GROUNDWATER AND DROUGHT MANAGEMENT IN THE SOUTHERN AFRICAN DEVELOPMENT COMMUNITY (SADC)

COMPONENT 2

REGIONAL GROUNDWATER DROUGHT MANAGEMENT SUPPORT

Contract 003D:

Regional Groundwater Monitoring Network

Transboundary Aquifers in SADC
Review and Classification with respect to Regional Groundwater Monitoring

FINAL REPORT

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1 Introduction

The Southern African Development Community (SADC) has the goal of fostering cooperation and mutual benefit from the resources of the region amongst its member countries – Angola, Botswana, DRC, Lesotho, Mauritius, Malawi, Mozambique, Namibia, Madagascar, Seychelles, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe. Through this mutual goal SADC has identified water as a key resource that can benefit from such cooperation.

The development and management of water resources in SADC Member States has traditionally focused on surface waters. However, increasing aridity and limited surface resources have resulted in increasing dependency among SADC Member States on groundwater for both domestic and commercial water needs. Recognizing this increasing dependency, the SADC has developed a Groundwater Management Programme (GMP). The overall objective of the GMP is to promote the sustainable development of groundwater resources at a regional level, incorporating research, assessment, exploitation and protection, particularly related to groundwater drought management.

However, the lack of detailed information pertaining to regional groundwater resources along with the transboundary nature of many of the aquifers is currently complicating the sustainable management and allocation of groundwater. To move towards the management of Transboundary Watercourses the SADC Members States are in the process of the creation and establishment of several River Basin Organizations: Limpopo River Basin Commission (LIMCOM), Orange-Senqu River Basin Commission (ORASECOM), Okavango River Basin Commission (OKACOM), the Rovuma Basin Committee, and Zambezi River Basin Commission (ZAMCOM).

To address these challenges SADC with the help of a GEF grant is currently undertaking a '**Groundwater and Drought Management Project**', of which the present Contract 003D: '**Regional Groundwater Monitoring**' is a component part. The Groundwater and Drought Management Project objective is defined as *"The development of consensus on a SADC regional strategic approach to support and enhance the capacity of its member States in the definition of drought management policies, specifically in relation to the role, availability and supply potential of groundwater resources."*

The **Regional Groundwater Monitoring** project aims to:

1. Investigation of the feasibility of a regional groundwater monitoring network.
2. Develop operational and management guidelines for regional groundwater monitoring.
3. Design a regional reference network with a view to addressing climate change and drought issues in the SADC region.
4. Develop specifications for the required monitoring and telemetry equipment and associated data management system.
5. Demonstrate the feasibility and value of a groundwater reference monitoring system in a Transboundary Aquifer context at pilot level.
6. Develop a draft Project Memorandum for a Regional Groundwater Monitoring Project.

This report forms an important component in the Regional Groundwater Monitoring Project output. The objective of the report is to describe and classify the international aquifers within the SADC region and to identify which aquifers should be monitored in order to enhance understanding between neighbour states.

An introductory chapter defines the concept of the transboundary aquifer (TBA). This is developed in Chapter 3 within the historical context of transboundary groundwater systems. TBAs that have been recognised within the SADC region and highlighted in the SADC Hydrogeological Map and are described in terms of their geology and hydrogeology. These descriptions are presented within an inventory in Annex 1to this report. The inventory shows that some of the transboundary situations that had previously been identified could be more active than others and a means of classifying them is established in Chapter 5. The classification comprises four discrete aspects: geological, socio-economic, institutional and environmental as show in Annex 2. These groups are brought together with the application of an algorithm chosen to best represent the level of activity in each transboundary aquifer, i.e. as active, moderately active and inactive. Finally, the report identifies active situations which can usefully be targeted for monitoring in order to enhance understanding of these respective aquifers. Guidelines for monitoring are presented in the form of a recommended monitoring protocol.

2. Definition

The Transboundary Aquifer (TBA) is a groundwater unit shared by two or more nations or managing states within a nation, for which equitable resource apportionment is required. One of the often reported examples is the management of the West Bank Mountain Aquifer which is recharged in Palestine but flows as a confined aquifer to spring discharges in neighbouring Israel (Mansour *et al*. 2012). Apportionment is controlled by Israel while Palestine, which Israel considers as an Occupied Territory, believes its resource allocation is inadequate. In most cases, however, the management of a TBA and the allocation of resources between neighbouring political units are carried out collaboratively and to the satisfaction of the stakeholders.

The concept of the TBA grew from the riparian ideal of shared surface water resources. Perhaps the oldest formalised shared water resource is that controlled by the Rhine Commission which oversees the equitable allocation of surface water from the Rhine catchment to the various riparian states in Europe. At the bottom end of this long chain of users is the Netherlands which pumps river water, now partly polluted by earlier riparian activities, into coastal dunes where it is naturally cleansed and filtered preparatory to being treated for use as drinking water. The maintenance of a synthetic high water table also acts as a hydraulic barrier to sea water intrusion through the dunes which could flood the low lying lands of this small country if left unchecked.

Transboundary Aquifer systems display features which differ in many respects from those of international rivers and a direct transfer of experiences gained with transboundary rivers is not appropriate. Hydrogeological features do have implications for transboundary governance, and one striking implication is that hydrogeological features establish a physical interdependency between the riparian countries. The differences between shared surface water and groundwater are not absolute but rather gradational. The most prominent of them are:

- The replenishment period of aquifers is long, and the provenance of groundwater generation may be unclear.
- Defining the boundaries of groundwater resources (the resource domain) and the users' domain is complicated and challenging with inherent uncertainties regarding:
    - recharge areas,
    - flow and discharge characteristics,
    - interrelationships with surface water bodies,
    - the fact that overexploitation and pollution is not immediately perceptible,
    - the difficulties of riparian states in monitoring extraction rates,
    - various sources of pollution, etc.
- Even with modern monitoring and modelling techniques to identify groundwater characteristics and boundary lines, it can be difficult to define the ownership of water resources (not only groundwater). Groundwater, of course, dissipates beneath the surface irrespective of national boundaries (Matsumoto 2002).
- Large-scale hydraulic facilities are more common in surface water use than in groundwater use. In irrigated agriculture, groundwater use is more likely to reflect small to medium-scale, low-intensity investment decisions on the part of millions of individual groundwater users (exceptions to this are, for example, Libya's Great Man-Made River Project and Egypt's New Valley Project).

- As pointed out by Puri et al. (2005), a major difference between surface water and groundwater systems is that the former are dominated by flow whereas groundwater systems are dominated by storage. The effects of direct human intervention in river systems (e.g. extraction through inter-basin transfers, large-scale irrigation schemes) may immediately emerge downstream. In contrast, the impact of human activity on aquifers may become evident only at a considerable distance from the point of intervention, and with a considerable time lag. It is, therefore, difficult to predict the impact of such transboundary events which are hidden from view and difficult to detect.
- Polluting substances may enter aquifer systems at either specific or diffuse and dispersed locations. In many cases, this can make it difficult to monitor them, to detect clear cause-and-effect patterns, and to assess the relative share of pollution from each source.
- Pollution follows the direction of groundwater flow. However, it may be difficult to identify this direction, and efforts are complicated as pollution only becomes apparent after a considerable time lag and the impact of pollution can emerge at a substantial distance from the sources.

So what exactly is a TBA? Different sources provide different definitions but the generally adopted principle is an aquifer that is shared by one or more country or is divided between more than one management unit. Matsumo (2002) talks about 'the notion of transboundary groundwater management, in which it is important to look at how the terms groundwater, aquifer, and transboundary are defined. Freeze and Cherry (1979, p. 47) describe the ambiguity of the definition of the aquifer from the hydrological science perspective: 'of all the words in the hydrologic vocabulary, there are probably none with more shades of meaning than the term aquifer.' Mazor (1995, p. 183) states 'Aquifer, the basic term of hydrology, has a countless number of definitions and applications, and as a result the term is esoteric'. The physical characteristics of the aquifer are indistinctly defined; for example, 'An aquifer is best defined as a saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydrologic gradients' (Freeze and Cherry 1979, p. 47). Fetter (1994, p 110) defines an aquifer as, 'a geologic unit that can store and transmit water at rates fast enough to supply reasonable amounts to well'. But none of these definitions uniquely cover all the characteristics of aquifers. It is perhaps more important to identify the properties of aquifers by measurements, where possible, because their geologic formations differ from place to place. Uncertainty over the physical properties of aquifers is a primary problem for management.

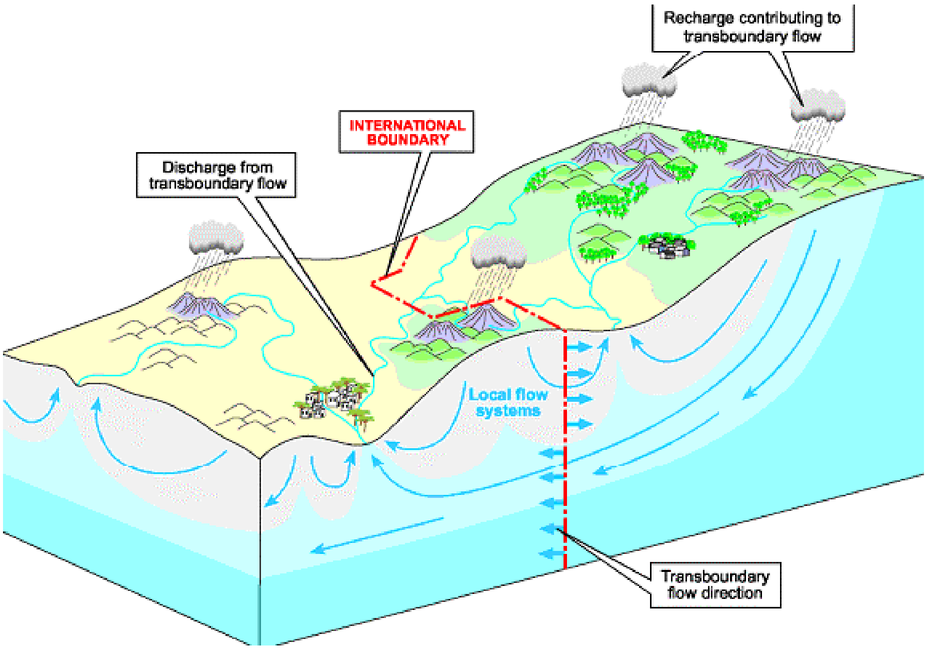
Furthermore, the difficulty of groundwater management often relates to transboundary issues between States. There are many scholars debating the best management of transboundary resources, such as the atmosphere, oceans, surface water, and even outer space. The complexity of the boundary issue is described by Feitelson (2000, p 53-54): 'Boundaries complicate the management of resources, as they create discrepancies between spheres of control and natural systems'. Compared with surface water, the delineation of the boundaries of groundwater is a challenging issue because of spatial considerations and groundwater disperses beneath the surface, irrespective of State boundaries. Although management of groundwater may include monitoring and other activities, in many areas the picture may still be incomplete.

Additionally, groundwater is influenced by land-development patterns. These influences can cause decreasing water levels and contamination of groundwater. It is important to protect the recharge area, which primarily captures precipitation on the surface, in order not to disturb water flow into the ground. Unfortunately, the question of how much land needs to be protected for the recharge area is currently unanswerable because scientists do not fully understand how groundwater behaves.

Without considering the properties of the land, groundwater management could not be complete. To account for these unique characteristics, transboundary groundwater management should utilize the three-dimensional approach, rather than the two-dimensional approach used for surface water. In the two-dimensional approach, scientists study the behaviour of surface water on a single plane. With groundwater, water percolates into the soil, drawn by gravity. It moves along more than one plane. It is hard to determine sovereignty of an aquifer with respect to the scale of both surface development and the underground flow system. However, five different cases can be used to determine sovereignty (Barberis 1991, p. 168):

1) A State-owned aquifer, which is the entire aquifer in a State
2) A confined aquifer divided by an international boundary
3) An aquifer that is entirely in the territory of a State linked hydrologically with an international river
4) An aquifer that is entirely in the territory of one State but is hydrologically linked with another aquifer in a neighbouring State
5) An aquifer that is entirely in the territory of one State but whose area of recharge is in a foreign State.

Thus it is entirely feasible to have deep groundwater flow passing from state A to state B while shallow groundwater flows in the opposite direction (Figure 1).



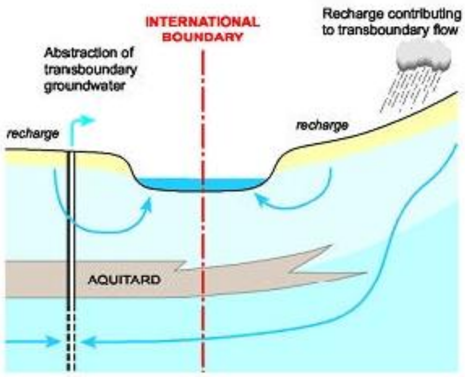


Figure 1 Examples of Cross Border Groundwater Flow

Whether the principle of the TBA can effectively be translated to arid and semi-arid climates where groundwater is scarce is questionable. There are two reasons why this is so: that many of the groundwater bodies have limited transmissive properties means that the potential for degradation is also limited, and those TBAs that are in hydraulic contact with international rivers are likely ephemeral flows of little importance. This report aims to illustrate the nature of the TBAs in SADC and to illustrate which, if any, are likely to pose a risk of international concern according to the classification of sovereignty defined by Barberis (1991).

3. History

3.1 Transboundary Aquifers

International law has paid only marginal attention to the management and protection of transboundary aquifers and only recently have such resources become a subject of international law in their own right. Existing efforts are generally inadequate for two reasons. The first is an incomplete understanding of the resource itself. Water resources managers and policy-makers remain fixated on surface water, all too often ignoring the reserves of groundwater and soil water, as well as the water used to produce tradable goods as 'virtual water'. Second, there is a collective failure to recognise that water security is not just about water. The hydrological cycle substantially affects and is impacted by other major global 'security areas', which include climate change, food security, energy security – and the international cooperation required to deliver regional, state, and human security. The growing interest in groundwater by the international water, security and legal communities partially redresses the inadequacies. The development and implementation of more effective international transboundary groundwater protection and allocation are currently guiding policy goals.

The main part of a Transboundary Aquifer analysis is the assessment of its hydrogeological situation. In principle, application of the hydrogeological methods is the same for national and international aquifers. More internationally specific are the processes of classification and zoning of the aquifers, while data comparison and harmonisation across the border is the main technical challenge. Non-technical challenges are primarily related to other aspects of TBAs, such as the socio-economical and political situation in the border region. The assessment of shared groundwater comprises:

- Delineation and description, inventory/characterisation
- Classification, diagnostic analysis and zoning.
- Data harmonisation and information management.

The classification provides stakeholders with information necessary for decision-making. This includes addressing problems that may develop and opportunities that could be forgone in the absence of coordinated groundwater resources development and management. The stakeholders also need to know which aquifers are likely to be the most responsive ones to Transboundary Aquifer management, and which zones within such aquifers should be targeted for highest positive impacts.

3.1.1 Issues

Data harmonisation and information management are important in the international context. They are difficult to carry out and may be politically sensitive. At the same time, they are also an opportunity for building trust and mutual understanding among the involved parties.

In a society, people basically try to fulfil their needs by deploying various activities like food production and trade. People do this on various scales ranging from the individual scale (basic survival), to family and community scales (subsistence and livelihood development) leading to higher order socio-economic development at national and ultimately regional scale. For many of the human activities, the use of water (a natural capital source) is essential and often non-substitutable (drinking and sanitation, watering, crop production, industrial activities).

A socio-economic assessment starts with analyzing which human activities are deployed in a certain area and how much water (more specifically groundwater) is needed for it. Water use can be categorized geographically, temporally (seasonality, trends) and functionally (domestic, agricultural and industrial). Another way of categorizing water use is by prioritization (based on essence and substitutability). For example, groundwater use for basic survival normally has a higher priority, than for food production and groundwater use for food production is preferred over industrial use.

From the socio-economic aspect, access, and even more importantly control over groundwater resources, may be different on either side of a border. Legitimate questions are whether there is a strong asymmetry in access and control over groundwater resources between different States and are groundwater resources in one state allocated to low-priority use while people in the neighbouring state are lacking water even for basic survival?

From an economic perspective groundwater is a unique type of good. Some groundwater resources are continually renewed and considered as a flow of goods while in non-renewable aquifers groundwater is a stock. Appropriation of groundwater is technically easy and groundwater abstraction may be on the location of demand without need for storage and distribution infrastructure. The quality of groundwater is generally such that only limited treatment is needed. The availability may be subject to seasonality and allocation of the secure and clean source may be required on a local basis and more specifically on a shared transboundary basis. From basic economic theory, groundwater is a so-called common pool resource. This basically means that the ability to withhold potential users from appropriating and using groundwater is limited (open access) while using the resources by one user will diminish the availability of groundwater for other

Aquifers are diffusive in nature and hence hydrogeological effects of an intervention in the aquifer at one location migrate through the aquifer to other locations. For example, groundwater pumping may derogate other users. A spillage of a toxic substance could migrate in a plume and contaminate sources down-gradient. A groundwater user at one location may affect the groundwater availability and quality at other locations and influence other users ability to source clean groundwater. When the impact is across a state border, it is apparent that the issue of such economic externalities is critical in the management of Transboundary Aquifer management. Therefore, an inventory of groundwater use induced externalities (scale and location, causes and consequences) is an important part of a TBA socio-economic analysis.

The notion of sustainability and concepts such as ecosystem services provide groundwater with a non-use value. Groundwater is of great importance in sustaining ecological systems such as groundwater fed wetlands, base flow to rivers, habitat, sustaining soils and inhibiting sea water intrusion. Environmental externalities may also occur in transboundary aquifers. In the socio-economic analysis of groundwater use and demand it is important to include groundwater dependent ecosystem sustainability in the countries sharing the aquifer system.

There is a strong relationship between the socio-economic aspects and the institutional and legal dimensions of TBA. The institutional and legal dimensions are not just abstract autonomies in a country being independent from the people living there. In countries with good governance such institutions are demand driven, representative and work in a participatory way. In countries with less democratic traditions often two types of institutions exist: formal (governmental) rules, rights, regulations and organizations and informal ones, often based on old traditions, local norms and beliefs.

Institutions, policies and laws influence groundwater use behaviour of the people. The success of any policy and/or environmental tax trying to regulate groundwater use is strongly dependent on people's willingness to comply with it. The same is true for legal arrangements dealing with Transboundary Aquifer management. Signing of an agreement by the States involved does not implicitly guarantee good Transboundary Aquifer management. Such agreements will only work out when people of all countries involved and at all levels are willing to commit to the agreement.

The environmental aspects of a TBA may not be obvious but is related to resource sustainability. Groundwater may sustain eco-systems, known as terrestrial groundwater-dependent ecosystems. Groundwater resources are thus partly environmentally committed while the aquifer may act to migrate and transform interventions in one state into hydrogeological and environmental consequences in another state. The concept of sustainability is associated with groundwater resources depletion and the possible compromising of future use. People value the natural environment and ecosystems since it provides essential ecological services for the human society. Sustainability is based on the motivation for the preservation of the natural environment. People value the non-use aspects of natural environments and ecosystems.

Various types of ecosystems are directly or indirectly dependent on groundwater. River ecosystems are dependent on a groundwater sustained base flow. Without this continuity most fluvial flora and fauna would not survive. Also lakes and wetlands may be totally or partly groundwater-fed. Without the groundwater influx these lakes and wetlands might dry up or have very shallow water depth resulting in a change of the aquatic ecosystem. Discharging groundwater may have a specific chemical and or temperature signature that favour the development of particular terrestrial ecosystems that would not develop in other habitats. When developing groundwater resources for productive use assessment is needed of where and how much groundwater is needed to sustain the ecological functions in the area to determine what part of the overall groundwater resource is environmentally committed.

In a transboundary context large-scale interventions in the environment in one state may impact the functioning of ecosystems in an adjacent state. Interventions at one place are migrated and transformed in the aquifer in hydrogeological and ecological consequences in another place. An environment assessment ideally studies where groundwater-dependent ecosystems are located, how much of the groundwater (flow) is environmentally committed and how the aquifer transfer function relates activities and interventions in one state to ecological consequences in neighbouring states.

In conclusion, there are four parts to assessing a TBA. They are geological, socio-economic, institutional and environmental. Proposed monitoring of a TBA should include assessment of all four drivers and could include:

- Groundwater level and water quality monitoring, meteorological monitoring.
- Socio-economic monitoring: demography, land use, industry, welfare etc.
- Institutional monitoring: governance, legal etc.
- Environmental monitoring: monitoring status of terrestrial groundwater dependent ecosystems, spring and base flow, discharge, habitat, etc.

3.2 International significance of TBAs and transboundary surface catchments

Who coined the term TBA? It is a term we are all familiar with today but who and when first recognised them as an issue? Exploitation of the big regional international aquifers such as the Nubian Sandstone in North Africa and the Guarani Aquifer in southern South America are currently topical, but only so because of increasing demand on the shared resources these aquifers contain, the Nubian Sandstone the more so as much of the abstraction is not renewable. Probably the first expressions of interest were between State managers in America, concerned about potential degradation from outside each individual State-wide management unit. A significant case is that of the Mississippi catchment and Lake Michigan catchment groundwater divide, described by Bradbury (2007) whereby the Lake Michigan / Mississippi divide has been pulled westwards from the Lake Michigan catchment into the Mississippi catchment with obvious implications for water management.

Lessons can be learnt from the transboundary surface water catchments, although groundwater issues tend to be more localised and of course are unseen and not so easily brought to a political forum. In certain transboundary dialogues, security issues are predominant and this heavily influences any attempt at bringing the co-riparian partners to a mutually beneficial conclusion (e.g. as in West Bank and Israel dialogue). In such scenarios the benefits must be packaged in such a fashion that they become acceptable within the existing political framework. It is notable in this case that international actors will have a critical role in bringing the co-riparians to the negotiating table by offering linked benefits such as funding for the necessary infrastructure, and other types of support. However, the drive for a peaceful solution to the dialogue between Palestine and Israel is exceptionally strong, and international political will exists in abundance.

The importance of economic parameters varies between different basins, and between each of the co-riparians within a given basin. While all States display a general desire for economic advancement, the routes this can take vary significantly in each instance, and benefit packages must be tailored with care to each stake holder within a basin. Thus, for example, such packages would be likely to be centred around water availability in Palestine but would not be the case in most other systems as the securitization dynamic is usually weaker. Other Governments are commonly interested in a range of potential benefits. The remit for the Kagera Basin Organization at its initial establishment reflects this especially well, and the ongoing attempts to re-establish a similar body within the broader framework of the Nile Basin Initiative are again addressing a broad package of benefits. In such circumstances, ‘trading water for other benefits’ becomes feasible, and the principle challenge lies in broadening the basket of available options and determining an equitable division of the various types of benefits. In the Kagera system, it is clear that such a process should not only derive an optimal benefit-sharing solution within the sub-basin, but should extend this to the Nile River basin as a whole. The possibility that large systems such as the Nile basin should be considered by sub-basin is noted.

