UNIVERSITY OF THE WESTERN CAPE

ENHANCING SUSTAINABLE GROUNDWATER USE IN SOUTH AFRICA

REPORT ON WP1: DATA COLLECTION AND HYDROGEOLOGICAL FIELD INVESTIGATIONS

Compiled by ;

Innocent Muchingami, PhD

Thokozani Kanyerere, PhD

Kevin Pietersen, PhD

Yongxin Xu, PhD

Robert Whitehead

Andrew Mkhali

Lusanda Vinqi

March 2020

ACKNOWLEDGEMENTS

The ESGUSA project team would like to appreciate and thank the sterling work done by the the support provided by the Danish Development Centre through providing financial support of the project Enhancing sustainable groundwater Use in south Africa, from which this work was part of. Further to this the authors also acknowledge Department of Water and Sanitation (Polokwane) ‘s resource assessment and monitoring department for equipment and manpower assistance provided during field

EXECUTIVE SUMMARY

The report presented herein is part of an integrated and multi-institutional project entitled Enhancing sustainable groundwater use in South Africa, (ESGUSA) that was being implemented by the University of the Western Cape in collaboration with international and local partners with support from the Denmark Development Fellowship (DFC) . The project is being held under the realization that there is an increasing use for groundwater in South Africa and in particular, the areas around the Hout river Catchment in Limpopo province, South Africa. As such the project is being implemented with the one of the key objectives being to improve the understanding of hydrogeological conditions in typical geological settings and farming communities within the Hout /Sand river catchment in Limpopo through application of modelling and resource indicator tools for integrated groundwater management. In this regard, in order to meet the set objectives, the project tasks are further expanded into work plans (WP1- WP5) where in UWC was specifically tasked with WP 1 on data collection and hydrogeological field investigations and given resources towards its implementation.

As such the report gives a detailed description of methodologies done under WP1. Initially, the specific experimental sites where further investigation and drilling of test boreholes are to be established was determined through a series of desk and field based assessments which were done within the project framework. The initial field recognisance visit undertaken by the UWC team identified four potential experimental sites based on different hydro-physical and geological parameters and observations that are explained in detail in the report. Three major assessments were done as part of the desk studies for the experimental sites, namely sentinel two analysis, assessment of the average static groundwater level from observation wells and aeromagnetic data analysis. From the three major desk study methodologies Site 3 and 4 would be the have a higher groundwater potential and suitable investigation into setting up experimental field sites. Further to this, a field trip was organized as a follow up to the desk study. Since the main aquifer units within the study catchment area are crystalline in nature, groundwater resources are controlled by weathering, fracturing and structural discontinuities within the study area. The verification managed to identify the most ideal site for experimentation, based on geological and hydrological features in each of the identified four sites.

The Ga-Mamadila Site (site 4) and the Kalkfontein site (site 3) were confirmed as the experimental sites. Afterwards, integrated methodology approach was applied in mapping of the subsurface in hydrogeological investigations at Mamadila site (priority area1) in order to identify potential drill targets so as to set up monitoring boreholes. The methods applied included surface geology and integrated geophysical methods. The results from magnetic and electromagnetic surveys were combined with geological observations and used to identify anomalous points where vertical electrical resistivity sounding was done in order to infer the depth of influence and vertical layering of geologic features such as dykes together with the structural extend of weathered and fractures zones. As such, the results of from the exploration work were used to inform the development of terms of reference in terms of the specific sites for borehole drilling as well as provide an estimate of depths to different water bearing sections. Line 2 in region Region 1 of Mamadila site was identified as an appropriate experimental site in line with the research objectives. Suggested depth of drilling within the study area should be over 80m as the electrical resistivity sounding results suggested that in general most of the fractured region was extending to over 70m.

After the borehole drilling sites were established and exercise was conducted under supervision from UWC and the Department of Water and Sanitation. The four experimental boreholes were successfully drilled at Mamadila site and was cutting through several hydrogeological structures including Diabese dykes and pegmatitic lineaments that are one of the major groundwater controllers in typical crystalline basement aquifer formation like the Houtriver gneiss. The boreholes were generally high yielding for crystalline basement formation with estimated blow yield being in the range of 5l/s- over 8l/s for three of the four boreholes. The two deep boreholes were fully developed and tested for both yield and chemical analysis. The pump testing, chemical analysis and procedures done within the project framework were presented and shared though the central project database. A site specific lithostratigraphic conceptual model was developed for Mamadila the drill logs that were obtained from the drill work.

In addition, automatic water level monitoring instrumentation for time series measurement for depth to water level data were successfully installed at Mamadila and Kalkfontein site. Various folders containing hydrogeological data have been compiled over the course of the project. Existing and new complimentary data sets

that were collected during the duration of the project will be used in the Work plan for development of hydrogeological model using MIKE SHE modelling. The data sets are all collected into a single data folder at UWC that was shared to all project partners. Downloading and sharing of depth to water level data will be a continuous process in arrangement with the necessary stake holders.

In terms of output and dissemination, WP 1 has managed to produce two conference presentations and two draft manuscripts have been prepared for publication. In addition, two MSc theses are under preparation (due for submission this year, 2020) by students from the University of the Western Cape who were directly involved in the project. More manuscripts and research output is envisaged to come from the MSc theses. A summary description in this regard is presented in the appendix.

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

The project “Enhancing sustainable groundwater use in South Africa” was implemented by University of Copenhagen Denmark,University of the Western Cape (UWC) South Africa, Department of Water and Sanitation (DWS), South Africa, International Water Management Institute (IWMI) South Africa, Municipality of Capricon, South Africa and EkoSource-South Africa. The project is being held under the realization that there is an increasing use for groundwater in South Africa and in particular, the areas around the Hout river Catchment in Limpopo province, South Africa. As such there is need to understand the groundwater resource occurrence within the catchment in terms of aquifer settings, recharge, interaction with river systems and the impacts of human interactions as well as come up with appropriate mitigationary recommendations Moreover, the project is being implemented under the background of a previous project which focused on at providing a supporting framework for sustainable groundwater utilization for agricultural purposes in the Sand and Hout river catchments of Limpopo River basin. Although several studies have been reported on the groundwater resources within the crystalline basement aquifers in Limpopo province, (eg in Holland and Witthüser 2011, Masiyandima et al 2002, Du Toit and Sonnekus, 2014, Fallon et al (2018), very few have focused on groundwater occurrence and sustainable utilisation within the Hout river gneiss formation and in particular, the role of river aquifer interaction within the Hout River catchment, area .

The Hout catchment is located in the Mpumalanga and Limpopo Province along the north-eastern boundary of the Republic of South Africa (RSA). It is an elongated catchment that measures at roughly 110km from north to south and an average of 32km from west to east and has an area of 2,478 km2. The catchment km2.The catchment area is divided into three quaternary (fourth-order) catchments (A71E, A71F, and A71G) (Ebrahim, Villholth, & Boulos, 2019). This area is surrounded by small farming towns such as Mogwadi (Dendron) situated 60 km northwest of the city of Polokwane, Limpopo. The Hout River is a tributary of the Sand River, which drains into the larger Limpopo River in the north-east and is an ephemeral River that flows intermittently following large and intense precipitation events during the wet season. The Dendron aquifer, which is located in the Hout catchment, although not accurately mapped, is reported to be 1,600 km2 (Fallon, Villholth, Ebrahim, Conway, & Lankford, 2018)

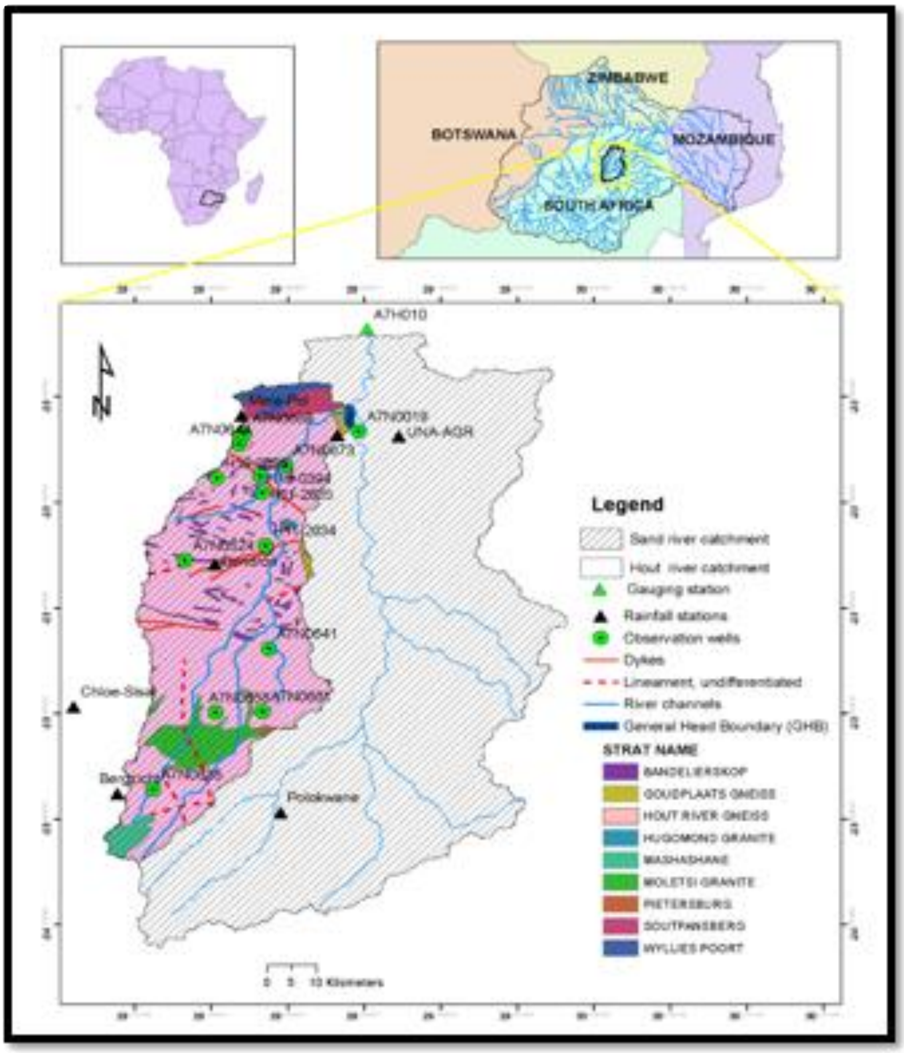


Figure 1.1: locality of the Hout Catchment. Data Source: Ebrahim et al., (2019)

The study area lies within regions that was historically declared a special water protection zone because of its strategic national importance in terms of agricultural food security through potato farming and cattle ranging.

The project is being implemented with the following objectives;

- Establish research partnerships between the Republic of South Africa (RSA) and Denmark
- Improve the understanding of hydrogeological conditions in typical geological settings and farming communities in RSA, exemplified by the Hout /Sand river catchment in Limpopo.
- Development of modelling and resource indicator tools for integrated groundwater management.
- Enable stakeholder involvement in development and promotion of sustainable groundwater management options.
- Increasing research capacity in RSA within integrated groundwater resource assessment and management.

One of the key driver for the implementation framework of the project is centered on the need to improve the understanding of the hydrogeological processes in typical geologic setting in South Africa , and in Particular the Limpopo mobile belt. In this regard, in order to meet the set objectives, the project tasks are further expanded into work plans (WP1- WP5) which are itemized as

WP1:Data collection and hydrogeological field investigations

WP2: Development and calibration of integrated hydrological model

WP3: Citizen science and capacitating local stakeholders

WP4: Development of integrated water management schemes

WP5: Capacity strengthening

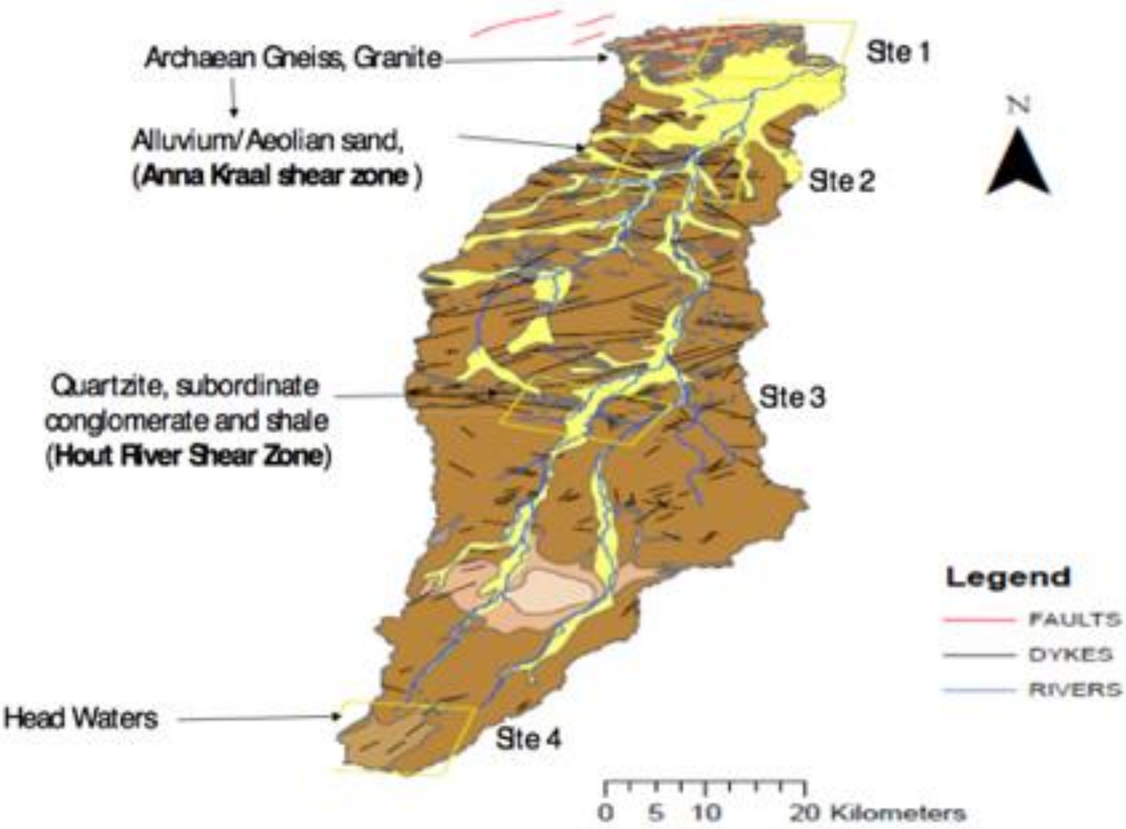
The activities of the work reported in this document form the specific work plan 1 on Data collection and Hydrogeological field investigations. As such the subsequent chapters will specifically describe in detail how each set activity (under WP1) was achieved.

CHAPTER 2

IDENTIFICATION OF POTENTIAL FIELD EXPERIMENTAL SITES

2.1 Introduction

In order to achieve the tasks set out in WP1 (field data collection and and hydrogeological field investigations) specific experimental sites where further investigation and drilling of test boreholes are to be done would need to be identified within the study area. To facilitate this, a field recognisance visit undertaken by the UWC team identified four potential experimental sites, (Figure 2.1) based on different hydro-physical and geological parameters and observations described herein. The regional geology and description was inferred from the 1:250 000 map of the study area. This was followed up by a detailed desk study involving remote sensing analysis using sentinel 2 and analysis of existing data sets. The chapter presents the desk stop study methodologies used to optimize the selection of potential study sites within the Hout River catchment.



Archaean Gneiss, Granite
Alluvium/Aeolian sand,
(Anna Kraal shear zone)
Quartzite, subordinate conglomerate and shale
(Hout River Shear Zone)
Head Waters
Site 1
Site 2
Site 3
Site 4
N
Legend
FAULTS
DYKES
RIVERS
0 5 10 20 Kilometers

+

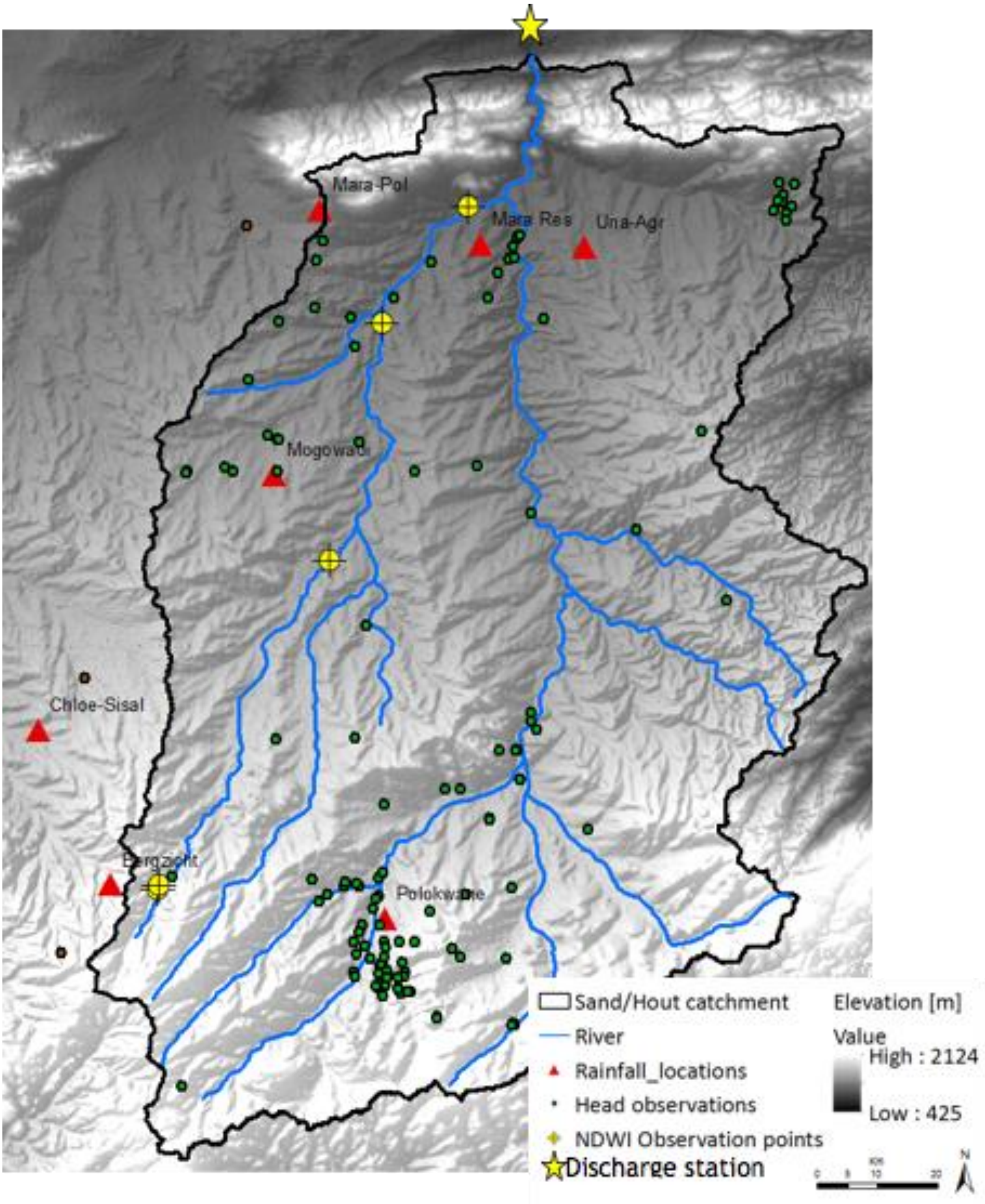


Figure 2.1. (a) Geological Map and (b) satellite imagery of the Hout River Catchment, Limpopo province, South Africa indicating the four potential experimental sites for the project.

Site 1 was selected on the strength that it is situated within Hout River Flood plain, in addition the geological setting falling within a region that has several faults and dykes structures inferred with a noticeable change in lithological contact. Site 2 was chosen because of its dense network of dykes and noticeable changes in lithological contact it is situated within alluvial flood plain of the Hout river. Moreover, there are visible surface water features which were observed along the river channel. Site 3 is situated within alluvial flood plain with an existing surface water feature in the form of a focused recharge dam. presence of Dykes. There are noticeable changes in geological contacts within the area. The fourth site, Site 4 is situated in the Headwaters of Hout river and is within the vicinity of the Hout River dam.

Several desk study methodologies (described in the sections following) were implemented in order to come up with an optimal experimental site prior to the second visit to the study area that would be aimed at coming up with the most ideal field experimental sites for further hydro-geophysical and hydrogeologic investigations.

2.2 Time series analysis of Sentinel 2 data for the years 2016 & 2017

The Sentinel 2 remote sensing technique (https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/sentinel-2) was used to investigate the presence of possible water indicators water in the river, and its surroundings with the aim of supporting the decision on the right location for field installations. Two indices, the Normalized Difference Water Index (NDWI) and Normalized Difference Vegetation Index (NDVI)were investigated. In addition, as the Hout river is relatively narrow compared to the spatial resolution of the sentinel data, and the water might be shallow and/or have a high content of sediments, the absolute NDWI values were always negative, the differential NDWI was also investigated. In the differential NDWI approach, the NDWI was divided by the $NDWI_{dry}$ during the dry period (average of May-September).

The time series analysis results for mNDWI shows the mNDWI variations from January 2016 to June 2018 together with daily rainfall data (Figure 2.2). At each location two observation points were located into the river and one outside, for reference. Subfigures a-d correspond to locations 1 to 4, respectively.

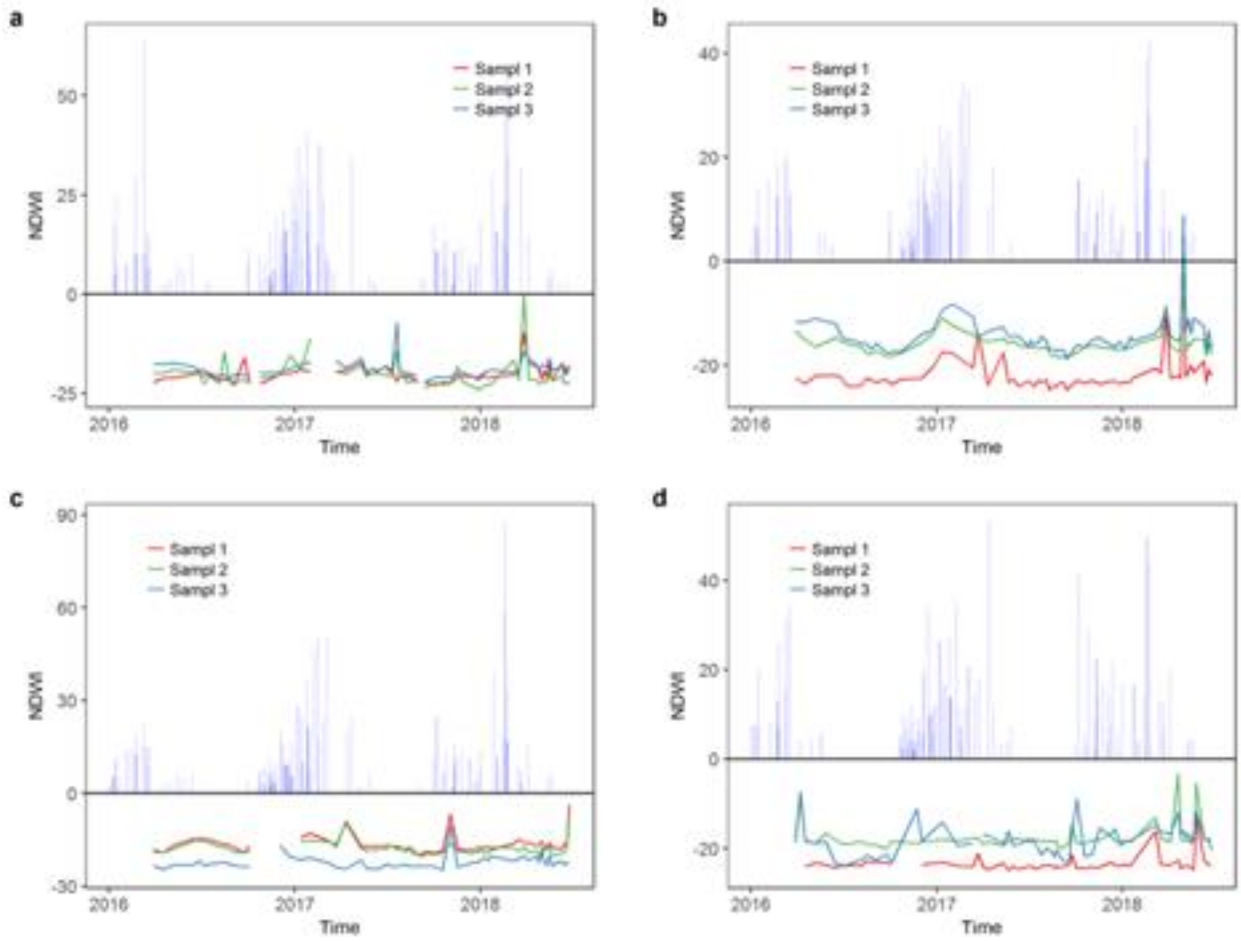


Figure 2.2: Time series analysis of mNDWI for the period of January 2016 to June 2018(a-d refer to locations 1-4 in Figure 2.1). The values of mNDWI were multiplied by 50. The bars represented the observed daily rainfall during the period.

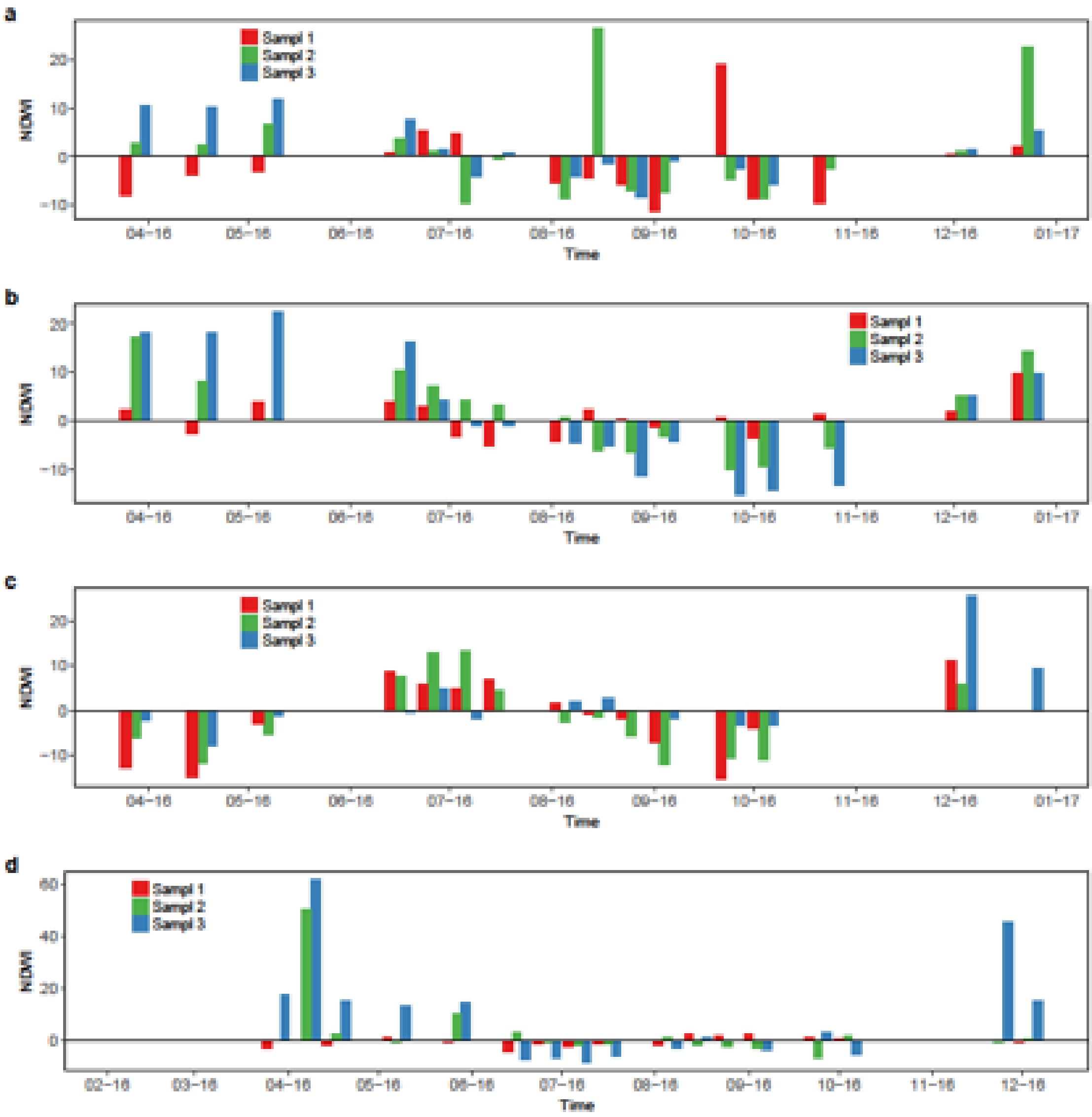


Figure 2.3: Variation of the differential mNDWI at the four locations (a-d refer to locations 1-4 in Figure 2.1) for 2016.

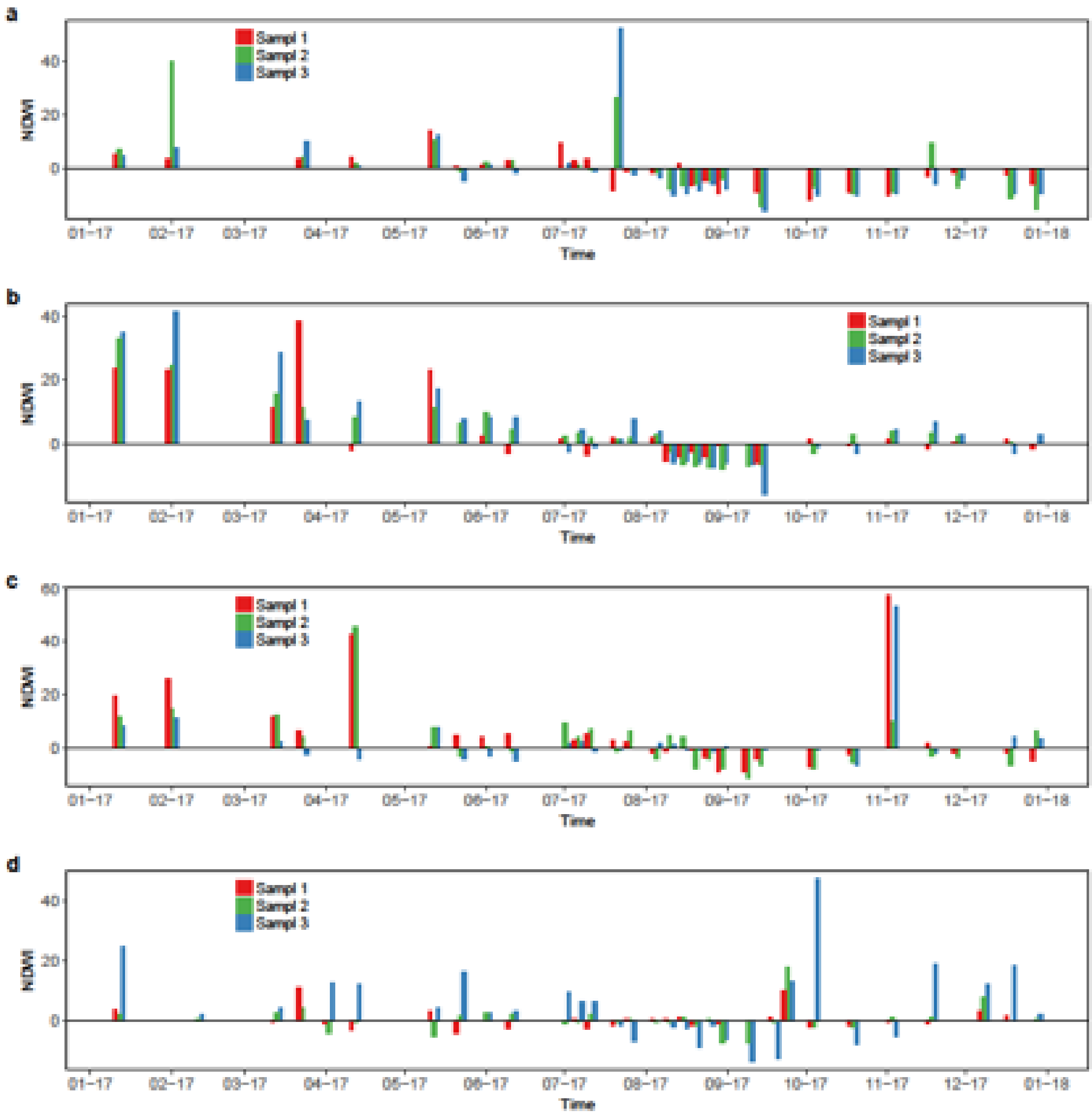


Figure 2.4: Variation of the differential mNDWI at the four locations (a-d refer to locations 1-4 in Figure 2.1) for 2017.

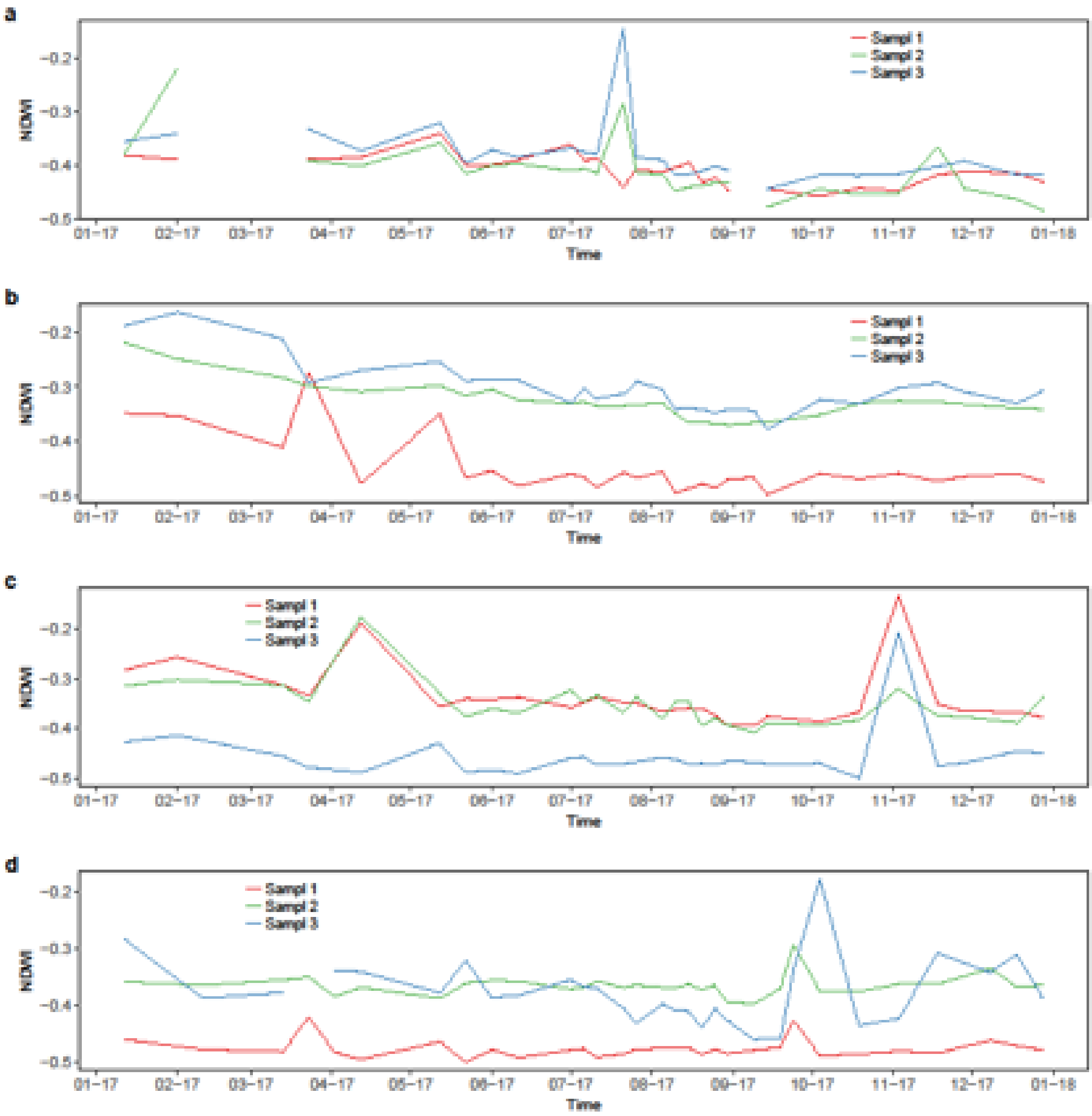


Figure 2.5: Yearly variation of mNDWI at the four locations (a-d refer to locations 1-4 in Figure 2.1a) for 2017.

Figures 2.4 and2.5 show the relative change in mNDWI, variations from January 2016 to June 2018 together with daily rainfall data. At Site 1 it was observed that there were no clear trend in mNDWI following wet and dry season. Peaks during dry season as a result of cloud cover disturbance. NDVI increases during the wet period at all observation points (indicating vegetation, no water). However, Site 2 showed clear increase in mNDWI in the wet season and decrease during dry season for 2016 and 2017. NDVI increases during the wet period at all observation points (indicating vegetation, no water).

Site 3 indicated a clear increase in mNDWI in wet season and decrease during dry season in 2017, but no clear trend in 2016. NDVI increases during the wet period at all observation points (indicating vegetation, no water). Site 4 shows clear increase in mNDWI in the wet season and decrease during dry season for 2016 and 2017. In 2016 site 4 shows the largest increase in (by ~60%) compared to the sites 1-3 (where it increases by ~20%). Site 4 is located upstream from the Hout river dam, and hence less influenced by dam operation. NDVI increases at two observation points during the wet period (indicating vegetation, no water). NDVI decreases at one observation point indicating water at this observation point.

2.3 Analysis of distribution of average static groundwater level and relation to topography

A total of 11 groundwater monitoring boreholes were identified within the study area using data availed from Phase 1 of the project. Their distribution is as described in Figure 2.6. In these boreholes, the data for the hourly variation for groundwater levels over a period spanning between 4-9 years was automatically measured. The spatial variation of the average groundwater levels was determined together with the maximum variance of these groundwater levels about the mean of each boreholes (Table 2.1). An assessment was then made of the distribution of static water levels in relation to potential experimental sites 1 to 4.

Figure 2.6. Distribution of groundwater observation wells within the Hout river catchment

Table 2.1: Average Static groundwater levels from observation wells within the Hout river catchment

BH No.	LEVEL (SWL)/m	VARIANCE/m	Topography ()	NOTES
A7N0635	-7.01	1	1322	upstream to the dam , headwaters, recharge could be from dam?
A7N0658	-12	2	1188	headwaters zone, upstream, in Moshoahleng community no visible river proximity,
A7N0642	-12.56	2	1314	central to upper part of the catchment no visible river proximity
A7N0661	-10.04	4	1213	central to upper part of the catchment no visible river proximity
A7N0641	-29.95	1	1096	lower part of the catchment, need to investigate spikes between Jan to march 2016
A7N0524	-31.24	1	1031	lower part of the catchment
H21-2634	-17.55	1	990	lower stream around ,
H11-2635	-64.92	2	953	Downstream
H019-0394	-51.63	1	1032	Downstream
H019-0344	-51.63	1	983	Downstream, same average with H019-0394 but with different hourly variations. Most likely same aquifer formation
AN70644	-78.06	1	1182	Downstream closer to the mountain

It is observed that there is a general increase in water levels from shallow depths near the stream head waters (closer to Site 4) up to relatively deep levels closer to the discharge point (closer to site 1). Site 4 has only one observation well (A7N 0635) with the shallowest water level depth within the catchment of around 7m. The upper region of the catchment has most of the observation wells with shallow observation wells (ranging from 10-12 m below the ground). The regions closer to site 2 have static groundwater levels are observed to be deeper at range between

29m to 31m except for H21-2634 which has an average static water level of nearly 18m. Boreholes around have the deepest water levels (upto 78m) , despite generally having the lowest topography. Based on the structural observations that can be further inferred from the Google earth image, the bedrock could be influenced by the mountainous features which are visible on the north western side of the catchment. Groundwater in this region could be influenced by a possibly available regional aquifer whose recharge may not be necessarily within the catchment (since the effect of topography seems not to be of influence to groundwater availability).

Furthermore, it is observed that the variance of most observation wells about their average value is generally small. As such, the average values can be used as a suitable desk study assessment of groundwater distribution within the study area. As there is no visible trend on the effect of topography on groundwater resources within the area and the fact that there are higher water levels within the head waters could likely be due to the thickness of the soil overburden. In fact although the number of observation wells are relatively few compared to the size of the catchment, there seems to be a general trend that despite some previous studies assumes the water table follows the shape of the ground surface; it is found that in the catchment the water table occupied a position below the ground surface in the regions of higher elevation; The distribution of the groundwater levels could either be attributed to the existence of several aquifer units within the study area, or the over abstraction of groundwater for agricultural purposes downstream, (to be assessed with land use variation , as site 4 is mostly communal area).

2.4 Aeromagnetic geophysics assessment

Since the main rock units within the study catchment area crystalline in nature groundwater resources occur within crystalline basement aquifer formation that is usually controlled by weathering and structural discontinuities within the study area. As such, groundwater is likely stored in open brittle geological discontinuities such as faults, dykes fractures and joints, constituting the fractured aquifers. Magnetic geophysical surveys (both ground and airborne) have a reported capability to infer the presence of such potential groundwater bearing discontinuities within the study area. In this regard an analysis of aero-magnetic data for the Hout river catchment was done with a focus of differentiating anomalous geological structures that could indicate groundwater potential within the study area. The catchment aeromagnetic data map was extracted from the national aeromagnetic map with a relative scale indicating red colour for high values and blue for lowest values.

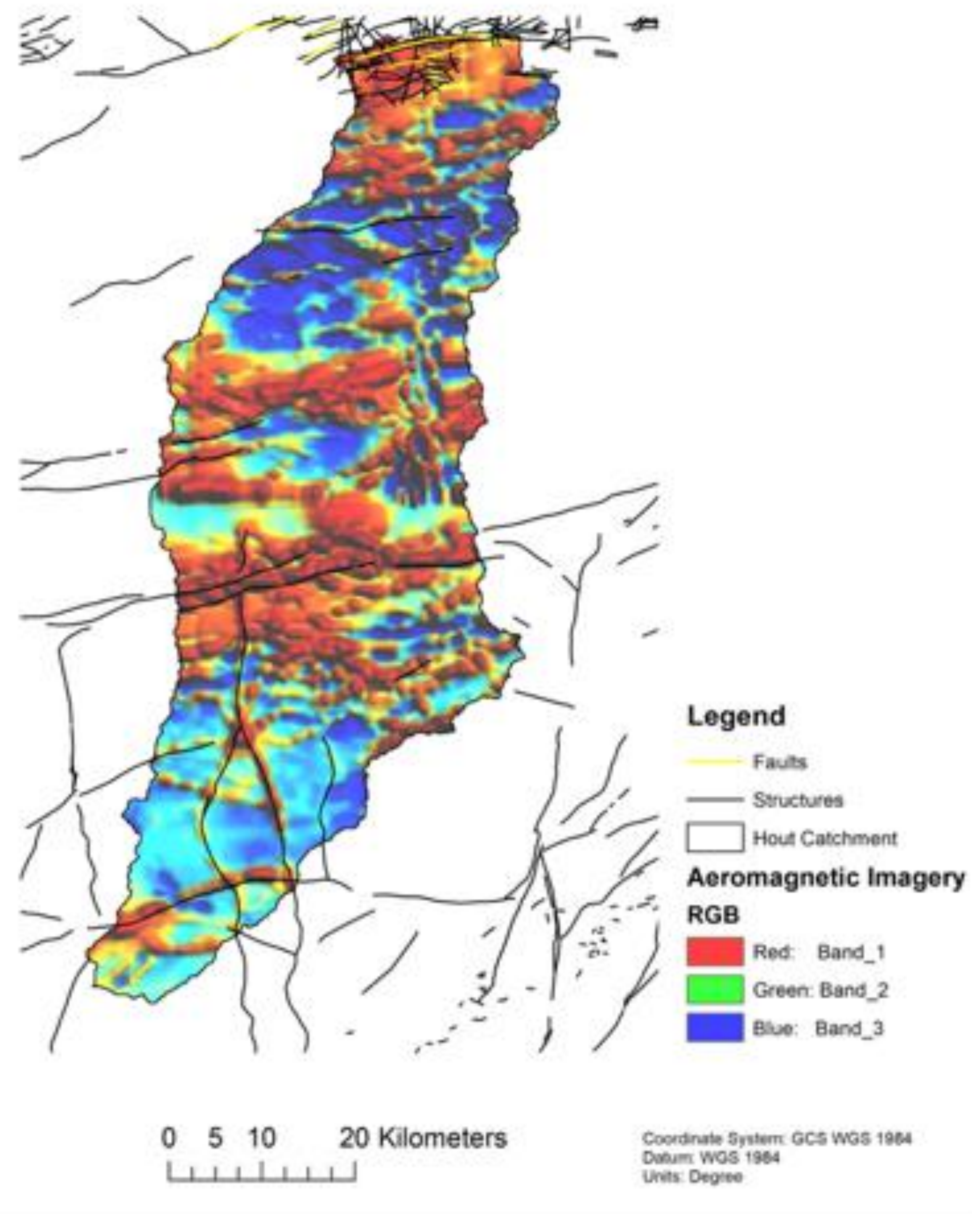


Figure 6. Aeromagnetic map of the Hout river catchment, Limpopo river basin, South Africa

The central region closer to region 3 is characterized by high magnetic susceptibility signatures. High signatures in crystalline rocks are usually indicative of a presence of geological structures like dykes and lineaments which could be groundwater controls within the study area. Structures around site 3 are also indicating that the site is within the Hout river shear zone and could be a control to the relatively high groundwater potential and shallow groundwater levels as observed in section 4 of the report .

Areas around Sites 1 and 2 also have high susceptibility signatures which are consistent with the inferred geological structures from the regional geology. These structures which include dykes which are usually one of the groundwater controllers in crystalline basement aquifers

Region closer to Site 4 are generally characterized by a low magnetic susceptibility which may be indicative of less structural lineaments and dykes within the region. In this case the groundwater level could be controlled mostly by the thickness of the overburden.

2.5 Summary and conclusions

Three major assessments were done as part of the desk studies for the experimental sites, namely sentinel two analysis, assessment of the average static groundwater level from observation wells and aeromagnetic data analysis. From the three major desk study methodologies Site 3 and 4 would be the have a higher groundwater potential and suitable investigation into setting up experimental field sites.

CHAPTER 3

FIELD VERIFICATION OF POTENTIAL EXPERIMENTAL SITES

3.1 Introduction

In order to facilitate the implementation of the ESGUSA project through confirmation of the river segments to set up monitoring equipment, a field trip was organized by the University of the Western Cape, International Water Management Institute (IWMI) and the University of Copenhagen from the 4th to the 6th of October 2018. The visit was scheduled as follow up to the desk study which had identified four potential experimental sites (Sites 1 to 4), (Figure 3.1) were identified along the Hout river based on geological and hydrogeological criteria. Since the main aquifer units within the study catchment area are crystalline in nature, groundwater resources are controlled by weathering, fracturing and structural discontinuities within the study area.

