

# **Ground Water Potential Zones Investigation Using Ground Magnetic Survey in South Africa**

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## **Abstract**

Shortage of adequate water sources in rural communities has become a global concern and severe in developing countries especially in African countries. This is due to the consistent increase in population, global warming and poor planning by municipalities in strategizing water supply and billing. The aim of this study was to apply a ground magnetic geophysical survey to investigate the geological structures or lineaments which are potential sources of ground water. To carry out the ground magnetic survey, six magnetic profiles 1 km long were designed to cut perpendicular to the general geological strike. All the profiles were spaced 500 m apart with a sampling interval of 20 m. The survey was carried out using a proton precision magnetometer-G856 kept at a constant height during the survey. Data was processed for artificial anomalies, diurnal variations as well as the geomagnetic field. Presentation of data was done in x-y distance against magnetic intensity graphs of all the profiles as well as a contour color map to delineate the potential structures. The findings of the study revealed several lineaments, most of which are low magnetic zones associated with geological structures such as faults, fractures and dykes. These provided potential zones of ground water where boreholes to supplement the community water needs can be drilled. The technique offers operational efficiency in water exploration projects.

**Keywords:** Ground magnetic survey, Ground water operations, Lineaments.

## **1. Introduction**

In many areas around the world especially in developing countries shortage of water is an increasingly major problem because of the global population which continues to increase on daily basis, leading to high demand of resources and forcing the discovery of alternative or new resources for sustainable living. In many rural areas communities usually depend on surface water from rivers and dams which, during dry seasons, can be completely or nearly dry (Yang 2018). For these reasons, ground water remains the only solution to the problem (Alsharhan et al., 2001). According to Alsharhan *et al.*, (2001), Ground caps water is the water which is located beneath the surface of the earth trapped in geological formations which are usually fractured or containing high pore spaces. Many boreholes in the past decades were drilled randomly without any scientific approach in determining the potential of ground water in terms of quantity and quality which is the reason some boreholes have low water yield or dry up during dry seasons.

Amongst many resources, water is the greatest need all over the world, the threat to this resource increase as the population and human activities increases. Nevertheless, the available surface water sources such as streams and rivers face a great threat as competition amongst living organisms.

According to Meinzer (1923) in the past hydro-geologists used to locate and design the wells to be drilled without considering any environmental assessments which led to numerous dysfunctional wells due to pollution, and currently before any construction of a well or any borehole is drilled, site assessments are done to determine the quality, quantity and the pollution status of the area as well as the location of monitoring wells to monitor the ground water levels. It is impossible to physically locate ground water; therefore, it is very important to apply different techniques in determining the potential zones with certainty. The use of ground geophysical methods such as resistivity, magnetic, electromagnetic and induced polarization used with the geological mapping of an area can determine the water

potential zones. Since ground water occurs within the fractured medium or within geological structures this study focuses on the identification of such structures not the chemistry of the water. The study focuses on application of the ground magnetic survey as a tool to explore for geological structures.

This study was conducted in Makula village in Limpopo in the Northern part of South Africa. The existence of basaltic lithology on the top part of the Mukula area as part of the Tshifhefhe Formation, which are highly magnetic (due to the presence of iron in the basalt) lead to the option of selecting ground magnetic method which works based on the response of magnetic containing mediums. Only the magnetic method can effectively detect any discontinuity in the geologic medium which gives magnetic response upon magnetic measurements. Mukula area is under laid by classic sediments, conglomerates and shale. These are good water aquifers as they can transmit and store water, capped with the basalt, which is an igneous formation preventing water from escaping, leading to the formation of a good aquifer zone for groundwater which can only be extracted upon drilling.

### **1.1 Problem statement**

Shortage of water has been a global problem especially in developing countries due to lack of sufficient water sources and lack of sound exploration techniques for potential sources of water other than surface water (Yang 2018). The Mukula area has limited water supply due to lack of water sources. Unlike towns and urban areas municipalities focus less on rural water supply because only houses in towns pay for services such as water leading to a minimum focus in developing water resources in rural areas. The South African population depends on surface water, which can be 6 km away from some households, as the only source of water supply, for the past years they have depended on rivers, and fountains which now dry up with the changing climatic conditions as well as the hand pump boreholes which no longer work due to lack of maintenance (Akinlalu 2017). In Mukula village there is a greater need for additional water sources to supplement the available water sources. There is no detailed data about the ground water potential zones in this area apart from the major geological contacts mapped by council for geosciences; the lack of such data is the reason many boreholes dry up in winter and dry seasons because they were drilled without any scientific exploration leading to less water yield. The use of the magnetic geophysical method will help in identification of detailed potential zones for the implementation of modern groundwater systems which can be used as a solution in this area by identifying lineaments which are zones of groundwater (Soro 2017).