Some trans-boundary watercourses have unique environmental characteristics which demand precedence where economic development scenarios are being generated or considered. The flood pulse in the Mekong River basin provides one such example, but there are also important environmental characteristics within sub-basins in other catchments (e.g. the wetlands in the Kagera basin and the Sudd in the Nile system; also the delta in the Okavango River basin. In at least some of these cases, there is a clear requirement for the maintenance of specific attributes of the systems concerned, often in a relatively pristine state. This does not, however, imply that economic development cannot take place – simply that it should rely on other options. For example, the largely unspoiled areas within the Kagera River basin (such as the Kagera National Park and the Minziro-Sango Bay forest ecosystem) merit sustainable development for tourism, with very considerable possibilities for foreign earnings. Rwanda has already begun to take advantage of such possibilities in the Virunga National Park and elsewhere, and the global thirst for ecotourism is such that these areas offer very great potential for enhancing livelihoods and the economic benefits available to the indigenous population.

3.3 Global Concerns

Some of the biggest transboundary aquifers in the world are located in South America and North Africa, such as the Guarani and Nubian Sandstone aquifers as well as the Nile and Mekong catchments. Those elsewhere in Africa remain largely unexploited (Figure 2). Since aquifers generally extend across several State boundaries, exploiting these presupposes agreements for managing them jointly, in order to prevent pollution or over-exploitation by particular States. Mechanisms of this kind have begun to emerge. For example, in the 1990s, Chad, Egypt, the Libyan Arab Jamahiriya and Sudan established a joint authority to manage the Nubian Sandstone aquifer system in a concerted manner. The West Bank of Palestine remains in discussion with Israel over the apportionment of the Mountain Aquifer groundwater resources against which Israel lays a large claim as Israel views Palestine as the Occupied Territories.

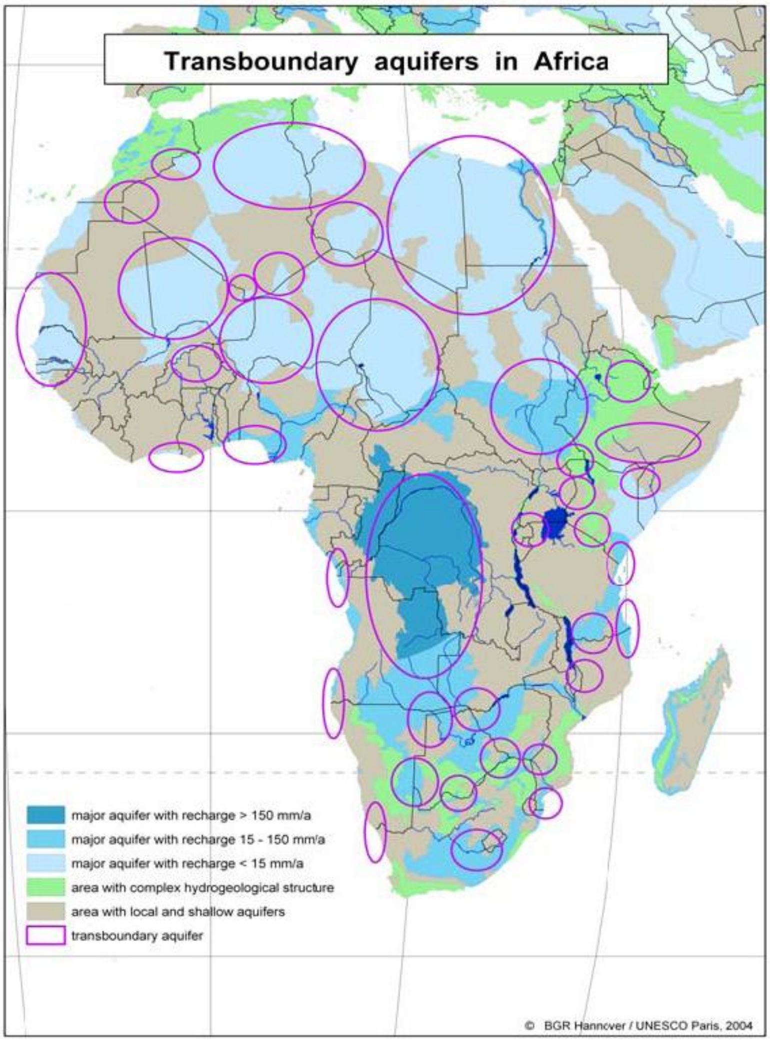


Figure 2 TBAs identified in Africa by ISARM-Africa

International oversight of TBAs is beginning to emerge with the UNESCO ISARM initiative taking a leading part.

3.4 Issues of Interstate Governance

A collaborative approach to dealing with cross border issues relating to shared aquifers will benefit both countries which may chose to pool resources needed to solve problems. To coordinate action, transboundary institutions need to be put in place. Institutions contain both rules and the organizations that develop need to comply with those same rules. Around the world, there is an enormous diversity in organizations within states that deal with groundwater management. It ranges from totally state-planned management with central government ministries and district-operating governmental agencies in one state to situations where groundwater management takes place locally. There are states where groundwater management is carried out by a multiple of organizations at multiple levels and in multiple sectors within the government, the market and the civil society. In this latter case of so-called groundwater governance (different) parts of the management are carried out by ministries, governmental agencies, companies, NGOs, users organizations and informal structures.

The organizations dealing with the inland groundwater management have a particular role with corresponding task, a mandate and responsibilities. None of the organizations however have a mandate or jurisdiction that crosses the national borders and that is why transboundary institutionalization is a complex issue. It is the state government that is allowed to handle international and transboundary issues. However, management of transboundary groundwater by cooperation limited to only a governmental level bears the risk of hydro-politicizing issues and it prevents possible solutions being found by other organizations dealing with groundwater management. There is no clear-cut solution for the institutional structure needed for Transboundary Aquifer management but that it needs to be context-specific and be based on the hydrogeological, socio-economic, political and socio-cultural aspects within the countries involved.

There is much to learn from the experiences in dealing with transboundary rivers and lakes, the Rhine Commission, for example, has more than 50 years experience. It makes sense to learn from river basin organizations and even to combine the management of internationally shared rivers, lakes and groundwater within such institutional structure.

Transboundary groundwater management institutional activities are not principally different from activities that need to be done in case of national groundwater management. The activities include in an iterative approach through:

- the monitoring of the groundwater system status and dynamics and of the groundwater use and needs,
- the development of institutional instruments (the rules) that enable that groundwater needs are met in an sustainable way,
- the implementation of these instruments,
- monitoring whether the implemented measures are effective
- monitoring of groundwater stakeholders compliance with the rules,
- dispute resolution.

Some of these activities may already be carried out by individual states and their organizations dealing within groundwater management.

Institutional instruments may be regulatory (like well registration, protection zones, licensing, allocation and property right, laws and agreement, binding agreements and policies), economic (subsidies, environmental taxes, tradable groundwater use and pollution rights, pricing of groundwater and electricity) or advisory (enabling access to information, expertise, funding and creating awareness, training and extension).

The ultimate crux of Transboundary Aquifer resources management is trying to find ways to jointly conduct those institutional activities and to develop institutional instruments that are multi-nationally accepted, applicable and valid. It is not hard to understand that this is a complicated issue since it invades the principle of national sovereignty.

Because of the complicating factors described above, institutionalizing of transboundary groundwater management should therefore rather be approached as an ongoing process of social learning. In this process it makes sense to start at a low-profile and low-risk level, then learn by doing and use that social knowledge to develop a process for dealing with constantly and incrementally more complex and sensitive issues. It seems logical to start this process with the exchange of ideas and information on low-profile issues by non-political stakeholders like scientists and groundwater system researchers. Then in the following phases exchange of more sensitive information could be organized and the monitoring carried out cooperatively or at least coordinated multi-laterally. In subsequent phases the activities of monitoring, problem identification, solution generation, implementation and even compliance monitoring should increasingly by carried out in a cooperative or even joint fashion.

To this end it is sensible to start with the physical aspects of shared groundwater resources and ultimately work towards a SADC Regional transboundary institute, which should be a part of the proposed SADC Groundwater Management Institute (GMI). Groundwater management either within the national or in the international context is very much about making informed decisions. Informed decisions can only be made by using relevant and up to date information based on collected and analyzed ‘groundwater data'. Transboundary Aquifer resources management should put priority in generating this information based on internationally accepted standards and make it accessible in a uniform and transparent way. Special effort should be placed in delivering information symmetrically to all stakeholders via various channels and at various platforms taking into account the different perspectives of the various stakeholders. One of the most complicating factors is the large number of individuals on the ground that determine the status of a groundwater system. That large number makes monitoring of the groundwater use and the users complicated and costly. Hard monitoring data is therefore an essential prerequisite to implementing any form of transboundary governance.

4. TBAs in SADC

4.1 Background

Concern over transboundary issues began in the 1990s as disputes arose in various parts of the world and between individual states in America. In every case, however, the aquifer under scrutiny was a major regional resource. The first inventory of shared aquifers in Africa was produced by technical experts at a workshop in Tripoli in 2002. In 1997 the International Association of Hydrogeologists (IAH) established the Transboundary Aquifer Resources Management commission, followed in 2000 by the establishment of the International Shared Aquifer Resource Management (ISARM) initiative (Puri and Aureli, 2005). Studies commissioned as a result of these initiatives included the map 'Groundwater Resources of the World – Transboundary Aquifer Systems' by Struckmeier et al. (2006). Since the initiation of the ISARM-Africa project in 2000 more than 40 transboundary aquifers have been identified in Africa (Figure 2) (Struckmeier et al., 2006). However, what the authors did not account for was groundwater availability, flow potential and demand so that many of the identified TBAs barely warrant such categorisation, although Struckmeier et al. (2006) recognises 'major groundwater basins', 'areas with complex hydrogeological structure' and 'areas with local and shallow aquifers' (Cobbing et al., 2008). The criteria used to identify TBAs on the SADC Hydrogeological Map (UNESO Groundwater Resources of the World) was a continuous groundwater unit shared by more than one state.

Cobbing et al. (2008) focussed on the transboundary aquifers nominated with South Africa and conclude:

"Based on this study of South African transboundary aquifers, it is proposed that the traditional understanding of transboundary groundwater issues as a potential source of conflict be modified. For most of the length of South Africa's border, potential dispute over transboundary groundwater is not a major concern. In general, transboundary aquifers such as the 'Coastal Sedimentary Basin' or the 'Karoo Sedimentary Aquifer' (Struckmeier et al., 2006) are potentially misleading in terms of the level of management required. Given the sparse data on southern African transboundary aquifers and the relatively low levels of technical cooperation between the riparian states, the region would be better served by using transboundary groundwater as a vehicle to improve technical cooperation, data sharing, training and research... Whilst this paper refers specifically to South Africa and her neighbours, many of the conclusions drawn apply to other parts of sub-Saharan Africa where similar circumstances prevail".

The questions need to be asked:

- if groundwater monitoring networks at TBAs are needed in SADC?
- if they can be installed?
- where they can be best installed with respect to the TBAs?
- how the implementation and operational aspects can be regionalised?

Cobbing et al. (2008) highlight an important problem in SADC, the lack of technical co-operation between states. SADC, however, faces an important opportunity to provide an umbrella institute to start to promote co-operation and Transboundary Aquifer monitoring is an important vehicle with which to promote such collaboration. Whether the ultimate goal of managing the TBAs for the benefit of the respective communities is either warranted or beneficial remains to be seen, but it is entirely feasible to start down the road towards that goal with a view towards Member States sharing information in order to collaborate in resource management. Thus the answer to the first question that needed asking, if regional groundwater monitoring networks are needed, has to be yes, partly in order to encourage technical collaboration between Member States and partly to better understand resources and in particular shared resources. Better understanding of the resources and the collection of hard data about them, both temporal and special has to be a given before any form of management can be initiated.

However, the question remains whether SADC actually has any active TBAs that warrant monitoring at all.

4.2 The SADC TBAs

There are 14 recognised TBAs in the SADC Hydrogeology Map (Table 1, Figure 3). The applicability of the TBA concept in SADC, much of which is semi-arid to arid, was reviewed by Cobbing *et al*. (2008) with specific regard to the borders of South Africa. They report that most are low yielding aquifers with only small water demand from a low population density so that the risk of over-pumping or pollution is generally low. They concluded that potential dispute over trans-boundary groundwater was not a major concern but rather an opportunity to improve technical cooperation and data sharing between neighbour states, and for collaborative training and research. The comment is also made that ‘the concept of transboundary groundwater must necessarily include aquifers where little cross-border flow occurs’, i.e. that flow is only one issue, equitable sharing of the resource and its sensible management another, and potential over-pumping and pollution of it a third key aspect, while attraction of international surface waters into a border aquifer is a fourth. An objective must be to promote better understanding of the impact of the water abstraction/recharge management processes involved and hydraulic conditions of aquifers common to contiguous borders.

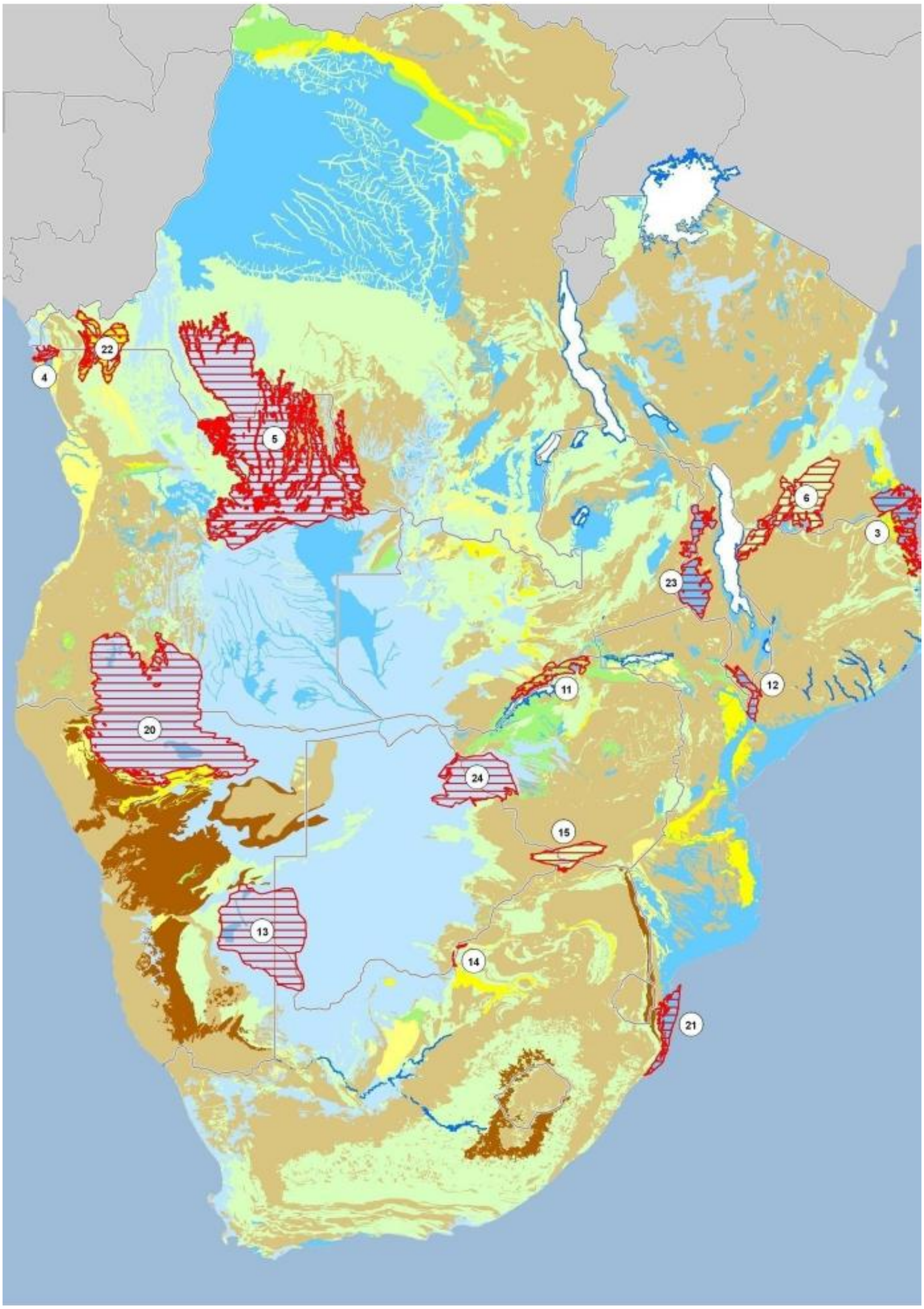


Figure 3 The SADC TBAs

The descriptions of the TBAs in SADC involve, almost without exception, low flow volumes with little if any potential for source degradation, surface or groundwater, across the border. Many of them are shallow alluvial or young sediments which straddle a river which acts also as a political boundary. In some cases the river loses to groundwater in other it gains base flow, but in both types the river, for the most part, is a constant head boundary which will not readily propagate cross-flow beneath it. Nevertheless, there remains a risk that a transboundary groundwater resource that is not managed in a cooperative and holistic way by one state, may be over-exploited to the detriment of another state (Godfrey and van Dyk, 2002; Jarvis et al., 2005). Similarly, there is a fear that pollutants might migrate across a border to contaminate a neighbour's aquifer (Puri, 2001). Transboundary water resource management aims to resolve disputes that might otherwise arise from an unmanaged resource (Turton et al., 2006a). However, Cobbing et al. (2008) argued that where transmissivities are low, the potential for groundwater movement is also low, and the concept of a shared transboundary resource becomes problematic. Besides uncertainty regarding water demand trends, impact of over-exploitation on riverine ecology, and the impact of groundwater resource development in tributary catchments on downstream shared aquifer resources collectively conspire to complicate the issue.

The geological and hydrogeological setting of each of the fourteen TBAs are reviewed and described separately in Appendix 1. For some of these a considerable knowledge base has been gathered while for others little information is available on the precise nature of the aquifers and their relationship to surface waters and other nearby or underlying aquifers. In some case knowledge and data are available on one side of the border but not on the other. Given the complex nature of the concept of a TBA, it is not, therefore, easy to judge between active and inactive TBAs, i.e. between those in which the resource apportionment may be disputed either now or at some time in the future subject to demographic, land use, climate variability institutional or other change. The bottom line is, of course, sustainability and should any of these changes start to have an impact on groundwater dependent ecosystems then dialogue between states is also essential. The ecological impact is hard to visualise, but a graphic example is a freshwater coastal aquifer in state A which depends on date palms for its livelihood, and which is derogated by groundwater abstraction inland in state B which has intensive groundwater fed irrigation. Demand in state A is small whereas State B is large – perhaps an ideal situation. But the reduction in the groundwater level in the coastal state A caused by pumping in state B causes sea water intrusion to occur killing off the date palms and local livelihoods.

The importance of groundwater to many rural communities in sub-Saharan Africa cannot be overstated. Any cross-border impact on either the groundwater or any surface water resource is, therefore, of critical importance throughout the large tracts of land near international borders where water is scarce. Any adverse impact such as degradation of supply or pollution of water will impact livelihoods and may become the cause of political disquiet.

Table 1 Summary aquifer characteristics and data sources for the 14 TBAs in SADC

Name	TBA No.	Member States	River Basin	Aquifer Characteristics	References from the SADC Groundwater Archive at: www.sadcgwarchive.net
Coastal Sedimentary Basin	3	Tanzania, Mozambique	Ruvuma	Tertiary to Quaternary age alluvial sands and gravels of the Ruvuma Delta, overlieing Cretaceous-age sedimentary strata. High permeability sediments that primarily draw water from the Ruvuma River and its tributaries.	Ferro & Bouman, 1987.; Lachelt, 2004.; Coster 1960.
Coastal Sedimentary Basin	4	D R Congo, Angola	Congo	Tertiary to Quaternary age alluvial sands and gravels of the Congo delta. High permeability sediments that primarily draw water from the Congo River and its tributaries.	Schermerhorn, L.J.G., 1961. , Snel, M.J., 1957.
Congo Intra-cratonic Basin	5	D R Congo, Angola	Congo	Tertiary alluvial sands and gravels – high yield porous sediments that draw water directly from the Congo River.	Snel, M.J., 1957.
Karoo Sandstone Aquifer	6	Tanzania, Mozambique	Ruvuma	Karoo sandstones beneath basaltic volcanics. Double porosity confined aquifer, yields enhanced by fracturing	Ferro & Bouman, 1987; Lachelt, 2004; Coster, 1960; Carl Bro, Cowiconsult , Kampsax-Kruger, CCKK, 1982.
Middle Zambezi Aquifer	11	Zambia and Zimbabwe	Zambezi	Upper Karoo sandstones beneath basaltic volcanics. Double porosity confined aquifer, yields enhanced by fracturing	Yachiyo Engineering Co Ltd, 1995; JICA, 1988; Interconsult, 1985.
Shire Valley Aquifer	12	Malawi, Mozambique	Zambezi	Tertiary to Quaternary and Recent alluvial sands and gravels. High yield, very porous sediments that draw water from the river.	Smith-Carington, A.K. & Chilton, P.J., 1983. Ferro & Bouman, 1987; Lachelt, 2004.
Kalahari/Karoo Basin	13	Botswana, Namibia, South Africa	Orange River	Kalahari Beds sands, cretes and clays over Karoo sandstones, mudstones, shales and coals, with alluvial sands and gravels along the Molopo River.	van Veelen & Baker, 2009; Christelis & Struckmeier, 2001; JICA, 2002; Geohydrology Division, 1993; Frommurze, 1937; Vegter, 2001; Peck, 2009.
Ramotswa Dolomite Basin	14	Botswana, South Africa	Limpopo	Karst Transvaal Dolomite aquifer	Farr & Baron, 1978; Farr, *et al.*, 1979; Key 1983; Frommurze, 1937; Vegter, 2001.

