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Evaluation and management of groundwater — sustainable exploitation

title: **Groundwater quality of the Limpopo Province basement aquifers and its impact on rural groundwater supply**

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INTRODUCTION

Crystalline basement rock aquifers are distributed extensively in Africa and underlay large parts of the semi-arid Limpopo Province in South Africa. Some of the greatest groundwater needs occur within the Limpopo Province and constitutes the only dependable source of water for many users. Surface water resources in many areas of the Limpopo Province are now fully utilized and almost the only opportunity left for further development lies in the exploitation of groundwater. Groundwater is available and widely used throughout the Province, but in varying quantities depending upon the hydrogeological characteristics of the underlying aquifer. However, the availability of groundwater and the suitability of its quality for different uses are inextricably intertwined. There is a perception amongst water users that groundwater resources are not as viable as surface water resources. Remote communities with no other source of water view abstractions from a borehole as second hand and regard it as a poor man's resource. The growing importance of groundwater is not yet reflected in the improved management of the resource and together with the vulnerability of basement aquifers has lead to wide spread pollution. Despite indications that groundwater resources are evidently under-utilized and under-developed, the prospect of groundwater to successfully eradicate backlogs in provision of community water could be severely jeopardised by inadequate control or management of groundwater qualities in the Limpopo Province.

STUDY AREA

The focus area of this study covers an area of 23 500 km^2 in the Limpopo Province, South Africa. It is almost entirely underlain by Achaean basement lithologies (gneiss, granite and greenstones), which outcrop in an approximately rectangular area bordered to the south by younger overlying sedimentary strata, to the north by the Soutpansberg Group (Volcanic rocks), to the west by the Northern limb of the Bushveld Complex and to the east by the Drakensberg basalts of the Lebombo mountains (Figure 1). The western portion of the area can be referred to as the Limpopo Plateau and the eastern portion as the Letaba Lowveld respectively (Figure 1). The Limpopo Plateau is flat and almost featureless with the Blouberg Mountains towards the west and the Soutpansberg Mountains towards the northeast forming topographic highs. The climate of the Limpopo Plateau is semi-arid with a mean annual rainfall from of 300 mm to 600 mm. The Lowveld region east of the watershed is generally characterised as a moderately undulating plain with highly irregular hilly surfaces associated with the escarpment (Figure 1). The Lowveld is characterised by sub tropic temperatures with a fairly high humidity. Orographic rains occur frequently along the escarpment and the mean annual rainfall varies accordingly from 1 000 mm in the west to only 300 mm in the east. The runoff is highly seasonal and variable, with intermittent flow in many of the tributaries. Only a number of major river courses are perennial and most rivers sustain flow only during the wet season (December to April) or during intense rainfall events.

The basement rocks of the Limpopo Province contain some of the world oldest known rocks and are geologically and structural complex, shaped by multiple tectono-metamorphic events spanning at least 600 million years (Kramers et al, 2006). The study area is located on the north-eastern part of the Kaapvaal craton and the southern marginal shear zone (SMZ) of the Limpopo Mobile Belt (LMB) (Figure 1). Some authors (e.g. Roering et al., 1992; Windley, 1993) have suggested that the LMB in the northern part of South Africa is the world's earliest example of a Himalayan-type continent-continent collisional orogeny between two large cratons (Kaapvaal- and Zimbabwe Cratons respectively). The northward dipping Hout River Shear Zone (HRSZ) on the southern side of the LMB forms the boundary between the low grade basement lithologies of the Kaapvaal Craton to the south and the higher grade rocks (amphibole and granulite) of the SMZ to the north.

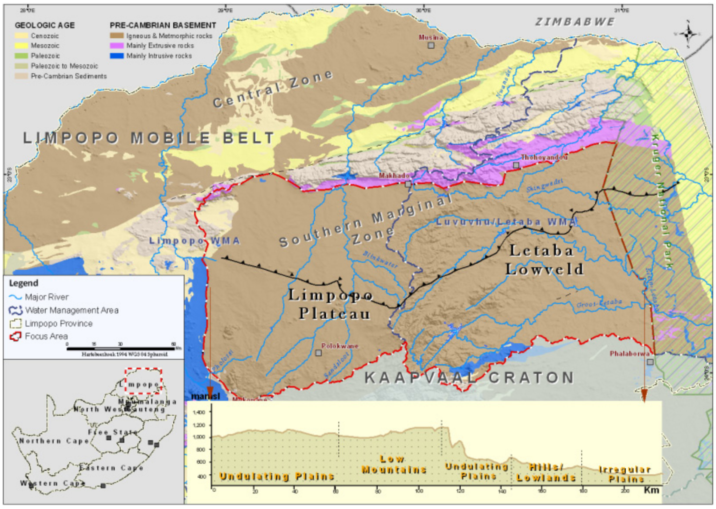

Figure 1. Area of investigation.

