The SADC Hydrogeological Map & Atlas:
Towards an improved understanding of groundwater regimes in Southern Africa

K. Pietersen[1], N. Kellgren[2], O. Katai[3] and M. Roos[4]

(1) Water Geosciences Consulting, Faerie Glen, South Africa, email: kpietersen@wgc.co.za
(2) Sweco International, Gothenburg, Sweden, email: nils.kellgren@sweco.se
(3) Water Division, SADC Secretariat, Gaborone, Botswana, email: okatai@sadc.int
(4) Council for Geoscience, Pretoria, South Africa, email: mroos@geoscience.org.za

ABSTRACT

The hydrogeology map of the Southern African Development Community (SADC) region is a comprehensive groundwater information system visualized by means of an interactive web- based regional hydrogeological map and atlas. The SADC hydrogeology map provides information on the extent and geometry of regional aquifer systems, and primarily serves as a base map for hydrogeologists and water resource planners. Many aquifer systems in SADC, including transboundary aquifers, have low transmissivities and are relatively low yielding. What constitutes an (transboundary) aquifer system and policy responses thus require further refinement. The SADC Hydrogeological Mapping Project has delineated 14 transboundary aquifer systems on the basis of inferred continuous and transmissive aquifers, SADC hydrolithological boundaries, and sub-basin river boundaries. Although the natural extent and hydrogeological significance of these systems will need further research and detailed field investigations, the mapping proved particularly useful for identifying data rich and data scarce areas in the SADC Region.

Key words: SADC, Southern Africa, Regional, Hydrogeological Map, Groundwater, Aquifer Systems

1. INTRODUCTION

1.1. The SADC Hydrogeological Map and Atlas

The Southern African Development Community hydrogeological map and atlas (SADC HGM) provides an overview of the groundwater resources of the SADC region by means of an interactive web-based regional map. The map is a first, but necessary, step to support groundwater resource planning at multi-national level as well as at regional trans-national scales. The preparation of a regional hydrogeological map was identified as a priority by SADC and was included as a component of the Regional Groundwater Management Programme in the Regional Strategic Action Plan for Integrated Water Resources Development and Management. The SADC hydrogeology map is a general hydrogeological map and is a valuable tool to advocate the importance of groundwater resources in the political and social development process (Struckmeier and Margat, 1995).

1.2. The SADC HGM Project

The compilation of the SADC hydrogeological map took place during the period June 2009 to March 2010 through a consultancy awarded to a consortium consisting of Sweco International (Sweden) as lead firm, Council for Geoscience (South Africa), Water Geosciences Consulting (South Africa) and Water Resources Consultants (Botswana). The project implementation agency (PIA) was the Department of Geological Survey (DGS), Botswana. The overall objective of the project was to improve the understanding of groundwater occurrence within the SADC region and to promote cooperation and better understanding of water resource planning and management.

2. COMPILATION OF THE SADC HYDROGEOLOGICAL MAP

2.1. Scale and themes

The interactive web-based hydrogeological map and atlas was produced at a scale of 1:2.500 000 and displays layers of lithology and geological structures, aquifer types and associated groundwater productivity, major transboundary aquifers, rainfall, recharge, groundwater quality, surface waters including perennial and non-perennial rivers, major river basins, and other topographical map features such as elevation, major towns and roads and international boundaries.

2.2. Groundwater information system

A major outcome was the completion of the SADC Hydrogeologic Borehole Database. The database was designed to support the hydrogeological mapping process and contains the data that was submitted by Member States. The database holds approximately 335 000 records.

2.3. Hydro-lithology base map

The hydro-lithology base map was compiled from the SADC geology map prepared by the South African Council for Geoscience (Hartzer, 2009). This was done through linking the stratigraphy to rock types. The geology map has been simplified to 12 hydro - lithological classes.

