the analysis data, the existing correlation between the water points and the various surrounding activities and structures, and the distribution of groundwater in groups are carried out using the Normalized Principal Component Analysis with R software. The study revealed different origins of groundwater contamination, namely, contamination by organic matter due mainly to the leaching of household waste dumps and their continuous infiltration, and finally the infiltration of water (loaded with nitrogenous fertilizers) which is considered to be the main origin of mineralization and water pollution. The hydrogeological and hydro chemical studies of the aquifer system of the Ouémé Delta have been able to provide us with the necessary data to define the risk caused by pollution. The resolution of Fick's second law, under the boundary conditions defined, allowed the estimation of the propagation of the nitrate pollutant (NO3-) in the groundwater. Several factors condition the progression of this pollution : the concentrations of pollutants in the wastewater, the nature of the soil, the lithology, the permeability of the exploited aquifer and the depth of the water table. The results obtained in this study also reveal the primordial influence of seasonal variations, as well as the role of precipitation.

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Understanding the hydro stratigraphic architecture of the Ganges River delta and its control on groundwater arsenic distribution

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The Ganges River delta aquifer system is a prolific transboundary aquifer system shared between India and Bangladesh that serves as the principal source of domestic and irrigation water needs for the densely populated settlements within the delta. However, widespread occurrences of toxic levels of arsenic (As) have been reported from the delta groundwater. Although numerous studies have attempted to understand the As dynamics of the delta, efforts to delineate the hydrostratigraphic architecture of the delta aquifer system and its control on groundwater As occurrences on a regional-scale are still lacking. This study aims to delineate the high-resolution regional-scale transboundary hydrostratigraphic architecture of the Ganges River delta and evaluate the control of delta hydrostratigraphy on the spatial distribution of groundwater As within the delta.

Figure 1.
a) Digital elevation map showing the extent of the study area within the Bengal basin

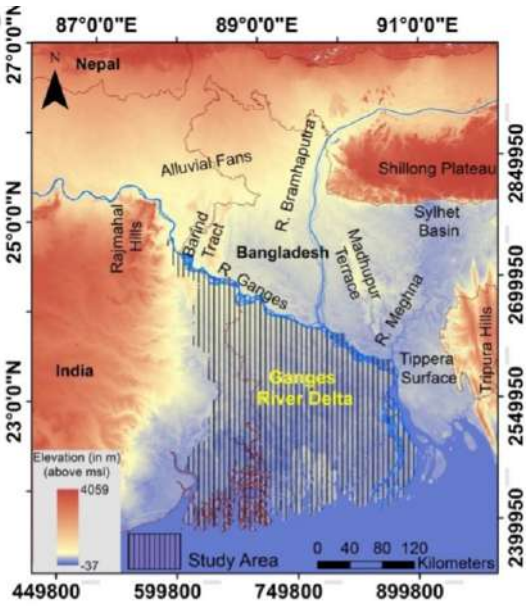

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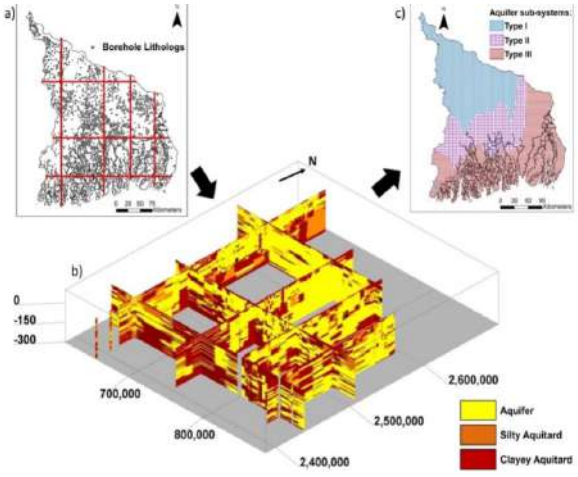
Figure 2.
(a) Map showing the lithological sections corresponding to figure 2(b) and distribution of the boreholes used for the hydro stratigraphic model (b) fence diagram showing the hydro stratigraphic framework of the Ganges River delta (c) map showing the aquifer sub-systems, as classified from the hydro stratigraphic model



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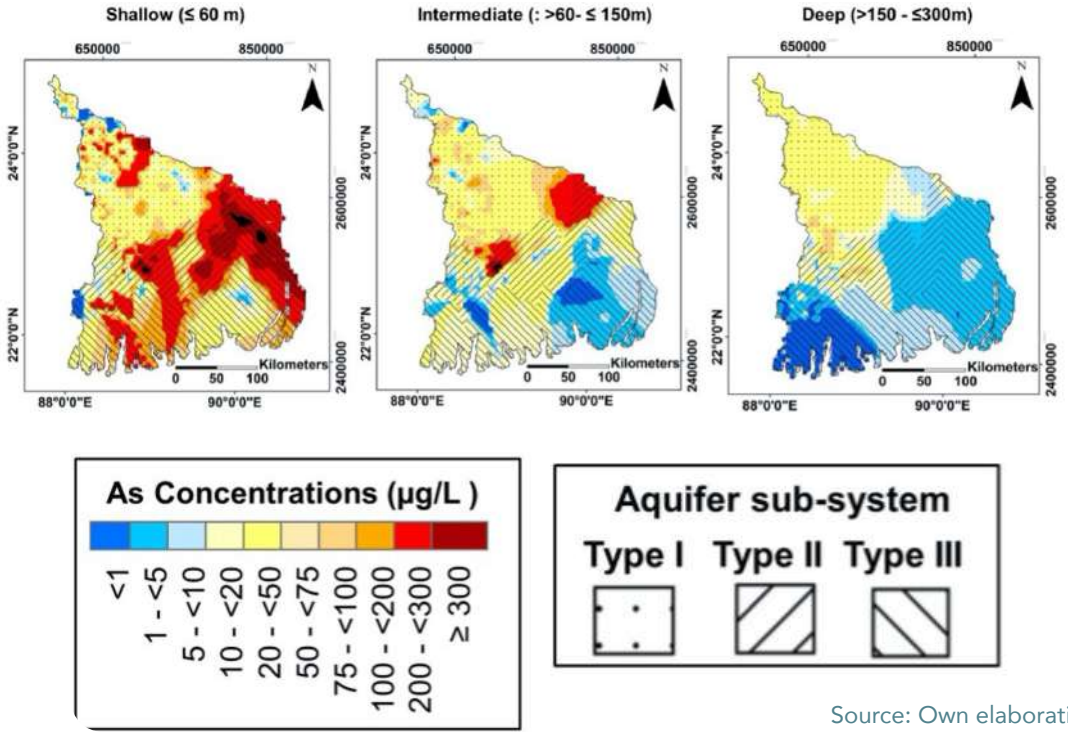
In this study, lithologic data from a total of 3112 georeferenced boreholes from both India and Bangladesh were used to develop a regional-scale hydrostratigraphic model of the Ganges River delta aquifer system upto a depth of 300 below mean sea level (msl) using RockWorks 17 (RockWare, Golden, CO, USA). Results indicate that the delta aquifer system is made up of a main aquifer complex that is overlain by a discontinuous surficial aquitard and underlain by a basal aquitard. The main aquifer system shows progressively increasing intercalation of discontinuous aquitard lenses to the south based on which the delta aquifer system has been classified into three sub-systems. To the north, the Type I sub-system is marked by a single, continuous, largely unconfined aquifer. The Type II sub-system is transitional between the Type I aquifer sub-system to the northwest and the Type III aquifer sub-system to the south and west and is characterized by vertically segregated semiconfined aquifer units with restricted hydraulic connectivity. The Type III aquifer system along the active delta mouth is marked by a horizontally stratified, multilayered and largely confined aquifer system, with extremely poor hydraulic connectivity among individual aquifer units.

Figure 3.
(a) Map showing the lithological sections corresponding to figure 2(b) and distribution of the boreholes used for the hydro stratigraphic model (b) fence diagram showing the hydro stratigraphic framework of the Ganges River delta (c) map showing the aquifer sub-systems, as classified from the hydro stratigraphic model



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Statistical analyses based on a dense (n=100358) network of groundwater As data points assimilated from various governmental databases indicate that the depth distribution of As is a function of the delta hydrostratigraphy. The unconfined aquifer the north (Type I) exhibits largely homogeneous As concentrations across all depths which is possibly a manifestation of uninhibited mixing of groundwater as a result of relatively large vertical gradients in the absence of intervening low-permeability units. Under deep irrigational pumping conditions, these aquifers are most susceptible to As mobilization/inflow by

infiltration of As or organic-matter-rich waters from the surficial layers. On the other hand, in the Type II sub-system the As concentrations decline substantially with increasing depth, and in the Type III sub-system the decrease is even more pronounced. These results indicate that low vertical connectivity in Type II and Type III sub-systems restricts the infiltration of shallow As or organic-matter-rich waters into the intermediate and deep aquifer units. Thus, the aquitards in these regions serve as a natural buffer against As contamination of deeper aquifers (Hoque et al., 2017). However, because these aquitards are not continuous across the delta, sustained deep irrigational pumping over a period of time would possibly generate focused vertical inflow through the windows where these aquitards are absent jeopardizing the sustainability of the As-safe intermediate and deep aquifers of the Type II and Type III sub-systems.

Contribution to the hydro chemical study and water recharge area of the Nekor basin aquifer (northern Morocco)

Nouayti Nordine[1], Driss Khattach[2], Abdrrahime Nouayti[3], El Khalil Cherif[4], Mohamed Hilali[5]

Summary The availability of groundwater in acceptable quality has become a difficult challenge in many regions of Morocco and more particularly in the region of the Nekor basin (northern Morocco) because of the severity of the climate and pollution (domestic, industrial , agricultural) which weakens and makes these waters vulnerable to various factors. The objective of this work is to assess the physico-chemical quality of groundwater in the region of the Nekor basin (northern Morocco) which presents great structural and lithostratigraphic complexity. To study and compare the spatial distribution, these results are presented in the form of aesthetic maps using the Geographic Information System (GIS) for the processing and statistical analysis of data from various sources (geology, geomorphology, hydrology, hydrogeology, geophysics …) Spatially referenced. The objective of this work is to determine the recharge zone and to assess the quality of groundwater in the region of the Nekor basin (northern Morocco) and to determine the quality of the water as well as the sources of pollution to establish a cartography of qualities of the aquifers and give stakeholders in the agricultural and industrial sector ... carrying out future projects in this region a concrete idea of the quality and characteristics of these aquifers. The use of GIS has enabled us to highlight complex links between different types of data.

Materials and Methods

Study Area

The Ghis-Nekkor aquifer covers an area of 100 km2 (Figure.3).and is located in the province of Al Hoceima, in the north of Morocco. It is delimited to the north by the Mediterranean sea and to the Southwest by the Dam Mohammed Ben Abdelkrim Al Khattabi (SMBA Al Khattabi)(Salhi, 2008).

Methods

A total of 20 wells representatively distributed to cover the entire aquifer of Ghiss-Nekkor were selected for the sampling campaign of january 2021 (Figure.1). In every well, two samples, one liter each, were taken in polyethylene bottles.

Physico-chemical parameters such as pH, Temperature, Electrical Conductivity (EC), Composite Alkalinity (TA) and Total Alkalinity (TAC) were measured in-situ using a multiparameter probe. While major cations and anions in the laboratory. The isotopic analysis concerned only 8 samples among the total 20 selected sites.

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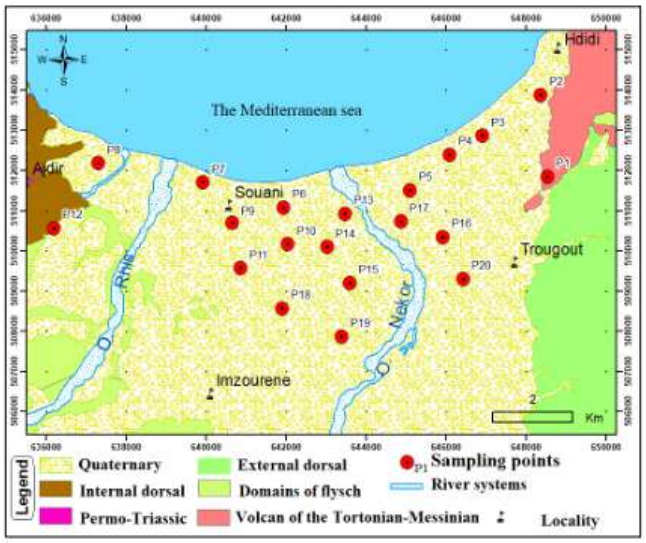
Results and Discussion

The analysis and interpretation of the results revealed that groundwater sample had temperatures between 17 °C (Well 4) and 28 °C (well 12), with an average of 23 °C. The temperature of groundwater samples is similar to the air temperature in the study area, due to the shallowness of the sampled aquifer. These values are typical in cold hypothermal water, reflecting the seasonal increase in temperature.

Analysis of these waters revealed that the pH is close to neutrality, at all water points, the values of the pH are between 7.3 (well 1) and 8.21 (well 7), indicating a neutral or slightly alkaline nature of groundwater in the plain of Ghis - Nekor.

The mineralization in the sampled water increases from south to north with values between 2596 and 6380 mS/cm. The important values result from the leaching of the aquifer material and the influence of marine intrusion.

Figure 1.
Study Area Geological map with location of the Ghis-Nekkor Aquifer and distribution of the sampling points.



Source: Open Street Maps, Own elaboration

Conclusions

This study presents the results of several isotopic tools in an attempt to reveal the origin of recharge water, the physico-chemical quality and origin of carbon in groundwater resources of the Ghis-Nekor aquifer in north Morocco.

The data revealed a complex hydrogeological system, such as the analysis and interpretation of the results allow us to conclude the following results:

- the results show that these waters belong to tow chemical facies:calcium chloride facies, a sodium chloride facies;

-the majority of the wells sampled indicate high values of electrical conductivity and total salinity which arrives between 2596 and 6380 mS / cm.

Hydrogeology and groundwater modeling of Middle Darb El Arbaein, South Western Desert, Egypt

Mohamed ElKashouty[1,2]

Darb El Arbaein area acquired its name from the old Darb El Arbaein Route (Fig. 1a). Darb El Arbaein means the forty days Route. The General Authority for Rehabilitation Projects and Agricultural Development (GARPAD) create a new community based on agricultural practices. In middle Darb El Arbaein, the groundwater is considered the actual source of water for agricultural and domestic purposes in the study area. The annual average precipitation is ≤ 5 mm/year. The mean monthly maximum temperature varies between 13.1 oC in January and 39.3 oC in July (Zamzam and Ali 2008). The main objective of this dissertation is to identify the changes in piezometric heads and TDS concentration of Nubian aquifer within different periods. The aquifer modeling was applied to select the best promising areas for groundwater exploration and exploitation. The ARCGIS aquifer model can be applied individually or used in sequence to model and analyze groundwater flow. The ARCGIS model uses spatial distribution of the hydrogeological parameters of the Nubian aquifer.

Proposal of one or multiple solutions

The hydrogeological and hydrogeochemical data are collected within different periods (2000, 2005, 2007, and 2012) from published dissertation. They gathered, analyzed, contoured, and interpreted. The hydrogeological data were fed into the ARCGIS model to estimate the groundwater volume balance residual, the groundwater seepage velocity vector (direction and magnitude) for steady flow (Fig. 1b). The available two ETM+ (Enhanced Thematic Mapper Plus) imagery was acquired by Landsat-8.The geological map scanned and geo-referenced according to coordinates of satellite images and digitized different rock units. The digitized different geology is valuable data for the supervised image classification accuracy assessment (Maximum Likelihood (ML) classifier). Envi 5.1, Erdas 2014, Global Mapper 16, and ARCMAP 10. 2 were used.

Results and discussion

The total drop in piezometric head within 2000 and 2012 periods was maximum (21-50 m) (Fig. 2a) by low transmissivity and hydraulic conductivity aquifer parameters. The total increase in TDS concentration within 2000 and 2012 periods ranged from (12-148 ppm) in the northwest to (543-800 ppm) due southwest (Fig. 2b). The pumping rate (180-250 m3/h) and low to very low hydrogeological properties (hydraulic conductivity, < 3 m/d), high evaporation, dissolution of geomedia, groundwater flow, all contributed to increase in TDS concentration in groundwater with time. The hydraulic conductivity, drawdown, transmissivity, effective porosity, and saturated thickness rasters are reclassified in ARCGIS model according to potentiality contribution to the aquifer. The best promising area was in the southwestern and northeastern parts (Fig. 3a) due to the lowest drawdown and good hydrogeological parameters. The total invested area was 33.2 km2 in Middle Darb El Arbaein, while the real irrigated area was 0.54 km2 per each central zones of the borehole as estimated by GIS model (Fig. 3b). The total watered area was 0.54 * 27 (no.

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of wells) equals 14.6 km2. The previous increase in TDS concentration in groundwater within 2000 and 2012 (12 y) was accompanied with watered area about 14.6 km2.

Conclusion

The historical reviews of TDS and potentiometric level fluctuation were determined within different periods. The total increase in TDS concentration within 2000 and 2012 periods ranged from (12-148 ppm) to (543-800 ppm). The groundwater modeling determines the average linear velocity, which ranged from 2 * 10-7 to 1.1 * 10-3 m/d, which caused by low hydrogeological parameters. The aquifer modeling clarifies the southwestern and northeastern parts were the best promising areas for aquifer exploration and exploitation.

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Figure 1.
Geology (a) and flow chart of the ARCGIS model of Nubian aquifer (b).

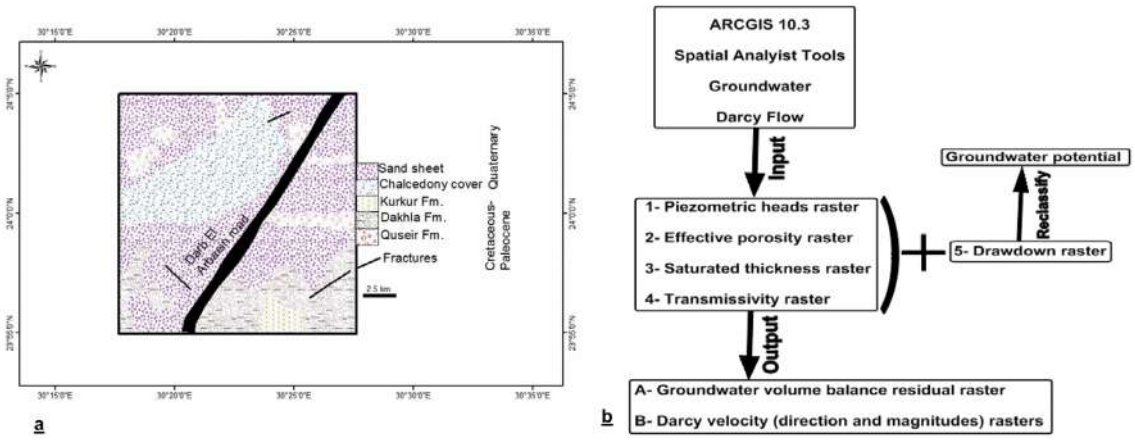

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Figure 2.
Potentiometric head and TDS drop within 2000 and 2012 periods

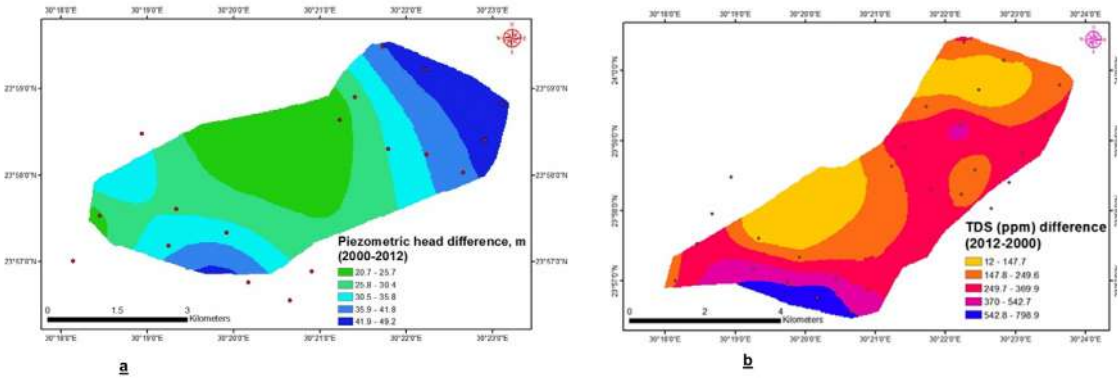

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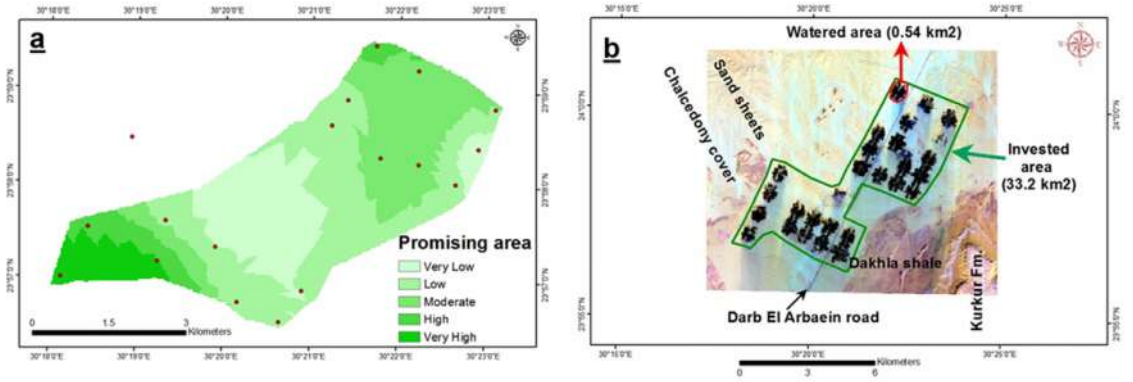
Figure 3.
Promising area (a) and remote sensing (b) of Middle Darb El Arbaein.



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International law of transboundary aquifers: prospects and opportunities for mutual cooperation of West African aquifer systems

Sessinou Emile Houedanou[1]

Transboundary aquifers are an indispensable natural resource for life, people, and ecosystems. The socio-economic and environmental challenges related to the management of aquifers or aquifer systems have increased considerably. The impacts of anthropogenic activities can be detrimental to groundwater. Hence the need to identify the legal status of such transboundary groundwaters. The basic rules applicable to transboundary aquifers can be clearly identified and reduced to two substantive rules: the principle of equitable and reasonable utilization and the principle of not causing significant harm to neighboring countries. To this must be added the obligation to cooperate which consists of a set of procedural requirements. These three basic principles of international water law together with the other rules form an integrated set of substantive and procedural obligations that apply to all aquifer States either under specific treaty provisions among the States concerned or under customary international law. In the region, the legal framework applicable to transboundary water resources remains sectoral, fragmented, and piecemeal and not specific to aquifers, thus undermining the sustainable, equitable and reasonable management of transboundary waters. Moreover, the existence of a range of multilevel institutions involved in their management creates unnecessary and inefficient overlapping responsibilities. Therefore, the adoption by the seven States of the Iullemeden-Taoudéni-Tanezrouft aquifer system of the Memorandum for the Establishment of a Consultative Mechanism for Integrated Water Resources Management of the Iullemeden-Taoudéni-Tanezrouft Aquifer System (ITTAS) in Abuja in 2014 is of interest for the construction of a regional law on transboundary aquifers. The adoption of common management principles enables States to manage and protect the SAIT as a resource of common interest in a transparent and equitable manner, while being convinced and aware of their role as custodial States of this resource for present and future generations. To this end, the SAIT States should also establish a permanent International Joint Commission with a mandate to manage and protect the SAIT. Finally, the mutual cooperation of the Iullemeden and Taoudéni-Tanezrouft system can be consolidated by specific protection measures such as ecosystemic management of transboundary aquifers, the information and monitoring system, the water education programme to form an environmental awareness and protection of water resources.

