ADDIS ABABA UNIVERSITY
COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES
SCHOOL OF EARTH SCIENCES

<u>TITLE</u>

The use of the resistivity and magnetic methods for the investigation of ground water, intermediate and shallow structures In Ajie Western Arsi zone

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Abstract

In this study a combined geophysical data was used for groundwater controlling factors; shallow and intermediate structures in the central main Ethiopian rift. This study focused on a assessing hydrogeological conditions of the area with the controlling factors subsurface layers and structures. Two Geophysical methods were employed in this study are, Vertical electrical sounding and magnetic survey technique. Electrical sounding the sculmerger method was used to investigate for the potential the groundwater in the study area. On the other hand, magnetic survey was used to delineate geological shallow and intermediate structures which control the groundwater flow system. The geophysical survey was conducted, twe15 VES readings by using Schlumberger array along three survey lines, and above two hundred and fifty magnetic reading at about 50meter interval along 4 profiles. The field data obtained was processed and analyzed by using special computer softwares. The2D model with geological layers and resistivity values was interpreted to enhance the result. The results of the geophysical survey are presented in the form of interpreted VES curves, sliced stacked map, pseudo depth section, geoelectric section, magnetic anomaly plot and 2D model. The study result revealed four to five (6) main geoelectric layers that differ in degree of weathering and fracturing. The highly weathered and fractured ignimbrite with is the main water bearing horizon which has good groundwater potential but it is deeply layed. The aquifer thickness in the area is obtained to range between 100m and 240m. The result also shows there are sub surface structures in the area is dividing the area by several subsurface geological shallow and intermediate structures that are important for the movement and occurrence of groundwater. It seems that, some well sites can be towards the end of profile -1 and along profile -3.Further hydrogeologicaland and geophysical survey and can be recommended along the proposed sites for farther studies.

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CHAPTER ONE

1. Introduction

1.1 Background

The electrical conductivity (resistivity) of the earth and its magnetic property can be studied by geophysical techniques. These two physical properties of earth materials may vary due to potential distribution of earth materials (rocks) and magnetic nature of the subsurface.

If an isotropic earth is assumed it may be possible to calculate the potential distribution and the resistivity of rocks. This may be observed by applying current to the ground of special interest and varying the spacing between the current electrodes either by fixing the potential reading electrodes or by moving (varying) their separation. This procedure will show if there is an anomalous physical property (in this case resistivity /conductivity) in the subsurface material.

On the other hand, conducting a magnetic survey also may show an anomalous reading due to subsurface variation (In this case magnetic susceptibility) as a result of the presence of weak or strong magnetic material in the subsurface.

Groundwater plays a vital role in the supply of water for communities in urban as well s rural areas. However groundwater may not manifest itself everywhere, there for; it has to be investigated and mapped. The study of ground water as a natural resource then needs a careful and planned study by different approaches .Two of these approaches are hydrogeology and geophysics. Ground water as a natural resource can be found in aquifers, these aquifers can be confined, unconfined, and semi confined. Groundwater resources are mostly developed in aquifers consisting of unconsolidated rocks chiefly in gravel and sand (Todd and Mays 2005)

Ground water research studies three or four factors. The aquifer‘s geologic nature, depth to the water table, quality; and controlling structures. The nature of aquifers may also depend on the geology, hydrogeology, hydrology; vegetation cover, and topography of the area. Aquifers depended on the degree of fracturing of rocks; and the open space between the pore spaces. The second factor is the depth to the water table. The depth to the water table may vary due to the overburden material; the geologic; and the hydrogeological conditions of the area. The third factor can be the quality of ground water. Saline water may invade fresh water aquifers and contaminate them. The fourth factor is that of controlling structures which may be part of the hydrogeological and geologic conditions. But structures control ground water flow direction and the nature of aquifers.

Clean potable water supply in the developing world does not meet the goals of clean water supply for the millennium in the year 2004. There were 1100 million people across the world who did not have access to clean water .This was a reality which gave a concern for planning the millennium development goals (Macdonald, et.al, 2005).

Shortage of clean water for urban and rural communities remains a serious problem. The supply of water can be achieved by studying the geology of the rocks. Furthermore; the depth to the water table and its abundance can be studied using geophysical methods.

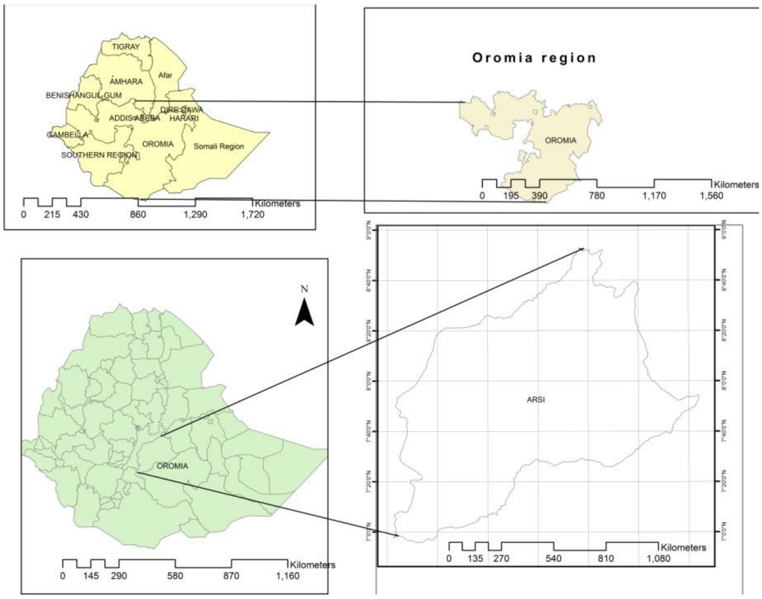
Therefore; building water supply wells (bore holes) for communities is an important and effective method of supplying water. The failure to achieve this goal of supplying potable water causes poor health conditions which can deteriorate the economic well-being of the society.

Therefore, water supply well sitting has to be preceded by studying the potential of the area using different and appropriate geophysical methods. In area like the study area the problem of water scarcity is so serious that the residents of the town my go long distances to fetch water. Different studies in the rift may indicate this problem of water.

1.2 Description of the Study Area

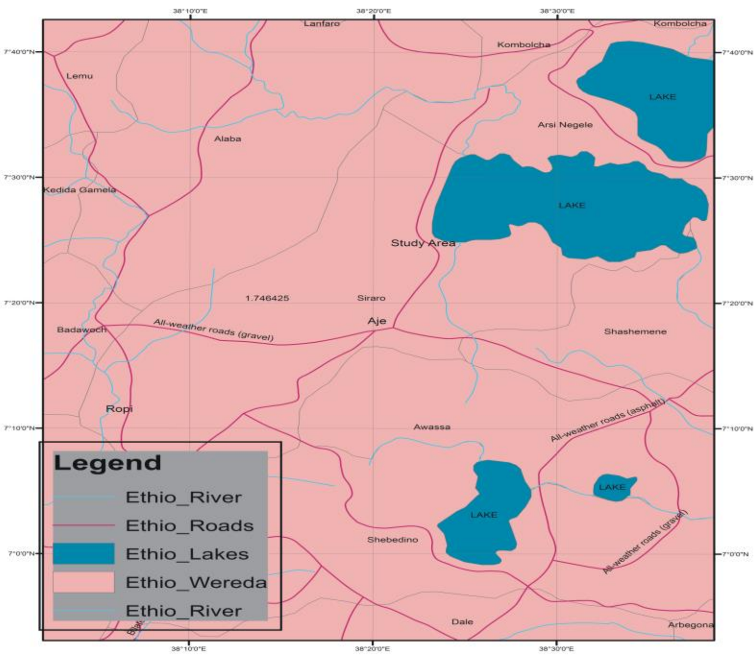
1.2.1 Location and Accessibility of the Study Area

The study area geographically found approximately $7^0 17' \, 54.73''$N and $38^0 21' \, 22.25''$ E It is found in Oromia regional state .The study area is accessed by asphalt road that runs from Addis Ababa to Aje. The town is 293 Km from Addis Ababa via the asphalt road from Addis Ababa to Butajira.



1.2.2 Physiography and Drainage

The study area is found in the main central rift section which is affected by continuous tectonic and volcanic activities. This section of the rift has low elevation points and the rift escarpment reaching elevations to a height of 1850m.The study area is located between the two lakes Awassa and Shalla.



1.2.3 Vegetation

The vegetation in the study area is mainly bush land toward the rift margin. The rift floor is mainly an open grass land with sparse population of endemic and exotic tree cover. The trees are Eucalyptus, Juniper, and Acacia.

1.2.4 Climate

The climate of the area may vary due to elevation differences. However; the main characterizing Woyena dega (sub-tropical) climate is moderate temperature of the rift floor. The elevation of the area may vary from 600m rift floor to 2300m on the rift escarpment. The climate of this area has characteristic wet and dry seasons. According to Koppen(1989)The Ethiopian rift valley floor is hot semiarid climate(Bsh) while the higher plateau by warm Cwb(warm temperature rainy season with dry winters).

1.3 Relevance of the Proposed Study

The ground water resources in the rift valley have a serious problem of fluoride contamination (source). However; it is not only the contamination of the water with fluorine but also the shortage of potable water that is a serious problem in some of the rift valley towns like Aje. The study uses new magnetic and electrical resistivity data to identify the possible sources of groundwater shortage in the study area. The research also tries to identify the controlling structures that are intermediate and shallow in depth which may affect the ground water in the study area. The result of this study may help the possible sources of shortage and scarcity of ground water for town like Aje.

1.4 Objectives

1.4.1 General objective

The general objective of this thesis is to delineate the location and nature of the tectonic and structural features which may control ground water flow and storage in the study area using electrical resistivity and magnetic methods.

1.4.2 Specific objectives

- Identify the major shallow and intermediate structural and lithological units of the study area.
- Determine the subsurface resistivity and susceptibility stratification of the study area.
- Determine nature of the water bearing formations/structures.
- Infer sites favorable for groundwater flow and storage capacity.

1.5 Methodology

The general methodology to conduct this research used follow a pre-field (desk) study, field collection of raw data, post field analysis of the data; and interpretation. The above mentioned objectives can be met using two geophysical methods. These two methods are the electrical method and the magnetic method. The electrical method is done using a profile line perpendicular to the general strike of the geology. The vertical electrical sounding is conducted along the chosen profile in order to determine the depth of ground water in the research area. The research area spacing can be varied according to the electrical sounding (VES) the depth to which the ground water can be detected. The spacing of the current electrodes AB/2 may vary from AB/2=1.5 to AB/2=750m.

For the electric survey alligator clips, stainless steel electrodes, and reels of wires will be used besides the main instrument. The spacing between the potential electrodes may vary with a spacing of 0.5m to 45m. The Schlumberger array is the array layout as this array is probably the most commonly used array type for groundwater exploration.

The other method the research used is the magnetic method. The magnetic survey will be conducted by precession magnetometer to measures the intensity of the Earth's magnetic field. In order to account the diurnal variation of the Earth's magnetic field base station readings was taken at the beginning and end of each survey. A station spacing of 50m was taken. These data were used to delineate the potential barriers and controlling structures of groundwater flow direction.

The researcher used different softwares such as surfer 10, Oasis Montaj; IPI2WN, Win resist, Map info, Arcgis10 and Autocad for the reduction processing, analysis and synthesis of the raw data collected from the field observation.

The research follows the following general methodology:

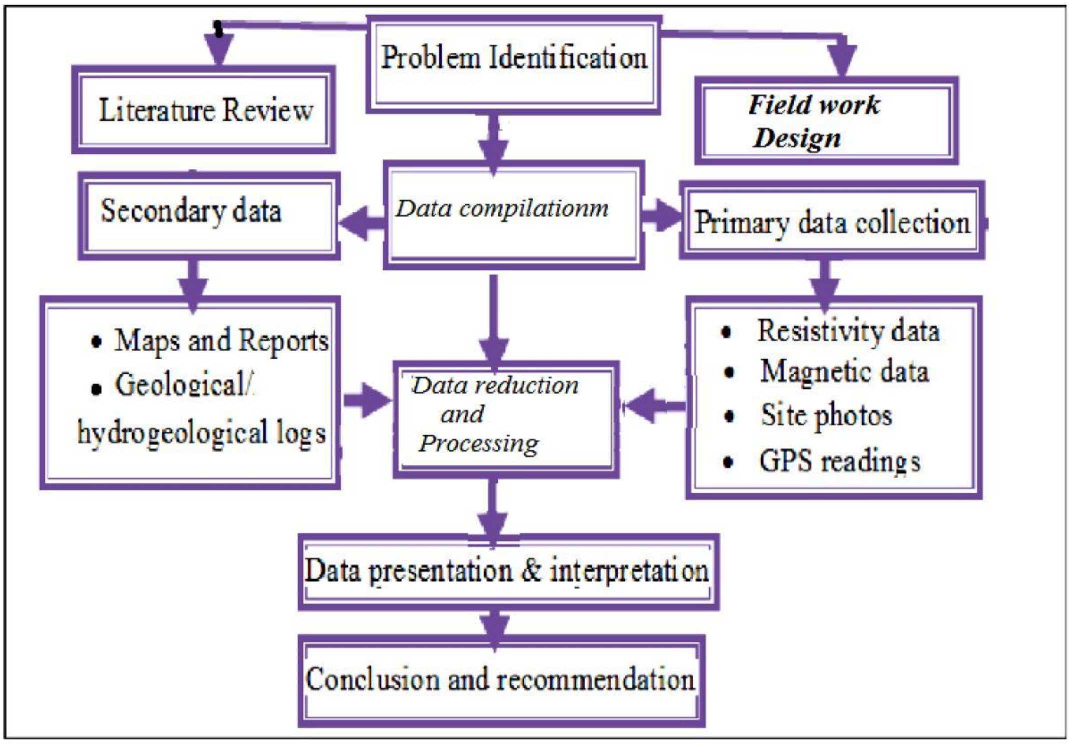


Fig: general methodology and data organization method flow chart of the research

1.4 Statement of the problem

Ethiopia has been trying to achieve the goals the millennium development goals. However, the rural mass has not been addressed for its demand for clean potable water. Not only have the rural mass; towns big or small fail short of supplying water for its populace.

Aje as a town is affected by the recurrent shortage of water in the surrounding rural areas also**.** This town faces serious shortage of water during most parts of the year. The probable source of this shortage of water for the town could be the nature of the water bearing rocks (aquifers) in its surroundings. The town's dwellers buy water at expensive prices or fetch for it going long distances.

It seems that there was not a properly conducted research for the supply of water in the vicinity of this town and the surrounding places. The geological survey of Ethiopia had conducted a geological mapping NB-37 (Hosaena Map sheet). JICA (the Japanese international aid organization) has conducted a hydrogeological study in the rift's different basins Hydrogeological mapping was also conducted by Ethiopian and Czech professionals (Hydrogeological map of Hosaena map-sheet). The only report which might have included geophysical report is the Ketar river basin project mentioned above. Considering the above mentioned studies, it seems that there is lack of detailed geophysical studies related to groundwater investigation in the study area.

1.5 Review of Previous Works

Ground water exploration has been done by different organizations in Ethiopia. Some of these organizations are government organizations like the geological survey of Ethiopia and water works design enterprise water enterprises of regional states. The others are non-governmental organizations (NGOs) like JICA (rift valley project). The geological survey of Ethiopia has conducted the geological mapping of the study area which includes rift and the rift escarpment.

Different researchers have studied the main Ethiopia rift including the study area as it draws scientific and academic research interest. The rift is in a setting of recent tectonic and volcanic activities.

This type of volcanic activity has been used to differentiate the different volcanic episodes e.g shield forming volcanism versus fissural flood basalt volcanism (Tefera et.al, 1996).The rocks in the central main Ethiopian rift can be: Pre-Rift Volcanic Rocks (Alajie group), Late Tertiary Volcanic Rocks (Nazreth group), Quaternary Volcanic rocks (Wonji Group); and Quaternary sediments (Basalefew et.al, 2012). . The rifting together with the continuous volcanic activity can create fracturing.

However, rifting might have resulted in considerable fracturing and shattering which has resulted in major water resources associated with these fracture zones (Kazmin V., 1973).

Ground water in this kind of volcanic terrain flows in extensive jointing can allow water to infiltrate and move through them making three or four groundwater targets:

- Thick paleosoils or loose pyroclastic material between lava flows
- Joints and fractures due to rapid cooling of the top of lava flows.
- Contact between lava flows and sedimentary rocks or earlier volcanic material
- Lava flows with significant gas bubbles, and porosity between ashes and agglomerate (Mac Donald et.al, 2005).

Ground water flow and storage in volcanic rocks is generally governed by:

- Vertical permeability due primary and secondary fractures
- Horizontal permeability due to horizons containing openings due to the lava flow and gas expansion during solidification
- Occurrence of impervious horizons and dikes (Tamiru2006)

Works conducted by different hydrogeologists of the geological survey of Ethiopia (Demis, 2009, Astatike, 2012, Bereket, 2011, Kefale, 2013) show the groundwater in the rift area has different aquifer types. Moderate aquifers of mixed permeability hosted mainly in ignimbrite, and sediments with a yield range between 3 to 5 l/s.

The study area (Aje) lies on pumice and unwedded tuff and ignimbrites (kefale, 2013); Pleistocene basalts, coarse unwedded pumiciouspyroclasics, ignimbrite tuffs (Basalefew et.al, 2012 and JICA, 2011) Bulbula Lacsturine Deposits; Lake deposits such as gravel, sand and mud. Corbetti Pumice Flow and Fall Deposits; Pumice falls and pumice flow deposits.

1.6 Significance of the Study

This research is the study of groundwater potential of the Aje area. The significance of the study in general is identifying shallow and intermediate structures which can control groundwater flow. The significance in some detail:

- The research about the ground potential of the aquifers in the study area
- The study in identifying the controlling structures for the flow of ground water
- The research can show the depth to the water bearing horizons
- It can be used as a borehole site selection in the study area
- The final product (the thesis) can be used to create interest in the nature of aquifers in the study area and for the dissemination of knowledge.

CHAPTER TWO

2. Geological and Hydrogeological Setting

2.1. