GROUNDWATER INVESTIGATIONS FOR THE PROPOSED ABSTRACTION BOREHOLES ON THE PORTION 10 OF THE FARM DOORNRUG 302 IN THE MPUMALANGA PROVINCE OF SOUTH AFRICA

Prepared by

Nyamoki Consulting Pty Ltd

E: info@nyamokiconsulting.co.za

Prepared for

SU CASA BE

Date: 05 January 2023

I, T Bengeza, declare that I:

- I consider myself bound to the rules and ethics of the South African Council for Natural Scientific Professions (SACNASP).
- At the time of conducting the study and compiling this report, I did not have any interest, hidden or otherwise, in the proposed development that this study has reference to, except for financial compensation for work done in a professional capacity.
- Work performed for this study was done in an objective manner. Even if this study results in views and findings that are not favorable to the client/applicant, I will not be affected in any manner by the outcome of any environmental process of which this report may form a part, other than being a member of the general public.
- I declare that there are no circumstances that may compromise my objectivity in performing this specialist investigation. I do not necessarily object to or endorse the proposed development, but aim to present facts, findings, and recommendations based on relevant professional experience and scientific data.
- I do not have any influence over decisions made by the governing authorities.
- I undertake to disclose all material information in my possession that reasonably has or may have the potential of influencing any decision to be taken with respect to the application by a competent authority to such a relevant authority and the applicant.
- I have expertise and experience in conducting specialist reports relevant to this application, including knowledge of the Act, regulations and any guidelines that have relevance to the proposed activity.
- I will comply with the Act, regulations and all other applicable legislation.
- I realize that a false declaration is an offense in terms of Regulation 71 of NEMA and is punishable in terms of section 24F of the Act.

Signature: ____________

Date: 06.02.2023

GLOSSARY OF TERMS

Aquifer: a geological formation, which has structures or textures that hold water or permit appreciable water movement through them [from National Water Act (Act No. 36 of 1998)].

Borehole: includes a well, excavation, or any other artificially constructed or improved groundwater cavity which can be used for the purpose of intercepting, collecting or storing water from an aquifer; observing or collecting data and information on water in an aquifer; or recharging an aquifer [from National Water Act (Act No. 36 of 1998)].

Fractured aquifer: fissured and fractured bedrock resulting from decompression and/or tectonic action. Groundwater occurs predominantly within fissures and fractures.

Groundwater: water found in the subsurface in the saturated zone below the water table or piezometric surface i.e. the water table marks the upper surface of groundwater systems.

Hydraulic conductivity: measure of the ease with which water will pass through earth material; defined as the rate of flow through a cross-section of one square metre under a unit hydraulic gradient at right angles to the direction of flow (in m/d)

Intergranular and fractured aquifers: largely medium to coarse grained granite, weathered to varying thicknesses, with groundwater contained in intergranular interstices in the saturated zone, and in jointed and occasionally fractured bedrock.

Intergranular Aquifer: generally unconsolidated but occasionally semi-consolidated aquifers. Groundwater occurs within intergranular interstices in porous medium. Typically occur as alluvial deposits along river terraces.

Piezometer: a piezometer is either a device used to measure liquid pressure in a system by measuring the height to which a column of the liquid rises against gravity, or a device which measures the pressure (more precisely, the piezometric head) of groundwater at a specific point. A piezometer is designed to measure static pressures.

Transmissivity: the rate at which a volume of water is transmitted through a unit width of aquifer under a unit hydraulic head (m2/d); product of the thickness and average hydraulic conductivity of an aquifer.

Vadose zone: the unsaturated zone above the water table and below the ground surface.

Well point: a well point installation, often incorrectly referred to as a borehole, is an affordable option to access ground water. The well point is usually installed by jetting a perforated pipe into the ground. The depth of installation is limited by any hard layers.

ABBREVIATIONS

CAPE	a geographic datum used in South Africa prior to 1999
ch	collar height
EC	Electrical Conductivity
ha	hectare
ℓ/s	litres per second
m	metres
mm	millimetres
MAE	Mean annual evaporation
mamsl	metres above mean sea level
MAP	Mean annual precipitation
mbch	metres below collar height
mbgl	metres below ground level
mg/ℓ	milligrams per litre
Mm/a	millimetres per annum
MRF	Materials Recovery Facility
mS/m	milliSiemens per meter
NGA	National Groundwater Archive
ohm.m	ohm metres (units of measure from resistivity geophysical profiling)
WGS84	Since the 1st January 1999, the official co-ordinate system for South Africa is based on the World Geodetic System 1984 ellipsoid, commonly known as WGS84.

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1. INTRODUCTION

Nyamoki Consulting Pty Ltd has been appointed by SUCASA BE to conduct pump testing for three boreholes, write the pump testing report on the characteristics for three boreholes regarding the characteristics of the aquifer (Ground study report) for the one borehole used for Cemetery purpose for the two existing boreholes.

2. GROUNDWATER STUDY OBJECTIVES

The groundwater impact assessment has the following objectives:

- A site visit to the study site and adjacent farms which could be impacted by the activities in order to observe the geology, specific features and rivers in the catchment. Identify features which have particular significance;
- Conduct a pump test to determine the yield of aquifer within the study area; and
- Define the aquifers underlying the Cemetery Project, as well as current groundwater table depth, and groundwater quality.
- Make recommendations for the use and consumption based on the pump testing and water quality analysis.

3. SITE DESCRIPTION

3.1. Location

The study area is located in portion 10 of the farm Doornrug 302 in the Mpumalanga province of South Africa. It is South of the N4 road towards Witbank, closer to the Elandsfontein Colliery on the western side see Figure1 below.

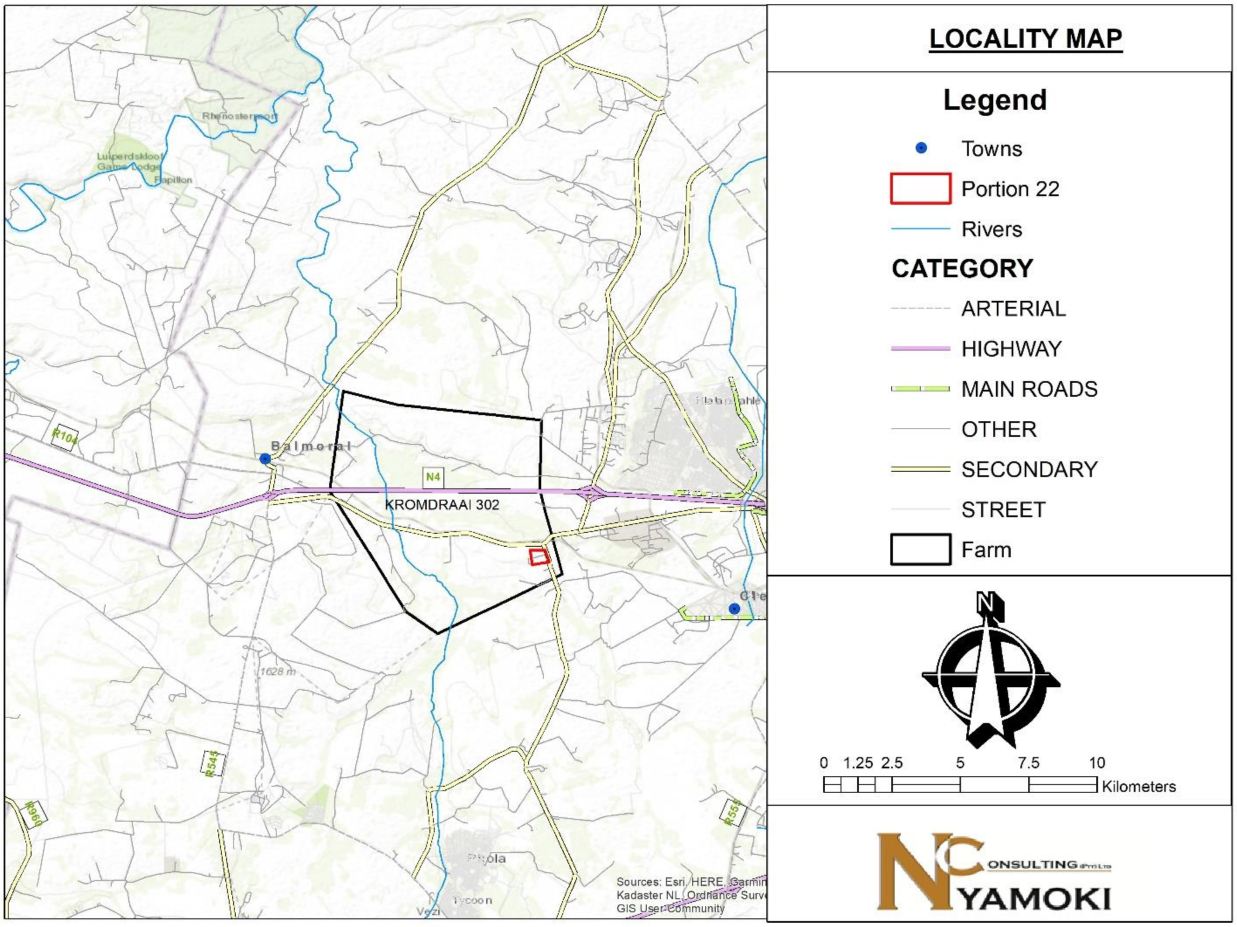

Figure 1: Locality Map

3.2. Topography

The topography of the greater study area is characterised by moderately undulating plains and pans. The north eastern perimeter is shaped by a topographical high at 335 meters above mean sea level (mamsl) and forms the watershed between quaternary catchments B20G and B11K. To the south and southeast, the landscape gradually flattens out towards the lower laying drainage system with the lowest on-site elevation recorded as 295 mamsl.