### **1.2 Location and geology**

Mukula Village is situated in South Africa, Limpopo Province under Thulamela Municipality. The study area is around the latitude -22 52 30 and longitude 30 33 30 at elevation of 430 m. geologically according to Barker (1983), the Mukula area forms part of the Soutpansberg rocks of the Limpopo belt and the Bandelierkop Complex. Brandl (1999) states that the Soutpansberg group represents the volcano to sedimentary succession within the seven formations it has. The Mukula area is part of the discontinuous basal formation known as the Tshifhefhe Formation which is a few meters in thickness formed with strongly epitomized clastic sediments including the shale, greywacke and conglomerates which are porous lithology and can transmit and store water, making them good aquifers. According to Johnson (2006), the classic sediments which include the metamorphic quartzite, conglomerate and shale are usually up to 400 m thick, whereas near the top approximately 50 m thick layers of basalt are intercalated with sediments forming amygdaloidal basalt which is rich in magnetic iron. According to Barker (1979) the general strike of the Soutpansberg strata is recognized to be trending in the north-east and south west direction.

## **2. Literature Review**

Magnetic survey is a geophysical method used to investigate the subsurface geology (Kearey 2002). According to Adagunodo (2013), magnetic surveys measure variations in the earth's magnetic field to locate subsurface structures such as fractures and joints using magnetic highs and magnetic lows, and geological structures containing no magnetic infill respond with low magnetic intensities whereas competent zones and areas with magnetic minerals infill respond with very high positive intensities. Adagunodo (2013) infers that the deeper fractures are important sources of groundwater because they allow free flow of groundwater and any well or borehole passing through these zones receives enough consumable water.

Ground magnetic survey consists of two techniques; which are airborne survey and ground-based survey. Airborne magnetic survey, which can be very costly to undertake, is done using magnetometers mounted on an air plane controlled by a specialist in geophysics. Ground based magnetic survey is done using a portable magnetometer carried

by a geophysics specialist. Ground based magnetic survey hold a number of advantages over airborne magnetic survey besides its cost effectiveness.

### **2.1 Advantages of ground magnetic surveying**

Ground magnetic surveys are fast and cheap to undertake compared to other geophysical techniques. In the absence of magnetic sediments, ground magnetic survey data can provide information on the nature and form of the crystalline basement. Ground magnetic surveys assist in reconnaissance for geological mapping based on widely-spaced grid samples, since aeromagnetic anomalies can be employed to delineate geological boundaries between sampling points.

### **2.2 Ground magnetic survey procedure**

Ground magnetic surveys are mostly undertaken on a small area with a station sampling spacing of ten to hundred meters, in such surveys, readings taken close to metallic objects which includes rail lines, power lines, fences, houses, and vehicles are noted down to be removed as they are part of artificial sources contributing to false anomalies and any operator of a measuring instrument should not wear any metallic object during survey (Kearay 2013). Desktop studies are done prior to the survey wherein all the literature materials including geological base maps from books, journals and internet about the survey and the instrument are studied, and the following that a reconnaissance survey is done as acquiring permission from the land owners is crucial to avoid trespassing (Muthamilselvan et al. 2017). This involves visiting the municipality in the urban areas for permission and visiting the chiefs in rural areas to engage in a community meeting to receive permissions from people's properties as well as involving the community about the project to be done on their land. Visiting the site of the project is crucial for magnetic survey to check the accessibility of the survey land and the design profiles as well as observing the geology and any artificial objects that might affect the survey (Kearay 2013).