The aquifers systems developed in the focus area are: 1) composite aquifers; comprising of a variable thickness of regolith overlying bedrock, the upper part of which is frequently fractured, 2) fractured aquifers; composed mainly of crystalline material (i.e. igneous and metamorphic rocks) characterised by an intact and relatively unweathered matrix with a complex arrangement of interconnected fracture system and 3) alluvial aquifers; alluvial material overlies or replaces the weathered overburden and creates a distinct intergranular aquifer type. These elongated aquifers with limited width and depth follow rivers (so called valley trains), sand rivers or drainage lines.

DATA ANALYSIS

The dataset is based on the national groundwater database obtained from the South African Department of Water Affairs and the Limpopo Province Groundwater Resources Information Project (GRIP) database. Approximately 2 500 boreholes were analysed during the last decade as part of these programmes. The analyses included mainly major ions pH, TDS and electrical conductivity.

GROUNDWATER QUALITY

The dominant water types in Limpopo Plateau vary from a Na-Mg-HCO_3 to a Na-Mg-Cl groundwater facies, with the first being found in recharge areas (e.g. Blouberg and Soutpansberg), and the latter a result of prolonged residence and fluid-rock interaction times in the subsurface in areas of discharge (e.g. alluvium along rivers) or low recharge (e.g. quaternary deposits in the northern part of the sub-region). Groundwater in the Letaba Lowveld is generally a fresher Mg-HCO_3 facies (in comparison to the Limpopo Plateau), with a recognizable pattern of elevated mineralization with reduced precipitation/recharge is.

Borehole yields in basement aquifers are typically relatively low (usually less than 5 l /s and often less than 1 l /s) and groundwater quantities are usually limited. The presence of undesirable natural hydrogeochemicals or by introduced contaminants reduces the exploitation value even further. Neglecting the variation in groundwater chemistry due to either ignorance or lack of information can cause harmful or even detrimental effect to the community who relies on the bad quality water as their domestic source. Table 1 presents the overall drinking guideline classification of the major ion chemistry of the Limpopo Plateau and Letaba Lowveld basement aquifer region under investigation.

Table 1. Potability classification of the area of investigation (EC in mS/m, all other in mg/l).

SANS*	EC	Ca	Mg	Na	K	SO_4	Cl	NO_3 as N	F	TDS	Final Class
Class I Rec. operational Limit	< 150	< 150	< 70	< 200	< 50	< 400	< 200	< 10	< 1	< 1000	
Class II Max. allowable limited	150-370	150-300	70-100	200-400	50-100	400-600	200-600	10-20	1-1.5	1000-2400	
Exceeding Class II (Consumption period)	7 years								1 year	7 years	
Limpopo Plateau											
Class I	70%	94%	75%	85%	99%	99%	73%	54%	87%	96%	34%
Class II	26%	4%	15%	11%	1%	0%	20%	27%	5%	0%	34%
> Class II	4%	2%	9%	4%	0%	1%	6%	19%	8%	4%	31%
Letaba Lowveld											
Class I	78%	96%	78%	90%	100%	100%	81%	60%	94%	98%	47%
Class II	19%	3%	13%	8%	0%	0%	15%	16%	4%	0%	24%
> Class II	6%	2%	17%	6%	0%	1%	9%	38%	8%	5%	54%

* SANS 241:2006 (SANS, 2006).

Thirty one percent of samples within the Limpopo Plateau and fifty four percent of samples within the Letaba Lowveld show major ion concentration far from ideal. The most noticeable elements of concern for water consumption are nitrate (measured as nitrogen (N)) and fluoride. In addition, several samples show major ion concentrations (e.g. Mg, Na, Cl) and subsequently electric conductivities beyond acceptable limits. This can mostly be related to evaporative concentration of elements in discharge areas or due to low recharge values as well as long residence times for selected samples. According to Marais (1999) the single most important reason for groundwater sources in South Africa to be declared unfit for drinking is nitrate levels exceeding 10 mg/l (as N). The main inputs of nitrate to groundwater in rural environments are derived from anthropogenic activities such as inappropriate on-site sanitation and wastewater treatment, improper sewage sludge, drying and disposal, and livestock concentration at watering points near boreholes. The extensive occurrence of nitrate in groundwater in uninhabited regions suggest non-anthropogenic sources possibly related to evaporative enrichment of dry and wet deposition, biogenic point sources through N-fixing organisms, or to a geogenic origin (Figure 2). In contrast to nitrate, the occurrence of fluoride is primarily controlled by geology and climate. Therefore, there are no preventative measures under the given spatial limits of a water supply to avoid contamination. High intake of fluoride from drinking water is the main cause of flourosis and may lead to many other health problems.

