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Contribution of hydrogeology to solving community water supply problems in South Africa

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Professor Tamiru Abiye is the recipient of the 2021/2022 NSTF-South32 TW Kambule-NSTF Researcher award in recognition of his dedication to water science. Professor Abiye has focused on building research capacity and solving community water supply problems to promote sustainable development and water security in South Africa in the face of population, industrial, climate change and pandemic pressures.

Significance:

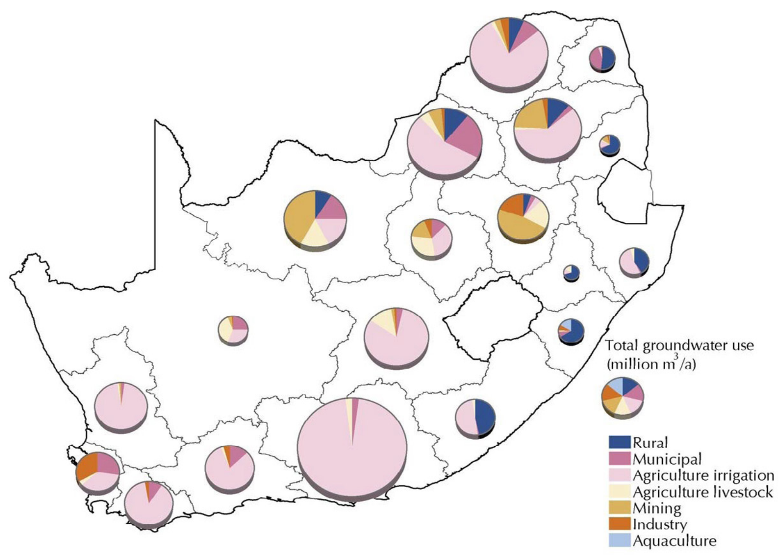
South Africa needs qualified hydrogeologists with high-level skills to address complex groundwater supply problems through research-based solutions. Water insecurity – due to population increases; expansion of industrial, agricultural and mining sectors; an increase in water pollution; impacts of climate change; and poor water resource management – affects sustainable development of the country. Often, groundwater is used to cover the water shortfall from surface water sources, and that use requires qualified hydrogeologists. Therefore, the training of qualified groundwater professionals at the MSc level is aimed to meet the demands of various stakeholders, which is our priority to facilitate groundwater management at all levels starting from municipalities to national government departments.

Background

Hydrogeology is the study of the occurrence of water in the subsurface geological environment. Therefore, a thorough understanding of rock formation, structural setting and geochemical composition of rocks help to conceptualise the occurrence and quality of groundwater. In South Africa, where climate change, water pollution and an increasing population challenge water security, hydrogeology plays a paramount role in the understanding of the groundwater reserve, quality and sustainability in order to supplement the current water supply, which is dependent on surface water. Therefore, in order to achieve successful management of water resources, particularly groundwater, the deployment of qualified hydrogeologists at all levels is important. The current reliance of authorities on surface water could be hampered by periodical droughts induced by El Nino, besides the disastrous effect of climate change in the long term.

Why does groundwater matter?

Groundwater occurs almost everywhere beneath the land surface under our feet. The quantity and quality of groundwater vary from place to place based on the geology and pollution sources. However, the crystalline nature of rocks in South Africa often makes it difficult to harvest a large quantity of groundwater, but it is still sufficient to supplement various economic sectors. Much of South Africa's food is produced by irrigated agriculture, which relies on groundwater. Groundwater, in the form of baseflow, plays a paramount role in sustaining streamflow, lakes, wetlands and aquatic ecosystems during dry periods, and hence, we can use them to infer the occurrence and circulation of groundwater. According to the South African Department of Water and Sanitation, only 20% of groundwater has been used so far in South Africa. This percentage underestimates the actual groundwater use pattern, which is extensive throughout the country in all economic sectors, particularly for more than 85% of agricultural, mining and domestic uses (rural areas). As shown in Figure 1, groundwater is used primarily by the agricultural sector in South Africa.[1]



Source: StatsSA[1]

Figure 1: Total groundwater use in South Africa is dominated by the agricultural sector.

Groundwater use has increased dramatically, from approximately 684 million m^3 in 1950 to 1770 million m^3 in 2004, mainly due to an increase in irrigation for which groundwater comprises over 64%, while mining and domestic consumption in urban and rural areas each account for 8% of use.[1] This shows that, in mining-dominated regions, such as in Gauteng, North West and Free State Provinces, groundwater sustains the mining sector, while in the dispersed human settlement areas of KwaZulu-Natal, Mpumalanga and Limpopo Provinces, groundwater supplies water for domestic use. The dependence of water users on groundwater has substantially increased due to recurrent droughts that affect dams and rainfed agriculture. This shows that groundwater provides a lifeline that needs to be focused on for further utilisation to advance the sustainable development of South Africa.