Profiles are designed usually cutting perpendicular to the general geological strike of the area (Telford 1990). Base station readings are very important for correction of diurnal variations, such readings are obtained at a fixed position called a base station which is constantly visited during the survey at a given time interval to correct for temporal variations (Milson 2003). Base stations and sampling stations are marked on the survey profiles and located using GPS and the measurement is done using the magnetometer which stores the magnetic response of each station. According to Ogagaru and Emudianughe (2016) magnetic surveys are conducted effectively in areas with good magnetic underlying rocks such as igneous rocks containing magnetic mineralization.

### **2.3 Survey Design and significance**

Ground magnetic surveys are done by a geophysical specialist along straight parallel designed profiles with constant sampling stations using a magnetometer (Gadallah and Fisher 2009). According to Kearay (2013), magnetic methods are cheap and fast to undertake, in the absence of magnetic fill or mineralization magnetic data gives the information about the subsurface geology of the area and they play a crucial role in reconnaissance for geological mapping as well as other follow-up geophysical methods, although they can render misleading results based on cultural features.

### **2.4 Instrumentation used in data acquisition**

According to Milson (2003) torsion magnetometers which used compass needles mounted on dip needles to measure vertical fields were used in the past until 1960 when they were replaced by fluxgate, vapor alkali and proton precession magnetometers. Numerous surveys are done using proton precession magnetometers, this is evident in the works of (Mohamed and Mansour 2007); (Ogagarue and Emidiangughe 2016); (Sunmonu, 2014); (Mattson *et al.* 2010) and (Adagunodo *et al.* 2012).

### **2.5 Processing of magnetic data**

Data Processing- this step involves data checking, editing, removal of unwanted artificial data, filtering, removal of diurnal variations and subtracting the geomagnetic field of the earth to get the accuracy in data interpretation. According to Muthamilselvan (2017), raw collected magnetic data requires corrections for ease in interpretations. Such interpretations involve diurnal variation corrections which are the daily magnetic changes which originates from earth's rotation, such variations are corrected by using the base station recordings at a constant time (Muthamilselvan et al. 2017); (Ogagarue and Emudianughe 2016). According to Ogagarue and Emudianughe, (2016)  $[F_{dc} = F_{observed} - (F_{base2} - F_{base1}) / (time_{base2} - time_{base1}) \times (time_{observed} - time_{base1})]$ , is usually used to calculate the variations, where in  $F_{dc}$  = Field diurnal correction,  $F_{base2}$  = second base station reading,  $F_{base1}$  = first base station reading,  $time_{base2}$  and  $time_{base1}$  = the time during the recording of the base stations and  $time_{observed}$  = time during the measurement. According to Amigun and Adelusi (2013), removal of the International Geomagnetic

Reference Field is done as part of processing from the diurnal corrected magnetic data using the IGRF model obtainable from <http://www.ngdc.noaa.gov/st>. The calculation of the IGRF value for corrections needs the use of a computer to calculate because of its complexity (Kearay (2013)).

### 3. Materials and methods

This part explains how the data was collected from the start of the survey until the end of it. Magnetic Data caps was acquired using a Proton Precession Magnetometer (G-856) (see fig. 3.3). The stations at each sampling point were continuously located using Garmin GPS. A base map extracted on online GIS was used to locate and mark all the stations along the designed profiles. The blue and yellow dots are base station mark points and the arrows are the indication of direction of movement during the survey. The GPS coordinates were recorded in a field data sheet. The survey covered 6 profiles 1 km long which were spaced 500 m apart from each other (see Fig. 3.1) with the sampling interval between the sampling stations of 20 m (see Fig. 3.1). The survey profiles were designed to cut perpendicular to the strike.

