2ND SADC GROUNDWATER CONFERENCE

Theme: Groundwater’s Contribution to the achievement of Sustainable Development Goals in the SADC Region.

VOLUME OF ABSTRACTS

Southern Sun Hotel, OR International Airport, Johannesburg, South Africa

4th - 6th September, 2019
2ND SADC GROUNDWATER CONFERENCE

Theme: Groundwater’s Contribution to the achievement of Sustainable Development Goals in the SADC Region.

CONFERENCE TECHNICAL COMMITTEE

Chair: James Sauramba (SADC-GMI)
Brighton Munyai (SADC-GMI)
Modreck Gomo (UFS-IGS)
Tales Carvalho-Resende (UNESCO-IHP)
Karen Villholth (IWMI)
Callist Tindimugaya (IAH)
Ramon Brentführer (BGR)
Ralf Klingbeil (BGR)
Piet Kenabatho (UB)
Neno Kukuric (IGRAC)
Geert-Jan (IGRAC)
Arnaud Sterckx (IGRAC)
Davies Saruchera (IUCN)
SYNTHESIS OF THE CONFERENCE

The 2nd SADC groundwater conference was held in Johannesburg, South Africa, from the 4th to 6th of September, 2019. The conference theme was ‘Groundwater’s contribution to the achievement of Sustainable development goals in the SADC Region’. It had three sub-themes, (1) contribution of research towards the understanding, the status, trends and risks to groundwater, (2) measuring progress towards attaining SDG targets, collection and management within the SADC member states, (3) Policy, legal and institutional considerations at the national and trans-boundary level. Seven keynotes were given and three panel discussions took place.

In sub-theme one, 36 oral presentation were planned and 29 took place. Sub-theme two and three, 10 and 11 presentation were planned respectively but only 9 and 10 happened, respectively. Only one poster was missing from the planned 10. From the 136 who registered, only 125 attended giving the conference a 90% attendance. The majority were from South Africa, given that it was the host of the conference. Out of 16 SADC states, three were not present at the conference, namely, Tanzania, DRC and Madagascar. The largest representation at the conference outside South Africa but within the SADC region was Botswana. Only 12 young scientists (5 females, 7 males) were at the conference. There is urgent need to keep encouraging the youth to participate at this forum.

The full outline of the conference programme is given in the appendix section. The official opening ceremony had three speaker, Mr. James Sauramba, the Executive Director, M’s Lindiwe Lusenga, Deputy Director General, Ministry of Water and Sanitation, South Africa and Eng. Remmy Makumbe from Global Water Partnership, South Africa. The key messages from the presentations in relation to the theme were the following:

- Given the importance of groundwater (G/W) in coping with water scarcity and challenges brought about by climate change, there is a need to develop regional G/W assessment and Exploration strategies.

- We should not leave anyone behind as we work towards achieving SDGs. We should endeavour to Couple citizen science with the research discourse.

- The 4th Industrial Revolution is here. Let us therefore apply innovation, research and development and evidence-based approaches. Use the technology and novel techniques in this age.

- Although none of the SDGs mention groundwater explicitly, 53 of the 169 targets have clear links to groundwater, particularly those pertaining to SDG 6, 12, 13 signifying the importance of groundwater for achieving these goals. This is therefore an opportunity for impact other interrelated sectors.

Several keynote speakers and presenters, as detailed in the programme gave presentation on research outputs. Key messages by theme are as follows:

1. **Sub Theme 1: Contribution of research towards understanding, the status, trends and risks to groundwater resources**

   - Efficient water use, adopting a broader water mix (e.g. desalination, deep borehole drilling) and a responsive governance system are effective pathways to manage a water crisis (based on experience from Cape town, Day Zero Case).

   - Management of groundwater resources at catchment level should include urban water management.
- Develop integrated modelling approaches (e.g. IHM) that support conjunctive use of water resources.
- Use of big data analytics show that the increased future dependence on groundwater irrigation will lead to an acute risk of Arsenic contaminated food crops in continents including sub-Saharan Africa.
- Groundwater should be incorporated in catchment management plan within clear objectives, components and an implementation plan.
- Protection of groundwater resources should be enhanced through development of ambient water guidelines.
- There is need to re-evaluate and interrogate some hydrological science frameworks e.g. dambos that are hosted underlain basement complex rocks, build the case for exploration of deep aquifers.
- There is need to define climate change tipping point for safe yield to ensure sustainable use.
- Recommendation to remodel the teaching of hydrogeology to incorporate technology.
- In data scarce areas and with large aquifer system, Grace data sets can be used to account for storage changes that could account for climate change impacts.
- Characterization of basement aquifer that are hosted in complex shear zone require integrated approaches e.g. hydrological, modelling and geophysical methods – Ramotswa Aquifer.
- In highly stressed aquifers, managed aquifer recharge can be explored through modelling approaches e.g. Ramotswa Aquifer.
- Deep aquifers should be considered as strategic resources that are an important component to reach water security in water scare regions (SDG 6.1).

2. Sub-theme 2: Measuring progress towards attaining SDG targets, data collection and management within the SADC member states.

- Multidisciplinary approaches should be used in order to ensure the groundwater ecosystem linkage (groundwater dependent ecosystems). Supports SDG 15.
- Integrated approaches as well as the establishment of the baseline are the main tool to be used to achieve the SDGs in the SADC region.
- For transboundary aquifer management, in each aquifer region (type or category) it is necessary to establish the monitoring network in order to get groundwater level status (%) instead of average groundwater level. This will inform prediction and management.
- Climate change threatens groundwater management in arid regions of SADC demonstrated in episodic recharge threats attainment of SDGs.
- There is also a need to involve citizens in data analysis and create ownership of data products.
- Data sharing should be seen as an instrument of cooperation and appropriate models are required.
- Big data analytic require downscaling tools that can assist filling gaps on data within the transboundary aquifer and assist with improved decision making on groundwater resources utilization and protection.
- Tracking process on SDGs should be through countries not RBOs (ownership of data is by countries) but there is need for streamlining to avoid duplication.
SDG reporting has raised the need for more funding and big data analytics may assist although not a panacea.

3. Sub theme 3: Policy, legal and institutional considerations at the national and trans-boundary levels
- Make sure that scientific research findings get to policy-makers and eventually translate into better management
- Share knowledge with all stakeholders that play a role in groundwater management, from policy-makers to groundwater users
- Groundwater regulation (e.g. licenses) requires enforcement and assessment (for potential improvement)
- Transboundary cooperation on groundwater resources is at the forefront of SADC. Investments must therefore continue.

Abstracts of the presentations made at the conference are provided in this volume.
# CONFERENCE PROGRAMME

**Wednesday, 4th September, 2019**

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>07:30Hrs-08:30Hrs</td>
<td>Registration of participants: Ilanga Conference Room</td>
</tr>
<tr>
<td>08:30Hrs-10:00Hrs</td>
<td>Official opening: Ilanga Conference Room</td>
</tr>
<tr>
<td>10:00Hrs-10:30Hrs</td>
<td>Conference key Address – Remigius Makumbe</td>
</tr>
<tr>
<td>10:30Hrs-10:50Hrs</td>
<td><strong>Key note 2 – Professor Yongxin Xu:</strong> Talk on Cape Town Water Crisis.</td>
</tr>
<tr>
<td>10:50Hrs-11:05Hrs</td>
<td>Kevin Pietersen, Hans Beekman and Thokozani Kanyere: Groundwater resources – The road to water resilience in urban water cycles.</td>
</tr>
<tr>
<td>11:20Hrs-11:35Hrs</td>
<td>Stanley Nzama, Thokozani Kanyere, Audrey Levine: Groundwater resources protection: Reflection on the relevance of the groundwater quality component of the Reserve for provision of clean water and sanitation.</td>
</tr>
<tr>
<td>11:35Hrs-11:50Hrs</td>
<td>Karen Grothe Villholth, Mohammad Faiz Alam &amp; Joel Podgorski: Human dietary exposure risk via crop consumption from arsenic-contaminated groundwater-irrigated areas and transmission through international trade.</td>
</tr>
<tr>
<td>11:50Hrs-12:05Hrs</td>
<td>Kiflom Degef Kahsay: Impact of Climate Change on Groundwater Recharge and Base Flow in the Catchment of Tekeze-Atbara Basin, Ethiopia</td>
</tr>
<tr>
<td>12:20Hrs-12:35Hrs</td>
<td>Shelta Majowa &amp; Charles Mazhazhate: Bridging the gap between ground water availability and logistics: Engineering for change from a Gender perspective.</td>
</tr>
<tr>
<td>12:35Hrs-12:50Hrs</td>
<td>Mfundi Biyela, Kevin Pietersen, C Nyirenda and Thokozani Kanyerere: Application of innovation technologies in managing water allocation reform process in Southern Africa, the case of South Africa.</td>
</tr>
<tr>
<td>14:00Hrs-14:20Hrs</td>
<td><strong>Key note 3:</strong> Dr. M.W. Lubczynski. Monitoring, remote sensing and integrated hydrological modelling for groundwater management in Southern Africa.</td>
</tr>
<tr>
<td>14:50Hrs-15:05Hrs</td>
<td>Andrew Joloza &amp; Eddie Banks: Hydrogeochemical characterization of groundwater in the major aquifers in Malawi.</td>
</tr>
</tbody>
</table>

**TEA BREAK AND POSTER SESSION**
<table>
<thead>
<tr>
<th>Time</th>
<th>Session Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>15:45-16:05Hrs</td>
<td><strong>Key Note 4 T. Himmelsbach:</strong> <em>Deep lying Groundwater – Is a strategic groundwater exploration an appropriate key to solve arising water crisis in Southern Africa?</em></td>
</tr>
<tr>
<td>16:05-16:20Hrs</td>
<td>Andrew Bullock: <em>Understanding African groundwater by unlocking a critical divergence in the hydrological science of headwater wetlands.</em></td>
</tr>
<tr>
<td>16:35Hrs-17:45Hrs</td>
<td><strong>Panel Discussion:</strong> Deep groundwater exploration in SADC. <strong>Panelists:</strong> From Botswana (Keodumetse Keetile), Namibia (Bertram Swartz), Prof Lubczynski, Kevin Pietersen.</td>
</tr>
</tbody>
</table>

**Thursday 5th September 2019**

**Sub-theme 1**

<table>
<thead>
<tr>
<th>Time</th>
<th>Session Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:30-08:45Hrs</td>
<td>Irene Kinoti, Marc Leblanc, Albert Olioso, Maciek Lubczynski, Piet Kenabatho, Bertram Swartz, Kwazikwakhe Majola and Tales Carvalho-Resende: <em>Application of remote sensing to assess recharge and discharge mechanism in the Stamriet Transboundary Aquifer System (STAS)</em></td>
</tr>
<tr>
<td>08:45-09:00Hrs</td>
<td>Piet Kenabatho, Thato Setloboko and Bertram Swartz: <em>Assessment of the impacts of climate variability on total water storage in the Orange-Senqu River Basin: implications for groundwater resources management</em></td>
</tr>
<tr>
<td>09:00-09:15Hrs</td>
<td>Manuel S Magombeyi, Karen G Villholth, Richard Healy, Girma Ebrahim: <em>Recharge assessments across the Limpopo River Basin, approaches and findings</em></td>
</tr>
<tr>
<td>09:15-09:30Hrs</td>
<td>Cesário Cambaza, Mieke Huls, Pieter van der Zaag and Paulo Saveca: <em>IRRIGATION PACKAGE FOR SAND RIVERS – A Feasibility Study in the Limpopo River, Mozambique</em></td>
</tr>
<tr>
<td>09:30-09:45Hrs</td>
<td>Phithlhoa Diloro Keitumetse, Nata Tadesse Tafesse, R. T. Ranganai and Kebabonye Laletsang: <em>Hydrogeological and Geophysical Characterization of Ramotswa transboundary dolomitic aquifer.</em></td>
</tr>
<tr>
<td>09:45-10:00Hrs</td>
<td>Girma Ebrahim, Karen Villholth, Jonathan Lautze, Keetile Keodumetse, Piet Kenabatho, Sakhile Mndaweni, Naicker Sivashni, Moses Moehad: <em>Hydrogeological model for the Ramotswa transboundary aquifer – How much do we know?</em></td>
</tr>
<tr>
<td>10:00-10:15Hrs</td>
<td>Girma Ebrahim, Karen Villholth, Jonathan Lautze, Keetile Keodumetse, Piet Kenabatho, Sakhile Mndaweni, Naicker Sivashni, Moses Moehad: <em>Assessing managed aquifer recharge potential in the RAMOTSWA transboundary aquifer area – a hydrogeological modelling approach.</em></td>
</tr>
</tbody>
</table>

**TEA BREAK AND POSTER SESSION**

<table>
<thead>
<tr>
<th>Time</th>
<th>Session Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>11:00-11:15Hrs</td>
<td>Lucas Filipe Tamele Junior, Paulino Vicente Muteto, Fatima Mussa, Dinis Juizo: <em>Assessment of groundwater quality in Great Maputo aquifer system.</em></td>
</tr>
<tr>
<td>11:30-11:45Hrs</td>
<td>Lusanda Vingi, Innocent Muchingami, Thokozani Kanyerere and Kevin Pietersen: <em>Using groundwater process model to assess aquifer-river interaction for groundwater dependent communities, semi-arid areas, Hout Catchment.</em></td>
</tr>
</tbody>
</table>
### Session 1: On the Use of Theis and Cooper-Jacob Methods to Interpret Multi-Well Aquifer Pumping Tests in Laterally Heterogeneous Confined Aquifer Systems

**Presenter:** Modreck Gomo  
**Title:** On the use of Theis and Cooper-Jacob methods to interpret multi-well aquifer pumping tests in laterally heterogeneous confined aquifer systems.

### Session 2: Strengthening Groundwater Management Through an Integrative Approach

**Presenters:** Lothar Schäfer, Thomas Himmelsbach, Hans Matthias Schöniger & Jan Gaebler  
**Title:** Strengthening groundwater management through an integrative approach.

### Session 3: Cape Town's Major Aquifer Systems as a Use Case Study for the Global Water Quality Assessment

**Presenters:** Dylan Blake, Hartwig Kremer, Rowena Hay, Kilian Christ, David McGibbon, Luke Towers  
**Title:** Cape Town’s Major Aquifer Systems as a Use Case Study for the Global Water Quality Assessment.

### Session 4: Barriers Against Groundwater Development

**Presenter:** Eva Masemola  
**Title:** Barriers Against Groundwater Development

### Session 5: SADC-wide Framework for Groundwater Data Collection and Data Management

**Presenters:** Nijsten, Gomo, Sterckx and Lukas  
**Title:** SADC-wide Framework for Groundwater Data Collection and Data Management.
<table>
<thead>
<tr>
<th>Time</th>
<th>Session Details</th>
</tr>
</thead>
</table>
| 08:30-08:50  | **Key Note 5:** K. Upton, R. Cornforth, J.W. Foppen, R. Hope, A. MacDonald & R. Taylor  
                 Addressing groundwater policy gaps: evidence from the UPGro Programme                                                                                                                                   |
<p>| 08:50-09:05  | Andrew Bullock: Unrealised opportunities for African groundwater from reconnection with science under alternative natural capitals.                                                                                |
| 09:05-09:20  | Michael Eichholz, Tobias Godau &amp; Tewodros Tena, Assessment of groundwater governance capacities in Lusaka.                                                                                                    |
| 09:35-10:05  | Mfundi Biyela, Kevin Pietersen, Theresa Mkandawire, Paul Mensah and Thokozani Kanyerere: Regulating the regulations for managing groundwater use to improve water security in Southern Africa: Reflection on water use license application process in South Africa. |
| 10:20-10:35  | Helen Seyler, Kai Witthueser and Kevin Pietersen: The framework for a Sustainable Water Supply Strategy to promote groundwater secure transboundary systems.                                                    |
| 11:10-11:30  | <strong>Key Note:</strong> Prof Gildo: SADC Water Protocols and the Duty to Cooperate in the Protection and Management of Ground Water: between soft and hard law                                                              |
| 11:30-11:45  | James Sauramba: Groundwater Policy Legal and Institutional Frameworks in the SADC region.                                                                                                                      |
| 11:45-12:00  | Member States (Eswatini, Tanzania), Sergio, James Sauramba, Derrick, Prof Gildo, Kevin Pietersen                                                                                                             |
|              | <strong>CLOSURE PROCEEDINGS</strong>                                                                                                                                                                                        |
| 12:30-12:40  | Dr. LaMoreaux: Getting your work published with the Sustainable Water Resources Management (SWAM) Journal.                                                                                                  |</p>
<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:40Hrs-12:50Hrs</td>
<td>Dr. Banda Kawawa. <strong>Chief Conference Rapporteur: Overview of the 2nd SADC-GMI Conference.</strong></td>
</tr>
<tr>
<td>12:50Hrs-13:00Hrs</td>
<td>Vote of Thanks: SADC- Secretariat</td>
</tr>
<tr>
<td>13:00Hrs-13:05Hrs</td>
<td>Announcements</td>
</tr>
<tr>
<td>13:05Hrs-</td>
<td>Lunch and Departure.</td>
</tr>
</tbody>
</table>
POSTERS:


Nelson Cornelio Malikito: Groundwater data collection and management: The role of community. Regional Water Administration of the Centre in Beira-Mozambique.

