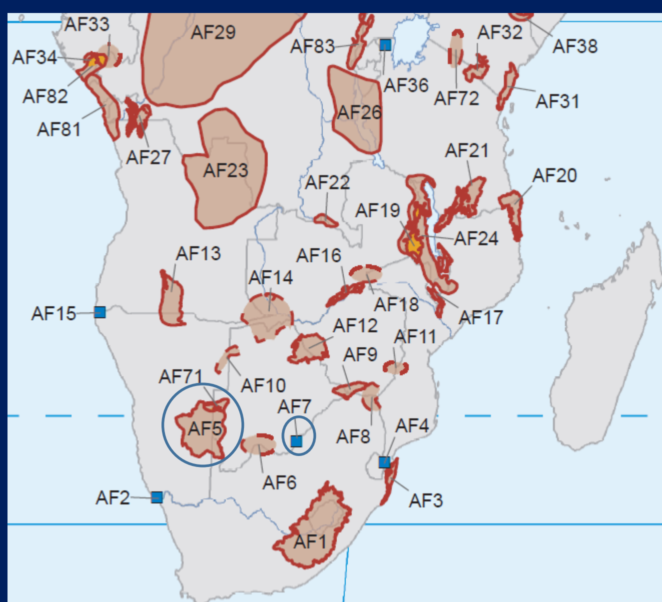
Policy Brief
Implementing transboundary aquifer cooperation in Africa: Lessons learned from two pilot approaches



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Summary

There is growing recognition of the importance of transboundary groundwater and transboundary aquifers in southern Africa, and a growing body of literature has now developed which is focused on topics such as integrating groundwater into RBOs and mapping aquifer boundaries. Despite this important progress, there has been relatively scant investigation on the practicalities of implementing transboundary aquifer management. To address this gap, this brief reviews two early experiences to strengthen cooperation on transboundary aquifers in the Southern African Development Community (SADC): projects on the Ramotswa (shared between Botswana and South Africa) and Stampriet systems (shared between Botswana, Namibia, and South Africa). The overarching aim of this brief is to compare the experiences on these two aquifers to generate guidance to inform and strengthen implementation of cooperative aquifer management in other shared aquifers in SADC. The paper reviews and compares the approaches of the two projects, highlighting alignment and divergence in project components and activities. Achievements and challenges are then highlighted and key common lessons distilled. While not indicating a blueprint approach to transboundary aquifer management in Southern Africa, at least five key lessons emerged:

1. While there is no blueprint to design of transboundary aquifer projects, certain components may be key to success
2. Think conjunctive: Aquifer projects benefit from considering surface waters
3. RBOs are key to sustainability of transboundary aquifer management
4. Pervasive data constraints call for greater focus on monitoring
5. Consider which areas require cooperation and which do not

Contents

1. Introduction

Transboundary groundwater in Southern Africa Cooperative management of shared water resources – aquifers and basins – is widely recognized to accelerate progress toward development goals including strengthening resilience, improving agricultural production, enhancing water security and achieving sustainable growth (Sadoff et al., 2015). In Africa and southern Africa, the importance of cooperation on transboundary surface waters has long been recognized (Lautze and Giordano, 2005; Lautze et al., 2017). Recently, a growing body of work (UNESCO, 2008; Altchenko and Villholth, 2013; Nijsten et al., 2018) has identified more than 30 transboundary aquifers in southern Africa and helped to catalyse more focus on enhancing cooperation on them.

Implementing groundwater-focused cooperation: How to? Despite widespread acknowledgement of the importance of transboundary aquifers in southern Africa (e.g., Braune et al., 2008) and a growing body of literature on both technical and institutional aspects related to their management (Christelis et al., 2010; Braune and Xu, 2011), there is relatively little work focused on practical aspects of implementing cooperation around shared aquifers – both lessons and challenges. There is best-practice style guidance from IGRAC focused on incorporating groundwater into River Basin Organizations (AGW-NET et al., 2015). Critical review and examination of the practical implementation of cooperation, however, has not been undertaken.

Aims of this brief This document reviews and mines the experience of RAMOTSWA and Governance of Groundwater Resources in Transboundary Aquifers (GGRETA) projects, focused on cooperation on Ramotswa and Stampriet aquifers, respectively, to identify shared lessons and challenges from the initial work on these transboundary groundwaters. The report first describes the location of the two study area areas and set of basic parameters at each area. Aims, timelines and components of the two projects are then reviewed. Differences and alignment between the two approaches are compared. Ultimately, a set of five lessons are identified.

