International Water Management Institute

Project Brief
Transboundary Water Management in Southern Africa

Enhancing resilience through managed aquifer recharge in the Tuli Karoo Transboundary Aquifer Area: What is the potential?

The Tuli Karoo Transboundary Aquifer Area (12,294 km²) – shared by Botswana, South Africa and Zimbabwe – is home to more than 120,000 people that utilize water for domestic needs, agriculture and mining. However, water availability for these uses is severely constrained by low rainfall, high evaporation and significant rainfall variability. About 97% of annual precipitation occurs in the rainy season from October to April with dry weather conditions in the other months. Furthermore, rivers in the Tuli Karoo Transboundary Aquifer Area are ephemeral and only flow seasonally mainly during high rainfall events. Improving water security in this area is essential to meet the demand for water in the face of increasing population, urbanization, recurrent droughts, and climate variability and change. Storing water in surface reservoirs is the most common way to regulate uneven distribution of river runoff. Yet, the benefits of such reservoir development are often reduced by high evaporation losses, sedimentation and the environmental and other impacts of physical infrastructure development.

Managed Aquifer Recharge (MAR) is a technique to increase groundwater availability, reduce evaporation losses, and support conjunctive groundwater and surface water management (Casanova et al. 2016). In simple terms, MAR comprises environmental alterations that facilitate the artificial infiltration of water into an aquifer.

Limpopo River crossing the Tuli Karoo Transboundary Aquifer Area (*photo:* Resego Mokomela).

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MAR can be achieved through methods such as surface water spreading or induced bank filtration. The *surface water spreading* method can make use of constructed ponds to recharge the underlying aquifer system, or alternatively divert water from rivers in a way that causes water to spread over a large surface area, thereby maximizing infiltration. *Induced bank filtration* is a process of increasing surface water infiltration from perennial rivers or lakes into an aquifer by pumping from wells located at the banks of the surface water bodies. Ultimately, by increasing groundwater availability during times of low or absent surface flows, MAR can enhance resilience and increase the reliability of water access in rural areas. The Tuli Karoo Transboundary Aquifer Area (Figure 1) presents a shared geography in which MAR could add substantial value.