What do hydrogeologists do?

- Identify rocks that host groundwater
- Divide the rocks into aquifers, aquitards, aquicludes and aquifuges
- Plan, design and construct boreholes for various economic uses
- Plan, conduct and analyse pumping test data
- Estimate groundwater storage
- Construct groundwater flow maps, identify recharge and discharge areas
- Estimate groundwater recharge, identify the source of recharge and residence time
- Investigate the quality of the groundwater to ensure that it is safe for the intended use
- Design aquifer clean-up techniques where aquifers are polluted
- Identify the source of groundwater pollution and suggest a remedy
- Design and construct dewatering schemes in mines
- Conduct field and lab-based measurements of water quality and geochemical modelling
- Conduct tracer tests and identify different water sources
- Operate scientific equipment that helps to generate data
- Predict groundwater abstraction, contaminant dispersion and aquifer potential based on numerical modelling
- Advise water managers, policy- and decision-makers, and water users on sustainable use of groundwater; food and energy production; environmental protection; and coping with the impact of climate change
- Engage and work closely with borehole owners (private owners, farmers, companies, industries, mines), contractors, scientists, engineers, geophysicists, agronomists, sociologists, economists, policy- and decision-makers, regulators, and planners.

Groundwater is resilient to climatic variability

Groundwater is often considered to be resilient to climatic variability, while surface water can be easily affected by extreme weather conditions. Shallow aquifers made of alluvials, weathered and intensively fractured rocks depend on periodical recharge (renewable recharge) and the interannual variation in rainfall could affect the storage. However, deep aquifers receive decadal or centennial recharge that may not be affected by the short- or medium-term changes in climate and hence such aquifers can provide groundwater throughout the year. In dolomitic aquifers in the Pretoria-Johannesburg region, the residence time of groundwater, which is currently extracted by water users, is in the range of 1650 ± 50 to 1850 ± 50 years, while in the Mogwadi (Dendron) area, the residence time of groundwater used by potato farmers ranges from 560 to 1400 ± 50 years; these are classified as aquifers with historical recharge.[2] Therefore, such aquifers may not be replenished from present-day rainfall. The importance of groundwater to combat hydrological drought in Cape Town was extensively presented in *Daily Maverick*.[3-7] Several emergency boreholes were installed during the 2015/2016 El Nino related drought across the country and later they were abandoned when dams were full. It is always recommended to supplement the water supply from boreholes as they are important for decentralised water provision. Even though the city of Cape Town embarked on developing the Table Mountain Group sedimentary rocks and the Cape Flat aquifers, there may not be a sufficient investment to exploit groundwater to meet the growing demand. In October 2022, when Rand Water reduced the water supply to the Gauteng municipalities for various reasons, groundwater provided a lifeline to the communities. The notion of using groundwater only during an emergency by authorities has to be replaced with necessity at all times.

Groundwater storage in South Africa

The total storage capacity of the 1086 dams in South Africa is 31 619 million m^3, which is about 65% of the mean annual run-off of 49 000 million m^3.[8] While the total groundwater storage estimated based on globally accepted methods for South Africa is about 17 400 km^3.[9] Not all of this groundwater storage is available for abstraction as it varies spatially, and the estimated groundwater storage does not consider water quality. However, it is extensively used for various economic and domestic activities all over the country and is still available for use. The Northern Cape and the western section of the North West Province, which are dominated by the Kalahari sediments underlain by Karoo sedimentary rocks, contain the largest groundwater storage in South Africa, often due to the confined nature of the aquifers. Recharge (current and historic), geology and regional geophysics-based approaches could help to identify large groundwater aquifers in South Africa.