2. Study Areas and Methods

2.1 Study Areas

Ramotswa Transboundary Aquifer Area (RTBAA) The Ramotswa Aquifer is located in the Upper Limpopo River Basin and is shared between South Africa and Botswana. The Ramotswa Aquifer corresponds to the Ramotswa dolomitic aquifer extent, mapped based on surface geology (Altchenko et al., 2017). The RTBAA is a slightly broader term than the strict aquifer boundary. RTBAA is used to capture areas in the subsurface that are hydrologically linked to the aquifer, but which lie outside the dolomitic aquifer boundaries delineated based solely on surface geology (Figure 1). The Gaborone catchment area (~4,300 km^2), located in the Upper Limpopo River Basin, reflects the immediate surface water boundaries within which the Ramotswa Aquifer is located. Given the linkages between surface and groundwater, the catchment is also relevant to management of the Ramotswa Aquifer.

RTBAA Geography The climate of the RTBAA region is semiarid with a wet season from October to March and high interannual variability. There is a trend of gradually decreasing average annual rainfall and, though not observed in the baseline report, there is some evidence of a possible increase of temperatures over a longer time series. Climate projections indicate that spatial and temporal rainfall variation may increase, and extreme climatic events (i.e. floods and droughts) may increase in frequency and intensity. These changes may have significant implications; the rainfall season is expected to shorten and river flows may decline. Economic activity is primarily agricultural (i.e. crops), with some game reserves and parks, tourism, and mining and industry. There are two aquifers in the RTBAA, the Lephala Aquifer and the Ramotswa Dolomite, with the latter being the major water-bearing aquifer and the focus of the Ramotswa project. The Ramotswa Dolomite is made up of five dolomites, with dikes creating relatively confined compartments within the Ramotswa Dolomite. At the time of the baseline study, the discharge locations (i.e. springs) within the aquifer were yet unconfirmed. A piezometric map of the study are was not constructed due to challenges with limited data, though it was determined that groundwater flowed northeast in the southern part of Ramotswa village and northwest in the northern part of the village. Based on this information, the groundwater flow direction was assumed northeast in Lobatse.

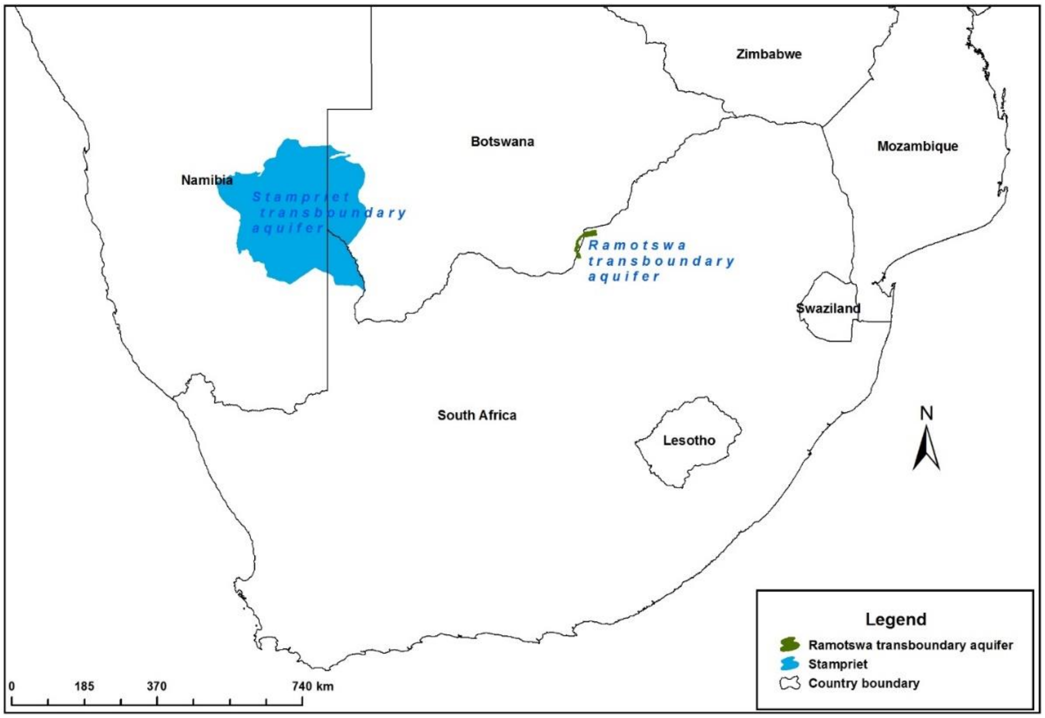

Figure 1: Ramotswa Transboundary Aquifer Area and Stampriet Aquifer System

The Stampriet Aquifer System (STAS) The STAS is located in a region of high short-term and seasonal temperature fluctuations due to the semi-arid conditions. The entire area of the STAS has an estimated population of 50,000 total, which has increased from about 30,000 in the early 1990s. The population is concentrated in small urban and rural settlements and farms. Agriculture is the primary land use in the STAS. Of the approximately 1200 farms in the region, most are located in Namibia. Of these, 80 are large commercial farms focused on irrigated crop production and some livestock. A significant portion of the STAS in Botswana is comprised of Wildlife Management Areas, with the Kgalagadi Transfrontier Park covering portions of Botswana and South Africa. The environment of the STAS is relatively pristine, with no significant mining or industrial activities.