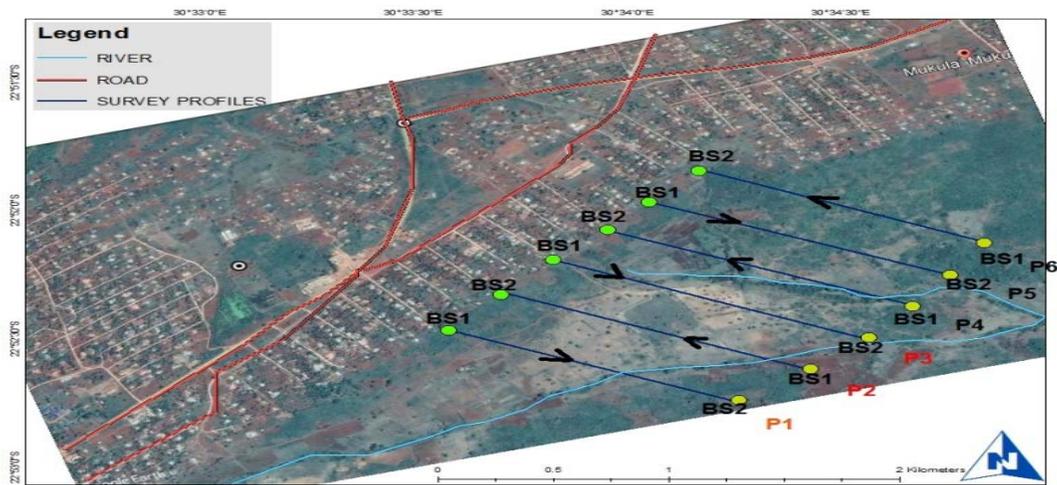


Figure 3.1: The study area and designed profiles with the survey direction (Source: Authors).

#### 3.1 Field procedure

Several checklists were consulted before field survey, the instrument battery was fully charged, and traverse lines designed. The data from previous work was cleared from the instrument and the new date and time were set. It was ensured that there was no metal close to traverse lines. Observations were made on the traverse lines. The data was acquired close to the ground level via a person carrying a magnetometer (see figure 3.3). To initiate the survey a base station at a constant point and measurement stations were planned along the traverse lines.

The data from the base station served as a control point for temporal changes of the magnetic field, which was subtracted from the measured survey data. The magnetometer height was maintained. At each survey point data was acquired by pressing the “read” button twice and once the reading flashed on the instrument screen it was stored by pressing the “store” button. This was repeated across all the points. The sampling points were obtained using Garmin GPS whose coordinates were recorded in the field note book. The data was downloaded to the laptop and opened using surfer software and stored as excel spread sheets.



Figure 3.2: Showing the magnetometer carried by the surveyor during measurement at a station (Source: Authors).

### 3.2 Data processing, analysis and interpretation.

This part presents data analysis, results and interpretation of the research findings. The data and results are presented in the form of figures, tables and text for interpretation.

#### 3.2.1. Data reduction and Processing

Reduction and processing of data involved several steps to remove signal and spurious noise from the data which is not related to the geology of the crust of the earth. Below is the summary of steps undertaken in this study.

##### (a) Data checking and editing

This was achieved by removing the spikes and spurious noise from the collected data. The sources of noise include; metallic structures, metallic fences, electrical power lines and any object which is magnetic.

##### (b) Diurnal removal

This step involved the removal of the temporal variations of the main magnetic field of the earth. This was achieved by negating the time recorded at the base station of the survey with a stationary magnetometer from all points of survey. The following formula was used:  $Fdc = (F_{observed}) - \left( \frac{F_{Base2} - F_{Base1}}{time\ Base2 - time\ Base1} \right) \times (time\ Observed - time\ Base1)$ , where in Fdc= Field diurnal correction, FBase2= second base station reading, FBase1= first base station reading, time Base2 and time Base1 = the time during the recording of the base stations and time Observed weird caps= time during the measurement. In magnetic surveys the diurnal variation is smooth and small; however, the electromagnetic induction effects are also small (see fig. 3.3) which shows a snapshot of the essential values recorded during field work through analysis stages.

	A	B	C	D	E	F	G	H	I	J	K
1	Id	MAGNETIC_F observed	INTERPOLATED	IGRF	DISTANCE	x	y	IGRF CORRECTED	TIME	DATE	station
2	0	29146	29146	24930	0	30.55963	-22.8744		4216 09:10:29.0	5/23/2018	Base 1
3	0	29160	29182	24930	20	30.55981	-22.8744		4252 09:11:16.0	5/23/2018	sampling
4	0	29150	29184	24930	40	30.55994	-22.8745		4254 09:11:42.0	5/23/2018	sampling
5	0	29128	29176	24930	60	30.5601	-22.8746		4246 09:12:12.0	5/23/2018	sampling
6	0	29133	29192	24930	80	30.56025	-22.8746		4261 09:12:35.0	5/23/2018	sampling
7	n	29142	29215	24930	100	30.56041	-22.8747		4284 09:13:03.0	5/23/2018	sampling

Figure 3.3: Showing a snapshot of magnetic readings generated and recorded during survey and used for processing calculations.