Tuli Karoo Sub-basin	15	Botswana, South Africa, Zimbabwe	Limpopo	Upper Karoo sandstones beneath basaltic volcanics. Double porosity confined aquifer, yields enhanced by fracturing	Interconsult, 1985; Water Surveys Botswana (Pty) Ltd, 2007; Wellfield Consulting Services , British Geological Survey and CSIR Environmentek, 2008; MacDonald Shand Consortium, 1991; CSIR Environmentek, 2003; Botha *et al*., 1998; Frommurze, 1937; Vegter, 2001.
Cuvelai and Ethosha	20	Angola, Namibia	Etosha – Cuvelai	Kalahari Sediments with crete deposits	Government of the Republic of Angola and Government of the Republic of Namibia, 2004; Mendelsohnet *et al*., 2000; Christelis & Struckmeier, 2001.
Coastal Sedimentary Basin	21	Mozambique, South Africa	Maputo, Umbeluzi, Incomati, Limpopo	Tertiary to Quaternary-age alluvial sands and gravels of the Inkomati and Limpopo deltas overlieing Cretaceous-age sedimentary strata. High permeability sediments that primarily draw water from the Inkomati and Limpopo Rivers and tributaries.	Ferro & Bouman, 1987; Lachelt, 2004; Frommurze, 1937; Vegter, 2001; Cobbing *et al*. 2008.
Dolomitic	22	D R Congo, Angola	Congo	Karst dolomite aquifer	Snel, 1957.
Sands and gravel/weathered Basement aquifer	23	Malawi, Zambia	Zambezi	Quaternary palaeo-fluvial sands and gravels deposited by pre-rifting valleys derived from weathered Basement.	Yachiyo Engineering Co Ltd, 1995; Smith-Carington & Chilton, 1983.
Eastern Kalahari/Karoo Basin	24	Botswana and Zimbabwe	Zambezi, Okavango/ Cubango	Upper Karoo sandstones partially covered by basaltic volcanics. Double porosity confined aquifer, yields enhanced by fracturing	Interconsult, 1985.

5. Proposed Classification

5.1 Basis of Classification

The TBAs in SADC can be classified according to a number of different elements. Clearly aquifer type, aquifer potential and groundwater demand are all important but so too are a number of other issues. These include other socio-economic factors, institutional elements and the will to co-operate and environmental issues such as sustainability and connectivity with surface waters. Some form of classification based on these five basic data sets is, therefore, desirable, i.e. comprising:

1. Groundwater flow and vulnerability (Table 3)
    a. Natural flow
    b. Induced flow
    c. Aquifer vulnerability
2. Groundwater knowledge and understanding (Table 4)
    a. Groundwater Quantity
    b. Groundwater Quality
    c. Vulnerability
3. Governance capability (Table 5)
    a. Management
    b. Knowledge
    c. Monitoring
4. Socio-economic/water demand capability (Table 6)
    a. Demography
    b. Land Use
    c. industry
5. Environmental capability (Table 7)
    a. Hydrology
    b. Sustainability
    c. Climate

Clearly a classification based on these five sets would need to weight the geological input as the underpinning contributor to the making of a TBA. In this way an overall score can be achieved and a threefold classification can be made in terms of the active potential of the TBA.

5.2 Proposed Classification

Three classes of TBA are proposed:

- **active** in which some form of international collaboration in monitoring, management and apportionment are needed now in order to avoid confrontation in the future should demography, land use or climate be changed.

- **moderately active** in which there is potential for transboundary degradation of some form or another, although it does not currently require international collaboration, i.e. the potential for degradation is so small it will not impact communities either side of the border.
- **Inert or non-active** in which there is no apparent potential for cross border degradation or any impact of any kind.

At issue are the uncertainties that arise over classification of the numerous data scarce TBAs. Where full classification is not robust the TBA should be upgraded to the next category in order to ensure that investigation is pursued in order to make a more robust categorisation. A sub-classification can be made to the active and moderately active TBAs to create five categories which describe the type of TBA according to sovereignty (Barberis, 1991) as well as degree of activity:

1. A State-owned aquifer, which is the entire aquifer in a State (*Inert*)
2. A confined aquifer divided by an international boundary (*Active/moderately active*)
3. An aquifer that is entirely within the territory of a State linked hydrologically with an international river (*Active/moderately active*)
4. An aquifer that is entirely within the territory of one State but is hydrologically linked with another aquifer in a neighbouring State (*Active/moderately active*)
5. An aquifer that is entirely within the territory of one State but whose area of recharge is in a foreign State (*Active/moderately active*).

5.3 Methodology, Classes, Criteria and TBA Codes

A series of tables (see also Annex 2) have been created for investigation of criteria identified in Section 4.1 for each of the 14 TBAs previously identified in SADC. These are:

Table 1 - SADC Transboundary Aquifers

Listing of TBAs recognised using the SADC hydrogeology map. Tabulate TBA code, countries, river basin, basic aquifer characteristics and sources of information as listed in the SADC grey data archive.

Table 2 - TBA Hydrogeology

Listing of TBAs by name and code in specific countries, with outline of basic aquifer geology and depth; aquifer type and style of permeability; recharge potential and proximity to major transboundary river. The aquifer summary provides a brief summary of hydrogeology with indications of potential through flow.

Table 2 is translated into Table A1by placing emphasis on the likely transboundary elements of natural and induced groundwater flow and is a surrogate of Table 2.

Table A1 - TBA Groundwater Flow and Vulnerability

Listing of TBAs by name and code in specific countries, with outline of rates of natural and pumping induced groundwater through flow together with potential vulnerability to pollution.

Table A2 - TBA Groundwater Knowledge

Listing of TBAs by name and code in specific countries, with broad assessments of the availability of data on and amount of information describing groundwater quantity, quality and vulnerability in each country TBA segment.

Table A3 - Governance Capability

Listing of TBAs by name and code in specific countries, with broad assessment of the nature of standards of institutional management, knowledge and monitoring of groundwater and related systems with each country TBA segment.

Table A4 - Socio-economic / Water Demand Capability

Listing of TBAs by name and code in specific countries, with broad assessment of water demand based upon demography in terms of population density and general access to water sources; broad land use in terms of irrigation and cattle rearing; and industrial activity in terms of manufacturing, mining and service activities.

Table A5 - Environmental Capability

Listing of TBAs by name and code in specific countries, with broad assessment of the impact of environmental factors upon groundwater resources in each TBA country segment in terms of Biota Conservation within National Parks and Game Reserves; The impact of groundwater abstraction upon river systems during the wet and dry seasons; and the impact of floods and prolonged droughts upon groundwater systems as they impact upon cycles of recharge.

Table 3 - TBA Ranking

This is an attempt to compare the country TBA segments by combining the scores from Tables 4 to 7 and multiplying by the ranked scores from Table 2. The broad ranks produced in Table 8 can then be used to identify which TBA systems are best understood and have a reasonable through flow that may be able to be monitored using telemetric systems. TBA segments that meet at international boundary rivers, and for which there are little data or knowledge available, score lowest and therefore are found in Rank C.

The relationship between the tables is summarised in Figure 4.

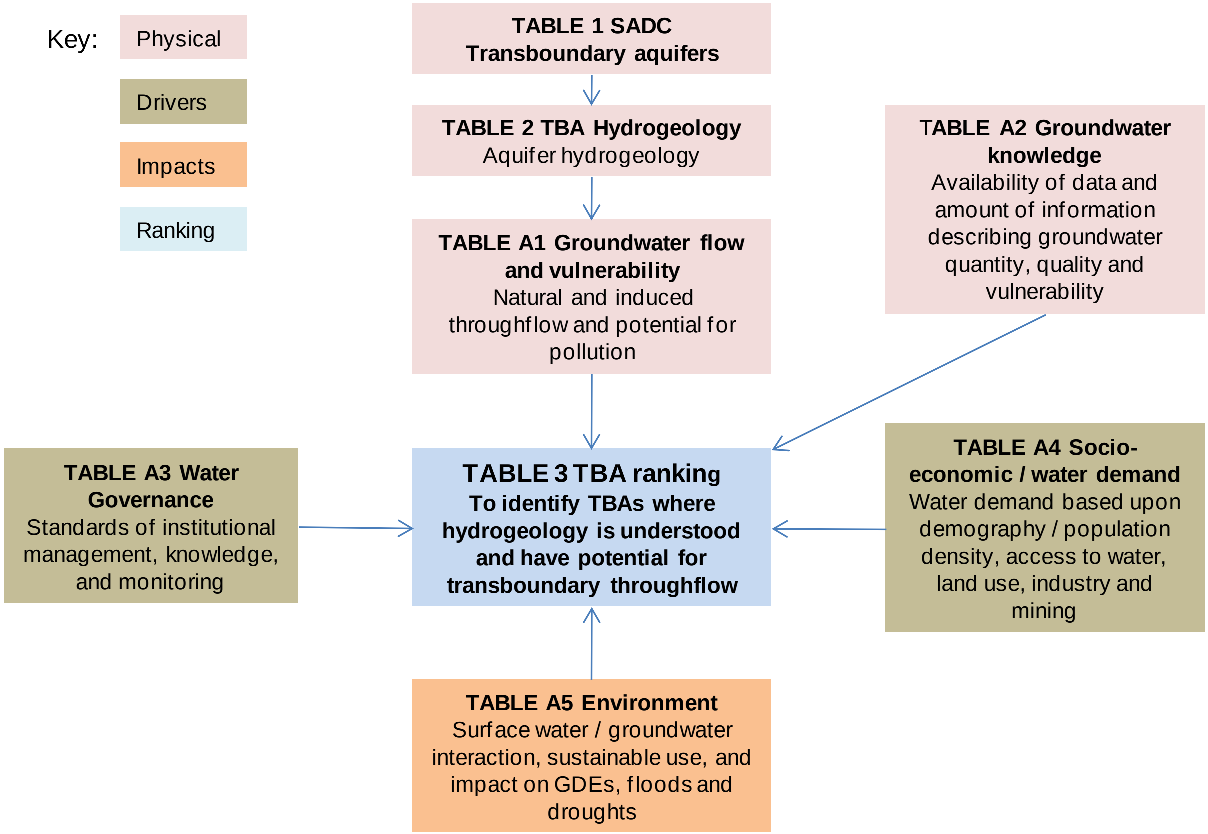


Figure 4 Relationship between analytical processes (Tables) to rank TBAs according to risk

Table 2 TBA Hydrogeology

Transboundary Aquifer	TBA Code	Member State	Geology		Hydrogeology		Recharge		Aquifer Summary
			Lithology	Depth	Type	Permeability	Potential	River Proximity	
Ruvuma Delta Coastal Sedimentary Basin Aquifer	3	Tanzania	Alluvium/ Sedimentary	Shallow-medium	Unconfined semi-confined	Primary	Medium to high/ seasonal	Adjacent to distant	Tertiary to Quaternary age alluvial sands and gravels with fresh groundwater of Ruvuma Delta, overlying Cretaceous-age marlstones with brackish to saline water. High permeability sediments mainly draw water from the Ruvuma River. Little TBA through-flow, flow mainly towards the coast, possible marine saline intrusion
		Mozambique	Alluvium/ Sedimentary	Shallow-medium	Unconfined semi-confined	Primary	Medium to high/ seasonal	Adjacent to distant	
Congo Delta Coastal Sedimentary Basin Aquifer	4	D R Congo	Alluvium/ Sedimentary	Shallow-medium	Unconfined semi-confined	Primary	High/ seasonal	Adjacent to near	Pliocene to Recent age alluvial sands and gravels of the Congo delta overly Cretaceous to Eocene marine sedimentary strata. High permeability alluvium mainly draws water from the Congo River. Little TBA through-flow, flow mainly towards the coast, possible marine saline intrusion
		Angola	Alluvium/ Sedimentary	Shallow-medium	Unconfined semi-confined	Primary	High/ seasonal	Near to distant	
Congo/Zambezi Basins Benguela Ridge Watershed Aquifer	5	D R Congo	Alluvium / weathered sandstone	Shallow-medium	Unconfined semi-confined	Primary / secondary fractured	Moderate/ periodic	Headwaters along watershed	Tertiary-age Kalahari alluvial and marine sands and gravels, overlying Cretaceous-age sandstones and shales – high yield porous sediments in Benguela Ridge watershed area between the Congo and Zambezi catchments. Some deep waters are saline. There is some potential for Transboundary Aquifer flow especially related to large scale abstraction for the processing of diamondiferous strata.
		Angola	Alluvium / weathered sandstone	Shallow-medium	Unconfined semi-confined	Primary / secondary fractured	Moderate/ periodic	Headwaters along watershed	
Tunduru/ Maniamba Basin Karoo Sandstone Aquifer	6	Tanzania	Sedimentary basaltic	Shallow-medium	Unconfined semi-confined	Secondary fractured	Moderate/ periodic	Adjacent to near	The Karoo Sandstones that underlie basalts have moderate yields and are artesian in part. The aquifer has some primary porosity and fractured permeability. The Ruvuma River forms the international boundary between the Tunduru and Maniamba parts of this basin. The prospects for transboundary flow are poor.
		Mozambique	Sedimentary basaltic	Shallow-medium	Unconfined semi-confined	Secondary fractured	Moderate/ periodic	Adjacent to near	
Middle Zambezi Rift Upper Karoo Aquifer	11	Zambia	Sedimentary basaltic	Shallow-medium	Semi-confined	Secondary fractured	Low to moderate/ periodic	Adjacent to near	Lower and Upper Karoo sandstones and siltstones underlie basalts within the down-faulted Zambezi Rift graben. The aquifer has some primary porosity and fractured permeability. The Zambezi River forms the international boundary between the upstream Zambian basin and the downstream
		Zimbabwe	Sedimentary basaltic	Shallow-medium	Semi-confined	Secondary fractured	Low to moderate / periodic	Adjacent to near	

									Zimbabwe basin. The prospects for transboundary flow are poor as the main source of groundwater, the river, forms the international boundary.
Shire Valley Alluvial Aquifer	12	Malawi	Alluvium	Shallow-medium	Unconfined semi-confined	Primary	High/ seasonal	Adjacent to near	Tertiary to Quaternary and Recent alluvial sands and gravels overlie Cretaceous age sandstones within the southern continuation of the Nyasa Rift graben. High yields are obtained from the, very porous Shire River alluvial sediments Some large areas with salinised waters do occur.
		Mozambique	Alluvium	Shallow-medium	Unconfined semi-confined	Primary	High/ seasonal	Adjacent to near	
South West Kalahari/ Karoo Basin Aquifer	13	Botswana	Continental Sediments sandstones	Medium - deep	Confined	Secondary fractured	Low/ periodic	Possible watershed	Thick Kalahari Beds sands, calcretes and clays confine productive Lower Karoo sandstones interbedded with mudstones, shales and coals. In Namibia, the Lower Karoo Stampriet Aquifer is a major source of water for domestic and agricultural use. Little development of this aquifer has been made in south western Botswana or the adjacent part of South Africa. Large parts of these areas have been demarcated as National Parks. Over-abstraction in Namibia may have caused a reduction in natural flow into areas of South Africa and Botswana within this aquifer.
		Namibia	Continental Sediments sandstones	Medium - deep	Confined	Secondary fractured	Low to Moderate/ periodic	Possible watershed	
		South Africa	Continental Sediments sandstones	Medium - deep	Confined	Secondary fractured	Low/ periodic	Possible watershed	
Zeerust – Ramotswa - Lobatse Dolomite Basin Aquifer	14	Botswana	Karst limestone	Shallow-medium	Unconfined semi-confined	Secondary karst	High/ periodic	Adjacent to distant	The Precambrian Transvaal Cherty Dolomite forms an arcuate karstic aquifer between Zeerust, Ramotswa, Lobatse and Mafokeng. Natural cross border flow and degradation are unlikely as groundwater occurs in a series of isolated basins. There is a minor risk of localised cross-border pollution.
		South Africa	Karst limestone	Shallow-medium	Unconfined semi-confined	Secondary karst	High/ periodic	Adjacent to distant	
Tuli Karoo Basin Aquifer	15	Botswana	Alluvium: Karoo sandstones and basalts	Shallow - deep	Unconfined to confined	primary; secondary fractured	High to moderate/ periodic	Alluvium along rivers; adjacent to near	The High porosity, high yield, unconfined sand and gravel alluvium sand river aquifers occur along the Shashe, Limpopo and Umzigwane rivers have been much developed a sources of irrigation water to such an extent that dry season flow along the Limpopo has all but ceased. The underlying Upper Karoo basalts and sandstones with some primary porosity and fractured permeability, form confined to semi-confined aquifers. Although moderate yields have been obtained from these aquifers, brackish to saline waters are occasionally produced. If exploitation of the resource were to increase, its apportionment and management could become significant, but for the moment, the potential for cross-border degradation is small.
		South Africa	Alluvium: Karoo sandstones and basalts	Shallow - deep	Unconfined to confined	primary; secondary fractured	High to moderate/ periodic	Alluvium along rivers; adjacent to near	
		Zimbabwe	Alluvium: Karoo sandstones and basalts	Shallow - deep	Unconfined to confined	primary; secondary fractured	High to moderate/ periodic	Alluvium along rivers; adjacent to near	
Cuvelai Delta and Ethosha Pan Alluvial	20	Angola	Alluvium	Shallow	Unconfined	Primary	High / periodic	Adjacent – Cuvelai delta	Cuvelai deltaic alluvial sediments underlie the area in Angola. In northern Namibia the deltaic

and Kalahari Sediments Aquifer		Namibia	Alluvium, calcretes and sandstones	Shallow - medium	Unconfined - semi-confined	Primary to secondary karst	High / periodic	Adjacent to near	sediments are underlain by Kalahari Sediments with calcretes, underlain by Karoo sandstones at depth. Ground waters of variable quality, fresh to saline in complex multi-layered aquifer. The viability of this aquifer system in Namibia is dependent upon seasonal cross-border flow
Coastal Tertiary to Recent Sedimentary Basin Aquifer	21	Mozambique	Alluvium/ Sedimentary	Shallow-medium	Unconfined semi-confined	Primary	High/ seasonal	Adjacent to distant	Tertiary to Quaternary-age alluvial deltaic sands and gravels and dune sands overlying Cretaceous-age sedimentary strata. High permeability sediments obtain water from local rivers and rainfall. Little TBA through-flow, flow mainly towards the coast, possible marine saline intrusion
		South Africa	Alluvium/ Sedimentary	Shallow-medium	Unconfined semi-confined	Primary	High/ seasonal	Adjacent to distant	
Lower Congo Precambrian Dolomite Aquifer	22	D R Congo	Karst limestone	Shallow-medium	Unconfined semi-confined	Secondary karst	High/ seasonal	Adjacent to distant	The Congo River flows across the outcrop of the Precambrian age Schisto-Calcaire Dolomites via a series of cataracts. This karst weathered dolomite aquifer receives recharge from the river within DR Congo. Away from the river in Angola the dominant direction of flow is towards the river.
		Angola	Karst limestone	Shallow-medium	Unconfined semi-confined	Secondary karst	High/ seasonal	Near to distant	
Sands and gravels of weathered Precambrian Basement Complex Aquifer	23	Malawi	Alluvium / weathered basement	Shallow-medium	Unconfined semi-confined	Primary / secondary fractured	Moderate/ periodic	Headwaters along watershed	Quaternary palaeo-fluvial sands and gravels deposited in dendritic dambo channels developed on the 'African Surface', an ancient late Cretaceous - early Miocene peneplain. These with the underlying weathered Crystalline Basement form a complex low to medium permeability aquifer within the plateau watershed area between eastern Zambia and western Malawi. The low regional hydraulic gradients, <0.005m/km, reflect the flat surface topography. There is some potential for cross-border flow to take place.
		Zambia	Alluvium / weathered basement	Shallow-medium	Unconfined semi-confined	Primary / secondary fractured	Moderate/ periodic	Headwaters along watershed	
Eastern Kalahari Karoo Basin Aquifer	24	Botswana	Karoo sandstones and basalts	Medium - deep	Confined	Some primary / mainly secondary fractured	Moderate/ periodic	Headwaters along watershed	Upper Karoo sandstones partially covered by basaltic volcanics with some primary porosity and fractured permeability, form confined to semi-confined aquifers. The aquifer is located on the plateau-like watershed between Zambezi to the north and Nata River to the west. Here, the Karoo aquifer is shared across the border with potential for cross border flow, degradation and even for one side of the border to pollute the other.
		Zimbabwe	Karoo sandstones and basalts	Medium - deep	Confined	Some primary / mainly secondary fractured	Moderate/ periodic	Headwaters along watershed	

The information presented in Table 2 and Tables A1 to A5 in Annex 2 and the summary Table 3 contain available information on selected themes which can be reduced by a process of ranking and scoring such that the potential activity of each TBA can be identified as a defensible although semi-quantifiable function.

Table 2 addresses the hydrogeological properties of each TBA and looks specifically at the geological setting in terms of lithology (rock type) and depth/thickness, hydrogeology in terms of aquifer type (confined, unconfined etc.) and perceived permeability of the aquifer and the recharge potential of the aquifer. This allows the key aquifer parameters to be identified, i.e. the storage potential of the aquifer, the transmissive properties of the aquifer and the recharge potential, which is used here as a surrogate for sustainability. This Table is for information only and is not used as part of the overall assessment of TBA activity. It is, nevertheless the basis on which Table A1 is established and is fundamental to understanding why some TBAs are likely to be active and, therefore, problematic, and why are others are likely to be inactive.

Table A1 adopts a scoring system based on the perceived strengths and weaknesses of natural and induced cross-border flow and cross border induced pollution or vulnerability as perceived on each side of the border. The highest scores, i.e. those with the most likelihood of cross-border degradation of some sort are the Cuvelai Delta and Ethosha Pan Alluvial and Kalahari Sediments Aquifer shared by Angola and Namibia and the Eastern Kalahari Karoo Basin Aquifer shared by Zimbabwe and Botswana. The next highest scores are for the South West Kalahari Karoo Basin Aquifer and the Zeerust-Ramotswa-Lobatse Dolomite Basin Aquifer.

Table A2 evaluates the level of knowledge and understanding attained for each TBA. This evaluation considers the known data holdings and the perceived level of information held on each side of the border at each TBA within the categories Groundwater Quantity, Groundwater Quality and Aquifer Vulnerability. Highest scores are held by Botswana, Namibia, South Africa and Zimbabwe. The poorest scores reflect both inadequate knowledge and in some cases poor availability and dissemination of knowledge and are held by Tanzania (although not consistently), DR Congo, and Angola. This is an important assessment as it also reflects the commitment to groundwater that is currently being carried out by each member state. DR Congo, which is more dependent on surface water resources than groundwater, is focussing not on groundwater but on surface water and its poor score is in no way an indictment on its activities. Similarly poor score attributed to Angola reflects inadequate knowledge of what the status of groundwater understanding is in this Member State, which may also be the case in Tanzania with one of its TBAs.

Table A3 is an attempt to compare the governance capability of each member state that has a TBA with specific regard to its capability in groundwater management, knowledge about its groundwater systems and the current level of groundwater monitoring. Highest scoring is South Africa, although not universally, Namibia, Botswana and Zambia. As with Table 5 the lowest scores fall to Angola, DR Congo and Tanzania and this reflects DR Congo's dependence on surface water rather than groundwater and may also inadequate dissemination of understanding by Angola and Tanzania.

Table A4 assesses demand and supply within the categories of demography (population and supply), Land Use notably use of water intensive agriculture, i.e. irrigation and cattle ranching, and presence of manufacturing industry or mining. Highest water demand occurs in South Africa, Namibia, Zimbabwe and Botswana as well as in Tanzania and Mozambique. Areas such as the national parks in South Africa score very low as do areas that are sparsely populated, i.e. with low demand, such as the Lower Congo Precambrian Dolomite Aquifer shared by DR Congo and Angola.