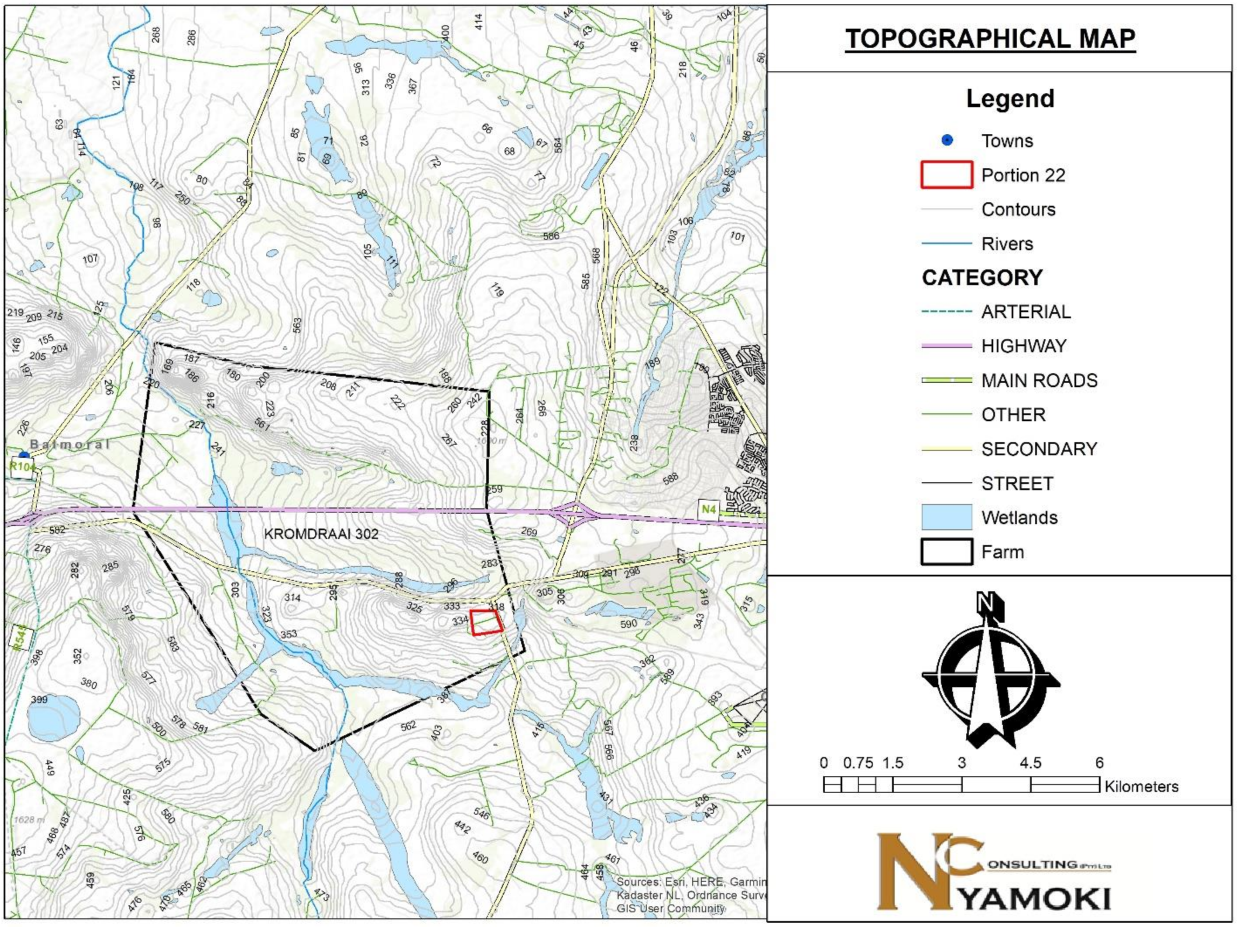

Figure 2: Topographical Map

3.3. Landuse

The study area is characterised by coal mines, farming both crop and livestock farming. Most of the area is covered by the farms surrounding the proposed cemetery, although coal mines are mostly located on the eastern side. Farmer houses are local houses adjacent to the site although they are very few in the south and on the western side (Figure 3).

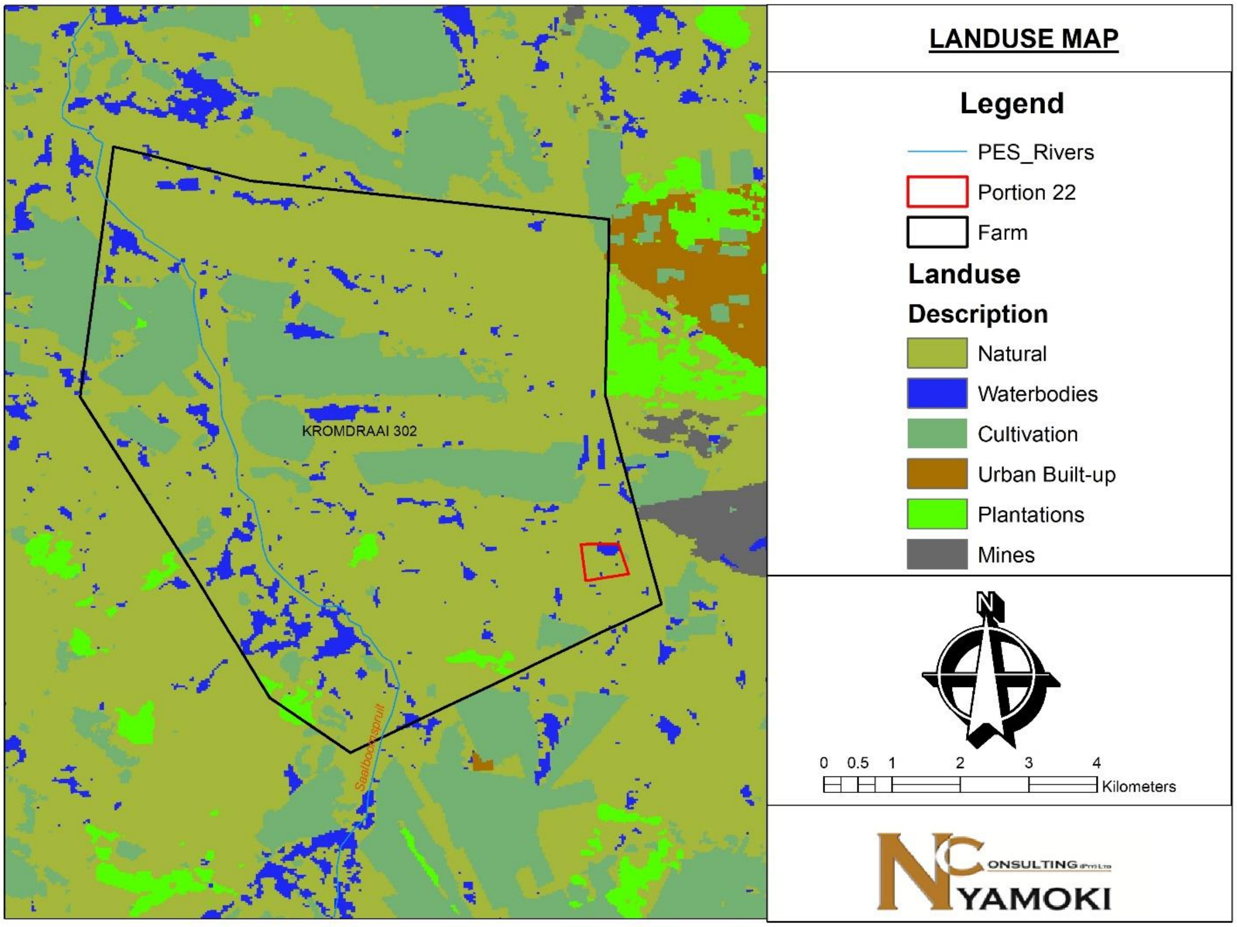

Figure 3: Landuse map.

3.4. Geology

3.4.1. Regional geology

The greater study area falls within the Ecca Group of the Karoo Supergroup, which consists of a sequence of units, mostly of nonmarine origin, deposited between the Late Carboniferous and Early Jurassic (Schlüter and Thomas, 2008). The Permian Ecca Group follows conformably after the Dwyka Group in certain sections, however in some localities overlies unconformably over older basement rocks. The Ecca Group underlies the Beaufort Group in all known outcrops and exposures and comprises a total of 16 formations consisting largely of shales and sandstones (Figure 4).

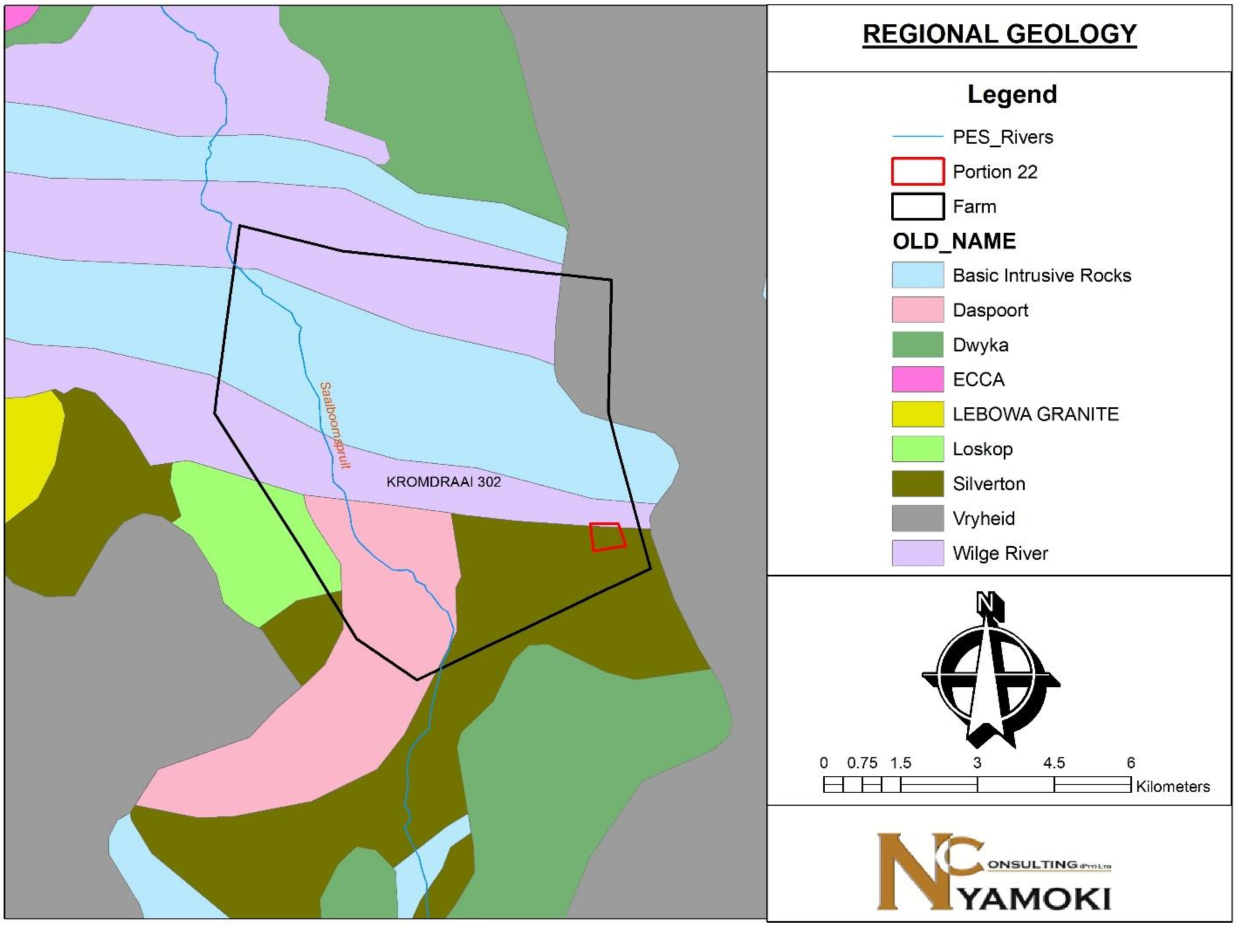

Figure 4: Regional Geology.

3.4.2. Local geology

According to the 1:250 000 geological map sheet (2528, Pretoria) the study area falls within the Madzaringwe formation with surficial geology consisting mainly of shale, shaly sandstone, grit, sandstone, conglomerate as well as interlaminated coal layers and entails predominantly arenaceous formations. Refer to Figure 5 and 6 for a simplified stratigraphic column of the study area (Figure 6).