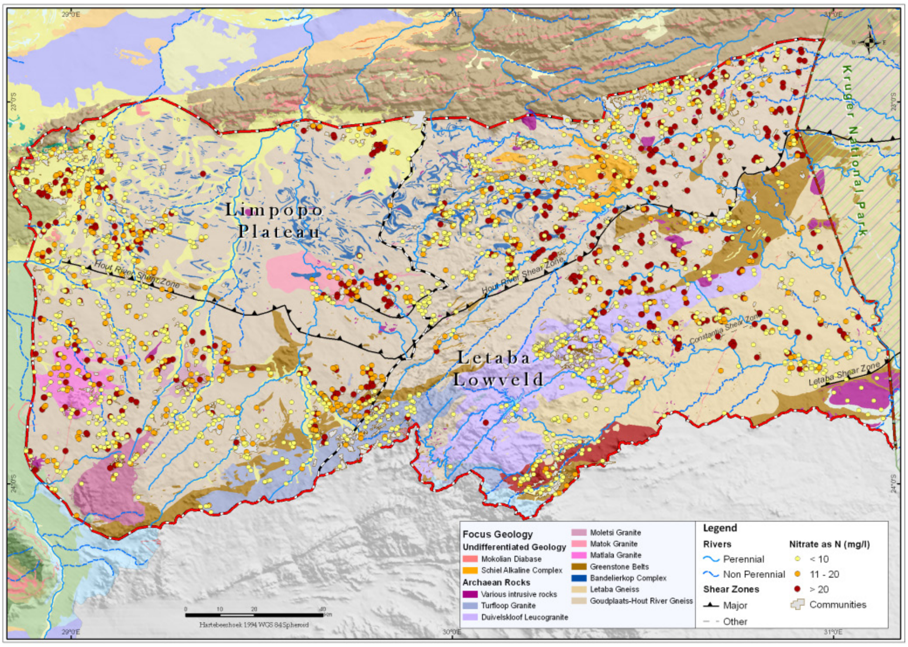

Figure 2. Map showing distribution of nitrate in groundwater in the Limpopo Plateau and Letaba Lowveld.

Heterotrophic bacterial counts are used to indicate the general microbiological quality of water, i.e. the amount of bacteria present in the water. The total coliform bacteria count, which includes bacteria from the faecal group, is an indicator of the general sanitary quality of the groundwater, with many of these bacterial colonies originating potentially from an aquatic environment. The total faecal coliform bacteria count, which is related to human or animal faecal pollution, refers to probable faecal pollution of water. The presence of coliform bacteria implies the potential presence of waterborne pathogens (DWAF, 1996). According to the Department of Water Affairs' water quality guidelines (DWAF, 1996) for domestic use, the total heterotrophic bacterial plate count of all groundwater samples from both areas indicates a slight or increased risk of bacterial infection and infectious disease transmission. Fourteen groundwater samples show a significantly increased risk for infectious disease transmission according to the total coliform bacterial range and two samples indicates a significant risk for faecal coliform and e.coli (Table 2).

Table 2. Microbiological analyses for selected boreholes in Muyexe village (DWAF, 1996).

Allowable compliance contribution*				
95% min.	*100*	*Not detected*	*Not detected*	*Not detected*
4% min.	*1 000*	*10*	*1*	*Not detected*
1% min.	*10 000*	*100*	*10*	*1*
Sample	Heterotrophic *count/ml*	Total Coliform *count/100ml*	Faecal Coliforms *count/100ml*	E.Coli *count/100ml*
Nr of Samples	51	19	10	10
Compliance 4% min.	45	4	5	5
Compliance 1% min.	11	14	2	2

* The allowable compliance contribution shall be at least 95% to the limits indicated with a maximum of 4% and 1% respectively.

IMPLICATION FOR RURAL WATER SUPPLIES

Results show that many rural groundwater supplies are contaminated. Approximately 35% of rural communities in the region are dependent on groundwater alone and 50% have conjunctive use of both surface- and groundwater. A large part of the rural population lives in areas underlain by basement rocks which might release fluoride to groundwater. In addition anthropogenic sources such as inappropriate on-site sanitation at rural villages, pit latrines and animal feedlots frequently lead to pollution and the abandoning of well fields. Protection of groundwater resources that serve as a drinking water supplies should be equally important target as creating new water supply infrastructure in a country. If mitigative measures are not established early, groundwater quality will have a severe impact on the exploitability of groundwater resources in the Limpopo Province. These measures may include the provision of accurately mapped water quality information, proper borehole construction, protection zoning and appropriate water treatment for drinking purposes. The management of groundwater has to date failed to feature prominently in the national and regional development plans. Despite the new national water Act (1998) which includes excellent general protection measures the challenge lies in the implementation of the available approaches and instruments. However, perhaps one of the biggest weights lies on water service providers to convey the value of groundwater to the communities. The consensus is that communities will only concern themselves with the quality of the water when there is enough to meet their basic needs.

ACKNOWLEDGEMENTS

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