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Identification of groundwater potential zones by combining remote sensing and multi-criteria decision analysis in the Ghiss Basin, Central Rif of Morocco

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1. Introduction

Surface water scarcity and the ongoing over-exploitation of groundwater in the Al Hoceima region, a semi-arid area which suffers from consecutive years of drought, require urgent intervention to confront the potential shortage of water resources in the near future. Mapping groundwater potential zones (GWPZ) to explore further groundwater resources can be an efficient way for a wiser water management in the Ghiss basin. The traditional methods used for this purpose are deemed to be expensive, exhausting, and limited in space (Aykut, 2021). However, geospatial tools namely Geographic Information System (GIS) and Remote Sensing (RS) are rapid, inexpensive, and spatially extensive. Many authors have noted the high reliability of the outcome when using geospatial tools, especially in combination with Analytical Hierarchy Process (AHP) (Adeyeye et al., 2019; Arulbalaji et al., 2019). Thus, this work aims to delineate GWPZ in the Ghiss basin for a better understanding of the groundwater distribution in the basin. To this end, eleven factors that most affect groundwater occurrence were employed (Lineament Density, Lithology, Drainage density, Land Use/Land Cover, Elevation, Curvature, Slope, Topographic Wetness Index (TWI), Topographic Position Index (TPI), Roughness, and Rainfall).

2. Materials and methods

To map the GWPZ in the Ghiss basin, 11 thematic maps were prepared from factors most affecting the occurrence of groundwater, using ArcGIS, Geomatica and RS data (Figure 5). The factors were weighted using the Pairwise Comparison Matrix (PCM), a method of Analytical Hierarchy Process (AHP) developed by (Saaty, 1980). These factors have been compared using Saaty's relative importance scale. The consistency ratio (CR) was calculated in order to test the consistency of the PCM, and the result showed an acceptable consistency (CR=0.099). Then, the subclasses in each factor were assigned using an evaluation scale of 1 to 9. Afterwards, to obtain the GWPZ map we used the "weighted overlay" tool to overlay the eleven generated maps based on the equation below:

$GWPZ = \sum_i^n (X_A \times Y_B)$ (X) is the weight of the factor (A), and (Y) is the rank of the factor's subclasses (B).

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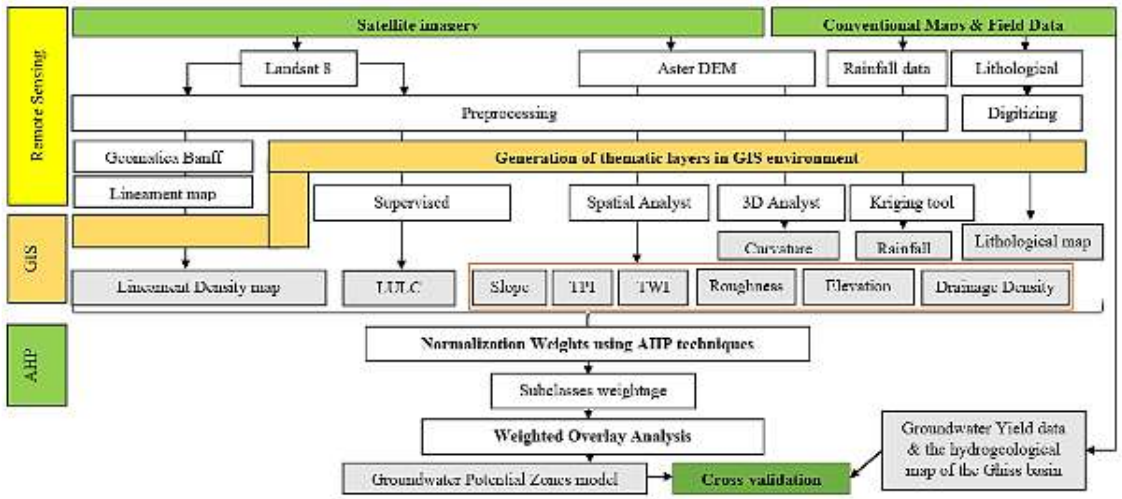
Figure 1.
Flowchart of the methodology used in the present study.

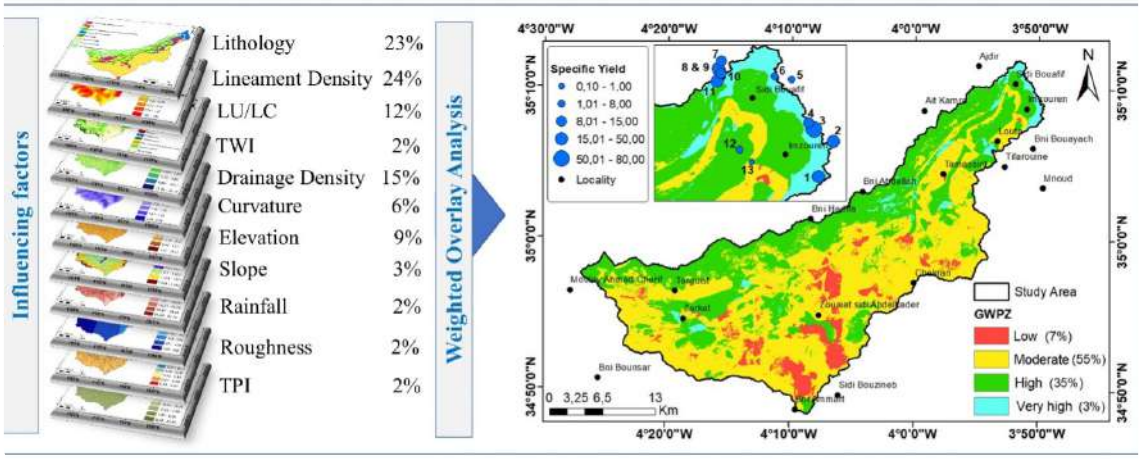


3. Results and Discussion

The final map (Figure 6) showed four categories of GWPZ in the Ghiss basin: low, moderate, high, and very high, covering 7% (58.59 km²), 55% (460.35 km²), 35% (292.95 km²), and 3% (25.11 km²) of the total area (837 km²), respectively. The high groundwater potential on the obtained map matches with locations of high lineament density, low and middle elevation, low slope and roughness values, and with those comprising modern alluvium, conglomerate, sandstone, and silt.

The validation of the results was processed by comparing the obtained model with : 1. the groundwater yield data of eight boreholes, two wells, and two springs measured in the Ghiss plain (the comparison showed a good concordance) and 2. the official hydro-geological map of the Ghiss watershed. The comparison has shown an acceptable conformity of the field data with GWPZ map of the Ghiss basin.

Figure 2.
Influencing factors and GWPZ Map; accompanied by groundwater yield in the Ghiss plain : 1, 2, 3, 4, 5, 6, 7, 10 and 11 represent boreholes; 8 and 9 represent wells, while 12 and 13 represent Springs.



Source: Own elaboration

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Identification of Transboundary aquifers in Afghanistan: way forward to a regional sustainability development

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Groundwater is critical for supporting socioeconomic development, but in the recent decades it has experienced gradual decrease in the potential due to climate changes, raped population growth and modernization of human lifestyles throughout the world. In the recent years, the utilization from transboundary groundwater resources globally has received extensive attention. Because transboundary aquifers do not follow geographical borders but it is concealed. Afghanistan has five major river basins which four of them have transboundary rivers but all of them has aquifers that shared with Iran in the west, Pakistan in the east and the south-east, Tajikistan, Turkmenistan and Uzbekistan in the north. Neighboring countries are prone to experience conflict over use of these transboundary groundwater resources. Which has a distinctive continental arid and semi-arid climate, also there is shortage of surface water resources through country transboundary lines except in the north-east and the south-east. In this study, used GIS software with geological map through remote sensing and desk studies to identify the transboundary aquifers and delineate around the neighboring countries. As a result, there are roughly identified totally 12 main transboundary aquifers with others aquifer parameters which is distributed along Afghanistan boundaries. In the north side, there are two aquifers with Tajikistan, one aquifer with Uzbekistan and three aquifers with Turkmenistan. In the west side, three aquifers are shared with Iran and in the south & south-east sides three aquifers are located with Pakistan. As a conclusion, there is required for more detail and comprehensive studies together with the adjacent countries related experts to prepare information and related documents for both countries higher policy makers' authorities for Enhancement of a sustainability development framework.

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A hydrogeological analysis and community perspective of the Vizcaíno Aquifer, Bcs, Mexico

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The Interstate Aquifer of Vizcaino, part of the Biosphere Reserve El Vizcaino (REBIVI), is located within the Mexican states of Baja California Sur (BCS) and Baja California (BC). The southern part of the aquifer (11,914 Km2) forms part of the Municipality of Mulegé (BCS), while the northern part (2,946 Km2) belongs to the municipality of Ensenada (BC). The Mexican National Water Commission (CONAGUA) recognized in 2009 an average annual recharge volume of 41.2 million m3, of which a volume of 37,8 million m3 per year was concessioned (93.03% agricultural use, 5.62% urban public, 0.092% livestock and domestic and 0.43% other services). Because of an estimated natural discharge of 5 million m3, a deficit of -0.13 m3 per year was calculated, with no possibility to grant new concessions. The mining company Mexicana del Arco, S.A. de C.V. carried out a mining project on Au-Ag-Cu-Mo anomalies in the northern part, which would require a water volume of 9.4 to 14 million m3 per year during the exploitation. The CONAGUA then divided the aquifer and published an average annual total recharge of 19.9 million m3/year for the northern part, then called aquifer Llanos del Berrendo, meanwhile the deficit of the remaining part of the aquifer increased only slightly to -1,7 million m3. In February and April 2017, six Community Participatory Workshops (CPWs) were organized in settlements with the highest population density within the REBIVI, to analyze the community's perceptions regarding the effects of climate change and propose measures for adaptation. Among the participants were experts from private enterprises, NGOs, academic institutions, and governmental institutions. A common concern was that opening the mine would lead to a shortage of groundwater quantity and a deterioration of groundwater quality in the southern part. According to the opinions in the PCWs, the main aspects to be strengthened were as follows: the management of the aquifers as a whole, use of new sources of drinking water (desalination/rainwater harvesting), improvements in existing infrastructure, and planning of new infrastructure to prevent current and future risk factors, the introduction of environmental education programs, use of alternative energy, the realization of reforestation and soil retention projects, more efficient wastewater management, the use of new technologies for water-saving, and diversifying productive activities. This resulted in the actualization of the action plan from the National Commission of Protected Natural Areas. However, concerning the division of the aquifer, the problem has not been resolved.

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Groundwater modeling for transboundary aquifers for sustainable management: a case study in Elbeyli Subbasin in Turkey

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This study aims to develop a groundwater flow model to identify how pumping water from wells and irrigation water from Kayacik Dam for agricultural activities affect groundwater levels in Elbeyli, Gaziantep subbasin which is a transboundary aquifer with Syria. The subbasin has high agricultural activities, and it was mainly irrigated from groundwater wells before Kayacik Dam was built, and approximately 12.93x10^6 m^3/year groundwater is used for irrigation now. After dam water is used for irrigation, it was observed that irrigation water from the dam caused an increase in groundwater levels in the dry wells in Elbeyli subbasin, and static level was measured 35.2 m. In addition, an increase in groundwater levels was reported on the Syria side, and approximately 10.15x10^6 m^3/year groundwater flows cross-border is estimated. A groundwater flow model is developed to conduct forward simulations to test different scenarios to evaluate groundwater usage and irrigation effects. This modeling study will improve the knowledge about the transboundary aquifers and will enable us to provide sustainable management of the aquifer. Hence, it would ease decision-makers to build more reliable policies for the future. To add that, the model results can be used to develop a contaminant transport model to investigate migration of contaminants if any detected in the future.

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New insights on groundwater flow in the Northern compartment of the Guarani Aquifer System (GAS) using Strontium isotopes

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The Guarani Aquifer System (GAS) is considered one of the most important transboundary groundwater reservoirs in Latin America. It is located in southern portion of South America, occupying important regions of Argentina, Brazil, Paraguay and Uruguay. Even though its geological aspects and hydraulic behavior are deeply studied, questions regarding hydraulics connections between GAS and the overlying (Post-GAS) and underlying (Pre-GAS) aquifers are recently being answered, with the assistance of hydrogeochemical model's simulation, to recognizing the existence of water mixture. In this sense, strontium isotopes represent excellent tracers of groundwater flow origin due to the capability of 87Sr/86Sr ratio variations indicate the water origin associated to the water rock interaction, mostly due to the strontium chemical similarity with calcium and the absence of fractionation of strontium isotopes. The main purpose of this work was to evaluate the spatial distribution of the groundwater 87Sr/86Sr isotopic ratios within northern portion of GAS, combining these results with the hydrogeological framework and hydrogeochemical conceptual model of GAS groundwater evolution to conceptualize a mixing model and test it in a Bayesian context in R interface. The isotopic data base is constituted by 58 published GAS samples and 3 GAS samples collected in July/2019. The 87Sr/86Sr isotopic ratios ranged from 0.70705 to 0.71754. Near the outcrop zones the strontium isotopes ratios shows more variable fingerprints, ranging from enriched values (more radiogenic 87Sr) associated to more GAS groundwater (39%), to depleted values (more non-radiogenic 86Sr), by the contribution from the Post-GAS (19%) and Pre-GAS (27%) units, and also from rainwater (15%); in transition waters, between the outcrop and confined GAS portions, there is still contribution from Post-GAS (36%) and Pre-GAS (31%) units, almost equal to GAS contribution (33%); while in GAS confined zone, where the contribution from rainwater and Post-GAS units is absent, the 87Sr/86Sr ratios is homogeneous and strong associated to waters from Pre-GAS (88%) units. This behavior indicates that the GAS physical limit represents a more complex and vulnerable system, close related to the geological context, than the supposed so far. The use of strontium isotopes as a hydrogeochemical tracer in GAS context contributes to the definition of the vertical regional flow and water origin, a critical insight that must be considered on its transboundary management, since GAS shows a heterogeneous geological framework according to the occurrence countries.

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Assessment of recharge processes in shared aquifers of the Senegalo-Mauritanian Basin

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The Senegalo-Mauritanian basin (SMB) is located in the western part of the West African Craton and extends over 159,000 km2 in Senegal, 111,000 km2 in Mauritania, 9,000 km2 in the Gambia and 20,100 km2 in Guinea Bissau. Three major aquifer systems are extensively exploited in this basin: i) the shallow aquifer system, which extends discontinuously throughout the entire basin, ii) the middle aquifer system, which includes Eocene and Paleocene carbonate formations, and iii) the deep Maastrichtian aquifer system, which extends almost over the entire sedimentary basin. The deep aquifer is shared between Senegal, Gambia, Mauritania and Guinea-Bissau and shows a significant hydrogeological potential. It is exploited mainly in Senegalese part of the basin. Some sectors of the SMB are considered vulnerable to various processes that can seriously affect water availability and quality. To better understand the aquifer's functioning, information is required on the present-day recharge processes, either through direct infiltration of rain and seepage from surface waters or deep groundwater units. The investigation presented here was carried out within the framework of two regional cooperation projects supported by the International Atomic Energy Agency. Isotope data compiled since 1969 to 2018 from the Maastrichtian aquifer helped delineate the recharge processes. The spatial distribution map of tritium showed that most of this aquifer contains non-renewable waters. Present-day recharge is minimal, and only occurs locally. This finding is supported by the available stable isotope results, where a significant part of groundwater showed isotopically depleted values (d18O contents in the range -8 to –6 ‰ vs-SMOW), compared to the contents of present-day precipitation over the area. The presence of fossil groundwaters is confirmed by low to very low values of 14C activities (less than 10 pmC), particularly in the central part of the basin. Corrected radiocarbon ages of groundwater, using the Fontes and Garnier model, reveal that most groundwater samples were recharged during the Late Pleistocene (20,000 to 35,000 yr. BP). The calculated ages indicated a groundwater flow direction towards the NW. Holocene recharge from the Senegal River is relatively minor, and groundwater flow is mainly driven by the recharge in the SE of the basin, along the "Senegal oriental" basement rocks. These findings on the local hydrogeology of these key shared aquifers should be integrated into the region's Strategic Management Programme. Indeed, groundwater resources in the SMB need to be correctly assessed, managed and protected as a key resource for the local population.

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The use of geochemical tracers to investigate groundwater quality and recharge of the shared Taoudeni aquifer system (Sahel Region)

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The Taoudeni is a closed Saharan basin extending over 2 M km2. It occupies a large portion of the West African craton in Mauritania, Mali, SW Burkina Faso and Algeria. The climate is characterized as Sahelo-Sudanese (rainfall between 600 and 1,000 mm) in the Southern part, and arid climate (rainfall <100 mm per year) in the Central and Northern sectors. Groundwater reserves in this basin are very abundant (around 11 billion m3). The Taoudeni basin presents a multi-layer aquifer system (TAS) contained in geological formations extending from the Infra-Cambrian (IC) up to the Quaternary. These groundwater resources support local livelihoods, maintain vital ecosystems, and strongly affect terrestrial water and energy budgets in the region. However, the hydrological processes that govern groundwater recharge and quality, and their sustainability and sensitivity to climatic variability, remain poorly known. Based on chemical and isotopic tracers combined with hydrogeological methods, this investigation presented here was carried out within the framework of two regional cooperation projects (RAF7011 and RAF7019) supported by the International Atomic Energy Agency. The results obtained showed that groundwater salinity is generally low, with about 77% of collected water samples characterized by TDS contents lower than 500 mg/l. The highest salinity values (>2g/l) were found in samples collected in the Cambrian and the Continental Intercalaire (CI) aquifers. The chemical composition reflects a large variability of facies: Ca-Mg-HCO3; Na-K-Cl; Ca-Cl-SO4; and Na-K-HCO3 water types. The less mineralized water samples exhibit a trend towards HCO3 component, with a cation evolution from the Ca/Mg to the Na/K. The dissolution of calcite, dolomite and aragonite explains the presence of these predominant ions in groundwater. Besides, cation exchange affects water chemistry in the most aquifers. Furthermore, point-sources of nitrate affect the shallow horizons of the IC and Cambrian aquifers. High levels of nitrate found in shallow groundwater are often related to natural processes, such as specific vegetation (acacia), or anthropogenic sources, such as extensive agricultural. Environmental isotope tracer results showed significant tritium levels in the most wells, indicating widespread recent recharge. As confirmed by the stable isotope composition, direct recharge by rainwater in the IC and Quaternary aquifers is supported by relatively high 14C activities. On the other hand, isotopically depleted 18O contents with low 14C activities are found in groundwaters collected in the Cambrian and CI aquifers in the Eastern sector of the basin, indicating the presence of fossil groundwaters, recharged under past climatic conditions.

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Hydro chemical appraisal of Nigerian coastal shared aquifers using integrated approaches: A comparative assessment of the Keta and Rio Delrey Transboundary aquifers, West Africa

Aniekan Effiom Edet[1]

Most existing studies on transboundary aquifers (TBA) have been on identification, evaluation, monitoring, management, sustainability, legislation, licensing, governance and strengthening social and political alliances. However, studies are rare on the chemistry and quality of groundwater of most TBAs and where available are localized and does not give adequate information on the processes that govern the chemical composition of the groundwater. The present study involves quality assessment and the processes contributing ions to groundwater of two Nigerian shared aquifers: the Keta (Benin, Nigeria and Togo) and the Rio Delrey (Cameroun and Nigeria). This work uses an integrated approach including cross plots, ionic ratios, multivariate statistics, water standards, irrigation indices and water quality index (WQI) to achieve the set-out objectives. Results show that on the basis of average values, groundwater in the two TBAs is acidic, fresh and soft to moderately hard. Concentration of ions in groundwater of the two TBAs are below WHO maximum admissible limit, suggesting good quality water for drinking. Generally, groundwater from Keta TBA had elevated values of ions compared to Rio Delrey TBA. The different approaches indicate weathering of rock as the main process contributing dissolved ions to groundwater of the TBAs. Silicate weathering and ion exchange constitute the main type of weathering process in Rio Delrey, while halite dissolution, silicate and carbonate weathering constitute the main chemical process in Keta TBA. The hydro chemical facies are of Na+-Cl- and Na+-HCO3- types in the Keta and Rio Delrey TBAs respectively. Irrigation indices (Sodium adsorption ratio, magnesium ratio, residual sodium carbonate) and (percent sodium, Kelly ratio, Permeability index) indicate the suitability and unsuitability of the groundwater in the two TBAs for irrigation use. Health risk assessment to determine the risk of noncarcinogenic risk due to nitrate in drinking water indicate acceptable limits. However, children are more exposed to health risk due to intake of nitrate contaminated water. Water quality index (WQI) on the average indicate water of moderate and excellent qualities for Keta and Rio Delrey TBAs respectively. This suggest that the groundwater of Rio Delrey TBA is of better quality relative to Keta TBA. The findings of this comparative study will act as a baseline for future groundwater pollution and sustainable development of groundwater in the TBAs, especially the Keta TBA with elevated ions.

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Law reinforcement and hydro geological database development for groundwater and Trans boundary aquifers assessment: Case of the Republic of Guinea

Joseph Dopavogui[1]

The Republic of Guinea, commonly known as "West Africa's water tower", is home to the source of several rivers in the sub-region, mainly Niger, Senegal (Bafing), Gambia, and their main tributaries. The World's Transboundary Aquifers Atlas published by IGRA in 2015 has identified 2 aquifer basins shared between Guinea and its neighboring countries: the Cestos - Danane aquifer of 9,403 km2 between Guinea, Liberia and Cote d'Ivoire in the south of the country and the South-eastern extension of Taoudeni Aquifer of 343,482 km2 between Guinea, Mali and Burkina Faso in the northeast. Beyond the country's strategic position in the field of water at the sub-regional level, groundwater is the main source of drinking water for the Guinean populations. The development of industrial units, in particular mining in the north - eastern and southern parts of the country, is taking place in a context of total ignorance of groundwater resources, the absence of a hydrogeological map and lack of knowledge of the country's transboundary aquifers. Worse, the overlapping of the responsibilities of the various state technical services has resulted in the total lack of administrative and technical monitoring of industrial and mining companies, local and foreign consultancies to capitalize field data and increase knowledge on available groundwater resources. Proposed presentation aims to share the experience of the Republic of Guinea on approaches undertaken to lay the foundations for better knowledge of the country's groundwater resources, through establishment of the country's hydrogeological data base system in 2018 and proposition of the presidential Decree on the modalities of declaration, monitoring and control of hydrogeological works in the Republic of Guinea, in order to strengthen the status and responsibilities of the specialized State Agency in charge of prospecting and evaluating groundwater resources and the establishment of hydrogeological infrastructure of the country. Presentation will also include the contribution of the Republic of Guinea to the Niger Basin Authority's piezometric project and prospective inventory of transboundary aquifers program envisioned by the country to ensure a sustainable concerted management of inter-state groundwater resources, while preserving them against pollution, overexploitation and conflicts related to their common use. Key learning is to show to participants how developing countries with limited resources and inexistence basics information could reinforce Law and regulations to achieve effective shared groundwater database systems to enable transboundary aquifers assessment and accelerate countries hydrogeological mapping.

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Hydro chemical and Isotopic Assessment of the Algerian part of the Saharan transboundary aquifers shared with Mali in the Tanezrouft and Niger in the Iullemeden basins

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The Tanezrouft region is a huge Saharan depression located west of the Ahaggar Massif. Its very weak precipitation is generated by the Sahelo-Sudanese monsoon through episodic thunderstorms. During the ancient Saharan humid times, rainwater that fell in the Ahaggar converged towards the Tanezrouft via Tamanrasset and Tekouiat wadis and recharged the transboundary aquifers shared by Mali and Algeria. Further east, the Iullemeden Aquifer System comprises the Tin Seririne basin (~45.000 km2) that is shared by Algeria and Niger. Groundwater is contained in the Cambro-Ordovician to Carboniferous deposits that lay in unconformity on the Ahaggar shield Precambrian basement. In Algeria, that basin is fully covered over ~ 21.000 km2 by the C O sandstones. The aquifer that is free on the flanks and in the northern syncline margins flow according to the NNE?SSW direction. Elsewhere, the aquifer becomes confined and artesian beyond the borderline with Niger. Three aquifers were targeted here namely: The Continental Intercalaire (CI) in the Tanezrouft, the Devonian/Cambro-Ordovician in the Iullemeden and the alluvial aquifer near Tin Zaouatine that directly lays on the fractured basement at the interface between the two basins. Hydrochemistry has revealed a varied and diverse fingerprint that derives from a combined physico-chemical alteration of the existing aquifers' minerals. The isotopic signature of most of the waters reflects a paleoclimatic feature (deuterium excess = +5). The representative points align far from the local meteoric waterline with values different from the weighted mean rainfall signal (2016 2020) for Algiers. The most isotopically depleted figures were recorded for the C O with an average of 9.4 et 69.5‰ for ?18O & ?2H respectively, whereas they are -8.3 & 63.2‰ respectively for the CI. The latter are comparable to those obtained for the same CI further north in the Great Oriental Erg. The paleoclimatic feature is well highlighted for both aquifers implying ancient colder and more humid recharge periods. Carbon isotopes brought to the fore a mixing of old and recent water components for some points (14C˜50pmC, ?13C˜-10‰) while for others 14C activities significantly decrease mirroring thus long transit times. This is also confirmed by ?13C results that express a good exchange with the aquifers' matrices. Paleowaters (14C = 10pmC) would correspond to groundwater originating from the late glacial episode of the late Pleistocene. On the other hand, it seems that the remaining waters with 10 < 14C < 50pmC, would have been inherited from the last humid pluvial Holocene period.