Hamilton Alberto João Baptista Junior: Groundwater exploration using geoelectrical resistivity/induced polarization techniques for agriculture activities Sustainability in Uige area.


Jack Hemingway, Alexandra Gormally: Groundwater Governance in South Africa: Domestic and Transboundary Governance, and Preparedness for Hydraulic Fracturing

Coira, Omar Sirage: Mozambique challenges in groundwater management.

Roland Baeumle and Marcus Fahle: Development of regional groundwater monitoring networks – Theoretical considerations and case study from the Upper Kafue, Zambia.

Lindelani Lalumbe: Groundwater quality status in the Eastern Kalahari Hydrogeological region: SDG 6.3.2 Reporting

Oudi Modisha: How effective is cover system design for mine closure?

Table of Contents
SYNTHESIS OF THE CONFERENCE.........................................................................................................................II
POSTERS:..............................................................................................................................................................................X
ABSTRACTS.............................................................................................................................................................................XVI
SUBTHEME 1: CONTRIBUTION OF RESEARCH TOWARDS UNDERSTANDING, THE STATUS, TRENDS AND RISKS TO GROUNDWATER RESOURCES.................................................................1
Y. Xu1, ..................................................................................................................................................................................2
1K Pietersen, 2T Kanyerere, 2H.E. Beekman, Groundwater Resources - The road to water resilience in urban water cycles .........................................................................................................................3
1E. Braune, 2JA (Kobus) du Plessis, Conjunctive Water Use Model for Local Authorities .........................4
1S Nzama, 2T Kanyerere, 2A Levine, Groundwater resources protection: Reflection on the relevance of the groundwater quality component of the Reserve for provision of clean water and sanitation .... 5
1K. G. Villholthol, 1M. FaizAllam, 2J. Podgorski, Human dietary exposure risk via crop consumption from arsenic-contaminated groundwater-irrigated areas and transmission through international trade .... 6
1K. D. Kahsay, 2S. M. Pingale, S. D. Hatiye, Impact of Climate Change on Groundwater Recharge and Base Flow in the Catchment of Tekeze-Atbara Basin, Ethiopia ......................................................7
1M. Fahle & 1R. Bäumle, How to Develop Groundwater Management Plans......................................................8
1M. Biyela, 1K. Pietersen, 1C. Nyirenda. and 1T. Kanyerere, Application of innovation technologies in managing water allocation reform process in Southern Africa, the case of South Africa ..........9
1M. Lubczynski, Monitoring, remote sensing and integrated hydrological modelling for groundwater management in Southern Africa .................................................................................................................10
1S. Owolabi, 1K. Madi, 2A. M. Kalumba, Mapping of groundwater potential zones using geoinformatics and multi-influencing factors. .................................................................................................11
1M. M. Kanaimba, 1N. T. Tafesse and 1K. Laletsang, Intrinsic groundwater pollution vulnerability of Masama East Wellfield, Khurutshe Area, Botswana. ........................................................................12
1A.A. Joloza, Hydrogeochemical characterisation of groundwater in the major aquifers in Malawi ... 13
1T. Himmelsbach, Deep lying Groundwater – Is a strategic groundwater exploration an appropriate key to solve arising water crisis in Southern Africa? ........................................................................14
1Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany .........................14
1T. Masaka and 1M.W. Lubczynski and 2Moiteela Lekula, Integrated hydrological modelling of river-aquifer interactions in the Boteti River, Botswana ........................................................................16
1A. Bullock, *Understanding African groundwater by unlocking a critical divergence in the hydrological science of headwater wetlands*. ................................................................................................................................. 17

1l Kinoti, M. 1Leblanc, 1A. Olioso, 2M. Lubczynski, 3P. Kenabatho, 4B. Swartz, 5K. Majola, 6C.R. Tales, *Application of remote sensing to assess recharge and discharge mechanism in the Stampriet Transboundary Aquifer System (STAS)*. ................................................................................................................................. 19

1P. Kenabatho, 2T. Setluboko, 3B. Swartz, 4M. Amakali, 5K. Majola, 6Sekwele, 7R. Pule, 8T.C. Resende, *Assessment of the impacts of climate variability on total water storage in the Orange-Senqu River Basin: implications for groundwater resources management* ................................................................................................................................. 20

1M.S. Magombeyi, 1K. G. Villholth, 2R. Healy, 3G. Ebrahim, *Recharge assessments across the Limpopo River Basin, approaches and findings* ................................................................................................................................. 21

1C. Cambaza, 1P. Saveca, 2M. Hushof and 3P. van der Zaag, *Irrigation package for sand rivers (Ipsar) – Feasibility Study - Case Study of Limpopo River, Mozambique* ................................................................................................................................. 22

1D. K. Phitlho, 2N.T. Tafesse, 3R.T. Ranganai and 4K. Laletsang, *Hydrogeological and geophysical characterisation of Ramotswa transboundary dolomitic aquifer* ................................................................................................................................. 23

1GY. Ebrahim, 1K. G. Villholth, 1J. Lautze, 2K. Keodumetse, 3P. Kenabatho, 4S. Mndaweni, 5N. Sivashni and 6M. Moehadu, *Hydrogeological model for the Ramotswa transboundary aquifer - How much do we know?* ................................................................................................................................. 24

1G. Y. Ebrahim, 1M. Magombeyi, 1K. G. Villholth, 1J. Lautze, 2S. Trust, 3G.J Nijsten, 4K. Keodumetse, 5P. Kenabatho, 6S. Mndaweni, 7M. Moehadu, *Assessing managed aquifer recharge potential in the RAMOTSWA transboundary aquifer area – a hydrogeological modelling approach* ................................................................................................................................. 26

1N. Mhlanga, M. Mathunjwa and 1L. Sifundza, *Groundwater monitoring and management protocols for Komati Basin* ................................................................................................................................................................. 28

1L. F. Tamele Jr. and 1P. V. Muteto, 2F. E. F. Mussá and 2D. Juizo, *Assessment of groundwater quality in Great Maputo aquifer system* ................................................................................................................................................................. 29

1P.S.L. Saveca, 2T.Y Stigter, 3E. Lukas and 4D. Juizo, *Investigation of hydrogeochemical processes and groundwater quality in the hókwé District, Mozambique* ................................................................................................................................................................. 30

1L. Vinqi, I. 1Muchingami, 1K. Pietersen, and 1T. Kanyerere, *Using groundwater process model to assess aquifer-river interaction for groundwater dependent communities, semi-arid areas, Hout Catchment* ................................................................................................................................................................. 31

1M. Gomo, *On the use Theis, and Cooper and Jacob methods to interpret multi-well aquifer pumping tests in laterally heterogeneous confined aquifer systems* ................................................................................................................................................................. 32

1L. Schäfer, 2T. Himmelsbach, 3H. M Schöniger, *Strengthening groundwater management through an integrative approach* ................................................................................................................................................................. 33

1D. Blake, 1R. Hay, 1D. McGibbon, 1L. Kremer, H. and 2Christ, K. Towers, *Cape Town’s Major Aquifer Systems as a Use Case Study for the Global Water Quality Assessment* ................................................................................................................................................................. 35

S. M. Pingale, S.D. Hatiye and K. D. Kahsay, *Impact of Climate Change on Groundwater Recharge and Base Flow in the Catchment of Tekeze-Atbara Basin, Ethiopia* ................................................................................................................................................................. 37

L. M. Sharma, *Creating fresh water source within saline aquifer* ................................................................................................................................................................. 38
M. Eichholz, T. Tena & T. Godau, Assessment of groundwater governance capacities in Lusaka. 56
Biyela M, Pietersen K, Kanyerere T, Mkandawire T. and Mensah P, Regulating the regulations for managing groundwater use to improve water security in Southern Africa: Reflection on water use licence application process in South Africa. 58
H. Seyler, K. Witthueser, Pietersen, B. Pietersen, The framework for a Sustainable Water Supply Strategy to promote groundwater secure transboundary systems. 61
M. Gildo, SADC Water Protocols and the Duty to Cooperate in the Protection and Management of Ground Water: between soft and hard law. 62
J. Sauramba, Groundwater Policy Legal and Institutional Frameworks in the SADC Region. 63
ABSTRACTS
SUBTHEME 1: CONTRIBUTION OF RESEARCH TOWARDS UNDERSTANDING, THE STATUS, TRENDS AND RISKS TO GROUNDWATER RESOURCES.
Y. Xu¹, Talk on Cape Town Water Crisis

¹UNESCO Chair Centre in Groundwater University of Western Cape Private Bag X17, Bellville 7535, Cape Town, South Africa. yxu@uwc.ac.za / 2938826017@qq.com

The infamous drought of 2015-2017 in Cape Town (South Africa) provides important lessons on water governance. While it is undeniable that an unprecedented sequence of three record-low rainfall years instigated the ‘water crisis’, this essay argues that the severity of the drought may have been mitigated by good governance, both in terms of diversifying water sources and managing existing supplies. Historically, water authorities have focused on surface-water resources for Cape Town’s water supply. Cape Town’s ample groundwater has not been utilized to any notable extent. It is concluded that the crisis, once passed, may be viewed as auspicious, for not only did it provide the impetus to adapt Cape Town’s water supply, and thereby better incorporating its groundwater resources, but the crisis stands as a case in point to justify future investments in water security, not only for Cape Town, but for other cities as well.
K Pietersen, T Kanyerere, H.E. Beekman, Groundwater Resources - The road to water resilience in urban water cycles

1Institute for Water Studies, University of the Western Cape; email: kpietersen@mweb.co.za, email: tkanyerere@uwc.ac.za

2GIZ-Consultant, Houtbay, South Africa; email: beekman@adept.co.za

Corresponding author: kpietersen@mweb.co.za

Abstract

Cities in the Africa region faces unplanned urban growth outpacing economic, social and institutional interventions providing many challenges to water planners to ensure water security. Although, the recent drought experiences in the City of Cape Town, South Africa has brought groundwater to the forefront and its potential role in ensuring resilience against recurring droughts and general water insecurity. However, groundwater role in resilience is inferred but poorly integrated in the urban areas of the South with mixed messages about groundwater storage, contemporary rates of resource renewability and the wider impacts of uncontrolled aquifer depletion and pollution (after Foster and Macdonald 2014). The presentation reflects on the groundwater challenges (e.g. rising groundwater levels, declining groundwater levels, groundwater quality deterioration; saline intrusion) facing selected urban areas of Africa: Blantyre, Cape Town, Dar es Salaam, Kampala, Johannesburg-Pretoria and Lusaka. A systems perspective on groundwater resilience within the context of urban water cycles are taken using an analytical framework. This allows better understanding of the complexity of groundwater to support urban living and the impact of urbanism on natural groundwater systems.

Keywords: Cape town, depletion, Urbanism, renewability, groundwater
1E. Braune, 2JA (Kobus) du Plessis, **Conjunctive Water Use Model for Local Authorities**

1Stellenbosch University; erikabraune95@gmail.com. cell: (+27) 71 352 8693, Stellenbosch University; jadup@sun.ac.za, cell: (+27) 83 560 5536

**Abstract**

South Africa has a broadly-developed water infrastructure based mainly on surface water, localised groundwater and limited desalination as resources. However, most economic viable surface water resources are already utilised. With increasing demands and climate variability, the risk for water shortage increases. Sustainable management practices need to ensure integrated and effective conjunctive management of surface water and groundwater resources.

To aid in the conjunctive management of all water resources at local authority scale, an excel based model was developed, which includes surface water, groundwater and desalination using a daily time-step. The important link between surface water and groundwater is recharge which is expressed as a percentage of rainfall. The model is stochastically driven by synthetically generated streamflow sequences. These sequences are disaggregated into daily streamflow and through a streamflow-rainfall relationship converted to rainfall sequences. Surface water is modelled using conventional dam balancing equations with daily streamflow. Groundwater is modelled using a similar approach as the Aquifer Firm Yield Model with the saturated volume fluctuation equation which relates stochastic rainfall, recharge and water levels to sustainable abstraction volumes. This model is paired with the Cooper-Jacob model and data from Groundwater Resource Assessment Phase 2 - project. Desalination is modelled as a source which provides water at 100% assurance of supply at different operational capacity levels over fixed three-monthly time steps.

The combined system yield is established through the analysis of stochastic sequences. The short-term and long-term assurance of supply is graphically presented and management suggestions and tools are provided. Case studies are used to verify and test the model.

**Keywords:** groundwater/surface water stochastic link, saturated volume fluctuation equation, conjunctive water resource management
S Nzama, T Kanyerere, A Levine, *Groundwater resources protection: Reflection on the relevance of the groundwater quality component of the Reserve for provision of clean water and sanitation*

1Reserve Determination, Department of Water and Sanitation, Pretoria, 0001, South Africa

2Water Quality Program, County of Santa Cruz-Health Services, Agency-Environmental Health Division, SantaCruz, CA 95060, United States

**Corresponding Author:** nzamas@dwa.gov.za

**Abstract**
The relevance of groundwater is on the increase worldwide. However, effectiveness of such approach remains poorly understood in the context of groundwater resource protection. Nevertheless, the increasing role of groundwater in municipal water networks serves as key for sustainable drinking water supplies thereby contributing to baseline estimates that contribute towards global monitoring of the 2030 Sustainable Development Goals (SDG) targets 6.1 on achieving universal and equitable access to safe and affordable drinking water for all. Since the access to clean drinking water and sanitation is an indicator for realizing SDG as well as fulfilment for Basic Human Needs, groundwater resource protection for promoting access to clean water is imperative. Measures to protect water resources such as resource directed measures (RDM’s) in South Africa are showing positive strides. However, relevance of groundwater quality component requires a reflection to showcase its effectiveness. This article provides an overview of the new approach that was followed in determining the groundwater quality component of the reserve. Furthermore, the article highlights how the knowledge of chemical aspects of groundwater resources serves as a fundamental tool for protecting groundwater resources and assuring the availability for sustainable drinking water supplies in the country which remains assured, thereby showcasing the potential of the new approach.

**Keywords:** Sustainable Development Goals, groundwater resource protection, resource directed measures, groundwater Reserve determination, groundwater quality.
K. G. Villholth, M. FaizAllam, J. Podgorski, Human dietary exposure risk via crop consumption from arsenic-contaminated groundwater-irrigated areas and transmission through international trade

IWMI, International Water Management Institute, Pretoria, South Africa
EAWAG, Swiss Federal Institute of Aquatic Science and Technology

Corresponding author: k.villholth@cgiar.org

Abstract

The long-term ingestion of arsenic-contaminated groundwater is well known to pose a significant human health burden in many parts of the world underlain by aquifers containing arsenic-laden sediments. Arsenic in the food-chain, from crop production in contaminated areas and through trade, has been recognized as a potential additional source of exposure risk, although there is limited understanding of its significance and extent globally. Using global data sets on crop production, global trade, irrigation and arsenic-contaminated groundwater hazard, we estimate that nearly 1.5 billion people may be exposed to significant arsenic dietary risk through major stable crops of rice, wheat, and maize irrigated with potentially arsenic-contaminated groundwater. We show that this food exposure risk primarily comes from the local production and consumption of rice. However, a significant risk is transferred via trade, to an estimated subgroup of about 50 million people, primarily from a few major crop-exporting countries, such as USA, India and Pakistan, to non-contaminated but import-dependent countries. These are typically smaller countries in arid regions (e.g. Middle East) and small island states. With growing food requirements, increasingly globalized food trade, intensifying climate variability and associated likelihood of expanding groundwater irrigation into contaminated regions of the world, predominantly presently rain-fed regions in tropical and semi-tropical regions, the enhanced risk to human health from arsenic exposure in food and via trade requires further attention. There is a need for interdisciplinary research, global collaboration and mitigation policies on integrated aspects of the risk chain, from groundwater and soil contamination, to crop uptake and international trade risk transmission.

Keywords: Arsenic contamination of groundwater, groundwater irrigation, risk transmission via crop uptake and dietary ingestion, risk transmission via international trade.
K. D. Kahsay, S. M. Pingale, S. D. Hatiye, Impact of Climate Change on Groundwater Recharge and Base Flow in the Catchment of Tekeze-Atbara Basin, Ethiopia

1Tigray Agricultural Research Institute, Alamata center, Ethiopia Email: kiflomdegef@gmail.com, 2Department of Water Resources and Irrigation Engineering, Arba Minch Institute of Technology, Arba Minch University, Arba Minch, Ethiopia

Abstract

The impacts of climate change are significant on both surface and groundwater resources. However, little attention has been given to the effect of climate change on groundwater resources. Therefore, the present study is concerned with the effect of climate change on groundwater recharge and base flow in Tekeze-Atbara catchment in Ethiopia. The future climate variables were obtained from Coordinated Regional Climate Downscaling Experiment (CORDEX)Africa program for Representative Concentration Pathways (RCPs) of RCP 2.6 and RCP 4.5 scenarios. The Mann-Kendall test and Sen's slope estimator were used for trend detection using XLSTAT software package. Further, the downscaled and bias corrected precipitation, temperature, and potential evapotranspiration were used as input to the WETSPA model to simulate future water balance changes. The results indicated a decreasing trend in annual rainfall and an increasing trend in average temperature and evapotranspiration for selected scenarios. At the catchment level, precipitation decreases by 20% for both RCP 2.6 and RCP 4.5 scenarios, and actual evapotranspiration shows 0.4% and 8.1% increase for RCP 2.6 and RCP 4.5, respectively. Consequently, the groundwater recharge decreases by 3.4% for RCP 2.6 and 1.3% for RCP 4.5. Baseflow will also decrease by 1.5% and 0.55% for RCP 2.6 and RCP 4.5, respectively. The results of this study would help policymakers, scientists, government officials and local stakeholders in planning and management of the surface and groundwater resources in the Ethiopian regions.

Keywords: Tekeze catchment, Climate change, Recharge, Base flow, Trend analysis, WETSPA.

1Federal Institute for Geosciences and Natural Resources (BGR), Germany

Corresponding author: marcus.fahle@bgr.de

Abstract

Groundwater management plans (GWMPs) aim at confronting the state of the groundwater, both quantity- and quality-wise, and the current and intended use of groundwater, drafting strategies to overcome existing shortcomings and to ensure sustainable use of the resource. Based on a review of existing literature and plans, we prepared a guideline to develop such plans. The guideline involves three parts: Definitions, components to be incorporated in a GWMP and implementation of a GWMP. First, it has to be defined what the aim of a GWMP is and on what scale it is set, e.g. national, catchment or subordinate level. Then the plan’s components and the approaches to derive them have to be specified. These components encompass groundwater monitoring and information management, assessment of quality and quantity, a survey of groundwater users and groundwater protection. These information might be summarized by hydrogeological maps. Recommendations will be given on when which component is needed as, for example, an evaluation of groundwater vulnerability will not be necessary in an area that is only sparsely settled. Finally, the derivation of actions and their implementations are discussed, which include the quantitative and qualitative management and steps towards groundwater protection or restoration as well as action plans for extraordinary conditions (e.g., droughts). The presentation will briefly summarize the guideline to develop GWMPs.

**Keywords:** Groundwater Resource Allocation, Groundwater Planning, Guideline
M. Biyela, K. Pietersen, C. Nyirenda, and T. Kanyerere, *Application of innovation technologies in managing water allocation reform process in Southern Africa, the case of South Africa*

*Department of Water and Sanitation, Free State, South Africa*

**Corresponding author:** Kanyerere T

**Abstract**

Water allocation reform process is associated with administrative burden which needs to be reduced so that the process is effective and efficient to facilitate water use license application. The availability of innovation technologies informs the basis for applying the appropriate ones in managing water allocation reform process. In this paper, the assessed administrative processes and innovation technologies are reported. In addition, near real time data acquisition approach, required data for effective and efficient water use and water allocation process, NydroNet-like model, groundwater resource assessment II method, SAPWAT4, None Point Source calculator and e-WULAAS technologies among others were studied with the aim of exploring the effectiveness and efficiency, appropriateness and sustainability of the innovation technologies that would reduce the administrative burden in the water allocation reform process. Various databases were accessed for the required data. A mixed-methods approach was followed where quantitative data from databases and records were collected and analysed in addition collecting qualitative data from interviews with various stakeholders. Preliminary analyses seem to show that application of mixed-match field-tested innovation technologies are effective, efficient and suitable in reducing the administrative burdens during water allocation process especially when the room for improving them is provided in the water management system. Based on such preliminary finding, in this paper we recommend the use of real time monitoring, evaluating and reporting system to fast track the progress of such technologies in performing their expected and intended purposes.

**Key Words:** Southern Africa, South Africa, water allocation process, administrative burden, near real time innovation technologies.

1University of Twente, Faculty of Geo-Information Science and Earth Observation, P.O. Box 217, 7500 AE Enschede, The Netherlands

Email: m.w.lubczynski@utwente.nl.

Abstract

Distributed numerical models, have typically been considered as optimal tools for groundwater resources management. Traditionally, standalone groundwater models have been used, although recently, the integrated hydrological models (IHM) became a new standard due to their unquestionable advantages. The main, is that they do not need any more the highly uncertain recharge and groundwater evapotranspiration as model driving force inputs, instead utilizing easier acquireable rainfall and PET. All advantages of the IHMs will be discussed based on examples.

Reliability of distributed models, also the IHMs, is highly dependent on quantity and quality of input data. In Southern Africa countries, the availability of the ground-based data is generally poor. Besides, in many cases, the reliability of such data is questionable. Establishing data acquisition routines/standards, eventually the same for all Southern African countries, and strictly following them, would help in short notice. Therefore, such routines will be proposed.

The scarcity of ground-based data in Southern Africa, cannot be improved in short notice. However, that problem can be mitigated by remote sensing (RS). There are now various, freely available web-based RS-products that can be directly integrated in hydrogeological studies, particularly in IHMs. If matching ground-data is available, it can be used to improve RS-products, for example by bias correction or by geostatistical eventually stochastic data integration.

To show integration of ground monitoring data and RS-products in IHMs, three study cases will be presented: 1) Sardon hard rock, granitic catchment in Spain; 2) Area adjacent to Turawa artificial lake in Poland; 3) Central Kalahari Basin in Botswana and Namibia. The review of the three study cases will be followed by a discussion on state of art (including limitations) of RS applications in IHMs and finally concluded with a vision for future developments in that field.

1Department of Geology, University of Fort Hare, Private Bag X1314, Alice, 5700, Eastern Cape, South Africa

2Department of Geography and Environmental Science, University of Fort Hare, Private Bag X1314, Alice, 5700, Eastern Cape, South Africa

**Corresponding Author:** solomonowolabi11@gmail.com

**Abstract**

In this paper, an attempt has been made to demonstrate the investigation of groundwater potential zone in Buffalo hydrological basin headwaters, Eastern Cape, South Africa. This was achieved by integrating hydrogeological, hydrological, geomorphological, meteorological and environmental factors contributing to groundwater development in geoinformatics environment. The zones of groundwater system is modelled using thematic layers of eleven indicators namely; lithology, lineament, drainage density, rainfall, normalized-difference-vegetation-index, geomorphology, soil, topographic-wetness-index, slope, land use/land cover and land-surface-temperature. Relative weights of the indicators were computed using knowledge-based multi-influencing factor. The computed relative weight were entered into columns provided in weight overlay engine in ArcMap 10.5.1 and after attaching the thematic layers. The result shows four zones of groundwater potential and their extent; the good (4%), moderate (33%), poor (60%) and the very poor (3%) zones for groundwater development. The favourable groundwater potential areas are dominant in the northwest and north while the poor zones dominate the south and southeast of the basin. Validation of this result was done by overlaying projected well-discharge rate point-map prepared from well-discharges rate data collated from 1990 to 2011. Visual correlation from the overlay validation is strong as major anomalous spot of groundwater potential were filled with regular gradient of well-discharge data information. The overall result revealed that groundwater system in this basin is driven by topography. The approach can be readily adopted in any other semi-arid/arid environment for zonation of groundwater potential.

**Keywords:** Groundwater potential zone, geoinformatics, multi-influencing factors, weighted overlay, and South Africa.

1Geology Department, Faculty of Science, University of Botswana, Gaborone, Botswana

Corresponding Author: Nata.tafesse@mopipi.ub.bw

Abstract

An intrinsic groundwater pollution vulnerability assessment was conducted in Masama east well field, Botswana. The well field is located in close proximity to residential and agricultural land and might be exposed to the risk of groundwater pollution. The DRASTIC index model was applied to assess the groundwater pollution vulnerability of the study area. The technique combined a series of mathematical equations, physio-chemical properties of the study area and GIS to produce the standard groundwater pollution vulnerability map. The map was then calibrated using the sensitivity analysis to reduce the subjectivity associated with the DRASTIC index model and increase its accuracy. Additionally, the land use parameter was incorporated into the calibrated DRASTIC map to reflect the direct impact of human activities on the environment. These adjustments resulted in the production of the groundwater pollution vulnerability map of Masama east well field. This map was classified into four groundwater vulnerability classes labeled very low, low, moderate and high groundwater vulnerability. The very low, low, moderate and high groundwater vulnerability zones accounted for 39.0%, 19.9%, 27.5% and 13.6% of the total study area, respectively. Model validation was achieved using the spearman rank correlation coefficient and by visually comparing the nitrate distribution map of the study area and the land use map. The outcome of this study can be utilized as a guide by the land use planners, decision makers and the general public to divert activities that present greater risk of groundwater pollution to low vulnerability zones and preserve the water quality in the well field.

**Keywords:** Drastic map, Groundwater, Masama, Pollution, Vulnerability map.
A.A, Joloza, *Hydrogeochemical characterisation of groundwater in the major aquifers in Malawi.*

Ministry of Agriculture, Irrigation and Water Development, Private Bag390, Capital City, Lilongwe 3, Malawi

Email: joloza.andrew@gmail.com

**Abstract**

The hydrochemistry of Malawi’s groundwater is highly variable due to the natural hydrochemical processes prevalent in different regions, affecting the suitability of the water for domestic supply. This study was undertaken to investigate the trends and the hydrogeochemical processes affecting groundwater quality in the weathered basement and alluvial aquifers across five districts in Malawi (Balaka, Lilongwe, Machinga, Mzimba and Nkhotakota). An analysis of the major and minor ions, and total dissolved solids (TDS) was undertaken on the 200 groundwater samples collected from hand-pumped boreholes. In general, groundwater in the weathered basement is of low mineralization (TDS range 40 – 1127 mg L\(^{-1}\)) and the water composition characterized by Ca/Mg – HCO\(_3\) water type. In the alluvial aquifer in Balaka and Machinga, the water composition was dominated by Mg – HCO\(_3\) water type while in Nkhotakota, the hydro-geochemical faces were dominated by Na – HCO\(_3\) water type. Notable differences were also observed on the TDS values as Balaka had relatively high values (range 243 – 2290 mg L\(^{-1}\)) in comparison to the other five districts, suggesting active mineralization, whereas in Nkhotakota, all the values were below the freshwater threshold value of 750 mg L\(^{-1}\). The results obtained in this study will aid the understanding of the hydrogeochemical processes influencing the water quality in the study areas. A better understanding of the spatial variation and processes affecting water quality is required to allow identification and development of usable water supplies in response to climate change and environmental pressures.

**Keywords:** Hydrogeochemical processes, spatial variation, mineralization, alluvial aquifers, weathered basement aquifer.
Deep lying Groundwater – Is a strategic groundwater exploration an appropriate key to solve arising water crisis in Southern Africa?

Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany

Thomas.Himmelsbach@bgr.de

Abstract

Southern Africa is facing an emerging water crisis within the next decades. Climate change will be characterised within the next 20 years by an increasing number of extreme events. Severe droughts will occur in subsequent years and will be likely followed by strong precipitation phases leading to widespread flooding and loss of arable land. The worldwide increase in temperature of 1.5 – 2.0°C may lead in some areas of Southern Africa to a temperature rise of 2.0 – 4.0°C. These effects will directly influence the demand of water and requires new strategies and considerable financial investment in the water sector. During the past decades water supply was focusing primarily on building new dams, with the largest number of newly build reservoirs in South Africa. Other countries in the SADC regions have only few reservoirs with comparable volumes. However, recent drought periods have shown drastically, that even these infrastructures cannot cope with the general water shortage if drought periods prolong beyond a specific time span.

Past and recent investigations of BGR in cooperation with geological surveys and government institutions in Southern Africa have led to the detection and exploration of new deep lying aquifers in the SADC region. Some examples are the Lethlakane Aquifer in Botswana and the Ohangwena II aquifer in Namibia. The latter, the most recent finding is by far the largest and has attracted a lot of interest, because it also stretches into Southern Angola. Both aquifers have in common that they contain very old groundwater in the range of 20,000 – 100,000 years and reflect periods of former groundwater recharge under completely different climate conditions. Using such old groundwater for drinking and general water supply always lead to the question, how long can such groundwater bodies be used before they are depleted? Fortunately, we found evidence that both aquifers today still receive considerable groundwater recharge. However, these recharge rates need to be determined in order to get reasonable figures as a basis for future sustainable management.

All above-mentioned results and ideas lead to the development of a new groundwater exploration strategy, which is comparable to the well-established strategies in the oil and gas industry. In order to find the “big shots” of new groundwater bodies we have to investigate firstly for either large regional tectonic features, such as Horst- and Graben-structures or deep lying sediment structures such as buried paleo deltas. Such exploration should be undertaken not only within the African continent but also along its outer continental rims. Once such potential aquifer structures are recognised, intense further investigations will be required to identify whether these objects still have contact to regions where actual groundwater replenishment and recharge occurs. Only these structures, we call them semi-fossil aquifers, offer a basis to be managed in a sustainable way, once the amount of recharge and sustainable abstraction scenarios are defined. Finally, it has to be underlined, that groundwater exploration will never be able to substitute surface water management, building and improving water infrastructure such as new dams and inter-basin water supply schemes. It will rather act as an inevitable supplement for the entire water sector during long drought periods.
Keywords: groundwater potential, groundwater exploration, geological evidence, new concepts, interdisciplinary approach

1Department of Water Resources, Faculty of Geo-information Science and Earth Observation (ITC), University of Twente, P.O. Box 217, 7500AA, Enschede, The Netherlands

2Department of Earth and Environmental Science, Botswana International University of Science & Technology (BIUST), Private bag 16, Palapye, Botswana

Corresponding Author: Tebogo Masaka (t.l.masaka@utwente.nl and tmasaka@gmail.com)

Abstract

The Boteti River, outflowing from the Okavango Delta (OD), is the main contemporary surface water body in the Boteti District and in the whole Kalahari south of OD. Its discharge is highly dependent on the OD outflow, being the highest in dry seasons when peak-floods occur. However, the river flow is uncertain, as for many years before 2010, the Boteti River was dry. We hypothesize that there are substantial groundwater resources in the study area due to river-groundwater interactions, at present and in the past. The objective of this study was to characterize river-groundwater interactions and sustainability of groundwater resources. For that, a preliminary, integrated hydrological model (IHM), MODFLOW-NWT with active UZF1 and SFR2 packages, was setup and transient-calibrated in ModelMuse within a 3-year period, 1-Sep-2014 to 31-Aug-2017. The water balance showed inflow from OD and precipitation representing 89.4% and 10.2% of the total model input (2.9 x 1014 m³/year) respectively, while the remaining 0.4% represented lateral groundwater inflow from outside the model domain. The major output was evapotranspiration (70.7%), river outflow (22.2%) and lateral groundwater outflow, out of the model domain (1.8%). Gross recharge (Rg) was ~74% of average precipitation (~400mm/year) while groundwater evapotranspiration (ETg), was 80%. Both Rg and ETg were the highest in the wet seasons and both spatially variable, the largest along the alluvial sediments of the river where the groundwater table was shallow. The shallow groundwater table in proximity of the river, with a generally decreasing head away from the river, showed potentially active aquifer recharge along the river course, although more investigation on that issue need to be carried out. This study revealed potential significance of the Boteti River in enhancing groundwater resources availability in dry Kalahari environment and will be continued by setting a more detailed IHM and its calibration.