STAS Hydrogeology and Groundwater Resources The STAS is part of a huge sedimentary basin composed of a thick sequence of layers, including carboniferous layers deposited through the Jurassic Age called the Karoo Supergroup. The Karoo Supergroup is economically important because of its coal deposits and scientifically important because of the rich non-marine fauna and flora from Permian and Triassic periods. The STAS is made up of three major aquifer systems, including two confined aquifers in the lower Karoo Supergroup sediments, called the Auob and Nossob aquifers, and one discontinuous aquifer system in the overlying Kalahari Group and Upper Karoo Supergroup sediments. Due to the climate and geography of the region, there are no permanent surface water resources in the STAS.

	Gaborone Dam Catchment (Ramotswa)	STAS
Area (km2)	4,300	87,000
Rainfall (mm)	250	minimal
Population (est)	100,000	50,000
Countries	Botswana, South Africa	Botswana, Namibia, South Africa

Table 1: Comparing Aquifers

2.2 Methods

Methods for the development of this brief are fairly straightforward. First, based on a compilation of project documents and narrative of project experiences, an overview of the objectives, partners and components for each of the two projects is provided. Second, approaches of the two projects – both consistency and variation – are compared as well as achievements and challenges. Third, achievements and performance of various project components is considered; as rigorous assessment was not possible, professional judgement is utilized to provide a crude estimate of the contributions of different components. Finally, lessons and recommendations are presented.

3. Project Aims, Approaches, Timelines

3.1 Ramotswa

Overall objectives The overall objective of the RAMOTSWA project was to support a long-term vision and cooperation on the shared groundwater resources of the RTBAA in the Upper Limpopo region of South Africa and Botswana. The project was implemented by the International Water Management Institute and the International Groundwater Resources Assessment Centre (IGRAC). The first phase of the project was co-funded through the *Resilience in the Limpopo Basin* (RESILIM) project of the United States Agency for International Development (USAID) and the CGIAR Research Program on Water, Land and Ecosystems, with the second phase directly funded by USAID. The project was conducted over a period of 4 years from mid-2015 through mid-2019.

Partnerships Key partners in the RAMOTSWA project include the Department of Water and Sanitation (DWS) of South Africa, the Department of Water and Sanitation (DWS) and Water Utilities Corporation (WUC) of Botswana, the University of Botswana, the University of the Free State, the Limpopo Watercourse Commission, the Joint Permanent Technical Committee between South Africa and Botswana, the Southern African Development Community, local municipalities, the University of Pretoria and the University of the Witwatersrand.

Key Components The Ramotswa project aimed to increase awareness of the importance and vulnerability of the RTBAA and to improve understanding of the socio-economic importance of the aquifer area and the challenges in water access and security. The project also aimed to assess the extent and hydrogeology of the aquifer under present and future climate and population projections and to develop tools for shared and harmonized management of groundwater monitoring, aligned with national water resource management processes. Lastly, the project aimed to develop human and institutional capacity for shared and harmonized management and monitoring of groundwater resources. This included establishing national and cross-border dialogue and cooperation on the RTBAA and encourage cooperation on other transboundary aquifers in the SADC region. Ultimately, the RAMOTSWA project was comprised of six components that brought together scientific information and regional diplomacy. These components include 1) a baseline report, 2) a hydrogeological study and model, 3) an assessment of the potential for managed aquifer recharge, 4) a study on agricultural water saving solutions, 5) the creation of the Ramotswa Information Management System, and 6) the development of a joint strategic action plan between South Africa and Botswana.

Baseline Report The baseline report synthesized existing data and information about the RTBAA, including biophysical features and socio-economic characteristics. The purpose of the baseline report was to inform future actions under the scope of the Ramotswa project, including informing priority issues to be addressed in the joint strategic action plan. The report was prepared by compiling and harmonizing national-level data and literature regarding the RTBAA (Altchenko et al., 2016). Five key issues emerged from the baseline report:

- The need to better understand the resource and fill the data gap
- Current groundwater contamination and vulnerability to future pollution
- Congruity between water requirements and available water
- Limited policy implementation
- Water and sanitation access for vulnerable people.