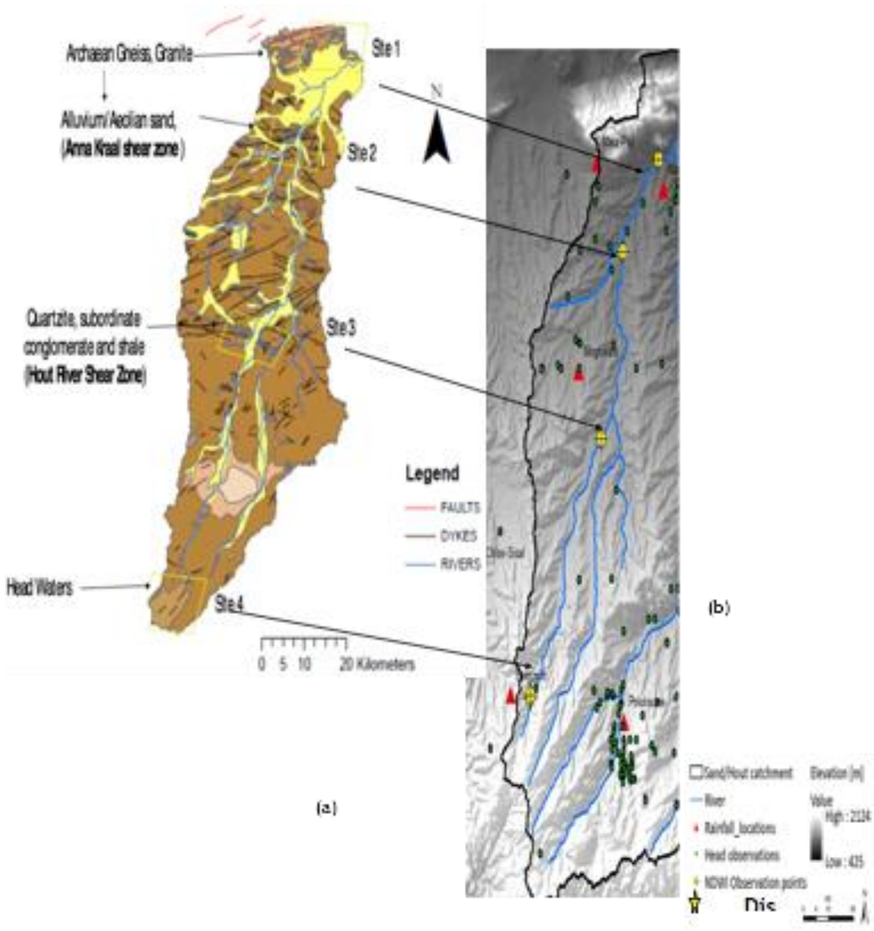


Figure 3.1. (a) Geological Map and (b) satellite topographic imagery of the Hout River Catchment indicating the four potential experimental sites for the project.

A coordinated and detailed field reconnaissance exercise was done at all sites in order to identify key geological and geomorphological features which could be influencing groundwater availability within the catchment and the details are presented in this Chapter. Key features used in field recognisance included;

- Structure and nature of existing geological features including rock types,
- Observable fracture patterns,
- Existence geological barriers/discontinuities like dykes and lineaments
- River bank geology and extent of thickness of the soil layer
- Number of accessible boreholes and accessibility for citizen science
- Geomorphological features including the drainage pattern
- Visible natural surface water features

3.1 Site 1

The site comprised of the confluence between the Sand river and the Hout river and was comprised of intrusive diabese dykes which were visible at the confluence (Figure 3.2). The dykes show some degree of fracturing. The riverbank also suggests that there is a thick weathered overburden which controls the thick vegetation (Figure 3.2).

Figure 3.2. The geological structure, layering structure and extent of the overburden thickness at Site 1, a confluence between Sand River and Hout river.

There is however no evidence of river aquifer interaction as there was no evidence of recent stream flow within the riverbed. The absence of flow in the river could be as a result of numerous farm dams upstream and as such this could not be the ideal experimental site.

3.2 Site 2

The site was situated at a point where Hout River two tributaries discharging into it. The river itself was characterised by a dry river channel which has good geomorphological features for groundwater studies, including a thick overburden (Fig 3.3). However, as the site is more towards the confluence with Hout river, this area is more impacted by upstream activities in the same way described for Site 1, and is not ideal for setting up experimental infrastructure.

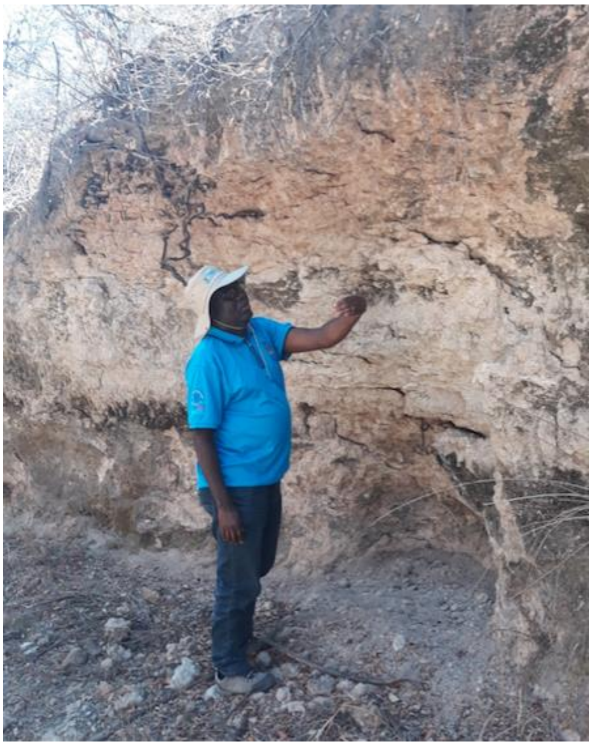


Figure 3.3. An illustration of the layering processes associated with groundwater flow in the unsaturated zone at Site 2.

3.3 Site 3

Situated in an area that has a dense network of intrusive Diabese dykes that are observed along the river bed. In addition, there is a thick layer of calcite rock in the form of compacted limestone that is visible across the section of the river segment. However, it was also observed from construction debris within the farm that the calcrete rock spread though out the greater portion of the farm. The area is also characterised by visible Hout river gneiss outcrops spread through out the whole area, with a dense network pumping and monitoring of both boreholes available within the area.

Figure 3. 4. Major geological features that control groundwater interaction in site three showing the fractured Hout river gneiss, intrusive dykes and a calcrete layer forming within the site.

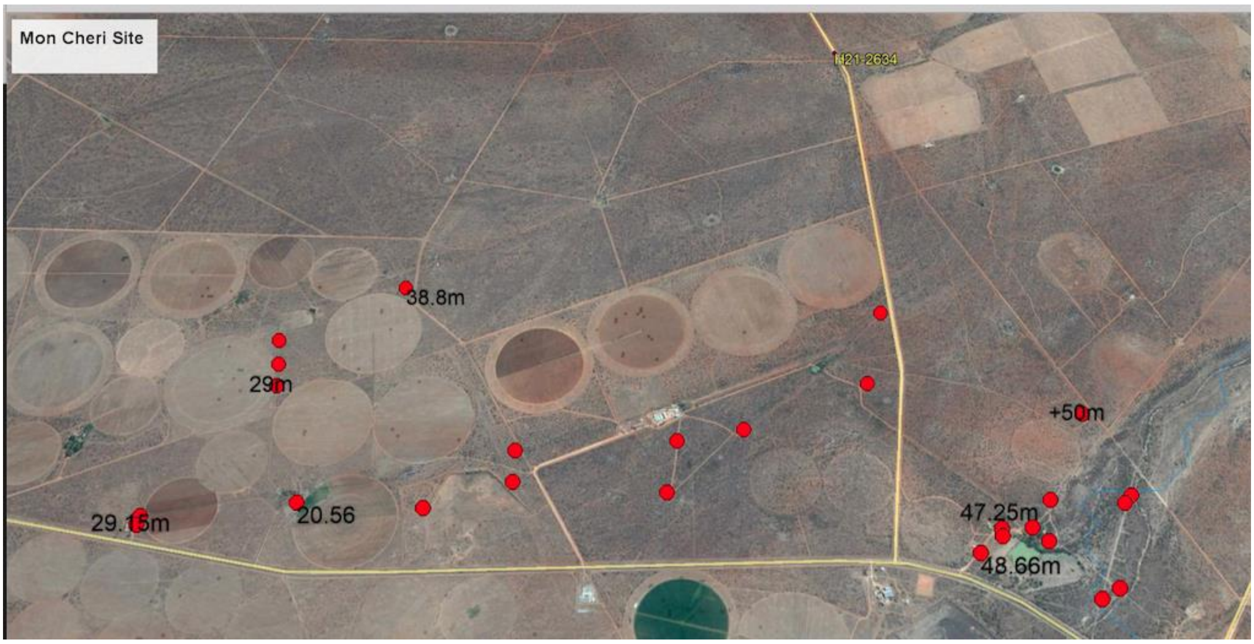


Figure 3.5. Distribution of boreholes with observed depth to water levels (10/10/2018) observed on some of the boreholes around site 3.

Because of these factors, coupled with the accessibility and availability of the existing boreholes, this site could be used as a complementary study area to investigate the river groundwater influence downstream as well as in establishing the role of regional aquifer system that could potentially be responsible for groundwater occurrence. This is regardless of the fact that there was no flow in the river with the local farmer reporting that the last flow occurred once in the previous five years.

3.4 Site 4

Situated in the upstream of Hout River dam and represent a generally undisturbed part of river system. Certain parts of the river segments had visible surface water features (bounded by solid Diabese dykes). The area is surrounded by a communal neighbourhood, and hence there is no impact on river flow through blockages by farm dams. In as much as the river segment is mainly comprised of alluvial material from which water could be obtained from hand dug wells along the stream channel, there are several geological features which may control groundwater dynamics within this site, and hence making the site ideal for further investigations. Rock exposures shows that the parent rock has heavily fractured pink pegmatite (Figure 3.6). The fracture pattern has no visible specific orientation, which suggests that the rock is capable of acting both as a groundwater storage and conduit, as typically expected in crystalline basement aquifers.

Figure 3.6. Photographic image of rock units showing the extent of fracturing within the Hout river gneiss at Site 4.

In addition to the fracture network within the parent rock unit site four is also characterised by several lineaments and intrusive dykes which are oriented in SW – NE direction and mostly cutting the river segment. An interesting feature is the existing pools of surface water being observed at points where the solid unweathered Diabese dyke structures cut across the river segments (Figure 3.7).

Figure 3.7. Evidence of surface water features associated with dykes along the river segment at Site 4.

The surface water features seem to be perennial features and thus suggest that the dykes are acting as deep extending groundwater flow barriers which may be responsible for rechannelling groundwater flow through to the surface and hence would control groundwater occurrence within the aquifer system. This therefore makes site 4 an ideal site to set up experimental infrastructure for further investigation of the river aquifer interaction. It is also noted that although there was flow at the time of the field verification, there is evidence of alluvial flow and the site has the highest chance for the type of study contained in the objectives.

3.5 Summary

After the field verification exercise, potential study sites were ranked according to the following summary table.

Ranking	Site no	Summary of reason
1	Site 4 (Renamed Ga-Mamadila site)	Un impacted river system, before the dam , high fracture network within the parent rock, existence of visible dykes on the river segment which act to control river aquifer interaction , visible surface water features at points where dykes are cutting the river, nearness to community for citizen science component.
2	Site 3 (Renamed Mon Cherie site)	A dense network of boreholes existing closer to the river, several dykes observed on the surface, ideal for regional groundwater conceptualization within the catchment. Could be used as a contrast study to an undisturbed system in site 4 i.e. Before and after Hout river dam ,and in terms of role of farming in citizen science
3	Site 1	There is no river flow and visible features for monitoring and hence it is not an ideal site.
4	Site 2	There is no river flow and in an isolated space whose accessibility and monitoring may be a challenge, hence not suitable

The verification managed to identify the most ideal site for experimentation, paving way for exploration geophysics planning for groundwater survey. The Ga-Mamadila Site was identified as the priority area while the Mon Cherrie site will be used for future installation s and conceptual study of the aquifer system downstream of the river.

CHAPTER 4

GROUNDWATER EXPLORATION AND IDENTIFICATION OF DRILL TARGETS USING GEOPHYSICAL METHODS

4.1 Introduction

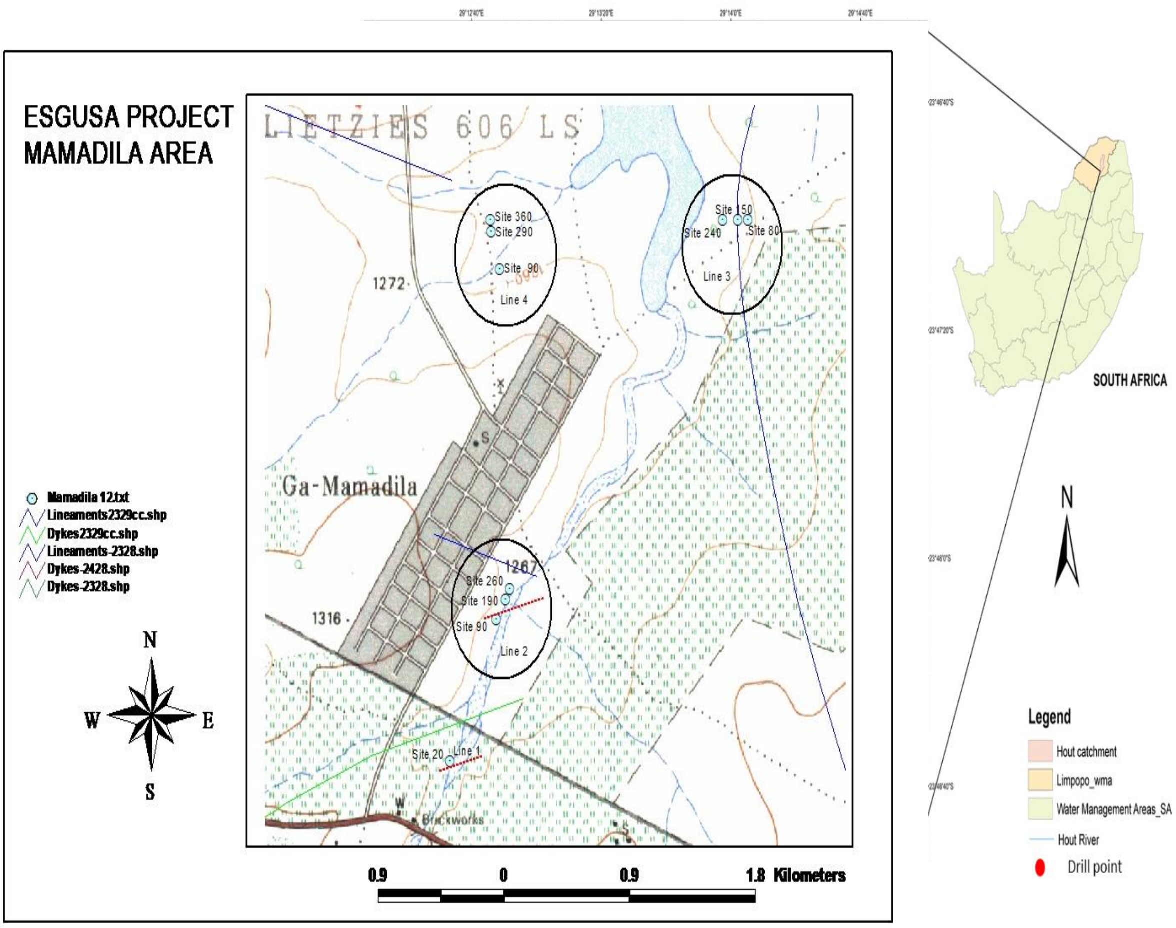
In order to assess the fracture connectivity and evaluate the groundwater potential of the underlying subsurface, it is important to understand the structural controls and lithological properties of an area. The current chapter describes the various methods used in mapping of the subsurface in hydrogeological investigations in order to identify potential drill targets within the project framework. The methods described herein includes surface geology and integrated geophysical methods. Interpretation of the three geophysical methods that were sequentially implemented is provided. The results of this work were used to inform the development of terms of reference in terms of the specific sites for borehole drilling as well as provide an estimate of depths to different water bearing sections

4.2 Study area description and Geological characterisation for groundwater investigations

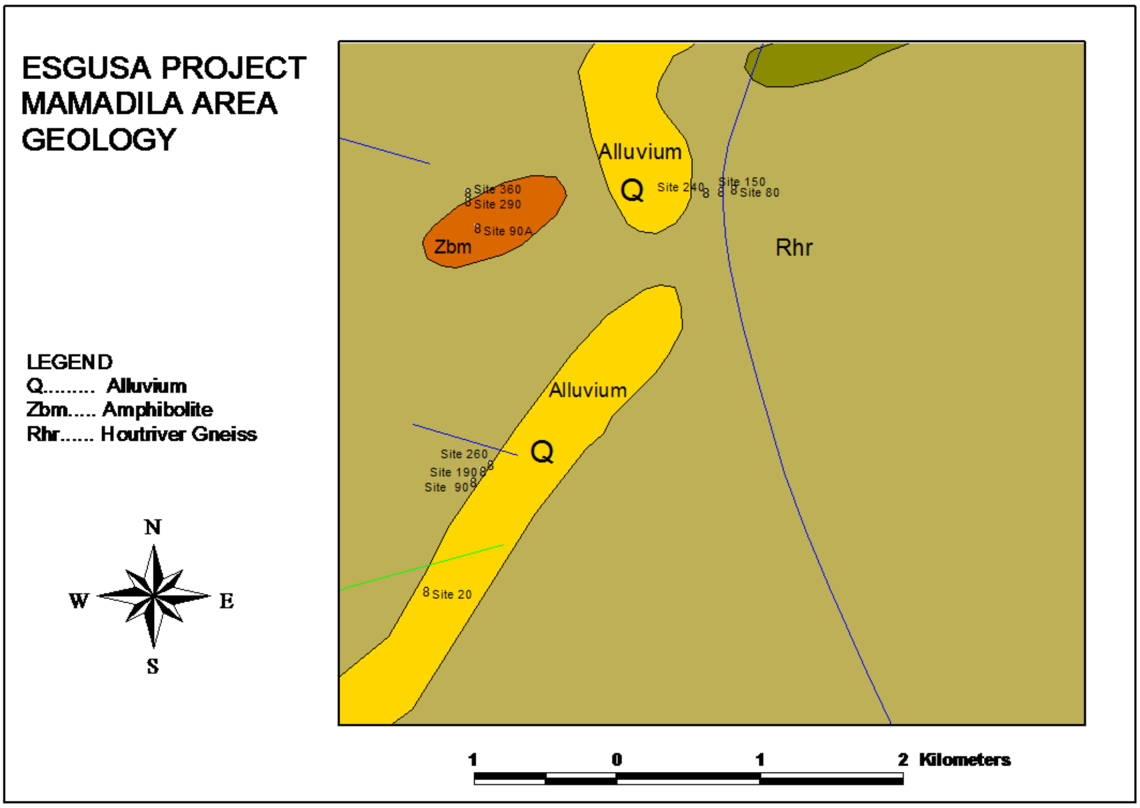
The geological investigations were aimed at providing a better understanding on the groundwater controlling structural features around the experimental site as these determine the trends in fracture connectivity and groundwater potential targets. In addition the geological would be used together with the geophysical mapping, in the development of the lithostratigraphic sections.

The experimental site is located within the Mamadila communal area, Polokwane municipality in the Limpopo province of South Africa (Fig 4.1). In terms of water management area, the area lies within the Hout river catchment of the Limpopo basin. The Hout catchment is located 60 km northwest of Polokwane city and has an area of 2478 km^2 with an elevation ranging from 840-1739 m above mean sea level (mamsl). The catchment river itself, Hout is an ephemeral river that flows intermittently following large and intense precipitation events into the Sand River, which eventually drains into the Limpopo River towards the northeast.

The main geological formation characterising the experimental site is the Hout river gneiss (Du Toit, 2001; Holland, 2011), which in most cases is exposed as coarse-grained, pinkish grey and pink leucocratic gneiss composed of orthoclase and quartz with minor plagioclase, biotite and hornblende. The Hout River Gneiss weathers into typical sandy soil that covers the the greater area of the catchment. According to Jolly (1986), the study area geologically consists of two aquifer units: a weathered aquifer and a high yielding fractured rock aquifer unit. The lower aquifer is known as high yielding for boreholes successfully drilled into connecting fractures. Dykes and pegmatite fracturing features which control most of the groundwater dynamics within the Houtriver gneiss are also visible in certain sections of the study area (Figs 4.2 and 4.3). Further more, the dykes were well exposed on some sections of the river segment with an orientation in SW –NE direction.



(a)



(b)

Fig 4.1. Locality map of the Ga-Mamadila ESGUSA research site showing (a) the topographic map and position of the geophysics lines constructed along the river segment and (b) geological map of the study area.

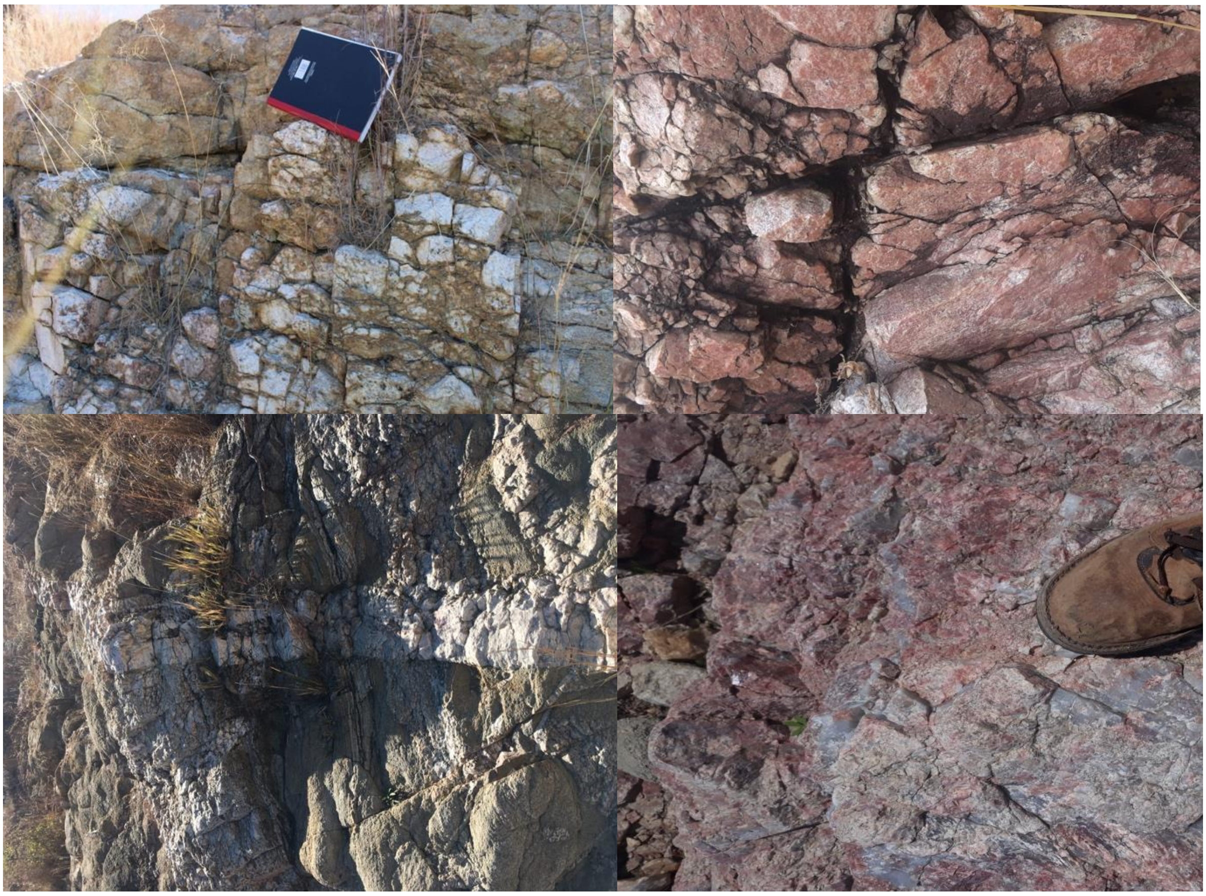


Figure 4.2. Photographic image of rock units showing the extent of fracturing and weathering, amongst other structural features within both the grey gneiss and pink pegmatite forming part of the Hout river gneiss formation characterising the study area. The interconnectivity of the fracturing provides evidence that the formation is likely to enhance groundwater movement and availability within the study area.

Figure 4.3. Evidence of dyke features cutting across some sections of the Hout river segment within the study area. Isolated perennial water pools are also observed at the dyke features, suggesting that in their unweathered form, the dykes may act to inhibit groundwater flow and rechanneling it to the surface. This therefore makes regions on the upstream of the dyke features potential groundwater target within the study area.