Keywords: River-aquifer interactions, Integrated hydrological modeling, Botswana, Kalahari, Boteti River.
A. Bullock, *Understanding African groundwater by unlocking a critical divergence in the hydrological science of headwater wetlands.*

Independent Senior Consultant, Ledbury, HR8 2DX, United Kingdom, Email: andybulloch61@btinternet.com.

Abstract

During the 1980s, extensive research work in southern Africa created a nascent understanding of the hydrogeological pathways of the Basement Complex and its extensive headwater wetlands conforming with a two-tier response model. Key quantifications of fluxes, recharge, aquifer transmissivity and contributions to river base flows - especially in Zimbabwe, but also in Malawi - led to conception of headwater wetlands as low-storage generators of rapid response runoff, barriers to vertical recharge and as consumptive buffers of groundwater contributions to river base flow.

Conversely, in the late 1990s and into the 2000s global environmental agencies increasingly coalesced around concepts of headwater wetlands as high-storage regulators, framed as 'sponges' performing flood flow attenuation, recharge promotion and dry season flow regulation. In 2003 a seminal global paper reviewed scientific evidence that argued against universal generalization of the sponge model. This paper will present updated consolidated evidence from science findings since 2003, including over 15 studies from the SADC region and Sub-Saharan Africa. Both recent global and African evidence are more congruent with the 1980s low-storage generator model, and show even less correspondence to the sponge generalization. So, this paper will recall the Southern Africa data, evidence and findings from the 1980s for the low-storage, generating model of headwater wetlands, and how that opened up an understanding of a two-tier hydro(geo)logical response model for Basement Aquifer complex.

Africa’s groundwater cannot be properly understood if interactions with the extensive headwater wetlands are misunderstood. Because wetland science is divergent so there is a real danger of distortion being introduced into African groundwater science. The paper will conclude by illustrating how the two divergent hydrological scientific foundations around wetlands could lead to fundamentally different conceptual framings of groundwater and surface water interactions.

**Keywords:** Groundwater, wetlands, hydrology, models, storage

University of Botswana, Department of Environmental Science, P/Bag UB 00704, Gaborone, Botswana

University of The Bahamas, School of Chemistry, Environmental and Life Sciences, PO Box N-4912, Nassau, Bahamas.

Corresponding author: kenabatho@mopipi.ub.bw

ABSTRACT

Groundwater resources in Botswana and many developing countries are declining due to abstraction that is higher than annual recharge. Despite this, groundwater and surface water (GW-SW) dynamics and their connections are poorly understood though they are key to unlocking water resources management in semi-arid areas. In order to address these important issues this study aims to investigate GW-SW interactions dynamics and their possible implications on the quality and quantity of water in the karstified dolomite-dominated Notwane River Catchment (NRC) in the south-eastern part of Botswana with the view to advance knowledge of groundwater resources in the study area. The key objectives of the study are to 1) determine the influence of the intermittent Notwane River on groundwater resources and vice versa in an area stressed by groundwater abstraction, 2) identify, quantify and map areas with potential pathways that facilitate GW-SW interactions in the study area and 3) to investigate seasonal dynamics and their potential effects on groundwater quantity in the NRC.

To achieve this, isotopic data specifically stable isotopes of Deuterium and Oxygen-18 are analysed from groundwater, surface water and rainfall samples. Analysis of isotopic data is based on a δD-δ18O diagram, where recharge/discharge points, sources of recharge along the river are determined. Chemical analysis and water rest level data from the available monitoring boreholes is used to validate the isotopic results. Seasonal dynamics on GW-SW interactions are investigated from the samples collected in the study area. Preliminary results from the isotopic and chemical analyses indicate possible areas of high GW-SW interactions between the nearby river and the underlying aquifer particularly those areas dominated by dolomite lithology. The results have implications on water resources management policies in the study area and potentially in similar areas within the Southern African region.

Keywords: Botswana, Semi-arid, Notwane River Catchment, Groundwater-surface water interactions, Stable isotopes.
I Kinoti, M. 1Leblanc, 1A. Olioso, 2M. Lubczynski, 3P. Kenabatho, 4B. Swartz, 5K. Majola, 6C.R. Tales, Application of remote sensing to assess recharge and discharge mechanism in the Stampriet Transboundary Aquifer System (STAS).

1UMR EMMAH, INRA—University of Avignon, 84000 Avignon, France
2University of Twente, Faculty Geoinformation Science and Earth Observation, 7514 AE Enschede, The Netherlands
3University of Botswana, Botswana
4Ministry of Agriculture, Water Affairs and Forestry, Namibia
5Department of Water and Sanitation, South Africa
6UNESCO, International Hydrological Programme, 75352 Paris Cedex 07 FRANCE

Corresponding Author: irene.kinoti@alumni.univ-avignon.fr; Tel.: +33666328744

Abstract

The Stampriet Transboundary Aquifer System (STAS) covers a large arid region stretching from Central Namibia into Western Botswana and South Africa’s Northern Cape Province. In this region, there are no permanent surface water bodies and groundwater is the only reliable water resource. Rainfall is the main input of water in the basin and evapotranspiration the main output with groundwater abstraction and lateral outflow across the south east boundary as the minor output. Due to high temperatures, hence high potential evapotranspiration, groundwater recharge occurs only during high intensity rainfall events. Lack of climatic monitoring network poses a major challenge in the assessment and management of water resources in the basin.

In this study, remote sensing data is used to investigate groundwater recharge and discharge processes in the basin. This is achieved through (1) analysis of spatial-temporal variability of rainfall and actual evapotranspiration, at both short (daily, monthly and seasonally) and long term (annually: 1980 to present) scale to better understand water budget dynamics in the basin; (2) investigation of the response of groundwater levels to high rainfall events (recharge events) as well as to drought; (3) reconstruction of time series evolution of groundwater irrigation in the basin and development of vegetation along river beds from Landsat time series data; (4) analysis of thermal anomalies to identify groundwater discharge zones; (5) mapping of sink holes following high intensity rainfall events using Normalised Difference Water Index. Preliminary results show high seasonal and inter-annual variability of rainfall and evapotranspiration in the basin. Groundwater levels respond to rainfall events with a rise after an intense rainfall and a decline after a drought. The results of this study will give a better understanding of spatial and temporal recharge and discharge dynamics within the basin and will form a basis for an integrated numerical model.

Keywords: groundwater recharge, groundwater discharge, remote sensing, water budget, Stampriet Transboundary Aquifer System (STAS)
P. Kenabatho, T. Setloboko, B. Swartz, M. Amakali, K. Majola, Sekwele, R. Pule, T.C. Resende, **Assessment of the impacts of climate variability on total water storage in the Orange-Senqu River Basin: implications for groundwater resources management.**

1University of Botswana, Botswana
2Department of Water Affairs, Botswana
3Department of Water Affairs and Forestry, Namibia
4Department of Water and Sanitation, South Africa
5Orange-Senqu River Commission – ORASECOM Secretariat, South Africa
6UNESCO International Hydrological Programme (IHP)

**ABSTRACT**

Due to global trends in climate and human activity, groundwater is becoming increasingly more important as a water source. Alongside the effects of climate change and anthropogenic factors, natural climate cycles have considerable impacts on the hydrologic cycle. In particular, they can affect groundwater recharge. In this paper we look at how global climatic oscillations cycles, like El Niño– Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) affect total water storage and groundwater storage in the Orange-Senqu River Basin by analysing two large aquifers (area > 100 000 km²): the Stampriet Transboundary Aquifer System (STAS) shared between Botswana, Namibia and South Africa, and the Karoo Sedimentary Aquifer shared between Lesotho and South Africa. To evaluate the impact of inter-annual and multi-decadal climate variability on groundwater resources, we look at time series of oceanic indices and compare them to total water storage estimates made from two approaches. The first one is made through the analysis of data from the Gravity Recovery and Climate Experiment (GRACE), which provides information from 2002 to 2017. The second is a through a climate-driven model which comprises of two-variables, precipitation and evapotranspiration, that reconstructs past water storage changes from 1980 to 2017. Observed groundwater levels are used to validate these estimates and adapt the methods where possible. Results are expected to show that rainfall patterns connected with the ENSO and IOD are the maindriver of changes in inter-annual groundwater storage in the Orange-Senqu River Basin. These results are aimed at helping to address the threat of water scarcity and the effects of climate variability and change, indicating where more detailed local studies are necessary, and further supply scientific information to support the development of long-term groundwater management strategies. This study is a contribution to the UNESCO-IHP Groundwater and Climate Change programme (GRAPHIC).

**Keywords:** Groundwater, climate variability, climate change, Managed Aquifer Recharge (MAR)
M.S. Magombeyi, K.G. Villholth, R. Healy, G. Ebrahim, Recharge assessments across the Limpopo River Basin, approaches and findings

1International water management institute, Pretoria, South Africa
2United States Geological Survey, United States

Abstract

The productive groundwater supply function from aquifers is important for effective and sustainable management of domestic, agricultural and environmental water supply. Groundwater recharge or replenishment either diffuse or focused is an important management parameter. However, no single comprehensive recharge estimation technique that give reliable results has been identified from a range of those available. The objective of this paper is assess recharge from three catchments (Hout, Letsitele and Ramotswa) of the Limpopo River Basin. These catchments cover both perennial and ephemeral rivers and are found in subhumid, semi-arid and arid areas. The recharge estimates were based on nine methods that include Water Table Fluctuation (WTF), improved WTF, Chloride Mass Balance (CMB) and baseflow separation methods of river water balance, water level transect monitoring, recursive digital filter, isotope (Oxygen-18 and hydrogen -2) and chemical (silica) hydrograph separation and a 3D hydrogeological flow model, based on the One-Water Hydrologic Flow Model (MODFLOW-OWHM) modeling. Overall, the diffuse recharge ranged from 0.4-14%, of the mean annual rainfall (407-800mm) in the three catchments, while focused recharge was 1.1% in one of the ephemeral river catchments. Multiple recharge estimates from several methods were comparable in each catchment. Application of WTF method for estimating recharge requires identification of the water level rises that are attributable to recharge from precipitation or surface water body, while the CMB requires chloride levels from rainfall and groundwater. The CMB and Oxygen-18, hydrogen-2 and silica separation are potentially more reliable and likely to give better results, especially in ungauged catchments, while recursive digital filter, WTF and improved WTF methods are easier to implement where groundwater levels are available. Isotope tracer applications require careful planning as they are relatively expensive to analyze compared to the chemical tracers. Background sources of the tracers that include geology of the area should be identified and accounted for, for accurate results. The application of several independent groundwater recharge methods to complement one another and reduce uncertainty is likely to improve our knowledge of aquifer recharge, provided that an adequate hydrogeologic database exists and is continuously being updated. The methods used in this study can be adopted in areas characterized by sensitive ecosystems and heavy conjunctive use of groundwater and surface water.

Keywords: Chemical and isotope hydrograph separation, Chloride Mass Balance, Diffuse recharge, Groundwater recharge, Tracer, Water levels
C. Cambaza, P. Saveca, M. Hushof and P. van der Zaag, **Irrigation package for sand rivers (IPSAR) – Feasibility Study - Case Study of Limpopo River, Mozambique**

*Instituto Superior Politécnico de Gaza (ISPG), Mozambique*

*ACACIA Water, The Netherlands*

*IHE Delft Institute for Water Education, The Netherlands*

**Corresponding Author:** email: ambaza@gmail.com.

**Abstract**

Arid lands are often crisscrossed by sand rivers, which flow only immediately after rainfall events, but have a river bed that is often filled with several meters of (coarse) sand. This bed forms a so-called aquifer, a shallow groundwater reservoir that is recharged every time the river flows. This feasibility study assesses the technical feasibility, the business case and the upscaling potential of an Irrigation Package for Sand Rivers (IPSAR) in the Limpopo River, Mozambique. IPSAR allows farmers to abstract water from the river dry bed and conduct it to the fields for immediate use. Four different packages where installed in different farmer fields across Chókwè and Guijà districts, the province of Gaza. The package components (type of well, pump, conveyance, and application system) are combined to meet the specific needs of each farmer. The research showed that the total cost of the IPSAR will vary between 675.00 and 1,420.00 USD (42,000.00 and 88,000.00 MT) for a plot size of 2,000 m². Under current conditions, smallholder farmers have an average net profit of 45,000 MT/ha/season, which would result in a payback time of 3 years for the package. Introducing the package was found to be feasible on 49,400 ha of land, enabling sustainable abstraction of 150 Mm³/year of water. IPSAR would allow 30,000 smallholder farmers along the Lower Limpopo to irrigate at least 15,000 ha of horticultural crops. The package provides a secure source of water, making it possible to invest in cash crops and increase net profit. The installation of the package will require government or donor funding to set up an adequate financing modality provided by a local institution with experience in agricultural finance. IPSAR has the potential to improve food security and raise the average income for thousands of smallholder farmers supporting their families in rural Mozambique.

**Keywords:** Mozambique, Limpopo River, Irrigation, Sand rivers, Chókwè, Guijà.

Geology Department, Faculty of Science, University of Botswana, Gaborone, Botswana,

**Corresponding Author:** Nata.tafesse@mopipi.ub.bw

**Abstract**

The study area is located in south eastern Botswana and extending into South Africa. An integrated analysis of hydrogeology, hydrochemistry, and geophysics data is undertaken to carry out characterization of Ramotswa Transboundary Dolomite Aquifer. Aeromagnetic and gravity data and their processed products were used for subsurface characterization and delineation of the structural framework of the Ramotswa Transboundary Dolomite Aquifer. Minor faults or dyke elements trending in NW-SE and NE-SW were delineated by both gravity and aeromagnetic data. Qualitative interpretation of processed gravity and aeromagnetic datasets showed the lateral extent of the Taupone dolomites to be greater than their surface outcrop between Ramotswa and Supingstad. Gravity 2.75D modelling revealed lateral extent of Taupone dolomites to between 500-600 metres. Groundwater flow follows topography with water table high in Ramotswa and lower in Lobatse within the Ramotswa Transboundary Dolomite Aquifer. Boreholes depths vary within the Ramotswa Transboundary Dolomite Aquifer, shallow to deeper boreholes in Ramotswa and deeper ones in Lobatse. Hydrostratigraphic mapping of the Ramotswa Transboundary Dolomite Aquifer from boreholes logs in Ramotswa well field identified the aquifer to be a multilayer confined and unconfined-leaky aquifer type. The depth to dolomite bedrock delineated from borehole logs is about 150 meters. Transmissivities for the Ramotswa Transboundary Dolomite Aquifer range between 250 to 3700 m²/day in Ramotswa and 1 to 400 m²/day in Lobatse. Borehole yield classification reveal existence of dry well, poor yields of about 0.1 to 5.9 l/s, moderate yields of about 6-9.9 l/s and high yields greater than 10 l/s. The high yields are within the Ramotswa Transboundary Dolomite Aquifer in Ramotswa and Lobatse. Time series plots of hydrochemistry data revealed elevated levels of Ca²⁺, NO₃⁻, and F⁻ in Ramotswa wellfield for a period from 1974 to 1996 though within the water drinking standards of the time except nitrates levels. Recent hydrochemistry data reveal the trend has not changed with elevated levels of nitrate. Sources of nitrate contamination in the Ramotswa Transboundary Dolomite Aquifer have been attributed to anthropogenic processes. Regional structures of areal extent do not exert control in groundwater flow in the Ramotswa Transboundary Dolomite Aquifer. The groundwater flow and occurrence in this aquifer is mainly through localised fractures developed through a process of karstification. This process has resulted the aquifer to be a highly permeable, heterogeneous and anisotropic aquifer. Overall results demonstrate that combined analysis of gravity, aeromagnetic, hydrogeological, hydrochemistry data provide the best approach in characterisation of the Ramotswa Transboundary Dolomite Aquifer in the study area.