The final assessment table, Table A5, considers environmental susceptibility or environmental capability in terms of their impact on groundwater resources. It considers transboundary hydrology both in terms of connectivity between groundwater and surface water bodies, it considers the sustainability of groundwater resources and the occurrence of groundwater dependent ecosystems and it assesses the occurrence and impact of flood and drought events. Highest scores, i.e. highest susceptibility are the Rovuma Delta Coastal Sedimentary Basin Aquifer shared by Tanzania and Mozambique and the Shire valley Alluvial Aquifer shared by Malawi and Mozambique. Lowest scores occur in water scarce areas where there are no significant groundwater dependent ecosystems and in areas of prolonged drought.

Tables A1 to A5 collectively provide a comprehensive scored and ranked evaluation of a set of diverse parameters all of which relate to the activity level of each TBA. It is acknowledged that not all the parameters that could influence the activity of a TBA have been included but all the major influences and some of the lesser influences have been included. An overall score for each TBA divided between each sharing neighbour will provide the initial classification for each TBA as A Active, B Moderately Active and C Inert. This can be achieved by application of an algorithm that allows some weighting of scores to attain a desired equalling of the influence of each major category (Tables A1 to A5).

The selection of an appropriate algorithm was a process of trial and error to achieve a meaningful best possible ranking of the activity level for each TBA. It is based on the premise that the key influence on activity must be hydrogeology, to include the various components of cross-border impact which are:

- the ability of an aquifer to transmit water across an international border,
- the ability of an aquifer to interact with surface water with international riparian ownership,
- the ability of an aquifer to transmit an impact, which could be an environmental impact, across a border.

While greatest weight is logically given in the algorithm it is difficult to sensibly weight the other four components: knowledge and understanding, governance, socio-economic, and environmental. For this reason they are each given an equal weighting.

The adopted algorithm that provides most emphasis on groundwater flow and aquifer vulnerability (which is indexed out of a possible maximum of 9 stars), is to multiply this score by the sum of the remaining scores (which have a maximum of 18 stars). It is acknowledged that this aggregate score could be derived with any number of variations within the adopted algorithm, but trial and error indicates that the adopted algorithm does provide a meaningful result that is fitting the overall perception for each TBA based on the evidence in Tables A2 to A5:

The algorithm is defined as:

TBA Activity Aggregate score =

Score Table 3 x (Score Table 4 + Score table 5 + Score Table 6 + Score Table 7)

Table 2 is not used for the assessment as the specific hydrogeological questions needed are given in Table 3, Table 2 being of an informative role only. The minimum score is 0 and the maximum is 648. This is divided between Rank A Active TBA score ≥200; Rank B Moderately Active score ≥100 and ≥199; and Inactive TBA score ≤199 (as presented in Table 3).

The broad ranks produced in Table 3 can then be used to identify which TBA systems are best understood and have a reasonable through flow that may be able to be monitored using telemetric systems. Those TBA segments that meet at international boundary rivers for which there are little data or knowledge available score lowest and Ranked C.

Two clear winners emerge as being potentially the most active of the 14 TBAs in SADC, the Tuli Karoo Basin shared by Botswana, South Africa and Zimbabwe, and the Eastern Kalahari Karoo Basin Aquifer shared by Botswana and Zimbabwe. There are three equally inactive TBAs: the Congo/Zambesi Basins Benguela Ridge Watershed Aquifer shared by DR Congo and Angola, the Coastal Tertiary to Recent Sedimentary Basin Aquifer shared by Mozambique and South Africa, and the Lower Congo Precambrian Dolomite Aquifer shared by D R Congo and Angola. The remaining nine TBAs are classed as moderately active of which the potentially Active ones are the South West Kalahari/Karoo Basin Aquifer shared by Botswana, Namibia and South Africa, the Zeerust-Ramotswa-Lobatse Dolomite Basin Aquifer shared by Botswana and South Africa, and the Cuevelai Delta and Ethosha pan Alluvial and Kalahari Sediments TBA shared by Angola and Namibia.

The focus for groundwater monitoring should be on the more active TBAs and in the first instance should consider those classed as Active and those that are Moderately Active with initial emphasis on the three described above which are Moderately Active to Active. There is little to be gained on instrumenting the Inactive TBAs in which water transfer and potential degradation are unlikely and which, in any case, may be situated in remote areas with little if any potential for growth in demand.

Table 3 TBA Ranking

Transboundary Aquifer	TBA No.	Country	Table 3	Table 4	Table 5	Table 6	Table 7	Total Score	Rank
Ruvuma Delta Coastal Sedimentary Basin Aquifer	3	Tanzania	4	6	6	11	15	152	B
		Mozambique	3	10	7	11	15	129	B
Congo Delta Coastal Sedimentary Basin Aquifer	4	D R Congo	3	6	6	9	13	102	B
		Angola	4	6	6	10	13	140	B
Congo/Zambezi Basins Benguela Ridge Watershed Aquifer	5	D R Congo	3	6	6	9	9	90	C
		Angola	3	6	6	9	9	90	C
Tunduru/ Maniamba Basin Karoo Sandstone Aquifer	6	Tanzania	3	9	6	9	13	111	B
		Mozambique	3	9	7	8	13	111	B
Middle Zambezi Rift Upper Karoo Aquifer	11	Zambia	3	16	14	9	11	150	B
		Zimbabwe	3	16	12	6	11	135	B
Shire Valley Alluvial Aquifer	12	Malawi	4	12	10	10	14	184	B
		Mozambique	3	9	7	10	14	120	B
South West Kalahari/ Karoo Basin Aquifer	13	Botswana	4	18	12	8	9	188	B
		Namibia	5	18	16	12	10	280	A
		South Africa	4	18	12	6	9	180	B
Zeerust – Ramotswa - Lobatse Dolomite Basin Aquifer	14	Botswana	5	18	15	13	9	275	A
		South Africa	4	18	13	9	9	196	B
Tuli Karoo Basin Aquifer	15	Botswana	4	18	16	10	12	224	A
		South Africa	4	18	18	14	12	248	A
		Zimbabwe	4	16	10	12	12	200	A
Cuvelai Delta and Ethosha Pan Alluvial and Kalahari Sediments	20	Angola	5	6	8	8	13	175	B
		Namibia	5	16	16	12	13	285	A
Coastal Tertiary to Recent Sedimentary Basin Aquifer	21	Mozambique	3	8	7	8	10	99	C
		South Africa	3	14	9	9	10	126	B
Lower Congo Precambrian Dolomite Aquifer	22	D R Congo	3	6	6	7	12	93	C
		Angola	4	6	6	7	12	124	B
Sands and gravels of weathered Precambrian Basement Complex	23	Malawi	4	14	10	10	11	180	B
		Zambia	4	14	11	10	11	184	B
Eastern Kalahari Karoo Basin Aquifer	24	Botswana	5	18	13	10	9	250	A
		Zimbabwe	5	18	12	12	9	255	A

Total score = sum of scores for Tables 4-7 x score Table 3. Rank A *Active* >200, B *Moderately Active* >100 and C *Inert*<100

6. TBAs and Groundwater Monitoring

6.1 Monitoring Objectives

The ultimate objectives of any groundwater monitoring network include:

1. Calculation of recharge and aquifer reaction to rainfall events.
2. Identification of trends in groundwater quantity, quality, demand etc.
3. Development of baseline information.
4. Spatial distribution of groundwater parameters.
5. Development of early warning mechanisms with respect to drought, climate change, over abstraction etc.
6. Variation of specific quality parameters relating to anthropogenic impacts.

In the first instance it is only the first three objectives that SADC will address, the others can build upon these as resources and the will to share on a regional scale develop. For example, annual sampling of groundwater at monitoring points can commence as funds are made available, with well-head tests and analytical results forming a long term time series of data. These data will all contribute to baseline knowledge of the various transboundary aquifers and will allow long term trends to be identified which may connect with phenomena such as climate variability, drought cycles, change in demography or land use, etc. Spatial distribution of groundwater parameters is scale dependent and the usefulness of this objective depends on the distribution of the monitoring points. It is unlikely, given the regional scale of aquifers within SADC that this objective will be achieved in the foreseeable future.

Development of early warning schemes is an important objective which essentially justifies investment in the monitoring programme. Within each topic area a set of triggers can be devised which raise alarm to a developing situation, be it the onset of periodic drought conditions, long term decline in effective rainfall as a result of climate variation, groundwater mining, groundwater pollution, loss of terrestrial groundwater dependent ecosystems, etc. As triggers are set off in any group of monitoring sites, so the potential danger area is widened and the severity of the impending situation can be assessed. Mitigating measures and coping strategies can be implemented accordingly.

The final objective is perhaps the most difficult. Although water quality analysis in Objective 2 will identify elevated nitrate concentrations, other nitrogen species and organic pollutants will not be monitored. Organic pollutants, in particular, are expensive to sample and analyse and, unless there is knowledge of which pollutants to look for, can be ineffective. Organic pollutants should only be included if a known product used in agriculture or an industrial spill is involved. Microbial assay is also expensive, but periodic tests for faecal coli and other pathogens should be carried out at intervals. Again, trigger levels can be set based on the WHO guideline levels of ions, compounds and microbial populations in drinking water.

Regional monitoring is nevertheless a valuable and productive means for SADC Member States to start to share issues and problems that are transboundary. This will also promote sharing of issues that may not immediately be transboundary, through the development of a regional monitoring network. Dissemination and regional workshops will help to promote interstate discussion and the will to participate in a regional monitoring programme. In the first instance it is recommended that the pilot study focuses on one of the active TBAs with indicator wells instrumented on each side of an international boundary.

6.2 Monitoring Guidelines

The SADC Groundwater Management Institute and Member States will require an agreed set of recommended guidelines for the integrated monitoring of Transboundary Aquifers, but see also IGRAC (2008) for technical guidance. This is translated into the form of a Terms of Reference for the development of the regional monitoring system in Annex 3.

This section sets out an initial set of recommended guidelines which will need to be remoulded in due course in the light of operational experience and other preferences. The monitoring guidelines are themselves the subject of a separate report. In order to initiate the monitoring programme it is recommended to work upwards towards a larger vision from a small and relatively simple start. It is, therefore, recommended that initial focus be on TBAs with indicative data gathering sites one on either side of an international boundary, looking additionally at the impact of climate change (trends) and drought warning (drought cycles).

The question first needs to be asked whether a regional monitoring network can be installed in SADC and this must attract a positive response. Given consent and guidance of Member States a network can be designed and installed that satisfies both regional inter-state needs and enhances national understanding of water resource and its potential to support abstraction and sustain ecosystems. That system should be based on three discrete scalar components comprising:

- Local maintenance – periodic validation of measurements by manual observation, cleaning and security.
- Regional gathering of data by telemetry to a central institution owned by the SADC Member States and dissemination of value added data to Member States.
- Bilateral management of shared groundwater units with guidance from central institution.

The system must be operationally effective, long-lasting and able to provide reliable and consistent data into the future. A groundwater monitoring system should thus have the following characteristics:

- Comprehensive – needs to spatially sample the key aquifer zones with sufficient density of sampling points in order to be able to determine both baseline ('natural') variations as well as anthropogenic impacts (e.g. abstraction, quality degradation, etc.).
- Robust – needs to comprise robust and reliable monitoring equipment capable of working without operator intervention in remote areas for long periods of time. Should be telemetry based for interrogation and real time acquisition of data if possible.
- Operator 'Friendly' – needs to be easy to maintain and operate, with standardised spare parts and easy removal. Also should be easy to download in the event of telemetry failure.
- Integrated – should be fully integrated into any existing national groundwater monitoring system network. It also needs to be integrated into the proposed regional network, and if feasible into an existing data telemetry system such as HYCOS to minimise development requirements.
- Cost Effective – since the requirement for groundwater monitoring is not well recognised by financial planners it is essential that any new network should be as

cost effective as possible (i.e. minimum cost without compromising reliability, data quality and operational aspects).

The guidelines set out here are, therefore, intended as a basis for future discussion and are laid out under the following headings:

- *What particular parameters should be monitored and why?*
- *What data should be collected?*
- *How should the data be collected?*
- *Where should the data be collected and why?*
- *How should data be archived and made both nationally and regionally available?*
- *How should the data be evaluated and utilised?*

6.2.1 What particular parameters should be monitored and why?

Following the idea of working upwards from a small beginning it is recommended that data gathering commences with high frequency groundwater level and rainfall observations. These will provide indicative data for critical aquifers (initially selected TBAs) for which only a conceptual understanding may yet be available. Groundwater level data gathered at high frequency allows trends to be observed, diurnal and seasonal cycles to be seen and impact of any external influences to found. Measurement of rainfall events allows trends to be measured and types of rainfall event to be observed. Comparison between high frequency groundwater level data and rainfall data allows initial estimates of recharge to be made, the delay between rainfall event and recharge to be measured, critical rainfall event and ambient conditions that cause recharge to be observed and long term changes in patterns to be recorded. As resources become available aspects of water quality can be monitored on an annual frequency. Parameters should include total dissolved solids, pH, Eh, Dissolved O and the eight major ions: Na, Ca, Mg, K, No_3, K, Cl and HCO_3.

These data, collected over a number of years, will provide invaluable information on the process and mechanics taking place within the selected TBAs and will go a long way towards elucidating the risk potential of cross border degradation.

6.2.2 What data should be collected?

Water level and rainfall data need to be collected at a high frequency but also at a manageable frequency. It is recommended in the first instance that data loggers are set to record data at an interval of 10 minutes. The frequency can be varied if initial data gathering suggest this could be useful. In addition a ground survey should be conducted on the aquifer with specific regard to socio-economic pressures, institutional background and environmental impact of groundwater level change on groundwater dependent wetlands, spring flow and base flow to surface waters. This ground survey will need to be repeated at intervals of not less than one year in order to monitor change and the impact of change on the behaviour of the aquifer.

6.2.3 How should the data be collected?

Data collection needs to be carried out cost effectively and with minimal effort on the ground. Digital time series loggers reporting via a telemetric system to a central data centre are the optimum means of collecting data on groundwater levels and rainfall. However, periodic validation will require observation boreholes to be measured by hand and the data reported to the centre. Data on socio-economic, environmental and institutional change needs to be measured in the field and reported to the centre.

6.2.4 Where should the data be collected and why?

In general, data gathering should be at a focus node within an aquifer at which a representative sample of the aquifer behaviour can be recorded along with the respective observations on socio-economic, institutional and environmental change. The location should be physically accessible.

6.2.5 How should the data be archived and made both nationally and regionally available?

The data will be archived in accordance with best current practice. Data will be subject to QA scrutiny before it is accepted into the archive to ensure that the data are within anticipated ranges and that no spurious data points are retained. The data will be reduced to daily and monthly means and all data including the raw data, archived within a data base that is universally available such as EXCEL. The data will be made available via the WWW with password controlled access.

The data processing will be based on one of the following procedures:

- Purchase webspace from an ISP (e.g. in UK or South Africa). The telemetred data are uploaded to a MySQL database on this webspace with a front end designed specially to display the data. The data will be uploaded automatically from a phone link or a dedicated PC running appropriate scripts/software. There will be an ongoing annual cost of the hosting for the webspace.
- Alternatively, the dedicated PC could act as the web server. As it is running as a webserver the front end scripts will sit on the same PC to serve the data to the web. Scripts would then assemble the data in graph form for dissemination.

There are issues that will need to be addressed including firewalls, backups and bandwidth.

6.2.6 How should the data be evaluated and utilised?

The data can be evaluated and utilised in a variety of ways depending on the degree to which the system is understood (see 6.2.1).

6.3 Selection of TBAs for Monitoring System

The selection of TBAs which warrant monitoring can be based on Table 8. Those sites which are active are priorities, but those that are moderately active should also be considered as many of these have considerable uncertainty attached to them. Thus TBA code numbers 15, Tuli Karoo Basin and 24 Eastern Kalahari Karoo Basin are active, while all but the Congo Zambesi Basin – Benguela Ridge Watershed, which is inert, have some limited potential as moderately active TBAs which deserves investigation. This is discussed in detail in the Monitoring Guidelines report.

7. Concluding Statement

The concept of the TBA was developed from operational experience with international catchment management of surface water such as that of the Rhine Commission. Transboundary Aquifer management is, however, quite different and hinges on degradation of supply due to impact on quantity and or quality usually caused by an imbalance of abstraction from one side of a border to the other. Degradation may be consequential, such as over-abstraction in one state causing seawater ingress in another and so impacting ecology and livelihood. Two parts to an impacted TBA are essential; there must be water available for abstraction in the first place and there must be demand for supply, at least on one side of the border. It is the potential imbalance in demand between neighbouring states that may be the cause of friction either now or at some stage in the future.

Fourteen TBAs were identified within the SADC Hydrogeological Map. These were selected because the aquifer unit crossed an international border or because an aquifer unit is in hydraulic contact with an international surface water course. They were not selected on any other grounds and no consideration was given to water availability, demand, or whether the transboundary element of flow was surface or groundwater. Water scarcity was not addressed either. It is nevertheless recognised that these TBAs offer a valuable starting point for a regional groundwater monitoring programme with indicator wells placed on either side of an international border. However, the choice of which TBA or group of TBAs is worthy of attention has required detailed assessment so that those that are active and a potential cause of friction between neighbouring states can be identified to form the focus group for the initial pilot monitoring programme.

The fourteen TBAs have been assessed according to a set of 5 categories of which the first, groundwater flow and vulnerability, is the over-arching influence on the activity of each TBA:

1. Groundwater flow and vulnerability (Table A1)
    a. Natural flow
    b. Induced flow
    c. Aquifer vulnerability
2. Groundwater knowledge and understanding (Table A2)
    a. Groundwater Quantity
    b. Groundwater Quality
    c. Vulnerability
3. Governance capability (Table A3)
    a. Management
    b. Knowledge
    c. Monitoring
4. Socio-economic/water demand capability (Table A4)
    a. Demography
    b. Land Use
    c. industry
5. Environmental capability (Table A5)
    d. Hydrology
    e. Sustainability
    f. Climate

Each of the sub-facets of each category are scored for each member state with a share in each TBA. A maximum of nine stars or points are available in category 1 and 18 in the other four categories. These are amalgamated by multiplying the sum of categories 2+3+4+5 by category 1 to give an overall score for each member state at each TBA. Whilst it is acknowledged that this algorithm is not the only approach that could be made, trial and error with other algorithms did not provide a set of scores that fitted the overall hydrogeological setting of each TBA. The assessment is, therefore, a semi-quantitative assessment that is defensible.

The assessment concludes as follows:

Active TBAs (likely to be the cause of friction between neighbouring states)
TBA 15, Tuli Karoo Basin Aquifer, and
TBA 24, Eastern Kalahari Karoo Basin Aquifer

Less active TBAs:
TBA 13, South West Kalahari/Karoo Basin Aquifer
TBA 14, Zeerust-Ramotswa-Lobatse Dolomite Basin Aquifer
TBA 20, Cuvelai Delta and Ethosha Pan Alluvial and Kalahari Sediments

Moderately active TBAs:
TBA 3, Ruvuma Delta Coastal Sedimentary Basin Aquifer
TBA 4, Congo Delta Coastal Sedimentary Basin Aquifer
TBA 6, Tunduru/Maniamba Basin Karoo Sandstone Aquifer
TBA 11, Middle Zambesi Rift Upper Karoo Aquifer
TBA 12, Shire Valley Alluvial Aquifer
TBA 23, Sands and gravels of weathered Precambrian Basement Complex

Inactive TBAs (unlikely to become the cause of friction between neighbouring states):
TBA 5, Congo/Zambesi basins Benguela Ridge watershed Aquifer
TBA 21, Coastal Tertiary to Recent Sedimentary Basin Aquifer
TBA 22, Lower Congo Precambrian Dolomite Aquifer

It is recommended that the initial focus from SADC should be on the Active and Less Active TBAs listed above. It is further recommended that monitoring will not contribute to the management of the Inactive TBAs although it would add to baseline knowledge. It is recognised that the classification of the TBAs will need revision as knowledge and understanding through monitoring and measurement progress. It is possible also that the classification scoring system may need modification in the future as understanding increases. In the meantime the real value of the classification is that it can be the basis on which to focus activity, with those in the top two categories being targets for monitoring while moderately active TBAs can form targets at a later stage.

The potential benefits of monitoring the active and less active TBAs derive from the concept of inter-state sharing and dialogue. Not only will knowledge of the aquifer systems be enhanced but so to will the technical capabilities of neighbour states who are required to discuss the management of their shared aquifer units. This they will do initially from a simple hydrogeological perspective but as understanding increases, the role of shared surface waters and the impact of groundwater abstraction on ecology and other systems will need consideration. This is critically important in those areas of SADC that are less well endowed with water resources, but where demand is nevertheless significant. It is only through monitoring and measurement that sufficient knowledge and understanding can be attained for neighbour states to jointly manage the resources they have. Although some TBAs currently appear inactive or at best moderately active, changing climate may require them to be reclassified once climate change scenario predictions become more robust. In the meantime the classification above is the best currently achievable.

It must also be remembered that the monitoring of selected active TBAs is only the beginning of a regional monitoring network. The Monitoring Guidelines report describes a selection process that focuses on the major aquifer systems – hard rock aquifers, weakly consolidated aquifers and weathered basement – with at least one indicator well in each member state as an initial objective. The monitored TBAs will form part of this network and will contribute to the regional understanding of the major groundwater systems.

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Annex A Inventory of Transboundary Aquifers in SADC

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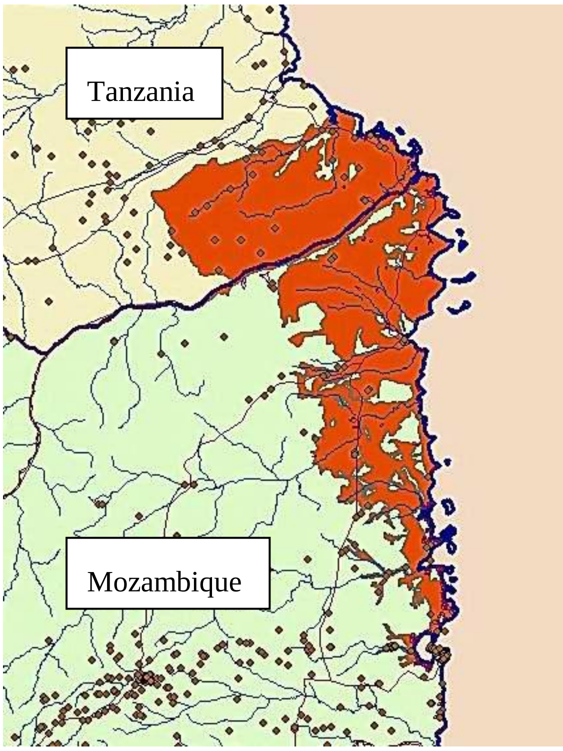

TBA 3 The Ruvuma Basin Between Tanzania and Mozambique

The triangular Ruvuma Basin is located between S.E. Tanzania and N.E. Mozambique encompassing the lower reaches of the Ruvuma River down-stream of the Gomba crossing, and the coastal area between Mtwara in the north to Pemba in the south. Tertiary to Quaternary age alluvial sands and gravels of the Ruvuma Delta overlie Cretaceous-age sedimentary strata, mainly marlstones. Higher permeability sedimentary aquifers near the coast primarily draw water from the Ruvuma River and its tributaries.