Using the unusable mine water

Acid mine drainage (AMD) is often a point of discussion due to its adverse environmental impact. The rising of acidic groundwater in abandoned mine shafts poses an environmental risk while the groundwater which was dewatered during gold mining is trying to establish its original hydraulic head. In addition, the leaching of toxic chemicals from tailings dams can be reused through efficient treatment technologies. The discharge of AMD, which amounts to 202 million L/day in the Johannesburg region, can be treated to obtain clean water that can supplement the current water supply, as well as to extract by-products such as metals, sulphuric acid and gypsum.[10] Currently, there is an effort by the South African Department of Water and Sanitation to control the water levels in mine voids below the Environmental Critical Levels by pumping it out, as well as treating AMD through neutralisation by alkaline materials such as lime and discharging the water into streams.[11] The eMalahleni Water Reclamation Plant is a very good example that can be replicated in the gold mining areas. It uses the Keyplan High Recovery Precipitating Reverse Osmosis (KHiPRO) technique, which provides about 24.2 million L/day of clean water to the local municipality with a recovery rate of 99%. As a by-product, the treatment process produces about 100 tons of gypsum per day that is used as a building material for local houses.[12] Appropriate investment either through the private sector or private–public partnership could help to manage AMD successfully for beneficial purposes.

Radioactivity in tailings and groundwater

The activity concentration for ^{238}U in rocks ranges from 1.06 Bq/kg to 35.2 Bq/kg, while for ^{235}U the activity concentration varies between 1.06 Bq/kg and 1.62 Bq/kg, as recorded in the quartzite of the Skunwerburg Formation (TMG). The activity concentration for ^{226}Ra was found to be high (72 Bq/kg) in the Ceres Subgroup shale (TMG) which also contains a high exposure dose rate of 185.7 nS/h. In the Thyspunt area in the Eastern Cape Province, the activity of the radiotoxic and carcinogenic uranium (^{238}U, ^{235}U) and radium (^{226}Ra) in water was found to be well above the World Health Organization (WHO) guidelines of 0.03 Bq/L and 1 Bq/L, respectively. The activity concentration of ^{238}U in deep groundwater varies between 17.6 Bq/L and 5060 Bq/L (above the WHO recommended drinking water limit of 190 Bq/L) along with high ^{226}Ra activity ranging from 1.1 Bq/L to 114 Bq/L, which is above the WHO recommended drinking water limit of 1.0 Bq/L.[13] The high radioactivity of groundwater has been attributed to the mineralisation of the TMG rocks due to metamorphism and subsequent release of radionuclides into groundwater through water-rock interaction processes.

The activity concentrations of ^{238}U in the gold mine tailings of Gauteng Province were found to range from 210.0 Bq/kg to 2578.9 Bq/kg, which is higher than the regulatory limit of 500 Bq/kg. Similarly, the annual effective radiation dose from the tailings dams varies between 0.14 mSv/y and 1.09 mSv/y, with an average of 0.51 mSv/y, above the recommended exposure dose limit of 0.25 mSv/y for humans.[14,15] Initial results of the radioactivity in fresh groundwater used for drinking show elevated activity concentrations in the West Rand region, Gauteng Province.[15] In general, the presence of high activity concentrations of toxic radionuclides in the tailings dams, rocks and groundwater means that the use of tailings and rocks for house construction should be regulated, and toxic groundwater must not be used for any activity unless it is treated.

Hydrogeology at Wits

Hydrogeology is an applied geoscience. It is a relatively new branch of geoscience that equips researchers in the physics, chemistry, mathematics, hydrology and geology needed to solve groundwater-related community problems onsite efficiently and independently. Confidence of hydrogeologists increases based on the application of integrated methods to obtain the required solution. With the prime aim of skilled human capacity building to alleviate the water shortage in South Africa at a time of increasing water insecurity, the School of Geosciences at the University of the Witwatersrand launched the MSc in Hydrogeology programme (Coursework and Research Report) in 2015; the programme has attracted more than 120 postgraduate students so far. An appropriate need assessment was conducted and relevant stakeholders participated in the formulation of the courses. The programme allows working professionals from all sectors of the community to upgrade/refocus their skills, which is beneficial in terms of demographic transformation in attracting students from disadvantaged communities in South Africa and other southern African countries. The graduates are highly employable with a specific degree of 'MSc in Hydrogeology' as they are equipped with various scientific methods acquired through advanced courses as well as projects that have applied aspects. The training programme involves the participation of professional hydrogeologists from the private sector, government departments and mining companies who share job and management-related experiences.

Conclusion

A tailor-made programme, MSc in Hydrogeology (Course Work and Research Report), dedicated to training qualified and motivated hydrogeologists, is very helpful for the exploration of groundwater, as well as to provide knowledge-based support to communities and water managers. It is also quite important to refocus the groundwater research on community-related water supply problems and engage decision-makers on the importance of groundwater as a dependable resource, which is buffered from climatic variabilities. Often groundwater is safe for use; however, in the case of high salinity, acidity and toxic metal content, there are readily available technologies to treat groundwater before use.

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Competing interests

I have no competing interests to declare.

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