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Rational development of transboundary groundwater use for irrigation an example from the Chu valley in Kyrgyzstan

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Irrigated agriculture is one of the main sources of subsistence for the population in Kyrgyzstan. In the Chu valley, total annual precipitation is about 400 mm. An average vaporability is 1000 mm per year while little rainfall occurs within a growing season. These facts show that no agricultural activities can be performed without irrigation. Mountain river runoff is the main water source for irrigation. It is obvious that the major danger of the climate change for intermountain basins in Kyrgyzstan is the reduced river runoff, which causes a threat to food security. One of the ways to mitigate a mentioned lack of irrigation water is to use groundwater. Within the central zone of the Kyrgyz part of the valley, Chu River runoff is mainly formed from transboundary groundwater discharge. On the Kyrgyzstan territory, it is mainly generated due to irrigation losses and underflow of mountain rivers of the Kyrgyz Ala-To Range northern slope. Decreased groundwater discharge into River Chu can lead to an international conflicts while settling issues of River Chu runoff allocation between Kyrgyzstan and Kazakhstan. To avoid this, all possible forecast scenarios for groundwater use for irrigation needs in the Kyrgyz part of Chu valley considering the neighboring country`s interests should be available. A possible choice of efficient groundwater use options is mainly provided with 2 factors. Firstly, this is a significant groundwater evaporation observed in intermountain valleys of Central Asia. While lowering the groundwater level, the evaporation inversion serves as an essential additional water source. Secondly, the delay of groundwater intake influence to the groundwater outflow to the neighboring country (under the conditions typical for intermountain valleys) can amount to tens of years. Under the conditions of the Chu valley, an influence delay, even if groundwater intake facilities are located about 20 km, is 15-20 years. In the suggested study, some efficient scenarios for use of an additional groundwater intake for irrigation have been developed on the basis of a non-stationary 3-D filtration model. Modflow program was used for modeling. Groundwater intake schematic and its operation mode are developed considering maximum use of additional groundwater recharge due to evaporation inversion. Under the conditions of the Chu valley, impact minimizing on the outflow to the neighboring country can be also reached by efficiently located additional groundwater intake facilities in relation to Kyrgyzstan state border.

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POSTER ABSTRACT

Assessment of strategic water resources of a large quaternary transboundary aquifer in the Chad Republic using isotope hydrology tools

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In recent years, the Chad Republic has experienced a strong environmental degradation following climatic fluctuations. This continuous climate impact is affecting the whole Sahel Region. The extreme climatic conditions have forced local population to use more groundwater to meet their daily needs as the economy is strongly dependent on agricultural activities. Within the Lake Chad Basin, the unconfined quaternary aquifer offers permanent and easy access to water resources. This transboundary regional aquifer is shared by Chad, Niger, Nigeria and Cameroon and extends over ~500,000 km2. Climatic conditions and repeated droughts have multiple negative impacts on this aquifer, both in terms of the changes in groundwater level as well as in the quality of the water resource. As a strategic water resource for the future of the Chad Republic, the groundwater potential of the quaternary aquifer must be better characterized and managed in order to understand its resilience to climate change. In this context, the International Atomic Energy Agency (IAEA) has supported hydrological investigations in the framework of technical cooperation projects RAF7011 (2013-2017) and RAF7019 (2018-2022) aimed to better understand and manage groundwater resources across the Sahel, including the Lake Chad basin. One of the key aspects of the hydrogeology of the region is that the quaternary aquifer occupies the central part of the hydrological basin and that it is shared between different countries with different exploitation strategies. Another major factor is that the aquifer is hydraulically connected to surface waters which are recharged in the upper watershed of the Chari River and extending towards the Central African Republic. In this work, assessment of these valuable groundwater resources has been conducted using geochemical and isotope hydrology tools (stable isotopes of the water molecule and tritium). In addition, the study included surface waters in order to trace potential hydraulic connections between underground reservoirs and surface water flows. Results of these studies showed active recharge processes to the quaternary aquifer as well as dynamic connections with surface waters (both river courses and wetlands). Even if groundwater showed evidence of evaporation and harmful water-rock interactions in some regions, groundwater from the quaternary aquifer appears in relatively good status, both in terms of quantity and quality. Therefore, the quaternary aquifer in the Chad Republic was found to be resilient to climate change but its hydrogeological specificities (dependence to surface water from the upstream basins and transboundary nature) can make it prone to inadequate management strategies.

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POSTER ABSTRACT

A comprehensive approach to the knowledge of the carbonate transboundary aquifers of the Adriatic Region

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The increasing groundwater exploitation and contamination risks due to the progressive population growth in coastal areas are emphasized in the case of carbonate coastal aquifers, the peculiarities of which, especially in the Mediterranean basin, constitute a scientific matter of worldwide relevance, especially as some of these are wide transboundary aquifers. These aquifers not only ensure the socio-economic development of the populations but feeds with their spring waters valuable wetland and coastal environments with relevant and highly positive effects on ecosystems. Their groundwater resources are highly vulnerable, especially if affected by karstic phenomena, to the quality and quantity degradation phenomena, not only for the increasing water demand and the decreasing recharge due to climate changes but also in relation to the sea level changes and the pollutant loads due to the contamination occurred in the whole hydrogeological basins. The aim of this study is to offer a systematic and synoptic view, useful for knowledge, management and forecast purposes, contributing to assure enduring availability of high-quality groundwater, conciliating water demand satisfaction with the ecological needs of coastal Adriatic and Ionian environments in which the role of groundwater is very important. A geodatabase, collecting information for all carbonate aquifers present along the Adriatic and Ionian coast, have been created. At the core, there is a Geographic Information System, in which are placed the spatial information regarding the geology of aquifers, hydrogeological and geochemical features, together with specific information concerning groundwater use of CCAs. The added value of this database is the availability of a wide bibliography related to CCAs, together with a schematized summary of key information realized considering available information in the whole geodatabase. This study meets the requirements connected with UN Sustainable Development Goals, SDG 6 – Environment (Ensure availability and sustainable management of water and sanitation for all). Basing on this broad approach, the conceptualization and the management of any transboundary aquifer could be planned, starting from the information sharing. The potentialities of the knowledge system are shown for selected study case, e.g. transboundary aquifers between Croatia, Slovenia, and Italy.

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POSTER ABSTRACT

Contribution of isotope hydrology to the integrated water resources management in the Lake Chad basin: focus on North Cameroon

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The transboundary Lake Chad basin contains important groundwater resources gathered in three aquifers : Continental Terminal (Cretaceous), Lower Pliocene and Quaternary – which have been subject to several regional programs from many international institutions (LCBC, UNESCO, IUCN, IAEA) in order to support the cross-border cooperation for water management since approximatelly four decades. Through time, isotope hydrology methods appeared very efficient and useful to obtain information which helped to understand the aquifer functioning and thus to implement pragmatic water management strategies. In Cameroon (southern part of the Lake Chad basin), these methods are applied since 1990 up to now through three regional projects supported by the International Atomic Energy Agency (IAEA): RAF/8/012, RAF/7/011 and RAF/7/019 with an emphasis on the shallow quaternary groundwater. This very strategic aquifer is intensively used for many purposes including drinking supply and irrigation. The water isotopic signature (18O, 2H, 3H, 13C, 14C) shows that the aquifer is continuously recharged by recent water (rainwater and evaporated surface water from adjacent Logone River) with some mixing with older ones. High concentrations in nitrate (up to 600 mg/l) are recorded in the aquifer and are related to local anthropogenic activities and to the very bad conditions of maintaining of wells and boreholes. From 1992 to 2019, the nitrate content has increased by an average factor of 6. New investigations on nitrate isotopic signatures have helped identifying the pollution sources and have helped proposing new regulation strategies in order to protect the groundwater resource. Amongst them, any activities presenting a risk of contamination for groundwater should be prohibited or controlled in the immediate vicinity of boreholes and wells by the establishment of protection perimeters around the water pumping points.

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POSTER ABSTRACT

The stable isotope composition of the precipitation as a tool for evaluation of the transboundary aquifers recharging patterns

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Southeastern Europe is under the strong impact of ongoing climate changes, with noticeable effects on agriculture productivity, water supply security and status of water ecosystems. However, little is known in the region on the age, recharge patterns and overall availability of transboundary aquifers, some of which stretch the borders of Romanian, Republic of Moldova and Ukraine. The determination of age, timing and mechanisms of groundwater recharge are of paramount importance for the elaboration of scenarios of future water usage. In this endeavor, stable isotope techniques have proved to be one of the most reliable tools. The aim of this study is an analysis of stable isotope composition (?2H and ?18O) from the existing GNIP network and other sources in Romania and Republic of Moldova. Five GNIP stations from Republic of Moldova and five other stations from Romania and Republic of Moldova were analyzed for this task. All stations are situated east of the Carpathian Mountains in a region fed by precipitation derived mainly from the Atlantic Ocean, the Mediterranean Sea and the Black Sea, with additional continental sources in Europe and Western Asia. Local Meteoric Water Lines (LMWL) for each station was compared with Global Meteoric Water Line (GMWL) for the period 2009 – 2019 years. The monthly and annual fluctuations were studied in relationship with the main climate parameters as well as large-scale circulation patterns across Europe. Our results indicate that, while the Atlantic Ocean is the main source of moisture feeding the region, the Black and Caspian Seas contribute up to 25 % of moisture delivered as precipitation, a share that increases to above 30 % in winter months. In autumns, northeastward travelling Mediterranean cyclones provide moisture, especially in the southern part of the studied region, while in summer, locally evaporated moisture is the most important source of water. Atlantic Multidecadal Oscillation is the main large-scale circulation pattern explaining the temporal and spatial distribution of ?2H and ?18O in precipitation; while in winter, a complex interplay between the Siberian High and the North Atlantic Oscillation influences the stable isotope patterns in precipitation. This study is a first step in the analysis of the interaction between precipitation, rivers, and the main transboundary aquifers between Romania and Republic of Moldova. This case study is the first assessment of the water sources in the frame of an ongoing IAEA-supported regional project (Romania, Bulgaria, Ukraine and Republic of Moldova).

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POSTER ABSTRACT

Delineating river water-groundwater interaction in a populated South Asian urban aquifer system of a transboundary river

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Groundwater pollution and over-exploitation has been an emerging crisis in recent years that has affected the aquifers of South Asian countries leaving behind an insufficient amount of sustainable drinking water for the dependent population. The fertile plains of river Ganges in India, that hosts one of the largest global populations, is currently under extreme stress due to both degrading water quality and decadal drying of river. Varanasi, which has been recently identified as one of India's future smart urban sectors, face extreme population stress and undergo unprecedented groundwater abstraction risking the water quality to its peak of vulnerability. Due to lack of extensive knowledge on Central Gangetic aquifer system, a detailed study of aquifer dynamics through surface water-groundwater interaction is of utmost importance for long term availability of sustainable water for the residing urban population. The present study focuses on multiple approaches to spatio-temporally delineate hydrological interaction between the river Ganges and its adjacent aquifer. High resolution chemical, isotopic and piezometric data has been used to understand groundwater evolution, seasonally varied subsurface hydrological flow patterns, contributing parameters to the river baseflow and sources of infiltration in the aquifer system of the studied area. Statistical analysis, three component mixing model through mass balance approach and geochemical inverse modelling has been used as tools to delineate hydrological exchange patterns. This present study provides one of the first, in-situ observations of the intricate, spatiotemporally variable, interaction processes between a large perennial river and adjoining groundwater in a growing urban regime. It is also a foundation for smart city planning that will help the government implement proper water management policies for future water security and save the groundwater from its peak of vulnerability.

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POSTER ABSTRACT

Geological and hydrogeological characterization of the western Burkina sedimentary basin (South-eastern of the Taoudeni Basin)

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The western Burkina sedimentary basin (45,000 km²) has a very favorable hydrogeological potential and is largely exploited for many uses (domestic, agricultural, industrial). Yet little is known about the aquifer system. The depth of boreholes in the area has never exceeded 300 m while the depth of the aquifer system could exceed 2000 m in some areas. Moreover, its hydrodynamic characteristics remain little known; thereby the available water resources are wrongly assessed and the water table's behavior against various stresses is insufficiently understood. This poor knowledge hampers a good management of the water resources. In order to overcome these shortcomings, the Water Supply and Sanitation Program (PAEA), co-financed by the World Bank and the Government of Burkina, is dedicated to improving knowledge on the basin's geology and hydrogeology using cutting-edge technical solutions. The activities include geophysical prospecting campaigns aimed at describing the different geological layers and structures down to the crystalline bedrock and at defining the sedimentary basin's lateral limit with the techniques of seismic reflection (400 km), magnetic and electromagnetic (300 km for each method) and electrical resistivity tomography (nearly 100 km). Subsequent to the completion of the geophysical prospecting campaigns, exploratory deep boreholes (fourteen 500-meter, one 1000-meter and one 2000-meter) and piezometers associated with the 500-meter boreholes will be drilled all across the sedimentary basin. These boreholes will be subject to log tests and many others (resistivity, gamma ray, flowmeter, imaging, temperature and conductivity, water sampling, pumping tests, tests under single or double shutter, etc.). These tests are meant to characterize either individually or globally the different formations and determine their fundamental hydrodynamic parameters up to 2000 m. All this information will be analyzed toward a better understanding of the different layers' geology and better estimates of the aquifers' hydrodynamic properties. Using this knowledge, the geological and the hydrogeological models will be developed successively. The latter will then make it possible to evaluate the hydrogeological potential of the area and to study the hydrodynamic behavior of the aquifer system.
Key word: Taoudeni Basin, hydrogeological characterization, Deep boreholes, seismic reflection.

1 WSSP, Water Supply and Sanitation Program
2 SP-GIRE, Permanent Secretariat for Integrated Water Resources Management; (3) General Directorate for Water Resources

POSTER ABSTRACT

Data-driven analysis and regional modelling for the assessment of Transboundary Aquifers in the Mediterranean region

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The Mediterranean region is recognized as a climate change and anthropogenic pressure hotspot. Today, increasing water demands and high variability in precipitation are already challenging the region's water future. Groundwater is considered as a strategic freshwater reserve and plays a vital role in supply for basic human needs and economic development. Transboundary aquifers (TBA) are important freshwater sources, particularly in arid and semi-arid regions, like the South Mediterranean. However, groundwater status in the South Mediterranean region remains poorly characterized, and its total water budget is uncertain. Lack of multistate systematic monitoring and data sharing are limiting the TBA assessment, delaying sustainable management. In recent years, groundwater modelling at a regional/global scale has offered further insights into groundwater status, especially in data-scarce regions. Even though it remains unclear to what extent those models can support management decisions, they will open new horizons on TBA assessment in limited-data conditions, such as the South Mediterranean region. A combination of regional-scale groundwater modelling and data-driven analysis has shown great potential for improving our physical understanding of groundwater systems functioning. This will guide for implementing science-based adaptation and sustainable management in the Mediterranean. In this study, we aim to first use available long-term groundwater level monitoring data, along with a review of regional assessments to identify and evaluate trends in groundwater storage where observations sites are available and identify their controlling factors. Then, we present a groundwater level regional model under steady-state and transient regimes in the Mediterranean region, calibrated with the collected data. These outcomes are expected to give insights in groundwater depletion at a regional scale, especially useful for the areas with low data availability and highly defragmented management strategies, like the Nubian Sandstone Aquifer System (NSAS) and the North-Western Sahara Aquifer System (NWSAS). This study provides a new step towards a better assessment of TBA. It contributes to enhancing the role of combining available observation data and regional-scale modelling, as an efficient tool in assessing and then predicting changes in groundwater resources availability under socio-economic and environmental management capacities within the sharing countries. This work was supported by Sustain-CAOST and InTheMED projects. Sustain-CAOST was funded by the German Federal Ministry of Education and Research (BMBF, Germany, Grant 01DH19015) under the EU PRIMA 2018 programme. InTheMED is part of the PRIMA programme supported by the European Union's Horizon 2020 research and innovation programme under grant agreement No 1923.

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POSTER ABSTRACT

Novel Application of remote sensing, geotechnical measurements, and groundwater models for improved water resources management

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The Limpopo River Basin, located in sub-Saharan Africa, is a transboundary river basin shared by Botswana, South Africa, Mozambique, and Zimbabwe. The water resources within the basin support approximately 18 million people and biodiversity. Due to the monsoonal climate and the high temporal and spatial variability, groundwater is a pivotal resource in the region. Population change and climate change create a complex management. The critical nature of the water resources in the Limpopo River Basin presents a need for improved data, models, and transboundary water resources management. This research involves the novel application of remote sensing, geotechnical measurements and groundwater models to better model groundwater flows and aquifer recharge in the Limpopo River Basin that is a prerequisite for water resources management. The method involves combining ground-based measurements with satellite-based measurements to determine groundwater recharge zones and precipitation patterns throughout the regions. Satellite-based measurements include water data from NASA's Gravity Recovery and Climate Experiment (GRACE) satellites and land cover information from Landsat satellites. The GRACE satellites measure changes in gravity based on monthly changes in mass. The mass changes are measured in terms of "water-equivalent thickness" changes that occur in a concentrated layer of water near the Earth's surface. Most of the monthly gravity changes are caused by changes in water storage, moving ocean, atmospheric and land ice masses, and by mass exchanges between these. By tracking water equivalent thickness at different points on Earth's surface, GRACE data can provide a picture of what groundwater storage may look like at a specific location. The Global Land Data Assimilation System (GLDAS) combines satellite and ground-based observational data via land surface modeling and data assimilation techniques to generate a model of land surface states and fluxes in order to support proposed weather and climate prediction. Ground-based measurements include precipitation data and aquifer location and characteristics from electrical resistivity tomography (ERT). The data collected will aid in the development of a groundwater model of the Limpopo River Basin that will identify key recharge zones for water resources.

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POSTER ABSTRACT

Evaluating sustainable groundwater management considering the effects of spatial and temporal scale in Semnan Plain, Iran

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Iran with an arid and semi-arid climate has witnessed tremendous climate change and population growth in recent years, which has significant impacts on the increase of the surface and groundwater consumptions for food production, domestic and industrial use. In other words, the reduction of surface water resources and the effects of climate change has led to more exploitation of groundwater and the instability of these resources in Iran. This study aims to estimate the sustainable performance of groundwater, investigate the effects of spatial and temporal scale, and consequently present a plan for sustainable use of groundwater in the Semnan plain, in eastern Iran. In this regard, the plain area is divided into several areas. To estimate the average amount of groundwater recharge and discharge and the effects of spatial scale, the plain is divided into several zones while the groundwater recharge and discharge for each distinction and the temporal scale, referring to the different time-scales had been considered. The results of the groundwater model of Semnan plain showed that the average annual groundwater discharge was about 330 million cubic meters over a period of 10 years, with an average of 9 meters of water loss. The results of the study showed that stable performance is in line with the temporal and spatial scale and also these scales increase the stable performance from 35% to 62%, equal to 110 million cubic meters of current pumping volume of water. Therefore, when limited to sustainable performance, groundwater abstraction minimizes social and economic adverse effects. It worth mentioning that the results of this study can be generalized to other parts of the country that have similar conditions.

Keywords: sustainable management , Groundwater modeling, spatial scale, governance policy.

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POSTER ABSTRACT

Delineation of Groundwater Potential zone based on Fuzzy Logic Algorithm, Maharloo Plain, Iran

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Groundwater crisis, especially in semi-arid and arid regions, involves manifold concerns and issues. Some of the main contributing criteria are land use and land cover change and urbanization. Underground aquifers are in a vulnerable stage due to overuse. The present study is conducted to identify potential groundwater areas in the Maharloo Basin of Iran, facing water shortages. Groundwater resource potential zoning has been used based on the Analytic Hierarchy Process (AHP), Geographic Information System (GIS) and Remote Sensing (RS) techniques. Fuzzy weights are divided into eleven physical parameters including land use, land cover, soil, geomorphology, geology, linear density, drainage density, distance from the river, slope, groundwater level fluctuation, normal water difference index (NDWI), and all maps are integrated by manipulating GIS. Groundwater potential of the region divided into five classes, which include very low potential (25.30%), low potential (30.42%), medium potential (25.9%), high potential (10.5%) and very high potential. (7.88%). In general, such studies provide novel perspectives and valuable perceptions to stakeholders for the sustainable management of water resources and the effective identification of proper sites for groundwater extraction.

Keywords: Sustainable Management ,Fuzzy AHP, Groundwater Potential Index, GIS.

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TOPIC 4 :

Governance of transboundary aquifers: strengthening cooperationgovernance of transboundary aquifers: strengthening cooperation

Transboundary diagnostic analysis of the eastern Kalahari-Karoo transboundary basin aquifer system (EKK-TBA)

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A Transboundary Diagnostic Analysis (TDA) of the Eastern Kalahari-Karoo Transboundary Basin Aquifer system (EKK-TBA) was conducted presenting a comprehensive understanding of the state of surface water and groundwater resources, their uses, spatial and temporal variability, interactions, and impacts as well as human benefits derived from ecosystem services and existing infrastructure. The EKK-TBA is shared between Botswana and Zimbabwe. Water-related issues of the Basin are identified and lay the foundation for a basin-wide Strategic Action Plan (SAP). The EKK-TBA straddles two river basins: Okavango and Zambezi and covers an area of 127 000 km2 (65% in Botswana and 35% in Zimbabwe). The topography is generally flat (880-1400 m amsl from southwest to northeast) and the climate is semi-arid. Surface water drainage is mainly through ephemeral rivers towards the Makgadikgadi Pans in the southern part of the Basin and through the Gwayi River system in the northeast towards the Zambezi River. The 2020 Basin human population is estimated at 595 000 (16% in Botswana and 84% in Zimbabwe) and the Basin's economy is mostly driven by diamond mining, ecotourism and agriculture (livestock and cropping). Groundwater forms the main source of potable water supply within the Basin for both humans and animals. Shallow aquifers are constituted by the Kalahari Group deposits whereas the main aquifers are the deep Ntane/Forest Sandstone and the Mea Arkose Sandstone. Wellfields have been developed along the southern and south-eastern fringes of the Basin where the sandstone aquifers outcrop and are recharged from rainfall (direct and indirect). The positioning of the EKK-TBA poses complexity and yet provides a unique opportunity for joint governance and management as the two transboundary river basin organizations, OKACOM and ZAMCOM, have to be involved. The joint governance and management of the EKK-TBA can be achieved through the SADC water institutional framework. Key issues emanating from the TDA include:

- Water insecurity due to increasing water demand against the backdrop of limited groundwater resources
- Data scarcity (central and northern EKK-TBA) and inaccessibility and poor quality of data
- Deforestation and poor agricultural practices resulting in land degradation
- Lack of adequate resources to carry out effective and efficient groundwater management including monitoring of water resources
- Need for a joint transboundary groundwater governance and management.

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Governance of the Guarani aquifer: creating a commission

Catherine J. Tinker[1]

Cooperation in prevention of harm to transboundary aquifers, "multiple, reasonable, sustainable and equitable use" of their waters, and peaceful resolution of disputes are legal duties as well as matters of diplomacy and international relations. Interpretation of these terms in agreements on transboundary aquifers and others like "significant harm" depends on a wide body of existing water law, international and regional environmental law, "soft law" declarations and resolutions, and policy studies from academia and non-governmental or intergovernmental organizations. Compliance with the law on transboundary aquifers depends on political will and the legitimacy of a clear framework agreement that accommodates social, economic and environmental policies and laws. One such regional aquifer agreement, the Guarani Aquifer Accord, entered into force in late November 2020, and a Commission will be created under this treaty. Challenges exist in defining the role of the new Commission, its funding, and its relationship to other institutions and stakeholders. This paper recommends considering the following:

- What has been learned under existing treaties like the Convention on Biological Diversity, Ramsar Convention and the Paris Agreement that might guide the development of the new Guarani Aquifer Commission and foster cooperation among the states party to the Accord?
- Can sharing of scientific research on TBA and the characteristics of the Guarani Aquifer be encouraged and made widely accessible through the Guarani Aquifer Commission?
- Will other global or intergovernmental institutions and programs serve as a scientific clearinghouse or legal backup center for materials and assistance in interpretation of treaty terms and states' compliance with obligations in the Guarani Aquifer Accord?
- Can the Accord's duties and dispute resolution provisions be legitimized and perceived as an aid to cooperation and possible future harmonization of national laws and development priorities in the four Guarani states?
- Does a "human rights approach" and the goals-targets-indicators method for policy-making under the 2030 Agenda for Sustainable Development provide guidance on governance of the Guarani Aquifer for the protection and use of this or other transboundary aquifers?