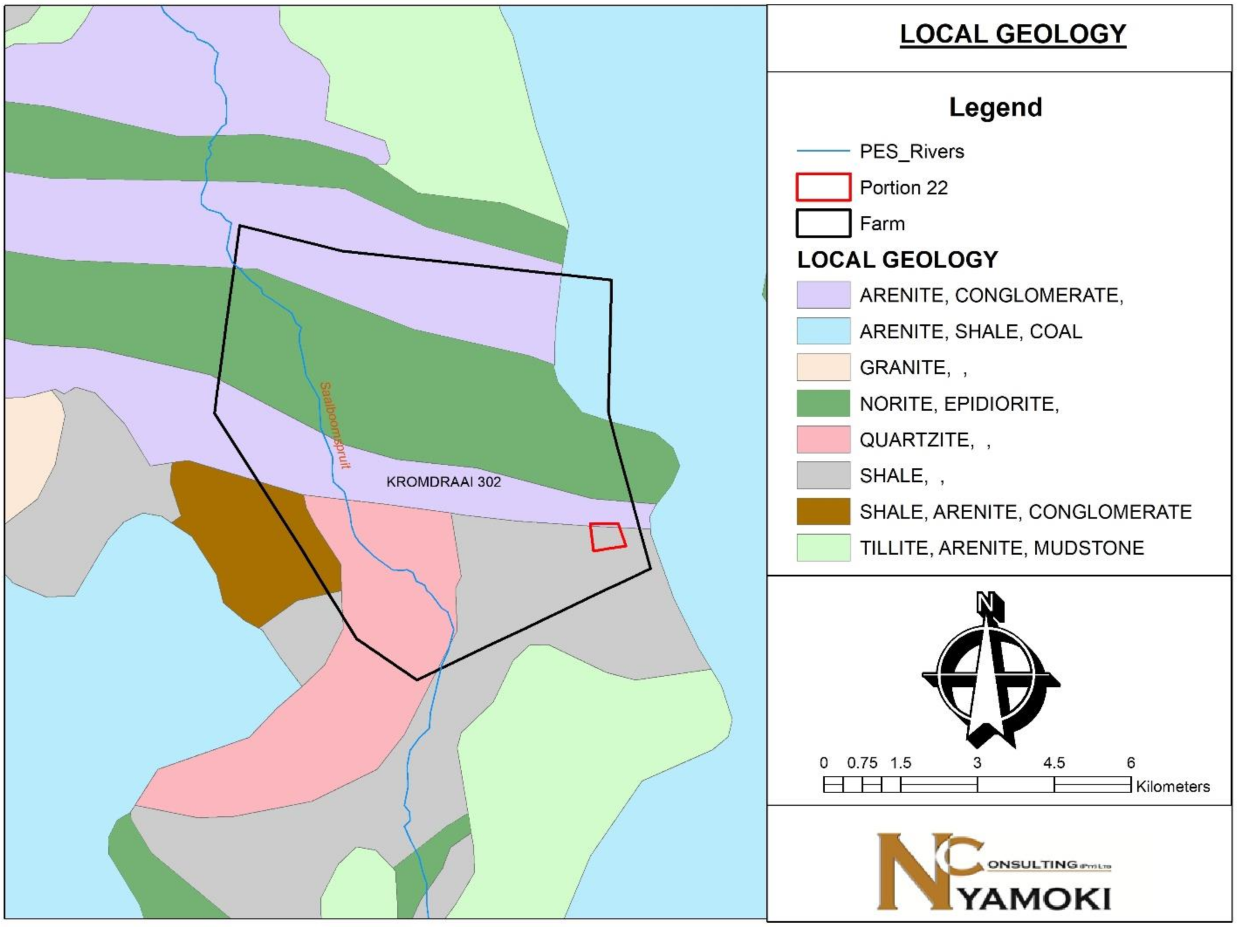

Figure 5: Local Geology

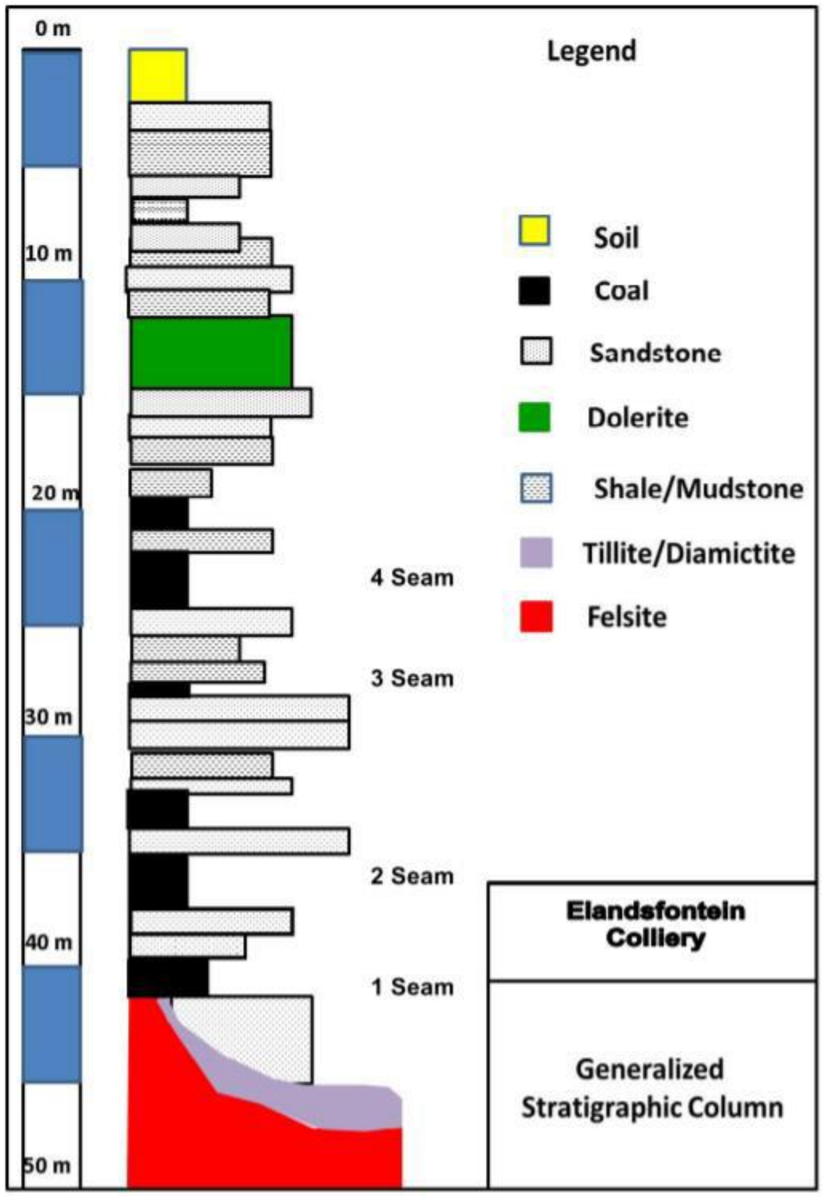

Figure 6: Simplified stratigraphic column of the greater study area (after Georoc, 2020).

3.4.3. Structural geology

On a regional scale, two geological lineaments (potentially faults zones) exist in close proximity to the greater study area, striking in a general north-south and southwest-northeast orientation respectively. Faults zones may have an impact on the local hydrogeological regime as it can serve as potential preferred pathways for groundwater flow and contaminant transport.

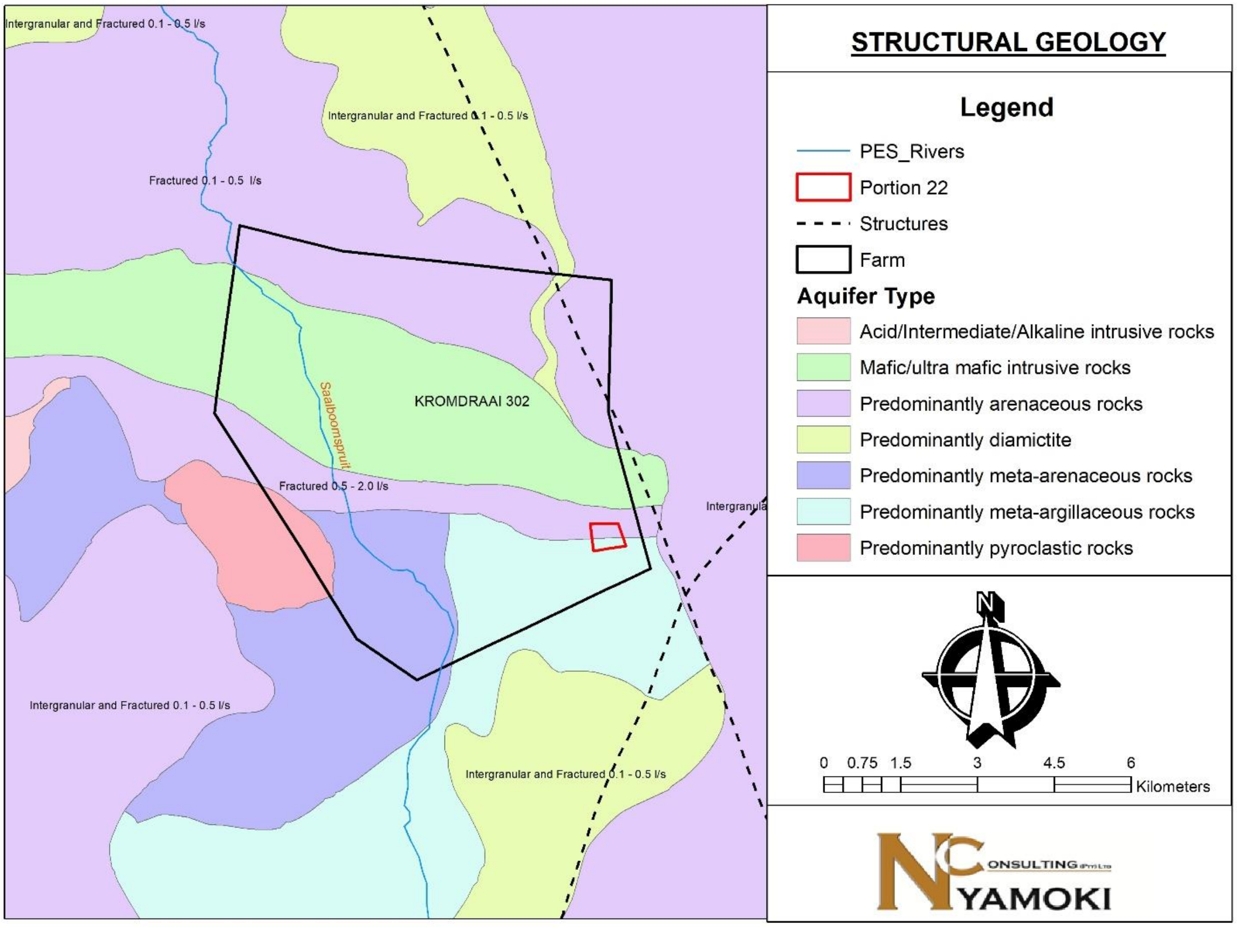

Figure 7: Structural Geology.