4.3 Integrated geophysical methods for groundwater potential evaluation

Since the advent of the application of geophysical methods in groundwater investigation, surface geophysical methods have become the standard for aiding in siting of new wells or well location investigations, and mapping of hydrogeologic units of shallow to relatively deep aquifers. Integrated geophysical methodologies(1D Ground Magnetic methods, Frequency Domain Electromagnetic (FDEM) methods, and Electrical Resistivity methods) were applied in selected river sites based off the occurrence of lineaments and other geological features along and around the river segment that were identified during the compilation of the hydrogeological base map. The objective was to obtain information on the presence of indirect groundwater features through the discovery of structures such as faults, lineaments and dykes that form aquifer boundary or act as controls to subsurface flow in crystalline basement aquifers.

Several geophysical methodologies were sequentially applied in three selected sections based off the occurrence of dykes and other geological features along and around the river segment (Fig. 4.4).

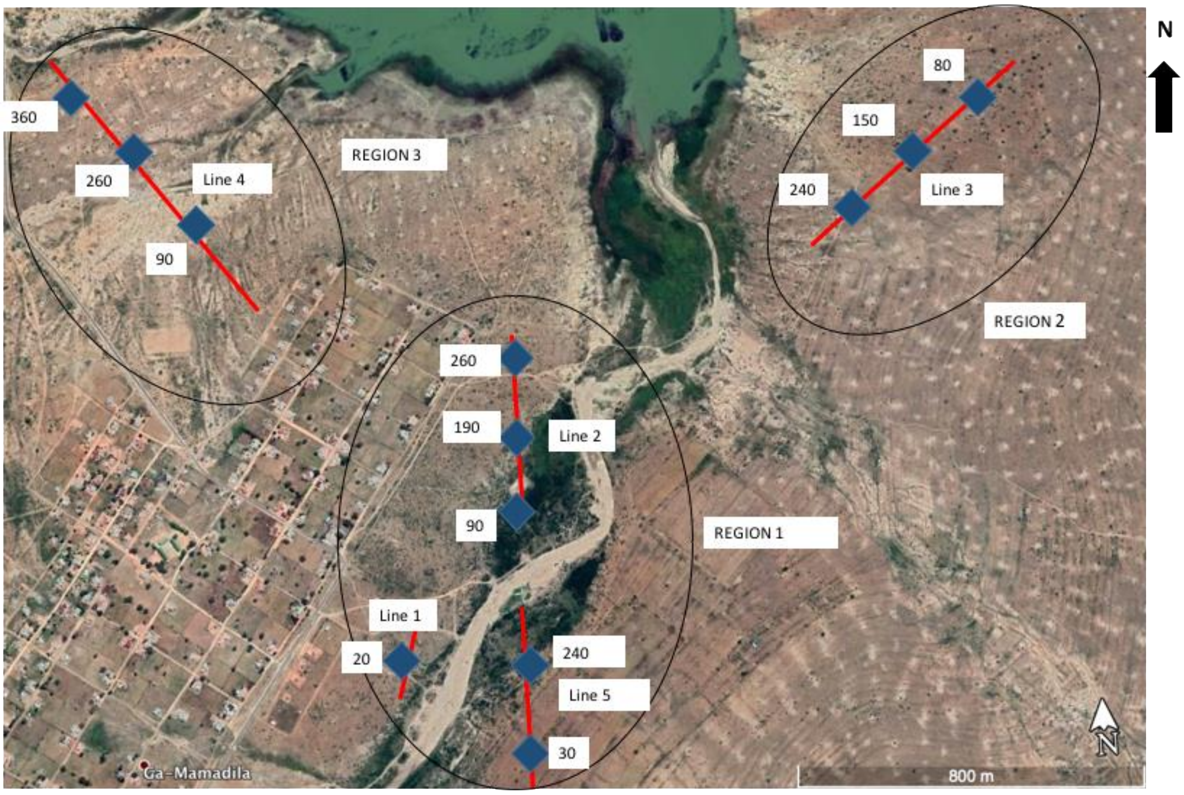


Figure 4.4. Google earth images of the Study area showing the horizontal profile lines and positions for vertical electrical sounding sites (in m) for survey regions 1-3.

4.3.1 Geophysical methodologies employed in the study

Three geophysical techniques were conducted which comprised of magnetic, electromagnetic and resistivity methods.

4.3.1.1 Magnetic method

The 1D ground magnetics method was performed using a proton magnetometer (Figure 4.5). The presence of fractures and dykes (which often control groundwater occurrence in crystalline aquifers) resulted in anomalous magnetic signatures thereby making the geomagnetic exploration method a useful tool in groundwater potential evaluation. The magnetic surveys were planned such that the lines were perpendicular to the regional trends in the geological strike of dykes and faults since they show up most clearly in a survey when traversed perpendicularly. Data was collected at 10 metre intervals within each line and collected using a proton precession magnetometer. A total magnetic profile line was produced and points with contrasting magnetic susceptibilities were identified.

Figure 4.5. A G5 Proton Memory magnetometer used to conduct geophysical measurements.

4.3.1.2 Frequency domain electromagnetic (FDEM) methods

In addition to the magnetic method, Frequency domain electromagnetic exploration method was performed using an EM34 unit as horizontal profiling methods to identify points of potential interest along the line. FDEM methods are widely used in groundwater investigation such as inferring preferential groundwater pathways, mapping fracture zones, dykes and faults. The EM method is sensitive to contrasts in electrical conductivity of the subsurface and involves the propagation of time-varying low-frequency (~100 Hz to 1MHz) electromagnetic fields in and over the earth (Telford et al., 1990). A transmitter coil radiates an electromagnetic field which induces eddy currents in the subsurface. The eddy currents, in turn, induce a secondary electromagnetic field. The secondary field is then intercepted by a receiver coil (Figure 4.6) and can be related to subsurface conditions. The conductivity of geologic materials is highly dependent upon the water content and the concentration of dissolved minerals (electrolytes).

Fig 4.6. Conducting the electromagnetic method with the support of the Department of Water and Sanitation.

4.3.1.3 Vertical electrical resistivity sounding (VES)

The most common mineral forming soils and rocks have very high resistivity in these dry condition of Limpopo. The resistivity of soils and rocks is therefore normally a function of the variations in water content and the concentration of dissolved ions in the groundwater. The Wenner electrode configuration was used on selected potential sites in order to infer the variation and thickness of the underlying layers at selected anomalous regions. This particular method utilises direct currents or low frequency alternating currents to investigate the electrical properties (electrical resistivity) of the subsurface and is based on the principle of existence of electrical resistivity contrasts between different earth materials in accordance to rock matrix, moisture, fluid saturation salinity and porosity factors. The measured apparent electrical resistivity, which is determined by measuring V (potential difference) and I (current) and knowing the electrode configuration, gives an idea of the nature of subsurface material present within the medium.

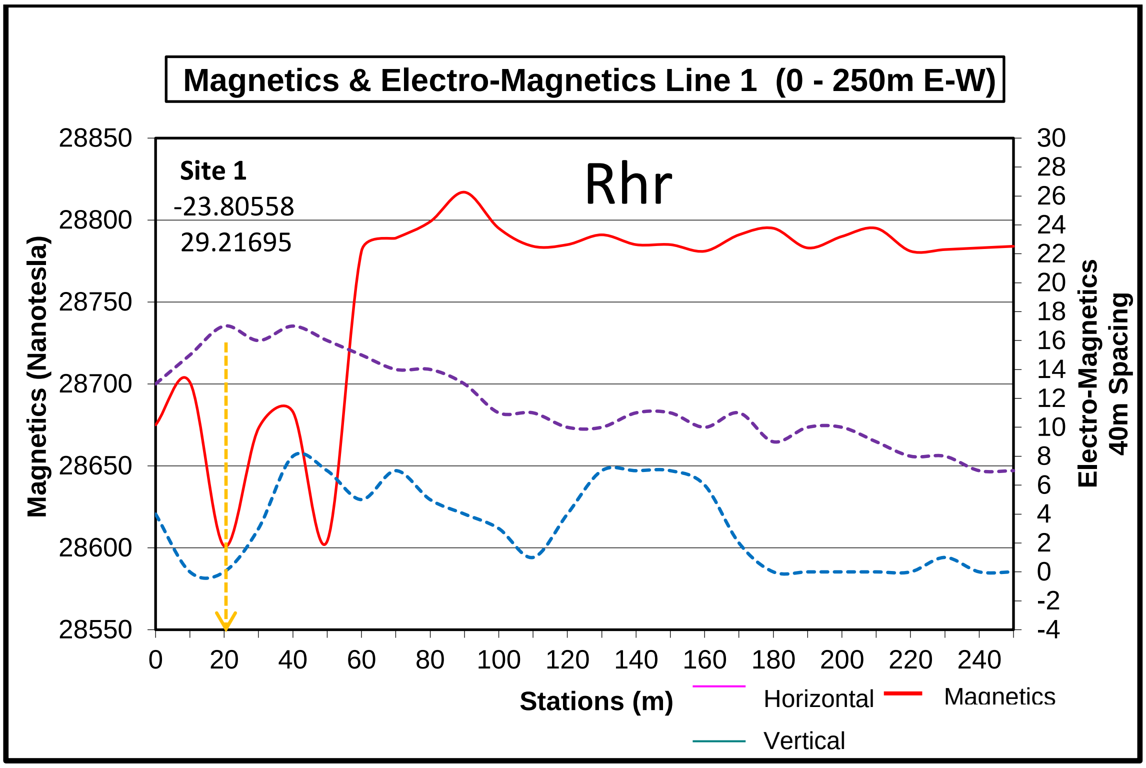
Fig 4.7. Field set up used for vertical electrical sounding on the experimental sites

4.3.2 Geophysical results and interpretation

Three sites (region 1-3) were described for the Ga-Mamadila experimental site were used to provide a representation of the structural conditions mapped in the four sites. The interpretation of results from the field investigation was based on Microsoft excel plots of both profiling (magnetic and EM) and VES field results (Figures 4.8 to 4.11). For each profile line in the respective regions, results of the lateral profiling using magnetic and electromagnetic methods were used to identify the anomalous sites (indicative of geological contacts or structures likely to control groundwater occurrence) are first presented. Anomalous zones from which the electrical resistivity sounding was then done to infer the probable depth layering and the possible distribution of various litho-stratigraphic sections that could influence the groundwater potential of the area are also indicated by arrows showing the respective position of the anomaly.

4.3.2.1 Region 1

Two profile lines were carried out during the field survey in region 1 and are described below as profile 1 and 2 respectively. Firstly, a 1D magnetics survey was carried out, followed by the horizontal and vertical electromagnetics were performed on profile line 1. An anomalous region was observed 20m away from the start of the traverse mark point, this is shown along the line in Figure. This point was further investigated in order to deduce the depth variation using electrical resistivity sounding. The results suggested a single fractured region between depths 24m to 54m from the ground surface (Fig 4.8). Other than the station 1-20m, there were no other distinct anomalies that suggested groundwater potential in the selected region.



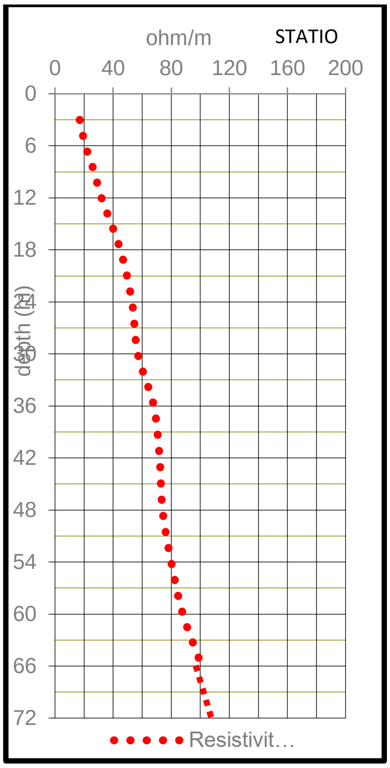


Figure 4.7. (a) Variation of magnetic susceptibility, the horizontal and vertical FDEM results along profile line 1 showing an anomaly at 20m and (b) The corresponding vertical electrical resistivity section together with the inferred depth variation profile from the interpretation of field electrical resistivity results.

Profile line 2 was done on the upstream of the Hout river dam at a total length of 300m as described in Figure 4.4. Three main anomalous regions were identified using the magnetic profiling and electromagnetic methods (both horizontal and vertical), (Figure 4.9a). The main anomalous points that needed further investigation in terms of groundwater potential were observed at sites 90m, 190m and 260m. The vertical electrical resistivity sounding investigations on the three identified sites suggests a predominantly multiple layered variation on the nature of the underlying Hout River gneiss formation, (Figure 4.9b). The sections have a varying thickness as shown in the constricted sections, despite the fact that they all consist of an inferred weathered regolith and a fractured zone confined by the solid gneiss formation. The inferred fractured region thickness varies from around 20m at 190 m to over 40m at 90m thus increasing the groundwater potential of the area.

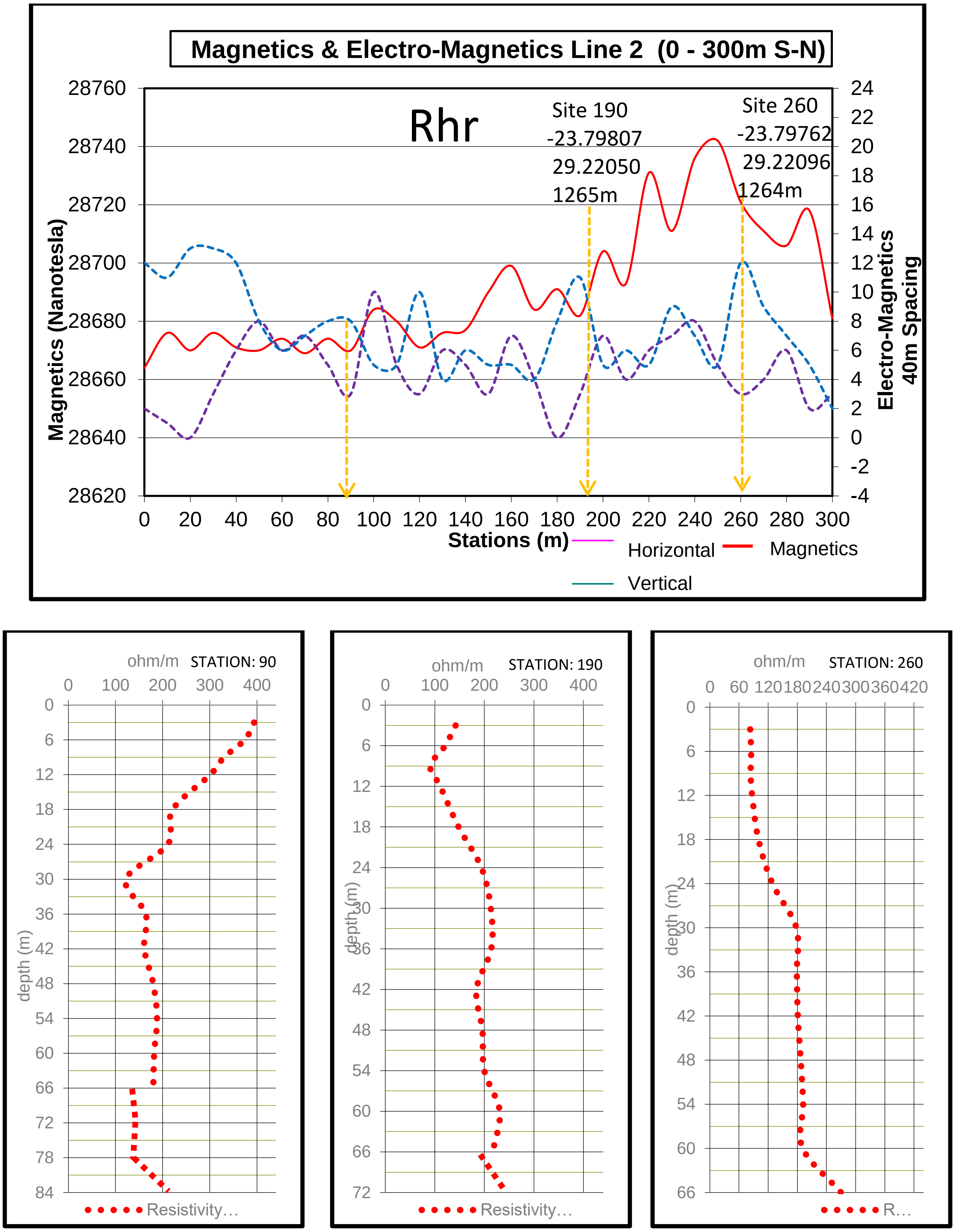
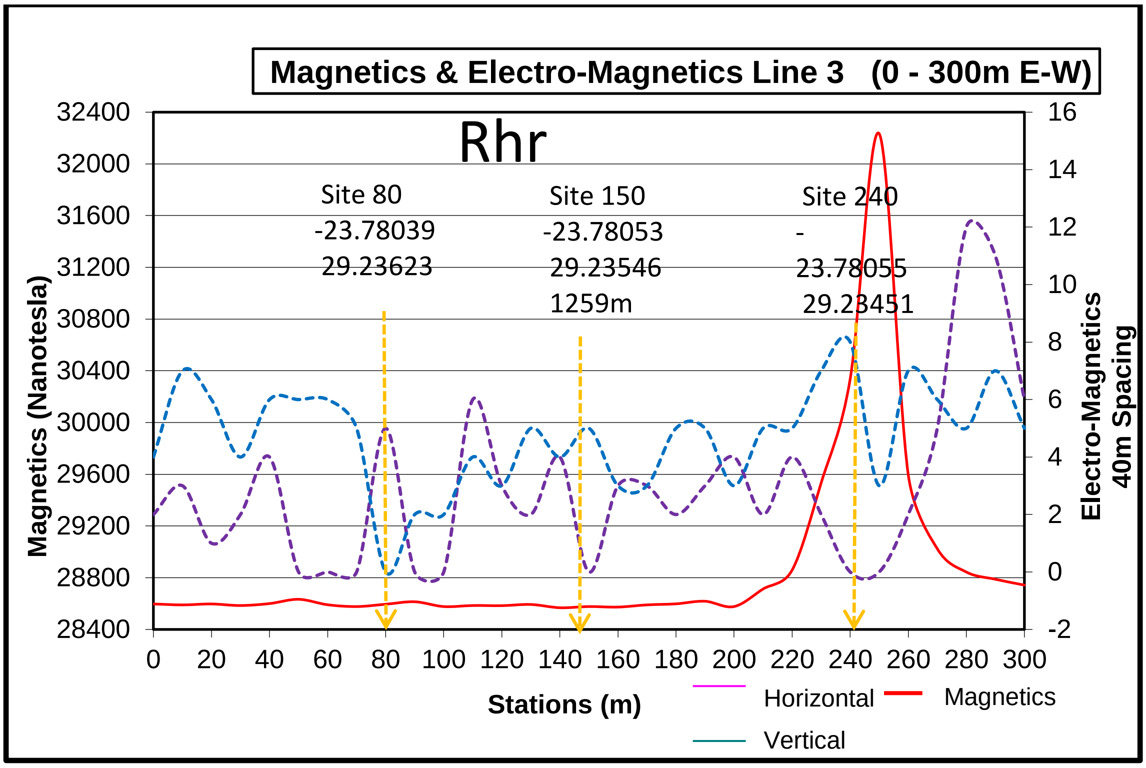


Figure 4.9. (a) Typical variation of magnetic susceptibility, the horizontal and vertical FDEM results along profile line 2 showing potential groundwater anomalies at 90m, 190m and 240m and (b) The corresponding vertical electrical resistivity sections together with the inferred depth variation profile from the interpretation of field electrical resistivity results.

4.3.2.2 Region 2

Region 2 was described by profile line 3, and was done with an orientation towards the East-West direction towards the Hout river dam and lying on a lineament as indicated in the geological map in Figure 4.2. The total length of the line was 300m. Three major anomalous zones were picked at 80m, 150m and 240m using the magnetics and both horizontal loop and vertical loop electromagnetic methods (Figure 4.10a). The cross-sections inferred from the vertical electrical resistivity sounding suggest highly weathered zone and several fractured sections as indicated in Figure 4.10b.



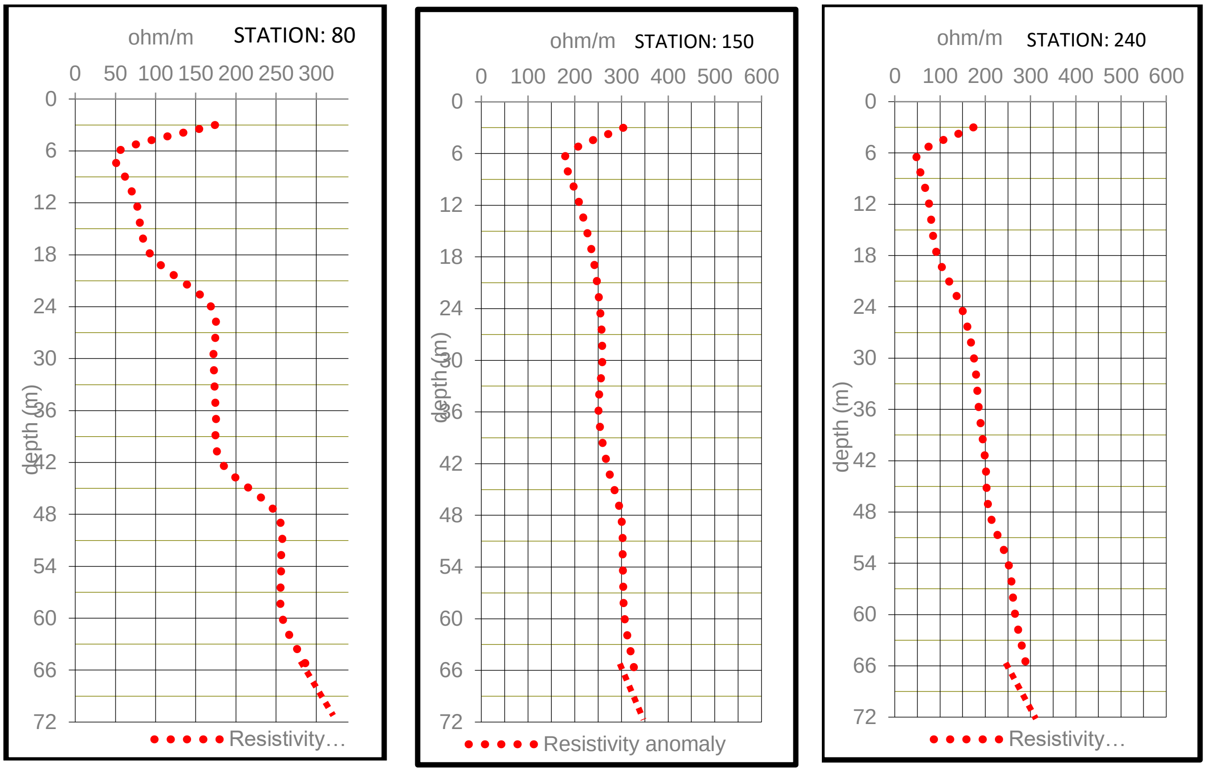
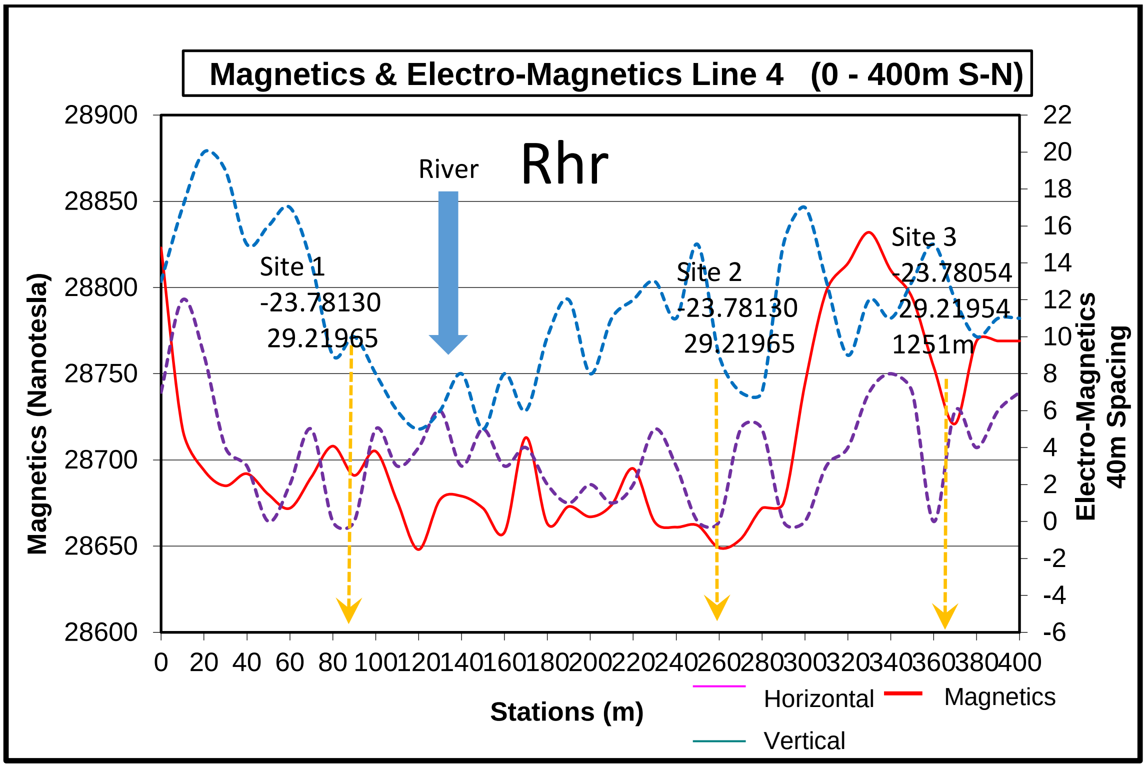


Figure 4.10. (a) Variation of magnetic susceptibility, the horizontal and vertical FDEM results along profile line 3 showing potential groundwater anomalies at 80m, 150m and 240m and (b) The corresponding vertical electrical resistivity sections together with the inferred depth variation profile from the interpretation of field electrical resistivity results.