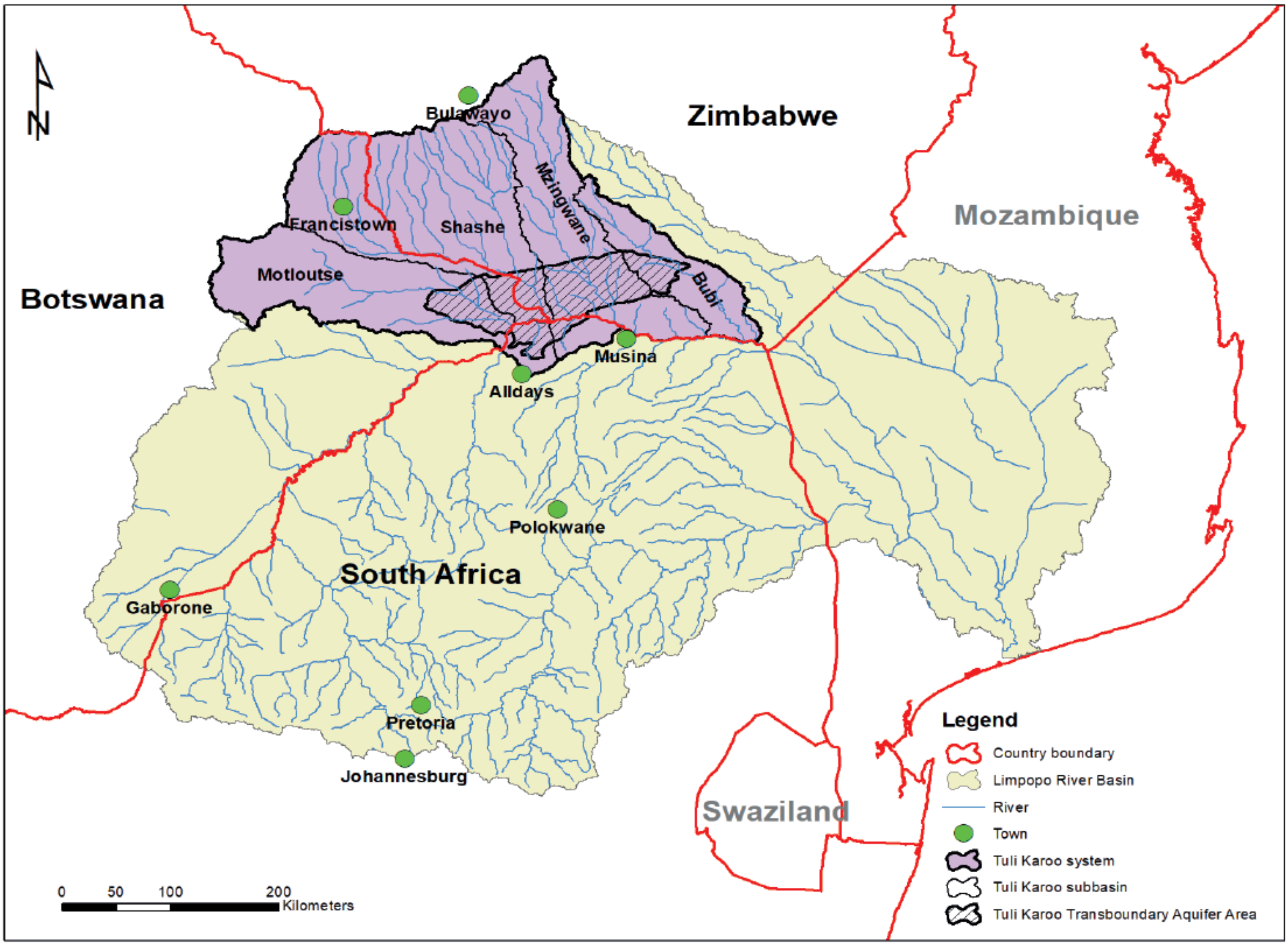

Figure 1. Map of the Tuli Karoo Transboundary Aquifer Area in the larger Limpopo River Basin.

Key messages

- **There is high potential for MAR in the Tuli Karoo Transboundary Aquifer Area.** Approximately 57% of the aquifer area is suitable for MAR and 7% of the area is highly suitable. While more in-depth investigations of potential sites should certainly follow, these initial results point to the opportunity for MAR to contribute to improved water resources management in the Tuli Karoo Transboundary Aquifer Area.
- **MAR development efforts can enhance resilience and food security, and modelling can guide the way forward.** Focused hydrogeological modelling can comprehensively characterize aquifer dynamics, which can contextualize the strategic role for MAR. In particular, a water balance model can account for groundwater levels, storage, and extraction and infiltration capacity. Within this frame, the role of MAR can be optimally utilized for maximum benefit.
- **It is critical to identify water sources that can be used for MAR.** Key water sources for MAR include seasonal flow and urban wastewater. Options for seasonal flow in the Tuli Karoo Transboundary Aquifer Area include the main Limpopo River and its tributaries such as Shashe, Mzingwane, Motloutse and Bubi. Rainfall that occurs from November to March may be the best time to recharge the aquifer. Potential sources of water reuse include wastewater from towns such as Bobonong.
- **Next steps: feasibility analysis.** Assessing the feasibility of MAR includes undertaking a technical feasibility study, and identifying the demand for water and availability of water sources. Based on these factors, one or more sites are selected, and pilot testing is carried out to ensure that the potential is high enough to warrant investing further resources.

One key step in identifying the potential for MAR in the Tuli Karoo Transboundary Aquifer Area is the development of a suitability map. Therefore, an aim of the *Conjunctive Water Resources Management across Borders in the Southern African Development Community (SADC) Region: Generating Principles through Fit-for-purpose Practice* project was to develop a MAR suitability map for this aquifer area using Geographic Information System-based Multi-Criteria Decision Analysis (GIS-MCDA). The suitability assessment provides a quantitative measure of MAR potential in the aquifer area, and supports the identification of suitable areas where MAR can be potentially implemented by the three countries sharing the aquifer.

Sand storage tank constructed on the tributary of Motloutse River, Botswana, to collect water flowing through the sand (*photo*: G. Y. Ebrahim).

Methods: Assessing MAR potential

Selecting a MAR method. We assumed that the preferred method of MAR in the Tuli Karoo Transboundary Aquifer Area is the surface water spreading method for at least three reasons. First, the spreading method is low cost and simple to apply, and sophisticated technology is not needed. Second, the data required to assess the suitability of this method to artificially recharge the aquifer are lower than the data required to assess the suitability of other MAR methods. Third, this method allows for a natural treatment process and the best opportunity to control clogging.

Defining the approach for suitability mapping. Five steps were employed to map potential MAR sites using GIS-MCDA.