Rainfall varies between 800 mm a^{-1} at the Pemba coast to over 1200 mm a^{-1} on the Mueda Plateau. The recharge capacity is medium to high in the north to low in the southern part of the basin, where soils are more clayey. Rivers are seasonal to ephemeral.

Groundwater prospects in bedrock are limited by the dominance of weakly permeable marlstones with brackish groundwater. In the more productive aquifers of the coastal zone, groundwater may be brackish or saline. The most favourable areas are found in the north and along the main alluvial valleys, especially at the contact with the Basement Complex. The likelihood of any significant cross-border flow in these strata is small.)

The alluvium along the main rivers, crossing the sedimentary terrains, includes the most productive aquifers of the basin. The Metuge wellfield, for example, which provides the water supply for Pemba is in a 40m thick alluvial fill with specific yields of between 1.2 and 12 m^3 hr^{-1} m. Other promising alluvial zones can be found at the contact with the Basement Complex. Wells in the Monapo Valley have yields between 40-60 m^3 h^{-1}. The alluvium of the Messalo seems to be the best developed for supply. The groundwater quality in the alluvial aquifers is generally good, but may be poor if the water originates from adjacent plains with mineralised groundwater, as is the case in the Muaguide valley near Bilibiza. The alluvium in the littoral zone is of little hydrogeological importance, being impermeable and containing brackish water. Small dune fields can form positive exceptions, but groundwater can still be rather brackish. Cross-border flow on the alluvium is unlikely as drainage to the river will prevent groundwater flowing beneath the river in either direction. It cannot, therefore, be considered as a TBA requiring apportionment interventions.

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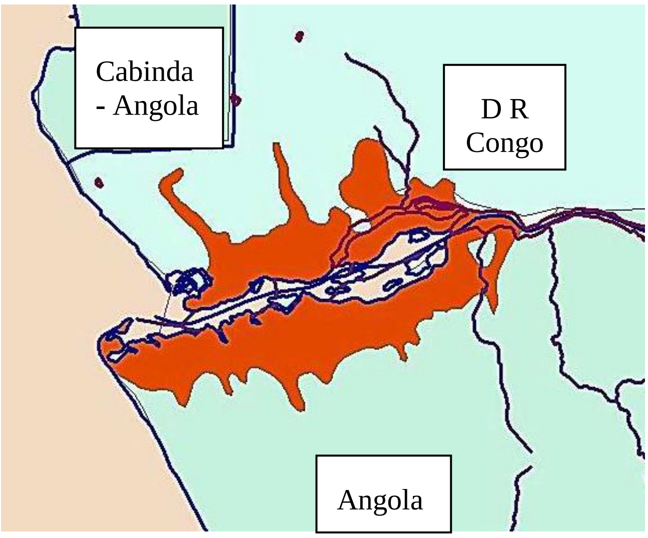

TBA 4: Coastal Sedimentary Basin between D R Congo and Angola

The Congo River passes through the Crystal Mountain range to the Atlantic Ocean through a narrow terraced coastal plain. The D.R.Congo gains access to the Atlantic Ocean via a 32 km wide corridor centred on the delta of the Congo River that separates the province of Cabinda to the north from the rest of Angola to the south.

The coastal strip to the south of the Congo Delta receives less than 760 mm a^{-1}, while the area to the north receives 930 to 1520 mm a^{-1}. Rainfall occurs between October-April with most falling during November-March.

Pliocene to Recent age alluvial sands and gravels of the Congo delta overlie marine and estuarine Cretaceous to Eocene sedimentary strata within the coastal plain area. The Cretaceous formations comprise marine limestones, shales and sandstones; the Tertiary sediments include sandstones and mudstones. These sedimentary strata are underlain by weathered granular crystalline basement granites that crop out to the east where they are capped with lateritic deposits. Recent interbedded very coarse- and fine-grained alluvial sand and gravel layers have been deposited along the present channel of the Congo River.

Limited amounts of groundwater are obtained in the narrow coastal plain from a 60 m thick unconfined aquifer that is underlain by strata containing intruded saline (marine) water. Away from the coast, the water table rises with ground surface elevation. Additional water is obtained from the weathered and fractured crystalline basement strata forming the Crystal Mountains. Most groundwater is obtained from the unconsolidated alluvial sand and gravel formations that fringe the Congo River. These formations essentially filter water directly recharged from the Congo River.

The dominant flow direction in the coastal plain alluvium is towards the sea and opportunity for flow north or south is minimal. The alluvial aquifer is shared where it crosses into Angola but the area involved is very small and does not qualify as a TBA that requires management and apportionment.

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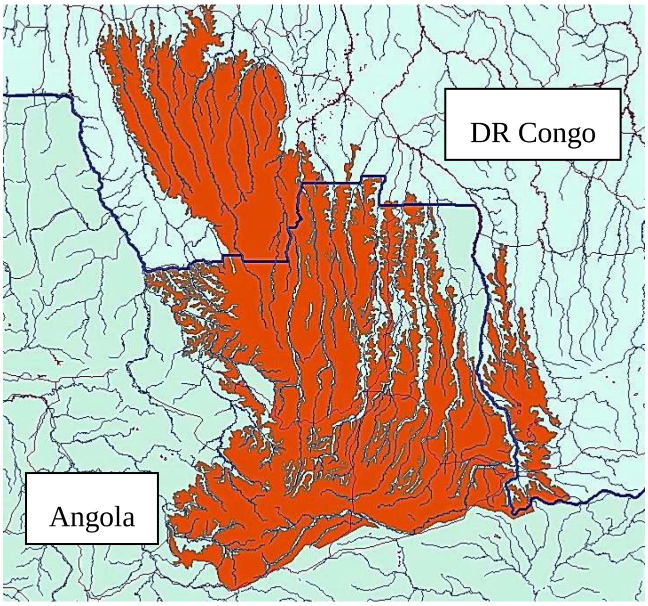

TBA 5: Congo Intra-cratonic Basin between D R Congo and Angola

Northward flowing tributaries of the Kasai, Kwango and Sankuru rivers, which occupy deep, thickly wooded valleys, rise on the Lunda plateau and the Benguela ridge watershed between the Congo basin and the Zambezi to the south. The poorly defined watershed is characterised by areas of open to bush-covered grassland of rolling aspect with many grass-covered and marshy hollows or "dambos" lying at an elevation of 1065 to 1370 m with some mountainous tracts. The upper Kasai and Kwango rivers run along parts of the boundary between Angola and the Belgian Congo. The climate is sub-tropical, with seasonal rains and cool nights. Rainfall varies from 102-127 mm a^{-1} in Angola to 178-203 mm a^{-1} in southern DR Congo. The dry season is between May and September. Soils are mainly laterite and infertile.

The Tertiary peneplain is partly covered by Plateau Gravels, which in turn are covered by Plateau Sands which may be up to 46 m thick. A peneplain, with a mantle of gravel and sand, is well developed north of the Congo-Angola frontier. In southern DR Congo the main aquifer unit is Tertiary age Kalahari System sediments made up of two main units: the lower Polymorphic Sandstone Series which is 80-100 m thick and comprises partially silicified sands; and the upper Ochre Sands Series which is up to 100 m thick and comprises ochre-coloured sands. The Kalahari System sands are underlain by Cretaceous age Kwango Series: mainly red continental to marine sandstones and shales. The diamond fields of Kasai (Congo) and Lunda (North-Angola) owe their origin to the kimberlitic pipes, one of which was located in Lunda. Alluvial diamonds are found in the basal conglomerate of the Kwango Series.

Reported hydrogeological data from these formations are scarce. Mirghani (2007) advises that the low potential Kalahari Sand Aquifer, which is no more than 80 m thick, occurs in southern DR Congo in Kasai Occidental. The hydraulic characteristics of this aquifer include yields of 4 to 11 l s^{-1}, depths to water level of 10 to 132 m, and drawdowns of 0.4 to 15 m. In the deeper more mixed Kwango Series aquifer in Kasai Occidental and Kasai Oriental hydraulic characteristics include yields of 12 to 15 l s^{-1}, typical depth to water of 100 m, aquifer transmissivity of is 2000 m^2 d^{-1} and the coefficient of storage of 10^{-5}. Some waters found at depth in this formation are saline.

The shallow unconsolidated units do contain and transmit some groundwater. Surface drainage is at right angles to the political border, incised within the plateau, with potential for transboundary surface water flow. The prevailing hydraulic gradient of the water table is likely to mirror the surface drainage and there is potential also for some limited transboundary flow of groundwater, possibly as a baseflow component to surface water flow. More significantly, pumping on one side of the border could induce degradation across the political border. However, the volumes involved are likely to be small and this TBA, moderated by paucity of supporting data, is neither likely to be significant in terms of cross-border flow or cross-border degradation.

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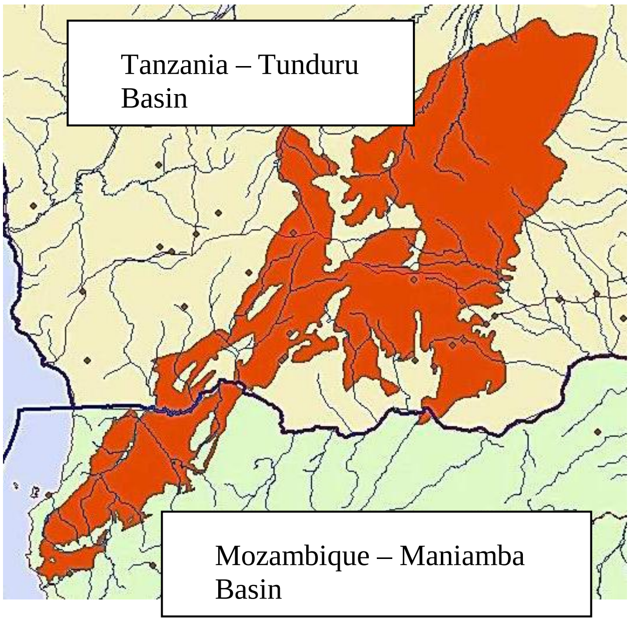

TBA 6: Karoo Sandstone Aquifer between Tanzania and Mozambique

The northeast –south west tending Karoo sandstone aquifer between Tanzania and Mozambique, lying astride the Ruvuma River that forms the international boundary, includes the Tunduru and Maniamba Basins.

The Tunduru Basin of Tanzania occupies 32 000 km^2 in Ruvuma Region at an elevation of 600-900 m asl. The area has a rolling topography with a dendritic drainage that includes south flowing tributaries of the Ruvuma River. The Basin receives a mean annual rainfall of 800 to 1200 mm a-1 during November to April. It is drier to the north-east and east. Well drained thick loamy sandy soils on sandstones and heavy clayey soils on mudstones and shales support a dense deciduous forest cover. Agricultural activity is centred on Tunduru. Communication across the basin is poor.

Head of valley springs are common, generally discharging groundwater at the foot of cliffs. With high infiltration capacity soils, groundwater recharge is also high. River base flow is mainly influenced by springs. Groundwater is discharged to the lower courses of rivers where the groundwater level coincides with river levels. The peak discharge based on monthly mean values is about 41 $l\ s^{-1}\ km^2$, and the minimum flow is 3 $l\ s^{-1}\ km^2$ in October indicating a minimum groundwater recharge of 90 mm a^{-1} or about 8% of rainfall. The Karoo rocks of the Tunduru Basin are mainly continental sandstones, siltstones, arkoses, and conglomerates deposited in north-east to north trending down-faulted sub-basins. The Karoo aquifers are intergranular stratiform to composite with primary porosity and some secondary fissure porosity. Artesian conditions occur although most of the water struck is semi-confined. Depths to water level are related to local topography and spring lines. Groundwater flow is directed towards springs and valleys. The arenaceous Karoo aquifers have yields of 0.7 to 1.5 $l\ s^{-1}$ with some overflowing artesian discharges. Transmissivities range from 66 to 35 000 $m^2\ d^{-1}$ and coefficient of storage are moderate. Groundwater is usually of good quality.

South of the Ruvuma River in Mozambique, the Maniamba Basin in the north-west of Niassa (7000 km2) receives rainfall of 1100-1400 mm a^{-1} within tropical rain savannah to humid temperate conditions with a dry winter. Recharge is high, streams are seasonal to ephemeral. The Maniamba Basin has a SW dipping axis and Karoo infill of more than 2000 m. The sedimentary sequence of Ecca and Beaufort Series, locally known as the Lunho Series consists of conglomeratic sandstones, mudstones, carbonaceous shales and siltstones, shales, conglomeratic sandstones with silicified wood, shales with calcareous concretions with argillaceous loose sandstones. Few boreholes have been drilled in the basin. The sedimentary sequence is dominated by low productive fine textured rocks with poor yield prospects; yields are usually below 0.8 $l\ s^{-1}$. Fracture zones in coarse-grained sandstones offer higher yields. Water quality is variable at 400-800 mg l^{-1} total dissolved solids. Thin Quaternary sands of coluvium, alluvial terraces and eolian sand form local aquifers tapped by dug wells. The best aquifers are found in the alluvial valleys.

The prospects for transboundary flow are poor. The Ruvuma River acts as the lowest point in the Karoo aquifer where the water table coincides with the valley bottom and the aquifer discharges to the river. As this happens both from the north and the south there is little prospect of flow beneath the river. Cross border interference is also moderated by the river which acts in the manner of a constant head boundary that coincides with a linear groundwater sink. This TBA is, therefore, of little significance and does not require inter-state management to ensure equitable distribution of the resource.

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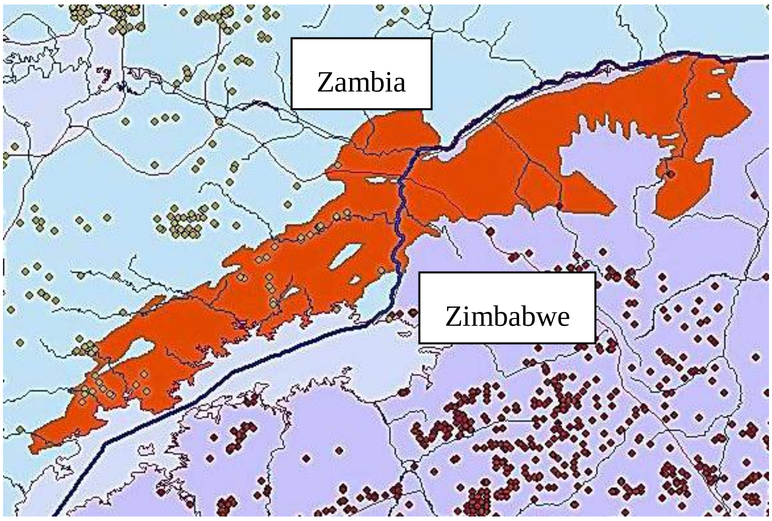

TBA 11: Middle Zambezi Aquifer between Zambia and Zimbabwe

The Middle Zambezi Basin Transboundary Aquifer includes a series of Lower and Upper Karoo age sedimentary strata with younger basalts deposited within the down-faulted graben of the Zambezi Rift Valley. The basin includes Lower to Upper Karoo strata cropping out along the northern side of Lake Kariba in Zambia as far east as the border town of Chirundu; and Upper Karoo strata occurring along the southern side of the Zambezi River down-stream of Kariba Dam to just upstream of the Cahorra Bassa Dam. The international boundary formed by the Zambezi River crosses the aquifer between Kariba and Chirundu.

The Karoo surface lies at 450 to 550 m above sea level within the wide NE-SW trending 800 m deep Zambezi rift valley, partly occupied by Lake Kariba. The topography within the Zambezi Rift is undulating to flat with isolated elongate northeast-southwest trending ridges composed of outcrops of more resistant basement rocks. The climate is hot and dry, with temperatures reaching their peak in October and November. Mean annual temperature is around 25-30^{o}C. Rainfall is seasonal and erratic, falling between mid November/December and February/March with a mean annual rainfall range of 300 to 800 mm and mean annual evaporation of 2000 to 2200 mm. Rivers including the Lusitu, Malanga and the Lufua, rise to the north, traversing the Zambezi Escarpment via deep gorges before passing across the floor of the rift. These rivers are ephemeral with courses that are choked with alluvial sediment to form "sand rivers". The Kafue River flows to the Zambezi at the north-eastern corner of the basin.

The Lower Karoo Group includes the basal Siankondobo Sandstone Formation, overlain by the Gwembe Coal Formation, in turn overlain by the Madumabisa Mudstone Formation of lacustrine mudstone, sandstone, and calcareous beds. The Upper Karoo Group includes the coarse-grained arenaceous Escarpment Grit, overlain by the fining-upwards Interbedded Sandstone and Mudstone, Red Sandstone; and Batoka Basalt Formations. The Karoo strata are indurated rocks with low permeabilities and porosities; groundwater only occurring in rocks fractured and/or weathered to significant depths. Water tables in the area may be 20-70 m below ground surface.

Data are not available with which to assess aspects of groundwater availability but borehole yields varying from <0.3 to 2 $l\ s^{-1}$ have been reported. Within the Siavonga area, north of Lake Kariba, water quality problems include dissolved hydrogen sulphide derived from gypsum within fine-grained Karoo deposits, high fluoride levels (up to 5 mg l^{-1}) and high ammonia and nitrite concentrations indicative of contamination of groundwater with human and/or animal effluent. The aquifer area downstream of Kariba Dam within Zimbabwe is occupied by the Mana Pools National Park and associated safari areas.

Groundwater availability in the Karoo strata is limited to secondary porosity and the volumes are too small to constitute a significant TBA. Any cross-border flow is likely to be very small and not a cause for management concerns by either state.

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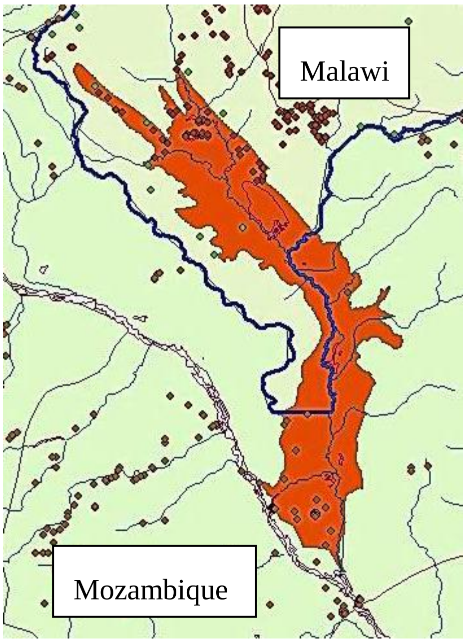

TBA 12: Shire Valley Aquifer between Malawi and Mozambique

The Southern Malawi Lower Shire Valley - northern Mozambique Zambezi sedimentary basin includes the N-S oriented Shire-Urema Graben, a continuation of the Lake Malawi Rift. This area receives rainfall of <800 - >1200 mm a^{-1}, mainly between November and March. Temperatures vary between 21 and 30°C. Evaporation of 2000-2200 mm a^{-1} greatly exceeds rainfall. Groundwater is used for irrigation of sugar cane in the Lower Shire valley and along the Zambezi. The Zambezi and Shire rivers are perennial, whereas tributary streams are generally ephemeral.

Tertiary to Quaternary and Recent alluvial sands and gravels floor the valley. Alluvium is >150 m thick in the central part of the Lower Shire Valley and in the Shire-Urema Graben. The Shire – Urema Graben is downfaulted into the Cretaceous continental arkosic Sena Sandstones, which can attain a thickness of more than 2500 m. Alluvium is widely developed in the Shire-Urema Graben.

There are high yielding, porous sediments that are hydraulically connected to buried river gravels and these may be straddled by low-yielding thick overbank flood mudstones. Along the Lower Shire, boreholes have an average yield of 0.9 l s^{-1} with the better yields as high as 15 l s^{-1}; transmissivities are in the range 30 to 300 m^2 d^{-1}. Groundwater flows towards the central axis of the valley. Recharge varies with the permeability of the surface deposits but the majority ingress is by seepage through coarse sediments in river beds. Within the Lower Shire valley some large areas of mineralised waters occur regardless of lithology.

North of the Zambezi valley, the coarse-grained arkosic Sena Sandstones have a low permeability and may contain brackish water with a mineralization up to 8500 mg l^{-1} total dissolved solids. Over 60% of all boreholes drilled are dry and of the productive boreholes only 40% contain fresh water. On the Sena Plains the best prospects are found in the river valleys, where well yields are higher and water quality can be good, again due to the infiltration of river water. The valley of the Sangadeze river, however, contains highly mineralised water.

Along the Lower Shire, the alluvium can be coarse-grained and be replenished by surface water. Boreholes and shallow wells in the Shire valley show a sharp rise in mineralisation towards the centre of the valley. Groundwater flows are towards the main river channel which is also the main sources of recharge especially during occasional floods. River gravels are the main sources of groundwater. There is little prospect for transboundary groundwater flow as the river (and political boundary) is the main source of the groundwater. As it acts as both source and constant head, interference from pumping is unlikely to propagate beneath the river and border.