3.5. Geohydrological

3.5.1. Regional hydrogeology

The Department have characterised South African aquifers based on host-rock formations in which it occurs together with its capacity to transmit water to boreholes drilled into relative formations. The water bearing properties of respective formations can be classified into four aquifer classes defined as:

a) **Class A:** Intergranular o Aquifers associated either with loose and unconsolidated formations such as sands and gravels or with rock that has weathered to only partially consolidated material.

b) **Class B:** Fractured o Aquifers associated with hard and compact rock formations in which fractures, fissures and/or joints occur that are capable of both storing and transmitting water in useful quantities.

c) **Class C:** Karst o Aquifers associated with carbonate rocks such as limestone and dolomite in which groundwater is predominantly stored in and transmitted through cavities that can develop in these rocks.

d) **Class D:** Intergranular and fractured o Aquifers that represent a combination of Class A and B aquifer types. This is a common characteristic of South African aquifers. Substantial quantities of water are stored in the intergranular voids of weathered rock but can only be tapped via fractures penetrated by boreholes drilled into it. Each of these classes is further subdivided into groups relating to the capacity of an aquifer to transmit water to boreholes, typically measured in l/s. The groups therefore represent various ranges of borehole yields.

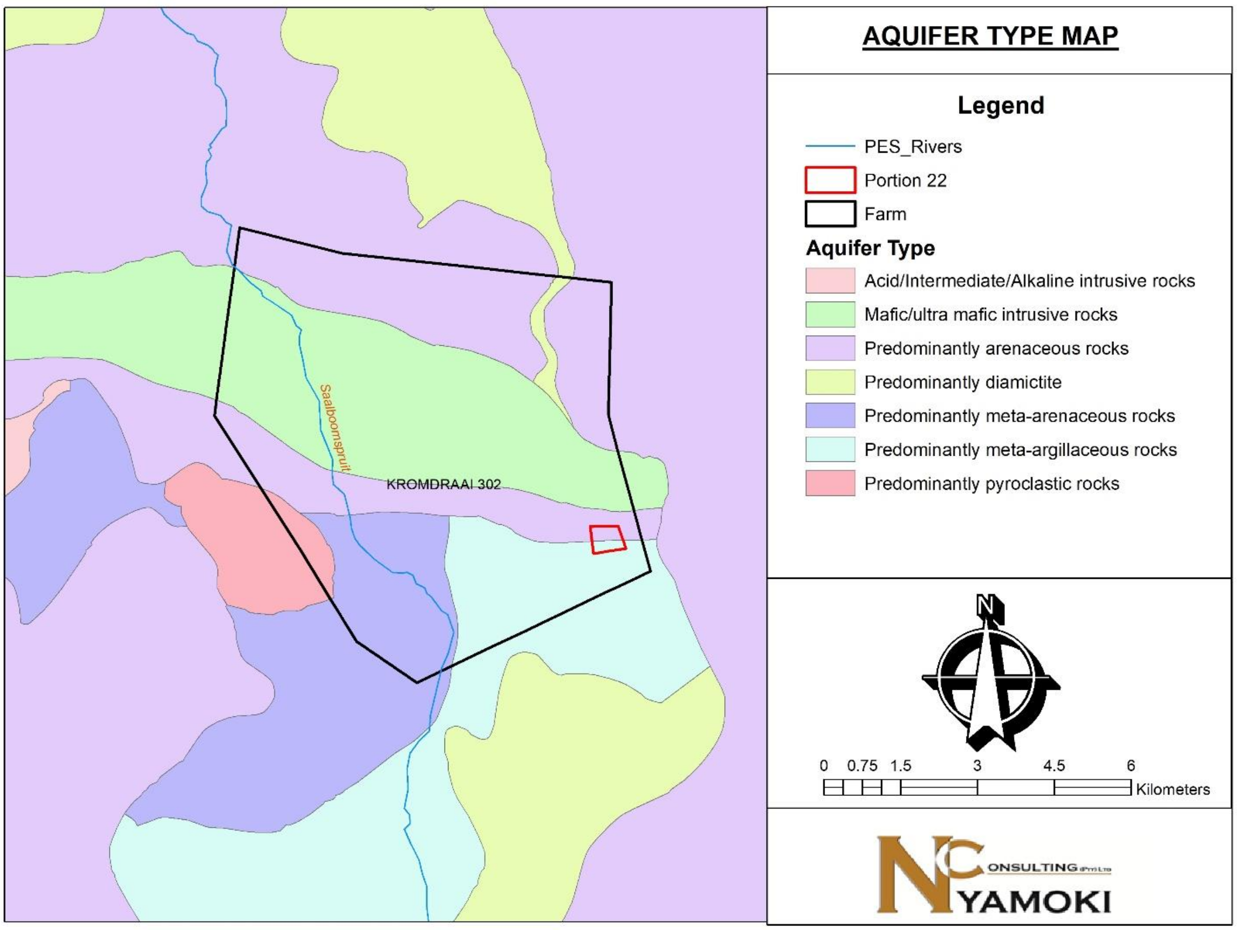

Figure 8: Aquifer map.

According to the DWS Hydrogeological map (DWS Hydrogeological map series 2526 Johannesburg) the site is predominantly underlain by an intergranular and fractured aquifer system (d3) comprising mostly fractured and weathered compact sedimentary/ arenaceous rocks (Figure 9). The Ecca Group consists mainly of shales and sandstones that are very dense with permeability usually very low due to poorly sorted matrices. Water is stored mainly in decomposed/partly decomposed rock and water bearing fractures are principally restricted to a shallow zone below the static groundwater level. Sustainable borehole yields are limited to < 0.5 l/s, while higher yielding boreholes (> 3.0 l/s) may occur along structural features i.e. fault and fracture zones (Barnard, 2000). Water levels are variable and controlled by topography, ranging from 10.0 mbgl (in low laying areas) to > 40.0 mbgl in higher elevated areas (Olifants ISP DWS, 2004). The maximum aquifer depth fluctuates between 30.0 – 50.0 mbgl.

3.5.2. Local hydrostratigraphic units

For the purposes of this investigation, two main hydrostratigraphic units can be inferred in the saturated zone:

i. A shallow, weathered zone aquifer occurring in the transitional soil and weathered bedrock formations underlain by more consolidated bedrock. Ecca sediments are weathered to depths between 5.0 – 15.0 mbgl (Digby Wells, 2018). Groundwater flow patterns usually follow the topography, discharging as natural springs and/or baseflow at topographic low-lying areas. Usually, this aquifer can be classified as a secondary porosity aquifer and is generally unconfined with phreatic water levels. Due to higher effective porosity (n) this aquifer is most susceptible to impacts from contaminant sources.

ii. An intermediate/deeper fractured aquifer where groundwater flow will be dictated by transmissive fracture zones that occur in the relatively competent host rock. Fractured sandstones and shale sequences are considered as hard-rock aquifers holding water in storage in both pore spaces and fractures. Groundwater yields, although more heterogeneous, can be expected to be higher than the weathered zone aquifer. This aquifer system usually displays semi-confined or confined characteristics with piezometric heads often significantly higher than the water-bearing fracture position

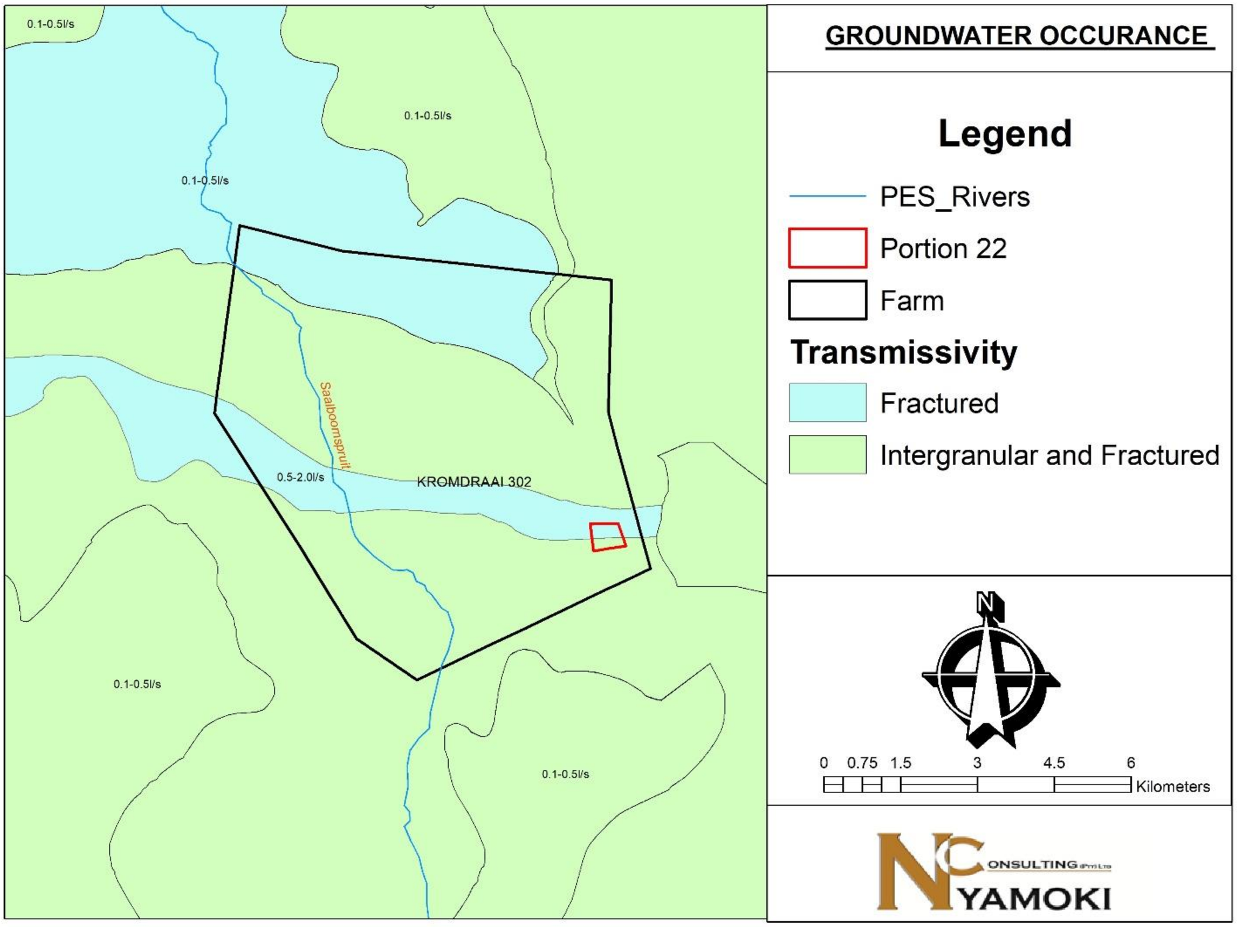

Figure 9: Hydrogeological map illustrating the typical groundwater occurrence for the study area.

4. GROUNDWATER QUALITY

Two (2) groundwater samples were collected during the December 2022 pump testing two for domestic use for cemetery. The water samples were submitted to Aquatico Laboratories for analysis; Aquatico is a SANAS accredited laboratory (South African National Accreditation System). The water samples were analysed for basic inorganic parameters and the results were compared against the SANS 241:2015 Drinking Water Standards.

Samples were taken using single valve, decontaminated bailers or from pump discharge lines in the case of boreholes which were equipped and in use. Sterilized 1 litre (L) sample bottles were used and filled to the top. Samples were stored in a cooler box during the site surveys.

Water quality data are presented by means of Table 4, and Piper and Stiff diagrams. The Piper (Figure 5) were created using the GWB software.

4.1. Water quality for consumption use and irrigation standards

A water sample was submitted to Aquatico Laboratories on 23 December 2022 for testing the quality for intended use as domestic water. The water quality test results are displayed in Table 4 below. Water quality is compared to the SANS 241-1:2015 and Drinking Water Standard (DWS, 1998).