**Keywords:** Dolomite, Groundwater flow, Karstification, Ramotswa, Transboundary Aquifer.
GY. Ebrahim, K. G. Villholth, J. Lautze, K. Keodumetse, P. Kenabatho, S. Mndaweni, N. Sivashni and M. Moehadu,

**Hydrogeological model for the Ramotswa transboundary aquifer - How much do we know?**

1International Water Management Institute, 141 Creswell Road, Weavind Park, Pretoria, South Africa
2Department of Water and Sanitation, Gaborone, Botswana
3University of Botswana, Gaborone, Botswana
4Department of Water and Sanitation, Pretoria, South Africa
5Water Utilities Corporation, Gaborone, Botswana

**Corresponding Author:** g.ebrahim@cgiar.org

**Abstract**

As is the case in many semi-arid /arid regions, surface water resources in the Ramotswa Transboundary Aquifer area shared between Botswana and South Africa are generally scarce or unreliable due to high temporal variability. Therefore, groundwater is being increasingly used for domestic water supply, livestock watering, industrial and agriculture uses. To provide guidance on groundwater use and management, better understanding of the groundwater recharge and flow processes in the dolomitic aquifer environment, water use and its dynamics in the area is required. In order to support this process, a transient three-dimensional hydrogeological model was developed using MODFLOW 2005 in Model Muse graphic user interface. The modelled area covers 80 km² and encompasses Ramotswa town and wellfield area. The transient model was calibrated using monthly observed water level data from 17 observation wells measured from 2000-2008 and validated for the period 2009-2012. In general, good agreement between observed and simulated water levels was obtained, both temporarily and as snapshot of the piezometric surface and despite lack of observed river flow data. The residuals are randomly distributed across the study area. The transient model reasonably reproduced the observed water level dynamics, which, however, generally showed smaller amplitude relatively to observations. Results showed that the water budget in the study area is highly variable on an annual scale. Recharge rate (total recharge, diffuse from rainfall and focused from the river) during the simulation period ranges from 0.43 – 53.2 mm/a (a mean of 24.5 ± 14.4 mm/a, or, of 5.6 ± 1.3 % mean annual rainfall). Evapotranspiration directly from the groundwater is a significant component of the groundwater budget and ranges from 14.7 – 40.0 mm/a (with a mean of 27.0 ± 6.8 mm/a), which exceeds the recharge rate in most years. Annual change in groundwater storage ranges from -31.4 – 15.7 mm/a (with a mean of -11.4 ± 11.3 mm/a) and is strongly correlated with annual rainfall (R²=0.88). While further understanding of focused recharge processes as a function of river flow and of groundwater loss to evaporation is needed, the modelling provides a better understanding of the dynamics and spatial and temporal variability in key parameters required for managing the groundwater resources sustainably, and for maintaining resilience in the context of increasing water demand and climate change.
Keywords: Hydrogeological modelling, MODFLOW, Ramotswa transboundary aquifer, groundwater recharge, water budget/dynamics, sustainability
Assessing managed aquifer recharge potential in the RAMOTSWA transboundary aquifer area– a hydrogeological modelling approach

1International Water Management Institute, 141 Creswell Road Weavind Park, Pretoria, South Africa,

2University of Freiburg, Germany

3International Groundwater Resources Assessment Centre (IGRAC), Delft, the Netherlands

4Department of Water and Sanitation, Gaborone, Botswana

5University of Botswana, Gaborone, Botswana

6Department of Water and Sanitation, Pretoria, South Africa

7Water Utilities Corporation, Gaborone, Botswana

Corresponding Author: g.ebrahim@cgiar.org

Abstract

Groundwater is the main water source for domestic and industrial water supply, livestock watering and vegetable garden irrigation in the Ramotswa transboundary aquifer area. Improving water security in this area is essential to meet water demand in the face of increasing population, urbanisation, recurrent droughts, climate change and variability. Managed aquifer recharge (MAR) has been practiced in many countries as a means of increasing groundwater availability and improving the overall reliability of water supplies. The main objective of this study was to assess the technical feasibility of surface spreading MAR using an integrated hydrogeological modelling approach. A calibrated transient hydrogeological model was coupled with linear programming optimization to determine the optimal recharge over a 8100 m² spreading basin (dictated by model grid size), based on infinite recharge water availability and field-constrained filtration rates for wet and dry year scenarios, while meeting operational constraints such as maximum acceptable water level mounding. Results of the study showed that the maximum total volume of recharged water for the three-month period [January- March] is 0.76 and 0.48 Million Cubic Meters for the dry and wet year’s scenario, respectively. During the dry season, the depth to groundwater increases (from 6.7 m to 7.0 m on average) allowing more space for recharge; conversely source water is limited during this period unless treated wastewater is considered. Results of Forward Particle Tracking using MODPATH showed that particles do not reach existing production boreholes during the simulation time. Travel time of 60 days is a regulatory limit required for inactivation of pathogens or other nutrients commonly present in recharge water. However, it is important to note that due to the karstic nature of the aquifer, travel times may be overestimated. Rapid flow through conduits, not accounted in the current model, may result in undesired short travel time that may affect the water quality of the recovered water, as well as complicate effective inter-season recovery. In conclusion, due to the observed relatively shallow depth to the groundwater and high evapotranspiration from groundwater, conditions seem unfavourable for effective recovery in the dry season of water recharged in the wet
season. Further research is needed to better understand the travel times in the aquifer.

**Keywords:** Managed aquifer recharge, Ramotswa transboundary aquifer area,

*Komati Basin Water Authority, Republic of South Africa & Swaziland*

**Abstract**

The Komati Basin Water Authority initiated a groundwater monitoring programme to develop its understanding on groundwater and surface water interaction with its water resources of the basin. The Komati river basin is believed to be water stressed and experiences water shortages especially during droughts. The population and economic growth development indicates that water demand will further increase and worsen the stress on water supply systems. Groundwater abstraction shows a great potential in its crucial role of augmenting surface water supply and improving water yield for sustainable activities.

Groundwater is used largely for domestic water supply and the level of understanding of the groundwater resource is very limited. This lack of understanding of the behavior of groundwater has led to neglect of this resource even when shared with other riparian states. Sound management and monitoring principles should be seen as being complimentary and as a vital tool for effective water management in larger river basins.

In order to draw-up a conclusive decision-making processes, we need a set of guiding principles to be defined and followed through the planning and implementation of groundwater augmentation networks which should amongst other principles enable the generation of information about quantity and quality of groundwater and the determination of feasibility of extracting the groundwater.

**Key words:** Augmenting, Basin, Groundwater, Monitoring, Interaction.

1Eduardo Mondlane University, Faculty of Sciences, Main University Campus, Maputo, Mozambique

2Eduardo Mondlane University, Faculty of Engineering, Maputo, Mozambique

**Corresponding Author:** L. F. Tamele Jr. tamelejrlucas@gmail.com

**Abstract**

Increased water demands and reduction in surface water availability due to rapid population growth has led to increased exploitation of groundwater sources by a large number of private operators given that the existing water supply network system doesn't reach all populated areas. For its nature of being a coastal aquifer system, the Great Maputo aquifer is prone to natural and anthropogenic contamination threats. This work aims to evaluate the influence of natural and anthropogenic activities in the groundwater quality of the study area.

Two sampling campaigns were carried out, the first sampling was conducted covering 10 observation wells of ARA-Sul (Pz samples, hereinafter) complemented by a second sampling covering 4 private operators wells (FEUI samples, hereinafter). In total, 25 physicochemical and 4 microbiological water quality parameters were determined in Situ, LNHAA and AdeM laboratories.

The study results showed that all samples presented at least one quality parameter above the maximum admissible values (MAV, hereinafter) established by official drinking water norm (MISAU ministerial diploma No. 180/2004 of 15 September). The groundwater contamination by NO3 in all FEUI samples is linked to in situ sanitation (FEUI-04, FEUI-61, and FEUI-92, respectively, 100, 100 and 200 mg/L) and agricultural activities (FEUI-08, 100 mg/L). Total coliforms bacteria were detected in FEUI-61 and FEUI-92, 2 and 3 coliforms/100 mL, respectively, caused by contamination by in situ sanitation systems predominately used by the population in sampled zones. Also, the dissolution of minerals of the study area geological formations has affected groundwater quality in Greater Maputo: all Pz samples presented Fe ion and Mn ion concentration above the MAV (0.3 and 0.1 mg/L, respectively). The ARA-Sul observation wells Pz-02, Pz-12, and Pz-17 (EC 3250, 4197, 5999 μS/cm, respectively) showed highest values of saline water, due to natural causes linked to the geological formation.

**Keywords:** Greater Maputo, groundwater quality, natural and anthropogenic activities
P.S.L. Saveca, T.Y. Stigter, E. Lukas and D. Juízo, *Investigation of hydrogeochemical processes and groundwater quality in the Chókwè District, Mozambique*

1Instituto Superior Politécnico de Gaza, Faculty of Agriculture, Londe Campus, PO Box 1, Chókwè District, Mozambique; email: paulosaveca@gmail.com

2IHE Delft Institute for Water Education, Department of Water Science and Engineering, 2611 AX Delft, the Netherlands.

3Institute for Groundwater Studies, Faculty of Natural and Agricultural Sciences, University of the Free State, PO Box 339, Bloemfontein 9300, South Africa.

4Universidade Eduardo Mondlane, Department of Engineering, 3453 Maputo, Mozambique

**Abstract**

The present study was carried out in Chókwè district, one of the semi-arid regions in Mozambique, within the Limpopo River basin. A total of 27 samples were collected at a depth ranging from 4 to 100 m. The study focused on investigating hydrogeochemical processes that influence the water quality, as well as their spatial variability in Chókwè district. Software for hydrogeological approaches (WISH) and geospatial tool (Quantum GIS) was combined with statistical analyses to assess the groundwater quality. Geochemical ratios, correlation and diagrams were also applied to understand the influence of the local geological formations on groundwater hydrochemistry. The Mozambican standards for drinking water and those of the World Health Organization were used for the assessment of groundwater quality. The groundwater chemistry indicated that the order of abundance of cations was Na⁺ > Mg²⁺ > Ca²⁺ > K⁺, while that of anions was Cl⁻ > HCO₃⁻ > SO₄²⁻. There was a dominance of Na-Cl hydrochemical facies and highly mineralised groundwater occurs where the aquifer is underlain by two geological deposits: 1) alluvium-sand-silt-gravel and 2) eluvial-floodplain-clayey-sand. Both geological deposits showed that the porewater EC and TDS values ranged from 522 µS/cm to 12000 µS/cm and 406 mg/L to 7626 mg/L, with an average of 2485 µS/cm and 1683 mg/L, respectively. About 15% and 30% of the groundwater samples were classified as poor and unacceptable for drinking, respectively. For hardness, 7% and 30% of groundwater was hard and very hard, respectively. Weathering, ion exchange, dissolution and precipitation were the main hydro-geochemical processes. The aquifer mineralogy is dominated by sodic plagioclase (Albite), calcic plagioclase (Anorthite), halite, dolomite and calcite.

The groundwater was classified as saline and 67% as freshwater. The land use, chemical evolution, as well as the local hydrogeology, were the factors affecting the spatial variability of water quality.

**Keywords:** Groundwater quality; hydrogeochemistry; weathering, ion exchange.

Department of Earth Sciences, University of the Western Cape, South Africa

Corresponding author: 3444709@myuwc.ac.za

Abstract

The use of groundwater for domestic, agriculture, industrial and environment especially in semi-arid environment continues to be fundamental. In this paper the argument is the knowledge on aquifer-river interaction remain poorly understood in terms of recharge (input), flow (storage) and discharge (output) of groundwater. In other words, unless knowledge improves on groundwater process, sustainable use for groundwater dependent communities is not guaranteed. In this paper, the question on what control groundwater processes was answered. The groundwater process model was developed to assess influence of geological structures on groundwater recharge, flow and discharge. The aquifer-river interaction was chosen as a unit of analysis. The Hout River Basin was used as a case study. The area is characterised by crystalline aquifer system with weathered zone, fractured rock and dikes. During the study, geological structures were mapped and a conceptual model for groundwater processes was produced which explained the recharge, flow and discharge dynamics. A fieldtest experimental design was followed whereby groundwater processes within the geological structures (dyke) were tested and compared to the control site. Preliminary results on mapping the geological structures showed that pools of water along the river were underlain by presence of dyke structure which confirmed by geophysical surveys and drill logs’ results validated dykes as aquifer path ways to rivers. One step would to set up a longitudinal study on isotope hydrology that would trace and confirm the source/origin of water in pools as discharged or recharged waters. Based on such recommendation it can be concluded that the conceptual model of groundwater process was adequate to achieve the aim of this study.

Key words: Aquifer-river interaction, geological structures, groundwater process, conceptual model
M. Gomo, *On the use Theis, and Cooper and Jacob methods to interpret multi-well aquifer pumping tests in laterally heterogeneous confined aquifer systems.*

University of the Free State, Institute for Groundwater Studies, Faculty of Natural and Agricultural Sciences PO Box 339, Bloemfontein 9300, South Africa.

Email: GomoM@ufs.ac.za

**Abstract**

The meaning of aquifer parameters estimated in heterogeneous is remains uncertain despite decades of research in groundwater hydraulics. While some studies have proposed new methods, the challenge will remain due to the inherent nature of the subsurface heterogeneities. The need to continuously improve the understanding of the application of classical methods of Thesis and Cooper and Jacob time-drawdown methods in heterogeneous aquifers is still very much important. While the nature and degree of aquifer heterogeneity varies in space, there are many environments which are characterised by laterally heterogeneous aquifers. Numerical evaluation of transmissivity estimates in laterally heterogeneous formations from single well aquifer test has been conducted. Estimation of parameters from multi-well test in laterally heterogeneous formations has not been numerically evaluated. The study numerically evaluates the application of Theis, and Cooper and Jacob to interpret aquifer pumping test in laterally heterogeneous aquifers. The study utilises numerical simulations in 3 multi-well aquifer pumping tests in aquifer systems with simple, arbitrary distributions of lateral aquifer zone heterogeneities where pumping and observation wells are located in different zones. Theis and Cooper-Jacob methods are used to analyse the data. Although the Thesis model can be matched to the observation data, transmissivity estimates from observation data are not meaningful. However estimates of storativity from observation data using the Theis are within the same range as the model prescribed. Analysing the pumping well data located in each aquifer zone with Cooper and Jacob method before the influence of lateral boundaries but after radial acting flow conditions are achieved gives the correct prescribed model transmissivity for the different aquifer zones. The findings suggest that a single-well test would be best suited to estimate the transmissivity for each aquifer zone of a laterally heterogeneous system.