##### (c) Geomagnetic reference field removal

In this step the removal of all the strong influences of the main field of the earth on the survey data recorded was accomplished. This was undertaken due to the utter fact that the earth's main field is usually under the influence of the dynamo action resulting from the core of the earth and not based on the upper crust's geology. This was accomplished by subtracting a model of the magnetic field from magnetic data as stated by Lowrie (2007). The undisturbed magnetic

field of any area is the IGRF which removes magnetic variations, the value circled in red was generated on the computer as depicted and subtracted on the magnetic field observed as showed on figure 3.3 above. The x and y coordinates, elevation above sea level of the area as well as the date of survey to compute and generate the IGRF value of Mukula area as indicated below. Rephrase -too long- grammar gets out of control. The International Geomagnetic Field was generated from the geomag7 software using a computer which was then used for the removal step and the results are shown below (see Fig. 3.4.).

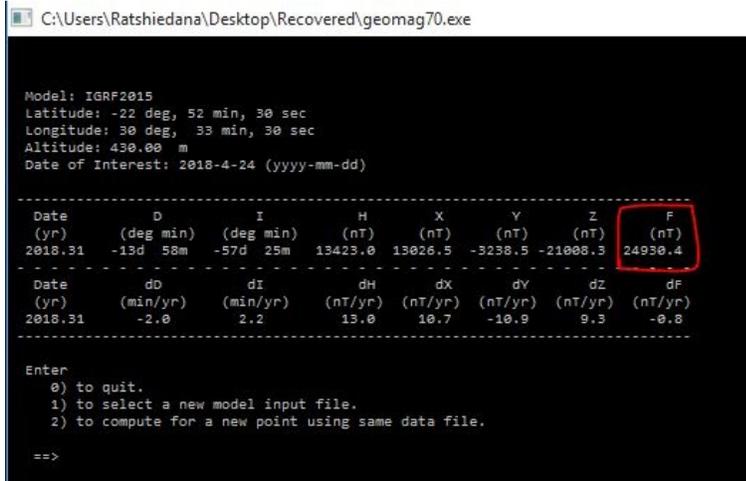


Figure 3.4.: Showing the results of IGRF Model used to subtract magnetic variations due to the earth from the total magnetic data recorded by the magnetometer (Source: Authors and <http://www.ngdc.noaa.gov>).

#### 4. Discussion of findings

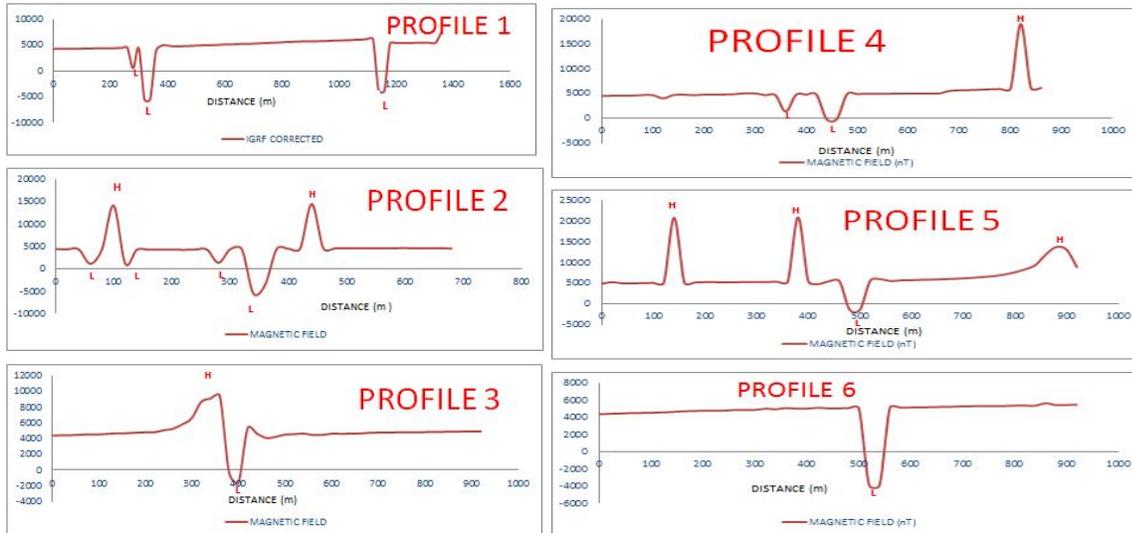


Figure 4.1: Showing magnetic profiles from profile one to six which is a snapshot of the profiles generated from the reading (Source: Authors).