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Characterizing legal implications of transboundary aquifers

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Groundwater resources that traverse political boundaries have become increasingly important sources of freshwater in international and intranational arenas worldwide. This is a direct extension of the growing need for new sources of freshwater, as well as the impact that excessive extraction, pollution, climate change, and other anthropogenic activities have had on surface waters (Mukherjee, et.al., 2021). It is also a function of the growing realization that groundwater respects no political boundaries, and that aquifers traverse jurisdictional lines at all levels of political geography. Due to this growing understanding, questions pertaining to responsibility and liability are now being raised in relation to the exploitation and administration of cross-border aquifers (Hayton and Utton, 1989; Eckstein 2017). This occurs both at the international level where two or more sovereign nations, as well as at the domestic level where two or more subnational political units, overlay a common aquifer. The law applicable to transboundary groundwater resources at both levels of governance is primitive and lacking. Moreover, the relationship of groundwater law to surface water law is often non-existent. While there are a few promising trends in the international realm (Eckstein, 2017), rules addressing questions of responsibility and liability in relation to the use, management, exploitation, and administration of transboundary aquifers remain elusive. To provide a foundation for the development of such laws and regulations, this presentation will explore circumstances under which the use, management, exploitation, or administration of a transboundary aquifer might cause harm to a neighboring political unit and, thereby, result in legal responsibility and/or liability. It will assess cause and effect relationships through the use of various conceptual models of transboundary aquifers. Notions of gaining and losing stream relationships, unconfined and confined aquifers, natural versus anthropogenic contamination, and other concepts will be utilized to describe scenarios in which harm could traverse a political boundary. The presentation will then translate that analysis into notions of responsibility and liability that are more common in the legal realm.

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Strengthening Cooperation on Transboundary Aquifers in the Arab Region

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The Arab region is one of the most water scarce regions with two-thirds of its freshwater resources crossing one or more international boundary. The number of transboundary aquifers in the region outnumbers that of transboundary surface water basins. There are 40 transboundary aquifers in 21 out of 22 Arab countries which cover almost 58 per cent of the region in terms of area. The dependency of Arab States on external water resources increases the need for better cooperation. This makes achieving water security especially challenging, particularly when also considering that growing demand, declining water quality and climate change are contributing to increasing water scarcity. Water cooperation in the Arab region has traditionally focused on surface water resources, which are easier to access and understand. However, increased stresses on these resources has increased interest and political motivation to improve cooperation on transboundary aquifers. This is demonstrated in reporting on the Sustainable Development Goal (SDG) indicator related to transboundary cooperation, SDG indicator 6.5.2. As with global reporting, only few countries from the region were able to report on groundwater under the indicator, either due to limited understanding or lack of cooperation arrangements. However, reference to groundwater marginally improved during the second reporting round. Strengthening cooperation on transboundary aquifers in the region requires a multifaceted approach that improves the knowledge base, develops capacities for cooperation including understanding of legal instruments and frameworks, and supports regional mechanisms to operationalize cooperative arrangements. This paper will take stock of regional initiatives for improving transboundary aquifers cooperation along these three tracks. On the knowledge base pillar, reference will be made to the use of the ESCWA-BGR Inventory of Shared Water Resources in Western Asia and related assessments to inform dialogue. On regulatory and legal frameworks, intergovernmental initiatives will be reviewed, including those mandated by the Arab Ministerial Water Council. The operationalization of existing cooperation mechanisms such as on the Disi aquifer or the North Western Sahara Aquifer System will also be examined as well as progress in regional reporting on transboundary aquifers and opportunities for financing. The paper closes by introducing an initiative for enhancing open access to knowledge on groundwater through a regional knowledge hub aimed at informing cooperation through increasing understanding among states and stakeholder groups.

1 United Nations Economic and Social Commission for Western Asia (UNESCWA)

Conjunctive management of water resources and governance of transboundary aquifers of Iullemeden-Taoudeni / Tanezrouft (ITTAS)

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The transboundary aquifers of Iullemeden (SAI) and Taoudeni / Tanezrouft (SAT), located in West Africa contain significant reserves (~15,000 billion m3). The two aquifers are connected and together form the Iullemeden-Taoudeni / Tanezrouft Aquifer System (ITTAS). The ITTAS groundwater resources, interconnected with those of the Niger River are shared between eleven countries: Algeria, Benin, Burkina Faso, Cameroon, Chad, Cote d'Ivoire, Guinea, Mali, Mauritania, Niger, Nigeria.

These water bodies are subject to various threats, mainly overexploitation (localized), pollution from various sources and the effects of climate change. Under the effect of climate change, for example, the Niger River has undergone substantial reductions in its flow volumes in all its compartments due to (i) decreased rainfall, (ii) increased evaporation and (iii) reduction of groundwater recharge.

It is in the perspective to supporting the countries concerned in mastering or even reducing the impacts of these threats on water resources in order to meet the water demands of neighboring populations, that the ITTAS project financed by the GEF is implemented by the ABN, OSS, UNIDO and UNESCO. It aims to support governance and management based on an ecosystem approach for joint management of the global strategic resource for the sustainable development of the concerned sub-region. Such management requires a better understanding of the dynamics of this hydraulic assembly and its relationship with its environment.

The project will also make it possible to operationalize the concerted governance of the ITTAS aquifer system already initiated through a memorandum of understanding signed by 4 countries for the creation of a Consultation Mechanism.

This communication aims to present a case study in progress, on the need to set up concerted governance of such management of interconnected groundwater and surface water resources shared by eleven countries, some of which are concerned only with surface water, others by groundwaters, and others by both at the same time.

It also highlights the various interventions and achievements of the project with a view to the effective operationalization of the conjunctive management of the water resources of the aquifer system of ITTAS and those of the Niger River.

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Collective aquifer governance through unitization

Jakob Wiley[1]

Groundwater governance is reaching a paradigm shift. The issues with groundwater extend not only to water quantity and access, but also to the indirect harms of groundwater development like degrading water quality, subsidence, transboundary political conflicts, and saltwater intrusion. At the same time, debates continue over the adoption of groundwater marketing and banking policies to improve resource utilization. Few policy tools appear to incorporate each of these components into a single approach to aquifer governance. The paradigm shift is the transition from groundwater management to aquifer governance, accomplished by focusing less on the contents of an aquifer but instead on the container itself. A similar transition occurred in another subterranean substance in the early 1900s: oil and gas. The current struggle to identify policy tools closely aligns with the debates in the early years of oil and gas development. Regulation proved ineffective in encouraging sustainable, controlled development of oil and gas resources. The result was large amounts of waste, environmental damages, and conflicts. To address these issues, developers negotiated the first cooperative agreements to maximize the benefits for all. Unitization agreements enabled collective, voluntary, and effective resource management for numerous stakeholders across international and domestic political boundaries. The principles of unitization agreements serve as the model for a new approach to aquifer governance. Unitization agreements follow a general set of principles that could be used to create aquifer unitization agreements. These agreements are essentially voluntary contracts that centralize resource use decision-making to a central committee of stakeholders yet distribute resource benefits to all participants in the agreement. Aquifer resource use is negotiated and based on scientific principles, negotiated goals, and local conditions. Multiple resources can be managed under a single agreement, including groundwater, geothermal heat, water quality, pressure, surface water interactions, subsidence, and biological factors. Each of these resources may form the basis for shares or interests owned by the participants to the agreement and redetermined as needed to ensure scientific accuracy. Just as in the oil and gas context, these agreements can span international borders and include offshore groundwater resources. As resource shares or interests are at the core of unitization agreements, markets could form around these agreements and directly incorporate negative externalities.

1 City of Oregon City

Slovenian contribution in the global efforts of governance, management, and protection of transboundary aquifers

Aleš Bizjak[1], Mihael Brencic[2]

Groundwater management in Slovenia is well established and based on tradition and good practices which are related to the fact that nearly 100% of drinking water is coming from groundwater. It is supported by extensive and detailed legal framework, water resources management and governance system and by profound scientific and engineering work. Slovenia has long established bilateral administrative and research-based exchange on transboundary groundwater bodies. With Republic of Austria (northern state boundary) transboundary water body with several karstic aquifers was established in 1990'. With Hungary (northern eastern state boundary) extensive work was performed on transboundary geothermal resources, with Republic of Italy (western state boundary) several projects were performed on transboundary karstic aquifers. With Republic of Croatia Slovenia has the longest state boundary on the south and east. There are extensive karstic aquifers which are part of larger Dinaric karstic system. In the frame of these aquifers Slovenia cooperates and transferred knowledge also to other Dinaric states (Bosnia and Hercegovina, Serbia, Montenegro, Albania). Based on these past activities and considerations of the role of water in international relations, groundwater became one of the priorities of the Slovenian water diplomacy. However, in order to support the SDG 6 implementation and contribute to the world's community efforts, acceleration of direct and specific actions are needed on all levels of water planning; national, bilateral, sub-regional, regional and global. Based on the tradition, experiences and good practices Slovenia can contribute to knowledge transfer and active role. In bridging the recognized gaps in the SDG 6 goals and targets, Slovenian actors could contribute to establishing transboundary groundwater governance and management, in enabling and establishing science/policy interface, in articulating and forming transboundary cross-sectoral partnerships, by raising awareness of the general transboundary public and by contributing to further development of water diplomacy. In the paper vision of Slovenian contribution in the global efforts of governance, management and protection of transboundary aquifers will be presented.

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A 30 Year Evaluation of JA-NSAS as a Pioneer Regional Organization for the Management of Transboundary Aquifers

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The Nubian Sandstone Aquifer System (NSAS) is one of the largest aquifer systems in the world, covering approximately 2.2 million km2 in Northeast Africa. It extends for over 1,500 km in the East-West direction and 1800 km in the North-South direction across Chad, Egypt, Libya, and Sudan. Near the oasis of Kufra, NSAS reaches a maximum thickness of more than 4000 m. The hydraulic head ranges from 570 m above sea level west of Darfur to 78 m in the Qattara depression. The total volume of freshwater stored in the NSAS was estimated at 450,000 km3, of which around 14,000 km3 are recoverable. Thirty years ago, the four NSAS countries laid the building blocks for cooperation in managing the shared aquifer system. Egypt and Libya started the process in the early 1980s and culminated in 1991 with the establishment of the Joint Authority for the Study and Development of NSAS (JA-NSAS). The constitution of the Joint Authority was adopted in 1992. Sudan joined the Joint Authority in 1996, and Chad followed suit in 1999, making all riparian states members of JA-NSAS and abiding by the principles of the joint management of this important transboundary basin. The functions of JA-NSAS include the periodic collection of field data, carrying out supplementary studies on the state of the aquifer, preparing plans for water resource development, proposing and implementing joint policies for the rational utilization of water resources and assessing their environmental impacts at the national and regional levels, and organizing training courses and capacity building. Over the past 30 years, more than 30 meetings of the Board of Directors have been held to set general policies and follow up the activities of the subsidiary offices in the Member States. International and regional organizations such as IFAD, UNESCO, IAEA, IDB, GEF were approached for funding regional hydrogeological studies and devising strategies for the sustainable exploitation of the shared aquifers, elaborating socio-economic studies, updating the mathematical model and database, and preparing a Strategic Action Program. Major steps have been taken thus far to enhance institutional capacity and secure the flow of technical information. They include establishing a common network of production and monitoring wells, developing mathematical models capable of simulating various exploitation scenarios, and signing a protocol for monitoring and exchanging groundwater information. Data on annual extraction, water quality and water levels from the regional monitoring network, as well as the socio-economic and environmental data and drilling results are systematically entered into the Nubian Aquifer Regional Information System (NARIS). Keywords: Nubian Sandstone Aquifer System, Joint Authority, Transboundary Aquifers, Groundwater Management.

1 General Water Resources Authority. Tripoli, Libya
2 Joint Authority for the Study and Development of the Nubian Sandstone Aquifer System (JA-NSAS). Department of Geology, Faculty of Science, University of Tripoli, P.O. Box 13258 -Tripoli, Libya

The Role of 'Convergence' in Clarifying the Boundaries of International Law on Transboundary Aquifers

Owen McIntyre[1]

Given the relative dearth of established State practice in respect of the emerging rules of international groundwater law, and the spectra of 'fragmentation' occurring between the rules applying to transboundary aquifers and to transboundary rivers and lakes, the phenomenon of 'convergence' may have a role in informing critical elements of both complementary fields of normativity. This is particularly likely to be the case in relation to specific objectives of international groundwater law, such as sustainable management of dependent ecosystems and equitable realization of water-related human rights entitlements. The phenomenon of 'convergence' can be understood as a systemic response to concerns regarding the 'fragmentation' of international law, which involves greater uniformity and congruence in approach across sectors and sub-sectors to the application of relevant rules and principles of international law. It is becoming sufficiently prevalent for commentators to note that 'convergence and unity are becoming more dominating features of international law discourse than the claims to autonomy and specificity of different regimes and disciplines which previously dominated' (Andenas, 2015). Such a process of 'convergence' has substantive, procedural, institutional and methodological elements, and is readily apparent in the recent development of international water law, where it occurs through a range of mutually complementary mechanisms, including:

- Emerging State practice (at the global, regional and bilateral levels);
- Judicial interpretation of treaties (e.g. the principles of 'contemporaneity' or 'systemic integration');
- Phenomena of 'inter-penetration' and 'cross-fertilization';
- Inter-regime institutional collaboration and cooperative elaboration (e.g. between international water law and the Ramsar and CBD regimes):
    - Codification initiatives taking account of developments in related fields;
    - Growing interaction between international, domestic law and novel hybrid rule-making; and
    - Rapid scientific, technological and methodological developments.

It is worth noting, for example, that ecosystems obligations arising under international law applying to both transboundary surface waters and groundwaters will be profoundly influenced by technical methodologies elaborated under the auspices of the Ramsar and CBD Conventions, while inter-State cooperation regarding both classes of transboundary water system is to be measured and reported against a single SDG Indicator (6.5.2). In the light of concerns regarding the fragmentation of international watercourses and groundwater law expressed after the adoption of the ILC's 2008 Draft Articles on the Law of Transboundary Aquifers, it is helpful to focus on the mechanisms by means of which these closely interrelated fields might be reconciled and rendered more mutually coherent and complementary.

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Transboundary aquifer governance in the context of transfrontier conservation areas - an opportunity for synergy in the Southern African Development Community

Karen G. Villholth[1]

Southern Arica has one of the highest concentrations of transfrontier conservation areas (TFCs) in the world. It counts on 18 TFCAs in the Southern African Development Community (SADC). A TFCA is defined in the SADC Protocol on Wildlife Conservation and Law Enforcement (1999) as 'the area or the component of a large ecological region that straddles the boundaries of two or more countries, encompassing one or more protected areas, as well as multiple resources use areas. TFCAs are established with the aim of collaboratively managing shared natural and cultural resources across international boundaries for improved biodiversity conservation and socio-economic development. The 18 existing or potential TFCAs in both terrestrial and marine environments covering over 700,000 km2 have been grouped into three categories based on the level of development: Category A (TFCAs with a treaty or other form of legally binding and mutually recognized agreement), Category B (TFCA with an MoU), and Category C (TFCAs at a conceptual stage). The Kavango Zambezi Transfrontier Conservation Area (KAZA TFCA) is the largest TFCA globally, covering 520,000 km2 and counting on unique natural systems, interlinked supporting water systems, and immense biodiversity. It includes parts of the Okavango-Cubango and the Zambezi River Basins and the associated iconic inland Okavango Delta besides numerous proclaimed protected areas. The five partner states sharing the established (Category A) TFCA (Angola, Botswana, Namibia, Zambia and Zimbabwe) are undergoing rapid economic growth as well as significant population growth, especially in upstream countries like Angola with an annual population growth rate of 2.7%. Water scarcity, climate change, inadequate water infrastructure, growing human-wildlife and land use conflicts call for more proactive natural and water resources management and transboundary cooperation to ensure the resilience of communities, wildlife and the ecosystems on which they rely, while simultaneously supporting resilient economic growth. This paper presents and discusses the recent novel progress in terms of assessing and managing transboundary aquifer (TBA) resources geographically overlapping with TFCAs in the SADC context - which is a prominent phenomenon in the region - with a pilot case in the KAZA TFCA, counting on at least five identified TBAs. The work critically supports building the knowledge base and conceptual management frameworks, while linking to the broader governance structure of the KAZA TFCA and existing institutionalization of river basin organizations (ZAMCOM and OKACOM), the TFCA secretariat, the Peace Parks Foundation, as well as national coordination mechanisms.

1 IWMI - International Water Management Institute

Groundwater based intensive farming in Indo-Bangladesh lower Ganges basin: consequences and mitigations

Dhananjoy Dutta[1]

Groundwater resource in lower Ganges basin is of crucial importance for agricultural growth and domestic use in India and Bangladesh. Mostly the drinking water and two-thirds of irrigation are supplied by groundwater. The increased water demand for intensive farming and inadequate development of surface irrigation are driving the resource towards over exploitation, which leads to strong negative externalities on the water resources and socio-economic life of Indo-Bangladesh region. Investigations are carried out to find the impacts of groundwater over-abstraction and the means of addressing the issues towards sustainable management of the transboundary unconfined aquifer. Field studies in 15 transboundary blocks (sub-districts) reveal that the groundwater resource becomes semi-critical as the withdrawal rate exceeds recharge, resulting in a declining trend of groundwater table, increasing the number of grey and dark blocks, rising the operational cost of pumping, non-functioning of shallow tube-wells, drying up of dug wells, diminishing availability of water and loss of farm output over the two decades. The exhaustive pumping for boro paddy irrigation depletes the water table faster and aggravates the contamination of groundwater by arsenic. 13 blocks out of 15 surveyed are exposed to severe arsenic pollution in groundwater and the arsenic content in 49 % of tube-well drinking water is above the WHO permissible limit 10µg/L and that of above 50µg/L in 31% of tube-well water. The toxicity level even exceeds 300µg/L in some pockets. Findings confirm that water-table depletion and aquifer pollution with leached-out arsenic is a direct off-shoot of groundwater over-abstraction. The number of villagers affected by 'arsenicosis' due to drinking of arsenic loaded water is increasing day by day. For mitigating these problems, the study suggests a framework for scientific management and development of transboundary aquifer through institutional integration by formation of Joint Transboundary Water Resources Commission, implementation of the regulatory laws and guidelines of sharing transboundary water, governance of groundwater based on a real-time hydrothermal meteorological database like surface water and groundwater flow information, rainfall distribution, aquifer recharge pattern, recharge-discharge phenomena etc., participation of local people in decision making process, raising awareness of farmers and capacity building, change in societal mindset about water usage, promotion of optimal irrigation technologies, adoption of water-saving cropping pattern and revival of the traditional rainwater harvesting systems for surface water development. The success of the transboundary water governance of the region will largely depend on the political will and commitment from all Governments at all levels.

1 Bidhan Chandra Krishi Viswavidyalaya (State Agricultural University)

Transboundary aquifer governance in Australian law- implementing international law principles

Jennifer Mckay[1]

Australia has three examples of transboundary aquifer governance which is the product of water law being the province of the sub national jurisdictions. These are analogous to international law and are long standing and generally very successful. The governance regimes have evolved to integrate more science and changing values such the requirement to achieve Ecologically Sustainable Development. The national government is not without power and the management scheme adopted in the Great Artesian Basin (GAB) does reflect national drivers. These have evolved and waxed and waned and this factors influencing this will be briefly examined. This paper will examine the major three regimes in the GAB, South Australia and Victoria and New South Wales and Queensland. These will be examined in the light of the norms of international law and the SDG.s. The norms of the obligation not to cause appreciable harm or appreciable risk and equitable and reasonable use. This last principle is implied in ESD and the cases examining this concept will be discussed. There have been recent cases, such as the Rocky Hill Case in one state really emphasize the importance of precaution and will be examined in detail. There are gaps and I have argued before, that the Australian States need an obligation to cooperate. This paper will suggest some law reforms in Australia to assert a more coherent approach to international norms being implemented in Australia and the SDGs especially 6. Australia, however, also provides lessons for other jurisdictions in shared resource management.

1 University of South Australia

Water for Djibouti: safeguarding shared interests on the verge of AF59

Jenny Grönwall[1], Tarik Hassan[2], Getachew Hailemichael[2]

A Water Supply Project has been inaugurated for pumping groundwater from 28 boreholes in the Kullen Valley, Ethiopia, piped in bulk to Djibouti to meet drinking water needs. Financed by the Export-Import Bank of China it involves a private contractor from the same country. However, the project raises questions concerning regulation and decision processes (governance), groundwater resources protection (management), international cooperation, and human rights. Complicating matters is the fact that the wellfield is located just outside the boundary of the AF59 Afar Rift valley/Afar Triangle Aquifer, which is shared between Djibouti and Ethiopia with a minor part in Eritrea. Nonetheless, recent mapping for climate resilient WASH in Ethiopia in the GW4E project led by UNICEF suggests that the Kullen wellfield may be part of the AF59 system. If this aquifer is not yet correctly outlined, certain governance aspects are of relevance for future cooperation. The Afar aquifer is not subject to any multilateral agreement, but the contract between FDR Ethiopia and the Republic of Djibouti is of mutual interests and the result of hydro-diplomacy. As a federal state, Ethiopia has pronounced multi-level governance features as well as a river basin management organization, with overlapping but also orphaned mandates. Unlike for transboundary rivers and lakes, over which the Federal Government has powers to determine and administer the utilization, the constitutional situation regarding transboundary groundwaters is unclear. It can be argued that the government agencies of the Somali Regional State, where Kullen is located, had the mandate to issue the groundwater abstraction permit and also the obligation to conduct an environmental impact assessment. However, being of strategic importance to the respective countries, the agreement is struck with the FDRE Ministry of Finance as the implementing party. The Basin Development Office for the Awash river basin, tasked to give advice and technical support on water resources allocation disputes to the federal Basin Development Authority, should also have been involved. Presently, it is unclear who is in charge of resources protection and management of the recharge zone, and how local residents are allowed to access groundwater from it to ensure their human right to water is realized in an area that is subject to cyclical droughts. To safeguard the sustainability of the project, and provide for the locally concerned water users' interests, the principles of transparency, accountability, participation, and equity must be upheld to remedy for shortcomings in the planning and implementation phases.

1 Stockholm International Water Institute
2 UNICEF

Monitoring trends in transboundary groundwater agreements

Melissa McCracken[1], Christopher McCracken[2]

Groundwater is a vital and abundant resource globally; it is heavily relied upon to meet domestic, industrial, and agricultural demands and support ecosystem functions. Groundwater can be found in most places, and much of this is within transboundary aquifers and groundwater bodies. Nearly 600 transboundary aquifers have been identified thus far, underlying approximately 20% of the world's land surface (excluding Antarctica) (IGRAC and UNESCO-IHP 2015). Groundwater is often perceived as a reliable, consistent source of water, compared to seasonably variable and often over-allocated surface water. With the increased pressure on surface water driven by economic development, climate change, and population growth, the demands on groundwater have also risen, highlighting the need for transboundary cooperation and shared management. As a hidden resource, managing transboundary aquifers is a challenge, particularly when compared to surface waters. Since the mid-1850s, over 700 treaties, agreements, and related documents have been signed on the world's 310 transboundary surface waters (TFDD 2019; McCracken and Wolf 2019). In comparison, only a handful of groundwater specific agreements have been signed. Some surface water agreements attempt to address groundwater with varying degrees of specificity – ranging from a singular mention to detailed provisions for conjunctive use (see Lautze et al. 2018). With the increased pressure on groundwaters, there has been a slow but steady increase in the negotiation and signing of agreements addressing transboundary groundwaters, with most signed since the 1970s. The research and literature have heavily focused on cooperation and trends in surface water agreements; however, since groundwater is a considerably different resource, there is a need for monitoring trends in cooperation and agreements specific to groundwater. This will inform future cooperative efforts over transboundary aquifers. This paper builds upon the International Freshwater Treaties Database (IFTD), housed at Oregon State University, by developing a new groundwater specific coding methodology to help monitor trends in groundwater only and conjunctive use agreements. As a part of this effort, a search has been conducted to update the IFTD to include new treaties that address groundwater. This paper will present preliminary trends in these documents; in particular, it aims to identify how groundwater is addressed in surface water agreements compared to groundwater specific agreements. This paper aims to support future efforts to develop cooperative arrangements over transboundary aquifers by better understanding the trends in the types of agreements and mechanisms.