1. Six criteria (slope, soil, land use/land cover, lithology, lineament density and drainage density) were selected for GIS-MCDA of the Tuli Karoo Aquifer.
2. Constraint mapping was used to exclude restricted areas deemed unfeasible for MAR implementation.
3. Individual criteria maps were standardized. Standardization involves describing each criteria map in a common scale – usually a range between 0 (zero) and 1 (higher the value the better).
4. Relative weights were assigned to each criteria map based on their importance to the process. The ranking method was used for assigning a weight for each criteria map. The ranking method involves ranking criteria according to their rank order from the most to least important. The weights are then calculated using the formula $((N-r+1)/\Sigma(N-r+1))$, where N is the total number of criteria and r is the rank order.
5. A sensitivity analysis is performed to determine the rate of change in MAR suitability classes by varying the weights, thus giving an understanding of how a change in the weights assigned to criteria influences the output of the suitability mapping.

Farm workers carrying newly harvested tomatoes in South Africa (*photo:* Dominique Rollin/IWMI).

Key findings

There is good potential for MAR in the Tuli Karoo Transboundary Aquifer Area (Figure 2). Areas suitable for MAR cover approximately 57% of the aquifer area and most of these areas are underlain by basalt. The concentration of areas with very high suitability along lineament routes (highlighted in dark green in Figure 2) shows the key influence of lineaments even though they are one of a number of influential factors.

Suitable areas cover most of the Tuli Karoo Transboundary Aquifer Area while less suitable areas are found towards the south of the aquifer in South Africa. A combination of factors, including low permeability, low soil infiltration rate, relatively steep slope and high drainage density, render this part of the aquifer unsuitable for MAR. Most of the aquifer area that lies in Botswana is in the suitable classes. Botswana's high suitability may be attributed to its comparatively high lineament density. Zimbabwe possesses the largest area of suitable and highly suitable areas, mainly because majority of the aquifer area lies within this country.