Figure 4.1 Showing profiles one to six, represents the total magnetic intensity along all the profiles after all the steps of data processing applied for this study, the vertical axis represent the magnetic intensity in Nanotesla (nT), whereas, the horizontal axis represents the distance of stations along each profile. All profiles were generated from the field recorded data as shown on Figure 3.3, processed on Microsoft excel. The profiles reflect differences in the magnetic intensities to those presented by Sunmonu et al., (2014) because of the difference in the geology of the areas. The profiles show high and low magnetic values. On the profiles the high magnetic zones are denoted by letter “H” and

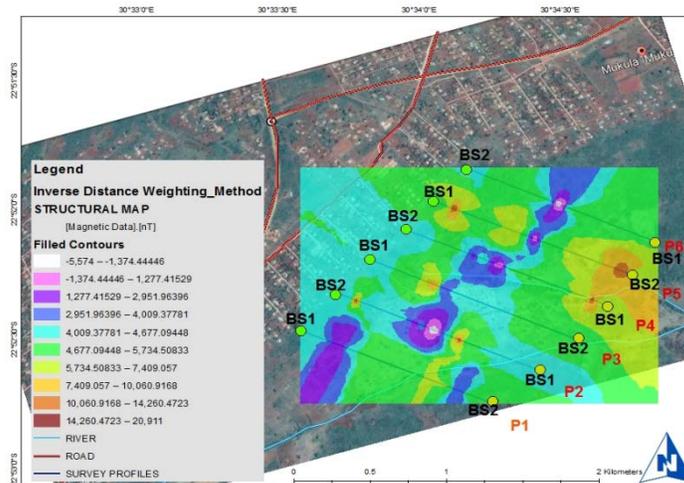
low magnetic zones are denoted by letter “L”. The high magnetic values indicated by letter “H” are zones with magnetic minerals, this is similar to the results presented in the work of Adagunodo et al., (2012) as well as Sunmonu et al., (2014) who reported that the high magnetic values are due to near surface magnetic minerals in igneous or metamorphic rocks, in the case of Mukula the igneous rock hosting magnetic minerals is the basalt which contains considerable amounts of iron, which is magnetic.

The negative values labeled “L” are the zones of nonmagnetic minerals in Mukula, ro according to Adagunodo et al. (2012) the low magnetic values indicate the presence of nonmagnetic minerals, faulted zones, fractured zones or contact of two lithology, such as the work of Adagunodo et al., (2012), the low values of nonmagnetic minerals zone might be the fractures or contact between the rocks which are the possible zones of ground water. According to Telford et al., (1990) the existence of positive and negative magnetic values adjacent to each other is what is expected in fault zones, this is evident in profile three at stations at a distance between 300 m and 450 m.

Like the work of Sunmonu et al., (2014); Adagunodo (2012) and Nyabeze et al., (2013), the magnetic survey showed the alternating zones of high and low magnetic intensities, the low magnetic zones are indicators of nonmagnetic minerals zones, faulted or fractured zones which reveal the contacts between lithology, the low negative magnetic intensity according to Telford et al., (1990) is what is expected in fault zones. The difference in the magnetic results in terms of magnetic intensity values are gr due to the geology of the areas which are gr different in the studies, the Mukula area is an igneous terrain.