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The bumpy road towards transboundary groundwater management: the case of the Guarani Aquifer system in South America

Roberto Kirchheim[1], Ricardo Hirata[2], Alberto Manganelli[3]

Since the early 1990s, a vast hydrogeological unit shared by Argentina, Brazil, Paraguay, and Uruguay, called the Guarani Aquifer System (GAS), with an area of than 1,088,000 km2, has been recognized as the largest transboundary aquifer in the region. The four countries have alluded to the GAS's importance as an inducer of socio-economic development since the 70s. The GAS is currently responsible for meeting water demands for various uses by more than 15 million people. As deep-well drilling techniques become more accessible and as infrastructure conditions improve (such as access to electricity), a clear tendency to develop this resource, even in the highly confined conditions of the GAS, has occurred in the last decades. The GAS was the subject of a regional cooperation initiative financed by the Global Environmental Facility within its operational program dedicated to international waters. The World Bank acted as the implementing agency, with the Organization of American States acting as the executing agency, jointly among the four countries. In 2010, these countries signed the Guarani Aquifer Treaty that was inspired by the Declaration of the 1972 United Nations Conference on the Environment, Rio 92, Agenda 21, the United Nations Assembly on Transboundary Aquifer Law, Rio+10, and the Mercosur Framework for Environment. This study's contribution is to provide the necessary historical background on the process that led to the treaty ratification, classify the actions that have worked and those that have not, and better understand the transboundary integrated management mechanisms and strategies. There is no doubt that this treaty is one of the first examples of groundwater-related hydro diplomacy - a negotiation process that seeks to simultaneously balance national interests and strengthen regional and local cooperative governance in aquifers shared between countries. This article also describes some ways to overcome the barriers identified to allow other initiatives to benefit from the GAS experience, including those related to the challenges and dilemmas involving water and diplomacy. In discussing these processes, the institutional arrangements, and the idiosyncrasies of each country, we seek to determine why integrated management measures between the four countries have not yet been implemented, despite the regional cooperation initiative having created cutting-edge water management tools.

1 Geological Survey of Brazil
2 USP
3 CEREGAS

International law and the governance of transboundary aquifers: strengthening cooperation

Joseph W Dellapenna[1]

Groundwater has been used by humans and others from time immemorial. The earliest laws in history all had rules applicable to water resources but said little or nothing about groundwater or aquifers primarily because of the modest scale of usage. Steam-powered pumps in the mid-seventeenth century and turbine pumps in the 1930s increased the pumping of groundwater, causing legal disputes to proliferate. Local and national laws began to address groundwater shortly after these technical changes made law necessary. International law emerged relatively slowly for water resources generally, and even more slowly for groundwater or aquifers. International agreements on shared water resources rarely mentioned groundwater or aquifers before the last quarter of the twentieth century, and when they did it was very much as an afterthought. In the last quarter of the twentieth century, a few agreements specifically focused on groundwater did emerge and efforts began to articulate the application of international legal principles to groundwater or aquifers. First was the International Law Association's rather limited Seoul Rules on Groundwater (1986). Shortly thereafter, the International Law Commission's Draft Articles on the Law of Non-Navigational Uses of International Watercourses (1994), and the ensuing UN Watercourses Convention (1997), included some groundwater within their scope without, however, giving any real attention to the general rules might actually be applied to groundwater. Both the International Law Association and the International Law Commission continued to study internationally shared groundwater or transboundary aquifers. The Association produced it's Berlin Rules on Water Resources in 2004, including chapter VIII, a more thorough and complete study of the customary international law applicable to groundwater. The Commission completed its flawed Draft Articles on the Law of Transboundary Aquifers in 2008. Neither set of rules has gained widespread acceptance, yet without some generally accepted legal rules applicable to internationally shared groundwater or transboundary aquifers, cooperation over these resources will be difficult or impossible. In this paper, I will explore the need for and potential roles of international law in strengthening cooperation over internationally shared groundwater or transboundary aquifers. In doing so, I will critique the two most recent studies and suggest how they might be brought together and made more relevant to today's problems.

1 Beijing University School of Transnational Law

Strengthening on the Agreement on the Guarani Aquifer

Juan Pablo Galeano[1]

Groundwater and surface water don´t have political limits, as Eckstein rightly points out. States do, and their rights and interests over those waters, too. How to make them compatible? How to change confrontation into cooperation? The ILC - supported by UNESCO and ISARM – adopted the first draft articles on the law of transboundary aquifers, which then were approved by the United Nations General Assembly in 2008. Nowadays, the ISARM - together with the International Hydrological Program (UNESCO-IHP) - have identified more than 360 transboundary Aquifers around the world. This situation will probably arise some potential controversies of interests between States if legal frameworks based on cooperation aren´t implemented. One of them is in South America: The Guaraní Aquifer System, shared by Argentina, Brazil, Paraguay and Uruguay. Between 2001 and 2010, important instruments were taken as reference to allow the signing of the Agreement on the Guaraní Aquifer (AAG) in San Juan, Argentina, in 2010, at the thirty-ninth MERCOSUR summit. The AAG was finally ratified by Paraguay, last Party to sign. The AAG is a first step. The second one is to create the conditions for its effective execution. For this reason, I propose to expose the institutional contributions which I consider necessary to progress in the governance and cooperation of the AAG. The development of an effective institutional framework is needed it to allow real cooperation and management in accordance with the demands of sustainable development, making reasonable and equitable use of the potential of the Guaraní Aquifer. The AAG is a valuable international document, but it requires a prompt institutional framework design which will allow concretize all its planned objectives in reality. I understand the Hispano-Lusa cooperation in matters of shared underground water resources (Albufeira Agreement of 1998) is a contribution that can be extrapolated to the management of the AAG 2020-2050. Indeed, I observe the Albufeira Convention is a "cooperation agreement", which includes modern concepts of shared water resources management, taking into account the protection of the ecosystem. The Agreement assigns effective capacity to their institutions, granting specific functions to each one of them. Finally, I consider the paragon between the AAG and the Albufeira Convention provides value, guarantee and inspiration to those of us who try to carry out, for the present and future generations, the governance based on the cooperation between States, contributing to peace and sustainable development of our region.

1 Lawyer Magister Environmental Law

Updated frontier management stripe delimitation to manage transboundary aquifer systems

Julio T S Kettelhut[1], Claudia F Lima[2]

This paper intends to explore the discussions and reflections addressed in a previous poster presented at the UNESCO International Conference on Transboundary Aquifers: Challenges and New Directions (ISARM 2010), named "Proposal Methodology for Establishing Limit Distances from Country Boundaries for the Management of Transboundary Aquifer Systems" (KETTELHUT, NIEMEYER AND LIMA, 2010), which discussed a methodology proposal for estimating the wide of a strategic stripe of land, in the country border lines, where any action in water use really could have repercussion in the neighbor country. Depending on the size of the TAS area, identifying these activities for their total area is not a simple task, as it is directly related to the uncertainty of how and when they can occur, in a few hours, days, hundreds or thousands of years, or never happen. Probably one of the most important causes for the difficulty of this determination is the availability of reliable and systematized information related to the TAS. Consequently, it is a reasonable assumption that the efficiency of aquifer management would be better when smaller its area is, since it would be greater the chance of having more and better data available to establish a minimum understanding of management. Considering these premises, the previous poster suggested a methodology to estimate a minimum area of a TAS, called the Frontier Management Stripe (FMS), based on a systematic and reliable way to incorporate essential data/information about physical, demographic, environmental, social and institutional aspects, where transboundary groundwater management is necessary to achieve the establishment of legal governance instruments. The possibility of applying the previously proposed methodology will be discussed in a more extensive way updating and adding additional information, in order to complement and facilitate its application to obtain the necessary convergence understanding among the actors involved.

Key-words: transboundary, aquifer, management, stripe, updated.

1 Independent Consultant
2 Professional Master´s Program in the National Network for the Management and Regulation of Water Resources (PROFAGUA)

The STAS and ATOC – Two success stories of incremental science-based cooperation backed up by international water law

Stefano Burchi[1], Alice Aureli[2], Tales Carvalho Resende[2], Marina Rubio[2]

With assistance from UNESCO and the Swiss Government, cooperation among the countries sharing, respectively, the Stampriet Transboundary Aquifer System (STAS, shared by Botswana, Namibia and South Africa) and the Ocotepeque-Citalá Transboundary Aquifer (ATOC from its acronym in Spanish, shared by El Salvador and Honduras) unfolded in a familiar pattern seen elsewhere. Cooperation among the concerned countries has progressed from trust and confidence-building in the course of data collection and exchange, and that generated a reliable knowledge base of the aquifers, to articulating a science-inspired multi-country response to the desirability of institutionalizing cooperation among the countries concerned. Despite substantial achievements, both – data collection and exchange, and the institutionalization of cooperation – remain "work-in-progress" to-date. In this presentation the incrementally-evolving cooperation and the emerging virtuous loop linking science to international water law, and vice-versa, will be illustrated by reference to climate change, environmental and ecosystems management, the Sustainable Development Goals, international relations, and indigenous communities.

1 International Association for Water Law (AIDA)
2 UNESCO

Agreements and arrangements on transboundary aquifers: clarifying key concepts from a legal perspective

Laura Movilla Pateiro[1]

Significantly few transboundary aquifers are governed by a legal instrument shaping the cooperation related to them. When these legal instruments exist, and contrary to what usually happens in the legal articulation of State cooperation regarding surface water, they are not always in the form of a treaty, as defined by the 1969 Vienna Convention on the Law of Treaties. The International Law Commission's draft articles on the Law of Transboundary Aquifers itself encourages aquifer states to enter into agreements and arrangements for the purpose of managing particular transboundary aquifers or aquifer systems. In practice, there is some confusion around the concepts of agreement, arrangement and other related expressions, especially among non-lawyers. Differentiations between terms such as formal and informal and binding and non-binding instruments are also common, although they are not always properly used from a legal point of view. More recently, the notion of operational arrangement, as found in the United Nations' Sustainable Development Goal indicator 6.5.2 emphasizes a legal instrument's effectiveness in fostering transboundary cooperation over its legal nature. The purpose of this paper is to clarify the main concepts surrounding agreements and arrangements concerning transboundary aquifers from a legal perspective and to reflect on their impact in the practice and the quality of these cooperative efforts. Keywords: agreement, arrangement, transboundary aquifers, cooperation.

1 University of Vigo

Transboundary groundwater bodies and monitoring networks of the Republic of Belarus and of Ukraine - developed under EUWI+

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The EU-funded program European Union Water Initiative Plus for Eastern Partnership Countries (EUWI+), which is the biggest commitment of the EU to the water sector in the EaP countries, helps Armenia, Azerbaijan, Belarus, Georgia, Moldova, and Ukraine to bring their legislation closer to EU policy in the field of water management, with a main focus on the management of transboundary river basins. It supports the development and implementation of pilot river basin management plans, building on the improved policy framework and ensuring a strong participation of local stakeholders. In the past two years EUWI+ stipulated and supported the close co-operation of groundwater experts from Ukraine and the Republic of Belarus to jointly identify transboundary groundwater aquifers in the Dnieper/Dnipro and the Pripyat river basins and to harmonize the delineation and characterization of transboundary groundwater bodies according to the requirements of the EU Water Framework Directive (WFD). The implementation of the first step of work resulted in the identification of 14 significantly large groundwater bodies (six in Belarus and eight in Ukraine) which are transboundary connected. In a second step, the groundwater experts of Ukrainian and Belarus elaborated a common approach to identify those sub-parts within the groundwater bodies which are supposed to be actually interconnected by transboundary flow of groundwater and potentially influenced by the effects of anthropogenic pressures in terms of groundwater quantity and quality. Finally transboundary corridors at a distance of 50 km from the State borders of Ukraine and the Republic of Belarus were identified as sub-zones of the existing large GWBs. This distance was chosen to capture the recharge areas of the zone of active water exchange (watersheds) and the areas of groundwater discharge (river valleys). Beside the financial support, EUWI+ accompanied the national expert's side-by-side, providing guidance, expertise and feedback in order to guarantee that the results of the work are in conformity with the requirements of the WFD and the River Basin Management Plans which were elaborated in parallel. Within this work a comprehensive set of analytical material on geological-hydrogeological, hydrogeochemical, hydrodynamic aspects of the study area was collected, a number of open issues were identified, which will substantially contribute to the development and harmonization of not only the groundwater monitoring system of the transboundary territory of the Pripyat and Dnieper river basins in Ukraine and the Republic of Belarus, but also the groundwater monitoring system of the countries as a whole.

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The Agreement on the Guarani Aquifer: what to expect?

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After a lengthy waiting process, Argentina, Brazil, Paraguay, and Uruguay have ratified the Agreement on the Guarani Aquifer, signed on August 2, 2010. The water community has extensively celebrated this achievement, which was supported by the end of the Guarani Aquifer System Project and the United Nations General Assembly Resolution 63/124 (2008) concerning to the Draft Articles on the Law of Transboundary Aquifers. The objective of this paper is to analyze how the entry into force of this Agreement influences governance of the Guarani Aquifer System. The agreement that went into effect on November 26, 2020 will allow the Guarani States to deepen the cooperation process, which will require the following steps: a) creating a commission for the Guarani aquifer (art. 15); b) defining the arbitration procedures for settling disputes by issuing an Additional Protocol (art. 19); c) implementing groundwater cooperation programs (art. 12); and d) identifying critical areas, especially near borders, where a transboundary groundwater flow exists. The delay caused by Brazil and Paraguay in the ratification process, as well as the time that Brazil, as the depositary of the agreement, is taking to publish it leads to the question of when and if this cooperative process will come to fruition anytime soon. The approval of another international project in the area called Implementation of the Guarani Aquifer Strategic Action Program: Enabling Actions – with the participation of the four countries, the Global Environmental Facility as financier, and UNESCO as the executive agency, and with technical support from the Regional Center for Groundwater Management (known as CeReGAS) – can encourage the Guarani States to implement the agreement and establish the commission. The most urgent action is the creation of the Guarani Aquifer commission, which is responsible for coordinating cooperation in compliance with the principles and objectives of the agreement. Without this commission, there is a significant risk that the cooperation process promised by the agreement will continue stagnate. Unfortunately, the international scenario in the region is not very optimistic for cooperation due to the COVID-19 pandemic and its economic effects, as well the national political context in Brazil.

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A systematic review of international cooperation on groundwater governance for enhanced water management

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With around two billion people worldwide depending on groundwater, and about 98 percent of accessible freshwater stored in aquifers, including approximately 300 transboundary systems, strengthening the global discourse on groundwater governance is a priority to ensure long-term functionality and sustainability. Careful attention should be paid to the regulation of transboundary aquifers. Cooperative governance approaches are crucial to foster collective actions for the protection, monitoring and socially-sustainable use of common resources. Equally important, participated and transparent decisions are fundamental to overcome the potential drama of the commons posed by shared water resources and preserve the hydrological, social and economic linkages created by interdependent water bodies. Cooperation over cross-boundary lake basins and watercourses is nowadays largely recognized as a valuable practice not only to prevent potential conflicts and pave the road for wider collaborations among States, but also to increase mutual benefits derived by enhanced management of joint resources. The "invisible" nature of groundwater, however, requires new approaches to find common grounds as it more often triggers unregulated consumption practices and individualistic exploitation of a common-pool resource. While governance frameworks for cross-boundary waters have a long history, cooperative approaches for transboundary aquifers are still in their infancy. Furthermore, joint governance mechanisms are often sectoral and do not respond to the fundamental need to consider aquifers as integrated systems to avoid the rise of conflicting interests. The "Shared global vision for Groundwater Governance", elaborated by a partnership of international institutions, outlines a series of guiding principles to translate groundwater governance into practice. The Vision recognizes the need to define effective governance arrangements linked to aquifer levels, also in the case of transboundary basins. Building on these principles, this paper presents a systematic review of existing international cooperation on groundwater governance in developing countries, considering varying types, modes and scales of international cooperation. The objective is to synthetize and assess the main characteristics of such cooperation and to measure the impacts on the multiple dimensions of water management, from sustainability and environmental aspects, to conflict resolution and peacekeeping, social and economic benefits, water use efficiency and productivity increase and agricultural production. In conjunction with the systematic review, a non-parametric estimation method is carried out for the meta-analysis of data that seeks for causal relationships between the key characteristics of the involved cases. The paper, finally, concludes evidence-driven recommendations on the future trajectories of strengthened cooperation in groundwater governance.

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Contribution of CAF, as a regional development bank, in the integrated management transboundary groundwater systems

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CAF, being the Development Bank of Latin America and the Caribbean, contributes to solve the structural aspects that impede the development of the region. This, by carrying out activities to support, promote, foster, and strengthen the capacities of its member states, emphasizing the will to promote universal access to quality services in the areas of health, water, and sanitation; requires the strengthening of scientific and technical knowledge on water and its services, and the development on solid economic, social, and environmental bases to support it governance. CAF has been selected by the governments of the countries that own the Guaraní Aquifer System (SAG): Argentina, Brazil, Paraguay, and Uruguay, as the GEF´s executing agency to begin implementation of the Strategic Plan of Action (SPA Guaraní). It signed an agreement with UNESCO to share scientific and technical knowledge and efforts, to execute the project, and to strength the governance of the SAG. With an area of 1 087 879 km2 and an estimated water volume of 37 km3, the SAG underlies the territory of the 4 countries. This huge transboundary groundwater resource is largely contained within the La Plata River Basin. It is a particularly rich region, with an important industrial, commercial, and service development. The SAG has been one of the determining factors of this development of the region. Greater knowledge of the SAG shows strong nexus of water recharge and discharge with the surface water system. The scenario for agreeing on integrated management is also being supported by CAF. The joint regional effort generated confidence from the parties. This laid the groundwork for the "Agreement on the Guaraní Aquifer", an initiative of the Presidents of the 4 countries to provide a legal framework for the sound management of the SAG. This Agreement has been recently ratified. The experience generated constitutes an advanced precedent that is currently being deepened based in the Guaraní SAP, as a pilot project to implement a first phase presented here, of its joint monitoring, sharing information; institutional legal framework consolidation, under the guidelines of the Guaraní Agreement and recognize the roles of women and the rights of indigenous peoples for their promotion. This is how CAF seeks to make a difference and manages to bring concrete solutions by projects financed from international green funds and its interventions in financing credit operations that are aligned with national and local priorities. Keywords: Guaraní Aquifer SAG, CAF, transboundary groundwater, sustainable use, protection, confidence, scientific and technical knowledge.

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Scientific basis for increasing cooperation to preservelong-termgroundwatersustainability along the northwestern Mexico-US border

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As is the case in many locations along international boundaries, there are problems on the northwestern Mexico-US border related to major groundwater extraction. Groundwater is an especially important resource in this densely populated area, where the Lower Colorado River Delta Aquifer (LCRDA) is located, representing an important transboundary water source. The water extracted in the LCRD is mainly used for domestic, agricultural lands, and industry; riparian ecosystems benefit from this resource too. Locally, the most important stakeholders are farmers, representing the most influential groups in water policy on both sides of the Mexico-US border. Farmers tend to protect their own interests rather than a shared local or regional interest in groundwater. Groundwater is managed using administrative delineation rather than hydrogeological boundaries, which involves many jurisdictions and interests and creates a significant challenge for transboundary collaboration. Most of the scientific knowledge of the LCRDA is scattered in isolated areas, without integration of data or a full understanding of the groundwater dynamics of the entire LCRDA system. Mapping, monitoring, and managing groundwater have been carried out primarily on a local scale. Furthermore, every new water project is planned without considering the possible effects on the other side of the border. One example is the lining of the All-American Canal that resulted in recharge reduction in the local aquifer, south of the border; another example is the uncontrolled and unmeasured pumping that takes place south of the border. Many looming issues have impacts and affect groundwater resources on both sides of the border, such as persistent droughts, urban growth, new industries, expansion of agricultural land, and changes in land use. Thus, the challenges to reach water security for both sides are immense, but so are the opportunities to achieve binational cooperation in terms of water security. Clearly, the state of affairs along this part of the Mexico-US border cannot remain the same for too long if groundwater is to be preserved in a sustainable way. Binational cooperation has proven to be possible thanks to Minutes 242 (1973) and 316 (2012) drown up under the Surface Water Treaty signed by the two countries in 1944. Under Minute 319, Mexico and the U.S. celebrated a cooperative approach to their "hydro-relations" on the Colorado River, highlighting the provision of water for the environment and hydraulic infrastructure projects. These are clear examples of progress on the path towards water sustainability. Current efforts include building a unified conceptual model that integrates surface water, groundwater, and transboundary effects, as a first step in a joint scientific assessment. These efforts represent the basis for future shared binational cooperation.

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Advancing transboundary cooperation in the Senegalo-Mauritanian Aquifer Basin

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The Senegalo-Mauritanian Aquifer Basin (SMAB) is a large sedimentary basin comprising several regional aquifers shared by the Gambia, Guinea-Bissau, Mauritania and Senegal. These aquifers provide drinking water to most of the cities. Groundwater is also supplying rural communities to a large extent. In the Gambia, all water needs are met by groundwater. Recognizing the strategic relevance of these groundwater resources, the four countries have engaged in 2019 in a dialogue to develop transboundary cooperation. Since the Gambia and Senegal river basins intersect the SMAB, the organisations of these river basins, OMVG and OMVS, take an active part in this dialogue. The initiative is further supported by the Geneva Water Hub, the Secretariat of the Convention on the Protection and Use of Transboundary Watercourses and International Lakes, hosted by the United Nations Economic Commission for Europe, and the International Groundwater Resources Assessment Centre. A Regional Working Group regrouping representative of the parties was set up in 2020 and endorsed by the four water ministers, in order to promote transboundary cooperation on groundwater management issues. With the support of regional and external consultants, the Regional Working Group prepared a series of reports describing and analyzing the status of groundwater resources in the SMAB, the legal/institutional framework in the four countries, as well as the capacity of the organisations in charge of groundwater management, among others. Challenges and gaps were identified, and recommendations were made to address them. Existing maps and datasets were collected and, when required, georeferenced and digitized. They were shared in a dedicated map viewer online. Based on this preliminary assessment, the Regional Working Group has been designing a regional project for advancing cooperation and water management in the SMAB, including a workplan of activities for the next five years. The ambition of the project is to improve the knowledge and the governance of groundwater resources, in relation with surface water resources. This is to exploit groundwater resources in a fair, efficient and sustainable way, in support to regional development. According to the workplan, the Regional Working Group will be replaced by a permanent mechanism for joint groundwater management.

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TBA agreements and arrangements: from paper tigers to effective implementation

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The first ISARM Conference on Transboundary Aquifers took place in December 2010, just a few months after the adoption of the Guarani Aquifer Agreement. In Paris, participants hailed the adoption of the agreement with some considering whether a trend was starting to occur. In fact, the Guarani Aquifer Agreement followed by just one-year United Nations General Assembly Resolution 63/124 that has annexed the UN International Law Commission Draft Articles on the Law of Transboundary Aquifers. The paper will discuss whether a trend leading to an increase in the development of transboundary aquifer cooperation has indeed (or not) taken place between the first and second ISARM Conference on Transboundary Aquifers. The emergence (or not) of a trend will be analyzed in light of the developments related to the Guarani Aquifer Agreement from its adoption to its entry into force in 2020. I will also review the transboundary aquifer normative and institutional developments that took place in Central America (the Ocotopeteque Citala), in Southern Africa (the Stampriet Aquifer System and the Ramotswa Aquifer), in Sub-Saharan Africa (the Iullemeden Aquifer), the Middle East (the Disi Aquifer) and in Europe (the Carbonifere Aquifer). The review of transboundary aquifer state practice between 2010 and 2020 shows a slow increase in numbers of agreements and arrangements related to specific transboundary aquifers. One key conclusion is that having an agreement or an arrangement is not an indication of success for governance per se. Transboundary aquifer agreements and arrangements are only paper tigers if they are not coupled with effective implementation. In order for the latter to be a reality, institutions are essential. However, even in this case, institutions per se will not deliver effective governance. Institutions need to be well resourced, both financially and in terms of human resources. The creation of a Commission ex article 15 of the Guarani Aquifer Agreement will be a test bed of this effective implementation and will show whether the agreement is only a paper tiger, or, indeed, a first step towards effective implementation. The paper will conclude with some more general remarks on the future of international law of transboundary aquifers given state practice over the past ten years and ahead of the topic being discussed in 2022 before the UN General Assembly Sixth Committee.