From the water quality data BH01 it was found the water has high turbidity which was found not compliant with the SANS 241:2015 guideline, which requires that before use it must be treated. The high turbidity might be a result that the borehole is taking water from shallow aquafers which are highly weathered. BH02 indicated that the nitrate and manganese level were not compliant with the DWS guideline standards. High levels of nitrate in drinking water may increase the risk of colon cancer. Nitrate may enhance the cancer potential of other compounds or may turn into cancer-causing chemicals like the body. Nitrate in drinking water has not been shown to increase the risk of other kinds of cancer. Children and adults who drink water with high levels of manganese for a long time may have problems with memory, attention, and motor skills. Infants (babies under one year old) may develop learning and behaviour problems if they drink water with too much manganese in it. It is recommended that before the water is consumed be treated since it is not good for long term consumption (Table 1).

Table 1: Boreholes Water Quality Results.

Sample ID		BH01	BH02	Drinking Water Standard	Domestic Water Limits
	Units	**22-Dec-22**		**SANS 241: 2015**	**DWS 1998**
pH	pH	6.22	4.99	5.0-9.7	>4.0
Electrical Conductivity (EC)	mS/m	6.22	15.9	170	0 -70
Total Dissolved Solids (TDS)	mg/l	32	96	1200	0 -450
Alkalinity (Alk)	mg $CaCO_3$/l	11.4	2.61		
Chloride (CL)	mg/l	-0.557	22.3	300	0 -100
Sulphate (SO4)	mg/l	8.29	9.55	500 (Health)	0 -200
Nitrate (NO3)	mg/l	1.77	8.06	11	0 -6
Ammonium (NH4)	mg/l	0.225	0.142	1.5	
Floride (F)	mg/l	-0.263	-0.263	1.5	0 -1.0
Calcium (Ca)	mg/l	3.36	9.22		0 -32
Manganese (Mg)	mg/l	1.18	4.5		0-30
Sodium (Na)	mg/l	2.33	7.52	200	0 -100
Potassium (K)	mg/l	1.99	5.79		0 -50
Aluminium (Al)	mg/l	0.079	0.175	0.3	
Iron (Fe)	mg/l	0.004	0.015	2 (health) (aesthetics)	0 -0.1
Manganese (Mn)	mg/l	0.235	0.553	0.1	
Chrome (Cr)	mg/l	-0.003	-0.003		
Copper (Cu)	mg/l	-0.002	-0.002	2	
Nickel (Ni)	mg/l	-0.002	-0.002	2	
Zinc (Zn)	mg/l	2.88	0.087	5	
Cadnium (Cd)	mg/l	-0.002	-0.002	≤0.03	
Lead (Pb)	mg/l	-0.004	-0.004	0.01	
NTU	NTU	19.3	0.55	<1	
Thard - cal	mg $CaCO_3$/l	13	42		
TOC	mg/l	0.819	1.42		
CN Screening	mg/l	-1.1	-1.1		
LSI - cal	LSI	-4.08	-5.55		
TON	mg/l	1.77	8.06		

4.2. Groundwater type

4.2.1. Piper diagram

The Piper diagram is one of the most commonly used techniques to interpret groundwater chemistry data. This method proposed the plotting of cations and anions on adjacent trilinear fields with these points then being extrapolated to a central diamond field. Here the chemical character of water, in relation to its environment, could be observed and changes in the quality interpreted. The cation and anion plotting points are derived by computing the percentage equivalents for the main diagnostic cations of Ca, Mg, Na and K, and anions Cl, SO_4 and HCO3. Water from different environments, i.e. water with different chemical properties, will plot in different diagnostic areas on the central diamond field, as seen in Figure 10. The upper half of the diamond normally contains water of static and disordinate regimes, while the middle area normally indicates an area of dissolution and mixing. Sodium sulphate and sodium chloride brines normally plot on the right-hand corner of the diamond shape while recently recharged water plots on the left-hand corner of the diamond plot.

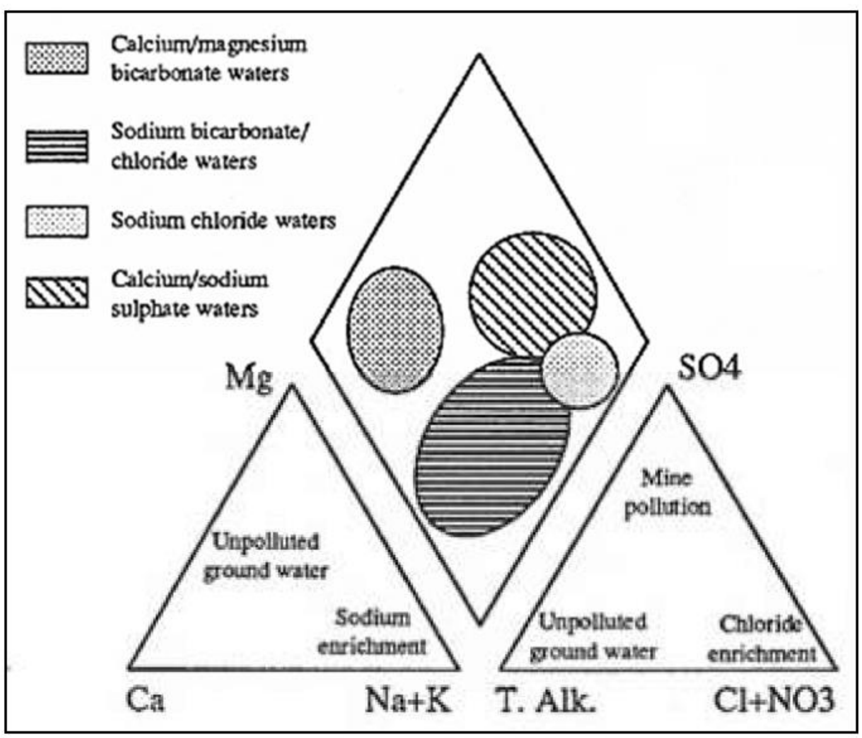

Figure 10: Piper Diagram Explained.

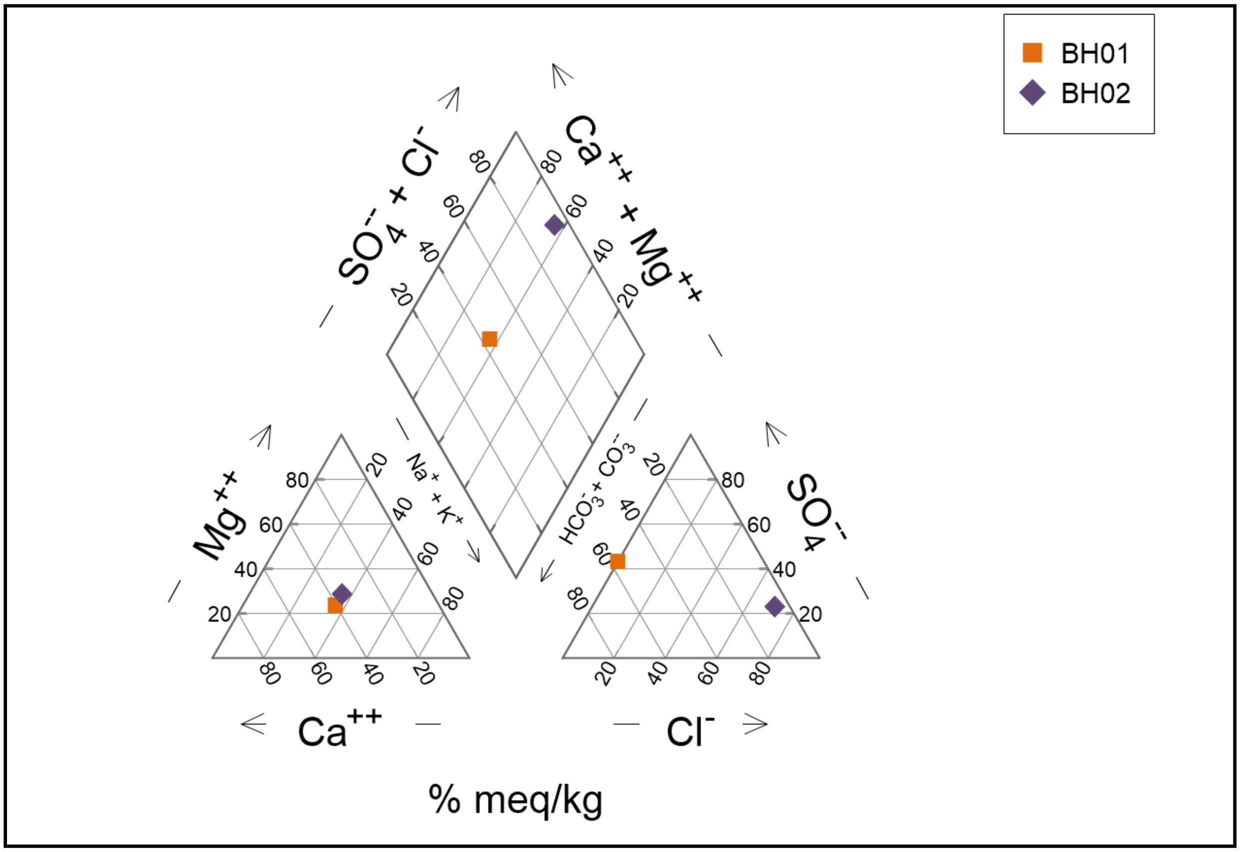

Figure 11: Pipe diagram for BH01 and BH02.

Piper diagrams are graphical representations of the major ion compositions of water samples. The Piper diagrams for the sampling points are illustrated in **Figure 11.** As expected from the piper diagram results, as the BH01 sample shows that the water type is mostly dominated by sodium bicarbonate/ chloride water anion composition while the BH02 shows that its water type is calcium/sodium sulphate water anion composition. In terms of cations, calcium is dominant in most samples.

BH01 shows Type 2: Sodium-bicarbonate groundwater −Groundwater with sodium as the dominant cation and bicarbonate as the dominant anion. Type 2 water is typically found in deeper portions of the aquifer.

BH02 shows Type 3: Calcium-bicarbonate/chloride/sulphate groundwater − Groundwater with calcium as the dominant cation and bicarbonate the dominant anion, but with relatively elevated chloride and sulphate concentrations. This water type consistently has higher levels of TDS than the other two types.

4.2.2. Stiff diagrams

The Stiff diagram (See Figure 12 and 13 X, Y and Z above) shows similar in shapes of the water sample analysed. The similarity of hexagonal shape in BH01, BH02 and BH03 indicate water type of similar characteristics. HCO_3^- is the dominant cation followed by the Ca^{2+} and on the anion's species, Mg^{2+} the is the most dominant in BH01 (Figure 12) while BH02 Cl^- is the dominant cation followed by the K^+ and on the anions species, SO_4 is the most dominant (Figure 13). By looking at the stiff diagram results, these 2 boreholes could be getting their water from the different aquifers.