Hydrogeological Investigations The hydrogeologic report was conducted to develop a better understanding of the hydrogeologic characteristics that may affect future joint groundwater management (Altchenko et al., 2017). The study was based on existing and field data collected from September of 2015 to November of 2016, highlighting the importance of the karstic dolomite aquifer that straddles the border between Botswana and South Africa. Recommendations from the study include the need to develop monitoring systems and harmonise data between countries, to rehabilitate existing boreholes and install new monitoring stations, to improve knowledge about aquifer mechanisms and structures (i.e. surface geophysics data, additional borehole geophysics, surface geology discrepancies, surface-groundwater interactions), to protect groundwater from contamination through land use planning, to engage stakeholders at all levels, and to explore the possibility to improve water security in the region through MAR. A hydrogeological model was created to better understand recharge and water withdrawal in the RTBAA and to project the impacts of future changes to water use and storage (Ebrahim et al., 2018). A 3D transient hydrogeological model was developed using MODFLOW 2005 in MODELUSE modelling environment to understand recharge, storage, flow processes, water use dynamics, and to develop a water budget. The aim of the model was to explore the potential to implement MAR, which requires a better understanding of aquifer response to additional recharge, the capacity of the aquifer to store water, and potential optimal locations of MAR injection and recovery systems. The results of the model showed groundwater replenishment from focused recharge is highly uncertain due to its dependence on the magnitude and frequency of river runoff and flooding. Evapotranspiration from groundwater was revealed to be a significant portion of the groundwater budget, with groundwater evapotranspiration occurring along the river channel with the depth of groundwater is shallow.

MAR potential The hydrogeological model created with the Ramotswa project was used to examine the potential for managed aquifer recharge (MAR), a method of intentional recharge of freshwater into an aquifer at times of excess for storage for periods of scarcity or high demand (Ebrahim et al., 2017; Ebrahim, Trust, et al., 2018). The advantages of MAR include reduced land and water losses from evaporation, but MAR is not feasible everywhere. Hydrogeological factors limit its application, and degradation of water quality due to mixing of recharge water with native groundwater is a concern. The hydrogeological model developed for the RTBAA was used to investigate the feasibility of MAR in the region using a simulation-optimization approach. The results showed that due to the shallow depth of the groundwater and high evapotranspiration rates, conditions seem less favourable for storage of groundwater unless short-term storage is desired. It was noted that uncertainty in the extinction depth used in the hydrogeological model was uncertain, thus the estimated evapotranspiration rates may be higher than actual rates.

Agricultural water solutions Improving water-nutrient-soil management has a role to play in alleviating poverty, reducing food insecurity, and improving rural livelihoods in the RTBAA. The project assessed the impact of simple water and nutrient saving tools (e.g., front detectors and chameleon detectors) for greater yield and gross irrigated water productivity for smallholder farms (Magombeyi et al., 2018). The assessment used experimental and control field plots in Molthaka, South Africa and Mogobane and Glen Valley, Botswana. The results revealed significant water savings, nutrient loss reduction, and improved yield and gross irrigated water productivity in experimental compared to control plots. Thus, it was recommended that the use of the monitoring be expanded in smallholder contexts in the RTBAA. It was also recommended that special focus be given to rolling out the monitoring tools to furrow irrigation systems and to conduct a mapping exercise to explore opportunities for use of such tools in contexts similar to the RTBAA. More research would be required to explore the potential for sprinkler irrigation systems and applications to a wider range of vegetable and cereal crops.

Ramotswa Information Management System The Ramotswa Information Management System (RIMS) was developed to provide access to maps, data and information related to groundwater in the study area (IGRAC, 2018b). The online portal is publicly available, providing information to a wide range of stakeholders who can access the database and create thematic maps on groundwater and groundwater-related themes through the online viewer. The development of the RIMS portal was accompanied with multiple capacity building sessions for those who may utilise RIMS after completion of the Ramotswa project.

Joint Strategic Action Plan A series of national consultations and joint workshops with the Department of Water Affairs Botswana, the Water Utility Corporation Botswana and the Department of Water and Sanitation South Africa led to the development of a Joint Strategic Action Plan (JSAP) for the RTBAA (Lautze et al., 2016, 2018). The goal of the JSAP was to contribute to sustainable and equitable joint development of the RTBAA through consensus building between South Africa and Botswana on priority activities and investments in the use and development of the transboundary RTBAA and related resources. The JSAP process drew from the key issues identified in the baseline report to develop a joint vision and framework for the RTBAA and to identify objectives, targets and actions to achieve the joint vision and framework. The actions were reviewed for their compatibility to the current institutional framework, and actions were classified according to cost and implementation timeline to find low-cost, immediately implementable priority actions. Consultations in the later stages of the JSAP process highlighted the need to establish joint data and monitoring systems and protocols and to put in place institutional structures that enable ongoing transboundary cooperation and to conduct further assessments and research to better understand the context for water management in the RTBAA. It is expected that advancement of JSAP priorities will rely on the leadership from respective government ministries, coupled with regional facilitation through the JPTC and LIMCOM.

3.2 Stampriet

Overall Objectives The overall objective of the GGRETA project was to enhance cooperation on water security, prevent transboundary and water-use conflicts, and improve overall environmental sustainability. The project was implemented by the United Nations Educational, Scientific and Cultural Organization International Hydrologic Program (UNESCO-IHP) and funded by Swiss Agency for Development and Cooperation (SDC). The GGRETA project focused on three pilot projects in transboundary aquifers representing different natural and socio-economic settings, one of which was the Stampriet Transboundary Aquifer System (STAS), an aquifer shared by Botswana, Namibia and South Africa. The project was conducted over a period of 4 years from 2015 through 2019 as a technical assistance effort to better integrate groundwater resources into the water budget of river basins, countries and regions.