**Keywords:** Aquifer pumping test; Cooper and Jacob method; Groundwater hydraulics; Heterogeneous aquifers; Multi-well tests and Theis method.
L. Schäfer, T. Himmelsbach, H. M Schöniger, **Strengthening groundwater management through an integrative approach.**

1Fraunhofer Institute for Surface Engineering and Thin Films (IST), Braunschweig, Germany Lothar.Schaefer@ist.fraunhofer.de

2Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany Thomas.Himmelsbach@bgr.de

3Technische Universität Braunschweig, Leichtweiß-Institute for Hydraulic Engineering and Water Resources, Hydrology, Water Management and Water Protection (LWI-HYWAG), Germany m.schoeniger@tu-bs.de

**Abstract**

The aim of our initiative is to demonstrate, that groundwater resources can become increasingly strategic in the SADC regions. Recently completed and current research and development projects in the SADC regions (e.g. Exploration of deep aquifer systems in the Northern Kalahari Basin, SASSCAL and the EU Project SafeWaterAfrica as well as the German Federal Ministry of Education and Research Project GRoW-go-CAM) provide essential building blocks for an integrative approach to enhance security of freshwater supply.

The importance of groundwater resources is highlighted by the fact that groundwater as an invisible resource under increasing pressure due to human activities and climate change worldwide. Advanced understanding of the groundwater/surface water interaction, a new exploration strategy for semi-fossil aquifers and the implementation of effective water infrastructure systems and technology are measures against supply shortages. Biggest challenges are the full exploration of deep aquifers, the understanding and modelling of their recharge processes and the integration of groundwater resources in the complex regional water system including surface hydrology (rivers and artificial reservoirs). In addition to the analysis of quantitative fresh water availability and its development (population growth, climate change), the focus is also on the quality of freshwater.

As an important part of an integrated groundwater management program the implementation and advancement of autonomous and decentralized water treatment systems for rural and periurban areas comes into focus. Newly developed treatment systems must be considered as an essential contribution to ensure the local water supply safety as they are highly efficient in the degradation of harmful pollutants and at the same time very effective in killing microbiological contaminants. Knowledge about the state of water resources derived from monitoring and modelling systems must be coupled with suitable and effective governance measures to respond to the challenges outlined.

A dialogue platform as developed in the go-CAM project is to be understood as a governance instrument that combines physically-based modelling results with multi-criteria decision analysis techniques (MCDA). In this platform, the assessment is based on physical indicators which are subordinated to the UN's SDG 6. Groundwater as an important water resource for water supply is currently not adequately represented in the UN-SDGs. Especially for South Africa, it is important to further develop physical based indicators for the assessment of groundwater availability and quality in the context of increasing water stress. The German consortium is looking for SADC-partners
in the water sector, on local rural communities or national organisation level to help exhaust local possibilities around this “blue gold”.

**Keywords:** groundwater potential, dialogue platform, physical indicators, water treatment

1Umvoto Africa (Pty) Ltd, PO Box 61, Muizenberg, Cape Town, South Africa, 7950

2GEMS/Water Unit, Science Division, UN Environment, P.O. Box 30552, Nairobi, Kenya, 00100

**Corresponding author:** dylan@umvoto.com

**Abstract**

The “Cape Town Major Aquifer Systems” use case study is one of three water quality case studies (the others being “Volta Pathogens in Ghana” and “Lake Victoria Ecosystems in Kenya”) that are a project recommendation of the United Nations Environment Programme (UNEP) and key implementing partners of the World Water Quality Alliance (WWQA). This project is part of the Global Water Quality Assessment (GWQA) mandated by UNEP member states, and aims to build the “use case” for a GWQA by means of the piloting and demonstration of current capabilities, future information and services of the WWQA through the three aforementioned African case studies.

An extreme, extended 1:590-year drought in the Western Cape of South Africa from 2015 to 2017 put such severe strain on surface water resources that the regional water supply system came close to failing in early 2018 (“Day Zero”), with potential devastating local to national societal and economic impacts.

As a result the City of Cape Town initiated its “New Water Programme” in earnest to a) diversify its water supply to improve its long-term water security and resilience against future droughts; and b) meet the demand by an ever-growing urban population, improving the standard of living of approximately half of the city’s population through achieving SDGs 6 and 11.

Groundwater from three major aquifer systems that the city has access to was identified as one of the alternative bulk water supply options, which includes: the primary sand Atlantis and Cape Flats Aquifers; and the regionally extensive, fractured Table Mountain Group Aquifers (TMGA). Water quality issues in the two primary aquifers include extensive natural hardness and iron fouling (which reduces borehole yield and requires frequent cleaning), and groundwater contamination (salinisation, nutrients, microbiological and industrial contaminants, hydrocarbons and potentially CECs) from a variety of point and diffuse sources. Improvement of primary aquifer groundwater quality is planned through the introduction of water-sensitive urban design, biomimicry, wetland restoration for natural bio-remediation and managed aquifer recharge with treated wastewater. The fractured TMGA contain naturally elevated acidity and iron/manganese concentrations that have to be reduced prior to distribution or mixing in surface water storage schemes, whereas it is essential that groundwater abstraction does not negatively impact surface and groundwater-dependent ecosystems through changes in aquifer hydrochemistry and reduction of flow.

The use case studies aim to engage with a range of stakeholders to better understand water quality requirements; undertake water quality data analysis and modelling; and develop solutions-oriented water quality action plans in order to assist operational services.
Keywords: Cape Town, primary and fractured aquifers, groundwater quality.

**Abstract**

The impacts of climate change are significant on both surface and groundwater resources. However, little attention has been given to the effect of climate change on ground water resources. Therefore, the present study is concerned with the effect of climate change on groundwater recharge and base flow in Tekeze-Atbara catchment in Ethiopia. The future climate variables were obtained from Coordinated Regional Climate Downscaling Experiment (CORDEX)Africa program for Representative Concentration Pathways (RCPs) of RCP 2.6 and RCP 4.5 scenarios. The Mann-Kendall test and Sen’s slope estimator were used for trend detection using XLSTAT software package. Further, the downscaled and bias corrected precipitation, temperature, and potential evapotranspiration were used as input to the WETSPA model to simulate future water balance changes. The results indicated a decreasing trend in annual rainfall and an increasing trend in average temperature and evapotranspiration for selected scenarios. At the catchment level, precipitation decreases by 20% for both RCP 2.6 and RCP 4.5 scenarios, and actual evapotranspiration shows 0.4% and 8.1% increment for RCP 2.6 and RCP 4.5, respectively. Consequently, the groundwater recharge decreases by 3.4% for RCP 2.6 and 1.3% for RCP 4.5. Baseflow will also decrease by 1.5% and 0.55% for RCP 2.6 and RCP 4.5, respectively. The results of this study would help policymakers, scientists, government officials and local stakeholders in planning and management of the surface and groundwater resources in the Ethiopian regions.

**Keywords:** Tekeze catchment, Climate change, Recharge, Base flow, Trend analysis, WetSpa
L. M. Sharma, **Creating fresh water source within saline aquifer.**

Lalit Mohan Sharma  
SM Sehgal Foundation, 34, Sector–44, Gurgaon (Haryana), INDIA lalit.water@gmail.com, lalit.sharma@smsfoundation.org M. Phone: + 91 9971695930

**Abstract**

Groundwater salinity is a widespread problem around the world with adverse consequences on health, soil quality and overall eco-systems. With the rapidly growing demands of groundwater, its exploitation is also accelerating. It is also changing the flow of the groundwater, which in turn causes ingress of sea water or intrusion of other saline groundwater or polluted water from the surrounding areas. The major consequences are scarcity of water even for domestic use and rise in the level and spread of groundwater salinity. An innovative technique of creating a pool of fresh groundwater within a saline aquifer is developed, which can address the issue. Technique is about recharging the saline aquifer with harvested rain water in such a way that recharged rain water does not get mixed with the existing saline groundwater rather it forms pool of fresh water in the saline aquifer. Water from this pool can be extracted without getting it mixed with saline groundwater. This innovation also eliminates the need of cost intensive provision of water storage structures to store rain water for fulfilling the domestic water needs. Thus, the saline aquifer unsuitable or otherwise useless for groundwater development can be used.

**Keywords:** Rainwater harvesting, hydrostatic pressure, aquifer, groundwater salinity
1M.E. Masemola, *Barriers against groundwater development.*

1Groundwater Specialists (Pty) Ltd, Pretoria, South Africa

**Corresponding author:** eva@nabla-h.co.za

**Abstract**

Groundwater development and management has been an ongoing topic, in particular, for the Department of Water and Sanitation as well institutions such as the Water Research Commission. Recent droughts conditions experienced in South Africa have highlighted groundwater as a resource that should be actively exploited, managed and protected. However, it is often viewed as unreliable and relegated to the emergency water supply section, as it has been noted with the response to the prevailing drought conditions in South Africa. It cannot be ignored that social and economic growth bring added pressure on water resources. Industries such as mining and agriculture increase the need to bring groundwater knowledge and management to the forefront of water resource management for socio-economic development and food security. The common narrative around challenges associated with groundwater development and management centre around data availability and inherent uncertainty of the resource characterization. However, this has not been a distinct finding from research. Studies have found that the challenges lie in 1) developing operational and maintenance systems to support groundwater supply schemes, 2) institutional capacity, including skills development to manage groundwater systems and 3) compliance monitoring and resource protection. Research suggests that at a national level, groundwater has received much needed attention. In comparison, at a local level, its development is lagging behind and/or poorly managed regardless of availability of the resource. There is an opportunity for groundwater scientists and water institutions in South Africa to shift the conversation on groundwater from a strategic level to sustainable implementation. The challenges highlighted present opportunities for skills development and transfer, inter-industry partnerships as well as innovation of operational and management systems.

**Keywords:** Groundwater Exploitation. Development. Socio-Economic

International Groundwater Resources Assessment Centre (IGRAC), Netherlands

Institute for Groundwater Studies (IGS), South Africa

Corresponding author: geert-jan.nijsten@un-igrac.org.

Abstract

The state of groundwater data collection and data management in SADC Member States has been assessed through interviews under groundwater professionals and review of groundwater data collection and management practices. The assessment indicated that the region faces challenges such as limited capacity for data collection, database management and analyses; inconsistence in data collection and routine quality controls; difficult access to data and limited interpretation of data. It is against this premise that a Framework for groundwater data collection and data management was developed. The framework aims to fill the gap between strategies and policies on water resources and technical guidelines and manuals, by providing organisational and planning structures for collection and management of groundwater data in a strategic, innovative and cost-effective way. The framework aims to assist Member States which are currently facing difficulties in groundwater data collection and management to develop adequate groundwater data collection and management procedures at the national level that match their current (financial and human) capacity and level of development; and it aims to enhance transboundary and/or regional cooperation through harmonization of data collection and data management practices and improved data-exchange across Member States. The framework addresses organisation and planning aspects of groundwater data collection and management from borehole siting, drilling and testing to groundwater monitoring, from field data collection to databases and data sharing. The framework includes aspects of national and transboundary institutional arrangements for groundwater data collection and data management. It is targeted at officials who have a coordinating role in the groundwater data collection and management, usually at a more senior level: professionals who interact with or coordinate field technicians and interact with managers and directors of departments. The framework emanated from the SADC-GMI project Capacity Building for Groundwater Data Collection and Management in SADC Member States.

Keywords: Groundwater data collection, Groundwater data management, Groundwater monitoring, Organisational and planning aspects, Transboundary institutional arrangements, SADC-region
SUBTHEME 2: MEASURING PROGRESS TOWARDS ATTAINING SDG TARGETS, DATA COLLECTION AND MANAGEMENT WITHIN THE SADC MEMBER STATES.
K. G. Villholth, *Groundwater and the Sustainable Development Goals – Interlinkages and supportive guideline development*

IWMI, International Water Management Institute, Pretoria, South Africa

Corresponding author: k.villholth@cgiar.org

**Abstract**

Groundwater remains a critical resource for human development, underpinning socio-economic as well as environmental goals. Groundwater provides 43% of irrigation water globally and supports more than one third of the human population with domestic water supplies, principally fundamental drinking water. Yet, policy and decision making at multiple levels generally falls short of accounting for the criticality of groundwater in long-term development planning. As a global set of guiding principles and associated targets and indicators for global sustainable development, the Sustainable Development Goals (SDGs) embrace groundwater to a certain level, but the explicit accounting for groundwater remains limited, with the risk that both the full potential of groundwater may not be materialized, or what is more critical, the risks associated with neglecting its proper accounting in sustainability factors may adversely affect human development, which is already evidenced around the world. In this paper, and building on two recent key documents developed in collaboration with international water organizations and focusing on groundwater and the SDGs, an inventory of groundwater interlinkages in the SDGs is firstly presented, presenting the role of groundwater across many SDGs and the trade-offs that need to be openly addressed in development discussions and planning. Secondly, the paper describes pioneering collaborative international work to develop guidelines and tools for groundwater accounting and monitoring in SDGs, with an example from SDG Indicator 6.4.2 on the level of water stress, to illustrate how to pave out institutional and technical pathways to get groundwater better represented and considered in the UN 2030 Agenda for Sustainable Development. Finally, new initiatives and SDG challenges in need of further work are presented.

**Keywords:** Groundwater, Sustainable Development Goals, interlinkages, trade-offs, indicator guidelines
F. Fourie, *Making the unseen groundwater levels an indicator of sustainability in South Africa (SDG 6.6.1).*

Department of Water and Sanitation, South Africa.

Corresponding author: fourief@dws.gov.za.

Abstract

The change of 1m in groundwater level at one borehole might be acceptable in terms of aquifer storage, but in another borehole, it may be catastrophic. The effects of drought and over abstraction on groundwater is sometimes very difficult to detect when the groundwater level ranges from 20m -120m.

The Department of Water and Sanitation monitors the water levels of 2007 geosites of which some monitored on a monthly, bi-monthly, quarterly and some bi-yearly base. The data is analysed from a regional aquifer perspective to assess the groundwater level trends made. The analysis indicates the decline or rise in groundwater levels for the last ten years. The analysis was extended to provide a “Groundwater level Status” for each geosite, boreholes can thus be compared with respect to geological settings, water levels and properties. The current groundwater level is given as the status allowing the shallowest and deepest groundwater levels ever measured at each geosite comparable to the current groundwater level. The “Status” can now be used to indicate the severity of the drought and thus a risk level indicator. SDG Goal 6.6.1 on the change of the groundwater level calculation is based on the groundwater level status methodology. The reporting of a change in 5 years can be done without any difficulty, and it provides a true reflection from a management, governance and sustainability point of view.

This paper will present a detailed methodology description and limitations of the methodology. The applicability to use the methodology from a national to a municipal level will be showcase through practical examples of the recent drought effects in South Africa as well as to report back results for the first two years.

**Key words:** Groundwater Level, SDG 6.6.1, Monitoring Risk
S. Kumwenda, D. Robertson and R. Kalin, *Tracking achievements towards Sustainable Development Goal number 6 through mWater rural water supply forensics (mForensics) in Traditional Authority Mazengera in Lilongwe, Malawi.*

Abstract

Malawi, as one of the United Nations member states, embraced the 2030 Agenda for Sustainable Development with the 17 global Sustainable Development Goals (SDGs). Of significance to this research is the SDG 6 which calls for universal access to safe water and sanitation with sustainable management by the year 2030. Despite the elaborated United Nations SDG Monitoring framework on follow-up and review on the SDG targets and indicators at global, regional and national level, there is still considerable inadequate statistical capacity by some member states to track progress towards achieving the SDGs.

The purpose of this research is to assess the status of household level access to safely managed water supply, sanitation and hygiene as per requirement of SDG 6.1.1 and SDG 6.2.2 indicators in Traditional Authority Mazengera in Lilongwe District of Malawi. Also, being appraised is the mWater rural water supply forensics methodology called mForensics, if whether the methodology relevantly provides the required robust tracking for SDG 6 indicators. The study employed a Management Information System platform called mWater to capture georeferenced water points infrastructure and household level data. Major variables included issues affecting water point functionality, household level access to a drinking water source, chemical and micro-biological water quality testing, sanitation and hygiene practices at household level.

The preliminary findings from this research indicate that 60.5% of water point infrastructure in TA Mazengera are functional thus surpassing the National's 40%. Of the 7,429 households surveyed, 51.2% have a basic level of service whilst 34.6% have limited level of service in relation to SDG 6 indicator 6.1.1. Eleven (11) % and 3.2% have unimproved and surface water sources of drinking water respectively. The study recommends for the mForensics methodology to be adopted and adapted by the Malawi Government.