The SADC geology map contains 730 different lithological units. For the SADC hydrogeological map the units were grouped together to form different lithological units based on hydraulic characteristics. For example, siliclastic sedimentary rocks, such as sandstone and gravel, were grouped in a different unit as chemical sedimentary rocks (e.g. limestone). In the same manner, a distinction was made between sands and clays and very coarse sedimentary rocks such as tillites and diamictites and volcanic rocks were separated from intrusive rocks. Furthermore, a chronologic distinction was made to separate older metamorphosed units from younger and less deformed and metamorphosed units. The result of this process was a simplified geological base map comprising of 12 hydro-lithological units (Fig 2).

2.4. Aquifer types

Main rock types have been grouped accordingly into permeable and low permeability formations (Fig 3) based on the lithology base map and expert judgement. Permeable formations have been further grouped into *unconsolidated intergranular aquifers* (gravel, alluvium, sand, etc.), *fissured aquifers* (sandstone, basalt, etc), *karst aquifers* (limestone, dolomite, gypsum, etc) and *layered aquifers* (e.g. Kalahari formations).

2.5. Aquifer productivity

The aquifer types were grouped into eight classes according to different aquifer productivity (Table 1) following the IAH standard legend for groundwater and rocks that combines information on aquifer productivity and the type of groundwater flow regime (intergranular or fissured; Struckmeier and Margat, 1995).

The aquifer productivity of permeable areas ranges from high to moderate productive was based on local expert knowledge, and information from national representatives of member states was used to verify and update the information. The low permeability formations were grouped into locally moderate productive and low productive. A scheme was adopted to facilitate the assignment of aquifer productivity to the different aquifer types (Fig 1), taking into account flow properties (transmissivity) and sustainability of the resource (local recharge). The general productivity is mainly dependent on a combination of recharge and aquifer transmissivity.

Table 1: Hydrogeology and aquifer productivity

Productivity Class / **Aquifer Type**	1. High productivity	2. Moderate productivity	3. General low productivity but locally moderate productivity	4. Generally low productivity
A. Unconsolidated Intergranular aquifers	A1	A2	X	X
A. Fissured aquifers	B1	B2	X	X
B. Karst aquifers	C1	C2	X	X
C. Low permeability formations	X	X	D1	D2
		Denotes an extensive aquifer overlain by cover		

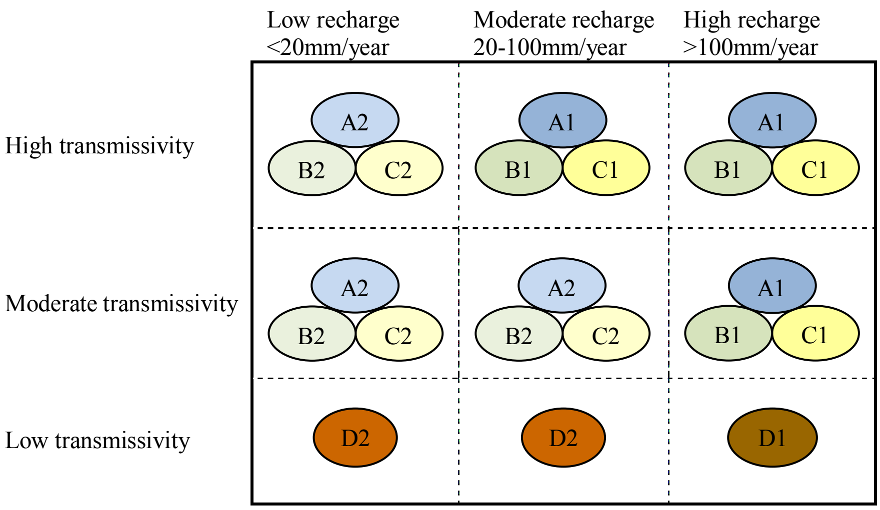

Figure 1: Scheme adopted for assigning aquifer long term productivity to hydro-lithological domains on the SADC hydrogeological map. (refer to Table 1).