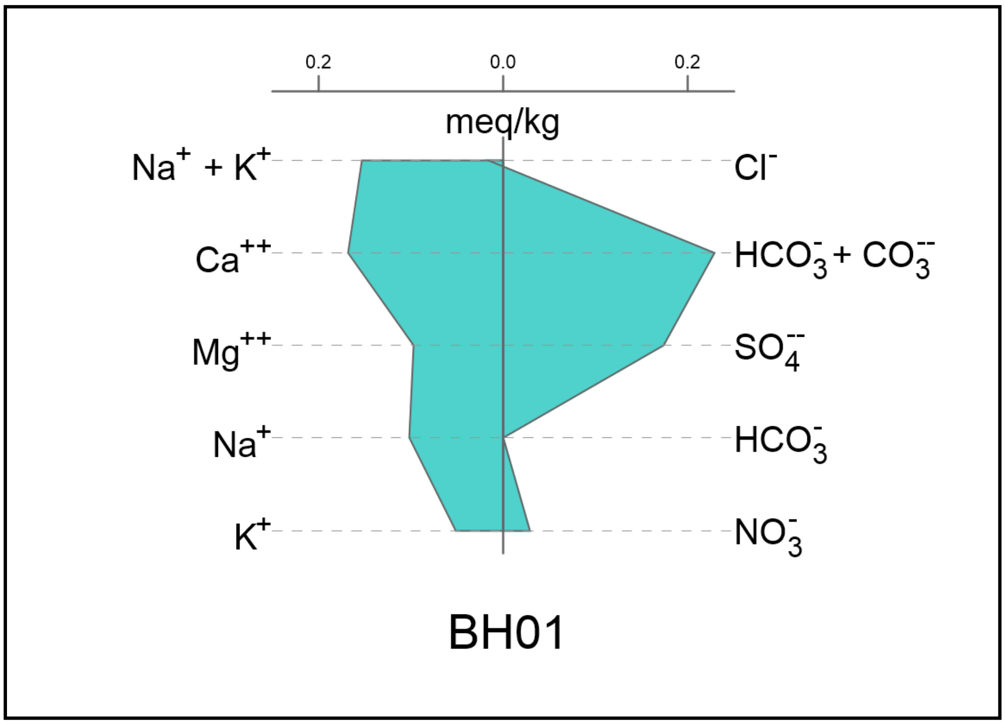

Figure 12: Stiff diagram for BH01

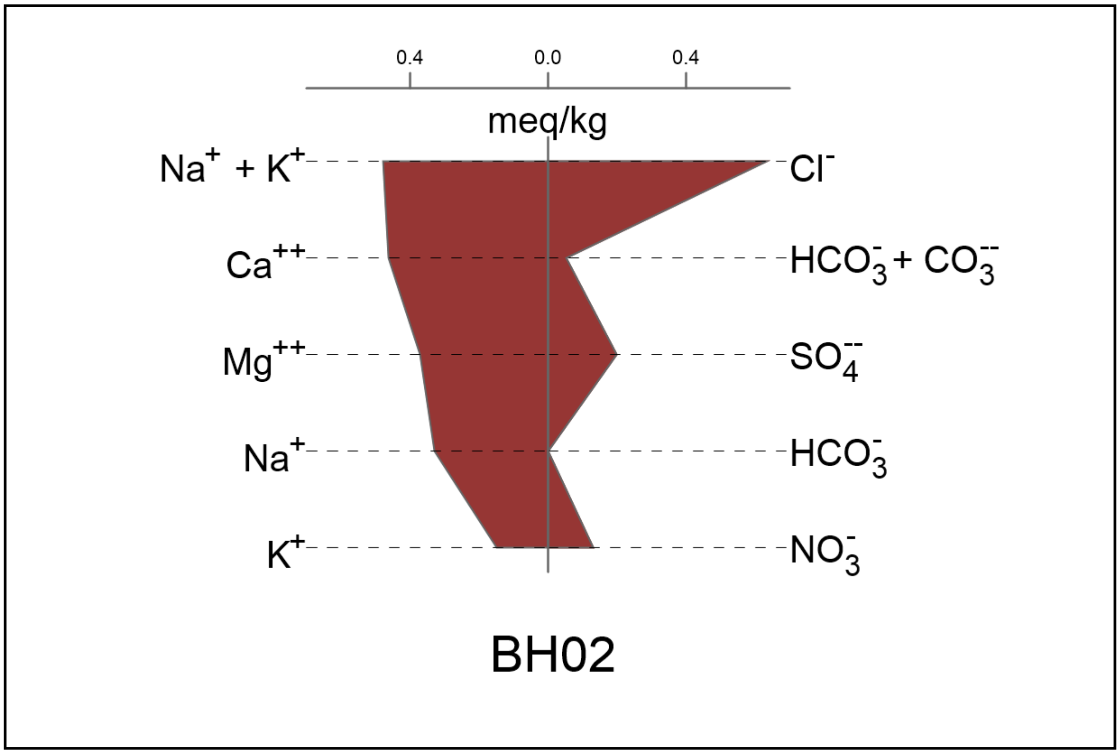

Figure 13: Figure 14: Stiff diagram for BH02

5. AQUIFER RISK AND VULNERABILITY ASSESSMENT

The risk assessment was carried out in terms of 3 stages: evaluation of aquifer's strategic value, identification of possible contamination risk and evaluation of aquifer's vulnerability to identified contamination risk.

5.1. Aquifer classification

The aquifer classification is done in accordance with the DWAF protocol "South African Aquifer System Management Classification, December 1995." Special attributes of aquifers related to structural features (such as fracturing along dyke/fault contact zones, or karst development) have been incorporated into the classification through the "Second Variable Classification". Classification is done in accordance with the following definitions for Aquifer System Management Classes:

Sole Aquifer System:

An aquifer which is used to supply 50 per cent or more of domestic water for a given area, and for which there is no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.

Major Aquifer System:

Highly permeable formations, usually with a known, or probable, presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (less than 150 mS/m Electrical Conductivity).

Minor Aquifer System:

These can be fractured or potentially fractured rocks which do not have a high primary permeability or other formations of variable permeability. Aquifer extent may be limited and water quality variables. Although these aquifers seldom produce large quantities of water, they are important for local supplies and in supplying base flow for rivers.

Non-Aquifer System:

These are formations with negligible permeability that are regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer unusable. However, groundwater flow through such rocks, although imperceptible, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.

Table 2: Ratings for the Aquifer System Management and Second Variable Classifications

Aquifer System Management Classification		
Class	Points	EIA Area
Sole Source Aquifer System:	6	-
Major Aquifer System:	4	-
Minor Aquifer system:	2	2
Non-Aquifer System:	0	-
Special Aquifer System:	0 – 6	-

Second variable Classification Weathering/ Fracturing		
Class	Points	EIA Area
High: Medium: Low:	3 2 1	- 2 -
Note: The aquifer has one borehole used by 1 household for domestic purposes		

The Karoo Aquifers present within the study area appear to have been locally impacted by underground mining operations as a result of dewatering and plume migration. This is observed by the localized drop in the water levels across the study area.

Table 3: Ratings for Groundwater Quality Management Classification System

Aquifer System Management Classification		
Class	Points	EIA Area
Sole Source Aquifer System: Major Aquifer System: Minor Aquifer system: Non-Aquifer System: Special Aquifer System:	6 4 2 0 0 – 6	- - 2 - -
Aquifer Vulnerability Classification		
Class	Points	EIA Area
High: Medium: Low:	3 2 1	- 2 -
Note: The aquifer is protected by a hard calcrete cappy of 1-3 m which makes is not easy to be polluted		

Aquifer System Management Classification Points = **2**

The indicated level of groundwater protection is derived from the Groundwater Quality Management Index (GQM Index).

GQM Index = Aquifer System Management Classification x Aquifer Vulnerability Classification
= 2 x 2
= **4**

Table 4: Aquifer System management

GQM Index	Level Of Protection	EIA Area
<1	Limited	-
1 – 3	Low Level	-
3 – 6	Medium Level	4
6 – 10	High Level	-
>10	Strictly non-degradable	-

Aquifer Protection Classification

The ratings for the Aquifer System Management Classification and Aquifer Vulnerability Classification yield a Ground Water Quality Management Index of 4 for the Shallow Weathered Zone Aquifers within the study area, indicating that **Medium Level** of ground water protection is required (Figure 16).

5.2. Aquifer Vulnerability

Groundwater plays an important role in supplying water to many regions of Southern Africa due to its low annual average precipitation of 460 mm, which is well below the world average of 860 mm. The quality of groundwater resources in South Africa has therefore received considerable focus and attention on the need for a proactive approach to protect these sources from contamination (Lynch *et. al.*, 1994). Groundwater protection needs to be prioritised based upon the susceptibility of an aquifer towards pollution. This can be done in two ways, namely i) pollution risk assessments and ii) aquifer vulnerability. Pollution risk assessments consider the characteristics of a specific pollutant, including source and loading while aquifer vulnerability considers the characteristics of the aquifer itself or parts of the aquifer in terms of its sensitivity to being adversely affected by a contaminant should it be released.

The DRASTIC method takes into account the following factors:

D = depth to groundwater (5)

R = recharge (4)

A = aquifer media (3)

S = soil type (2)

T = topography (1)

I = impact of the vadose zone (5)

C = conductivity (hydraulic) (3)

The study area is characterised by the predominantly arenaceous rocks (sandstone, feldspathic sandstone, arkose, sandstone-becoming-quartzitic-in-places) of the sedimentary types of rocks and predominantly meta-argillaceous rocks (slate, phyllite, meta-pelite, schist, serpentine, amphibolite, hornfels) which are metamorphosed rocks (Figure 8). The study area is deposited within the karoo supergroup rocks.