Partnerships The Stampriet project aimed to improve knowledge and recognition of the importance and vulnerability of transboundary groundwater resources and to strengthen cross border dialogue and cooperation. The project also aimed to develop shared management tools and to facilitate governance reforms that improve livelihoods, economic development and environmental sustainability. Key partners in the Stampriet project include a group of professionals from Botswana, South Africa and Namibia, in addition to the Department of Water Affairs and Forestry of Namibia, the Department of Water Affairs of Botswana, and the Department of Water and Sanitation of South Africa. Other partners include the University of Botswana and University of Avignon.

Project Components The GGRETA project was comprised of at least three components that combined scientific assessment and governance reforms, including 1) a detailed indicators-based assessment of the STAS packaged in an aquifer assessment, 2) the creation of a centralised information management system and related thematic maps, and 3) support for the creation the Multi-Country Cooperation Mechanism (MCCM) for ongoing joint management of the STAS.

Aquifer Assessment The Stampriet Transboundary Aquifer System Assessment was a technical report prepared using a multi-disciplinary methodology to articulate a biophysical, socio-economic and institutional baseline for the region and to diagnose key issues (UNESCO-IHP, 2016). The diagnostic used the Driver-Pressures-States-Impacts-Results (DPSIR) framework to understand the human and ecosystem uses of groundwater, linkages to surface water and land use systems, future water quality and use conditions, and key emerging issues. The assessment utilised a combination of national data types, harmonized cross the three countries, in addition to literature assessment and GIS mapping. The assessment identified several potential threats to groundwater development and use in the STAS, including

- Groundwater pollution
- Groundwater depletion
- Alien invasive species
- Climate change.

Information Management System The GGRETA Information Management System (IMS) is a web-based IMS that was created to store information that could be used during assessment, management and governance of transboundary aquifers (IGRAC, 2018a). The structure of the IMS focuses on thematic maps that include multiple types of relevant information for groundwater resources management. Joint control of the flow of data and information feeding into the IMS is managed through the newly created MCCM.

Multi-Country Cooperation Mechanism The STAS assessment investigated institutions for groundwater governance in the region. The expected value-add of the MCCM was expected to be consistency of purpose and direction of domestic STAS-relevant activities, joint control of the flow of data and information feeding into the IMS, and an ongoing STAS vision and perspective. In May of 2017, members of the STAS team attended meetings of the ORASECOM groundwater hydrology committee and technical task team to support a proposal to establish an MCCM for the STAS within the structures of ORASECOM. The proposal was discussed at the 34th ordinary meeting of the ORASECOM Council, and it was resolved that the MCCM be housed within the ORASECOM groundwater hydrology committee. The decision was endorsed in November of 2017. The creation of the MCCM under ORASECOM is noteworthy, as prior to ORASECOM's decision there had only been 6 formal and 2 informal agreements regarding transboundary aquifer management documented worldwide. In addition, it was the first operational mechanism for governance nested under the river basin organisation. The MCCM was brought into the structures of ORASECOM in one year; the time efficiency of the institutional was facilitated by the multi-layered structures of ORASECOM (Council, Secretariat, Task Teams and Committees).

4. Alignment and Divergence, Achievements and Performance

4.1 Alignment and Divergence

Common threads There are at least four elements common to the projects on the Ramotswa and Stampriet, which were likely key to project development. These elements may form a part of future projects on shared aquifers. These elements are:

- **A Baseline Report, Transboundary Aquifer Assessment, or Transboundary Diagnostic Analysis** A central part of both projects was focused on compiling and synthesizing existing data to understand the current state of conditions, and to distil key issues or messages based on the synthesis. This initial effort in many ways serves as a starting point for the project, a necessary step after which focus can be confidently applied or targeted to priority areas.
- **Hydrogeological Modelling** A core component of both projects was to develop a hydrogeological model based on existing data in the aquifer system. The aim of these efforts was to develop a better understanding of hydrogeologic characteristics that may affect joint aquifer management and to provide a shared understanding of the dynamics of the resource.
- **Information Management System** Both projects included the development of an online portal for sharing groundwater-related data between countries. In both cases, this portal was meant to provide information to stakeholders through access to a database and generation of thematic maps in an online viewer.
- **Dialogues** Another similarity between the two projects was the importance of stakeholder dialogue through various elements of the process. Consultation through stakeholder dialogue was critical to solicit input and feedback on project direction and key project deliverables.