4.2.2.3 Region 3

Region three comprised of profile line 4 which was done with a total length of 400 m and a North South orientation as shown in Figure. The magnetics and electromagnetic survey results showed three anomalous regions at 80m, 260m and 360m (Figure 4.11a). These were further investigated using the electrical resistivity sounding for vertical investigation on the variation of weathered and fractured regions. Results suggested a fractured region mainly in the depths from 42m to 70 m with less potential to get any groundwater strikes before this region, except on the 360m mark which has two fractured sections (18m-36m and 40m-60m) that are inferred from the results.

Figure. Google earth images showing the positions for vertical sounding points for survey region 3 within the study area.



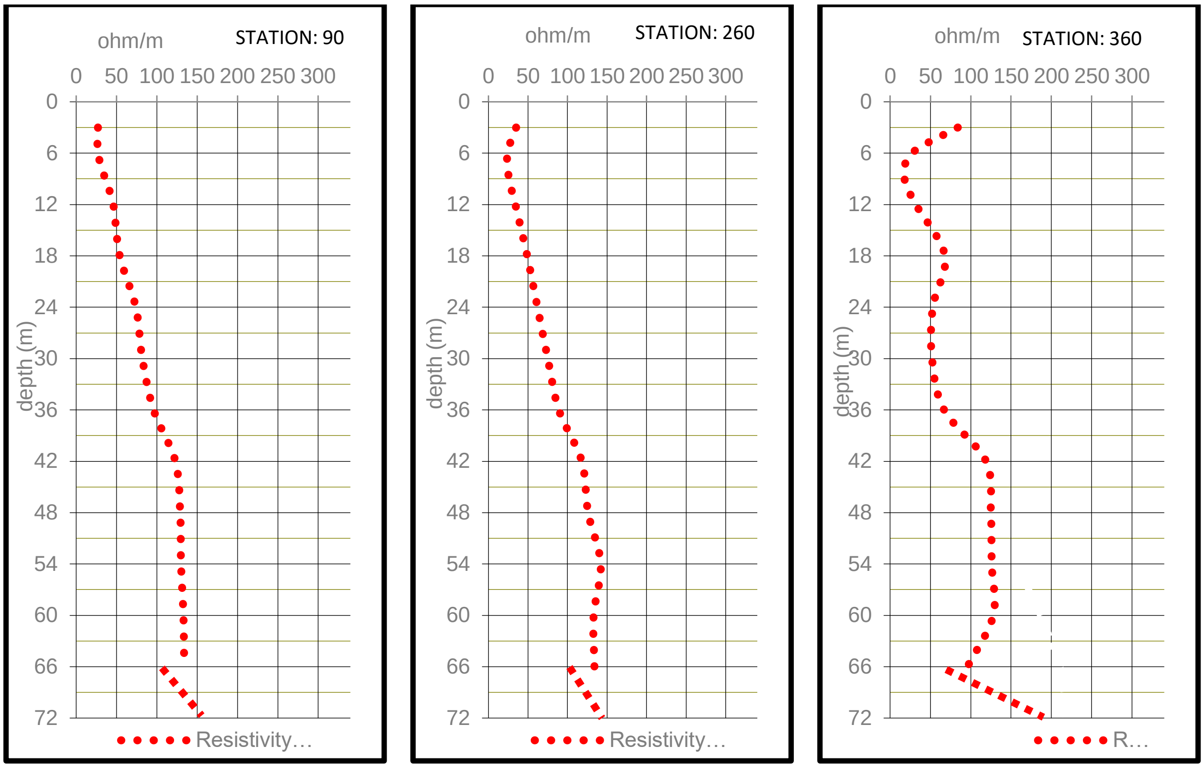


Figure 4.11. (a) Variation of magnetic susceptibility, the horizontal and vertical FDEM results along profile line 4 showing potential groundwater anomalies at 80m, 260m and 360m and (b) The corresponding vertical electrical resistivity sections together with the inferred depth variation profile from the interpretation of field electrical resistivity results

4.3 Summary and conclusions

In summary, the geophysical surveys provided the necessary data to identify suitable positions for the drilling of the boreholes and obtaining groundwater. Line 2 in region Region 1 was identified as an appropriate experimental site in line with the research objectives. The groundwater bearing zones in all the VES sections are characterized by very low resistivity values as typical of groundwater bearing with, in contrast with solid crystalline rocks predominating within the formation. This distinct difference in resistivity within the formation in the profiles are thus attributed to elevated water content of crystalline rocks which are mainly controlled by the level of fracturing at deeper sections. The VES section obtained from the field results presents a multi-layered cross section with a crystalline basement that is overlain by a regolith of varying depth bet with consistently lower resistivities of between 40-100 Ω-m.. Solid bedrock is characterised by high resistivities (often bigger than 400 Ωm in this study) compared to the weathered and fracturing bearing formations (mostly in the 40-120 Ωm range). Because of such contrast between the groundwater being and dry sections, it is easy to infer sections of localized occurrence of groundwater in the Houtriver gneiss hard-rock formations owing to the lower resistivities of these water-rich zones compared with typical high resistivities of crystalline rocks. The weathered overburden is usually porous which may enable it to store groundwater, hence, making it a possible aquifer.

A relatively unweathered portion of the volcanic rocks is inferred at a depth of approximately thirty meters below ground surface and is characterized by a resistivity values in excess of 300 Ω-m, and characterised by sections of reduced resistivity values which are inferred as fractured zones occurring within the solid bedrock. This fact is further supported geologically by the presence of geologic structures such as pegmatite lineaments and dykes as inferred from geological mapping and magnetic and electromagnetic geophysical surveys. This therefore means that the formation has an increased groundwater potential than common crystalline formations in the Southern African region.

As such, the results from magnetic and electromagnetic surveys were combined with geological observations and used to identify anomalous points where vertical electrical resistivity sounding was done in order to infer the depth of influence and vertical layering of geologic features such as dykes together with the structural extend of weathered and fractures zones. The utilized geophysical methods provide promising input to groundwater evaluation in the area. For setting up a borehole network within a regions 1 and 2 are most likely suited in terms of groundwater potential evaluation and proximity to the river/dam as a sources of recharge. Suggested depth of drilling within the study area should be over 80m as the electrical resistivity sounding results suggested that in general most of the fractured region was extending to over 70m.

CHAPTER 5

BOREHOLE DRILLING, TESTING AND INSTRUMENTATION

5.1 Introduction

After the geophysical methods were conducted, borehole drilling sites were established. The drilling exercise was conducted in collaboration with the Department of Water and Sanitation. Four experimental boreholes were drilled in the Ga-Mamadila site from the 3rd – 8th of June 2019 by the Ramotse development company under supervision of the UWC and the Department of Water and Sanitation. The selection of drill the sites was informed from a detailed desktop study, accompanied by on site geological mapping and geophysical investigations conducted in 2018. In addition to this, drilling logs from the DWS were used in order to create a more comprehensive analysis of the study area. This section describes the drilling and borehole development procedures that were undertaken to set up monitoring wells as outlined in the project objectives. It also describes the pump testing, chemical analysis and instrumentation procedures done within the project framework.

5.2 Borehole drilling procedure

The study used air-rotary as a drilling technique in order to establish the characteristics of the aquifer materials and geological units within the study area. Air-rotary drilling is a technique which uses a rotating drill bit that grinds through soil and rock as the drill bit advances and then uses compressed air in order to transport the drill cuttings up to the ground surface. A driven steel casing (6 m in this case) is used to help reinforce the drilled borehole and prevent borehole collapse, while facilitating the transport of aquifer material out of the borehole. This then allows for the collection of soils at various intervals for borehole logging. The positioning of these boreholes was ideal for the monitoring of the water level fluctuations in comparison to the surrounding boreholes reactions and will obtain good data during high flow events within the area.

Fig 5.1. Air-rotary drilling on the Ga-Mamadila site

The drill used a pneumatic reciprocating piston-driven ‘hammer’ made from solid steel to energetically drive a heavy drill bit into the rock solid steel and has ~20 mm thick tungsten rods protruding from the steel matrix as ‘buttons’. The tungsten buttons are the cutting face of the bit (Fig 5.2).

.

Fig 5.2. Steel rods and drilling bit

Samples were collected at 1 meter intervals during the drilling process as the drill bit penetrated the geological material using a spade (figure 5.3) and images of the samples were taken in order to identify the rock materials at respective depths. Air rotary drilling is especially useful for drilling in very coarse and/or dense soils such as those found in crystalline bedrock environments, as it is relatively unaffected by the presence of hard material

Fig 5.3. Sampling during air-rotary drilling

The lithological description of the area is dependent on the method of sampling that was used during the drilling process. The sampling method allowed for the collection of relatively undisturbed samples as the release of air constantly clears the bottom of the borehole and this allows for consistent contact between the drill bit and the rock formation. As this occurs, the air pushes the rock material to the surface and this allows for systematic collection of samples. Properties of the rock such as, chip size, primary lithology, secondary lithology, trace elements, weathering, grain size, and colour were then captured into an excel spreadsheet. This allows a more precise delineation of weathered and hard rock material.

5.3 Borehole development

After drilling the boreholes were cased with 165 mm steel pipes, slotted steel pipes were installed at water strikes which were gravel packed on the outsides. Finally, the boreholes were capped and marked. The four newly drilled boreholes were marked HO4-3125, HO4-3126, HO4-3127 and HO4-3128 (shown in Figure 5.2) in order to keep consistency DWS nomenclature on monitoring boreholes under the HYDSTRA platform. Table 5.4 presents a summary of the borehole details.

Number	lat	long	Elevation
H04-3125	-23.79785	29.22157	1272
H04-3126	-23.79762	29.22096	1276
H04-3127	-23.79872	29.21987	1278
H04-3128	-23.79836	29.22057	1275

Figure 5.4. Locality map and coordinates of monitoring wells drilled at Mamadila experimental site

Table 5.1: Information summary of boreholes drilled at the Ga-Mamadila site

Number	depth /m	blow yield(l/s)	Summary
HO43125	60	0.34	Drilled into the shallow alluvial layer and shallow weathered regolith of the aquifer underlain by a solid Diabese dyke
HO43126	84	5	Cutting across different bands of solid Hout River gneiss and highly weathered and potentially water bearing weathered pegmatite lineament
HO43127	120	5.6	Cutting through an highly fractured pegmatite layers and weathered Diabese dyke
HO43128	48	8.4	Cutting through highly fractured pegmatite layers and at the edge of a Diabese dyke

5.4 Lithological development and development of lithostratigraphic conceptual model

Sampling of the drill chippings were collected at meter intervals for the description of lithostratigraphic layers. The boreholes on the Ga-Mamadila site, which is situated along the Hout River consists mainly of quartzitic-gneissic rocks whose properties range between weathered and coarse-grained units. The following lithological logs are described in Fig 5.5.

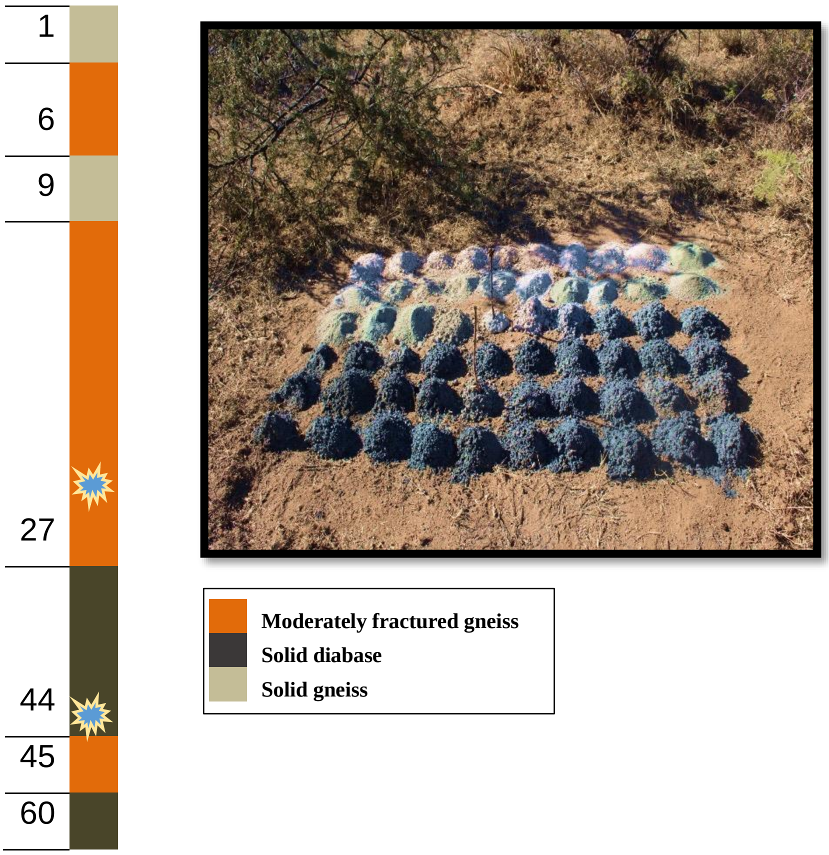


Fig 5.5. well profile and sample images for borehole HO4-3125

Lithological analysis of borehole HO4-3125 shows that the drill penetrated through various layers of gneissic rock that displayed different states of weathering. The first 9 m displayed instances of solid and fractured gneiss. This was followed by a layer of Mica-rich gneiss at 10 m for roughly a meter. Layers of weathered and solid gneiss were then penetrated up until 24 m where the material changed to fractured gneiss. The fractured layer occurred up to 27 m where it changed to a layer of solid diabase. The diabase layer extends to 44 m before the drill bit penetrated into a 1 m layer of fractured gneiss before returning to a diabase layer that extends a further 5 m, drilling stopped at 60m. Water strikes were observed at 25m and 45m. A final blow yield was measured to be 0.3l/s.

For borehole HO4-3126, fractured gneiss occurred from the surface to a depth of around 48 m, this is then followed by a highly fractured pegmatite layer that extends for 24 m before it changes to solid gneiss. Three water strikes were observed during drilling: 49 m, 65m and 69m with a final blow yield of 5 l/s (Fig 5.6).

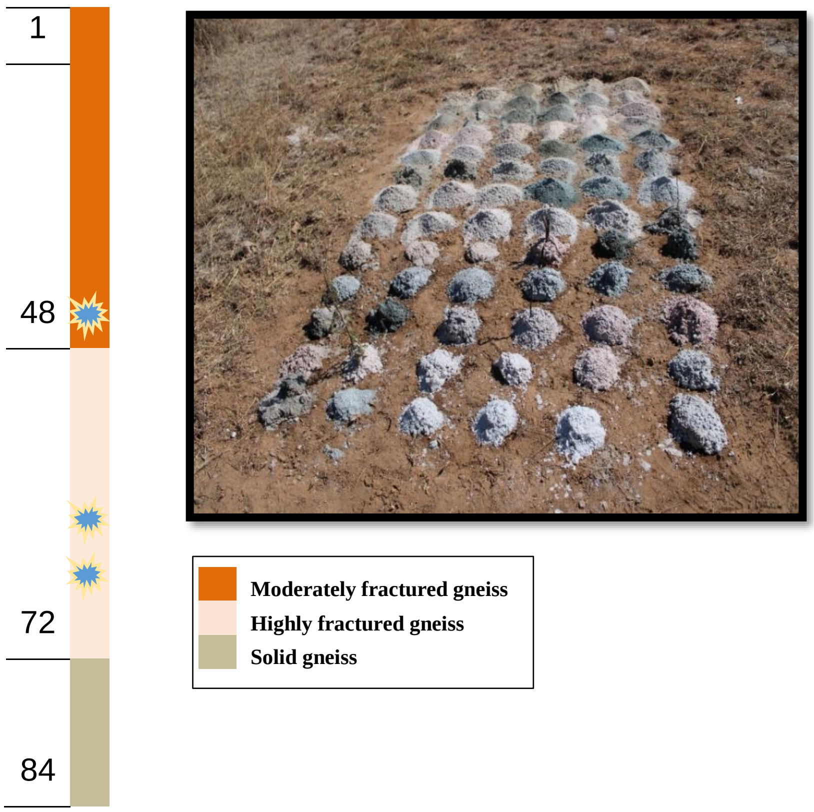


Figure 5.6. well profile and sample images for borehole HO4-3126

Figure displays borehole HO4-3127 which shows the first 2m to be comprised of fractured pegmatite Lithological. Alternating layers of gneissic and pegmatite rocks occurred within the unit. This is then followed by 24m of mica rich gneiss before a water strike is exhibited at 33m. Thereafter, two more water strikes occurred at 43m and 114m. A final blow yield of 5.5l/s was encountered.

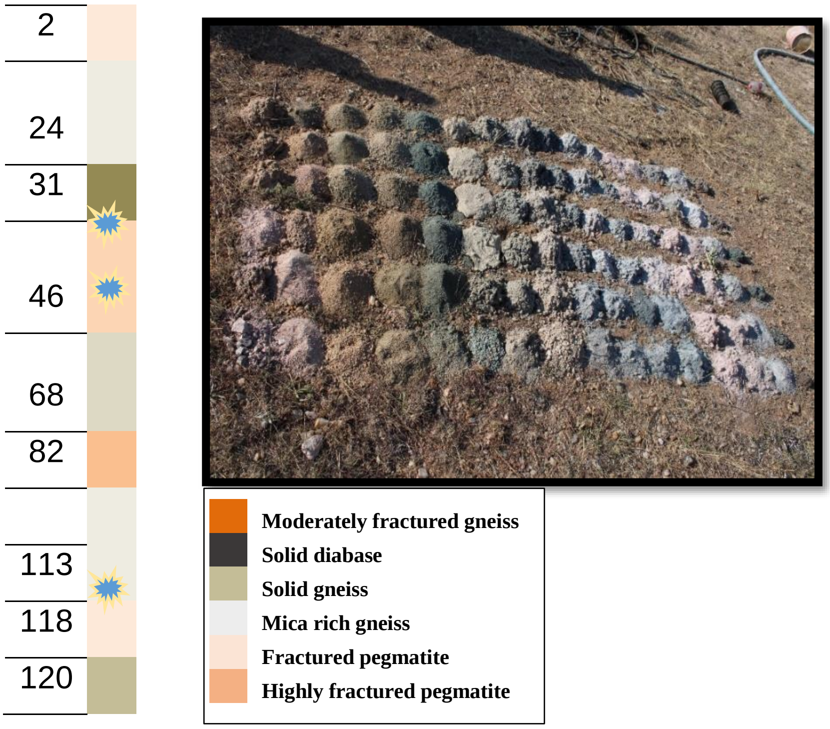


Figure 5.7. Lithological profile and sample images for borehole HO4-3127

The first 30m of borehole HO4-3128 were characterised by predominantly fractured pegmatite rocks. Highly fractured pegmatite was found below the predominantly fractured pegmatite just before two water strikes at 30m and 32m. This was then followed by a final water strike at 37m. The final blow yield of 8.4l/s was measured. Lastly, solid gneiss was observed from approximately between 35-48m.

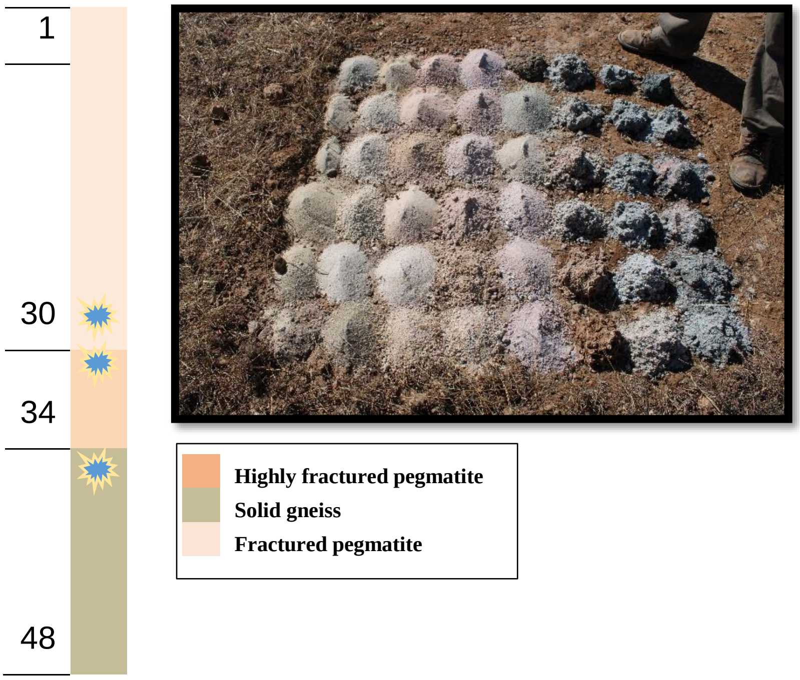


Figure 5.8. Lithological profile and sample images for borehole HO4-3128

A correlation of drill logs with the geophysical sections was done on boreholes that were drilled within the study area (Fig 5.9). The developed cross section confirms the complexity that is associated with the typical Houtriver gneiss aquifer formation whose groundwater occurrence is controlled by many structures inclusive of Diabese dykes, pegmatite lineaments and varying degrees in weathering and fracturing in different sections of the parent gneiss. This aspect is also confirmed by the constructed pseudo sections from electrical resistivity sounding results discussed earlier. The blue arrows indicate points of major water strikes as observed during the drilling process.