The long-term aquifer productivity of hydro-lithological domains is primarily controlled by both lithology (i.e. conductive material properties) and water supply (i.e. groundwater recharge). Hydro-lithological domains can be classified by these two basic parameters. For example, moderate recharge conditions combined with a highly transmissive aquifer will be ranked as 1 (high productivity). Domains in the upper right corner of the matrix are more productive than those of the lower left corner. Hydro-lithologic domains to the left require boreholes over a larger area than the domains to the right.

2.6. Transboundary Aquifer Systems

Groundwater systems, including Transboundary Aquifer Systems, cannot be delineated by lithological domains only. Detailed information on e.g. topography, soils, depths of over burdens groundwater flow, extent of fracture systems, identification of recharge- and discharge areas is also needed, but rarely available. As a consequence, transboundary aquifers map layers on global and regional scales are commonly broadly marked as conceptual circles and ellipses.

Many aquifer systems in SADC are low yielding. Groundwater movement is controlled by the hydraulic properties of the aquifer. In the case of low-yielding aquifers, where the transmissivities are low, the concept of a transboundary aquifer requires re-consideration. Groundwater movement is either slow or occurs within local and disconnected packets (Cobbing, et al. 2008). What constitutes a transboundary aquifer or aquifer system requires further refinement in this case as the cross border impact of abstraction-, recharge-, pollution- and remediation of groundwater is difficult to assess. Following the Atlas of Transboundary Aquifers (Puri and Aureli, 2009) as a point of departure, transboundary Aquifers were delineated (Fig 3 and Table 2) using the following criteria: 1) Shared by more than one SADC country, 2) Continuous and permeable aquifers, 3) Sub-basin river boundaries, and 4) SADC HGM hydro-lithological boundaries.

Table 2: SADC HGM Transboundary Aquifers

Name	Code	States
Karoo Sandstone Aquifer	6	Tanzania, Mozambique
Tuli Karoo Sub-basin	15	Botswana, South Africa, Zimbabwe
Ramotswa Dolomite Basin	14	Botswana, South Africa
Cuvelai and Etosha Basin	20	Angola, Namibia
Coastal Sedimentary Basin 1	3	Tanzania, Mozambique
Shire Valley Aquifer	12	Malawi, Mozambique
Congo Intra-cratonic Basin	5	D R Congo , Angola
Coastal Sedimentary Basin 2	4	D R Congo , Angola
Coastal Sedimentary Basin 6	21	Mozambique, South Africa
Medium Zambezi Aquifer	11	Zambia and Zimbabwe
Dolomitic	22	D R Congo , Angola
Sands and gravel aquifer	23	Malawi, Zambia
Kalahari/Karoo Basin	13	Botswana, Namibia, South Africa
Eastern Kalahari/Karoo basin	24	Botswana and Zimbabwe

3. DISCUSSION AND CONCLUSION

The project has produced a comprehensive, interactive web-based hydrogeological map and atlas of the SADC region as well as enhanced institutional capacity in SADC member states for producing and using hydrogeological maps in water resources planning, development and management. The use and application of the SADC HGM will be crucial for the sustainability of the regional hydrogeological mapping programme. The map should be used to: Guide policy making and influence political decision-making on natural resource issues, support in transboundary groundwater planning and management, create awareness related to groundwater issues, assist in regional development planning, and to serve as a platform to update national maps.

The SADC hydrogeological map and atlas will require regular updating when relevant new information is available. Key to updating the map is the improvement of groundwater data sets and information systems in the various countries. There needs to be a concerted effort to address shortcomings. A future update of the map requires a bottom-up approach to work with countries to ensure representative datasets are obtained from the various geological domains. The ideal approach would be to move from large-scale hydrogeological mapping programmes to medium-scale and finally smaller-scale programmes.