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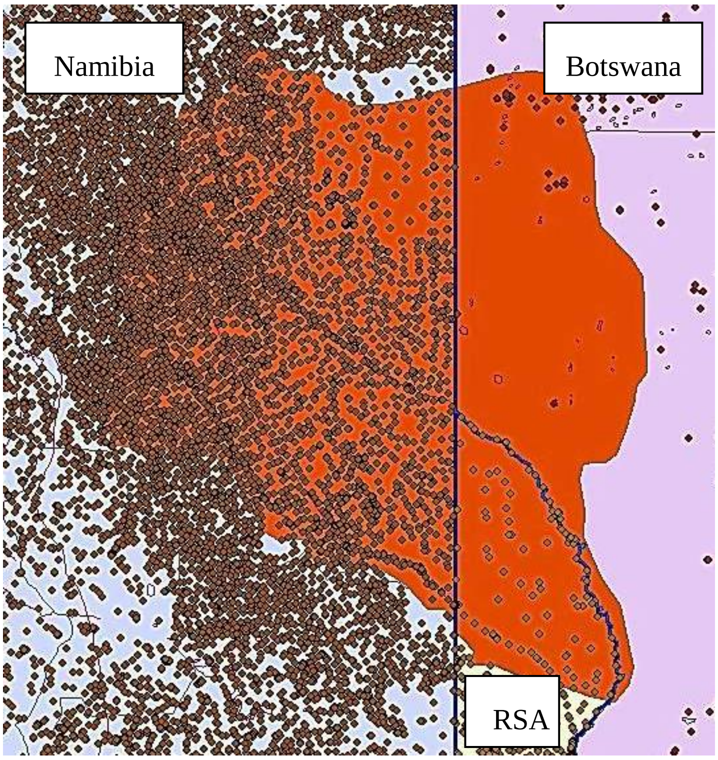

TBA 13: Kalahari/Karoo Basin between Botswana, Namibia and South Africa

The Stampreit Basin aquifer is probably the most intensely investigated TBA within the SADC region (Peck, 2009). The aquifer comprises Karoo sandstone, mudstones and shales under Kalahari Beds and is recharged to the north west of the artesian basin and flows south east from Namibia towards Botswana and South Africa. However, the long term average annual rainfall is only 150 to 300 mm within the area and significant rainfall events are not guaranteed every year. Annual potential evaporation is between 3200 and 3800 mm a^{-1}. The artesian basin supplies municipal requirements at Stampreit as well as irrigation and stock watering needs and JICA (2002) estimate this may amount to as much as 15 Mm^3 a^{-1}. Groundwater modelling (Peck, 2008) indicates that most of the potential crossflow is intercepted in Namibia with little if any potential for water to cross the border into Botswana or South Africa. This is based on a recharge estimate of 1% of the long term average rainfall.

In western Botswana boreholes drilled into the Lower Karoo Ecca sandstones in the Ncojane basin have produced blow yields of 3 to 14 l s^{-1}. This basin may extend westward to the border linking up with the Stampriet Artesian Basin in Namibia. Boreholes in the Ncojane village, obtaining water from aquifers confined below coal and dolerite layers, may have the potential to supply up to 28 l s^{-1}. The aquifer transmissibility is about 200 m^2 d^{-1}. West and south of Ncojane is largely unknown as data are scarce. The basalt which confines the Namibian basin does not appear to be present on the Botswana side. Dolerite sills, intersected during the Ncojane drilling programme, may enhance fracturing in the Ecca increasing yields. At Ncojane, groundwater from the Ecca have a total dissolved solids concentration <1000 mg l^{-1} and water types range from Ca-HCO_3 to (Na-Mg-Ca)-HCO_3 to Na-HCO_3 to Na-Cl waters. The groundwater in the Ntane sandstone is Na-HCO_3 type. Groundwater flows in the Ntane and Ecca from west to east. Within the Ncojane transitional zone fresh groundwater occurs whereas saline groundwater is associated with the Ecca Group marine sediments of the Nossop Basin.

There is potential for conflict in this TBA in which Botswana and South Africa may have grounds for degradation of their confined aquifers caused by abstraction in neighbouring Namibia despite the recharge area being situated also in Namibia.

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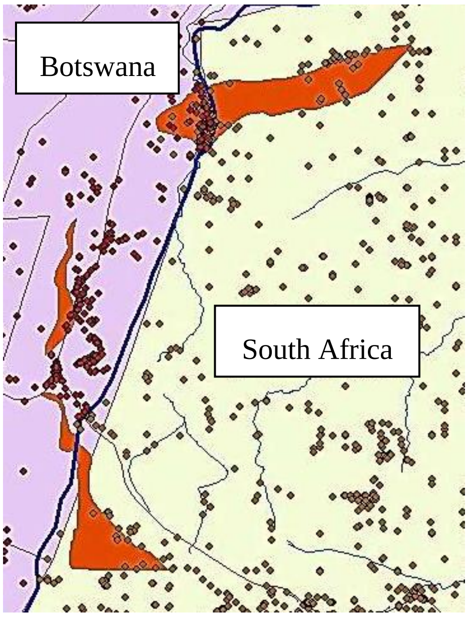

TBA 14: Ramotswa-Lobatse Dolomite Basin between Botswana and South Africa

Cherty dolomites and chert-free dolomites of the Malmani Subgroup unit of the Chuniespoort Group form an arcuate deposit cropping out at Ramotswa and Lobatse in Botswana across the border in South Africa. In Botswana these cherty dolomites are mapped as part of the Taupone Dolomite Group that comprises three units; a lower Ramoswa Dolomite Formation, a middle Maholobata Dolomite-chert Formation and an upper Mogopane Chert-dolomite Formation where they have a combined thickness of 1700 to 1850 m.

The Lobatse-Ramotswa area is hilly with the dolomitic lower unit forming the flatter, lower lying country. The cherty upper dolomites often stand out as low hills. On hillslopes, soils are thin. In lower lying areas dark clayey soils up to 2-3 m thick overlie up to 5 m of rubbly material. The dolomites may be manganiferous and a manganese 'wad' (mud) accumulates in weathered zones and fissures. In South Africa, The Malmani dolomite forms generally flat to gently rolling landscape. The dolomite is intruded by numerous dolerite dykes that have effectively sub-divided the dolomite into a series of compartments which may or may not be hydraulically linked. Springs rising from the dolomite contribute base flow to the Groot Marico, Ngotwane and Molopo catchments. Average annual rainfall varies from 600-800 mm with most occurring during January to March. June to August is often dry. Recharge is believed to be 7.5% of mean annual rainfall.

The basal dolomites are poor aquifers where they are still fresh but where weathered they are more significant. The main aquifer appears to be at the base of the weathered, locally manganiferous, rock which is up to 30 m thick. Karst cavities in the dolomites promote important aquifers, especially along faults. The depth of boreholes sunk into the Taupone Dolomite Group is rarely greater than 100 m (average 70 m) and depth to groundwater ranges from 10 to 55 m, most from 20 to 30 m. Yields of boreholes in this formation are variable and range from zero to 8 $l\ s^{-1}$. However, the range in yield is 1.5 to 20 $1\ s^{-1}$. Formation transmissivities are moderate to high. A test borehole pumped at 3.7 $l\ s^{-1}$, yielded a transmissivity of between 40 and 60 $m^2\ d^{-1}$ and storage coefficient of $6.5x10^{-3}$.

Water tends to be hard and of Na-Ca-HCO_3 type and total dissolved solid (TDS) contents of 300-400 mg l^{-1}. Groundwaters at Lobatse and Ramotswa are reported to be Na-Cl type and have high nitrate contents due to anthropogenic pollution. There is significant abstraction to supply Mafikeng, and Zeerust. Communal areas and cattle ranches obtain limited water supplies from the dolomites, while the Madikwe Game Reserve covers much of the area north of the dolomite.

Natural cross border flow and degradation are unlikely as groundwater flow is essentially local with valley bottom springs in the wet season. There is a minor risk of localised cross-border pollution.

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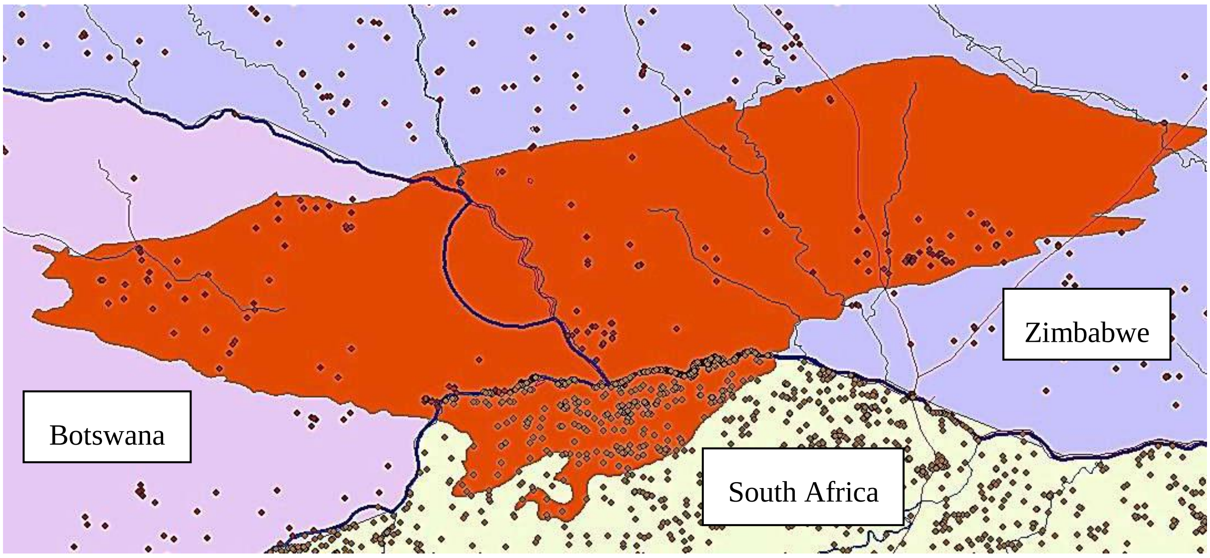

TBA 15: Tuli Karoo Sub-basin between Botswana, South Africa and Zimbabwe

The Tuli Karoo Sub-basin area has a semi-arid to savannah climate, with low surface runoff and high moisture deficits. About 250 mm a^{-1} of rain falls during November to March. Potential evaporation is high at 2000 mm a^{-1}. The area is susceptible to progressive desertification with dry season maximum temperatures of 32 to 40°C. The region has experienced 18-20 year duration wet/dry climate cycles delineated by severe droughts. Major flood events have also affected the Limpopo. Mean monthly minimum temperatures range from 16 to20°C in summer, and –6 to 14°C in winter. Rainfall over Botswana falls mainly between November and March. Groundwater recharge can only occur during extremely large storms and groundwater abstraction usually exceeds recharge leading to groundwater mining.

Flows from Botswana along the Upper Limpopo have been reduced by the constructed Letsibogo Dam on the Motloutse River and additional dams are being planned on the Tati, Thune, Lotsane and lower Shashe tributaries. The impact of damming and increased abstraction may increase the downstream areas susceptibility to drought. In the Middle Reach, the Shashe, Umzingwane and Bubye Rivers join the Limpopo River from the north. Flow along the Umzingwane River is reduced by the Zhorve Dam, north of Beitbridge.

Irrigation occurs along the Limpopo River using water drawn from the 'sand-river' at Talana and Seleka Farms, and at schemes at Pontdrift/Weipe. Limited irrigation used to be practiced in Zimbabwe in the Tuli River and Umzingwane River catchments and on the Zimbabwe side of the Limpopo River. Livestock obtain water from shallow wells in sand-rivers. Groundwater is supplied to villages using boreholes equipped with motorised pumps.

Alluvial aquifers along the Limpopo River have sediment thickness and lateral extent that promote higher yields. Alluvial aquifers along tributaries, the Shashe, and Masunga rivers, have lower potential due to limited aquifer extent and finer-grained sediments. The alluvial aquifers supply local farming, mining and domestic water needs, the Venetia diamond Mine and irrigation at Pontdrif. The alluvial aquifers along the major rivers in Zimbabwe have thick deposits of clean sands and groundwater potential is high with yields in the range of 0.3 to 55 l s^{-1}. Water quality is good although the resource is vulnerable to pollution. Recharge occurs through annual flood events. There is very little groundwater inflow into the Limpopo River; an indication of low groundwater recharge in the area. There are several areas of high nitrate concentrations (>250 mg l^{-1}) that are linked to agricultural activities along the Limpopo River. The Limpopo and Shashe Rivers form transboundary or international aquifers.

The Karoo sediments are of continental origin, sediments being deposited in river, lake and desert environments. They occur in block-faulted grabens and are often intruded by sills and west-north-west to east-south-east trending dolerite dykes. The basal Lower Karoo units include fine-grained compact glacially derived micrites, overlain by mudstones that form aquitards with poor porosity and water quality. The coarser-grained upper Karoo sedimentary formations contain water bearing sandstones often under confined conditions and at depth. The upper part of the Karoo sequence is formed by basalt lavas of the Drakensberg Group.

In the Tuli Karoo sedimentary Basin fractured sandstone aquifers have good groundwater potential. The Ntane Sandstone Formation fractured-porous aquifer near Bobonong is characterised by good groundwater potential and high yields (28 to 42 $l\ s^{-1}$) of good water quality. Upper Karoo-age Batoka Basalt outcrops in the south and southeast of the Tuli (Karoo) Basin where it is underlain by the Forest Sandstone Formation. In the Batoka Basalt Formation groundwater occurs in weathered and/or fractured zones with yields of 0.3 to 1 $l\ s^{-1}$. Water quality is generally good. The confined Forest Sandstone aquifer underlying the basalt is laterally extensive and has both primary and secondary porosity. Boreholes yield between 0.6 to 3.3 $l\ s^{-1}$ and water quality is good. Recharge is estimated to be only about $100x10^6\ m^3$.

The basalts in the Tuli syncline in Botswana contain fine-grained sandy intercalations and lacustrine sediments. Water levels in boreholes vary from near surface to up to 77 m bgl. This suggests that conduit fractures and weathered zones are laterally limited in extend and in general are not interconnected. Yields are in the range1.5 to 2.2 $l\ s^{-1}$, although yields of up to 5.5 $l\ s^{-1}$ have been recorded. Transmissivity values range from 0.15 to 80 $m^2\ d^{-1}$ Within the Basalt in the Bobonong area is a thin (1-2 m thick) bed of sandstone, in which groundwater abstraction is recorded up to a yield of 11 $l\ s^{-1}$.

An area that requires further investigation is the Ntane Sandstone Basin in the Tuli area near Bobonong. The Ntane Sandstone consists of graded fine-grained sandstone that reaches considerable thickness (10 to >250 m). It overlays the Ecca Formation, is mostly confined below the Stormberg Basalt, and continues eastwards to Zimbabwe and South Africa. The aquifer is laterally extensive and is more or less hydraulically continuous. It is characterised by primary porosity, which is enhanced considerably by secondary porosity developed during the basin development. Secondary porosity is particularly enhanced at the indurated basalt-sandstone contact. Artesian conditions have been recorded in the western margin of the basin around Bobonong. Individual borehole yields are high and are in the range 7 to 28 $l\ s^{-1}$. The Ntane Sandstone here has a mean transmissivity of 20 $m^2\ d^{-1}$. Regionally, the groundwater flow is towards the SSE direction with a regional hydraulic gradient of 1.5 $m\ km^{-1}$. The water being generally a Ca-Mg-HCO_3 type indicates modern recharge. There is an outcrop area of sandstone to the south, which acts as a recharge area. Part of the water collected by the Thune Dam (when built) will be located on the sandstone. As this area already acts as the recharge point for the aquifer, the additional water impounded by Thune Dam will inevitably increase this effect. The resource has not been quantified in detail but must be a considerable regional resource as the areal extent of the sandstone (both outcrop and confined) is close to 4000 km^2.

If exploitation of the resource were to increase, its apportionment and management could become significant, but for the moment, the potential for cross-border degradation is small.

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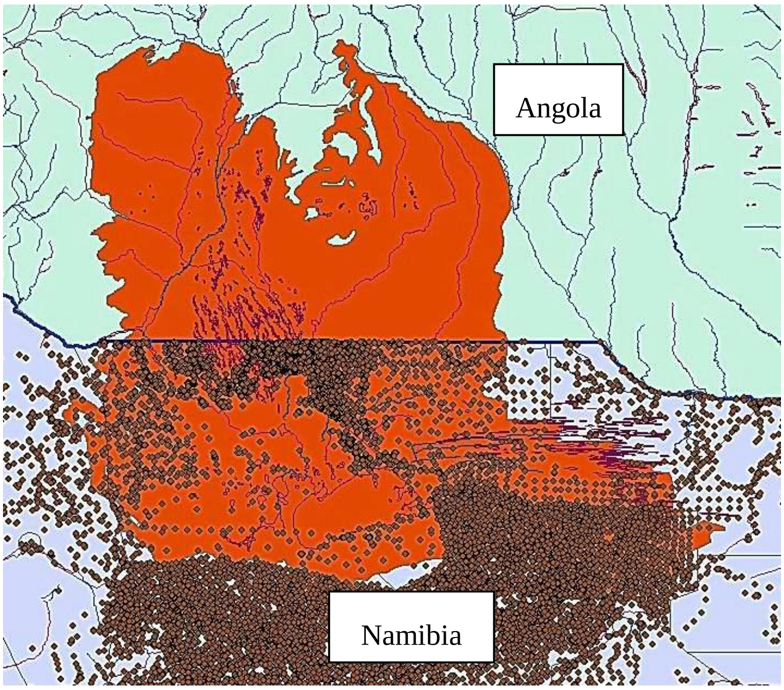

TBA 20: Cuvelai and Ethosha between Angola and Namibia

The Etosha – Cuvelai Basin is a vast area of internal drainage that straddles the Angola-Namibia border, bounded by the catchment of the Cunene to the west, the Cubango to the east and Etosha Pan to the south. The Cuveli delta drainage system obtains seasonal outflow resulting from heavy rainfall (800 mm a^{-1}) and surface flow from the Angolan Highlands through southern Angola. The resultant flood occurs in about four out of ten years.

The Cuvelai Drainage System, initiated by flooding of the Kunene River, is a series of broad, shallow channels superimposed on the Kunene Megafan and overlaps onto the western edge of the Cubango Megafan. The distance from the Angolan highlands to the mouth of the Ekuma River at Etosha Pan is 330 km. The Cuvelai system consists of two parts. The eastern presently active part of the system is fed by river flood from the central Angolan highlands and by local rains. The western part is a palaeo system fed by local rains. The Cuvelai system has a well defined, southeasterly-orientated subfan 130 km long and 100 km wide encompassing both the palaeo and active parts of the system.

South of the foothills, to approximately 100 km north of the Angola/Namibia border, the region is heavily overgrown and swampy with poor channel development. The braided channel system evolves towards the south into a system of sub-parallel interlinked channels or Oshanas draining to the south-southeast. From a width of 140 km just south of the Angolan- Namibian border the system tapers to converge at the Omadhiya Lakes which overflow into Etosha Pan. This water is joined by small volumes of water from the easternmost channels of the Cuvelai system. The Cuvelai River coming off the Angolan highlands is perennial but the water disappears underground 100 km north of the Angola/Namibia border. Many of the channels in the palaeo Cuvelai system are significantly narrower than those in the active system.

The Oshana floodwaters flow south through the dendritic system of channels. These form a massive inland delta, where occasional very variable summer rains falling during November to April (two thirds falls between January and March) add to the southward surface flow. Although more reliable rains fall in the east than in the west the high evaporation rates and temperatures mean that the region is too dry for crop production. These seasonal surface flows recharge shallow groundwater aquifers.

The southern Etosha – Cuvelai Basin is a sediment filled rift valley comprising interbedded fluvial and aeolian sands, silts and clays. The Owambo Basin now forms a small western lobe of the greater Kalahari Basin and is infilled with sand, silt and clay washed and blown in from the higher ground surrounding the basin. The sediments of the Kalahari Sequence are over 500 m thick.

The shallowest aquifer in the Cuvelai, the Discontinuous Perched Aquifer, receives seasonal rainfall and floods. This aquifer, lying at depths to 25m, comprises discontinuous layers of sands, calcretes and clays and is accessed using shallow dug wells often in groups of five, six or more, to provide water through the dry season. The deeper Main Shallow Aquifer lies at 20 and 40 m below ground level and is often too brackish or saline even for livestock to use. It is also accessed by groups of deep wells. Elsewhere, where recharged by summer rains, fresher water can be obtained as a layer on top of the denser salt water. In a few areas the water is artesian. The Discontinuous Perched and Main Shallow Aquifers in Kalahari deposits largely comprise sands, calcretes and clays. Below these two aquifers is a complex series of discontinuous aquifers found within a thick sequence of Kalahari sediments, each holding water of different qualities. Under the Kalahari sediments are the Karoo and the Damara Sequences. The Karoo rocks, lying at depths of 30 - 140 m bgl, contain brackish waters that can be used for drinking purposes. The Damara Sequence, found at depths to 670 m bgl, contains saline to slightly brackish groundwater.

Shallow, hand-dug wells that are replenished by the floods support a dense local population in the northern half of the Namibian part of the system. Borehole yields of 0.3 to 1.4 $l\ s^{-1}$ occur throughout the region. The quality of water varies greatly and is poor in many places.

Although there is potential for cross-border surface water flow, the potential for cross-border groundwater flow is limited even in the shallow sand aquifers. There is no potential for cross-border flow beneath the shallow sand aquifer which overlies the deeper brackish and saline groundwater in bedrock. However, data are scarce with which to judge this TBA.

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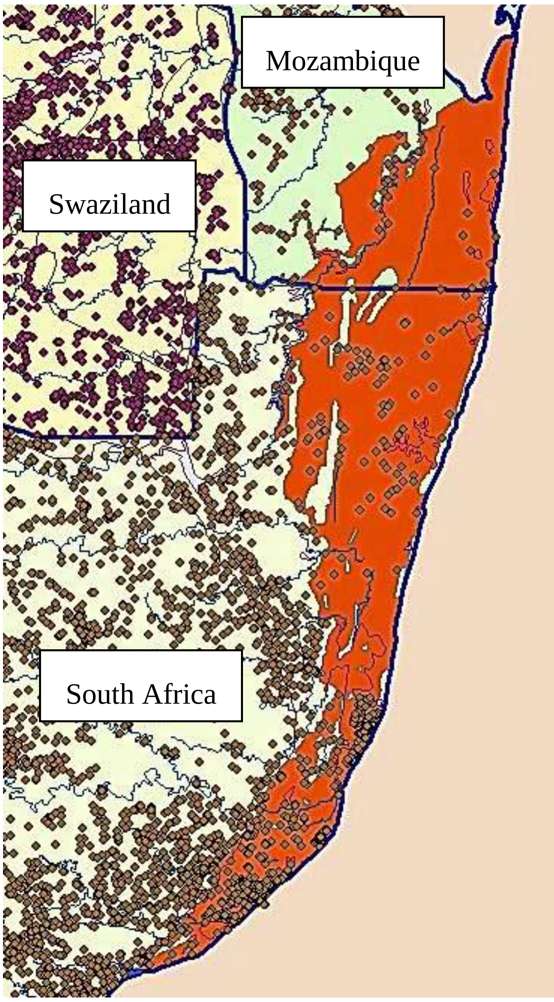

TBA 21: Coastal Sedimentary Basin between Mozambique and South Africa

The Southern or Mozambique Sedimentary Basin covers about 32% of Mozambique and stretches from 17°20'S to 29°S latitude in Natal (South Africa). Its maximum width of 440 km occurs at 22°30'S latitude. The sedimentary basin was subject to several marine transgressions, starting in the Lower Cretaceous. The Marine transgressions occurred in the Upper Cretaceous, Eocene, Oligocene and Miocene.