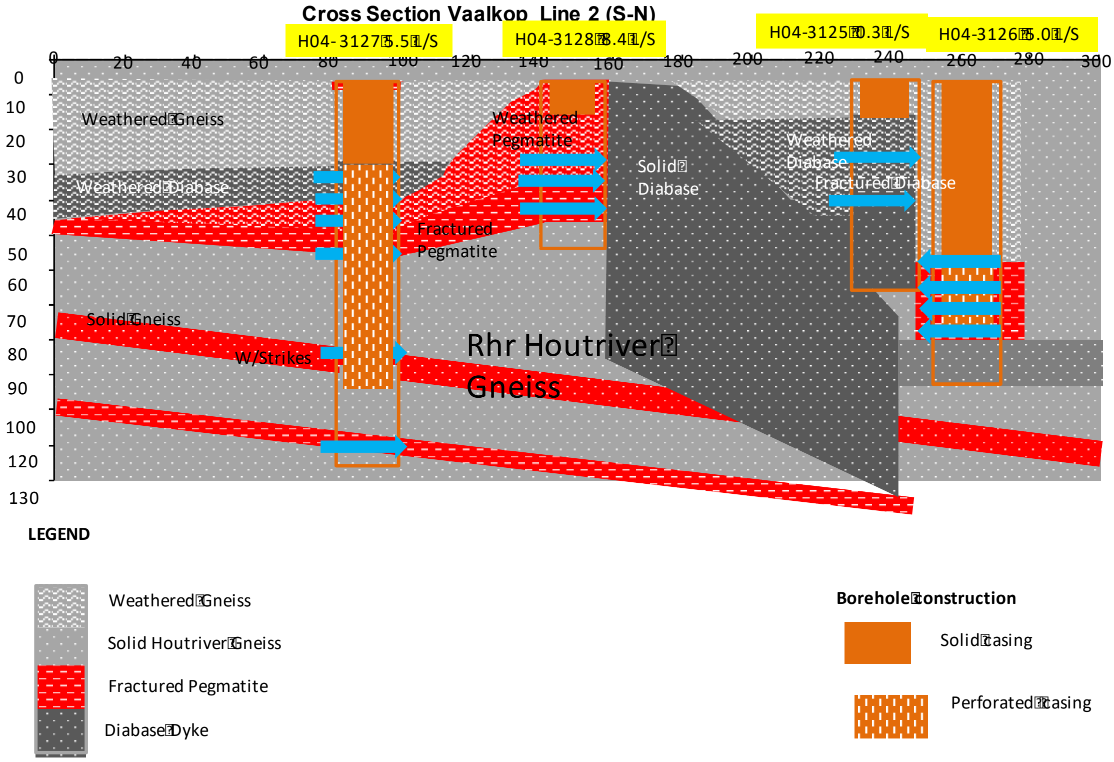


Fig 5.9. Inferred lithological cross-section developed from boreholes drilled within Houtriver gneiss aquifer formation. The cross section was developed from test boreholes drilled within the study area under the ESGUSA project framework.

5.5 Borehole testing and chemical analysis procedures

Aquifer tests were performed in order to determine the maximum yield below which pumping must be done during constant discharge test as well as the strengths of the boreholes by determining their storativity and transmissivity values by using constant discharge methods and recovery tests. The hydraulic response to pumping is measured and analysed with the objective to;

1) characterise an aquifer,

2) quantify its hydraulic properties, and

3) determine the efficiency and sustainable yield.

The type of tests done included multiple discharge test (step-drawdown test) and a constant discharge test and a recovery test. In crystalline aquifers short-term pumping tests (i.e. 24-48 hrs) may be adequate to predict the sustainability of an abstraction if the abstraction rate is small and the aquifer relatively uniform.

5.8.1 Experimental procedure for pump tests

Aquifer tests are conducted in order to gain additional insight on aquifer properties such as transmissivity (T) and storativity (S) values. Theses hydraulic properties facilitate the movement and storage of groundwater. In this study, step-down and constant rate pumping tests were performed on two boreholes; HO4-3126 and HO4-3127 as these were the deeper boreholes on the site. The tests were analysed as multi-tests with either one of the aforementioned boreholes as a pumping well while the other three boreholes acted as monitoring wells (Fig 5.10).

Fig 5.10. Experimental set up of the pump testing rig

Recovery tests were then performed to establish the aquifer response in a natural state, however, this is also essential as it accounts for disturbances such as turbulence to the water during the pumping test. The raw data for the tests is available in excel format as listed in section 1 on the data summary.

Analysis of pump test data is underway and will be presented in a report and in theses for MSc Students

5.9 Chemical analysis

The water samples were collected from two the newly established monitoring boreholes and sent to an accredited laboratory for chemical analysis. The results chemical analysis is presented in table below. Isotope data was collected along the river bed during the drilling exercise and was sent for analysis in the NRF Ithemba labs as part of capacity building agreement in support to MSc students. As such isotope data will be presented under framework of the MSc theses by one of the co-authors.

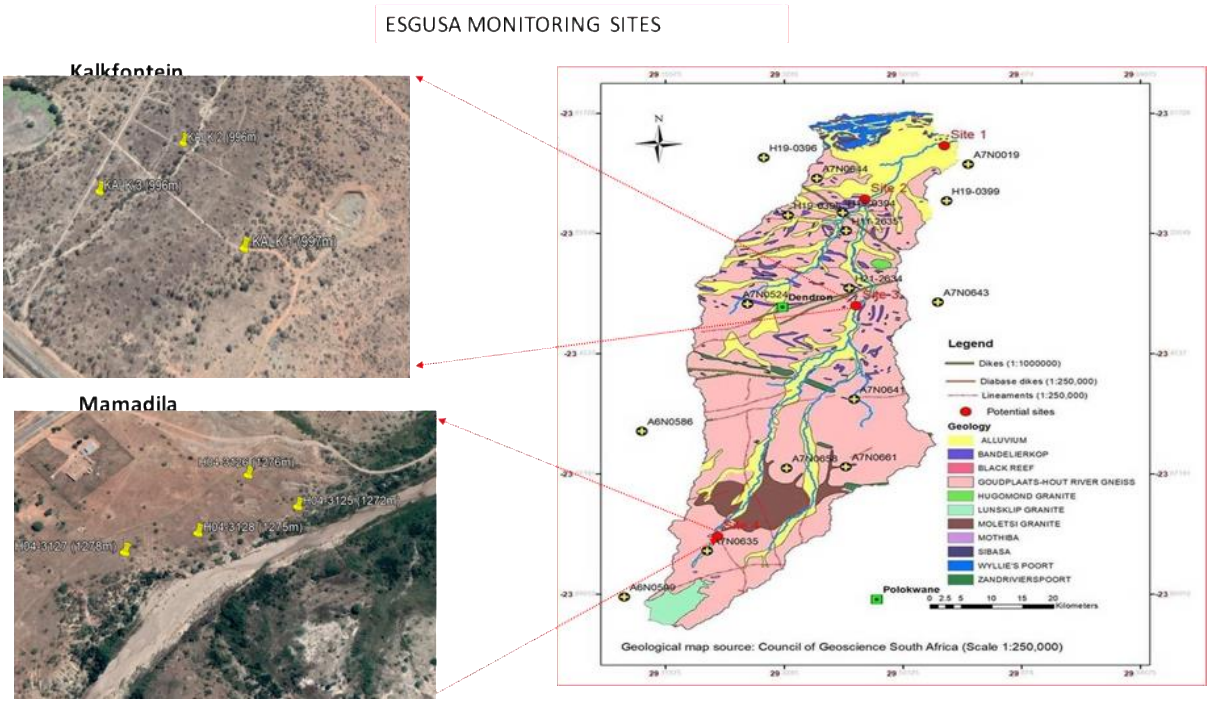
Table 5.2 Chemical analysis from newly established wells

Determinand	Test Method Reference	Unit	1-19/2478	2-19/2478
			H04-3126 11-06-2019 07:40AM	H04-3127 17/06/2019 08:20AM
Physical and aggregate properties				
pH @ 25℃	CH-METH-001	pH units	6.7	6.6
Conductivity @25℃	CH-METH-002	mS/m	71.3	71.3
Langelier saturation index	-	-	-1.30	-1.35
Alkalinity				
*Bicarbonate alkalinity as $CaCO_3$	CH-METH-054	mg/l	106.7	108.0
*Carbonate alkalinity as $CaCO_3$		mg/l	0.0	0.0
Metals				
Aluminium as Al	CH-METH-020	mg/l	0.04	<0.01
Arsenic as As	CH-METH-020	mg/l	<0.03	<0.03
Cadmium as Cd			<0.01	<0.01
Calcium as Ca	CH-METH-020	mg/l	39.23	38.56
Copper as Cu	CH-METH-020	mg/l	<0.01	<0.01
Iron as Fe	CH-METH-020	mg/l	<0.01	<0.01
Magnesium as Mg	CH-METH-020	mg/l	26.45	28.13
Manganese as Mn	CH-METH-020	mg/l	0.01	<0.01
Potassium as K	CH-METH-020	mg/l	6.90	7.22
Lead as Pb	CH-METH-020	mg/l	<0.09	<0.09
Sodium as Na	CH-METH-020	mg/l	53.84	55.75
Zinc as Zn	CH-METH-020	mg/l	0.01	0.02
Inorganic non-metallic constituents				
Chloride as Cl	CH-METH-050	mg/l	59.9	61.6
Fluoride as F	CH-METH-013	mg/l	<0.10	<0.10
Nitrogen				
Nitrate as NO_3-N	CH-METH-050	mg/l	26.46	27.26
*Nitrite as NO_2-N	CH-METH-011	mg/l	0.01	<0.01
Phosphorus				
Ortophosphate as PO_4-P	CH-METH-032	mg/l	<0.05	<0.05
Sulphur				
Sulphate as SO_4	CH-METH-050	mg/l	43.71	44.61
Aggregate organic constituents				
*DOC as C	CH-METH-061	mg/l	<5.0	<5.0
*Total Organic Carbon C	CH-METH-060	mg/l	<5.0	<5.0

5.10Installation of monitoring instrumentation

After the establishment and yield testing of monitoring wells, all the four boreholes at Mamadila research site were equipped with automatic water level loggers. The monitoring instruments installed at the site included four water level loggers (solinst, one for each monitoring well) and a single barologger for data compensation. The water level loggers were programmed to be able to remotely measure and store depth to water level measurements at hourly intervals. Data download and compensation was done at different intervals using a summarised procedure outlined in Appendix D. A trend analysis of variation of hydraulic heads (converted from depth to water level as at 27 January 2020) are presented in Figure 5.12(a-d).

In addition, three monitoring wells were also availed to by the farmer (through citizen science engagement) at the Hout river segment in site three (Kalkfontein farm). The three boreholes were instrumented with water level loggers and one barologger for pressure compensation. Data recoding and download is schedules to continue for both sites , (locations shown in Figure 5.11).



MAMADILA

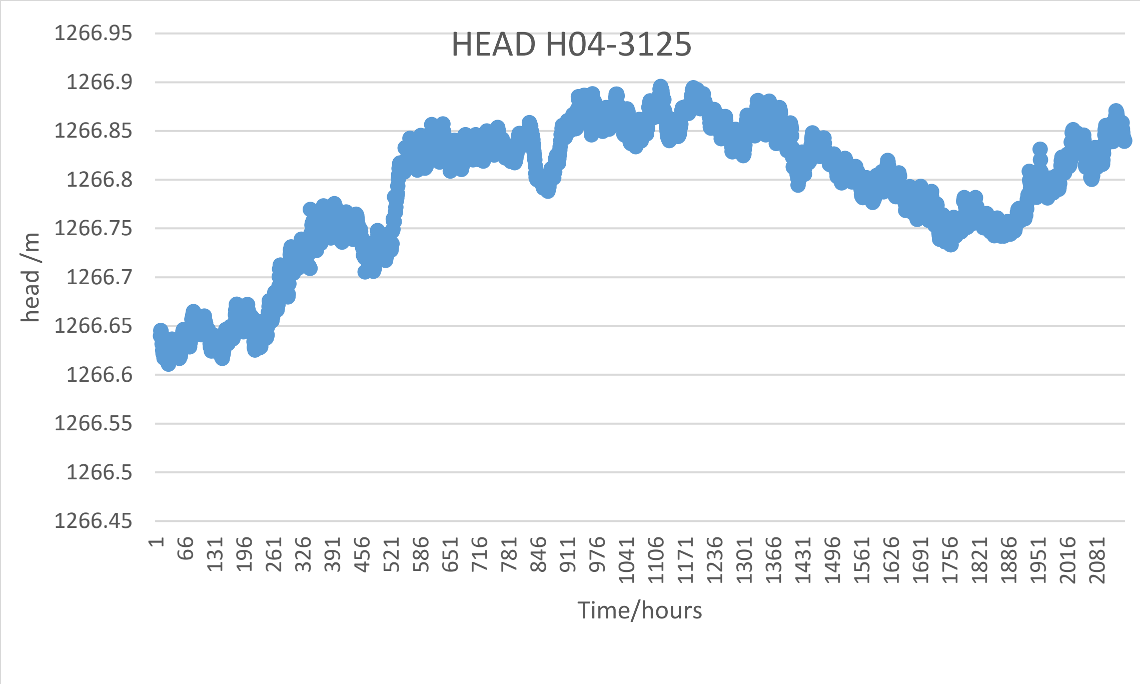
Number		Y	Elevation
H04-3125	-23.79785	29.22157	1272
H04-3126	-23.79762	29.22096	1276
H04-3127	-23.79872	29.21987	1278
H04-3128	-23.79836	29.22057	1275

KALKFONTEIN

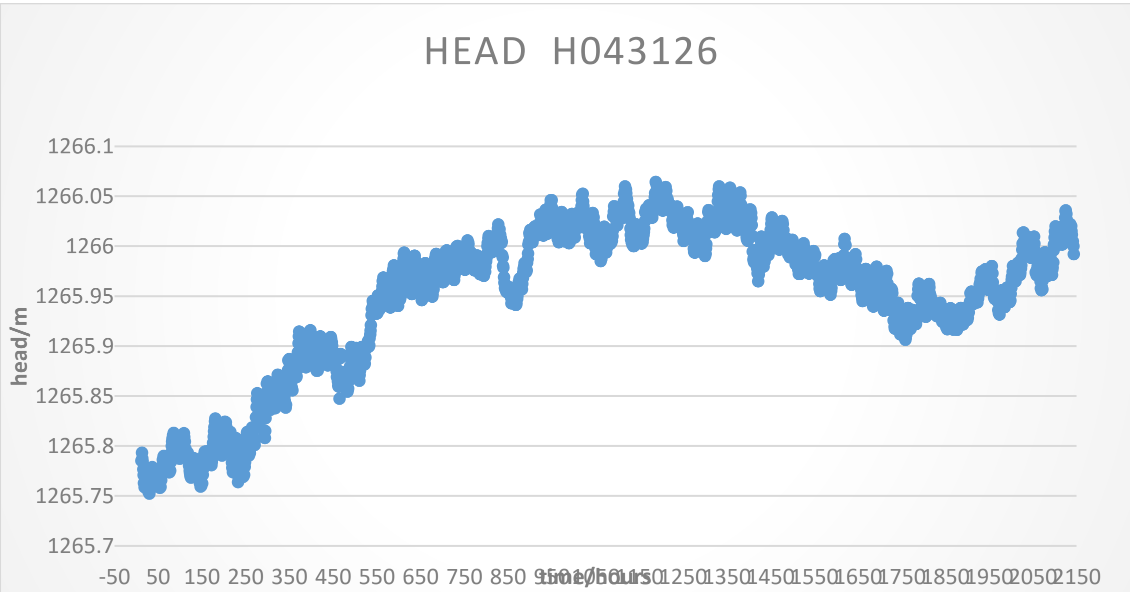
	LAT	LONG	Elevation
Kalk1	-23.36989	29.43745	997
Kalk2	-23.36798	29.43653	996
Kalk3	-23.36893	29.43508	996

Figure 5.11 Locality of monitoring boreholes where new monitoring instrumentation was established for the ESGUSA research project

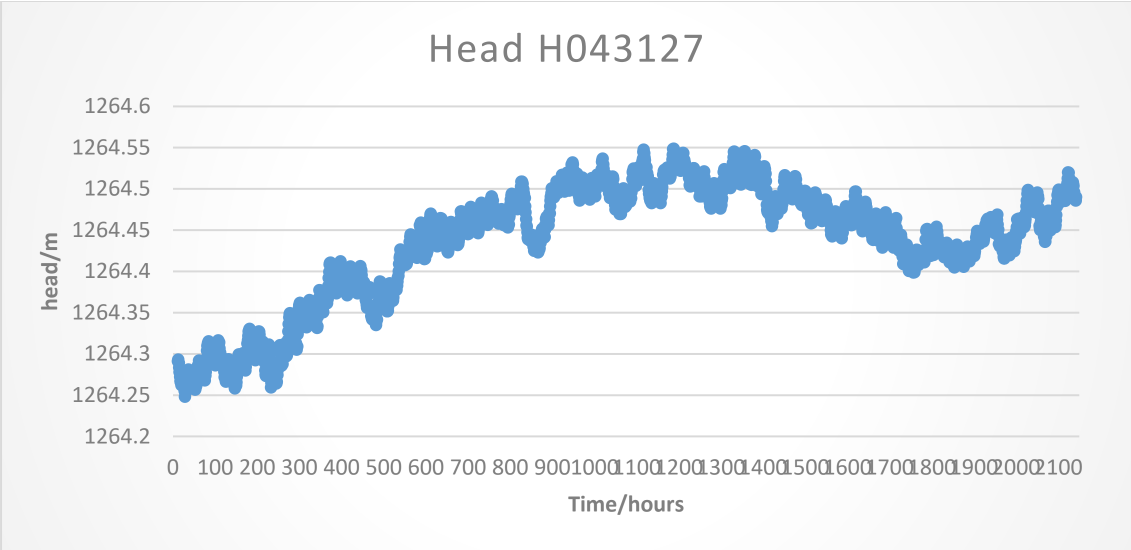
The Time series hourly data for 30 0ctober 2019-27 January 2020 for Mamadila research site is presented below.


HEAD H04-3125
head /m
1266.95
1266.9
1266.85
1266.8
1266.75
1266.7
1266.65
1266.6
1266.55
1266.5
1266.45
1
66
131
196
261
326
391
456
521
586
651
716
781
846
911
976
1041
1106
1171
1236
1301
1366
1431
1496
1561
1626
1691
1756
1821
1886
1951
2016
2081
Time/hours

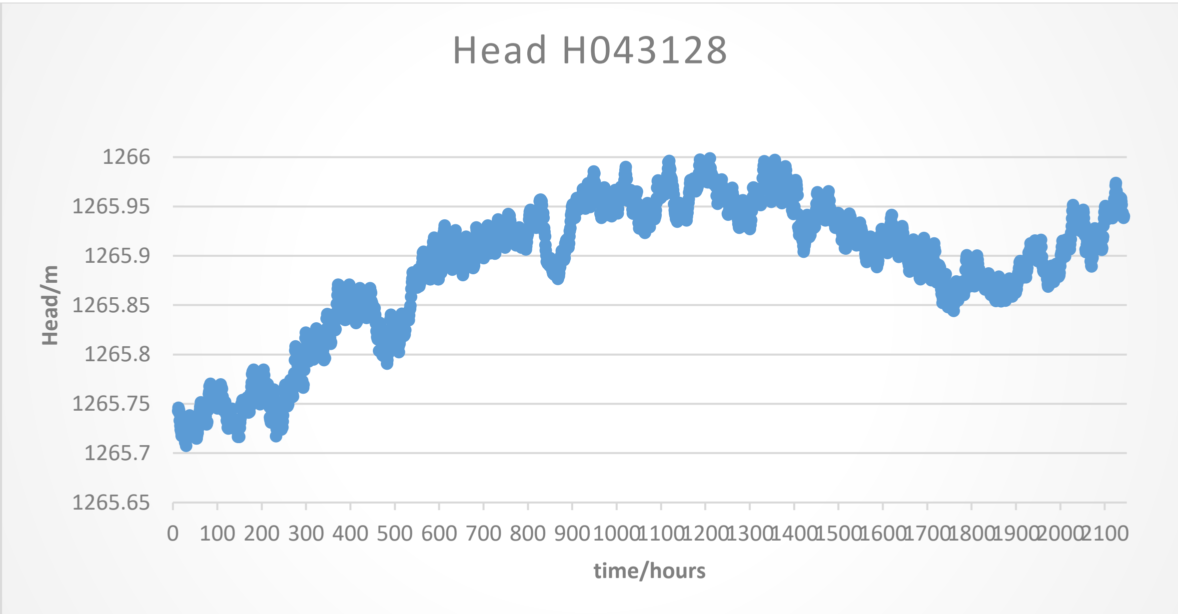
(a)


HEAD H043126
head/m
1266.1
1266.05
1266
1265.95
1265.9
1265.85
1265.8
1265.75
1265.7
-50 50 150 250 350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850 1950 2050 2150
time/hours

(b)



(c)



(d)

Figure 5.12. Time series variation of hydraulic head with time from 31 October 2019 to 27 January 2020

5.11 Summary and conclusion

The four experimental boreholes were successfully drilled at Mamadila site with favourable blow yield upto 8l/s. The two high yielding boreholes were fully developed and tested for both yield and chemical analysis. The pump testing, chemical analysis and instrumentation procedures done within the project framework were presented and shared though the central project database were explained in detail. In addition, automatic water level monitoring instrumentation for time series measurement for depth to water level data were successfully installed at Mamadila and Kalkfontein site. The data is being compiled at regular intervals and will be used in model validation of the hydrogeologic model developed in MIKE-SHE. In addition to this, drilling logs from the DWS were used in order to create a site specific lithostratigraphic conceptual model of the experimental site.

CHAPTER 6

SUMMARY OF COMPILED META- DATA

6.1 Introduction

Various folders containing hydrogeological data have been compiled over the course of the project. Hydrocensus data of various communities in the area of interest was collected from the DWS, the data from the census include subfolders titled; Data, Field Forms, KMLs etc., This section gives a list of all existing and new complimentary data sets that were collected during the duration of the project. The chapter also presents the concluding remark of the main activities done and expectations under work plan 1.

6.2 Brief description of the data sets

- The Climate folder is comprised of information with regards to various weather stations around the area of interest, these include Water poort, Chloe sasil project, Bengzicht, Dendron, Mokopane, Marken, Mara and Makhado air force base. The data set is divided into two, one group consist of stations with an .xls of rainfall data. Group 2 consists of stations with climate data such as temperature, wind speed and direction. Majority of the information on station data is provided from 2015 to 2018, Water poort station however, consists of data from the years 2010 to 2018.
- A 1_50 000 land use map was obtained from the NGI was mosaicked and was used to produce a land use map of the catchment. Hydrogeological units of the sites under investigation were also digitized from this data.
- high resolution digital elevation model (DEM) (spatial resolution of approximately 5 m) produced by the Centre for Geographical Analysis (CGA), Stellenbosch University; The SUDEM was produced from the Shuttle Radar Topography Mission DEM, contour data and point data. An ALOS Global Digital Surface Model at a resolution of 30 x 30m is also available for analysis as well as Landsat data is also available to download provided a specific temporal period is stated as this data tends to contain large files.
- The geology folder contains .shp files of the structures present within the study area compiled by the Dept. of water and Sanitation. Features include; orientation of faults, dykes and lineaments within study area. The dataset also

includes a site specific-digitised layer of the alluvium within the Ga-Mamadila site according to field investigations and 1:50 000 land use map

- Geophysics data on the Ga-Mamadila experimental site is available as .xls tables of the traverses that were delineated. Aerial images of the traverse lines that were made is also available.
- Isotope data was collected along the river bed during the drilling exercise and was sent for analysis in the Ithemba labs during 1-20th August.
- Drill logs and Pumping data on 4 boreholes that were developed in Ga-mamadila site include yields, drawdown, SWL and chemistry data (EC, Temp, Alkalinity, TDS).

6.3 Hydrogeological investigations and borehole logging of existing wells

This part has been retarded by the unavailabity of accessible monitoring wells within the catchment. However, a great deal of work was done on the geophysical log data sets for Matlala Area which were obtained through The Department of Water and Sanitation was analysed. Although this area is not part of the Hout River catchment, they are part of the main formation, Hout river gneiss (though in some sections it is overlain by granites) that is controlling the crystalline basement aquifers within the catchment itself. A multiple geophysical log approach was used in inferring the points of water strike and zones of fracturing within the boreholes (e.g. in Fig 6.1). Geophysical logs provide a continuous analogue or digital record that can be used to interpret lithology, bed thickness, potential aquifers or confining units, permeability, moisture content etc. Self potential (SP) and Neutron logs which are used mostly for delineation of porous formations and determination of porosity since they respond to the changes in electrolytic concentration (or dilution) and amount of hydrogen present respectively in the formation are used in the interpretation of the geophysical logs. Neutrons are electrically neutral particles, each having a mass almost identical to the mass of a hydrogen atom. Because collisions with heavy nuclei do not slow the neutron down very much, it bounces off with very little loss in energy. Energy loss is greatest when the neutron strikes a nucleus of practically equal mass such as the hydrogen atom, hence interpretation of such logs for groundwater purposes are strongly based on neutron logs. In addition, the electrical resistivity log which responds when there is introduction of water into the system (dilution) is also used for interpreting the geophysical logs.