The natural extent of SADC transboundary aquifer systems as well as their hydrogeological, social and economical significance needs to be verified by thorough research and extensive detailed field investigations.

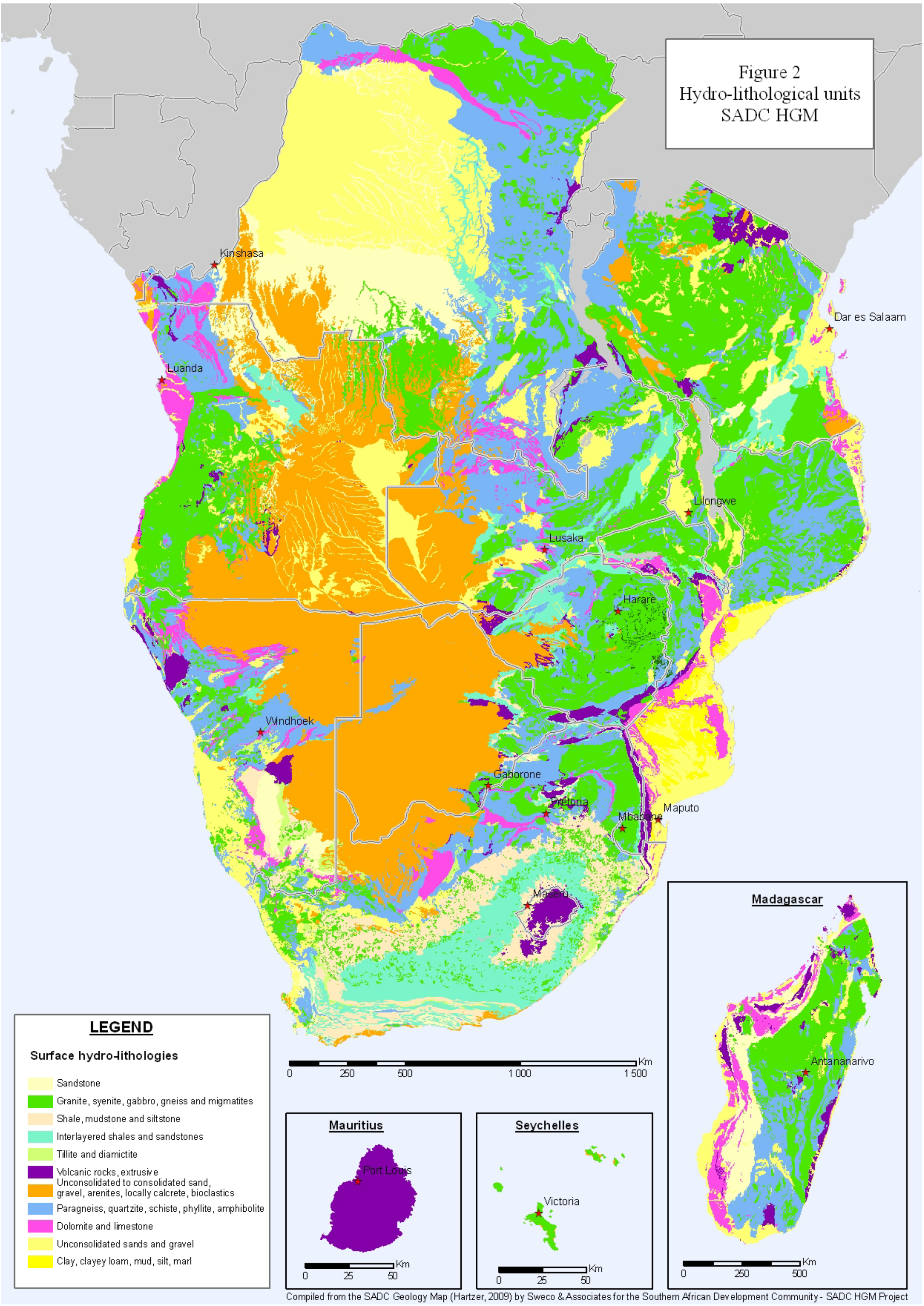
Figure 2
Hydro-lithological units
SADC HGM
Kinshasa
Dar es Salaam
Luanda
Lilongwe
Lusaka
Harare
Windhoek
Gaborone
Pretoria
Mbabane
Maputo
Maseru
LEGEND
Surface hydro-lithologies
Sandstone
Granite, syenite, gabbro, gneiss and migmatites
Shale, mudstone and siltstone
Interlayered shales and sandstones
Tillite and diamictite
Volcanic rocks, extrusive
Unconsolidated to consolidated sand, gravel, arenites, locally calcrete, bioclastics
Paragneiss, quartzite, schiste, phyllite, amphibolite
Dolomite and limestone
Unconsolidated sands and gravel
Clay, clayey loam, mud, silt, marl
Km
0 250 500 1 000 1 500
Mauritius
Port Louis
Km
0 25 50
Seychelles
Victoria
Km
0 25 50
Madagascar
Antananarivo
Km
0 250 500
Compiled from the SADC Geology Map (Hartzer, 2009) by Sweco & Associates for the Southern African Development Community - SADC HGM Project