The Cretaceous formations of the Coastal Belt are mainly shales, marls and glauconitic sandstones. The Aptian to Albian age Maputo Formation consists of argillaceous glauconitic sandstones. The Tertiary marine calcareous medium-grained sandstones of the Salamanga Formation, which outcrop along the Maputo River, are locally productive but may contain saline water near the river. Along the Libombos, the fine textured marine Cretaceous and Lower Tertiary formations are poorly productive and highly mineralised. Eastwards, the calcarenites and limestones of the Lower Tertiary Mangulane Formation and the Miocene Santaca Formation are more productive. Water quality is mostly poor. Depth to water table and poor recharge conditions limit groundwater development.

The coastal dune belt consists of a narrow strip of recent dune sands and older dunes up to 100 km wide. The recent littoral dunes consist of clean medium- to coarse-grained sands. The ancient dunes are composed of orange-brown to reddish coloured clayey sands of fine to medium texture up to 100 m thick. The Dune Belt is developed along the entire coast south of the Save. The porous eolian sands form a regional phreatic aquifer with fresh groundwater. The permeability decreases from the coast inland, as the clay content increases. The narrow strip of recent dunes along the present coastline can be very productive, as, for examples, is the case in the wells at Ponto do Ouro and Tofo. But the small distance from the sea and from lagoonal inland depressions, often containing brackish to saline water, is a limiting factor for groundwater extractions. there is a coastal zone with yields over 0.8 l $s^{-1}$and permeabilities of 4-8 m d^{-1}, and an inland zone with lower yields and permeabilities of 0.5-3 m d^{-1}.

In South Africa the coastal belt is sparsely populated with rainfall declining from 1200 mm a-1 along the coast to about half that inland. Tertiary to Quaternary-age alluvial sands and gravels overlie Cretaceous-age sedimentary strata. The sands are moderately permeable and sustain high hydraulic gradients up to 1 in 50 in the least permeable areas. A north-south orientated groundwater divide crosses the border between South Africa and Mozambique and separates groundwater draining east to the sea and west to the Pongola River. Currently the aquifer supports a population of only 200 000 people within an area 50 km either side of the border. Significant demographic growth is unlikely as land is increasingly taken up for wetland conservation park areas. Cobbing et al. (2008) report that this TBA is not at risk of competition for water between South Africa and Mozambique and that the aquifer will not need the development of management plans, government structures or intervention from political authorities.

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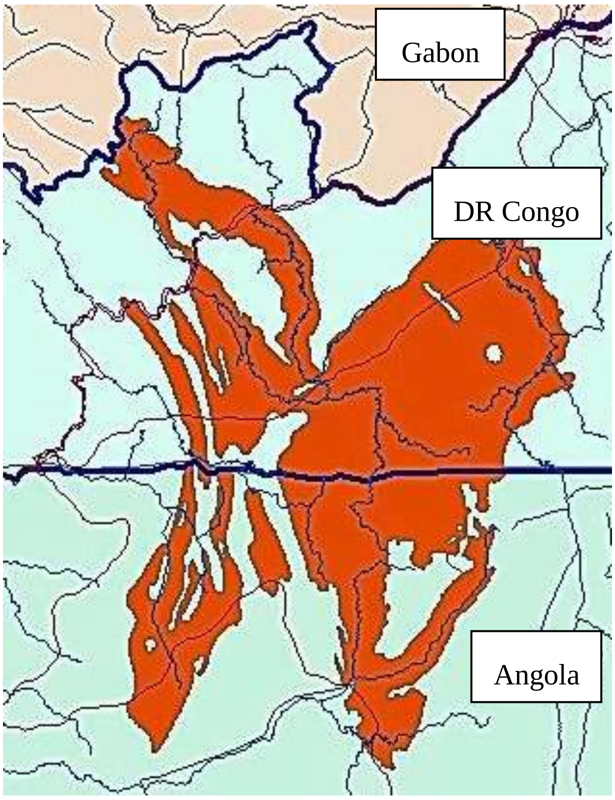

TBA 22: Dolomitic Limestone Aquifer Between D R Congo and Angola

During its passage through the Crystal Mountain range to the Atlantic Ocean the Congo River flows over a series of cataracts downstream of Matadi (Naval Intelligence Division, 1944). These cataracts are formed in part by outcrops of Neoproterozoic dolomitic limestones. This 300 - 1000 m thick sequence of stromatolitic limestones and dolomites of the Schisto-Calcaire Subgroup crop out in a series of elongate north-south trending folded basins along the western edge of the Congo Basin between Gabon to the north and Angola to the south. Much bare limestone is seen at outcrop, typical of karst weathered pavement. Soil cover appears to be both patchy and thin

Although there are no data readily available regarding the hydrogeological characteristics of the Schisto-Calcaire Subgroup in the lower reaches of the Congo, given the high annual rainfall of 930 to 1520 mm a^{-1} received between October-April, the karstic nature of weathering should ensure high potential borehole yields (Préat ,et al., 2011). Within the vicinity of the Congo River the dolomitic limestone aquifer will be readily recharged by river water. Lesser rates of recharge will be attained across the border in Angola from ephemeral streams and directly from rainfall. Similar age dolomitic limestones occur in the Copperbelt region of Zambia where, due to karstic weathering they form highly productive aquifers.

The dominant flow direction in the dolomitic limestone is towards the Congo River and opportunity for flow north or south is minimal. The dolomitic limestone aquifer is shared where it crosses into Angola to the south and to the north into Gabon but the areas involved are very small and do not qualify as a TBA that requires management and apportionment.

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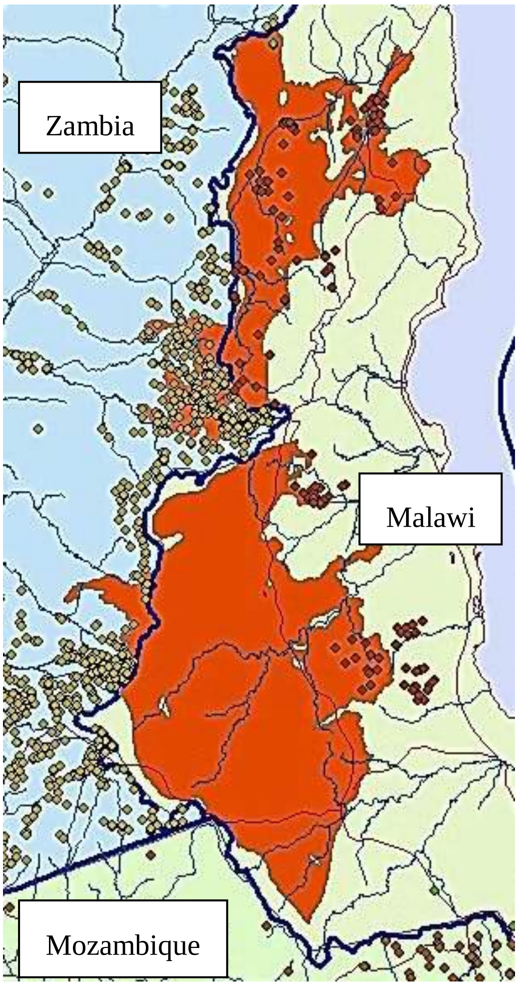

TBA 23: Sands and gravel aquifer between Malawi and Zambia

Geographically, the area includes the towns of Lilongwe, Mchinji and Mzimba, as well as parts of the Vwaza Game Reserve and the Kasungu National Park in Malawi, and the towns of Chipata, Lundazi and Mbeya, as well as part of the Lukusuzi National Park in Zambia.

The border between Eastern Province in Zambia and central Malawi is part of the Central African Plateau that ranges up to 1600 m in elevation. The gently undulating surface is a degraded plateau that supports a dendritic network of rivers and dambos and occasional swamps and isolated hills. The area forms part of the watershed between Luangua Rift Valley to the west and the Lake Malawi Rift to the east. In Malawi the Bua, Dwangwa and South Rukuru/North Rumphi rivers drain north-eastward toward Lake Malawi; in Zambia the headwaters of the Luia, Vuboe and Muangadeza drain south to the Zambezi, and the Lupandi, Lukuzye, Lukusuzi and Lundazi flow westward to the Luangua. The plateau area receives mean annual rainfall of 800 to 1000 mm and the mean monthly temperature ranges from 16 to 26°C with average annual pan evaporation recorded within the range 1600 to 1950 mm.

The weathered basement aquifer of the plateau area is relatively thin (10 to 25 m) with low permeabilities and potential yields of only 0.5 to 3 $l\ s^{-1}$. The aquifer material is variable, with the most permeable material occurring towards the base of the weathered profile although this may be semi-confined by compacted shallow clay-grade material. The aquifer supports rural domestic supplies forming an extensive source of protected safe water. Seasonal water level fluctuations range between 2 and 4 m. The groundwater quality is generally good with low mineralisation; it is usually potable although high iron concentrations make it unpalatable in places, and some localised saline groundwater also occurs.

The principle erosion surfaces are:

a) the Gondwana and post-Gondwana erosion surfaces of Jurassic-Cretaceous age found as remnants at the summits of the highlands reaching altitudes of 2000-3000 m above sea level.

b) the African surface of late Cretaceous-Miocene age lies between 900-1300 m above sea level forming an extensive plateau area that extends into Zambia.

Most of the area comprises a gently undulating plateau at an altitude of between 800 and 1600 m. The valleys are broad, the slopes less than 2° with large level areas on the interfluves. This ‘African Surface’ is an ancient late Cretaceous - early Miocene peneplain. The plateau is largely drained by dambos which are broad, periodically inundated, grass-covered swampy depressions with poorly defined channels. Some areas of highland, such as the Mchinji Hills, rise abruptly above the plateau in a ridge rising to over 1700 m – a remnant of the Post Gondwana Jurassic to mid-Cretaceous erosion surface. The surfaces tilt away from the escarpment zones as a result of uplift along the Lake Malawi rift valley. Rejuvenation has kept pace with these earth movements and rivers largely drain towards the rift valley; as a consequence the valleys become more incised towards the escarpment. Coarse-grained quartz fluvial sands, derived from the quartzites of the uplands, have been transported downslope by rivers and offer some groundwater potential with relatively high recharge potential. The main soils include latosols, found on the gentle slopes of the plateau, and hydromorphic soils with swelling clays found in dambo floors on the plateau.

The plateau area of Eastern Province and north central Malawi is underlain by weathered and fractured Basement Complex gneiss, granite, schist and quartzite and forms low-yielding aquifers with limited potential for groundwater supply in plateau area. The aquifer is more or less continuous and an important source of rural domestic water supply. Yields are greatest where the bedrock is coarsest and the weathered zone is thickest. On the basis that the estimated transmissivity of the weathered aquifer in the plateau area is 1.4 to 2.8 ls^{-1} and that the aquifer is typically 10 - 20 m thick, the average permeability is likely to be in the range 0.3 to 1 m d^{-1}. The permeability is likely to vary considerably both laterally and vertically in different layers of the aquifer. The low regional hydraulic gradients, <0.005m km^{-1}, reflect the flat surface topography.

Although there is some potential for cross-border flow to take place, the low permeability nature of the main parts of this aquifer sequence indicates that even prolonged pumping should not produce any significant effects.

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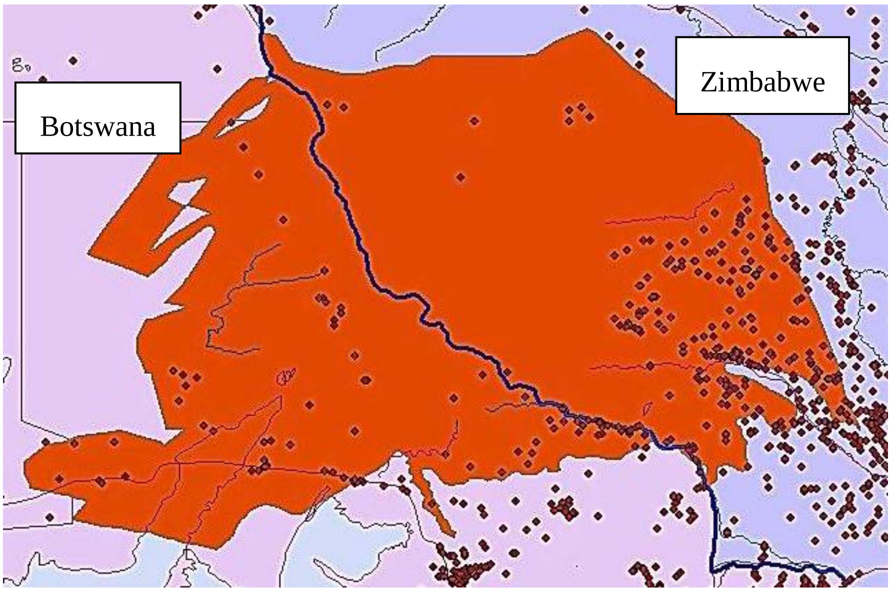

TBA 24: Eastern Kalahari/Karoo Basin between Botswana and Zimbabwe

The climate of this flat-lying continental area is arid to semi-arid with maximum temperature range from 29-37°C in summer, and 19-29°C in winter and minimum temperatures range from 16-20°C in summer and –6-14°C in winter. Rainfall is associated with tropical cyclones and movements of the ITCZ and occurs during November through to March. The main centres of population are Maitengwe, Tutume, Nata and Masunga in Botswana and Bulawayo, Tsholotsho and Nyamandlhlovu in Zimbabwe.

The TBA receives short seasonal rains and often experiences prolonged drought. It is located on the watershed between the ephemeral west flowing Nata and north flowing Gwayi river systems. In Botswana the Nata and Maitengwe drain westwards into the Makgadigkadi internal basin. In Zimbabwe the ephemeral Amanzamnyama, Tegwani and Maitengwe, headwaters of the Nata, and in the east, the Gwayi and Umgaza, drain northwards to the Zambezi. The mantle of Kalahari sediments produces an undulating to flat topography within this watershed area.

In Zimbabwe, Kalahari sediments mantle Upper Karoo Stormberg/Batoka basalts that partially confine Upper Karoo Forest Beds/Ntane Sandstones and underlying Escarpment Grits/Lekotsana Formation. The Karoo is a fracture porosity confined aquifer. The basalts comprise amygdaloidal lava flows with interbedded tuff horizons. The Forest Sandstone comprises partially cemented feldspathic whitish to yellowish fine-grained silty sand. The Molteno Beds are fine- to very fine-grained red siltstone with thin shale intercalations. Coarse-grained partly cemented sandstone constitutes the Escarpment Grits. The Forest Sandstone and the underlying Escarpment Grits form an extensive regional aquifer between the Nyamandhlovu area in western Zimbabwe and Maitengwe in North-eastern Botswana. In Botswana it is confined by Upper Karoo Stromberg/Batoka Basalts. High yields have been obtained from some boreholes. Localised aquifers are present at the contact with a pebbly arkose and the Batoka Basalt. The water levels in the Nyamandhlovu area, for the combined Forest Sandstone and Escarpment Grit Formations, are <10m in 35%, and below 20m in 40% of the boreholes. In the Forest Sandstone aquifer in the Nyamandhlovu area, high transmissivities of up to 200 m^2 d^{-1} and specific capacities of up to 40 m^3 d^{-1} m^{-1} have been recorded from boreholes 60 to 80 m deep, borehole yields of 2.8 to 14 l s^{-1} are feasible. An average coefficient of storage of 10^{-4} indicates a semi-confined aquifer. Groundwater quality is good. In the Nyamandhlovu area, the Escarpment Grits that underlie the Forest Beds are coarse-grained feldspathic sandstones which are 30 to 40m thick. This aquifer has some primary porosity and permeability but it is enhanced by secondary fracture permeability. Borehole yields range from 5.3 to 55 l s^{-1}, aquifer transmissivity range is from 3 to 30 m^2 d^{-1}, permeabilities between 3 to 30 m d^{-1} and specific capacities vary from 0.8 to 27.6 m^3 d^{-1} m^{-1}. The groundwater is also of good quality (Interconsult, 1985).

In Botswana, the Ntane Sandstone at Maitengwe is confined by the Stormberg Basalt. Recharge occurring in the Ntane sub-crop area and through thin basalt cover along major drainage courses has been estimated at 2.5 mm a^{-1} in the Maitengwe River area, decreasing to 0.5 mm a^{-1} in the thinner basalts. Elsewhere recharge is likely absent. The Maitengwe wellfield abstracts groundwater from the Ntane Sandstone within the regional Karoo Basin, which extends northeastwards into Zimbabwe. The Ntane Sandstone aquifer is in hydraulic continuity with the aquifer north of the border forming an active TBA. The high transmissivity values lie at the eastern end of the wellfield. The Upper Ntane in the east has a mean hydraulic conductivity of around 1-2 m d^{-1} due to fracture flow and weathering. However, the background primary hydraulic conductivity is lower at between 0.3 and 0.5 m d^{-1}. Groundwater flows westwards from the recharge area in the east and southeast through the Upper Ntane Sandstone, but to the west groundwater flow is mainly through the thick overlying basalts. Groundwater of the eastern zone wellfield area is characterised by low total dissolved solids, generally below 500 mg l^{-1}, of Ca-HCO_3 type. Away from the Maitengwe River and the Ntane Sandstone outcrop the water type changes from Ca-HCO_3 to Na-Ca-HCO_3 type. Groundwater quality deteriorates towards the northwest (Snowy Mountains Engineering Corporation and Ehes Consulting Engineers (Botswana), 2006).

The resources of this unit are suitable for primary water supply, small and medium piped water supplies for growth points and business centres and small and medium irrigation schemes. The Karoo aquifer is shared across the border with potential for cross border flow, degradation and even for one side of the border to pollute the other. The hydraulic continuity and potential flow across the border, coupled with likely enhanced demand in the future, makes this active TBA a priority for monitoring.

Sources of Information:

Interconsult 1985. National Master Plan for Rural Water Supply and Sanitation: Hydrogeology, Ministry of Energy and Water Resources and Development, Republic of Zimbabwe. Volume 2/2.

Snowy Mountains Engineering Corporation and Ehes Consulting Engineers (Botswana), 2006. *National Water Master Plan, Volume 4: Groundwater Resources*. Department of Water Affairs, Government of Botswana.

Annex B Assessment of TBAs

Table A1 TBA Groundwater Flow and Vulnerability

Listing of TBAs by name and code in specific countries, with outline of rates of natural and induced groundwater through flow together with potential vulnerability to pollution. These are scored on the basis of 1 point per star, of which there can be up to three stars per category.

Transboundary Aquifer	TBA Code	Member State	TB Natural Flow	TB Induced Flow	TB Vulnerability	Groundwater Risks Comments	Score
Ruvuma Delta Coastal Sedimentary Basin Aquifer	3	Tanzania	*	*	**	Natural flow towards and recharge from Ruvuma River that follows international boundary; potential pollution from upstream gold mining	4
		Mozambique	*	*	*	Natural flow towards and recharge from Ruvuma River that follows international boundary; potential pollution from upstream gold mining	3
Congo Delta Coastal Sedimentary Basin Aquifer	4	D R Congo	*	*	*	Natural flow towards and recharge from Congo River that follows international boundary	3
		Angola	**	*	*	Natural flow towards and recharge from Congo River within DR Congo	4
Congo/Zambezi Basins Benguela Ridge Watershed Aquifer	5	D R Congo	*	*	*	Natural flow northward away from watershed international boundary	3
		Angola	*	*	*	Natural flow southward away from watershed international boundary	3
Tunduru/ Maniamba Basin Karoo Sandstone Aquifer	6	Tanzania	*	*	*	Natural flow towards and recharge from Ruvuma River that follows international boundary	3
		Mozambique	*	*	*	Natural flow towards and recharge from Ruvuma River that follows international boundary	3
Middle Zambezi Rift Upper Karoo Aquifer	11	Zambia	*	*	*	Natural flow towards and recharge from Zambezi River that follows international boundary	3
		Zimbabwe	*	*	*	Natural flow towards and recharge from Zambezi River that follows international boundary	3
Shire Valley Alluvial Aquifer	12	Malawi	**	*	*	Natural flow towards and recharge from Shire River towards the international boundary	4
		Mozambique	*	*	*	Natural flow towards and recharge from Shire River towards the Zambezi	3
South West Kalahari/ Karoo Basin Aquifer	13	Botswana	**	*	*	Confined natural flow into Botswana, eastwards from the international boundary	4
		Namibia	**	**	*	Natural flow towards international boundary reversed by over pumping of Stampriet aquifer	5
		South Africa	**	*	*	Natural flow towards the Molopo/Orange River to the south	4

Zeerust – Ramotswa - Lobatse Dolomite Basin Aquifer	14	Botswana	**	*	**	Natural flow towards and recharge from the Tlokweng River that follows international boundary; potential pollution from anthropogenic sources	5
		South Africa	**	*	*	Natural flow towards and recharge from the Tlokweng River that follows international boundary	4
Tuli Karoo Basin Aquifer	15	Botswana	**	*	*	Natural flow towards and recharge from Limpopo and Shashi Rivers that follows international boundaries	4
		South Africa	**	*	*	Natural flow towards and recharge from Limpopo River that follows international boundary	4
		Zimbabwe	**	*	*	Natural flow towards and recharge from Limpopo and Shashi Rivers that follows international boundaries	4
Cuvelai Delta and Ethosha Pan Alluvial and Kalahari Sediments Aquifer	20	Angola	***	*	*	Natural flow southwards and recharge along the Cuvelai River towards the international boundary;	5
		Namibia	***	*	*	Natural flow southwards and recharge along the Cuvelai River away from the international boundary	5
Coastal Tertiary to Recent Sedimentary Basin Aquifer	21	Mozambique	*	*	*	Natural flow towards the coast	3
		South Africa	*	*	*	Natural flow towards the coast	3
Lower Congo Precambrian Dolomite Aquifer	22	D R Congo	*	*	*	Natural flow towards and recharge from The Congo River that follows international boundary	3
		Angola	**	*	*	Natural flow towards and recharge from the Congo River crossing the international boundary	4
Sands and gravels of weathered Precambrian Basement Complex Aquifer	23	Malawi	**	*	*	Natural flow to the east away from and recharge along the watershed between Malawi and Zambia; some localised TBA flow	4
		Zambia	**	*	*	Natural flow to the west away from and recharge along the watershed between Malawi and Zambia; some localised TBA flow	4
Eastern Kalahari Karoo Basin Aquifer	24	Botswana	**	**	*	Natural flow to the west away from and recharge along the watershed between Botswana and Zimbabwe; some localised TBA flow	5
		Zimbabwe	**	**	*	Natural flow to the east away from and recharge along the watershed between Botswana and Zimbabwe; some localised TBA flow	5

Table A2 TBA Groundwater Knowledge

Listing of TBAs by name and code in specific countries, with broad assessments of the availability of data on and amount of information describing groundwater quantity, quality and vulnerability in each country TBA segment. These are scored on the basis of 1 point per star, of which there can be up to three stars per category.