**Keywords:** Tracking SDGs, Indicators, Service levels, mWater, mForensics
S Naicker and F Ramusiya, *Overview of the Coordination of SDG 6 (Water and Sanitation) and Groundwater Indicator Reporting.*

Department of Water and Sanitation, Private Bag X313, Pretoria, 0001, South Africa

E-mail: naickers@dws.gov.za

Abstract

South Africa has committed to achieving the United Nations Sustainable Development Goals (SDG’s) by 2030. But what does this mean and how does groundwater fit in to this? SDG 6 in particular focuses on ensuring universal access to safe and affordable drinking water for all by 2030. SDG 6 requires that the country protects and restores water-related ecosystems such as forests, mountains, wetlands, aquifers and rivers which are essential if we are to mitigate water scarcity. To accomplish this, South Africa has proceeded to align various plans, strategies, and policies to encompass the targets of the SDG’s. The structure for reporting SDG 6 includes the United Nations, Statistics South Africa, and the Department of Water and Sanitation (DWS). Each Sub-goal has a separate task team assigned to it with a task leader, these task teams report directly to the Department of Water and Sanitation’s Working Group which comprises all task team leaders. The DWS has also included two additional task teams focused on Research and Innovation and the Water Sector Skills Leadership Group to assist with technical input in the various indicator methodologies. The DWS currently has a working website on SDG 6 and has developed an online Monitoring and Evaluation System to keep track of SDG 6 trends, developments and reporting. Groundwater indicators included in the SDG 6 Sub-goals are:

- SDG 6.3.2 – Good Ambient Water Quality
- SDG 6.4.2 – Level of Water Stress
- SDG 6.5.1 – Integrated Water Resource Management
- SDG 6.5.2 – Transboundary Basin Area with Water Cooperation
- SDG 6.6.1 – Change in Aquifer Storage

The DWS has domesticated (that is adapted a **Target** or **Indicator** to suit the South African Context or to align with South Africa’s current reporting) the indicators for SDG 6.3.2, SDG 6.5.1 and SDG 6.6.1. These targets are well documented in the National Water and Sanitation Masterplan. The UN itself has given global criteria that allow determining whether the cooperation arrangement on a particular aquifer is operational for SDG 6.5.2. Currently, the DWS National Groundwater Level Monitoring Programme does not have enough geo sites (coverage) to measure aquifer drawdown effects on ecosystems. There needs to be a dedicated Ecosystems Monitoring Programme to receive accurate information on ecosystem health and impeding trends that require urgent action from a catchment management approach, this can only be achieved through stakeholder participation. These SDG targets reporting has given the Water and Sanitation sector a new look at data. It has forced us to critically think of concepts such as baseline and performance monitoring. We now know where our data gaps and targets are, and we have to provide an action plan to address these.

**Keywords:** Domesticate, South Africa, United Nations
F. Ramusiya, L. Lalumbe, **Reporting on Groundwater Quality in South Africa: Baseline determination and status of compliance**

1Department of Water and Sanitation, Private bag X313 Pretoria, 0001. ramusiyaf@dws.gov.za

2Department of Water and Sanitation, Private bag X313 Pretoria, 0001 lalumbel@dws.gov.za

**Corresponding Author:** lalumbel@dws.gov.za

**Abstract**

In order to achieve goal 6 (target 6.3) of the Sustainable Development Goal by 2030, there is a need to determine the baseline concentration for nitrate, electrical conductivity, sulphate and pH in groundwater. The national groundwater quality monitoring network has been active for the past 25 years where 379 monitoring stations are currently active. These monitoring stations are being monitored twice each year before and after the rainfall season. Groundwater quality data collected and analysed between 2013 and 2017 is relevant to determine the baseline concentration and status of compliance to the target water quality guidelines for domestic use. Data was delineated by Vegter hydrogeological regions. Mean groundwater quality concentrations for each parameter were determined per Vegter hydrogeological regions. The mean groundwater quality concentrations were then compared to the target water quality guidelines for domestic use to determine the status of compliance for each Vegter hydrogeological regions. The overall status of compliance was determined by comparing the regions that complies against those regions that are not complying with the target water quality guidelines for domestic use. The study managed to determine the baseline concentration for all four parameters, the status of compliance to target water quality guidelines for domestic use across all Vegter hydrological regions and the overall status of groundwater quality in South Africa. The study also determined that some of the Vegter hydrogeological regions have some parameters that are naturally higher and are not the results of pollution or contamination.

**Keywords:** Groundwater quality, compliance, baseline, monitoring
V. Mvandaba, ¹R. Bugan, ¹E. Kapangaziwiri, ¹L. Hill, ¹P. McMillan, ¹P.J. Hobbs ²L. Smith, *Groundwater monitoring and reporting for SDG 6 - a case study in the Cradle of Humankind World Heritage Site, South Africa*

¹CSIR, Smart Places, PO Box 395, Pretoria, 0001, South Africa

²Managing Authority, Cradle of Humankind World Heritage Site, P/Bag x112, Marshalltown, Johannesburg, 2017, South Africa

**Corresponding Author:** mvandabav@gmail.com

**Abstract**

The sixth sustainable development goal (SDG 6) of the United Nations is centred on ensuring availability and sustainable management of clean water and sanitation for all. Two of the indicators identified for meeting this goal, SDGs 6.3.2 and 6.6.1, respectively focus on improving water quality and protecting and restoring water-related ecosystems such as forests, mountains, wetlands, aquifers and rivers. In relation to groundwater, the focus turns to addressing issues of groundwater quality and management of groundwater quantity in various geohydrological environments. This paper highlights the achievements of a surface water and groundwater resources monitoring programme that has been carried out in the dolomitic setting of the Cradle of Humankind World Heritage Site, South Africa since 2012 and presents the data collection and processing as a benchmark for ‘best practises’ in monitoring and reporting on groundwater resources in the SADC region. Key aspects of the programme include monitoring the impact of acid mine drainage and municipal effluent on groundwater quality and river health, and analyzing surface water and groundwater interactions in an effort to provide a holistic view on the state of conservation of the world-renowned site. To address a few knowledge gaps within the monitoring programme, the study recommends hydrological modelling to account for uncertainties related to streamflow losses and to address any future climate change-related vulnerabilities in the area.

**Keywords:** Acid mine drainage, Groundwater modelling, Karst hydrology, Surface water-groundwater interactions, Sustainable development goals
T. Kanyerere, K. Pietersen, J. Goldin, K. Villholth, A. D. Levine, Using citizen science in groundwater data generation research to improve decision-making support on water information

1Department of Earth Sciences, University of the Western Cape, Bellville, South Africa
2Institute of Water Studies, University of the Western Cape, Bellville, South Africa
3International Water Management Institute, Pretoria, South Africa
4Water Quality Program, County of Santa Cruz-Health Services, Agency-Environmental Health Division, Santa Cruz, CA 95060, United States

Corresponding Author: tkanyerere@uwc.ac.za Tel +27 021 959 9292

Abstract

The involvement of communities in research design, data collection and interpretation process alongside scientists is referred to as citizen science. While citizen science itself has existed since the start of scientific practice, developments in technology, data processing and visualization, and communication of ideas and results, are creating new opportunities for community involvement in scientific research. Although such approach is becoming common in water resource management, the citizens are often neither involved in research designs nor in data analyses/interpretations. In this paper, aspects of citizen science in a hydrogeological research projects are discussed. The involvement of citizens beyond data collection is demonstrated. The potential of citizen science to complement more traditional ways of scientific data collection and knowledge generation for hydrological sciences and water resources management is exemplified. The use of advanced technology in hydrogeology for data collection in a citizen science context have shown promising improvement in generating water information for time series analyses on hydrogeological parameters. The importance of such data for characterizing process of heterogeneity, regions of various settings, and human impacts on hydrological cycle has been validated. Although the nature and quality of data collected in citizen science experiments might be different from those of traditional monitoring networks, the room for improvement exists. Despite the involvement of citizens in data collection being practical, the research design and data analysis and interpretation aspects of research projects remains a gap that require redress. When advantages of involving the citizens in water research projects were investigated and analysed, opportunities in the integration of hydrologically-oriented citizen science in water resources management outweighed the challenges. Although the case studies for the current study were few, the insights generated provided a basis for a comprehensive approach on the designing of citizen science eco-hydrogeologically-led projects in co-generating new knowledge on groundwater resources.

Keywords: Citizen Science, research design, data processing and visualization, monitoring networks
P. Mukuyu, 1J. Lautze, 2A. Rieu-Clarke and 3D. Saruchera, **Data exchange in transboundary waters: developing a framework for assessing implementation, and identifying models of success.**

1 (IWMI)  
2 (University of Northumbria)  
3 (IUCN)

**Abstract**

Data exchange is universally recognized as being central to fostering equitable and sustainable cooperation on transboundary watercourses. Numerous global transboundary conventions, laws and protocols highlight the need for regular and timely exchange of information among states sharing transboundary waters (rivers, lakes and aquifers). Challenges in the practical exchange of data have nonetheless been widely noted in transboundary waters, which questions whether there might be a disconnect between commitment and compliance. Ultimately, there is need for extensive analysis on how much data, and of what quality, are exchanged between states in transboundary waters. Drawing from and complementing SDG indicator 6.5.2 (Progress on Transboundary Water Cooperation), this study provides such an analysis through the development of a data assessment framework, and its application to a representative set of transboundary rivers, lakes and aquifers. Key aspects of data exchange examined by the assessment framework include, (i) diversity in types of data that are exchanged, (ii) the frequency and timeliness of exchange, (iii) the methods on how data are collected to enable optimal exchange, and (iv) the modalities of exchange. Preliminary results indicate that while substantial room for improving data exchange in transboundary rivers, lakes and aquifers exists, there are several key successful examples which can be built on.

**Keywords:** data exchange, transboundary, SDG 6 reporting, data collection, joint monitoring

1Department of Earth Sciences, University of the Western Cape, Cape Town, South Africa

2Centre for Scientific and Industrial Research, Stellenbosch, South Africa

3Department of Computer Science, University of the Western Cape, Cape Town, South Africa

Corresponding author: kpietersen@mweb.co.za

Abstract

Regional data generated from remote sensing applications or global circulation models provide a wealth of information, especially where in-situ information is scarce. Remote sensing data are also often updated at a temporal scale which allows near real time analysis making them useful for decision-making. However, a scale mismatch between regional data and the level at which operational decisions are made, hinders its useful to local groundwater management. The downscaling of regional datasets to provide locally relevant data for groundwater management has often been challenging. Data driven solutions such as Big Data Analytics provides advantages in addressing some of the challenges. To bridge the gap between the regional datasets and required resolution for practical applications, Big Data Analytics (BDA) methods for downscaling are reviewed. The BDA methods are evaluated in terms of their merits and constraints in localizing regional datasets. This review also provides the accuracy of these methods based on published studies. Difficulties and future trends associated with these methods are also analysed. The outcomes include a procedural framework for transforming regional datasets, particularly from remote sensing missions, into locally scaled BDA methods. The paper further bridges the gap between water and data driven science.

**Keywords:** Big Data Analytics, downscaling, groundwater management, remote sensing, regional.
A. Gemmell, E. Abrahams, R. Hugman, C. Ruz Vargas, G. Nijsten and T. Flügel, **Consolidation of transboundary datasets to enhance decision-making: Lessons learnt from the Ramotswa aquifer Southern Africa.**

**Umvoto Africa (Pty) Ltd, Cape Town, South Africa**

**International Groundwater Resources Assessment Centre (IGRAC), Westvest 7, The Netherlands**

**Department of Geographical and Environmental Studies, Stellenbosch University, South Africa**

**Abstract**

We present an initial assessment of an ongoing work that forms part of a larger Water Research Commission project entitled “Big Data Analytics and Transboundary Water Collaboration in Southern Africa”. This larger project aims to investigate techniques and methodologies that can be used to ensure more effective decision making for aquifers that span across national borders, in order to ensure greater water security for all stakeholders.

Working across national boundaries is not easy, due to differences in nomenclature, data capturing systems, water use frameworks, etc. This means that creation of common databases for transboundary resource can be resource intensive, and often with variable success. Our chosen transboundary aquifer is the Ramotswa aquifer (Botswana and South Africa) where the primary data custodians and providers are the Botswana and South Africa Departments of Water and Sanitation. This aquifer was chosen because of pre-existing work undertaken on the aquifer by the International Groundwater Resources Assessment Centre and the International Water Management Institute that has provided an initial framework for data assessment, capture and storage.

The project aims include improved data sharing with integrated and reformatted datasets; development of a standardised quality control system and data collection protocols; and applying big data analytics to create new insights for improved local decision making. Among others, this requires assessment of current data to identify anomalies, data gaps, errors, etc. Data is to be analysed using statistical techniques to identify outliers, trends and patterns. Machine learning algorithms can be trained on existing datasets to identify patterns, model data and flag new data for inconsistency. The resulting information can then be made accessible through online GIS platforms.

We present our initial assessment of approaches used to collect data, assess data, and generate proxy information for groundwater data in data sparse environments utilizing big data tools.

**Keywords:** Big data analytics, transboundary water, Ramotswa aquifer, groundwater
SUB-THEME 3: POLICY LEGAL AND INSTITUTIONAL CONSIDERATION AT NATIONAL AND TRANSBOUNDARY LEVELS.
K. Upton¹, R. Cornforth², J.W. Foppen³, R. Hope⁴, A. MacDonald¹ & R. Taylor⁵

Addressing groundwater policy gaps: evidence from the UPGro Programme.

¹ British Geological Survey, Lyell Centre, Edinburgh, UK
² Walker Institute, University of Reading, UK
³ UNESCO-IHE, Delft, Netherlands
⁴ University of Oxford, UK
⁵ University College London, UK

* Corresponding author: kirito@bgs.ac.uk

Abstract

Evidence-based policy to support sustainable groundwater development and management is critical to achieving all targets of SDG6, including that for integrated water resources management. UPGro (Unlocking the Potential of Groundwater for the Poor) is a seven-year research programme involving 150 interdisciplinary researchers and practitioners from across sub-Saharan Africa (SSA) and Europe arranged in 5 consortia and 15 catalyst grants. The programme focusses on various aspects of groundwater and water security to support social and economic development on the continent. It is generating a significant body of evidence on the role that groundwater plays in providing secure water supplies, with implications for groundwater management and policy, particularly within the context of climate change. For example: (1) analysis of long-term groundwater level records from across SSA suggests that groundwater recharge in more arid areas is dependent on heavy rainfall events linked to large-scale climate phenomena such as the El Nino Southern Oscillation; (2) detailed surveys across 3 countries indicate that the measuring and reporting of borehole functionality may be hiding more serious issues of service delivery; (3) the examination of different modes of rural waterpoint management provides fresh insight to the efficacy of community management and the important role of external support from both the private and public sector; (4) detailed sampling in urban areas has identified a high pathogenic load and persistence of viruses in many urban groundwater systems. Other emerging results from the programme tackle challenges such as increasing demand and competition for groundwater, particularly where it is used for industry and intensive agriculture, and inequality of access. UPGro researchers are working with various stakeholders to address these issues, using novel approaches such as transition management and multi-criteria mapping, to inform policies that promote sustainable groundwater development as part of an integrated water resource management framework.
A. Bullock, *Unrealised opportunities for African groundwater from reconnecting policy with science under alternative natural capitals.*

*Independent Senior Consultant, Ledbury, HR8 2DX, United Kingdom*

Email: andybullock61@btinternet.com.

**Abstract**

Policy evolutions around wetland systems as natural capital have been tracked since publication of the Millennium Ecosystem Assessment 15 years ago. Findings reveal how a hegemonic view on wetlands as high-storage regulators has advocated management responses - including through Ramsar Convention - grounded on wetlands performing the most valued regulatory services. However, also over the past 15 years, increasing hydrogeological evidence has shown that African headwater wetlands do not perform as high-storage regulators - instead, the dominant science is towards them acting as low-storage generators. So, a major policy: science disconnect has taken hold in which land and water management decisions and guidelines are founded on one presumption of science, when in reality the actual hydrogeological performance of wetlands and other landscape stores - notably groundwater - runs counter to that presumption. Policy implications and outcome opportunities of the alternate science case remain unexplored and unrealised.