The results provided herein gives evidence for varying depths of fracturing in bedrock with significant strikes being also inferred in the contact zone of sub-vertical intrusions like lineament. A summary of the water strikes within the different sections inferred from the borehole log data within the Houtriver gneiss formation is presented in Table 6.1.

In summary it was noted that most groundwater bearing fractures and zones started at around 15 to 90 m with a huge network distributed between 21 to 60m, with some deep boreholes showing a high yielding zone between 80 and 90m. The data sets were obtained from previous engagements with DWS and availed to the team.

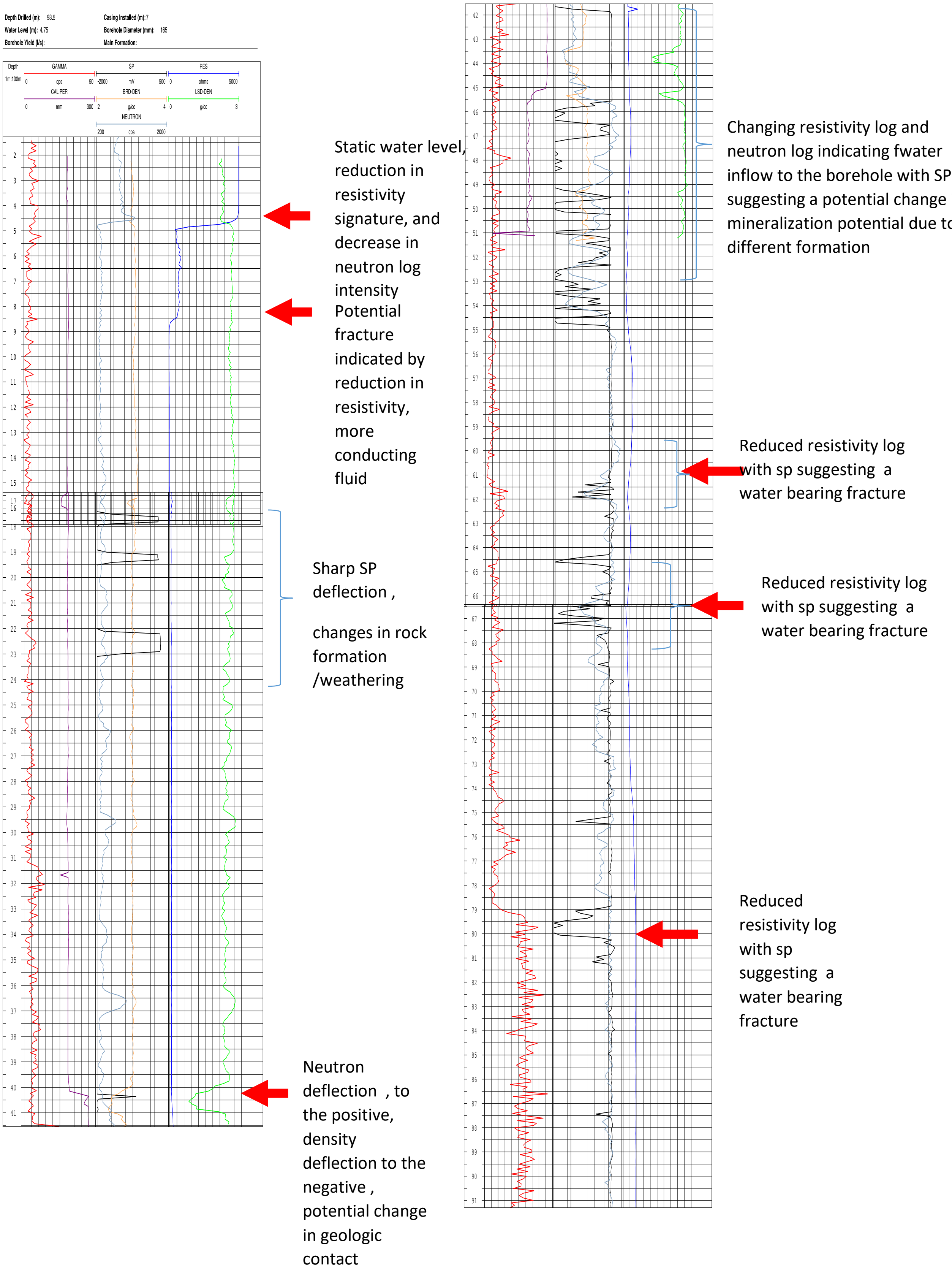


Figure 6.1. Typical geophysical logs for a water bearing borehole (depth 91m) in the Matlala area suggesting existence of groundwater bearing fractures extending to deeper sections.

Table 6.1. A summary of the inferred water strike positions for boreholes logs from Matlala area

				Inferred water strike positions and summary

				• Change in geological contact at 8m, inferred as the end of soil layer • Several water strikes between 15 to 18m and 22 to 23 m, likely controlled by the weathered zone • End of weathered zone / or new geological contact interpreted from increase in gamma ray intensity inferred at 31m • Highly fractured zone between 40 to 54 m. Water bearing fractures inferred at 40, 42-44,47, 51 to 54m • 61 change in geological formation, solid gneiss with fewer water fractures at 64, 67 • 79m solid bed rock

				• 3.0m deflections of gamma logs indicating end of soil layer • 13-13.5m first water strike within the weathered regolith • 19 changes in geologic formation, suggested by sudden increase in resistivity and high gamma ray energy • 20-21m groundwater bearing zone • 27 to 31m high water bearing layer mostly within the lower base of the regolith. Changes in electrolytic potential indicated by SP logs suggest changes in geologic layer. • 34 -41m highly fractured zone with several water strikes. • 47m soft layer with a large water strike, suggesting a fracture • 50-52 changes in geological contact with no water strike, suggesting start of solid bed rock
				• 3m , Gamma and N logs show end of soil layer • first major water strike at 12 m • 14 sudden responses in all logs which could indicate change in geological contact within the weathered regolith • 25 to 34 highly fractured geologic formation, with water strikes at 26, 29 and 31m • 53-55m another lithological contact indicating start of solid bedrock with

				water strikes likely associated with fracturing in regions 59-61m, • 61-69 m , lithology changes to hard rock but with water bearing fractures still inferred at 70m • 73 m start of solid bedrock inferred
				• 3.5 increase in gamma ray deflection inferred as end of the top soil layer/start of saprolite • 5-8 m gamma and N logs responsive to an inferred soil moisture within the saprolite • 12m change of geological layer in the weathered base, minor water strikes at 14m and 18m. • 27 -29 m major water strikes within the same geologic zone • 31m change of geological formation, inferred as start of fractured zone • 39 -41 smaller water bearing fractures • 45-85 highly fractured hard rock with major water strikes at 50- 53, • several multiple water strikes between 57 and 88m • 90 and above start of solid bedrock with a water yielding fracture at 117m
				• first major water strike between 19.5 and 20m

				• 19-30 soft lithology inferred as weathered zone with more water strikes at 21,23, 25, 27 and 28m • 31 to 72, fractured bedrock with water strikes at 32, 34, 45 , 54-55, 64 and 70m
				• 4.5m change most likely induced by end of top soil layer • 12.5 minor water strike within the weathered regolith and initiation of a softer rock formation at 14.5m • major water bearing and fractured zone at 19-22m • 31m changes in electrolytic response suggesting end of weathered regolith or a new geological contact between weathered granites and gneiss

				• 40-41m , 44-50m , 60-63 m, 75-81m, water strikes controlled by fracturing • 82 m start of solid bedrock after which there are very small fractures
				• 3.5 to 4m change in the topsoil structure likely controlled by variations in moisture • 4-8 m reduction in N energy suggestion unsaturated zone moisture • 12.5m, 14m, and 18m water strikes inferred within the weathered regolith • 23-25 high yielding water strikes • 30 -38 changes in gamma, N and resistivity logs, suggesting a different rock formation. • 38-41, highly fractured water bearing section of the new formation • 45-74 highly fractured zone with several water strikes, which suggest a high yielding borehole. Changes in SP logs between 67-74 suggest changes in geological contact. Several fractures intercepted between this region. • 80m start of bedrock with very few fractures up to 98m

				• 3m end of soil layer inferred due to deflections in N and gamma logs • 5m N deflection suggesting a moist lower soil profile • 9m geological change on inferred , likely caused by start of weathered zone • 15-16 first water strike within the weathered zone • 25-29 changes in electrolytic potential, suggesting a new rock formation • 32-46 high water bearing fractures intercepted at several pints • 47-52 a hard rock layer • 50- soft rock from deflection son SP and gamma, with a water strike at 51,
				• 13 to 16 soft or weathered saprolite • major water strike at 15-17m • 17-32 inferred as part of weathered regolith with water strikes at 19, 21-22, 26, 29, 31 • 32m start of fractured hard rock with several water strikes at 35, 37-39,41, 43,47,53 and 57m • 57-70m solid formation

6.4 Conclusions

In principle the activities outlined in the initial project document under Work Plan 1 were satisfactorily and successfully achieved.

Various folders containing hydrogeological data have been compiled over the course of the project. Existing and new meta data sets that were collected during the duration of the project will be used in the Work plan for development of hydrogeological model using MIKE SHE modelling approach (Being implemented by a separate project partner in WP 2). The data sets are all collected into a single data folder at UWC that was shared to all project partners. Downloading and sharing of depth to water level data will be a continuous process in arrangement with the necessary stake holders.

In terms of output and dissemination, WP 1 has managed to produce two conference presentations and two draft manuscripts have been prepared for publication. In addition, two MSc theses are under preparation (due for submission this year, 2020) by students from the University of the Western Cape who were directly involved in the project. More manuscripts and research output is envisaged to come from the MSs theses.

BIBLIOGRAPHY

Acworth, R.I., 1987. The development of crystalline basement aquifer in a tropical environment. Q. J. Eng. Geol. 20, 265–272.

Adams, S. (2009). Basement aquifers of southern Africa: overview and research needs. In: Titus, R., Beekman, H., Adams, S. and Strachan, L. (Eds.). (2009). The basement aquifers of South Africa. WRC Report No. TT 428/09. Water Research Commission. Pretoria. Pp1-4.

Chandra S, Dewandel B. , Dutta S. , Ahmed S., 2010. Analyzing small scale variability of electrical resistivity for groundwater occurrences. Journal of Applied Geophysics 71 137–148

Chilton, P.J., Foster, S.S.D., 1995. Hydrogeological characterization and water-supply potential of basement aquifers in tropical Africa. Hydrogeology Journal 3 (1), 36–49

Chilton, P.J., Smith-Carington, A.K., 1984. Characteristics of the Weathered Basement Aquifer in Malawi in Relation to Rural Water Supplies. Challenges in African Hydrology and Water Resources, proc. Harare Symposium, July 1984, pp. 57–72.

Davis, S.N., Turk, L.J., 1964. Optimum depth of well in crystalline rocks. Ground Water 2, 6-11

Du Toit WH (2001) The influence of granite intrusions on the host rock in terms of occurrence in groundwater in the Pietersburg area. M.Tech. (Geology) Thesis. Technicon Pretoria, South Africa

Eswaran, H., Bin, W.C., 1978. A study of deep weathering profile on granite in peninsular Malaysia: I. Physico-chemical and micromorphological properties. J. Soil Sci. Soc. Am. 42, 144–149

Holland M and Witthüser KT (2011). Evaluation of geologic and geomorphologic influences on borehole productivity in crystalline bedrock aquifers of Limpopo Province, South Africa. Hydrogeology Journal 19 1065-1083.

Jolly, J. Borehole/Irrigation Survey and Groundwater Evaluation of the Doringlaagte Drainage Basin. Report No. GH 3495, DWAF, Pretoria, 1986.

Ledger, E.B., Rowe, M.W., 1980. Release of uranium from granitic rocks during in situ weathering and initial erosion (central Texas). Chem. Geol. 29, 227–248.

Love D. , Hamer Wd. , Owen R. , Booij M. , Uhlenbrook S. , Hoekstra A. , Zaag P. (2007), Case studies of groundwater: surface water interactions and scale relationships in small alluvial aquifers 8th WATERNET/WARFSA/GWP-SA Symposium p. 6

Martinelli, E., Hubert, G.L., 1985. A report to the ministry of energy and water resources and development. Master plan for rural water supply and sanitation, Norad. Hydrogeology 2, 109–118.

Metwaly, M., El-Qady, G., Massoud, U., El-Kenawy, A., Matsushima, J., Al-Arifi, N., 2009. Integrated geoelectrical survey for groundwater and shallow subsurface evaluation: case study at Siliyin spring, El-Fayoum, Egypt. Int. J. Earth Sci. 99,1427–1436.

Muchingami I, C Chuma, M Gumbo, D Hlatywayo (2019) Approaches to groundwater exploration and resource evaluation in the crystalline basement aquifers of Zimbabwe. Hydrogeology Journal, 2019

Nahon, D.B., 1991. Introduction to the Petrology of Soils and Chemical Weathering. Ed. Wiley.

Owen R J, Gwavava O, Gwaze P. 2005. Multi- electrode resistivity survey for groundwater exploration in the Harare greenstone belt, Zimbabwe. Hydrogeol J 14: 244-252.

Pickens, J.F., Grisak, G.E., Avis, J.D., Belanger, D.W., Thury, M., 1987. Analysis and interpretation of borehole hydraulic tests in deep boreholes; principles model development, and applications. Water Resources Research 23 (7), 1341–1375.

Tardy, Y., 1971. Characterization of the principal weathering types by the geochemistry of waters from some European and African crystalline massifs. Chem. Geol. 7, 253–271

Taylor RC, Howard KWF. 1998. Post-Paleozoic evolution of weathered land surfaces in Uganda by tectonically controlled deep weathering and stripping. Geomorph 25: 173-192.

Taylor RC, Howard KWF. 1999. Lithological evidence for the evolution of weathered mantles in Uganda by tectonically controlled cycles of deep weathering and stripping. Catena 35 (1): 65-94.

Telford, E., Geldart, W.M., Sheriff, R.E., 1990. Applied Geophysics. Cambridge University Press, UK.

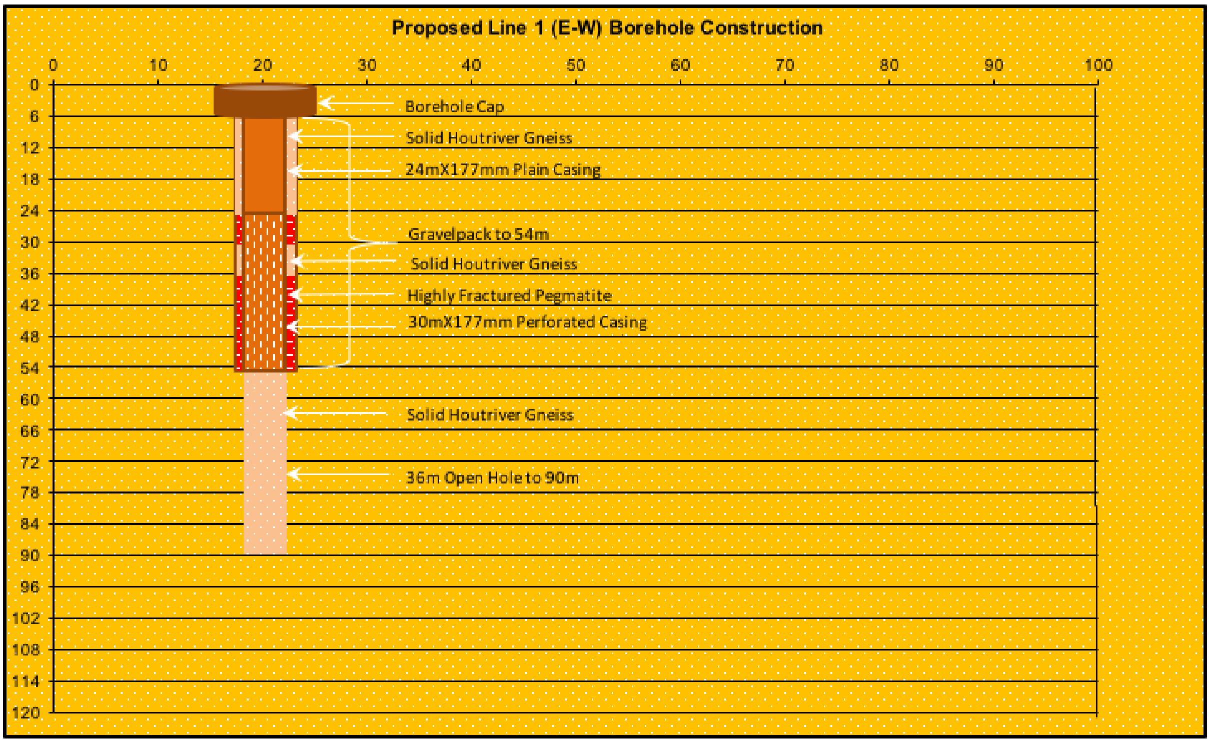
Titus, R.A., Adams S. and Strachan, L. (eds.) (2009) The basement aquifers of Southern Africa.WRC Report Nr. TT 428/09. Water Research Commission, Pretoria.

Witthüser, K. T., Holland, M., Rossouw, T. G., Rambau, E., Bumby, A. J., Petzer, K. J., Dennis, I., Beekman, H, Van Rooy, J. L., Dippenaar, M. and De Wit, M. (2010). Hydrogeology of basement aquifers in the Limpopo Province. WRC Report No. 1693/1/10. Water Research Commission. Pretoria.

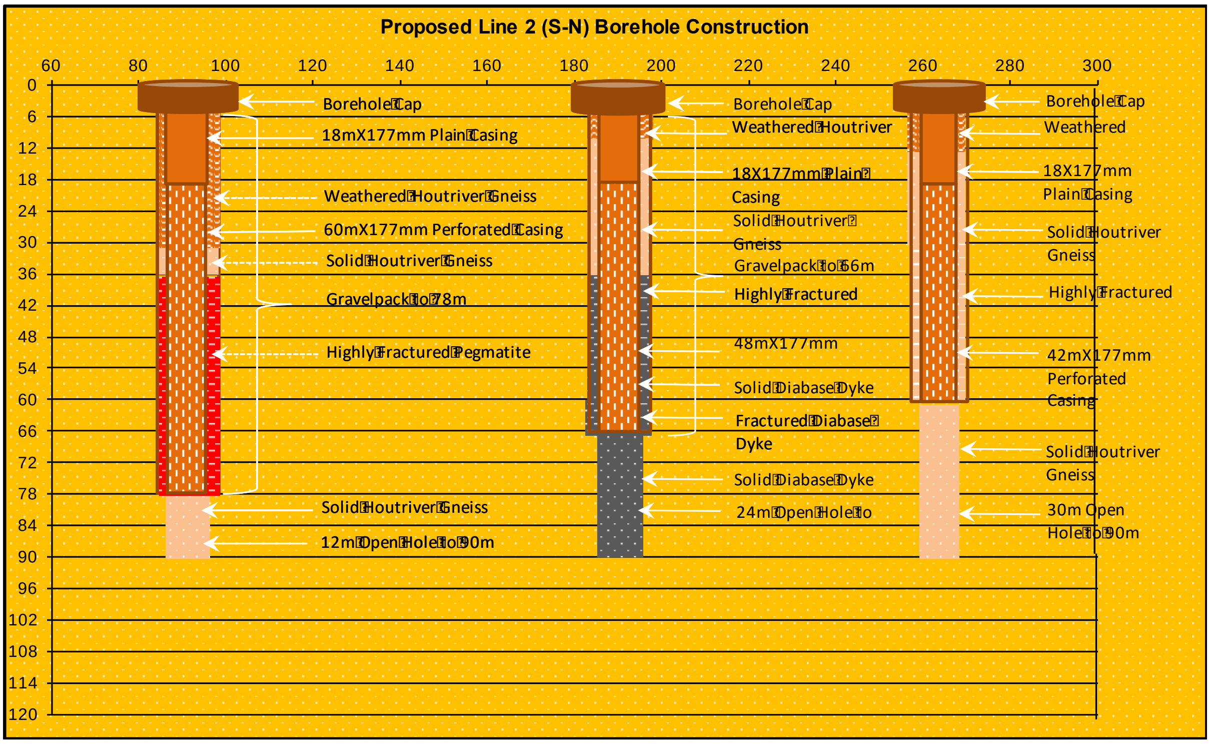
Wright, E.P., 1992. The hydrogeology of crystalline basement aquifers in Africa. Geol. Soc. London Spec. Publ. 66, 1–27.

APPENDICES

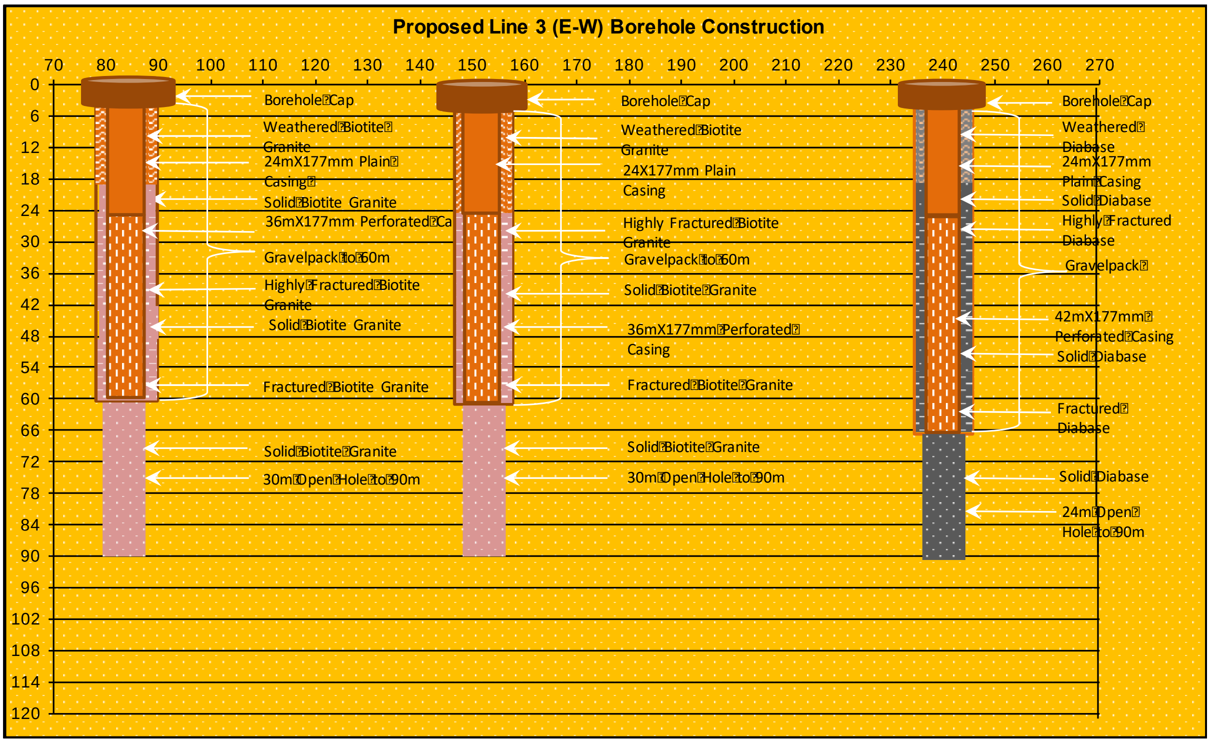
APPENDIX A PROPOSED BOREHOLE CONSTRUCTION FOR MAMADILA FROM GEOPHYSICS

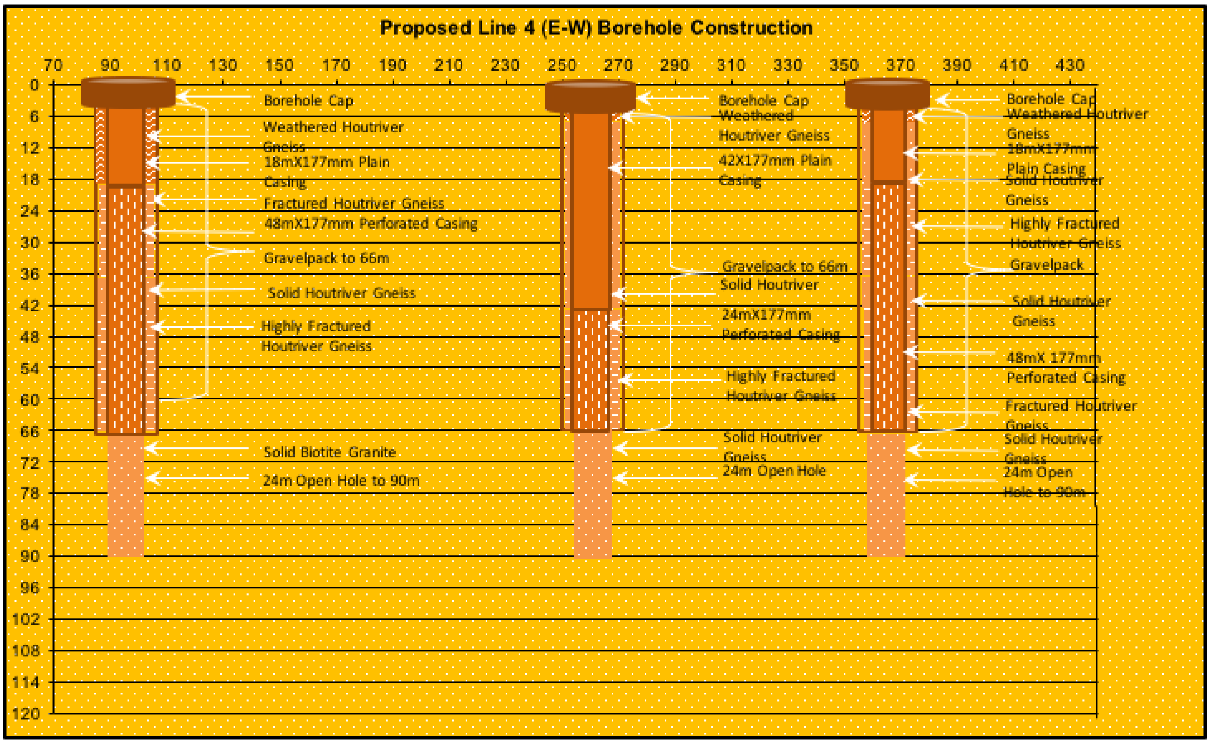


Proposed Line 1 (E-W) Borehole Construction
Borehole Cap
Solid Houtriver Gneiss
24mX177mm Plain Casing
Gravelpack to 54m
Solid Houtriver Gneiss
Highly Fractured Pegmatite
30mX177mm Perforated Casing
Solid Houtriver Gneiss
36m Open Hole to 90m