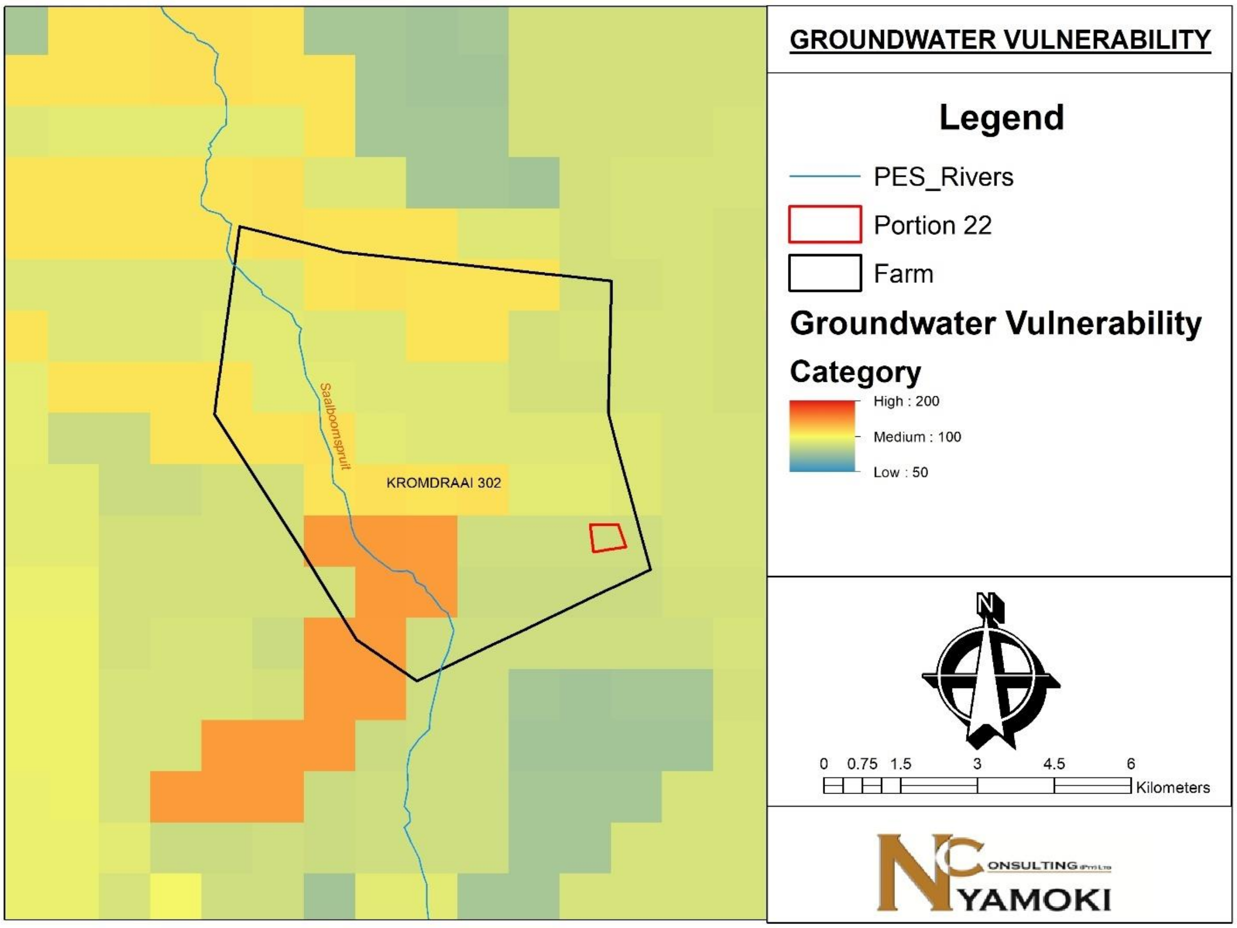

Figure 15: Groundwater vulnerability.

5.3. Aquifer testing

Following completion of the drilling programme, an aquifer test programme was initiated to determine the hydrogeological characteristics of the local aquifers. This includes defining:

- Borehole drawdown and recovery characteristics.

- Aquifer hydraulic parameters:
    - Transmissivity (T) defined as the product of the average hydraulic conductivity (K) and the saturated aquifer thickness. It is a measure of the rate of flow under a unit hydraulic gradient through a cross-section of unit width over the whole saturated thickness of the aquifer. The unit of measurement is m2/day.
    - Aquifer storage, either storativity (confined storage) or specific yield (unconfined storage). Storativity (S) is the volume of water released from storage per unit surface area per unit change in head. It is a dimensionless quantity. Specific yield (s) is a ratio between 0 and 1 indicating the amount of water released due to drainage, from lowering the water table.
- Characterisation of aquifer flow boundaries such as low permeable, no-flow or recharge boundaries. No-flow or low permeable boundaries refer to a lower transmissivity structure (e.g. fracture with a lower conductance or low permeable dyke) or aquifer boundary (limit of aquifer – no-flow boundary) that results in an increase in groundwater drawdown during borehole abstraction. Recharge boundaries relate often to leakage from surface water bodies.

The aquifer testing programme included two Cemetery boreholes for Portion 10 Doornrug 302. The Cemetery boreholes were selected to identify current aquifer properties in that specific area, identify borehole yield trends and to improve on the understanding of aquifer behaviour. Nyamoki Consulting Pty Ltd was subcontracted to carry out the aquifer testing during 23 December 2022. Aquifer testing was undertaken on the following boreholes (Table 5):

Table 5: Boreholes Construction data.

BH ID	**Latitude**	**Longitude**
BH01	29.0579	-25.8916
BH02	29.0607	-25.8926

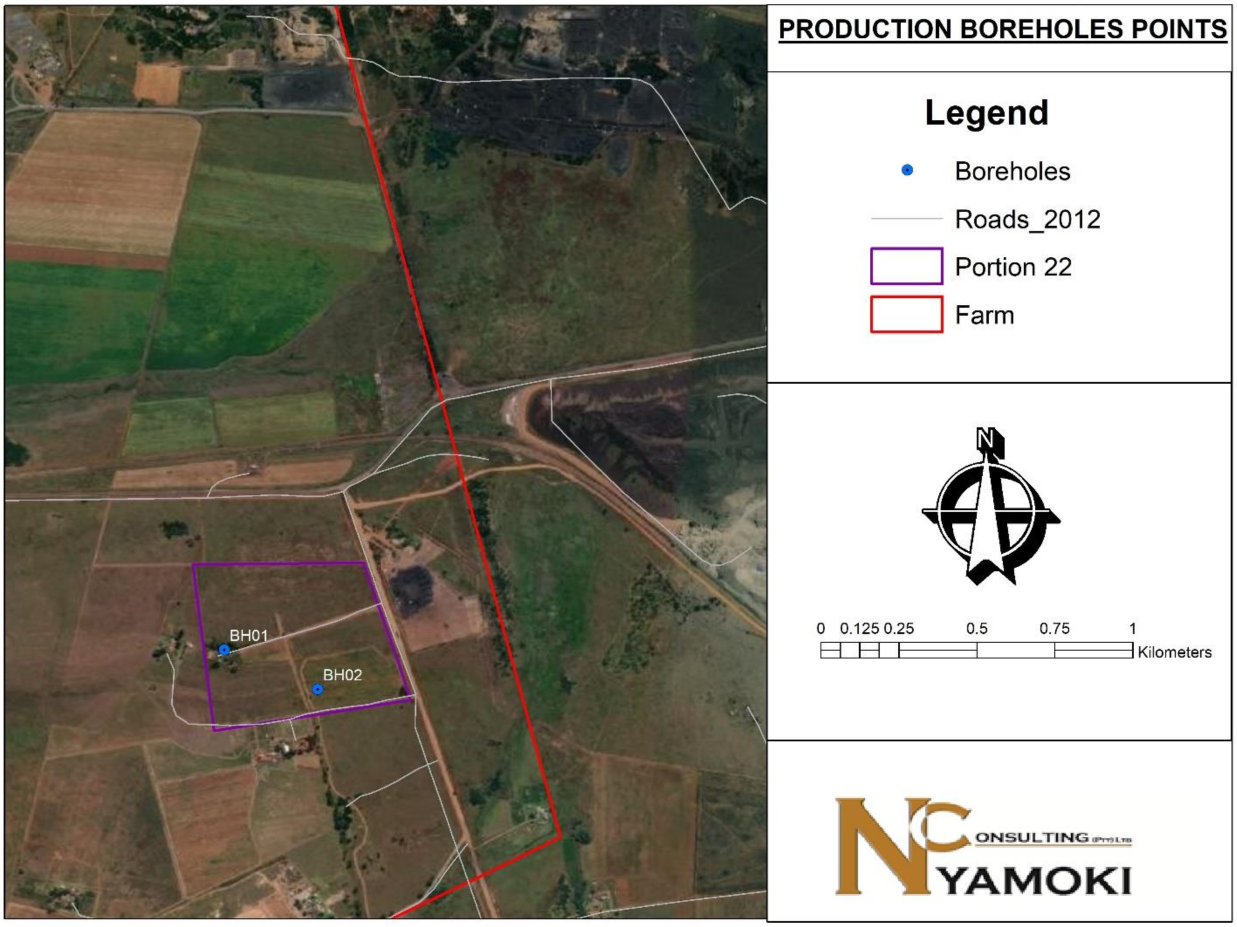

Figure 16: Boreholes positions

Figure 17: BH01 site photograph.

Figure 18: BH02 site photograph.

Prior to the aquifer test, static groundwater levels are measured in the pumping and observation boreholes (if available) to enable drawdown calculations during test pumping. Pumped water was released via a discharge pipe at least 100 m from the test borehole, to avoid rapid recharge from the discharged water. During the test, the abstraction rate is continuously monitored by means of electronic flow meters and calibrated by manually measuring the time it takes to fill a container of known volume, with a stopwatch and drum.

The pumping test programme included the following different tests:

- Firstly, a step drawdown test (SDT) is performed. During the SDT the borehole is pumped at a constant discharge rate for 60 minutes, where after the step is repeated at a progressively higher discharge rate. During the SDT the drawdown over time is recorded in pumping and observation boreholes. The advantage of this test is that the pumping rate for any specific drawdown can easily be determined from the relationship between laminar and turbulent flow. After the test stopped, residual drawdown is measured until approximately 90% recovery of the water level has been reached. The discharge rate for the constant discharge test (see below) is calculated from the interpretation of the time drawdown data generated during the SDT.

- The constant discharge test (CDT) follows the SDT. During a CDT a borehole is pumped for a predetermined time at a constant rate. During the CDT test the drawdown over time is recorded in the pumping and observation boreholes. Discharge measurements are taken at predetermined time intervals to ensure that the constant discharge rate is maintained throughout the test period. Any changes in discharge rate are recorded. The duration of CDT at Portion 22 Kromdraai 302 was 3-hours. During CDT, the aquifer needs to be stressed sufficiently to identify boundary effects that may impact on long-term aquifer utilization.

- The recovery test (RT) follows directly after pump shut down, at the end of the SDT and CDT. The residual drawdown over time (water level recovery) is measured in production and observation boreholes until approximately 90% recovery is reached. Aquifer parameters and sustainable borehole yields can be derived from the time drawdown data of the CDT and recovery tests by application of a variety of analytical methods.

Most of the boreholes tested indicate a low water yield, plus slow recovery. The recovery of the groundwater table after abstraction is a good indicator of the aquifer yield potential. The volume of abstracted water should not exceed the rate of recovery of the system, to ensure that the aquifer is not over-utilised, which might have a negative impact on other groundwater users within the same hydrogeological system. The recovery test data (for the tested boreholes) indicate that the recovery is slow and that full recovery (100%) is often not achieved within the predetermined testing timeframe.

The low borehole yields, fast water level drawdown and slow recovery observed during the aquifer testing indicate low transmissivity (T) aquifers, with low recharge. The highest pump rate measured (0.21 to 0.80 L/s) was observed at boreholes BH 02 and borehole BH01 showed low water availability while only these are the only two boreholes that yielded a good quantity of water, and intercepted good water bearing fractures.

Table 6: Summarised borehole yield results

BH ID	BH Depth	Static Level	MP Above Ground Level	Available Drawdown	Pump depth	Pump Type	Length of Pump (Hours)	Pump rate l/s	Recovery (min)
BH01	25.22	14.04	0.36	23.00	24.11	WA 22/3	3	0.16 to 0.51	300
BH02	55.01	21.8	0.48	40.30	45	WA 22/3	3	0.21 to 0.80	150

5.4. Proposed monitoring

Table 7: proposed monitoring programme requirements

Class	Parameter	Frequency	Motivation
Physical	Static groundwater levels	Monthly	Time dependent data is required to understand the groundwater flow dynamics of the site. An anomaly in static water levels caused by mounding below the drainage field may give early warning to spillages or leakages from lined/unlined facilities.
	Rainfall	Daily	Recharge to the saturated zone is an important parameter in assessing groundwater vulnerability. Time dependent data is required to understand the groundwater flow dynamics of the site.
	Groundwater abstraction rates (if present)	Monthly	Response of groundwater levels to abstraction rates could be useful to calculate aquifer storativity – important for groundwater management. Could also explain anomalous groundwater level measurements.
Chemical	Major chemical parameters: Ca, Mg, Na, K, NO3, NH4, SO4, Cl, Fe, Mn, F, Alkalinity, pH, EC, TDS.	Quarterly (Jan., Apr., Jul., Sept) May be reduced to biannual (April & Sept.) as more data becomes available)	Background information is crucial to assess impacts during operation and thereafter. Changes in chemical composition may indicate areas of groundwater contamination and be used as an early warning system to implement management/remedial actions. Legal requirement.
	Minor chemical Constituents Cr & Cr6, Ni, As, Cu, Pb, Cd, Zn Stable isotopes	Ad hoc Basis.	Changes in chemical composition may indicate areas of groundwater contamination and be used as an early warning system to implement management/remedial actions. The monitoring program should allow for research and refinement of the conceptual hydrogeological model. This may, from time to time, require special analyses like stable isotopes.