Transboundary Aquifer	TBA Code	Member State	GW Quantity		GW Quality		Vulnerability		Groundwater Knowledge Capability	Score
			Data	Information	Data	Information	Data	Information		
Ruvuma Delta Coastal Sedimentary Basin Aquifer	3	Tanzania	*	*	*	*	*	*	No data and little information available, only 1:1 000 000 map	6
		Mozambique	**	**	**	**	*	**	Some data and information from national report and map	10
Congo Delta Coastal Sedimentary Basin Aquifer	4	D R Congo	*	*	*	*	*	*	No data and little information	6
		Angola	*	*	*	*	*	*	No data and little information	6
Congo/Zambezi Basins Benguela Ridge Watershed Aquifer	5	D R Congo	*	*	*	*	*	*	No data and little information	6
		Angola	*	*	*	*	*	*	No data and little information	6
Tunduru/Maniamba Basin Karoo Sandstone Aquifer	6	Tanzania	**	**	*	**	*	*	Little data and some information WMP	9
		Mozambique	**	**	*	**	*	*	Little data and some information from national report	9
Middle Zambezi Rift Upper Karoo Aquifer	11	Zambia	***	***	***	***	**	**	Data and information from database, NWMP and area studies	16
		Zimbabwe	***	***	***	***	**	**	Data and information from database and NWMP	16
Shire Valley Alluvial Aquifer	12	Malawi	**	**	**	**	**	**	Data and information from database and national study	12
		Mozambique	**	**	*	**	*	*	Data and information from map and national study	9
South West Kalahari/ Karoo Basin Aquifer	13	Botswana	***	***	***	***	***	***	Data and information from database, NWMP and area studies	18
		Namibia	***	***	***	***	***	***	Data and information from database and area studies	18
		South Africa	***	***	***	***	***	***	Data and information from database and area studies	18
Zeerust – Ramotswa - Lobatse	14	Botswana	***	***	***	***	***	***	Data and information from database, NWMP and area studies	18

Dolomite Basin Aquifer		South Africa	***	***	***	***	***	***	Data and information from database, District WMP and area studies	18
Tuli Karoo Basin Aquifer	15	Botswana	***	***	***	***	***	***	Data and information from database, NWMP and area studies	18
		South Africa	***	***	***	***	***	***	Data and information from database and area studies	18
		Zimbabwe	***	***	***	***	**	**	Data and information from database, NWMP and area studies	16
Cuvelai Delta and Ethosha Pan Alluvial and Kalahari Sediments Aquifer	20	Angola	*	*	*	*	*	*	No data and limited information	6
		Namibia	***	***	***	***	**	**	Data and information from database, NWMP and area studies	16
Coastal Tertiary to Recent Sedimentary Basin Aquifer	21	Mozambique	*	**	*	**	*	*	Data and information from map and national study	8
		South Africa	***	***	**	**	**	**	Data and information from database and area studies	14
Lower Congo Precambrian Dolomite Aquifer	22	D R Congo	*	*	*	*	*	*	No data and limited information	6
		Angola	*	*	*	*	*	*	No data and limited information	6
Sands and gravels of weathered Precambrian Basement Complex Aquifer	23	Malawi	***	***	**	**	**	**	Data and information from database and national study	14
		Zambia	***	***	**	**	**	**	Data and information from database and national WMP	14
Eastern Kalahari Karoo Basin Aquifer	24	Botswana	***	***	***	***	***	***	Data and information from database, NWMP and area studies	18
		Zimbabwe	***	***	***	***	***	***	Data and information from database, NWMP and area studies	18

Table A3 Governance Capability

Listing of TBAs by name and code in specific countries, with broad assessment of the nature of standards of institutional management, knowledge and monitoring of groundwater and related systems with each country TBA segment. These are scored on the basis of 1 point per star, of which there can be up to three stars per category.

Transboundary Aquifer	TBA Code	Member State	Management		Knowledge		Monitoring		Governance Capability	Score
			Ground-water	Related	Ground-water	Others	Ground-water systems	Other Systems		
Ruvuma Delta Coastal Sedimentary Basin Aquifer	3	Tanzania	*	*	*	*	*	*	Apparent poor understanding of groundwater and related systems in the area	6
		Mozambique	*	*	**	*	*	*	Apparent poor understanding of groundwater and related systems in the area	7
Congo Delta Coastal Sedimentary Basin Aquifer	4	D R Congo	*	*	*	*	*	*	Apparent poor understanding of groundwater and related systems in the area	6
		Angola	*	*	*	*	*	*	Apparent poor understanding of groundwater and related systems in the area	6
Congo/Zambezi Basins Benguela Ridge Watershed Aquifer	5	D R Congo	*	*	*	*	*	*	Apparent poor understanding of groundwater and related systems in the area	6
		Angola	*	*	*	*	*	*	Apparent poor understanding of groundwater and related systems in the area	6
Tunduru/ Maniamba Basin Karoo Sandstone Aquifer	6	Tanzania	*	*	*	*	*	*	Apparent poor understanding of groundwater and related systems in the area	6
		Mozambique	*	*	**	*	*	*	Apparent poor understanding of groundwater and related systems in the area	7
Middle Zambezi Rift Upper Karoo Aquifer	11	Zambia	***	**	***	**	**	**	Good poor understanding of groundwater and related systems in the area with limited monitoring	14
		Zimbabwe	**	**	***	***	*	*	Moderate to good understanding of groundwater and related systems in the area	12
Shire Valley Alluvial Aquifer	12	Malawi	**	**	**	**	*	*	Moderate understanding of groundwater and related systems in the area	10
		Mozambique	*	*	**	*	*	*	Apparent poor to moderate understanding of groundwater and related systems in the area	7
South West Kalahari/ Karoo Basin Aquifer	13	Botswana	**	**	**	**	**	**	Moderate understanding of groundwater and related systems in the area, limited monitoring	12

		Namibia	***	***	***	***	**	**	Good understanding of groundwater and related systems in the area, with some monitoring	16
		South Africa	**	**	**	**	**	**	Moderate understanding of groundwater and related systems in the area, limited monitoring	12
Zeerust – Ramotswa - Lobatse Dolomite Basin Aquifer	14	Botswana	**	***	***	***	**	**	Moderate to good understanding of groundwater and related systems in the area, some monitoring	15
		South Africa	**	**	***	**	**	**	Moderate to good understanding of groundwater and related systems in the area, limited monitoring	13
Tuli Karoo Basin Aquifer	15	Botswana	***	***	***	***	**	**	Good understanding of groundwater and related systems in the area, some monitoring	16
		South Africa	***	***	***	***	***	***	Good understanding of groundwater and related systems in the area, good monitoring	18
		Zimbabwe	**	**	**	**	*	*	Moderate understanding of groundwater and related systems in the area	10
Cuvelai Delta and Ethosha Pan Alluvial and Kalahari Sediments Aquifer	20	Angola	*	**	*	**	*	*	Poor understanding of groundwater and related systems in the area	8
		Namibia	***	***	***	***	**	**	Good understanding of groundwater and related systems in the area, limited monitoring	16
Coastal Tertiary to Recent Sedimentary Basin Aquifer	21	Mozambique	*	*	**	*	*	*	Apparent poor understanding of groundwater and related systems in the area	7
		South Africa	**	**	**	*	*	*	Moderate understanding of groundwater and related systems in the area	9
Lower Congo Precambrian Dolomite Aquifer	22	D R Congo	*	*	*	*	*	*	Apparent poor understanding of groundwater and related systems in the area	6
		Angola	*	*	*	*	*	*	Apparent poor understanding of groundwater and related systems in the area	6
Sands and gravels of weathered Precambrian Basement Complex Aquifer	23	Malawi	**	**	**	**	*	*	Moderate understanding of groundwater and related systems in the area	10
		Zambia	**	**	**	**	**	*	Moderate understanding of groundwater and related systems in the area, limited monitoring	11
Eastern Kalahari Karoo Basin Aquifer	24	Botswana	***	**	***	**	**	*	Good to moderate understanding of groundwater and related systems in the area, some monitoring	13
		Zimbabwe	***	**	***	**	*	*	Good to moderate understanding of groundwater and related systems in the area	12

Table A4 Socio-economic / Water Demand Capability

Listing of TBAs by name and code in specific countries, with broad assessment of water demand based upon demography in terms of population density and general access to water sources; broad land use in terms of irrigation and cattle rearing; and industrial activity in terms of manufacturing, mining and service activities. These are scored on the basis of 1 point per star, of which there can be up to three stars per category.

Transboundary Aquifer	TBA Code	Member State	Demography		Land use		Industry		Socio-economic Capability	Score
			Population	Water sources	Irrigation	Cattle	Manufac-turing	Mining/ services		
Ruvuma Delta Coastal Sedimentary Basin Aquifer	3	Tanzania	**	**	**	**	*	**	Moderate population; some crop irrigation and cattle; pollution from upstream gold mining	11
		Mozambique	**	**	**	**	*	**	Moderate population; some crop irrigation and cattle; potential coal mining	11
Congo Delta Coastal Sedimentary Basin Aquifer	4	D R Congo	**	*	**	*	*	**	Moderate population; some crop irrigation; potential oil abstraction	9
		Angola	**	*	**	**	*	**	Moderate population; some crop irrigation and cattle rearing; potential oil abstraction	10
Congo/Zambezi Basins Benguela Ridge Watershed Aquifer	5	D R Congo	*	*	*	***	*	**	Low population; much cattle rearing; some diamond mining	9
		Angola	*	*	*	***	*	**	Low population; much cattle rearing; some diamond mining	9
Tunduru/ Maniamba Basin Karoo Sandstone Aquifer	6	Tanzania	*	*	**	**	*	**	Low population; some irrigation and cattle rearing; potential coal mining	9
		Mozambique	*	*	**	**	*	*	Low population; some irrigation and cattle rearing; potential coal mining	8
Middle Zambezi Rift Upper Karoo Aquifer	11	Zambia	**	**	*	**	*	*	Moderate population; some cattle rearing; some tourism	9
		Zimbabwe	*	*	*	*	*	*	Low population in game/safari park area; much tourism	6
Shire Valley Alluvial Aquifer	12	Malawi	**	**	***	*	*	*	Moderate population; much irrigation of sugar and maize	10
		Mozambique	**	**	***	*	*	*	Moderate population; much irrigation of sugar and maize	10
South West Kalahari/ Karoo Basin Aquifer	13	Botswana	*	*	*	***	*	*	Low population; much cattle rearing; some tourism	8
		Namibia	**	***	**	***	*	*	Moderate population ; large number of boreholes; some crop irrigation; much cattle rearing	12
		South Africa	*	*	*	*	*	*	Low population in national park area; some tourism	6

Zeerust – Ramotswa - Lobatse Dolomite Basin Aquifer	14	Botswana	***	**	**	***	**	*	High population; large number of boreholes; moderate crop irrigation; much cattle rearing; some manufacturing	13
		South Africa	*	**	*	***	*	*	Low population; much cattle rearing	9
Tuli Karoo Basin Aquifer	15	Botswana	*	**	**	***	*	*	Low population; some crop irrigation; much cattle rearing	10
		South Africa	**	***	***	***	*	**	Moderate population; many boreholes; much crop irrigation and cattle rearing; mining of diamonds	14
		Zimbabwe	*	**	***	***	*	**	Low population; much crop irrigation and cattle rearing; potential coal mining	12
Cuvelai Delta and Ethosha Pan Alluvial and Kalahari Sediments Aquifer	20	Angola	*	*	*	***	*	*	Low population; much cattle rearing	8
		Namibia	***	***	**	**	*	*	High population with many wells and boreholes; some irrigation; much cattle rearing; much tourism	12
Coastal Tertiary to Recent Sedimentary Basin Aquifer	21	Mozambique	*	*	**	**	*	*	Low population; some crop irrigation and cattle rearing	8
		South Africa	*	*	**	**	*	**	Low population; some crop irrigation and cattle rearing; moderate tourism	9
Lower Congo Precambrian Dolomite Aquifer	22	D R Congo	*	*	**	*	*	*	Low population; some crop irrigation	7
		Angola	*	*	**	*	*	*	Low population; some crop irrigation	7
Sands and gravels of weathered Precambrian Basement Complex Aquifer	23	Malawi	**	**	**	**	*	*	Low population; some crop irrigation and cattle rearing	10
		Zambia	**	**	**	**	*	*	Low population; some crop irrigation and cattle rearing	10
Eastern Kalahari Karoo Basin Aquifer	24	Botswana	**	**	*	***	*	*	Moderate population; much cattle rearing	10
		Zimbabwe	**	**	**	***	**	*	Moderate population; some crop irrigation and cattle rearing; moderate manufacturing	12

Table A5 Environmental Capability

Listing of TBAs by name and code in specific countries, with broad assessment of the impact of environmental factors upon groundwater resources in each TBA country segment in terms of Biota Conservation within National Parks and Game Reserves; The impact of groundwater abstraction upon river systems during the wet and dry seasons; and the impact of floods and prolonged droughts upon groundwater systems as they impact upon cycles of recharge. These are scored on the basis of 1 point per star, of which there can be up to three stars per category.

Transboundary Aquifer	TBA Code	Member States	Transboundary Hydrology		Water Sources Sustainability		Climate Impact		Environment Capability	Score
			SW-GW inter-action	TB River	Ground water	GDEs	Droughts	Floods		
Ruvuma Delta Coastal Sedimentary Basin Aquifer	3	Tanzania	**	***	**	***	**	***	Good connectivity between perennial TB Ruvuma River and alluvium, GW abstraction greater during drought, floods main source of recharge, GDEs little affected	15
		Mozambique	**	***	**	***	**	***	Good connectivity between perennial TB Ruvuma River and alluvium, GW abstraction greater during drought, floods main source of recharge, GDEs little affected	15
Congo Delta Coastal Sedimentary Basin Aquifer	4	D R Congo	**	***	**	***	*	**	Good connectivity between perennial TB Congo River and alluvium, GW abstraction greater during drought, floods main source of recharge, GDEs little affected	13
		Angola	**	***	**	***	*	**	Good connectivity between perennial TB Congo River and alluvium, GW abstraction greater during drought, floods main source of recharge, GDEs little affected	13
Congo/Zambezi Basins Benguela Ridge Watershed Aquifer	5	D R Congo	*	*	*	**	**	**	Prolonged drought increases abstraction, floods a source of recharge, GDEs moderately affected	9
		Angola	*	*	*	**	**	**	Prolonged drought increases abstraction, floods a source of recharge, GDEs moderately affected	9
Tunduru/ Maniamba Basin Karoo Sandstone Aquifer	6	Tanzania	***	**	**	**	**	**	Limited connectivity between perennial TB Ruvuma River and alluvium, prolonged drought increases abstraction and, ephemeral rivers dry up, floods a source of recharge, GDEs moderately affected	13
		Mozambique	***	**	**	**	**	**	Limited connectivity between perennial TB Ruvuma River and alluvium, prolonged drought increases abstraction and, ephemeral rivers dry up, floods a source of recharge, GDEs moderately affected	13
Middle Zambezi Rift Upper Karoo Aquifer	11	Zambia	*	**	*	**	***	**	Limited connectivity between perennial TB Zambezi River and Karoo sandstones, prolonged drought increases abstraction and, ephemeral rivers dry up, floods a source of recharge, GDEs moderately affected	11
		Zimbabwe	*	**	*	**	***	**	Limited connectivity between perennial TB Zambezi River and Karoo sandstones, prolonged drought increases abstraction and, ephemeral rivers dry up, floods a source of recharge, GDEs moderately affected	11

Shire Valley Alluvial Aquifer	12	Malawi	***	**	**	**	**	***	Good connectivity between perennial TB Shire River and alluvium, prolonged drought negative impact upon ecology, increased abstraction for irrigation; ephemeral rivers dry up; floods a source of recharge	14
		Mozambique	***	**	**	**	**	***	Good connectivity between perennial TB Shire River and alluvium, prolonged drought negative impact upon ecology, increased abstraction for irrigation; ephemeral rivers dry up; floods a source of recharge	14
South West Kalahari/ Karoo Basin Aquifer	13	Botswana	*	*	*	*	***	**	Perpetual drought, no GDEs; ephemeral rivers dry up; occasional floods only source of recharge	9
		Namibia	*	*	**	*	***	**	Perpetual drought, no GDEs; ephemeral rivers dry up; occasional floods only source of recharge	10
		South Africa	*	*	*	*	***	**	Perpetual drought, no GDEs; ephemeral rivers dry up; occasional floods only source of recharge	9
Zeerust – Ramotswa - Lobatse Dolomite Basin Aquifer	14	Botswana	**	*	**	**	*	*	Some recharge of karst aquifer from local surface water; ephemeral rivers dry up; floods main source of recharge; GDEs few and little affected	9
		South Africa	**	*	**	**	*	*	Some recharge of karst aquifer from local surface water; ephemeral rivers dry up; floods main source of recharge; GDEs few and little affected	9
Tuli Karoo Basin Aquifer	15	Botswana	**	**	**	**	**	**	Good connectivity between ephemeral TB Shashe/Limpopo Rivers and tributaries and alluvium, prolonged drought negative impact upon ecology, increased abstraction for irrigation; ephemeral rivers dry up; floods a main source of recharge	12
		South Africa	**	**	**	**	**	**	Good connectivity between ephemeral TB Shashe/Limpopo Rivers and tributaries and alluvium, prolonged drought negative impact upon ecology, increased abstraction for irrigation; ephemeral rivers dry up; floods a main source of recharge	12
		Zimbabwe	**	**	**	**	**	**	Good connectivity between ephemeral TB Shashe/Limpopo Rivers and tributaries and alluvium, prolonged drought negative impact upon ecology, increased abstraction for irrigation; ephemeral rivers dry up; floods a main source of recharge	12
Cuvelai Delta and Ethosha Pan Alluvial and Kalahari Sediments Aquifer	20	Angola	**	**	*	**	***	***	Good connectivity between ephemeral TB Cuvelai River and tributaries and delta alluvium, prolonged drought negative impact upon GDEs, ephemeral rivers dry up; floods main source of recharge	13
		Namibia	**	**	*	**	***	***	Good connectivity between ephemeral TB Cuvelai River and tributaries and delta alluvium, prolonged drought negative impact upon GDEs, ephemeral rivers dry up; floods main source of recharge	13
Coastal Tertiary to Recent Sedimentary Basin Aquifer	21	Mozambique	**	*	*	**	**	**	Connectivity between local streams/rivers and aquifer, thatdrain towards coast; prolonged drought negative impact on GDEs, increased abstraction for irrigation; ephemeral rivers dry up; floods main source of recharge	10
		South Africa	**	*	*	**	**	**	Connectivity between local streams/rivers and aquifer, thatdrain towards coast; prolonged drought negative impact on GDEs, increased abstraction for irrigation; ephemeral rivers dry up; floods main source of recharge	10
Lower Congo	22	D R Congo	**	***	**	***	*	*	Good connectivity between perennial TB Congo River and karst, GW	12

Precambrian Dolomite Aquifer									abstraction greater during drought, floods main source of recharge, GDEs little affected	
		Angola	**	***	**	***	*	*	Good connectivity between perennial TB Congo River and karst, GW abstraction greater during drought, floods main source of recharge, GDEs little affected	12
Sands and gravels of weathered Precambrian Basement Complex Aquifer	23	Malawi	**	*	**	**	**	**	Some SW/GW interaction along dambos; prolonged drought negative impact upon ecology, increased abstraction for irrigation; ephemeral rivers dry up; GDEs moderately affected; floods main source of recharge	11
		Zambia	**	*	**	**	**	**	Some SW/GW interaction along dambos; prolonged drought negative impact upon ecology, increased abstraction for irrigation; ephemeral rivers dry up; GDEs moderately affected; floods main source of recharge	11
Eastern Kalahari Karoo Basin Aquifer	24	Botswana	*	*	**	*	**	**	Perpetual drought, GDEs limited to ephemeral rivers and pans; occasional floods only source of recharge	9
		Zimbabwe	*	*	**	*	**	**	Perpetual drought, GDEs limited to ephemeral rivers and pans; occasional floods only source of recharge	9

Annex C Terms of Reference for Regional Monitoring Network

The **key objectives** of the Regional Groundwater Monitoring network are:

1. Calculation of recharge and aquifer reaction to rainfall events.
2. Identification of trends in groundwater quantity, quality, demand etc.
3. Development of baseline information.
4. Spatial distribution of groundwater parameters.
5. Development of early warning mechanisms with respect to drought, climate change, over abstraction etc.
6. Variation of specific quality parameters relating to anthropogenic impacts.
7. Inter-state ownership and sharing of data.

The **Regional Monitoring Network** shall be designed around three discrete scalar components comprising:

- Local maintenance – periodic validation of measurements by manual observation, maintenance, cleaning and security of observation site.
- Regional gathering of data by telemetry to the SADC Groundwater Management Institute (GMI) and web-based dissemination of value added data to Member States.
- Bilateral management of shared inter-state groundwater units with guidance from GMI and unilateral management of groundwater units within a single member state with guidance from GMI.

The system must be operationally effective, long-lasting and able to provide reliable and consistent data into the future. A groundwater monitoring system should thus have the following characteristics:

- Comprehensive – needs to spatially sample the key aquifer zones with a density of sampling points that inform the management of each aquifer unit by determining both baseline (‘natural’) variations as well as anthropogenic impacts (e.g. abstraction, quality degradation, etc.).
- Robust – needs to comprise robust and reliable monitoring equipment capable of working without operator intervention in remote areas for long periods of time. Should be telemetry-based for interrogation and real time acquisition of data.
- Operator ‘Friendly’ – needs to be easy to maintain and operate, with standardised spare parts and easy maintenance. Also should be easy to download in the event of telemetry failure.
- Integrated – should be fully integrated into any existing national groundwater monitoring system network. It also needs to be integrated into the proposed regional network, and if feasible into an existing data telemetry system such as HYCOS to minimise development requirements.
- Cost Effective – since the requirement for groundwater monitoring is not well recognised by financial planners it is essential that the new network should be as cost effective as possible (i.e. minimum cost without compromising reliability, data quality and operational aspects).

A key to the successful implementation of the Regional Groundwater Monitoring system is encapsulated in the following questions:

- What particular parameters should be monitored and why?
- What data should be collected?
- How should the data be collected?
- Where should the data be collected and why?
- How should data be archived and made both nationally and regionally available?
- How should the data be evaluated and utilised?

The **Project Tasks** are as follows:

1. Review and design the project goal, i.e. define the size and coverage for the network and what the network is to measure as the initial 'Phase 1' roll-out following the pilot stage.
2. Review the Pilot Stage outcomes and lessons learnt.
3. In collaboration with appropriately empowered personnel from each member state, identify observation sites with at least one site located in each member state, while focussing on active TBAs and major aquifer units.
4. Install and test equipment and provide for local maintenance.
5. Reporting:
    a. Tasks 1 and 2 – Inception Report
    b. Tasks 3 and 4 – Final Report
    c. Workshop for SADC member States and GMI to demonstrate the web site and to discuss data evaluation procedures, sharing of data and experience with drought indicators.