There are two important sets of ramifications. First, risks to society and environmental integrity from poor outcomes due to policy being insufficiently based in evidence. Second, the as yet unrealised opportunities of land and water management if policy were more in tune with the dominant African evidence. Those opportunities are initially envisaged in three areas, and are especially relevant to African groundwater policy, laws and institutions at different scales. First, the primacy of groundwater aquifers as key basin regulators and the role of wetlands in evacuating economically-crucial rapid flows can underpin a new and more realistic suite of ecosystem services. There are policy implications at basin scales for ecosystem service payments, protected zones and RAMSAR Guidelines. Second, potential for small-scale (possibly gravity) groundwater-fed supplementary irrigation of productive wetland soils within national food and nutrition security strategies. Third, potential identification of critical fracture zones for new, more reliable domestic rural water supply on Basement Complex.

**Keywords:** Groundwater, wetland, policy, natural capital.

1Integrated Water Resource Management Centre, C/O Department of Geology, University of Zambia, P.O. Box 32379, Lusaka, Zambia

2Department of Geology and Environmental Earth Science, 120 Shideler Hall, Miami University, Miami, USA

3National Park Services, 9017th Street NW, 4th Floor, Washington DC, USA

Corresponding author: Kawawa.Banda@unza.zm.

Abstract

Lusaka and the surrounding areas are underlain by a dolomitic karstic aquifer that supplies at least 60% of the area’s drinking water supply. The increase in industrial activities such as quarrying necessitate the need to develop ways to better understand, manage and protect the groundwater resources. The Laughing Waters area west of Lusaka comprises farmland and an unplanned community with on-site sanitation that results in groundwater contamination. Groundwater quality testing has demonstrated a dis-link between deep seated boreholes typically 50 m and shallow wells usually less than 15 m. The water source level has a distinct chemistry and vastly different in bacteria presence, with the deeper borehole water being relative free of faecal bacteria and the near-surface groundwater being highly polluted. Both are common water sources in this area. Dye tracing was thus undertaken to establish groundwater flow direction and velocity, especially in the shallow system, to enhance groundwater protection and management. Rhodamine and fluorescein were injected into latrines, and receptors, consisting of activated charcoal placed in wire mesh bags, were placed in numerous potential recovery points, springs and shallow wells. Positive dye breakthrough has been difficult to determine. There have been some dramatic increases in dye concentrations but also fluctuating background concentrations that make interpretation difficult. Some preliminary data indicated that groundwater flow is towards the northwest at velocities of between 35 and 140 m/d, but more testing at higher dye concentrations is needed to eliminate the uncertainty of these estimates.

**Key words:** Groundwater flow, Lusaka, Protection, Sanitation, Shallow wells

1German Federal Institute for Geosciences and Natural Resources (BGR)

2Groundwater Resources Management Support Programme (GReSP)

Corresponding author: tewodros.gresp@gmail.com

Abstract

Lusaka has been dependent on the supply of groundwater resources from a local aquifer system for drinking and commercial purpose since its early days. Groundwater plays a vital role for the city’s water supply and is highly vulnerable. While many studies on groundwater in Lusaka have been undertaken in the past decades an effective pollution control remains a central governance challenge. This study applies a Water Governance Capacity Framework (Koop et al. 2017) to assess the ability of different actors in Lusaka to handle the groundwater pollution. This framework defines three core dimensions for high governance capacities (Knowing, Wanting, Enabling) and a detailed set of indicators to assess the status of governance capacities. Information has been gathered in eight group discussions and expert interviews with different national and municipal institutions from the water and urban planning sector, as well as with NGOs, professional organizations and international cooperation. The result of the study indicates the strong link of groundwater protection with land use management and regulation. Related to this, the extension of sanitation services to peri-urban settlements is crucial to secure good groundwater quality and the future groundwater supply for Lusaka. Better governance of the groundwater pollution challenge requires cross-sectoral thinking, in Zambian authorities but – given the importance of external funds - also in the cooperation and donor community. There are promising initiatives that foster knowledge exchange, common problem framing and joint search for solutions. Commitment and integrity of decision-makers and implementers are also crucial for advancing the protection of the aquifers.

Keywords: Groundwater management, Groundwater governance, Urban groundwater, Groundwater pollution, Zambia

Geological Engineering Department, University of Mines and Technology (UMaT), Tarkwa

**Abstract**

Sustainability of water resources is a major concern in most countries especially developing countries. In Ghana, the Ministry of Water, Works and Housing published the Ghana National Water policy in 2007 of which the principal objective was to provide a framework for sustainable development of Ghana’s water resources. The target group for this policy included all water users, water managers and practitioners, investors, decision makers and policy makers within the central Government and district assemblies, non-governmental organisations and international agencies. Almost twelve years after this policy, the abstraction of both surface and groundwater are still ongoing with an increase in demand for water resources due to population increase. But with the rapid population increase, the challenge now is how to protect and treat these water bodies to an acceptable standard to serve present and future use in the context of sustainable development goal 6. This paper presents how water resources are governed in Ghana, the management processes and the actors responsible for effective water management. It deals with eminent challenges such as surface water pollution from mining activities and groundwater contamination. It also addresses the supply of adequate water for both domestic and agricultural activities, as well as waste management.

**Keywords:** Water Resources, Groundwater, Surface Water, Management, Ghana

Department of Water and Sanitation, Free State, South Africa

University of the Western Cape, Private Bag X17, Bellville, 7535 South Africa

University of Malawi, The Polytechnic, Blantyre, Malawi

Corresponding Author: Kanyerere T

Abstract

In the management of water resources especially groundwater resources, implementing existing regulations is one of the much needed aspects ensuring water security through the regulated use. However, such regulations are not regulated to ensure that they served the intended purpose in their original formulation. In South Africa, a study was carried out to assess the relevance and efficient of adhering to procedural requirements during water use licence application (WULA) process. Lived-experiences and observation methods were used to collect data. The department of water and sanitation was used as a case study. Interpretative analysis approach was used to provide the meaning on the analysed information. The WARMS database was accessed where the number of days that WULA process was extracted. The regulation No. 40713 about WULA process was analysed. The five-year-data prior and post the promulgation of regulation No. 40713 were extracted from WARMS database and evaluated in terms of the duration each application took to be processed for WULA. Data on water use for abstractions from all the regions were obtained from WARMS database and assessed. Dates when applications were submitted and when such applications were finalised were analysis per month and per years for temporal analysis. The number of entitlements received during the particular period and the number of applications recommended to be declined and issued were assessed using exploratory data analysis methods. Graphical method was adapted to increase results visualisation on water use entitlements.

Key results showed that the process of WULA was generally slow and reasons were provided for such outcome. However, the temporal analysis revealed an increasing trend in the post promulgation of regulation No. 40713 suggesting that regulations when re-regulated serve its intended purpose. Although such findings are not conclusive but they inform a basis for re-regulating enforcement regulations in Southern African countries with issues similar to South Africa on water entitlement.

Key words: water entitlement, regulations, WARMS, Southern Africa, South Africa
The use real-time model to fast track progress of water entitlements: Rethinking groundwater allocation reform in Southern Africa, Free State Province, South Africa

Department of Water and Sanitation, Free State, South Africa

University of the Western Cape, Private Bag X17, Bellville, 7535 South Africa

University of Malawi, Box 280, Zomba, Malawi

Corresponding authors: Kanyerere T.

Abstract

The National Water Act (Act 36 of 1996) aims at redressing inequalities in water allocation. Historically, water resources were allocated to few white people who owned land and actively participated in agribusinesses. The need for widening access to water-related business was agreed and water allocation reform (WAR) model was developed and implemented to redress such past inequality.

However, limited progress has been registered because there is no real-time model to monitor, evaluate and report the progress of the four water entitlements. The current study focused on groundwater abstraction/use to assess the reported limited progress in WAR. Data report and active groundwater use from WARMS database were collected, filtered and analysed for parameters as set out in the water use license conditions. WARMS database contains information on parameters regarding water use in the water allocation process. Statistical techniques were utilised to establish change detection, trend analyses and correlations including multiple regression analysis in order to establish the magnitude and direction of relationships between factors. Preliminary results showed that several communities did not make significant improvement with regard to WAR. When population groups were compared, results showed that majority of black people lagged behind in accessing water resources for economic use implying that they will continue facing difficulties to participate in agribusiness-related activities. When WAR targets were assessed, findings showed such targets were not achieved. Further analysis showed that water use entitlements and participating in the economic activities are attached to land ownership. The current study recommends that a real-time model is required to monitor, evaluate and report the progress of four water entitlements and to fast tracking land reform tasks which promote the transfer of land from white people to black people because this has been viewed as one of the ways through which progress on water allocation reform process can be fast tracked.

Keywords: WARMS, groundwater use, agribusiness, WAR, WAR targets
Towards improved governance of transboundary aquifers in Southern Africa: the operationalization of the Stampriet Transboundary Aquifer System (STAS) Multi-Country Cooperation Mechanism (MCCM)

Abstract

The Stampriet Transboundary Aquifer System (STAS) is the only permanent and dependable water resource for the local population living in an area that covers 87000 km² from Central Namibia into Western Botswana and South Africa’s Northern Cape Province. Understanding and managing this precious groundwater resource sustainably is essential to achieving water security in the area, and thus, improving the quality of life of neighboring and resident communities. With this in mind, the Governments of Botswana, Namibia and South Africa, jointly with the UNESCO’s International Hydrological Programme (UNESCO-IHP), started an in-depth multi-disciplinary assessment of the aquifer system in 2013. In order to consolidate the achieved technical results, these three Governments decided to establish a Multi-Country Cooperation Mechanism (MCCM) for the joint governance and management of the STAS in August 2017, and nest it in a river basin organization called the Orange-Senqu River Commission (ORASECOM). This was the first example of institutionalizing cooperation over a transboundary aquifer in Southern Africa. Nesting in an active RBO was hoped to ensure continuous consideration of STAS specific activities into the ORASECOM projects/work-plans.

The process that led to the establishment of the STAS-MCCM is a breakthrough in many aspects. First, it was the first arrangement on transboundary aquifers since the Sustainable Development Goals (SDGs) were adopted in 2016. Prior to the decision of establishing this mechanism, out of the almost 600 transboundary aquifers that have been identified, only six formal and two informal agreements had been documented worldwide. Second, it was the first operational governance mechanism to be nested in a river basin organization, thus fully capturing the IWRM approach and directly contributing to the implementation of SDG Target 6.5 (“By 2030, implement integrated water resource management at all levels, including through transboundary cooperation as appropriate”).

Keywords: transboundary aquifer, governance, cooperation
H. Seyler, K. Witthueser, K. Pietersen, The framework for a Sustainable Water Supply Strategy to promote groundwater secure transboundary systems

Delta-h Groundwater Systems, South Africa

Department of Earth Sciences, University of the Western Cape, Cape Town, South Africa

Corresponding Author: Helen Seyler; Delta-h Groundwater Systems, P O Box 48474, Kommetjie, 7976. Email: helen@delta-h.co.za.

Abstract

Around 70% of the SADC region is rural in nature, and more than 60% of communities in the region rely on groundwater (GWC, 2001). Many aquifer systems are shared across international borders and it has been noted that “proper development and management systems need to be in place in order to jointly manage and harness this resource [transboundary aquifers, TBAs] in an economically, environmentally and socially sustainable manner” (GWC, 2001). Fundamental to the management of any aquifer is knowledge of: the groundwater flow directions, long term change in groundwater levels and storage, recharge, discharge to surface water, changes in flow regime when pumped and sources of pumped water; all of which influence groundwater availability. This kind of hydrogeological assessment forms the foundation for the determination of limits of future abstraction or indicators of unacceptable impact, and provides a tool against which to compare future datasets and make groundwater management decisions.

To establish groundwater-secure transboundary aquifer systems requires that this kind of baseline hydrogeological assessment is in place, is routinely updated, and that it is used to influence groundwater management decisions. Whilst there are many standards and best practice guidelines for groundwater development at scheme level in the SADC region (for example GWC, 2001), there are none for regional aquifer resources management. A framework for a Sustainable Water Supply Strategy (SWSS) is therefore proposed that has sustainable groundwater management as its focus, based on the Groundwater Sustainability Plans” (GSPs) required in California under the new sustainable Groundwater Management Act, (California State, 2014), and on previous WRC studies in South Africa. Future research aims to pilot various aspects of the SWSS that can be supported with new approaches including machine and deep learning techniques.

Eduardo Mondlane University

Abstract

This paper examines the duty to cooperate in the protection and management of Ground Water in the SADC Region. The Revised Protocol on Shared Watercourses in the SADC region was adopted in 2000 and entered into force in 2003. SADC protocols do have rules on water / groundwater interactions, focusing specifically on the alluvial aquifers occurring along river channels. Besides that, groundwater is mentioned as a component in the water balance in terms of a) transboundary (trans-basin) aquifer flows and b) extraction of groundwater for consumptive use. It is clear that SADC countries are concerned about the impact of groundwater abstraction on river flow, the adequacy of the groundwater and environmental management aspects, legal regimes, and the need to assure the balance between aquifers and the rivers themselves. It is also clear that this is a duty all member states should respect.

However, there is need to clarify which legal instruments may be called upon to formally request SADC countries to implement rules on use and management of ground water. Thus, considering the rules of the SADC Revised Protocol on Shared Watercourse, the problem we study is what are the challenges for the use and management of ground water in the SADC region, and if there are binding rules which may assure the implementation of a common view a in the specific case of ground water?

For this study, we considered the treaties and protocols related to water use and management which bind SADC countries, and we limited our research to a desk job based on available literature and municipal laws, treaties and protocols. The main objective was to find out if we have binding laws which may assure a steady and uniform implementation of rules on ground water in the SADC region, and we conclude that the best solution is to have a basin approach through the river basins commissions.

**Keywords:** SADC; Groundwater; Laws; Implementation


J. Sauramba, *Groundwater Policy Legal and Institutional Frameworks in the SADC Region.*

SADC Groundwater Management Institute (SADC-GMI),

PO Box 339, Bloemfontein 9300, South Africa

* Corresponding author jamess@sadc-gmi.org

**Abstract**

It is estimated that more than 70% of the 280 million Southern African Development Community (SADC) inhabitants depend on groundwater for their livelihoods. As the impact of climate change intensify and surface water resources are increasing polluted as they also dwindle, the dependency on groundwater increases both at national and across political boundaries. However, the existing policy, legal and institutional frameworks are heavily biased towards surface water resources and they don’t promote the conjunctive and sustainable use of groundwater. The SADC Groundwater Management Institute (SADC-GMI) was established as a Centre of Excellence to enhance the sustainable utilisation of this hidden resource.

From May 2018, SADC-GMI has been implementing the Capacity Building for creation of an enabling Policy, Legal and Institutional framework for effective groundwater management in the SADC Member States project through the identification of gaps at national and regional levels, development of action plans for addressing the gaps, development and dissemination of relevant guidelines and piloting some quick-win actions. The Gap-analyses is now complete in 15 SADC Member States as well as at regional level. A pilot road-map development project to close the gaps has been completed in Tanzania. Moreover, five guidelines have been developed to assist the SADC Member States in addressing some of the challenges inhibiting the creation of appropriate enabling national environments for sustainable groundwater management. The guidelines developed to date pertain to (a) Development of a Roadmap to address Gaps in the National Policy, Legal and Institutional Framework; (b) Effective Operation and Maintenance of Groundwater Schemes; (c) Building Groundwater Resilience; (d) Institutional Arrangements for Groundwater Management; and (e) Financing Groundwater Schemes. This paper will present the key findings from the Policy, Legal and Institutional development project implemented by the SADC-GMI across the SADC region since May 2018 to date.

**Keywords:** Policy, legal, institutional, groundwater, management, guidelines, resilience, operation & maintenance