6. CONCLUSIONS

- The study area is characterised by coal mines, farming both crop and livestock farming. Most of the area is covered by the farms surrounding the proposed cemetery, although coal mines are mostly located on the eastern side. Farmer houses are local houses adjacent to the site although they are very few in the south and on the western side.

- Faults zones may have an impact on the local hydrogeological regime as it can serve as potential preferred pathways for groundwater flow and contaminant transport. The Cemetery is located within the Class B fractured aquifers which is associated with hard and compact rock formations in which fractures, fissures and/or joints occur that are capable of both storing and transmitting water in useful quantities.

- The Ecca Group consists mainly of shales and sandstones that are very dense with permeability usually very low due to poorly sorted matrices. Water is stored mainly in decomposed/partly decomposed rock and water bearing fractures are principally restricted to a shallow zone below the static groundwater level. Sustainable borehole yields are limited to < 0.5 l/s, while higher yielding boreholes (> 3.0 l/s) may occur along structural features i.e. fault and fracture zones. The study area shows that the genera yield is 0.5 to 2.0 L/s influenced by fractured zone.

- From the water quality data BH01 it was found the water has high turbidity which was found not compliant with the SANS 241:2015 guideline, which requires that before use it must be treated. The high turbidity might be a result that the borehole is taking water from shallow aquafers which are highly weathered. BH02 indicated that the nitrate and manganese level were not compliant with the DWS guideline standards. High levels of nitrate in drinking water may increase the risk of colon cancer. Nitrate may enhance the cancer potential of other compounds or may turn into cancer-causing chemicals like the body. Nitrate in drinking water has not been shown to increase the risk of other kinds of cancer. Children and adults who drink water with high levels of manganese for a long time may have problems with memory, attention, and motor skills. Infants (babies under one year old) may develop learning and behaviour problems if they drink water with too much manganese in it. It is recommended that before the water is consumed be treated since it is not good for long term consumption.

- BH01 shows Type 2: Sodium-bicarbonate groundwater −Groundwater with sodium as the dominant cation and bicarbonate as the dominant anion. Type 2 water is typically found in deeper portions of the aquifer.

- BH02 shows Type 3: Calcium-bicarbonate/chloride/sulphate groundwater − Groundwater with calcium as the dominant cation and bicarbonate the dominant anion, but with relatively elevated chloride and sulphate concentrations. This water type consistently has higher levels of TDS than the other two types.,

- The similarity of hexagonal shape in BH01, BH02 and BH03 indicate water type of similar characteristics. $HCO\text{-}_3$ is the dominant cation followed by the Ca^{2+} and on the anion's species, Mg^{2+} the is the most dominant in BH01 while BH02 Cl^- is the dominant cation followed by the K^+ and on the anions species, SO_4 is the most dominant. By looking at the stiff diagram results, these 2 boreholes could be getting their water from the different aquifers.

- The ratings for the Aquifer System Management Classification and Aquifer Vulnerability Classification yield a Ground Water Quality Management Index of 4 for the Shallow Weathered Zone Aquifers within the study area, indicating that a Medium Level of groundwater protection is required.

- The study area is characterised by the predominantly arenaceous rocks (sandstone, feldspathic sandstone, arkose, sandstone-becoming-quartzitic-in-places) of the sedimentary types of rocks and predominantly meta-argillaceous rocks (slate, phyllite, meta-pelite, schist, serpentine, amphibolite, hornfels) which are metamorphosed rocks. The study area is deposited within the karoo supergroup rocks.

- The low borehole yields, fast water level drawdown and slow recovery observed during the aquifer testing indicate low transmissivity (T) aquifers, with low recharge. The highest pump rate measured (0.21 to 0.80 L/s) was observed at boreholes BH 02 and borehole BH01 showed low water availability while only these are the only two boreholes that yielded a good quantity of water, and intercepted good water bearing fractures.

7. RECOMMENDATIONS

- The aquifer in the cemetery is located within shallow zones which pose risk to the local users since the area is going to be used for the burial of human remains, therefore, it is recommended that monitoring and sampling of water quality be done in accordance with the proposed motoring requirements. Monitoring programmes must be effectively done on a monthly basis in order to monitor seepages that might to the groundwater course.

- It is recommended that the area might be used as a cemetery as it is zoned within the farming zone. The certain measure needs to be taken into consideration during the construction of the cemetery such as the depth as the geology of the area indicate fractured lithologies.

- It is recommended that two boreholes must be used as a position to monitor the pollution downstream and upstream of the Cemetery.

- Care must be followed in case the water is used for human consumption, the water quality from the boreholes is not suitable for human health, therefore, it is recommended that the water be treated especially for the nitrate level in BH02 and high turbidity in BH01.

- The two boreholes' yields were measured hence the BH01 showed low yield due to shallow aquifer water availability which for human consumption or domestic use might be useful while borehole BH02 indicated high water yield which in this case of use of the water by human consumption is very sustainable. The two boreholes may be used for domestic use, while in case of the cemetery use, it is recommended.

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DWS. Anker Coal Elandsfontein Colliery *Unofficial Water use licence (WUL)*. Ref.No.: Licence No.:04/B20G/CGI/3843.

APPENDICE A: WATER QUALITY RESULTS

aquatico Laboratories (Pty). Ltd.

ilac-MRA sanas T0685

Test Report

Client:	Nyamoki Consulting Pty Ltd	**Date of report:**	05 January 2023
Address:	850 Berg Avenue, 77 Richmond, Akasia, 0182	**Date accepted:**	22 December 2022
Report no:	142806	**Date completed:**	05 January 2023
Project:	Nyamoki Consulting Pty Ltd	**Date received:**	22 December 2022

				217155	217156
Date sampled:				22-Dec-22	22-Dec-22
Aquatico sampled:				No	No
Sample type:				Water	Water
Locality description:				BH01	BH02
	Analyses	**Unit**	**Method**		
A	pH @ 25°C	pH	ALM 20	6.22	4.99
A	Electrical conductivity(EC) @ 25°C	mS/m	ALM 20	6.22	15.9
A	Total dissolved solids (TDS)	mg/l	ALM 26	32	96
A	Total Alkalinity	mg $CaCO_3$/l	ALM 01	11.4	2.61
A	Chloride (Cl)	mg/l	ALM 02	<0.557	22.3
A	Sulphate (SO_4)	mg/l	ALM 03	8.29	9.55
A	Nitrate (NO_3) as N	mg/l	ALM 06	1.77	8.06
A	Ammonium (NH_4) as N	mg/l	ALM 05	0.225	0.142
A	Fluoride (F)	mg/l	ALM 08	<0.263	<0.263
A	Calcium (Ca)	mg/l	ALM 30	3.36	9.22
A	Magnesium (Mg)	mg/l	ALM 30	1.18	4.50
A	Sodium (Na)	mg/l	ALM 30	2.33	7.52
A	Potassium (K)	mg/l	ALM 30	1.99	5.79
A	Aluminium (Al)	mg/l	ALM 31	0.079	0.175
A	Iron (Fe)	mg/l	ALM 31	0.004	0.015
A	Manganese (Mn)	mg/l	ALM 31	0.235	0.553
A	Chromium (Cr)	mg/l	ALM 31	<0.003	<0.003
A	Copper (Cu)	mg/l	ALM 31	<0.002	<0.002
A	Nickel (Ni)	mg/l	ALM 31	<0.002	<0.002
A	Zinc (Zn)	mg/l	ALM 31	2.88	0.087
A	Cadmium (Cd)	mg/l	ALM 31	<0.002	<0.002
A	Lead (Pb)	mg/l	ALM 31	<0.004	<0.004
A	Turbidity	NTU	ALM 21	19.3	0.550
A	Total hardness	mg $CaCO_3$/l	ALM 26	13	42
A	Total organic carbon (TOC)	mg/l	ALM 63	0.819	1.42
A	Cyanide Screening	mg/l	ALM 13	Absent	Absent
A	Langelier Saturation Index	LSI	ALM 26	-4.08	-5.55
A	Total oxidised nitrogen as N	mg/l	ALM 06	1.77	8.06

A = Accredited N = Non accredited Sub = Sub-contracted NR = Not requested RTF = Results to follow NATD = Not able to determine ATR = Alternative test report ; Results relate only to the items sampled and tested ; Results reported against the limit of detection; Results marked 'Non SANAS Accredited' in this report are not included in the SANAS Schedule of Accreditation for this laboratory; Uncertainty of measurement available on request for all methods included in the SANAS Schedule of Accreditation; The report shall not be reproduced except in full without approval of the laboratory

M. Swanepoel
Technical Signatory

www.aquatico.co.za 89 Regency Drive, R21 Corporate Park, Centurion, South Africa Tel: +27 12 450 3800 Fax: +27 12 450 3851

APPENDICE B: PUMP TESTING DATA

Date					Time			
Borehole Number			BH01		MAP			
Borehole Depth			25.22 m		Availability Drawdown		7.6	
Static Water Level			14.04 m		Pump Depth		24.16	
Casing Details					Pump Type		WA 22/3	
Time	**Time Reading**	**Step 1**	**Rate L/S**	**Step 2**	**Rate L/S**	**Step 3**	**Rate L/S**	**Recovery**
1		1.12		6.2				24.16
2		1.59		6.99				23.05
3		1.88		8.24				22.14
5		2.28		10.69	0.76			21.01
7		2.59	0.21	13.92				19.01
10		2.93		16.46	0.51			18.45
15		3.35		21.1				17.1
20		3.7		22.69				16.21
30		4		24.16				15.3
40		4.18						14.11
50		4.22						13.09
60		4.31						12.9
90								11.67
120								10.19
150								8.9
180								7.34
210								5.4
240								0.36
300								0.07

Date					Time			
Borehole Number			BH02		MAP			
Borehole Depth			55.01m		Availability Drawdown		53.1	
Static Water Level			21.80m		Pump Depth		45m	
Casing Details					Pump Type		WA 22/3	
Time	**Time Reading Time**	**Step 1**	**Rate L/S**	**Step 2**	**Rate L/S**	**Step 3**	**Rate L/S**	**Recovery**
1		1.23		5.82		22.53		51.26
2		1.76		6.54		24.69		49.94
3		2.1		7.25	0.56	26.68	0.8	48.2
5		2.68		8.52		28.73		47.9
7		3.08	0.2	9.31		34.18		43.1
10		3.49		10.17		38.88	0.8	40.54
15		4		11.84	0.56	45.75		31.98
20		4.35		13.19		51.26		25.9
30		4.67	0.2	15.67				23.21
40		4.88		17.83				19.2
50		4.96		19.11				10.92
60		4.99		20.22				5.27
90								0.53
120								0.15
150								0.1
180								
210								
240								
300								