Elements unique to Ramotswa Three activities were only found in the project on the Ramotswa Aquifer. First, the Ramotswa JSAP was undertaken. The JSAP was the first strategic action plan developed for a transboundary aquifer in SADC. The JSAP fostered convergence toward a common vision for shared management of the Ramotswa and identified a set of actions that can be pursued to realize this vision. Second, an activity on Ag-Water Solutions was undertaken. Work on Ag-Water Solutions contributed to improved water efficiency in the RTBAA, highlighting ways to stretch limited water resources farther by matching water application to water needs. Lastly, the investigation of MAR potential was unique to the RAMOTSWA project, exploring potential for the aquifer to be used as nature infrastructure.

Element unique to Stampriet Prior to the implementation of the MCCM, there was no legal instrument specific to management of transboundary aquifers, both at a regional SADC level and at the level of the STAS. Groundwater has been integrated into the Revised SADC Protocol on Shared Watercourses, only insofar as surface water bodies are linked to groundwater aquifers. Within the SADC Secretariat, the SADC Water Division is responsible for facilitating and increasing cooperation in water. Surface and groundwater governance shared by Botswana, South Africa, Namibia and the Kingdom of Lesotho is governed by ORASECOM. The assessment showed that while administrative systems of the countries of the STAS differ (i.e. Namibia and South Africa operate under a 3-tiered, decentralized system and Botswana operate under a 2-tiered centralized system), the domestic, policy, legal and institutional framework for groundwater is in place in all three STAS countries. In addition, all three countries had compatible laws, as they regulate abstraction and potential point-source pollution through a permit system.

4.2 Achievements and Performance

Overarching Project Achievements: Improved Understanding Vastly improved understanding of the boundaries, physical layout and dynamics of the shared aquifer and related socioeconomic and institutional conditions in the shared aquifers. The broader significance of this should not be taken lightly, as groundwater resources are playing an increasingly important role in the drive for resilience and sustainable development in Africa and the importance of transboundary waters on the continent has long been recognized. All this said, the nature of groundwater poses major challenges to joint understanding and management, so transboundary groundwater has been relatively scantly explored in Africa, and there is no proven template for doing this. In this context, the projects have taken important initial steps to understand aquifer conditions and to elaborate and implement a participative process for doing so. Much of the initial data collection effort was bundled into reports, which marked the most comprehensive set of hydrologic, institutional and socioeconomic information on the shared aquifers.

Overarching Project Achievements: Cooperation Cross-border collaboration did not exist on either aquifer 5 years ago, and now exists on both. A notable set of stakeholders (in and outside the government) in aquifer-sharing states have been engaged and actively contributed to technical reports and dialogues on various aspects of water management and related issues in the aquifer area. Previously, such cooperative interactions were limited, especially at the international level. Such engagement has led to an appreciation of the role of the aquifer and clear demand to upscale cooperation to enhance and maximize the benefits derived from its use. A Joint Strategic Action Plan is now under development on the Ramotswa, for example, which will prioritize specific joint investments that the two countries will take forward together on the aquifer. On the Stampriet, cooperation has been nested in ORASECOM.

Overarching Project Achievements: Progress toward aquifer management Work on the Ramotswa and Stampriet aquifers has laid the basis for cooperation and joint management of the aquifers – a notable (and positive) departure from the traditional scope and focus of national management by the concerned countries. While no doubt still in its infancy, the joint aquifer management that the projects has facilitated can contribute to a range of positive outcomes, like improved monitoring of the resource, information sharing on national development plans in the aquifer area, joint agreements on the development of the resource, mechanisms for sharing data, knowledge and management approaches, some of these ideally even beyond the scope of the particular aquifers. Many of such outcomes stem from the logic that water is best managed at the scale of hydrologic units – often described in terms of basins but also aquifers. Integrated management at logical scales, which also considers aquifers, can help optimize water use, pollution control, and maximize benefits according to a suite of criteria such as water security and resilience.

Performance across components was generally good, but variability exists Establishment of the MCCM under ORASECOM for the Stampriet Aquifer can be described as "very good", as it is the first such nested structure for transboundary aquifer governance under an RBO in the region. The process for establishing the committee enhanced sustainability, ownership and legitimacy, in addition to providing an example for similar structures in other RBOs containing transboundary aquifers. The baseline assessments for both projects can be described as "good", as they provided important information for stakeholders to understand and agree on a common foundation on which to advance joint management. The multi-stakeholder dialogues in both projects were "good", because of their role in incorporating stakeholders into the process of knowledge development and aquifer cooperation. Lastly, the Ag-Water Solutions and MAR components of the RAMOTSWA project can also be described as "good", as they each explored specific concreate topics aimed at bringing on the ground change; in both cases, good progress was made (Table 2).