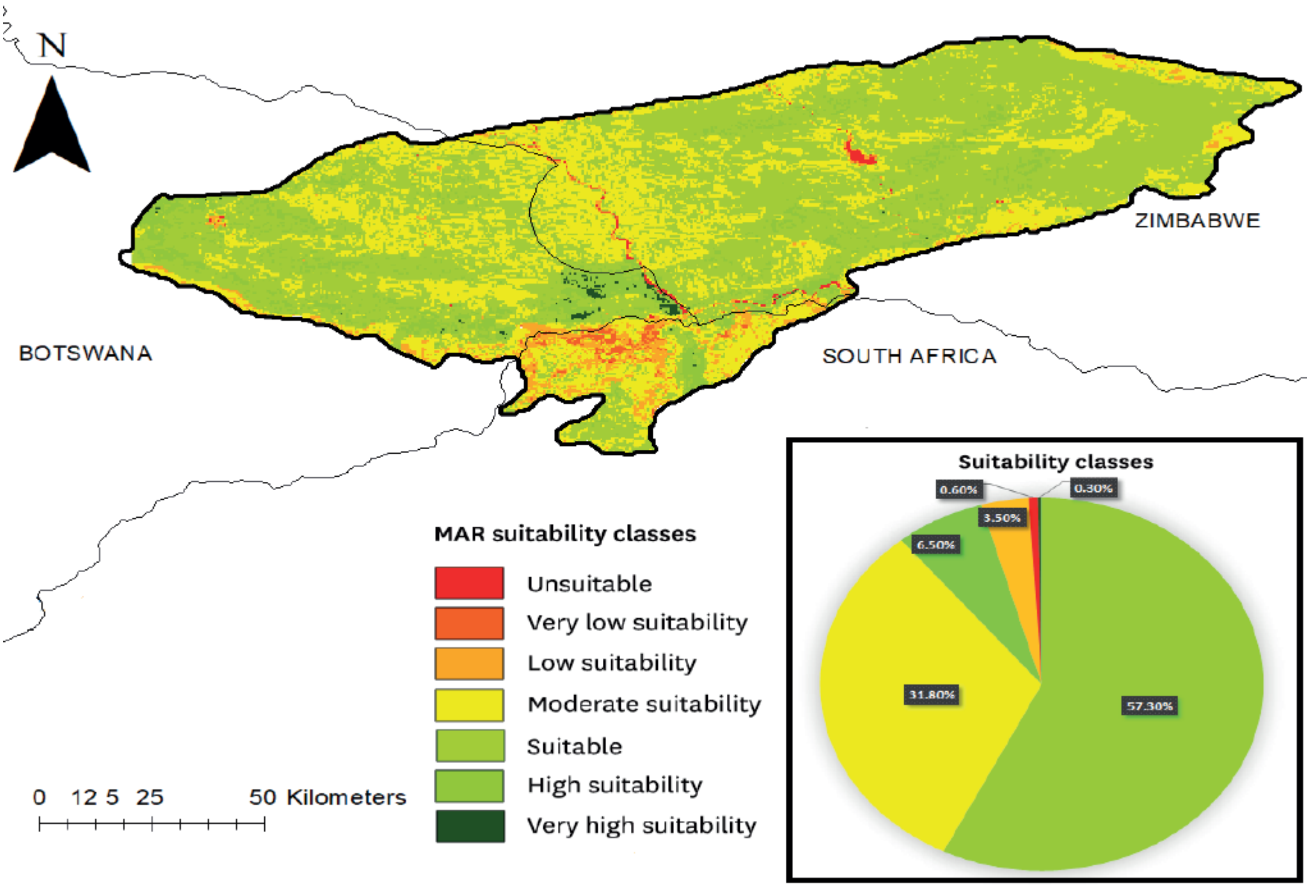

Figure 2. MAR suitability map for the Tuli Karoo Transboundary Aquifer Area.

Sensitivity analysis to reveal the relative importance of criteria. A sensitivity analysis is useful to identify criteria that have the largest influence on evidenced suitability. Therefore, a sensitivity analysis was carried out by increasing the weights assigned to criteria by 10% and identifying the resulting change in area under each suitability class. This showed that lineament density is the most sensitive criterion (Figure 3). Changing the weight assigned to lineament density by 10% results in a substantial change in the area under the suitable classes (17.4%) and a 17.8% change in the area under the moderately suitable class. Slope also proved to be quite an influential factor; a change in the weight assigned to slope by 10% results in a 11.3% change in the area under the high suitability class and a 13.9% change in the area under the suitable class.

Benefits and risks of MAR. Benefits of MAR implementation in the Tuli Karoo Transboundary Aquifer Area include the ability to balance the seasonal mismatch between water supply and demand, expand the volume of water in the aquifer for use during periods of drought, increase water storage for beneficial uses such as irrigation, and reduce the impacts of flooding by capturing excess stormwater or floodwater. However, implementation of MAR in the Tuli Karoo Transboundary Aquifer Area may also carry risks such as those related to water quality and clogging (Page et al. 2010; Rodríguez-Escales et al. 2018). The use of treated wastewater, for example, may alter water quality negatively. Furthermore, chemical differences between the water injected into and water inherent in the receiving aquifer may trigger chemical reactions. Clogging, i.e., restriction on the volume of water that can infiltrate or be injected into the target aquifer, can reduce the amount of recharged water.