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Making a case for groundwater governance in southern africa and the role of rbos in implementation of groundwater governance regimes: the case of the Stampriet Transboundary Aquifer System (STAS) in the Orange Senqu River Basin

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Groundwater is the primary source of water in many African countries, including Southern Africa. It is estimated that more than 75% of the African rural population relies on groundwater. Despite its strategic role in people's livelihood, groundwater in Africa is poorly understood and managed due to limited resources and inefficient groundwater monitoring networks. Consequently, governance of groundwater is compromised particularly at transboundary levels. Sustainable management of groundwater is thus essential to achieving water security in water stressed environments. In this paper, a case study on groundwater governance in Southern Africa is discussed: The Stampriet Transboundary Aquifer System (STAS) shared between Botswana, Namibia and South Africa and implemented by the governments of these three countries, jointly with the Orange-Senqu River Basin Commission (ORASECOM), UNESCO's Intergovernmental Hydrological Programme (UNESCO-IHP) and the Swiss Agency for Development and Cooperation (SDC) within the auspices of UNESCO's Governance of Groundwater Resources in Transboundary Aquifers (GGRETA) project (2013-2021). The methodology of and insights from the scientific assessment are discussed, as well as the role of river basin organisations (RBOs) and the process leading to the establishment of STAS groundwater governance model. Key achievements, opportunities, challenges and lessons learnt during the implementation of the project are highlighted. The STAS is the only dependable water resource for the 50 000 inhabitants in an 87 000 km2 STAS area. The main highlights are that the STAS has three main aquifers: the top unconfined and intensively used Kalahari aquifers with thickness of up to 350m. Below the Kalahari aquifers and separated from them by the Rietmond and Mukarob aquitards are the two artesian and confined Ecca group sandstones aquifers of Auob and Nossob, respectively, which are part of the so-called Stampriet Artesian Basin, and can be as thick as 150m, and 60m, respectively. Groundwater is mainly used for irrigation (52%), livestock (32%) and domestic purposes (16%). Annual groundwater abstraction is about 20 million cubic meters (Mm3), with 70% used for irrigation in Namibia. Although there is no mining activity in the area at present, unregulated mining activities in the future might lead to pollution of the aquifer. Regarding groundwater governance, the STAS countries used an existing structure of ORASECOM, to institutionalize the STAS governance mechanism for joint management of the STAS. This becomes the first example of institutionalizing cooperation of a transboundary aquifer within an RBO in Southern Africa to ensure continuous operationalization of STAS specific priority issues beyond the project life.

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Latin America's perspectives on the governance of transboundary aquifers: the protection of indigenous peoples in the Guarani Aquifer System

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This paper aims to analyze the rights of indigenous peoples in the context of the governance of transboundary aquifers in South America, with special regard to the Guarani Aquifer System. The Law of Transboundary Aquifers was codified by the International Law Commission in 2008, following the normative elements consolidated in the Convention on the Law of the Non-Navigable Uses of International Watercourses. In this context, the Guarani Aquifer Agreement was drafted and adopted by Argentina, Brazil, Paraguay, and Uruguay, which endorsed the normative elements of the Draft Articles on the Law of Transboundary Aquifers, but also reiterated the sovereignty of each State over the respective parts of the aquifer, despite the legal and scientific challenges of this reserve. The Agreement establishes, among others, the duties to manage the aquifer on the basis of reasonable and sustainable uses criteria, respecting the obligation of not causing significant harm to the other Parties or the environment. Furthermore, the State parties must exchange information and cooperate, which is overseen by a Commission established under the Treaty of the Plata River Basin.

Given the Guarani Aquifer Agreement's recent entry into force, the consideration of Indigenous Peoples in the institutional framework of this international agreement is essential for their protection. In this regard, the research presents the consolidated jurisprudence of the Inter-American Court of Human Rights (IACtHR) on the rights of Indigenous Peoples to manage and use water resources according to their customs. The considerations for the protection of Indigenous Peoples are analyzed in the light of the principles codified by the Guarani Aquifer Agreement for water allocation and for the prevention of environmental harm.

The Inter-American Court of Human Rights has expanded the scope of the human right to life, provided in article 4 of the American Convention on Human Rights, to encompass the right to a dignified life. In this way, the interpretation of the Inter-American Court of Human Rights has integrated normative elements of economic, social and cultural human rights into a civil and political human right. In this sense, based on the concept of dignified life, the Inter-American Court of Human Rights has determined that the human right to life presupposes not only negative obligations, which determine that no person will be deprived of his or her life, but also positive obligations, which entail the adoption of all measures necessary to guarantee a dignified existence, including access to water. Therefore, the Inter-American Court of Human Rights has developed the normative elements of the human right to water in several cases, mostly dedicated to vulnerable groups, such as Indigenous Peoples. In these cases, the Inter-American Court of Human Rights not only stated that the State must provide sufficient water to

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guarantee a dignified life, as they face a situation of vulnerability, but it must also follow due diligence requirements for the protection of these communities. For instance, the obligation to protect the nature reserve areas and the territories of the indigenous communities entails a duty of monitoring and oversight. Furthermore, Indigenous Peoples have the right to consultation and to participation at all stages of the planning and implementation of a project or measure that might affect them.

The paper concludes that the protection of the rights of Indigenous Peoples enshrined in the jurisprudence of the IACtHR represents lex specialist in relation to the norms regulating the utilization of water and the exercise of due diligence in the context of the Guarani Aquifer System. Hence, the research concludes that the analysis of the equitable use of the Guarani Aquifer's water must take into consideration the States' obligations towards Indigenous Peoples and the vital human needs of these populations, whilst the due diligence processes shall comply with special measures when there is a risk of affecting the groups concerned. To address these issues, the Commission referred by the Guarani Aquifer Agreement must regulate the interlocution with the Indigenous Peoples that might be affected by the management of the aquifer.

The impact of climate change and water governance on groundwater resources in the Medjerda River Basin

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In addition to the existing governance systems in the neighbouring states, groundwater management in the transboundary basins is affected by uncertainties related to climate change. The Medjera River Basin (MRB) is shared between Algeria and Tunisia. In Algeria, groundwater is an essential capital regarding the water reserves and in Tunisia, groundwater use has given rise to several terms of short- and medium-term socio-economic benefits. Groundwater management is affected by uncertainties related to climate change as well as inefficient governance structures affect resource use. The impact of climate change on groundwater resources is likely to be serious. It should be noted that groundwater is the main source of drinking water in the basin. This paper assesses the impact of climate change on the groundwater resources of the Medjerda River Basin using the Water Evaluations and Planning (WEAP) model under two scenarios of Representative Concentration Pathways: RCP 2.6 and 6.0. The main groundwater basin was divided into two sub-basins. Five demand sites were selected from the 5 cities which are in Algeria (Souk Ahars) and Tunisia (Jendouba, Beja, Siliana and Le Kef), namely, agriculture sector, industry sector, domestic sector, tourism sector, and collective uses sector to represent the impact of climate change on groundwater resources.

In WEAP, the typical scenario consists of three steps a current account year selected as the model base year a reference scenario established from the current account and used to simulate the likely evolution, without interposition, of other scenarios to assess the effects of climate change for the future year or project. The climate sequences scenario is assessing the impact of climate change on water resources in relation to user's needs. GCMs have been used to predict the impact future of climate change by various institutions specialising in climate research. Their models and analyses data were taken from the IPCC Data Distribution Centre at http://www.ipcc-data.or. The RCP (2.6 and 6.0) scenarios allow to model the future climate, each RCP scenario gives a variant of the climate that is considered likely to result from the level of emissions chosen as a working hypothesis.

Based on the simulations, the following are the results:

- The simulation results show that the variations in groundwater storage and recharge under RCP 2.6 and RCP 6.0 scenarios are similar in storage variation except for April 2025 and July 2050. Some years show an increase in groundwater storage, while other years showed a decrease.
- In relation to the unmet demand, it was seen that the unmet demands were zero

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under the three climatic scenarios (RCP 2.6 and 6.0 and dry climate sequence), which means non-renewable groundwater will be used due to the decrease in groundwater storage.

- The predicted simulations showed a decrease in groundwater storage, which highlighted the need to address climatic challenges and to propose sustainable transboundary water resources management plan based on stakeholder involvement and regional cooperation.
- Climatic models are based on assumptions and predictions. Therefore, climate change impact on groundwater on MRB needs further research work assessment using other climatic models to improve our knowledge regarding the way that climate change can impact the hydrological cycle and water uses in Algeria and Tunisia.
- Government structures and cooperation frameworks need more studies for better sustainable transboundary water management in Algeria and Tunisia.

Development of framework to assess the groundwater governance in transboundary aquifers of rapidly urbanizing cities

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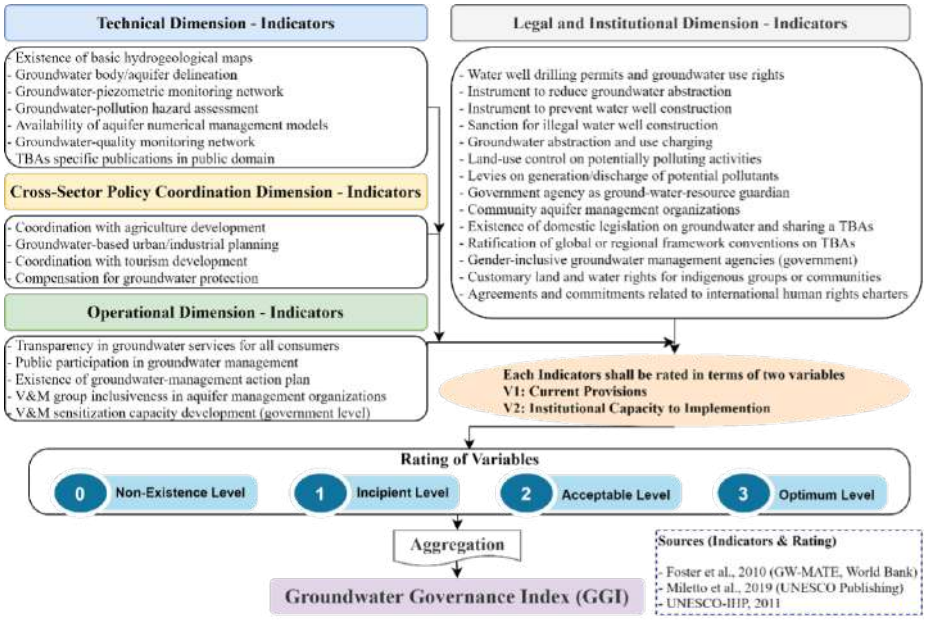
Globally, 68% of the world's population is estimated to reside in cities by 2050, rising the number of small, medium-sized and megacities. These rapidly urbanizing cities are crucial in the overall national economy and thus are highly stressed in public service delivery. One of them is the delivery of water supply and sanitation with rapidly increasing demand. Groundwater, a common-pool resource and the source of one-third of all freshwater withdrawals for domestic, agricultural, and industrial sectors, have been threatened due to its increased demand and exploitation. This scenario is more challenging among transboundary aquifers (TBAs) shared by these rapidly urbanizing cities where sustainable management becomes very complex. In addition to its vulnerability to availability and quality, the unfair access to the resource, social, cultural, and other contextual differences among the sharing cities or countries and inadequate knowledge, information and understanding of own's prevailing state of groundwater governance has hindered consultation and collaboration among these shared aquifers. This has also increased the possibilities for several social, sectoral, and right-based conflicts. Thus, this study develops a framework for diagnosing the existing state of groundwater governance (GWG) in an individual segment of TBAs using an indicators-based approach. The framework (Fig. 1) comprises 4 dimensions and 30 indicators addressing the components of GWG, which are rated using 2 variables.

Figure 1.
Framework with dimensions, indicators, variables, and rating mechanism to assess the groundwater governance



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The rating of each variable is on a range of 0-3, where 0 represents the non-existence state, and 3 represents the optimal state (Foster et al., 2010). The aggregation of the variables within each indicator (eq.1) and aggregation of the indicators within each dimension (eq.2) is done using,

$$I_{xy} = \frac{V_1 + V_2}{2} \qquad \text{eq.1}$$

$$D_x = \frac{\sum_{y=1}^{n} W_y * I_{xy}}{\sum_{k=1}^{n} W_y} \qquad \text{eq.2}$$

And finally, the GGI is calculated by using the formula,

$$GGI = \frac{\sum_{x=1}^{n} W_x * D_x}{\sum_{x=1}^{n} W_x} \qquad \text{eq.3}$$

where, D = Dimensions; I = Indicators; V = Variables; W = Weightage; and x, y represents number of dimensions and number of indicators within in each dimensions respectively.

The values are normalized in a comparable form, and the aggregation of all the framework elements provides a single quantitative value known as the Groundwater Governance Index (GGI). The GGI value signifies the present state of GWG, which thresholds range from 0-3, indicating the different states of GWG (Table 1) in the applied segment of TBA. The framework shall be useful for policy and decision-makers, managers, and related actors in stocktaking their provisions and capacity for groundwater governance and management, understanding their strengths, gaps, areas for improvement, and visualizing their prevailing state of groundwater governance for possible TBA cooperation. Furthermore, the framework also incorporates the provisions of including vulnerable and marginalized groups in the governance mechanism. This individual appraisal on both sides of the aquifer shall ultimately facilitate developing suitable collaboration strategies, identifying the joint benefits, strengthening the groundwater governance, and implementing effective operational management approaches for the development, protection, and sustainable management of shared urban aquifers.

Table 1.
Interpretation of the results of groundwater governance index

Threshold	State of Groundwater Governance
0	Non-Existent State of Governance
0.01 - ≤ 1	Incipient State of Governance
1.01 - ≤ 2	Acceptable State of Governance
2.01 - ≤ 3	Optimum State of Governance

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The ILC Draft Articles – a governance scenario retrospective from 2060, based on alternative projections in six transboundary aquifer systems – the impact of the "Red Queen Effect"

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This paper will discuss the likely 2030 (the SDG year) and 2060 conditions (key year in climate change) for six transboundary aquifers system: The Guarani, The Rum-Saq, The Nubian, The NW Sahara, The Iullemeden-Tadjouni and The Stampriet aquifer systems, and match their evolution to the provisions of the Draft Articles. The study will analyse unfolding scenarios that might occur with, and without, the adoption of the Draft Articles. The forecasting aims to reflect on how alternate policies could play out on hydrogeological conditions, and as a result the potential impacts on national water security. Since each of the listed transboundary aquifer systems has a mathematical model that has been constructed and calibrated for reasonable forecasting accuracy, making a projection of the impact of alternate governance frameworks, will provide interesting insights. In particular these will inform resource consumption, the trajectory of inter country hydro diplomacy that may take place, and the probable socio-economic impacts. The paper aims to offer some insights for the hydrogeological and socio-economic practitioners to help them to better focus on the needs of those who adopt policies, by reflecting on "what is the science that a policy adopter needs?" rather than "here is the science" and then expecting the policy maker to understand and implement it. Why is future forecasting with and without the ILC Draft Articles relevant? Because although over 200 hydrogeologists were consulted during the formulation of the UN ILC's Draft Articles during their drafting (2000 to 2008) to ascertain their applicability, yet in 2021 their status remains unclear – the "Red Queen" effect is evident. The accumulated wisdom and experience of those experts coupled with the knowledge and experience of international water law experts were submitted to the UN ILC's Special Rapporteur during his pioneering work. Almost two decades have passed since the Articles were presented to the UN General Assembly, and the topic of transboundary aquifers has become one of the hottest items appearing in the international literature on this subject. The exponential increase in the number of studies on transboundary aquifers and the mid-point progress of SDG 6.4.2 (in 2018) show very limited coincidence. The question that could now be considered is: how are such studies informing the adoption of policies on transboundary aquifers today, and what can be expected in the run up to the final year of Agenda 2030 and beyond, to 2060, a time when climate change impact might be ruinous in some regions? The latter time frame also reflects the probable "peak aquifer" conditions when abstractions started around the year 2000, may well have extracted over 50% of storage in both replenishing and non-replenishing aquifers.

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Groundwater and socio-economic development: Implications for cross-sector related groundwater policies in Thailand

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Groundwater a key foundation for socio-economic development including food security, drinking water and sanitation, economic development, sustaining ecosystems (Ferchichi et al., 2020). However, it is overlooked by governments as it is the invisible resources (Chambel, 2015) and difficult to monitor both supply and demand sides (Rajeevan & Mishra, 2020). As a result, groundwater resources are often under pressure due to human development (Smith et al., 2016). Groundwater depletion and deterioration is associated with pollution and over abstraction (Prajapati et al., 2021).

This study aims to examine groundwater withdrawal state and socio-economic and environmental pressures on groundwater resources in Khon Kaen, Thailand, one of among rapid urbanizing and drought prone areas in Lower Mekong region. We assess socio-economic activity development in the last 20 years (2000-2019) which may transcend the catchment level and have regional implications for cross-sectoral groundwater policies. Mann Kendall test and Sen's slope estimation are applied to examine the trend of groundwater withdrawals overtime, while ARIMA model is used to assess how socio-economic and climate factors affecting groundwater withdrawals.

According to data provided by Department of Groundwater Resources in Khon Kaen province, the annual groundwater withdrawal increased from 43,070 m3/year in 2000 to 18,996,425 m3/year in 2019. Business sector is the largest groundwater consumer, accounting for 12,385,545 m3/year. In the last 20 years, there has been a moderate increase rate in population number (+3.1%), but the province has become a rapid urbanized province and tourist destination with an increase of +42.65% in urban areas and +353.4% in tourist visitors since 2000. Although agricultural land has decreased +6.3%, groundwater withdrawal for irrigation has increased +517.5% over last 20 years. The number of industrial establishments have been significantly dropped between 2011 and 2012 due to the introduction of policies on industrial waste disposal fee, but industry is the major groundwater user which accounts for 13,148 m3/day and 883 wells (DGR, 2020). Business sectors has competed with households and agriculture for groundwater consumption.

Trend analyses showed significant increasing trends in groundwater withdrawals, urbanizing areas, tourist arrivals, hotels, and restaurants new establishments; and at the same time, Provincial Gross Productions in different economic sectors have been also increased over the last 20 years. The groundwater withdrawal trend has been associated with the increased urbanized areas and economic development.

The trend analyses also showed that precipitation had no change, but annual average

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temperature increased +0.02 oC/year between 2000 and 2019. Although groundwater level is stable and/or slightly decreasing in some locations in the last decades, the effect of increased temperature and drought together with high pressure of economic development would cause groundwater depletion in both medium term and long-term period in the province.

Royal Thai government issued Groundwater Act in 1977 to control groundwater well drilling and withdrawals. The Act was revised and added some regulations to control intensive groundwater use on land subsidence in 2003 (DGR, 2020). There have been also many policies at both national and provincial levels introduced regarding groundwater use and management after 2003, however the groundwater abstraction has been tremendously increased in the last two decades. This is because many economic development policies such as urbanization, tourist development, intensive agriculture and industrial development have been launched in the province in the last 20 years. At the same time, national and provincial groundwater policies have mainly focused on groundwater abstraction, infrastructure and well establishment rather than groundwater conservation and sustainable groundwater use in economic sectors.

Although Royal Thai government has started experimenting groundwater decentralization model in some provinces, the groundwater management is still top-down and lacks coordination between groundwater management and other sectors such as environment, agriculture, business, and industrial development. This study provides an understanding of groundwater and socio-economic development interactions and appeals for cross-sector dialogue and participatory water-food-energy approach (Ghafoori-Kharanagh et al. 2021) for groundwater governance ensuring sustainable groundwater resources management and enhancing economic development in the country.

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Sovereignty over shared groundwater: Reason for cooperation

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That there is a tension between sovereignty and transboundary water cooperation is a generally prevailing presumption in international law.[1] Adoption of ILC Draft Article on Transboundary Aquifers (the Draft Articles hereinafter) has brought the issue to the forefront. Inclusion of sovereignty (article 3)[2] as one of the governing principle concerning transboundary aquifer (TBA) concedes two types of reactions: first, one group considers, the mention of sovereignty in any form will have a truckling effect on the cooperation effort garnered by the international community so far[3] ; second, the other cautiously optimistic group[4] considers, the good faith reading of article 3 in its entirety would mean, states cannot claim absolute sovereignty over TBAs within their territory, instead they must tailor their sovereignty claim with due consideration to the principles listed in the later part of the Draft Articles. Is there a third way sovereignty over natural resources can be understood, that strengthens international cooperation on shared groundwater?

The Draft Articles refers to GA resolution 1803 (xvii) of 1962[5] in its preambular paragraph, meaning, countries have permanent sovereignty (PSNR) over TBA within their territory.[6] So it is consequential to contemplate on the concept of Permanent Sovereignty over Natural Resources (PSNR) and the legal significance of its inclusion in the Draft Articles. Would PSNR arm the states, unwilling to perform their duties under principle of equitable and reasonable utilization (ERU, article 4), not to cause significant harm (article 6), obligation of regular exchange of information (article 8), with alternate legality?[7] PSNR has long been established as a principle that embodies a balance of rights and duties.[8] Schrijver in his comprehensive book on PSNR lists several duties that are correlative to the widely acknowledged rights of states. Among the duties Schrijver identifies, following are relevant in case of TBA ; 1) Duty to have due care for the environment, 2) Duty to recognize the correlative rights of other states to transboundary resources and at least to consult with them as regards concurrent uses with a view to arriving at equitable apportionment and use of these resources and 3) Duty to observe international agreements to respect the rights of other states and to fulfil in good faith international obligations in the exercise of sovereignty[9]. It is evident then, that equitable and reasonable utilization principle has complimentary relationship with permanent sovereignty. Recognizing rights of co-sharing countries and due diligence towards equitable utilization figures in in the concept of PSNR. International cooperation among states is a recurring theme throughout Charter of Economic Rights and Duties of States (CERDS).[10] Article 3[11] of CERDS applies specifically in transboundary contexts like TBA. Article 3 provides how states sharing natural resources would exploit those natural resources. Its application in TBA implies: 1) In managing and using shared aquifer water, countries sharing it must cooperate with each other[12], 2) cooperation must be based on a system of information and prior consultation, 3) optimal use of the aquifer will have to be the final goal of cooperation, 4) legitimate interest of other states cannot be damaged through exploitation of shared water of TBA. It reflects, that cooperation

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form as an intrinsic component of exploitation process itself. Observance of principle of no harm also form part of PSNR in case of shared natural resources. CERDS directs a 'system of information and prior consultation' which implies, a systematic joint action in term of collecting and synthesizing information.[13] Therefore it is impossible for any state to legally claim sovereignty over a portion of TBA while denying the correlative duties arising out of principle of ERU, no significant harm and duty to share information. Reading of PSNR with article 4-9 of the Draft Articles therefore leads to the demand of a higher standard of cooperation.

The next relevant question is, how the above understanding of PSNR, may influence TBA related negotiations. One of the most concerning implication anticipated, regarding inclusion of sovereignty principle is, that it would bring back the absolute sovereignty narrative and obstruct negotiation toward cooperation.[14] Being Part of customary international law, understanding of permanent sovereignty as expression of rights and duties can influence good faith negotiations on shared water and generate a positive force towards cooperation.[15]

How a concept is conceived has bearing on how it influences the narrative on which it operates. Sovereignty principle steaming out of GA resolution 1803 (xvii), with reference to article 3 CERDS can be harmoniously read with principle of ERU, principle not to cause significant harm and duty to exchange information. As all these principles form part of the concept of permanent sovereignty in some form, when a state would resort to the claim of permanent sovereignty over shared water from a TBA, it would have to satisfy its duty owned under principle of ERU, principle of not to cause significant harm, duty to exchange information, not only under the draft articles but also as part of its claim of permanent sovereignty.

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10. To grasp the fuller construct of PSNR, it is incumbent to see its expression in the form envisioned by the originators of the principle. CERDS embodies the most ambitious consensus on PSNR reached by the 'newly independent' states rallying for their economic sovereignty; UNGA Resolution 3281 (XXIX), Charter of Economic Rights and Duties of States of 12 December 1974.
11. Article 3 CSRDS lays as, "In the exploitation of natural resources shared by two or more countries, each State must cooperate in the basis of a system of information and prior consultations in order to achieve optimum use of such resources without causing damage to the legitimate interest of others".
12. Water Resources from TBA would be considered 'shared water' as Article 3, CERDS deals with, ".. Exploitation of natural resources shared by two or more countries.".
13. The Draft Articles requires due diligence on exchanging information between states sharing TBA accorded by separate effort while suggesting joint effort. In this aspect CERDS requires an alleviated form of cooperation apropos information sharing that is closer to the cooperation required in integrated management approach.
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Rolling out institutional arrangements for TBA governance in SADC

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Existing examples of aquifers with models for cooperation include the Genevese Aquifer agreement of 1977, revised 2007 Nubian Sandstone Aquifer System (NSAS), 1992 revised 2000, the North-Western Sahara Aquifer System Protocol drafted in 2015, Iullemeden Aquifer System agreement of 2009, the Guarani Aquifer 2010 and the Al-Sag/Al-Disi Aquifer of 2015 and recently the in the SADC region the Multi-Country Cooperation Mechanism (MCCM) of the Stampriet Transboundary Aquifer System (STAS).