Component	Ramotswa	Stampriet	Evaluation
Baseline Report / Aquifer Assessment	✓	✓	Good: Important assessment that helped to characterize the system and get countries on same page
Hydrogeologic Modelling	✓	✓	Good but constrained by quantity and quality of data
Information Management System	✓	✓	Good but constrained by quantity and quality of data
Dialogues	✓	✓	Good: Important to share findings and discuss next steps
MCCM		✓	Very Good: Enhanced sustainability, ownership, legitimacy
Ag-Water Solutions	✓		Very Good: Fostered on-the-ground improvements, engaged with local stakeholders, determined solutions
MAR	✓		Good: Explored a potential solution, exposed critical data gaps
JSAP	✓		Good: Enhanced likelihood of sustainability, created project momentum, ownership

Table 2: Project Components

Despite positive progress, potential of two components limited by data availability The RAMOTSWA project and the Stampriet project both contributed to significant progress in the advancement of transboundary groundwater management in SADC. However, the quantity and quality of data constrained project process. These data gaps inhibited the utility of the hydrogeological models, as the models required assumptions that could not be fully validated with high quality data. These data-related challenges also affected the comprehensiveness of the information management systems for both the Ramotswa and Stampriet aquifers.

5. Lessons and Recommendations

The RAMOTSWA and Stampriet projects: five lessons for transboundary aquifer management The RAMOTSWA Project and the GGRETA (Stampriet) Project both contributed significantly to the advancement of transboundary groundwater management in two distinct geographies in SADC. It is critical that others leverage these lessons learned as transboundary aquifer management becomes a priority in different geographies in SADC and around the world. At least five lessons can be drawn from the RAMOTSWA and Stampriet:

1. While there is no blueprint to design of transboundary aquifer projects, certain components may be key to success
2. Think conjunctive: Aquifer projects benefit from considering surface waters
3. RBOs are key to sustainability of transboundary aquifer management
4. Pervasive data constraints call for greater focus on monitoring

5. Consider which areas require cooperation and which do not

1. There are different ways to formulate transboundary aquifer projects: TDAs, dialogues, & RBO linkages may be important in any formulation Experiences in the Ramotswa and Strampriet highlighted good degrees of variation in project design. This variation underscores the need to match the design of a transboundary aquifer management project to an aquifer's unique local context. Nonetheless, certain elements may be critical regardless of context. These elements are i) a TDA, critical to create an initial knowledge platform for cooperation, ii) dialogues, critical to essential engagement with and among stakeholders, iii) RBO linkages, critical to sustainability and ownership. Furthermore, while not essential, at least two other elements may be helpful regardless of context: i) information management, important to host and disseminate data and knowledge related to a shared resource, ii) a Strategic Action Plan, important to elaborating common ways forward in the joint management of a shared system.

2. There are limits to sole focus on groundwater Despite the growing recognition for the need to focus on shared aquifers, *isolated* focus on shared aquifers – i.e., without also considering surface waters – may not match the practical realities of water management. The need for conjunctive water management is explained by fairly ubiquitous realities in which rivers flow over aquifer outcrops and water from different sources interact. Ultimately, it may be best to emphasize incorporation of aquifers into existing water management frameworks rather than treating aquifer management as a distinct new endeavour. The importance of linking water sources is reflected in the next lesson.

3. Transboundary River Basin Organisations (RBOs) provide a useful resource for institutionalizing and sustaining transboundary aquifer management Efforts to institutionalize transboundary aquifer cooperation can take advantage of the relative maturity of transboundary basin-wide RBOs, which possess several-decade histories of multi-country cooperation over (mostly surface) water resources. The GGRETA (Stampriet) project demonstrated the value of leveraging the basin-wide RBO of ORASECOM to develop the necessary structures for transboundary aquifers shared by some or all member states and to provide the procedures required to establish long-term cooperation. Notably, incorporation of aquifer focus into RBO mandates also promoted conjunctive management, as RBOs typically focus mainly on surface waters yet incorporation of aquifers obviously brings groundwater focus.

4. The lack of high-quality data may be a critical project constraint; this calls for more upstream emphasis on monitoring Data gaps should not be underestimated and are far greater in size on transboundary ground than surface waters. In the RAMOTSWA project, data gaps limited the long-term utility of the hydrogeological model and the comprehensiveness of information management systems. These efforts are particularly complex in linked surface water and groundwater systems, such as the Ramotswa Aquifer and the Ngotwane River, where conjunctive management of transboundary surface water and groundwater calls for more robust datasets to model interactions between different resources. Ultimately, one way to address the pervasive data gaps likely to constrain understanding and cooperation on shared aquifers is to build monitoring programs into projects earlier on – so that new data is generated. Clearly, it is important to be strategic and targeted in the installation of monitoring equipment; this nonetheless looks to be best done sooner than later.

5. Consider which areas require cooperation and which do not While many actions and issues on a shared aquifer may benefit from cross-country coordination, there may also be many that do not. Indeed, actions in many parts of a transboundary aquifer may not have transboundary impacts. In fact, the hydrogeology of an aquifer may render significant parts of a transboundary aquifer de facto national. For example, geophysical work in the Ramotswa identified that the dolomite aquifer is configured into 13 compartments, which may be relatively confined. Of these, four cross the international border. It is in these four compartments where transboundary impacts are most likely to be felt – and where joint action may be most needed. This finding underscores the need to understand the hydrogeology of the aquifer in detail, so that efforts at joint management are targeted to areas that may most benefit from it – and, alternatively, cooperative efforts are not invested in those areas that are unlikely to benefit from them.