Proposed Line 2 (S-N) Borehole Construction
Borehole Cap
18mX177mm Plain Casing
Weathered Houtriver Gneiss
60mX177mm Perforated Casing
Solid Houtriver Gneiss
Gravelpack to 78m
Highly Fractured Pegmatite
Solid Houtriver Gneiss
12m Open Hole to 90m
Borehole Cap
Weathered Houtriver
18X177mm Plain Casing
Solid Houtriver Gneiss
Gravelpack to 66m
Highly Fractured
48mX177mm
Solid Diabase Dyke
Fractured Diabase Dyke
Solid Diabase Dyke
24m Open Hole to
Borehole Cap
Weathered
18X177mm Plain Casing
Solid Houtriver Gneiss
Highly Fractured
42mX177mm Perforated Casing
Solid Houtriver Gneiss
30m Open Hole to 90m


Proposed Line 3 (E-W) Borehole Construction
Borehole Cap
Weathered Biotite Granite
24mX177mm Plain Casing
Solid Biotite Granite
36mX177mm Perforated Ca
Gravelpack to 60m
Highly Fractured Biotite Granite
Solid Biotite Granite
Fractured Biotite Granite
Solid Biotite Granite
30m Open Hole to 90m
Borehole Cap
Weathered Biotite Granite
24X177mm Plain Casing
Highly Fractured Biotite Granite
Gravelpack to 60m
Solid Biotite Granite
36mX177mm Perforated Casing
Fractured Biotite Granite
Solid Biotite Granite
30m Open Hole to 90m
Borehole Cap
Weathered Diabase
24mX177mm Plain Casing
Solid Diabase
Highly Fractured Diabase
Gravelpack
42mX177mm Perforated Casing
Solid Diabase
Fractured Diabase
Solid Diabase
24m Open Hole to 90m


Proposed Line 4 (E-W) Borehole Construction
Borehole Cap
Weathered Houtriver Gneiss
18mX177mm Plain Casing
Fractured Houtriver Gneiss
48mX177mm Perforated Casing
Gravelpack to 66m
Solid Houtriver Gneiss
Highly Fractured Houtriver Gneiss
Solid Biotite Granite
24m Open Hole to 90m
Borehole Cap
Weathered Houtriver Gneiss
42mX177mm Plain Casing
Gravelpack to 66m
Solid Houtriver
24mX177mm Perforated Casing
Highly Fractured Houtriver Gneiss
Solid Houtriver Gneiss
24m Open Hole
Borehole Cap
Weathered Houtriver Gneiss
18mX177mm Plain Casing
Solid Houtriver Gneiss
Highly Fractured Houtriver Gneiss
Gravelpack
Solid Houtriver Gneiss
48mX 177mm Perforated Casing
Fractured Houtriver Gneiss
Solid Houtriver Gneiss
24m Open Hole to 90m

APPENDIX B SUMMARY OF DRILL REPORT FOR MONITORING BOREHOLES AT MAMADILA

BOREHOLE FIELD LOGGING FORM

Borehole No:	H04-3125	Project:	ESGUSA

Farm Name	Cadastral Number (eg. 367MT)	Village name
MALIETZIES	606LS	Mamadila

Coordinate Ref. Pnt.	WGS 84	Secondary Drainage Region	A7	1:50 000 Map Reference	2329CC
Co-ordinates (Decimal Degrees)		Drilling Date		GPS Altitude	1259m
Latitude	-23.79785	Date started	03.06.2019	Collar height	0.41m
Longitude	29.22157	Date ended	03.06.2019	Final Depth	60m
Site Purpose	MONITORING	Water Level (below collar height)	5.49m	Date Measured	05.06.2019

Water strike	Depth 1 :	25m	45m		Final Blow Yield	0.3l/s
Blow yield		0.1l/s	0.2l/s			

Casing Details	Depth From (m)	Depth To (m)	Diameter (mm)	Casing Type	Borehole Diameter		
Plain Casing	0	6	165	Steel	Depth from (m)	Depth to (m)	Diam (mm)
					0	6	250
					6	60	165
Perforated Casing	Depth From (m)	Depth To (m)	Diameter (mm)				
Perforation Details	Nr Rows:	Length:					

Sanitation Seal	Depth (m):	Gravel Pack	Depth (m):	Backfill	Depth (m):
	Diam (mm):		Diam (mm):		

GEOLOGY

Depth from	Depth to	Lithology Description
0	1	Solid Gneiss
1	6	Fractured Gneiss
6	9	Solid Gneiss
9	27	Fractured Gneiss
27	44	Solid Diabase
44	45	Fractured Gneiss
45	60	Solid Diabase

Water Sample or Field Measurement	pH	EC (mS/cm)	Temprature	TDS (mg/l)	Other	Date Measured

Comments					
Technician Name:		DWAF Driller	RAMOTSE	DWAF Drilling Inspector	
Technician Contact number:		Signature		Date	11.06.2019

BOREHOLE FIELD LOGGING FORM

Borehole No:	H04-3126		Project:	ESGUSA			
Farm Name		Cadastral Number (eg. 367MT)			Village name		
MALIETZIES		606LS			MAMADILA		
Coordinate Ref. Pnt.	WGS 84		Secondary Drainage Region	A7	1:50 000 Map Reference	2329CC	
Co-ordinates (Decimal Degrees)			Drilling Date		GPS Altitude		
Latitude	-23.79762		Date started	03.06.2019	Collar height		1264m
Longitude	29.22096		Date ended	05.06.2019	Final Depth		84m
Site Purpose	MONITORING		Water Level (below collar height)	11.45m	Date Measured		06.06.2019
Water strike	Depth 1 :	49m	65m	69m	Final Blow Yield		5 l/s
Blow yield		1l/s	2l/s	2l/s			
Casing Details	Depth From (m)	Depth To (m)	Diameter (mm)	Casing Type	Borehole Diameter		
Plain Casing	0	30	165	Steel	Depth from (m)	Depth to (m)	Diam (mm)
					0	78	250
					78	84	165
Perforated Casing	Depth From (m)	Depth To (m)	Diameter (mm)				
	30	84	165	Steel			
Perforation Details	Nr Rows:	Length:					
Sanitation Seal	Depth (m):	Gravel Pack	Depth (m):	Backfill	Depth (m):		
	Diam (mm):		Diam (mm):				

GEOLOGY

Depth from	Depth to	Lithology Description
0	2	Fractured Gneiss
2	48	Fractured Gneiss
48	72	Highly Fractured Pegmatite
72	84	Solid Gneiss

BOREHOLE FIELD LOGGING FORM

Borehole No:	H04-3127	Project:	ESGUSA			
Farm Name		Cadastral Number (eg. 367MT)		Village name		
MALIETZIES		606LS		MAMADILA		
Coordinate Ref. Pnt.	WGS 84	Secondary Drainage Region	A7	1:50 000 Map Reference	2329CC	
Co-ordinates (Decimal Degrees)		Drilling Date		GPS Altitude	1260m	
Latitude	-23.79872	Date started	05.06.2019	Collar height		
Longitude	29.21987	Date ended	07.06.2019	Final Depth	120m	
Site Purpose	MONITORING	Water Level (below collar height)	11.45m	Date Measured	10.06.2019	

Water strike	Depth 1 :	33m	43m	114m	Final Blow Yield	5.5 l/s
Blow yield		1l/s	3.5l/s	1l/s		

Casing Details	Depth From (m)	Depth To (m)	Diameter (mm)	Casing Type	Borehole Diameter		
					Depth from (m)	Depth to (m)	Diam (mm)
Plain Casing	0	30	165	Steel			
					0	84	250
					84	120	165
Perforated Casing	Depth From (m)	Depth To (m)	Diameter (mm)				
	30	84	165	Steel			
Perforation Details	Nr Rows:	Length:					

Sanitation Seal	Depth (m):	Gravel Pack	Depth (m):	Backfill	Depth (m):
	Diam (mm):		Diam (mm):		

GEOLOGY

Depth from	Depth to	Lithology Description
0	2	Fractured Pegmatite
2	24	Weathered Gneiss
24	31	Weathered Diabase
31	46	Highly Fractured Pegmatite
46	68	Solid Gneiss
68	82	Solid Pegmatite
82	90	Fractured Mica Rich Gneiss
90	113	Solid Mica Rich Gneiss
113	118	Fractured Pegmatite
118	120	Solid Gneiss

Water Sample or Field Measurement	pH	EC (mS/cm)	Temprature	TDS (mg/l)	Other	Date Measured

Comments					
Technician Name:		DWAF Driller	RAMOTSE	DWAF Drilling Inspector	
Technician Contact number:		Signature		Date	11.06.2019

BOREHOLE FIELD LOGGING FORM

Borehole No:	H04-3128	Project:	ESGUSA

Farm Name	Cadastral Number (eg. 367MT)	Village name
MALIETZIES	606LS	MAMADILA

Coordinate Ref. Pnt.	WGS 84	Secondary Drainage Region	A7	1:50 000 Map Reference	2329CC
Co-ordinates (Decimal Degrees)		Drilling Date		GPS Altitude	1270m
Latitude	-23.79836	Date started	08.06.2019	Collar height	
Longitude	29.22057	Date ended	08.06.2019	Final Depth	48m
Site Purpose	MONITORING	Water Level (below collar height)	9.07m	Date Measured	10.06.2019

Water strike	Depth 1 :	30m	32m	37m	Final Blow Yield	8.4 l/s
Blow yield		2 l/s	4.4 l/s	2 l/s		

Casing Details	Depth From (m)	Depth To (m)	Diameter (mm)	Casing Type
Plain Casing	0	6	165	Steel
Perforated Casing	Depth From (m)	Depth To (m)	Diameter (mm)	
Perforation Details	Nr Rows:	Length:		

Borehole Diameter		
Depth from (m)	Depth to (m)	Diam (mm)
0	6	250
6	48	165

Sanitation Seal	Depth (m):	Gravel Pack	Depth (m):	Backfill	Depth (m):
	Diam (mm):		Diam (mm):		

GEOLOGY

Depth from	Depth to	Lithology Description
0	30	Weathered Pegmatite
30	34	Highly Fractured Pegmatite
34	48	Solid Gneiss

Water Sample or Field Measurement	pH	EC (mS/cm)	Temprature	TDS (mg/l)	Other	Date Measured

Comments					
Technician Name:		DWAF Driller	RAMOTSE	DWAF Drilling Inspector	
Technician Contact number:		Signature		Date	11.06.2019

APPENDIX C SUMMARY OF DATA COLLECTION AND COMPENSATION STEPS

A. STEPS TO BE FOLLOWED WHEN DOWNLOADING DATA FROM WATER LEVEL LOGGER

1. Pull the connecting string off the well and collect the water level logger, (Unscrew from the cap)
2. Connect the optical read out unit to the laptop
3. Insert the logger on its position on the connected unit
4. Open the solinst software program (downloaded from www.solinst.com)
5. Click once on the DATA CONTROL FUNCTION BUTTON
6. Click once on the data download  arrow
7. After clicking on the download arrow icon choose the ALL DATA option (Download will start automatically and will be displayed)
8. Save the data in a folder of your choice on your laptop by clicking the file---- save as option (the usual way of saving)
9. Manually measure the depth to water using a dip meter (Value needed for compensation)

B. STEPS TO BE FOLLOWED AFTER DOWNLOADING THE DATA (RESETTING THE LEVEL LOGGER)

1. Click the icon DATA LOGGER SETTINGS on the opened program
2. Click once on the STOP NOW icon
3. Check click on FUTURE START option that appears on the window
4. Type in the next hour on the time box (eg 1500 hours)
5. Click on the green FUTURE START arrow that appears on the  screen
6. You will be asked if you are aware that the next action deletes the data in the logger (resets it), click YES
7. Click YES on DO YOU WANT TO SYNCRONISE LOGGER TIME TO SYSTEM TIME

8. A yellow bar line will appear to your that your logger has been future started and you need to return the logger back into the well immediately before moving to the next station/borehole.

C. STEPS TO BE FOLLOWED IN DATA COMPENSATION WITH BARO LOGGER

1. Open the solinst program from your laptop
2. Open the data file that is saved on your laptop (collected from field) , (use file open function, raw data will be opened, with two trend shown blue(water level) and red (temperature))
3. Open the baro data file though FILE-----OPEN BARO DATA, the two files are openat the same time
4. Click once to open the DATA WIZZARD icon
5. Tick to select the ADVANCED COMPENSATION OPTION
6. Open the DATA DISPLAY icon
7. Select the DEPTH TO WATER LEVEL option
8. Select your choice YES on compensation with barologger
9. ALWAYS CLICK NO on DO YOU NEED TO CHANGE ANY PARAMETERS OPTION
10. Click the NEXT button
11. After clicking the NEXT icon, both baro logger and level logger data will be appearing
12. Click the NEXT button
13. Choose the type of compensation you need to implement, FORWARD / BACKWARD compensation. Forward compensation uses the previously measured manual reading , while the Backward compensation uses the most recently measured
manual reading). In our case we use the backward compensation.

14. Select the back ward compensation and scroll to the last reading on the data set (check if its comparable to the second from last one in case the logger measured when it was out of the well)
15. Enter the manually measured water level value in the A FIELD text box
16. Click on the ADD icon
17. Click on the UPDATE icon
18. Click on the NEXT icon, the FINISH icon immediately appears, as data would have been automatically compensated.
19. Click the OPEN icon to see the compensated data
20. Export/save the compensated data by clicking once on EXPORT DATA icon
21. On the option of the item to be exported (DATA/GRAPH) choose DATA
22. Give the data file name, e.g. Mamadila march
23. Click the SAVE button to save the file in the form of a text or csv file
24. Open the saved file to check if the last reading of the data is still the same as that was manually measured (quality check)

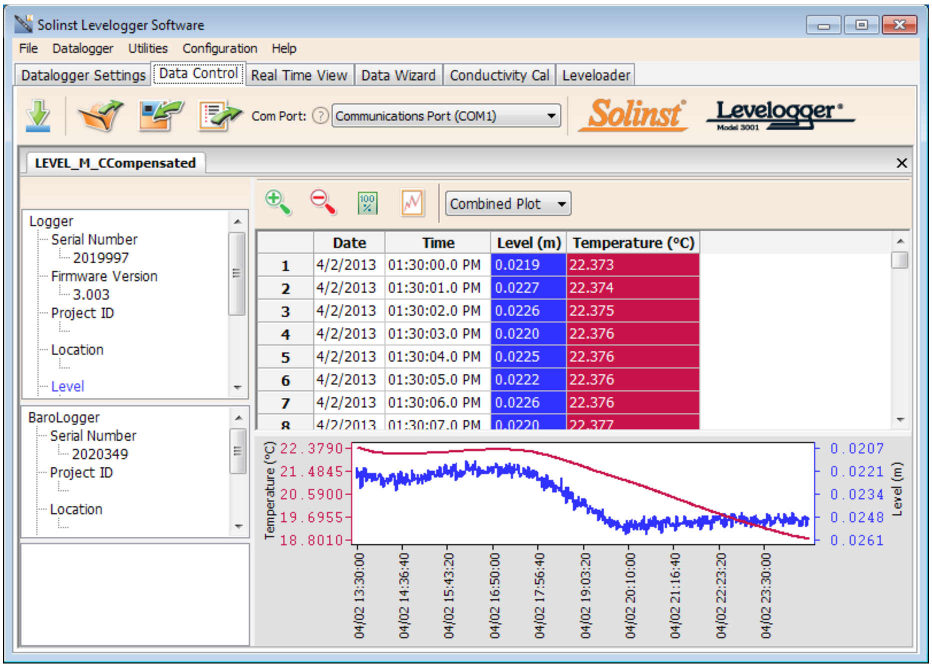


Figure 1. Presentation of compensated data

D. STEPS TO BE FOLLOWED IN DATA COMPENSATION WITHOUT BARO LOGGER

1. Open the solinst program from your laptop
2. Open the data file that is saved on your laptop (collected from field) , (use file open function, raw data will be opened, with two trend shown blue(water level) and red (temperature))
3. Click once to open the DATA WIZZARD icon
4. Tick to select the ADVANCED COMPENSATION OPTION
5. Open the DATA DISPLAY icon
6. Select the DEPTH TO WATER LEVEL
7. Select your choice YES/NO on compensation with barologger (in this case we choose NO)
8. ALWAYS CLICK NO on DO YOU NEED TO CHANGE ANY PARAMETERS OPTION
9. Click the NEXT button
10. Choose the type of compensation you need to implement, FORWARD / BACKWARD compensation. Forward compensation uses the previously measured manual reading , while the Backward compensation uses the most recently measured
 manual reading). In our case we use the backward compensation.
11. Select the back ward compensation and scroll to the last reading on the data set (check if its comparable to the second from last one in case the logger measured when it was out of the well)
12. Enter the manually measured water level value in the A FIELD text box
13. Click on the ADD icon
14. Click on the UPDATE icon
15. Click on the NEXT icon, the FINISH icon immediately appears, as data would have been automatically compensated.
16. Click the OPEN icon to see the compensated data
17. Export/save the compensated data by clicking once on EXPORT DATA icon
18. On the option of the item to be exported (DATA/GRAPH) choose DATA
19. Give the data file name, e.g. Mamadila march
20. Click the SAVE button to save the file in the form of a text or csv file

21. Open the saved file to check if the last reading of the data is still the same as that was manually measured (quality check)

APPENDIX D: OUTPUT AND DISSEMINATION

- Two draft manuscripts and two regional conference presentations have been produced based on the review work and field investigations. In addition, part of the work is also being utilised by the Two Masters Students, Andrew and Lusanda whose thesis are based on the project under supervision of the Project management at UWC. Output is also expected from these studies.

- The titles and stages of development of the two manuscripts are;
    - Role of hydrogeophysics in enhancing groundwater potential assessment in crystalline basement aquifers with a case of Houtriver gneiss formation, South Africa

  This draft has been corrected and modified in line with what was internally circulated in the first stage amongst the post doc and students, and has now been forwarded to the UWC project managers for proof reading before being forwarded to external co-authors.

  Abstract of manuscript:

  Groundwater exploration in crystalline basement aquifers is often more complex as its occurrence and characteristics are largely a consequence of the interaction of several processes related to recharge and groundwater through-flow within a particular system. Integrated geophysical methods can be useful tools in mapping the subsurface characteristics that are likely to control groundwater occurrence and hence are useful tools in identifying potential drill targets in crystalline basement formation. The report presents an account on how multiple hydrogeophysical methods were applied to identify potential groundwater bearing targets as controlled by several geologic structures within the

Houtriver gneiss crystalline basement aquifer system in Limpopo province of South Africa, at Mamadila area, Hout river catchment. The results from magnetic and frequency domain electromagnetic surveys were combined with geological observations and used to identify anomalous points where vertical electrical resistivity sounding was done in order to infer the thickness and layering of weathered and fractured zones, as well as to assess the area for groundwater potential targets. The magnetic method, horizontal and vertical frequency domain electromagnetic geophysical methods presented herein managed to delineate the main dykes and lineament features associated with groundwater occurrence in typical basement aquifers. The vertical electrical sounding (VES) sections done on ten (10) sites suggest that groundwater occurrence is characterized by a multiple layer of varying depths inferred to be caused by different levels of weathering, geology and fracturing within the study area. The VES sections constructed from field measurements suggested a high groundwater potential zone to be mostly in range of 30m to 72m, and being mostly controlled by the highly weathered pegmatite lineaments characterizing the study area. Hence a technical recommendation of above 80m for sustainable boreholes is made for potential supply boreholes, with the suggested borehole construction for drilling developed from the VES results. The integration of several geophysical methods for groundwater evaluation provided a more comprehensive approach for the resource assessment in crystalline basement aquifers, thereby resulting in increased accuracy in borehole siting as suggested from the drilled test holes. Results from this study are useful for technical groundwater management and addressing water security issues as they clearly identified suitable borehole locations for long term groundwater prospecting.

- Review; Groundwater resource occurrence in Hout river gneiss crystalline basement formation characterising part of the Limpopo Basin, South Africa.

The first draft has been compiled by the post doc fellow and circulated for proof reading within UWC before circulating to other co –authors

Abstract of the draft

The understanding of the occurrence and sustainability of groundwater resources within the crystalline basement lithological environment in northern parts of South Africa is of paramount importance for as it is the sorely available water resource for domestic and agricultural use. The region, situate mostly in the Limpopo province, forms part of the Limpopo mobile belt and has substantial geological features influencing groundwater occurrence and recharge, including the Hout river gneiss formation. This study reviews the hydrogeologic controls and factors that influences the groundwater occurrence and utilization within the Hout river gneiss, which forms part of the Limpopo mobile belt, South Africa. The major drivers of groundwater resources, hence areas of high groundwater potential within the study area are compartmentalised in weathered pegmatitic regolith and the fractured rock aquifers which in some cases extends to depths in excess of 120m and is high yielding. However, the spatial variability and variation in structural extend of the system often present limitation in the groundwater abstraction and resource utilisation. The work presented herein is thus expected to build a platform for future groundwater development and research within the system, thereby enabling the establishment of the facts which controls the groundwater occurrence, and potential drivers for recharge mechanisms within the Hout river gneiss crystalline basement aquifer formation. The study lays a framework for scientific approach for sustainable groundwater utilisation for socioeconomic benefit for groundwater dependant ecosystems and communities.

- The title of the conference proceedings

- Framework for assessing aquifer-river interaction for crystalline basement formations in semi-arid areas, with case study in Hout River catchment, Limpopo basin, South Africa. Proceedings of the 2nd SADIC GMI conference, 4-6 September 2019, Pretoria
- Groundwater Exploration in Crystalline Basement Aquifers with A Case of Houtriver Gneiss Formation, South Africa. Proceedings of the 13th Biannual GSSA Groundwater conference, 21-23 October 2019, Port Elizabeth.