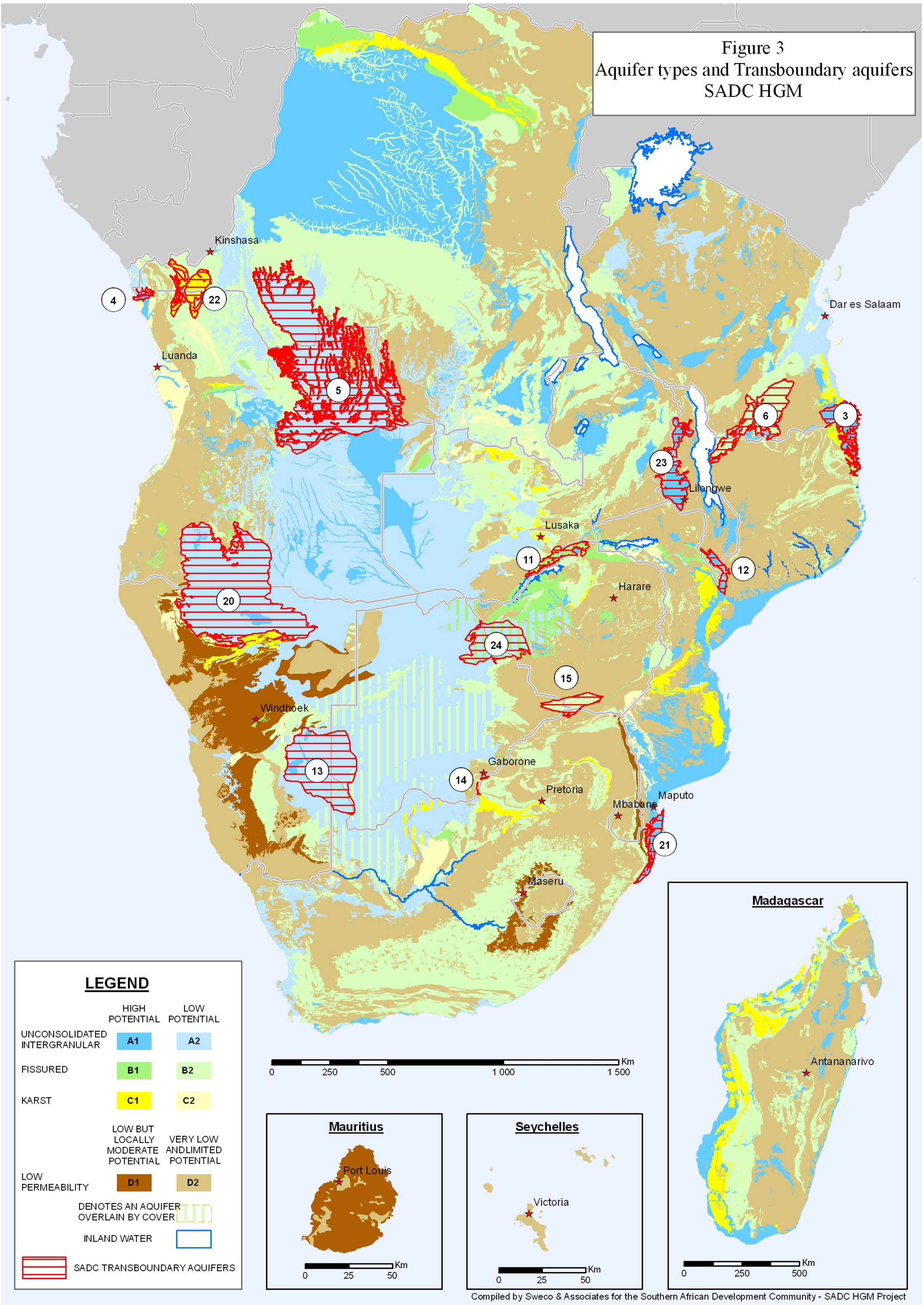
Figure 3
Aquifer types and Transboundary aquifers
SADC HGM
Kinshasa
Luanda
Dar es Salaam
Lilongwe
Lusaka
Harare
Windhoek
Gaborone
Pretoria
Mbabane
Maputo
Maseru
4
22
5
6
3
23
11
12
20
24
15
13
14
21
LEGEND
HIGH POTENTIAL
LOW POTENTIAL
UNCONSOLIDATED INTERGRANULAR
A1
A2
FISSURED
B1
B2
KARST
C1
C2
LOW BUT LOCALLY MODERATE POTENTIAL
VERY LOW ANDLIMITED POTENTIAL
LOW PERMEABILITY
D1
D2
DENOTES AN AQUIFER OVERLAIN BY COVER
INLAND WATER
SADC TRANSBOUNDARY AQUIFERS
0 250 500 1 000 1 500 Km
Mauritius
Port Louis
0 25 50 Km
Seychelles
Victoria
0 25 50 Km
Madagascar
Antananarivo
0 250 500 Km
Compiled by Sweco & Associates for the Southern African Development Community - SADC HGM Project