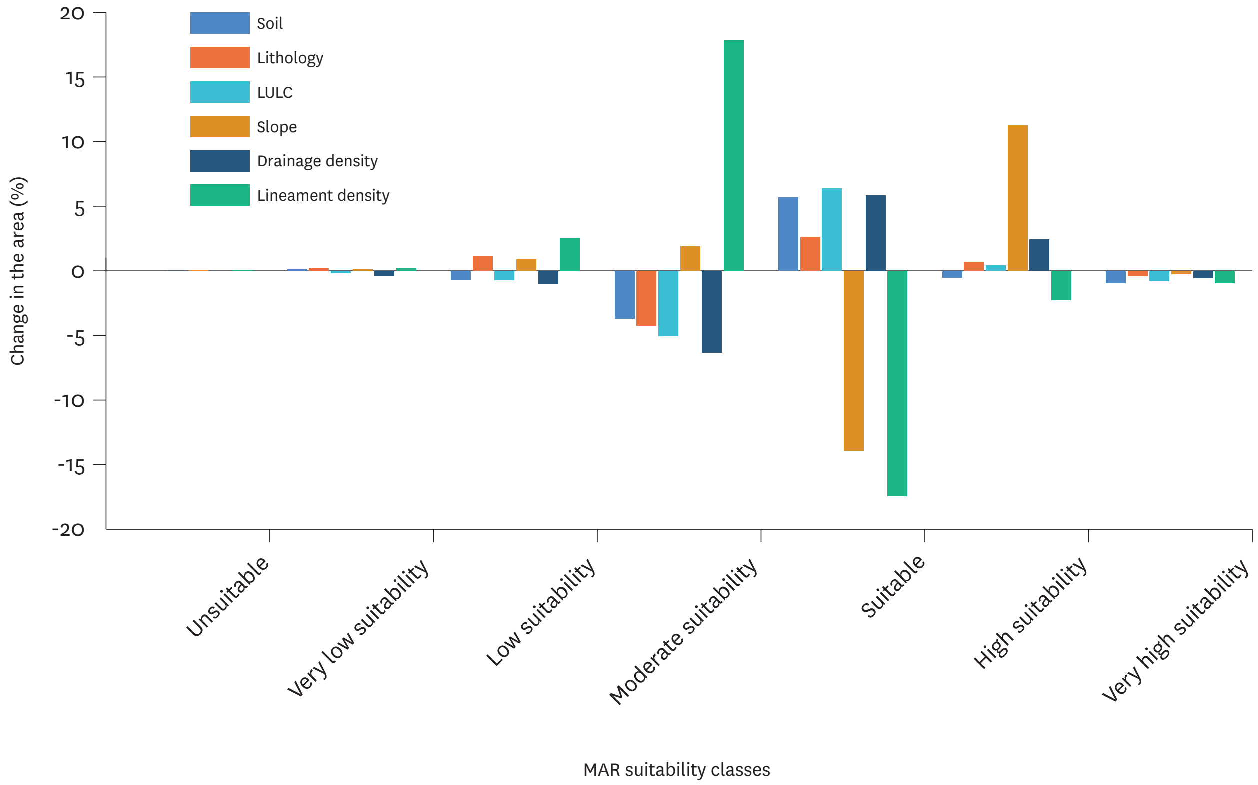

Figure 3. Results of the sensitivity analysis where weights assigned to criteria were increased by 10% to identify the change in the area under each MAR suitability class.

A female farmer with her produce in Zimbabwe (*photo:* David Brazier/IWMI).

Conclusion

The suitability mapping conducted provides a clear picture of the areas suitable for MAR implementation in the Tuli Karoo Transboundary Aquifer Area. The suitability map constitutes an important tool that can be used by decision makers as one contribution to an integrated groundwater management plan. Additional contributions to such a plan, which can be coupled with the suitability map, include water demand, availability of water resources, and wastewater treatment. Accurate identification of prospective MAR sites serves as one of the first stages in the successful implementation of a MAR project.

In order to build on the results of this work, specific sites in areas suitable for MAR could be subjected to further investigation focused on factors including (i) demand for additional water, (ii) financial capacity to support MAR implementation, (iii) technical capacity to sustain a MAR scheme, and (iv) availability of a water source that can be used to artificially infiltrate the aquifer. Ultimately, this initial investigation of the entire aquifer supports a positive outlook in identifying sites suitable for MAR implementation. There is, indeed, good potential for MAR to alleviate the water challenges of the Tuli Karoo Transboundary Aquifer Area.

Surface water harvesting pond for wild animal watering at Northern Tuli Game Reserve, Botswana (*photo:* G. Y. Ebrahim).

References

Casanova, J.; Devau, N.; Pettenati, M. 2016. Managed aquifer recharge: An overview of issues and options. In: Jakeman, A.J.; Barreteau, O.; Hunt, R.J.; Rinaudo, J.-D.; Ross, A. (eds.) *Integrated groundwater management: Concepts, approaches and challenges*. SpringerOpen. pp.413–434.

Page, D.; Dillon, P.; Vanderzalm, J.; Bekele, E.; Barry, K.; Miotlinski, K.; Levett, K. 2010. *Managed aquifer recharge case study risk assessments*. CSIRO: Water for a Healthy Country National Research Flagship. Canberra, Australia: Commonwealth Scientific and Industrial Research Organisation (CSIRO).

Rodríguez-Escales, P.; Canelles, A.; Sanchez-Vila, X.; Folch, A.; Kurtzman, D.; Rossetto, R.; Fernández-Escalante, E.; Lobo-Ferreira, J.-P.; Sapiano, M.; San-Sebastián, J.; Schüth, C. 2018. A risk assessment methodology to evaluate the risk failure of managed aquifer recharge in the Mediterranean Basin. *Hydrology and Earth System Sciences* 22(6): 3213–3227. https://doi.org/10.5194/hess-22-3213-2018

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Project

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For more information, visit http://conjunctivecooperation.iwmi.org

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Contacts

Girma Yimer Ebrahim, Regional Researcher: Hydrogeology and Water Resources, IWMI, Addis Ababa, Ethiopia (g.ebrahim@cgiar.org)

Jonathan Lautze, Research Group Leader – Integrated Basin & Aquifer Management, IWMI, Pretoria, South Africa (j.lautze@cgiar,org)

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International Water Management Institute (IWMI)

Headquarters
127 Sunil Mawatha, Pelawatte,
Battaramulla, Sri Lanka

Mailing address:
P. O. Box 2075, Colombo, Sri Lanka
Tel: +94 11 2880000
Fax: +94 11 2786854
Email: iwmi@cgiar.org
www.iwmi.org

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