The Framework for governance of TBAs in the SADC region is guided by the United Nations "Draft articles on the law of transboundary aquifers" and the "SADC protocol on shared watercourses of 2002, as amended". The STAS model which is being piloted in the Orange Senqu Watercourse Commission is explored further concerning its suitability and modifications for rolling out in the SADC.

The STAS aquifer of the Orange Senqu River Basin is the first in the region with a formal institutional arrangement for its governance. This formalisation is a culmination of a series of resolutions undertaken between May 2017 and November 2017 by the ORASECOM Ground Water Hydrology Committee (GWHC) and the Technical Task Team (TTT), the ORASECOM council, and the Ordinary meeting of the ORASECOM Forum of the Parties (Ministers responsible for water), to support the establishment and nesting of the STAS MCCM within the ORASECOM structures. The long-term vision of the MCCM is to joint strategizing and advising STAS countries on the management of the aquifer and its resources.

Using the inspiration from the MCCM, a Project Advisory Committee (PAC) was established for the Ramotswa TBA (RTBA) of the Limpopo River Basin in 2018. The PAC comprises of representatives from the riparian countries of Botswana and South Africa as well as from the SADC Groundwater Management Institute (SADC-GMI) and is coordinated by LIMCOM. The role of the PAC is to provide advice to the project management team and provide linkages with the organizations represented on the PAC so to ensure advancement of the Ramotswa Strategic Action Plan (SAP), and any other matters that may arise in the RTBA.

From 2018 the SADC-GMI has led the Integration of Groundwater Management into River Basin Organisations (RBOs) in the SADC region and exploring ways of rolling out the MCCM model in others TBAs and RBOs.

Notable strengths observed in the SADC region are the relatively mature RBOs, which have acknowledged groundwater as their primary responsibility guided by the SADC Protocol on Shared Water Courses and the subsequent RBO agreements.

The process that led to the establishment of the STAS joint governance mechanism is a breakthrough in many aspects summarised as;

- It is amongst the first six formal agreements for joint TBA management.
- It is the first operational governance mechanism to be nested in a RBO.

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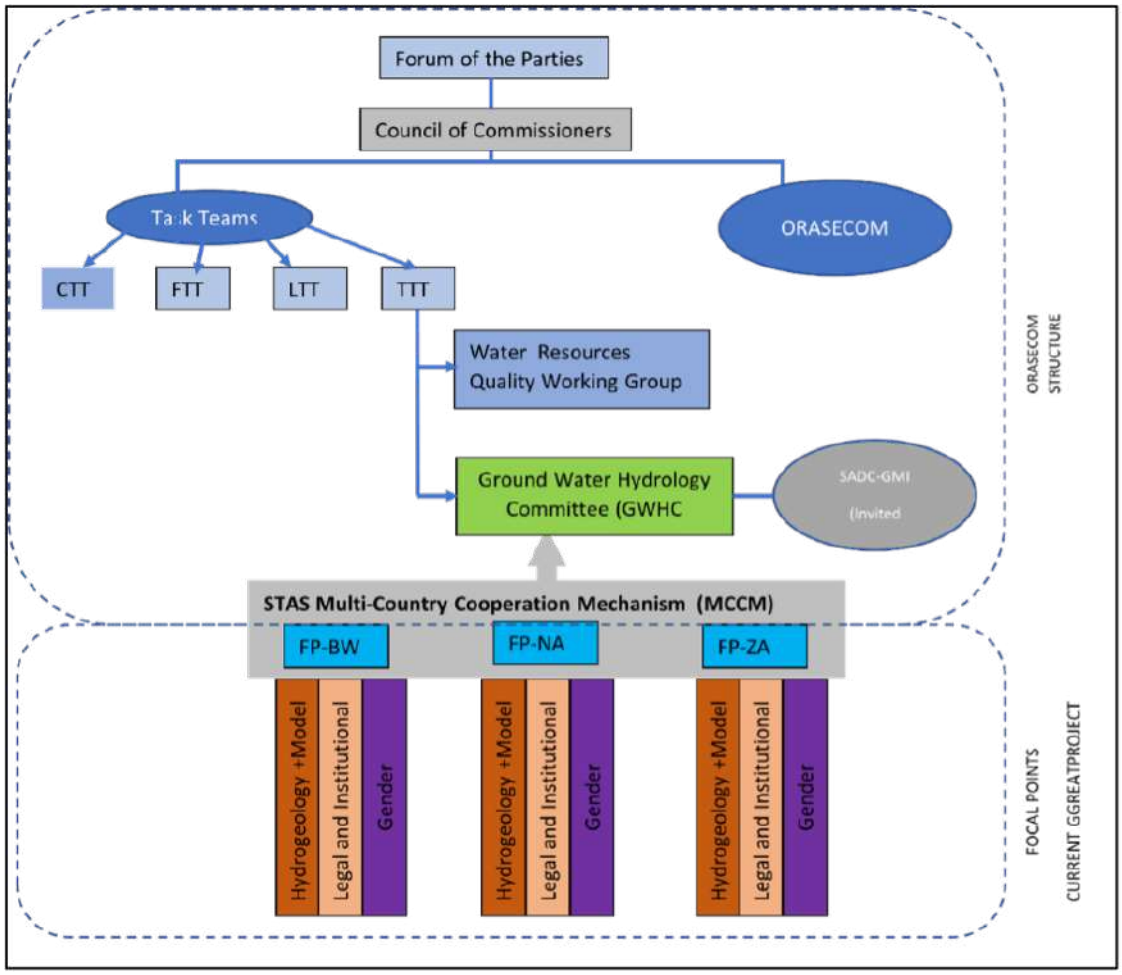
- Activities related to the STAS are part of ORASECOM's 10-year IWRM Plan (2015-2024).
- the process that led to institutionalizing cooperation over the STAS was expeditious i.e., accomplished in one year.

Nesting of MCCM in the ORASECOM structures is represented in the figure below.



The RTBA PAC is yet to be fully nested in the LIMCOM structures. However, it is crucial that the SADC region builds on the success of the STAS MCCM

While the STAS's MCCM provides a model that can be replicated in other TBAs, some scenarios found in the SADC are considered i.e., 1) where a country has more than one TBA 2) where an RBO has more than one TBA. 3) where the TBA straddles more than one RBO, and 4) where a TBA does not fall within an RBO. SADC-GMI is proposing a model for replicating in the SADC region based on the STAS MCCM model, recognising the need to transition from TBA projects to Institutions fully nested in RBOs to promote conjunctive management of transboundary water resources.

In conclusion, establishing the cooperation mechanisms within existing RBOs has numerous advantages over setting up Coordination Committees that are solely to facilitate cooperation in the governance of the TBAs. The RBOs provide the advantage that they already have binding agreements regarding the management of transboundary waters, which in most cases can be interpreted to include groundwater. Lastly it is observed that the MCCM model provides a platform for inclusive governance for the individual TBAs.

Public Policies in Brazil and the Guarani Aquifer

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The Guarani Aquifer is one of the largest groundwater bodies in the world, beneath the territory of Argentina (20,98%), Brazil (61,65%), Paraguay (8,05%), and Uruguay (3,32%), stretching through approximately 1 km 2. After 6 years of negotiation, a treaty about the Aquifer was signed on August 2, 2010, under the auspices of Mercosur. imposes legal obligations concerning the protection and management of groundwater and its land surface.

The main goal of Mercosur's member States was to proclaim their sovereign rights over their respective groundwater. There are explicit references to the principle of state sovereignty in the first three articles of the 22 that comprise the treaty. The treaty defines the Guarani as a "transboundary water resource that integrates the sovereign territorial domain" of the four states parties (art. 1), each of them "exercising sovereign territorial domain" over their respective portions of the aquifer (art. 2). Worthy of mention is Art. 3, which contains references to sustainability and the rational use of water: "The Parties exercise in their respective territories the sovereign right to promote the management, monitoring and sustainable use of the water resources of the Guarani Aquifer System and will use these resources based on criteria of rational and sustainable use and respecting the obligation not to cause appreciable damage to the other Parties or the environment". The 4th article of the Guarani Aquifer Agreement confers on each member State the right to promote the conservation and protection of the aquifer; and Art. 6 requires each Member State to adopt the necessary measures to prevent harm to other Parties or the environment. No criteria of what rational and sustainable use can be found, nor precise legal obligations that comprehend "conservation" and "protection" of groundwater. It is worthy to mention that the terms "preservation," "prevention," "precaution," "risk," "pollution" and "contamination" do not appear in the treaty text, as it was expected after so many years of environmental debates at the international arena.

The Guarani treaty has provisions on duty to notify or enter into consultations with neighbors when a state is planning to implement projects that may have transboundary impacts (art. 5). Parties have to take "the necessary measures to avoid causing significant damage to other parties or the environment" (art. 6) and should this occur, the responsible party must "take all necessary measures to eliminate or reduce it" (art. 7), with no mention of international responsibility. Also relevant is the absence of mention of climate change and the impacts that aquifers - and the hydrological cycle as a whole - will suffer. Articles 8, 9, 13, and 14 contemplate the duty of cooperation for the exchange of technical and scientific information about the aquifer, about the use of its waters, management practices, and the identification of critical border zones that require specific treatment measures. There is also a system of consultation and dispute settlement.

The Guarani Aquifer Agreement finally came into force in 2017 with Brazil's ratification. Notwithstanding the laxity of the treaty's legal clauses, it is important to evaluate how each member State is implementing its obligations. This paper aims to investigate what has been done by Brazilian authorities to the fulfillment of the Guarani treaty's

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obligations, specifically at the State of Paraná.

The Republic of Brazil is organized as a Federation of three levels: Union, States, and Municipalities). There is a complex distribution of constitutional competencies between them and about environmental matters, all political entities have competencies to legislate and to act. According to the Brazilian Constitution, the Union has the power to set general rules on water resources (Law 9433/1977), and also has dominion over surface waters that are within its domain, over those that flow through more than one State, those that serve as boundaries with other countries, or those that extend into foreign territory or proceed therefrom; as well as over mineral resources (art. 20, IX of the Constitution). The federal States, on the other hand, have ownership over all groundwater and the legislative power to supplement federal rules. So, when federal States legislate about water resources, they can only complement federal rules.

In Brazilian territory, the aquifer is found in eight states of the Federation: Rio Grande do Sul, Santa Catarina, Paraná, São Paulo, Mato Grosso, Mato Grosso do Sul, and Minas Gerais. To assess whether groundwater protection measures are being implemented - to observe art. 4 from the Guarani Aquifer Agreement - it is necessary to investigate public policies in each one of the 8 States where occur the Guarani Aquifer, as well as those implemented at the federal level.

Brazil has enacted Law 9.433 in 1997, establishing the National Policy of water resources. Water is recognized as a public good, with economic value; in case of scarcity, priority should be given to human needs; water management should be integrated (considering the unity of the hydrological cycle) and decisions should be made by river basin committees, with public participation, based on planning that conciliates multiple uses of water resources. Policy tools are foreseen in art. 5 of Law 9433/1997: the use of water resources is subject to pricing; there must be a license to authorize each use (called outorga); planning at different levels (basin level, state level, regional, federal level); classification of water bodies in classes, according to the preponderant uses; and a water resources information system. About transboundary water resources, the Law only mentions the need for participation from a representative of the Ministry of Foreign Affairs at the river basin committee (art. 39).

About groundwater, Law 94333/1997 establishes the need for a license/permit to grant its use (art. 12, II); since groundwater is not contemplated on river basin committees, planning, licensing and monitoring are completely under the responsibility of the political entity that upholds the domain of the water body. After 24 years, some of Law 9433/1997 provisions are not fully implemented yet. There haven't been substantial modifications of the legal framework and the fact that the Guarani Aquifer Agreement entered into force did not lead to changes in federal policy. The search for relevant information about the Guarani Aquifer in federal government websites (Ministry of Environment, Ministry of Foreign Affairs, and National Water Agency) revealed no concrete or planned measures about preservation or conservation of groundwater. An integrated information system about groundwater, coordinating data from federal states, is yet to be implemented.

The State of Paraná doesn't have a legal framework for groundwater. The State Policy for water resources was created by Law 12.726/1999, which has goals, principles, and instruments similar to those of the federal policy. However, in Paraná water is recognized as "a limited natural heritage endowed with economic, social, and environmental value" (art. 2, II, Law 12.726/1999). But the state policy is also focused on surface water, dedicating

few articles to groundwater, mentioning the need to preserve its physical, chemical, and biological quality (art. 26-29, Law 12.726/1999). A proposal for uses of "natural deposits of groundwater" in the State of Paraná should be developed and subject to the approval of the State Water Resources Council (art. 27, Law 12.726/1999), but the diagnosis, planning, granting permits of use, and monitoring of these uses are all attributions of the Executive Branch (art. 31, Law 12.726). Since 2019 (Law 20.070) the Paraná Land and Water Institute is the executive agency of the management system. Charging a price for water use is one of the tools of Paraná policy (art. 53, Law 12.726/1999), following general rules given by the federal government law, however, there is a provision for a waiver for agricultural producers. Therefore, the Paraná policy releases the main stakeholder from paying for the right to use water resources.

The search for updated information on official websites shows that groundwater, nor the Guarani aquifer are the main concerns of Paraná policy or institutions. In 2020, the first State report of water resources dedicates 9 pages to groundwater resources. The Guarani Aquifer is mentioned, as one of the most important water bodies in the world, with an important discharge area in Paraná territory. The productive potential is estimated at 300.000 l/h, but the numbers of wells are not informed (it is known that there are over 2000 wells licensed in Paraná). Most groundwater bodies in Paraná are vulnerable to pollution and contamination, 69,7% of the Guarani discharge area is considered to be highly vulnerable, even though most of the aquifer is confined. No specific measure to protect the aquifer was planned or implemented, according to the Land and Water Institute of Paraná, but the agency is making efforts to monitor water quality and quantity in all groundwater bodies.

An analysis of the treaty on the Guaraní aquifer reveals that each of the Mercosur states should undertake measures to promote the conservation of its waters. In the case of Brazil, measures to conserve the aquifer would require a major concerted effort by the eight states of the Federation where it occurs, together with the federal government. The study of the Brazilian water resources policy and the Paraná water resources policy shows that groundwater has not been a concern of the legislators. The few legal provisions on groundwater in both levels are restricted to submitting the use of groundwater to the granting of permits, leaving it up to the authorities of the executive power to decide on the amount of water granted and for which users. In Paraná, the law allowed a waiver of the charge for the agricultural sector, a device of doubtful constitutionality, since charging a price of the use of water is one of the policy tools. Those in charge of implementing these policies have not even provided up-to-date and transparent information about the uses of the waters of the Guaraní Aquifer, which leads to doubts about the treaty's effectiveness.

Governance of Umm er Radhuma Aquifer: strengthening cooperation via a transboundary water agreement

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1. Introduction with brief literature of the relevant topic

Umm er Radhuma Aquifer is shared between Qatar, Iraq, Kuwait, Oman, Saudi Arabia and the United Arab Emirates. Its use has begun in Qatar in the 1950s. The aquifer is being heavily exploited for agricultural purposes mostly by Saudi Arabia. It is also being used for irrigation, domestic and industrial purposes by all the nations sharing it. The aquifer faces salinization threats because of seawater intrusion and over-pumping. The aquifer has been investigated geologically and hydro geologically since the 1940s. The unsustainable use of the aquifer in the last four decades has already restricted its use in some parts of the countries sharing it where the major risks are the complete depletion and salinization. In fact, some expect that the aquifer will be completely depleted in few decades. Current withdrawal from the aquifer far exceed the annual recharge levels resulting in lowering the water table, deteriorating the water quality and producing further saline intrusion. Groundwater is being used for various purposes -mainly agriculture- that is heavily dependent on this resource. Other uses include water consumption for households. The traditional water-related problems mentioned above are further exacerbated because of the diverging interests of each state, their need for water, the inability to control groundwater exploitation and withdrawal of each state, different administrative, local and domestic rules addressing the resource, geopolitics, the size of each country among many other reasons.

2. Proposal of one or multiple solutions

Despite the importance of this aquifer especially for Qatar, so far there is no water agreement regulating its exploitation and long-term preservation and protection as well as conflict prevention. Cooperation between the countries can be noticed only with the Gulf Cooperation Council in the form of investments in water infrastructure projects. Still, certain countries sharing the aquifer have highlighted their willingness and the need for cooperation in the management of the aquifer. Cooperation and joint management between countries is needed to ensure the long-term sustainability of the aquifer and to prevent the existing risks from completely depleting it through the adoption of joint policies for groundwater resources management.

3. A need to implement the suggested solutions

The main problem regarding the management of the transboundary aquifer mentioned above is the absence of concrete cooperation between all the nations sharing the groundwater. Such absence can be noticed at all levels. In certain instances, one could notice some kind of collaboration which may have occurred. Still, even then such collaboration was very modest, which means that there is a clear need for great cooperation in different fields, ranging from engineering, geology, law, political science,

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economy … to guarantee that all the aspects related to the management of these aquifers are being considered. Interdisciplinary research across all these fields and many others is a must to ensure the adoption of laws and policies that can guarantee the good governance of the aquifers. Consequently, the gap does not only refer to the absence of collaboration but also to the absence of interdisciplinary research and cooperation. Moreover, international legal conventions and rules have not been considered so far in the management of these aquifers even though, for instance, Qatar, since 2002, is a member to the Convention on the Law of the Non-Navigational Uses of International Watercourses of 1997. Therefore, interdisciplinary research is needed to address the governance gaps related to the aquifer on the basis of international rules where the end goal is to establish transboundary water agreements taking into account the research outcomes from the different fields mentioned above as well as international rules.

4. Conclusion

There is a need to address the governance of this transboundary aquifer in order to strengthen cooperation between the countries sharing it. There is also a need to figure out the ways through which the various states sharing the aquifer can be incentivized to cooperate for the establishment of transboundary water agreement.

The Women, Water Security and Peace Nexus: opportunities and challenges of gendering hydro-diplomacy in Central America

Maureen Walschot[1]

Central America is a complex mix of different climatic and natural environments, as well as different cultures and populations. In the 1990s, rural development policies, as well as environmental conservation measures, were put into place so to enhance transregional cooperation, over-crossing borders between the seven countries. While the region is endowed with water resources, water scarcity remains a concern in the region given the lack of mechanisms and actions for water management. Moreover, vulnerability to climate change such as droughts is a critical issue in Central America. Given the number of internationally shared water resources, cooperation and joint management is critical to minimize tensions and unsustainable use. Nevertheless, "the intergovernmental instruments signed so far have proved insufficient to establish and implement agreements for managing and integrating development of international watercourses" (GWP, 2016). Besides the lack of regional cooperation, gender in the context of water security in Central America can manifest itself through various modalities and dynamics. As the active participation of women in water diplomacy is critical to ensure the sustainable management of shared water resources and to ensure peace and stability in the region, the role of women in Central America is subject to particularly heavy patriarchal patterns.

Linked to this idea of water diplomacy is the notion of regionalism, where actions and solutions are taken at the regional level to face shared insecurities. Regionalism, however, experiences some particularities in Latin America and thus in Central America. For instance, regional organizations tend to regulate less in the area of gender, and social policy in general. Studies have illustrated the importance of localized transnational networks in Central America (Medina, 2014). We thus highlight the possibilities for women leaders from civil movements to have an increasing role in hydro-diplomacy in the region. Gendering water diplomacy is a great opportunity to go over non-decisions and/or status quo at the national levels. Transboundary cooperation at the local level may give space to the prevention of conflict at the regional level, therefore giving great importance to water diplomacy emanating from the civil society level. However, these opportunities also come with challenges, as "local transboundary water politics generally reflect local power (a)symmetries, while regional norms highlight the shared values of cooperation" (Koff, 2017). The implementation of norms decided at the regional level can therefore face some resistance "due to the disconnect between localized power-based discussions and regional influence-based norms" (Koff et al., 2020). Gender can also be a component of these local asymmetries.

This study highlights how the Central American Integration System (SICA) could represent a tool to enhance local and transnational female leadership in water diplomacy. For instance, in 2013, SICA approved the Regional Policy for Gender Equality and Equity

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of the System Central American Integration. This regional public instrument enhances gender equality and non-discrimination against women through the implementation of measures in seven strategic areas. The sixth area is dealing with the political participation and decision-making. It establishes a regional roadmap for national legislation to coincide with the international legal mechanisms adopted by the States in matters of political rights and citizenship of women. It has also shown an impetus with the creation of the Agenda for sustainable water use in 2017, that aims at dealing with water issues as a matter of discussion and cooperation. The development, integration and merging of both agendas is now the next crucial step to ensure an effective gendering of water diplomacy at all levels in the region.

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Regulatory tools for TBA Governance: a legal vision

Nicolas Gonzalez del Solar[1], Mariana Rugoso[1]

Throughout our investigations we have found ourselves faced with a vacuum in transboundary aquifer management matter based on the fact that the tools provided for managing surface waters cannot be applied for underground waters.

The situation is even more complex in order that these aquifers geologically do not know of geopolitical barriers and extend over more than only one jurisdiction, in addition to the fact that few national water policies focused on interjurisdictional aquifer systems as a necessary part of Integrated Resource Management Hydric.

While treaties to regulate surface water abound, groundwater is not even nominally included in the scope of these instruments or is not mentioned at all.

This raises the need to establish in the management of shared underground water resources, regulations on shared management, rational and equitable use, notions on the scope of the "water basin", matters about joint use, pollution, depletion, etc., as has always been done in relation to surface waters.

It can also be observed, for example in Argentina, that there are no land-use or water resource management plans for most of the aquifers it shares with other countries, much less at the local level due to its federal organization. Most land-use or water resource management plans are still unilateral, and often do not focus specifically on aquifer management.

The transboundary aquifer system should be conceived as a complete unit, and not depend exclusively on the response of each of the countries or states that share it, individually.

Warning that we are in a context where the use of groundwater is increasing and where most of the most important aquifers in the world are transboundary, that is, they lie under two or more countries, which means that the extractions or any kind of use carried out can generate effects for the other neighboring country generating different conflicts or interference among users of that resource.

A case that shows the difficulties in managing this water resource due to the lack of regulatory tools for its management has been the guaraní aquifer system, where until 2010, the regulation was in the hands of each of the countries that make up the system individually, generating conflicts in terms of the use of the resource by each one is very different. Despite the existence of a treaty for its management, we are far from an adequate and sustainable regulation.

Conclusions and Recomendations

- Transboundary aquifer system must be conceived as a complete unit, and not depend exclusively on the response of each of the countries that share it, individually.
- Need to establish in the management of shared TBA: rules on shared management, rational and equitable use, notions on the scope of the "basin-aquifer", questions on joint use, pollution, depletion, etc.

1 University of Mendoza

- Need to prepare land use planning plans and water resources management plans for shared aquifers as any other natural resource on Surface
- Need to create joint organizational structures for the management of the TBA at all level (National and International)
- Importance of incorporating cooperation as the creation of coordination mechanisms between the different Countries
- Urge Countries to adequate and upgrade their legal systems and regulations (Federations and Confederations)
- Give or provide a basic framework in order to ease conventions and agreements about use and protection
- Urge Countries to implement programs of study and characterization (deficiency in aquifers knowledge: location, dimension, capacity, depth, connection and interconnection level, etc.)

Achieving SDG 6.5.2: Transboundary aquifers, water governance in a new light

Bidisha Roy[1], Anuruddha Roy[2]

Trans-boundary aquifer is recognized as an important source of water for riparian states those who majorly depend on this invisible resource for social development and improvement of socio-economic conditions. Ground water also provides a valuable base flow for the river for survival and the surrounding ecosystem to thrive. Despite this TBAs (Transboundary aquifers) draw less attention at regional level across the globe. In fact, bilateral or multilateral treaties are almost non-existing between many countries to manage groundwater effectively and efficiently as humanity is facing one of the most difficult times in the form of climate change; every drop of water matters.