References

AG-WAT Net (2015) "Integration of Groundwater Management into Transboundary Basin Organizations in Africa - a Training Manual by AGW-Net, BGR, IWMI, CapNet, ANBO, & IGRAC". Available online: https://www.gwp.org/globalassets/global/toolbox/references/trainingsmanual.pdf

Altchenko, Y., Genco, A., Piers, K., Woolf, R., Nijsten, G. J., Ansems, N., … Kenabatho, P. (2017). *Resilience in the Limpopo Basin: The Potential Role of the Transboundary Ramotswa Aquifer - Hydrogeology report - Final draft 28th February 2017*.

Altchenko, Y., Lefore, N., Villholth, K., Genco, A., Pierce, K., Woolf, R., … Nijsten, G.-J. (2016). *Resilience in the Limpopo Basin: The Potential Role of the Transboundary Ramotswa Aquifer - Baseline Report*.

Braune, E., Hollingworth, B., Xu, Y., Nel, M., Mahed, G., and Solomon, H. (2008). Protocol for the Assessment of the Status of Sustainable Utilization and Management of Groundwater Resources - With Special Reference to Southern Africa. Pretoria. Water Research Commission Braune and Xu, 2011

Christelis et al. (2010) Towards Transboundary Aquifer Management in southern Africa. Available online: https://pdfs.semanticscholar.org/9741/0112df4ff70734308d427fea3d1e469294db.pdf

Ebrahim, G., Fathi, S., Lautze, J., Ansems, N., Villholth, K., Nijsten, G. ., … Kealeboga, D. (2017). *Review of Managed Aquifer Recharge (MAR) Experience in Africa and Suitability Mapping for Ramotswa Transboundary Aquifer Area*.

Ebrahim, G., Magombeyi, M., Villholth, K., Lautze, K., Nijsten, G. J., Keodumetse, K., … Nkile, C. (2018). *Hydrogeological Modelling for Ramotswa Transboundary Aquifer Area*. https://doi.org/10.2519/jospt.2018.48.12.986

Ebrahim, G., Trust, S., Magombeyi, M., Villholth, K., Lautze, J., Nijsten, G. ., … Nkile, C. (2018). *Assessing the feasibility of Managed Aquifer Recharge in Ramotswa Transboundary Aquifer Area*. https://doi.org/10.2519/jospt.2018.48.12.986

IGRAC. (2018a). GGRETA Information Management System. Retrieved from https://apps.geodan.nl/igrac/ggis-viewer/ggreta/regions

IGRAC. (2018b). RIMS: Ramotswa Information Management System (Brochure). IGRAC.

Lautze, J**.,** and Giordano, M. (2005). Transboundary Water Law in Africa: Development, Nature, and Geography. Natural Resources Journal 45(4): 1053-1087.

Lautze, J., Phiri, Z, Smakhtin, V., Saruchera, D. (2017). The Zambezi Basin: Water and Sustainable Development. Earthscan.

Lautze, J., Hawkins, S., Villholth, K., Lefore, N., Altchenko, Y., Nkile, C., … Lebeloane, M. (2016). *Joint Strategic Action Plan for the Ramotswa Transboundary Aquifer Area - Roadmap*.

Lautze, J., Saruchera, D., Hawkins, S., Villholth, K., Ebrahim, G., Nkile, C., … Gaebee, S. (2018). *Draft Joint Strategic Action Plan for the Ramotswa Transboundary Aquifer Area*.

Magombeyi, M., Lautze, J., Sebogodi, T., Okonkwo, A., Nkile, C., Motlalenkwe, T., … Villholth, K. (2018). *Agricultural Water Management Solutions for smallholder farmers in the Ramotswa Transboundary Aquifer Area*. https://doi.org/10.2519/jospt.2018.48.12.986

Nijsten. G. et al. (2018) Transboundary aquifers of Africa: Review of the current state of knowledge and progress towards sustainable development and management Journal of Hydrology 20: 21-34.

Sadoff, C.W., Hall, J.W., Grey, D., Aerts, J.C.J.H., Ait-Kadi, M., Brown, C., Cox, A., Dadson, S., Garrick, D., Kelman, J., McCornick, P., Ringler, C., Rosegrant, M., Whittington, D. and Wiberg, D. (2015) Securing Water, Sustaining Growth: Report of the GWP/OECD Task Force on Water Security and Sustainable Growth, University of Oxford, UK, 180pp

UNESCO-IHP. (2016). *Stampriet Transboundary Aquifer System Assessment - Governance of Groundwater Resources in Transboundary Aquifers (GGRETA) - Phase 1*. Paris.