### Vertical Derivative Magnetic Intensity Color Map

The vertical derivative total magnetic intensity color map is presented in the figure below. Vertical derivative of magnetic data aids the interpretation process as it enhances and sharpens geophysical anomalies. This filtering method is effective in enhancing anomalies due to shallow sources; it narrows the width anomalies and a very effective in locating source bodies more accurately (Cooper and Cowan, 2004). Vertical derivative was done by applying low pass filters to remove long-wavelengths thereby enhancing the short-wavelength component of the magnetic spectrum. The vertical derivative of the total magnetic intensity was derived in Surfer software as shown in figure 4.2. The map reveals a maximum intensity of 20.911 nT and a minimum of -1.374 nT. The high magnetic zones (in brown color) are the zones enriched with high magnetic minerals and the low zones (in white and purple) are the possible geological structures which may be contacts, faults, fractures or dykes which are the potential zones of ground water as stated on the works of Sunmonu et al., (2014); Adagunodo (2012) and Nyabeze (2013).



4.2: Vertical derivative contour map with magnetic lineaments (Source: Authors).

Like the work of Nyabeze et al. (2013), the magnetic results show some lineaments obtained from the survey, the lineaments on the map reflects the high and low magnetic intensities explained in the magnetic profiles above. Fig. 4.3 shows the different lineaments over zones of low magnetic values and over the zones of high magnetic values. The S-E direction towards the west can be observed with low magnetic values indicated by a bluish color on the color scale, the lineaments indicates gr the presence of nonmagnetic minerals or the contact between rocks. Lineaments can be observed showing a smaller trend of the basalt intrusions trending in an N-E direction which are the fault, fractures

or dykes as shown in figure 4.4. The difference in the magnetic survey lineaments map of this work compared to the work of Nyabeze et al. (2013) is the values of magnetic intensities on the map which is due to the difference in the geology of the two areas. They are different as the Tshipise which not good split it up is under the Soutpansberg group is a sedimentary area and the Mukula area is the igneous area as well as the difference in the filtering technique which on Nyabeze's work it was vertical derivative convolution and on this work it is vertical derivative.

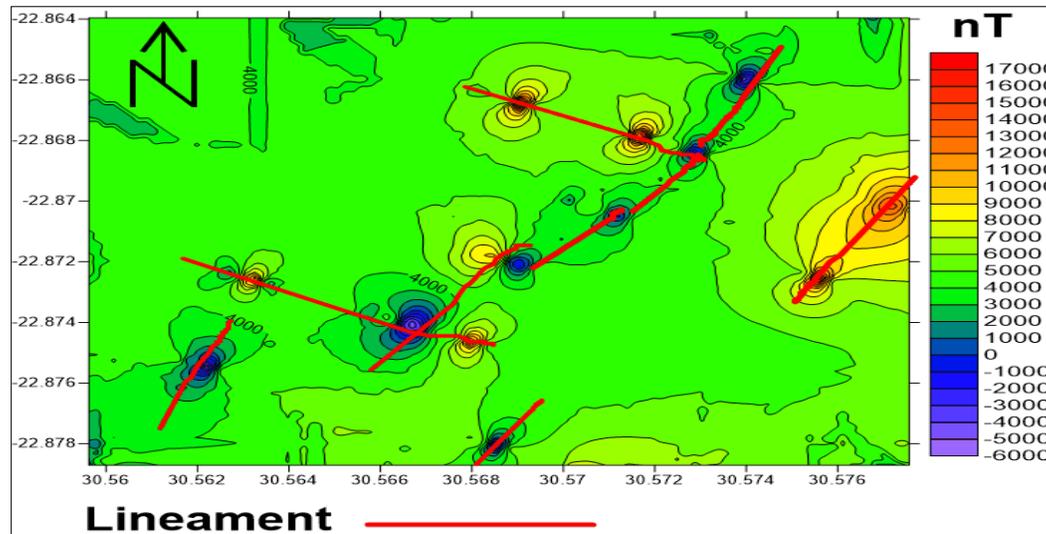


Figure 4.4: Vertical derivative contour color map of the total magnetic intensity showing intersected lineaments (Source: Authors).

#### 4. Conclusions

The study revealed the basement geological structures showed as lineaments in the study which are the potential zones of ground water, meaning that the objective of this study has been achieved with the most favorable outcomes. Based on the findings of this study, the following recommendations for further studies are suggested; more work needs to be done around the extent of Mukula village to detect other potential zones; detailed geophysical survey needs to be done to ascertain the potential water zones as follow up work prior to any drilling. Furthermore, a detailed geological mapping is needed to back up the geophysical data for lithological references.

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