Asia is the home for around 59.76% of the total population of the world. A vast area of this continent consisting of an overcrowded population is in the deltas of the rivers. Simultaneously, Asia is the home for many people who live in the deserted land. In the absence of the surface water, ground water is a major source of freshwater for the communities. The diversity of Geo-morphology and over exploitation of ground water resources creates a serious problem of ground water quality in the Asian countries. In Asia Transboundary Rivers draw attention to some extent to form treaties between the few countries and create a platform, whereas cooperation for TBA remains silent like many other TBAs in the globe. The lack of transparency between nations makes the situation even grimmer for the integrated water resources management and assessment of internationally shared aquifers; brings suffering to riparian communities. The way forward leads to even more obstacles to achieve sustainable development goals no 6.5.2.

In the region water is majorly consumed for irrigation of agricultural land, industry, to some extent mining and domestic uses. The dissimilar distribution of riparian communities and the activity in the boundaries of countries makes water scarce resources for development. Major rivers like Ganga, Indus, Brahmaputra, and Mekong creates ecologically well-resourced plenty of available water in the deltas. Despite this fact anthropogenic activity mainly depends on the ground water. In recent times it has been observed that consumption pattern of water by the communities for land irrigation of agriculture has increased for food security for increased population. It is also observed, the production of a variety of crops has increased, creates surplus food in many parts of the continent. Recent trends show that, utilization of non-suitability of species of crop as per local environment has increased whereas ground water table depleted drastically.

Climate change creates an impact on the hydrological cycle. Under the circumstance of climate change majorly four incidents observed such as change in precipitation pattern, temperature variation, sea level rise as the effect of changes in Cryosphere and land erosion which leads to non-fertility of agriculture land. Changes in precipitation patterns caused either flood or drought. In both scenarios changes in ground water recharge is observed. Additionally, abstraction of ground water due to anthropogenic activities

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disrupts ground water flow and characteristics. Simultaneously, depletion of groundwater tables impacted not only agricultural land, but also surrounding ecology. Countries that are sharing TBA identify the need for formation of a platform to share water resources without any ambiguity. However, in this context Asian countries have not responded so far.

In Asia there are a total of 48 countries. However, each Asian country is not sharing the Transboundary aquifer. Based on geomorphology and geography out of 48 countries only 23 countries are sharing 129 numbers of TBA. Parameters such as population densities and area of TBA primarily considered for detailed studies for 21 countries which are sharing 18 numbers trans-boundary aquifers. In Asia, few major trans-boundary water cooperation took place, including treaties among Cambodia, Lao, Thailand and Viet Nam. Whereas in South-East Asia treaties formed between India, Pakistan, Nepal and Bangladesh. In regard to these treaties multilateral and bilateral river commission has been formed. In many cases commissions are active to resolve issues during operation and maintain harmony in the region relating to sharing of water using the frameworks which have developed to enforce the treaties.

This study will attempt to create a data model based on the available secondary data to identify the key factors that play a major role to make Transboundary Water Corporation in Asian countries successful, failed and absent. A focus will be given on each Transboundary aquifer in Asian countries that faces challenges from anthropogenic activities, socio-economic conditions and geopolitical situation. This study will attempt to assess the challenges faced by transboundary water cooperation between riparian states in the Asian countries and will focus on water governance within the area of transboundary aquifer through transparent institutional mechanism, sharing of knowledge, sharing of standard data and improved strategy to incorporate all of the relevant stakeholder including riparian communities in the connection of the formation or improvement of treaties between countries to achieve sustainability of water resource in transboundary aquifers.

Development of uncertain bankruptcy models for groundwater management in damghan plain, Iran

Samaneh Sabri[1], Mahdi Zarghami[2]

In recent decades, increasing population, and then water demand intensified by the climatic-change have led to exploitation of groundwater resources, resulting negative social, economic and environmental consequences. Lack of water with its disproportionate distribution causes problems and conflicts between its sharing stakeholders. Often in most of these conflicts, the amount of water demand by the stakeholders is more than the amount of available water. For this reason, there are different ways to allocate limited groundwater between stakeholders. One of the practical methods to solve this problem is bankruptcy theory and, in this study, the approaches of Proportional (P), Constrained Equal Award (CEA), Constrained Equal Loss (CEL), Talmud (T), Piniles (Pin), Constrained Egalitarian (CE), and Adjusted Proportional (AP) have been used to allocate limited groundwater resources under uncertainty. The study area in this study is Damghan fertile plain at the semi-arid Semnan province in Central Iran. The annual water requirement of this region is about 110 million cubic meters and the annual water withdrawal from the aquifer is about 90 million cubic meters. The groundwater exploitation is very high and there is about 30 centimeters of water level shortfall which have put the aquifer in the critical situation. Therefore, the deficit of at least 20 million cubic meters should be allocated among the stakeholders. In this study, 10 stakeholder regions from the agriculture, urban and industry sections are considered. Finally, the best stable bankruptcy method is selected and the most suitable allocations among the stakeholders are obtained. The method is successful and then is strongly advised to be used in other transboundary groundwater problems.

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Effective leadership roles of local government to strengthen the transboundary aquifer governance in Malaysia

Minhaz Farid Ahmed[1]

Water pollution disasters including aquifer contamination caused by human activities are getting more rampant and intense of late, due to several reasons, including inadequate governance at local levels. The global goals and standards are also criticized for not being able to channel the promised actions effectively at the local level, in managing the transboundary aquifers. Management of water resources nowadays is very challenging because of rapid urbanization and development activities. The transboundary aquifer management is becoming more complex than that for surface water because of overlapping and opposing jurisdictions, and different management practices within certain basins. The transboundary aquifer management in Malaysia is highly affected by the demands upon surface water for drinking, agriculture and industries, which accounted for about 98% of the water demand. However, the chemical pollution of surface water is happening more frequently due to inadequate governance; and to repair and rehabilitate affected ecosystems, and to recover economic losses due to damages upon ecosystem and human health are very expensive. Therefore, Malaysian authorities have to step up efforts to focus more on the utilization of groundwater to meet the future water demand, including in basins in which the aquifers are shared with neighboring countries. The utilization and management of aquifers are very dynamic because of changes of land cover and land uses, and also due to deforestation and biodiversity loses. Deforestation with prolonged drought situations might enhance the loses of water content from soils, and this might lower the groundwater levels. The land use and land cover changes might also alter the soil properties and degrade the groundwater quality due to changes in geochemical processes. Therefore, the role of local authorities and states' district offices are very crucial because they are in charge of enforcement of legislation, and in managing natural resources within their respective jurisdictions. Local governments are expected to play more enhanced roles via the multi stakeholder's platforms of cooperation and collaboration and are expected to take more proactive leadership roles especially in usage of good scientific data and information generated by various agencies and other relevant stakeholders for wise decision making. Decision making processes of local governments should be based on sustainability science approaches, including those frameworks that are promoted by international organisations such as UNESCO, GWP, IHP, etc., for sustainable water resources management. These local level actions for transboundary aquifer management should also be supported by the national, regional and global level's expertise, knowledge and standards in line with the integrated and holistic approaches of water resources management. The effective leadership roles of local governments are, therefore, vital for aquifer management via appropriate assessment, management and monitoring, carried out with cooperation of the nearest universities, and other relevant stakeholders, in striving together for a sustainable transboundary aquifer management.

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Flow systems and their importance in the Mexico-USA governance of transboundary groundwater

Gonzalo Hatch Kuri[1], José Joel Carrillo-Rivera[2], María del Carmen Carmona-Lara[3], Marcos Adrián Ortega-Guerrero[4]

The "Transboundary Aquifer" concept envisaged in the United Nations Resolution 63/124 as "The Law of Transboundary Aquifers", has had a significant impact on the evaluation of transboundary aquifers around the world. The Mexico-USA case waits for the official determination of the overall number of shared aquifers, in which groundwater is the resulting core of interest. Therefore, the assessment of the systemic functioning as transboundary groundwater waits to be a concept included in international transboundary water enactments. Mexico and the USA lack a federal policy for the management of their transboundary aquifers. Based on the guidelines and international instruments developed for this purpose and considering the technical, social and economic asymmetries characterizing the management of transboundary groundwater between Mexico and the USA a management analysis is proposed. Analysis made on scientific evidence and legal documents defining the nature of current conceptual discrepancies between the scientific definitions of "Transboundary Aquifer" and those of "Transboundary Groundwater". Results support the need to incorporate a system view of groundwater functioning, as well as a scientific based homologation of concepts and methodologies applied by those states interested in the jointly groundwater assessment to avoid water related conflicts in the context of its incipient integrated management. A proposal is also presented for the joint management of international waters courses aiming to protect and proper management of this water, where the principles of sovereignty, territorial integrity and sustainable development need to be acknowledged.

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Layers of regulation in transboundary aquifer governance: the case of the Guarani Aquifer

Otto Spijkers[1]

The Agreement on the Guarani Aquifer, concluded between Argentina, Brazil, Paraguay, and Uruguay, entered into force in November of 2020. The agreement refers to the Draft Articles on The Law of Transboundary Aquifers, adopted by the International Law Commission (ILC) at its sixtieth session in 2008. The ILC's draft articles purport to contribute to the progressive development of the international law relating to transboundary aquifers and its codification. The general principles identified in the ILC's draft articles - the principles of sovereignty of aquifer States, and of equitable and reasonable utilization, the obligations not to cause significant harm and to cooperate, as well as the principle of protection and preservation of transboundary aquifer ecosystems – are all mentioned in the Agreement on the Guarani Aquifer, but with slightly different formulation and content. The global and aquifer-specific layers of governance thus intersect and overlap, establishing layers of regulation. The layers are not entirely consistent, and the precise content, interpretation, and application of some of the principles and obligations remains unclear. My poster proposes to examine this legal problématique, identifying a series of problems and possible solutions.

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POSTER ABSTRACT

Transboundary or not transboundary: the case of the Guarani aquifer system in the Cuareim river basin between Brazil and Uruguay

Vitor Malagutti[1], Alexandra Suhogusoff[2], Roberto Kirchheim[3], Alberto Manganelli[4]

The Cuareim River Basin is a transboundary basin, of which approximately 45% is inserted in Brazilian territory and the remaining 55% belongs to the north portion of Uruguay. The river course determines the international border and places side-by-side two cities: Quaraí (Brazil) and Artigas (Uruguay). Both countries had long been cooperating on water resources issues in the whole region (the Cuareim basin belongs to the hydrographic region of the Uruguay river within the la Plata basin). In the late nineties, these two countries also realized that there was a contiguous aquifer (the Guarani Aquifer System-GAS) to be taken into consideration. This perception is seen as one of the ways that led to the development of the GAS regional project, later on. Subsequently, this river basin was selected as a demonstrating groundwater pilot project under the framework of the Plata Basin Project. It became clear that there were no major groundwater transboundary problems affecting Brazil and Uruguay in the basin. But, on the other hand, the local importance of the GAS groundwater, whose extractions supplied the demands on both sides of the border, was evident. Hydrogeological studies have shown that GAS transboundary effects imposed by changes in the natural flow network due to pumping were quite restricted. There is no doubt that the whole region benefits from cooperative actions. Better groundwater knowledge adds significantly to the water resources management strategies that countries are still trying to implement individually. The GAS is subject of a specific agreement, which establishes a framework for cooperation towards its use and protection. How shall this transboundary condition be translated into benefits for the region and become an institutional strengthening mechanism for integrated water resources management? By answering this question, the present study identifies and analyzes the whole set of hydrogeological information obtained through regional and local scale approaches. It generates primary information and evaluates the local measurable transboundary effects. This study is also dedicated to an assessment of the legal and institutional framework of national, subnational and local management of the groundwater resources. Proposals are made on how to move forward in an integrated water resources management agenda, based on cooperation efforts that also include the groundwater potential and protection requirements. The case-study of the Cuareim River basin may serve as a reference to be replicated in analogous situations in the GAS or other transboundary aquifers around the world.

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2 Groundwater Research Center, University of São Paulo; CPRM
3 Geological Survey of Brazil
4 CeReGAS - Centro Regional para la Gestion de Aguas Subterraneas - America Latina y el Caribe

POSTER ABSTRACT

International groundwater law and policy: case of the North Western Sahara Aquifer system project (Algeria, Tunisia and Libya)

Rachid Bouajila[1]

International groundwater resources have not received their full share of legal investigation. The prospected paper will devise a legal and institutional framework for analyzing the North Western Sahara Aquifer System (NWSAS) shared between Algeria, Tunisia and Libya as a regional case study. Freshwater scarcity ranks highest amongst the challenges facing North Africa, given its impact on good security, economic development and poverty reduction, and socio-political stability (Lezzaik& Milewski, 2017). The main purpose of this paper is to analyse the existing legal and institutional frameworks, which form the basis of the NWSAS basin cooperation in this field, and to determine whether and to what extent they are adequate in dealing with water challenges facing the three states. The adequacy of the system will be assessed in terms of its formal coherence, consistency and consonance with modern international practice. However, the real measure of success of any transboundary water system should include consideration also of the concrete results on the ground, such as improved water resource management, reduced transboundary pollution and improved water quality.).The legal review, where appropriate, will use as a benchmark the most relevant provisions in this field, e.g. the International Law Commission's Draft Articles on Transboundary Aquifers of 2008, the 1997 Convention on the Law of Non -Navigational Uses of International Watercourses and the Model Provisions on Groundwater Resources of the United Nations Economic Commission for Europe (UNECE). Occasionally, a comparative analysis will also be employed by juxtaposing the NWSAS regulatory system with relevant normative frameworks for transboundary aquifers.

1 University of Bayreuth

POSTER ABSTRACT

MEWF webinar – New Insights from on-line polling of the community of experts in transboundary aquifer governance.

Hassan Aboelnga[1], Shammy Puri[1], Hazim Elnaser[1]

Bringing UpToDate results of on-line polling, giving newest insights (July 2021) of the community of experts who are currently engaged in the arena of transboundary aquifers. Aggregated findings of views of a large number of experts are very valuable in detecting trends of thinking. In Oct 2020 the Middle East Water Forum (MEWF), a platform for civil society, water managers and decision makers (numbering around 3000 contacts) conducted a webinar on the subject of 'Transboundary water resources – hydro diplomacy, cooperation, international water law and conventions'. Live polling among the 400 or so participants of the webinar gave some new, and quite novel insights into the subject. Since transboundary aquifers were not addressed explicitly, the MEWF has agreed with the ISARM 2021 Conference organizers to conduct a second webinar as a buildup to the ISARM 2021 conference and to seek specific insights from participants regarding transboundary aquifers and the key contemporary issues that affect them. The webinar will be conducted in July 2021 and will be open to a very wide range of global audience with an interest in ongoing and future governance of transboundary aquifers. The presenters in the webinar will be drawn from UNESCO, UN ECE, IAH, IWRA, AIDA, IWMI and others. Live on-line polling will be conducted, with targeted questions that will be prepared in advance with advice from experts in the field (covering hydrogeology, legal frameworks, inter country hydro diplomatic relations, data scarcity and institutional aspects). The results of this live polling and some additional analysis of selected country / aquifer conditions will be presented to the ISARM 2021 Conference as a building block to the next stage of progress with the ILC's Draft Articles that are due for consideration in UN General Assembly in 2022.

1 Middle East Water Forum

POSTER ABSTRACT

Application of principles of right to information, public participation, access to justice in aquifer management

Gayathri D Naik[1]

Aquifers are lifelines of many countries. For instance, Groundwater support majority of the water demands of countries like India where half of the drinking water and irrigation water demands are met by groundwater alone. However, anthropogenic water demands due to burgeoning population and their increasing water needs have caused over exploitation of groundwater threatening quality and quantity of water in aquifers and plummeting water tables. These situations are worsened in transboundary aquifers where the same aquifer is relied by more than one or two countries. The 2008 Draft Articles on Transboundary Aquifers requires the riparian states to engage in regular exchange of data and information [art 8] and also notify prior planned activities [art 15] that might impact the shared aquifers. This paper premises these two articles to examine the significance of right to information in utilization of groundwater in shared aquifers, its protection, preservation, and management. While these articles requires States to share information, it is silent on access to information for affected population of riparian countries. Similarly, Draft Articles provides the scope for any regional or bilateral agreements for aquifer management, it opens the need to think about inclusion of public participation in decision making in such management. Additionally, it also raises the need for inclusion of provision of access to justice in case of any transboundary harm to aquifers caused by riparian states whereby population of other riparian states are denied their basic human rights like right to life, water, food and livelihood. Hence, this paper aims to explore the significance of principles of right to information, public participation in decision making and access to justice promoted by international agreements like Rio Declaration of 1992, Aarhus Convention of 1998 in management and governance of transboundary aquifers. It also examines the best ways these principles could be implemented including the best possible forum for access to justice so as to ensure water justice among all water users and water uses.

1 SOAS University of London

POSTER ABSTRACT

Regional capacities for isotope based assessments of transboundary water resources from the view of a large-scale technical cooperation project in Europe and Central Asia

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Understanding complex and transboundary aquifer systems and groundwater-surface-water interactions is indispensable for effective integrated water management, particularly under the stress associated with groundwater depletion, quality deterioration and the regional effects observed under climate change.

Under the new four-year IAEA Technical Cooperation project RER7013, 38 institutions from 27 countries in Europe and the Central Asia region grouped together into 7 case studies with different geographic and thematic focuses to enhance cooperation in the field of water and isotope hydrology in the region, support the development of new technical capacities and competencies, as well as help clarify persisting issues in the region related to the sustainable management of transboundary water resources.

These case studies cover several regional and transboundary problems, including the impact of climate change on karst aquifers and groundwater/surface water interactions in the Western Balkans, groundwater nitrate contamination in Eastern Europe and Caucasus, the vulnerability of stratified transboundary aquifers to over-abstraction and pollution, as well as contamination problems of selected costal aquifers in Europe. Other topics include water balance and quality control in Central Asia, and the influence of climate change on the water resources used for irrigation in the SW East-European plain.

In this project, isotope hydrology laboratories in the Europe and Central Asia region with different levels of capacity are thus cooperating and working on solutions to a common, often transboundary, water resources management related questions. This collaboration provides a favorable opportunity and unprecedented insights to jointly analyse the status of existing technical capacities and competencies in isotope hydrology in the participating countries: How many isotopes enabled research groups are active and working on transboundary questions? Are research groups in the region equipped on a state-of-the-art level? Are scientific capacities sufficiently developed to cover the demand in the region and to provide answers to relevant water management questions raised by water authorities and policy makers?

Naturally, the answer to these questions is of high importance to efficiently manage the development of national and regional capacities, both from the viewpoints of the individual Member States and from the view of regional actors in technical collaboration, such as the IAEA. Furthermore, the use of isotope methods in the region will be strengthened by investigating collective measures for quality control of isotope analyses and results, and by exploring efforts to harmonize the technical approaches of the different participating laboratories.

1 International Atomic Energy Agency

TOPIC 5 :

Education, capacity development and raising awareness

Evaluating and developing regional capacities for isotope based assessment of transboundary water resources in Sahel Africa

Oliver Kracht[1], Florent Barbecot[2], Najiba Chkir[3], Laurence Gourcy[4], Frederic Huneau[5], Rim Trabelsi[6], Yves Travi[7], Kamel Zouari[8], Neil V. Jarvis[1], Luis. J. Araguas[1]

With the growing demand for freshwater resources in the Sahel, the need to better understand the local water cycle and address the constraints governing groundwater sustainability (quantity, quality, renewability) and other water issues remain a pressing challenge to scientists, water authorities, and policymakers in this region. Increasing water demand resulting from exponential population growth and intensified land use, and the uncertainties caused by the substantial variability of rainfall at interannual and decadal time scales, raise the question of how to ensure the safe and sufficient supply of clean water for human use, a situation that is possibly aggravated by the adverse effects of climate change. In response to these issues, the International Atomic Energy Agency launched in 2012 a regional technical cooperation project towards the integrated assessment and development of shared groundwater resources in the Sahel region (RAF7011), promoting the use of isotope hydrology techniques in addressing key hydrological questions in the Sahel. Furthermore, since 2018 a follow-up regional project (RAF7019) is building upon the significant outcomes obtained so far. In these projects, scientists and water professionals from thirteen African IAEA Member States (Algeria, Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Ghana, Mali, Mauritania, Niger, Nigeria, Senegal and Togo) grouped to tackle existing hydrological knowledge gaps by jointly investigating five major transboundary aquifer systems in the region: the Iullemeden Aquifer System, the Liptako-Gourma/Upper Volta System, the Senegalo-Mauritanian Basin, the Lake Chad Basin and the Taoudeni Basin.

The primary objective of these projects was to enhance regional human capacities for the routine use of isotope techniques to support science-based evidence for sustainable groundwater resources assessment and management. In this conference contribution, we explore the achievements and lessons learned by developing new technical capacities for isotope hydrology in the region and how effectively these newly built scientific and technical infrastructures complement existing competencies and institutional frameworks for hydrogeological investigations. Other topics addressed are: (1) Are scientific capacities and infrastructures of participating Member States sufficiently developed to investigate and monitor the hydrological cycle's key parameters effectively?; (2) How many isotope-enabled research groups are active, and are these laboratories sufficiently equipped to cover the demand in the region?; (3) How are these capacities distributed in-between regional basins and over the five major transboundary aquifer systems?; and (4) Will research groups in the Sahel countries be able to provide answers to relevant water assessment and management questions raised by water authorities and policymakers?

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Using public perceptions in transboundary aquifer management

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Aquifer boundaries rarely coincide with jurisdictional boundaries, and sustainable management involves transboundary governance. However, although neighboring, building transnational groundwater management institutions is a laborious process. This is primarily because groundwater is hidden by nature and its issues are more difficult to perceive. Secondly, neighboring countries often have difficulties in implementing collaboration for water resource management due to historical, political, economic, and cultural factors. For these reasons, the successful management of transboundary aquifers is based on sustained political motivation. Depending on the case, this critical leadership factor can be generated or consolidated by popular will. This study focuses on the coastal aquifers of Togo, which are shared with Ghana, Benin, and Nigeria. As part of a research that involves stakeholders (citizens, public institutions, private sector, etc.) for a sustainable management program, a questionnaire survey is planned for the summer of 2021 in Togo to measure their preferences regarding the international dimension of groundwater. The objective of the survey is: (i) to provide information on the level of awareness and preferences of stakeholders on international groundwater issues, and (ii) to measure in which ways populations better informed on transboundary groundwater issues could act on the construction of integrated management of international groundwater resources. By replicating such studies in the other three countries, it would be possible to identify and build pragmatic local approaches, which would enable effective aquifer management at the regional level.

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Mitigating the effects of poor transboundary aquifers (TBAs) management on vulnerable populations

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Adequate access to safe and reliable water sources is essential for good health and economic prosperity. Transboundary Aquifers (TBAs) have been crucial in sustaining water supply for drinking, farming, and supporting the lives of millions of poor people. The human cost of lack of access to water supplies contributes to an estimated 6000 children dying daily due to water-borne illnesses such as diarrhea. In Sub-Saharan Africa, 29% of the population live 30 minutes from improved drinking water sources affecting women and girls the most. Women and girls bear the responsibility of fetching water for their families for an estimated 200 million hours daily, leaving them with less time allocated to their education and income generating activities. Access to a safe water supply can reduce a family's health care expenses and save time improving household finances and the local economy, but data on the impact of poor management of the use of TBAs on poverty are limited. In Africa, in rural and poor communities, groundwater is usually the only source of water supply covering 30% of the population. In areas where water sources are scarce, poor management of TBAs, and lack of shared knowledge and policies worsen the already existing negative impact that hinder social and economic development for vulnerable populations and are sources of regional conflicts across concerned borders. Intervention: More research is needed to generate data to inform on the impact of TBA mismanagement on poverty, and on policies and strategies to mitigate them. This will allow for raising awareness in populations and will help policy makers to better understand the multisectoral interventions needed to address the political, social, and economic outcomes caused by poor management of TBAs and its effects on the vulnerable. A collaboration and partnership with neighboring countries is needed to holistically invest in developing a framework that trains and empowers communities as key contributors to TBAs management to ensure that shared water resources are utilized in mutually benefiting ways for all. This is why at the University of Global Health Equity; we teach students the importance of environmental health coupled with advocacy and managerial skills across all disciplines to help the vulnerable. Conclusion: Lack of knowledge and poor management of TBAs exacerbate gender inequities, public health concerns and poverty. Building knowledge and collaboration in and across countries are important to ensure sustainable solutions to TBAs mismanagement and reduce its impact on vulnerable communities.

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This book is a contribution to the UNESCO IHP studies
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