Acknowledgements

The Southern African Development Community (SADC) hydrogeological map has been planned for since the early nineties. Numerous persons have been involved in the conceptualisation of the SADC hydrogeological map and their contributions to the project are gratefully acknowledged. We express our gratitude to the Water Division of the SADC Secretariat, the Project Steering Committee and other contact persons of the Member States for their input during the course of the consultancy. In particular, the project team acknowledges their time and effort in making data and information available for use in the compilation in the SADC hydrogeological map, and their active participation in workshops to edit and review the map. The staff and the Department of Geological Survey in Botswana are greatly acknowledged for hosting the project and the project team members. We are grateful to the European Union, GTZ and UK Aid for their financial support to the project.

REFERENCES

Struckmeier, W. F., and Margat, J., (1995) *Hydrogeological Maps A Guide and Standard Legend*. Vol. 17. Hannover: Heise: International Association of Hydrogeologists, 1995.

Hartzer, FJ. (Compiler).(2009) *Geological map of the Southern African Development Community (SADC)* Countries, 1 : 2 500 000 scale. Published by the Council for Geoscience, South Africa, 2009.

Cobbing, J.E., Hobbs P.J., Meyer, R., and Davies J., (2008) A critical overview of transboundary aquifers shared by South Africa. *Hydrogeology Journal* 16, 1207-1214.

Puri, S., and Aureli, A. (Editors), *Atlas of Transboundary Aquifers*, ISARM Programme, UNESCO – International Hydrological Programme, Division of Water Sciences, 2009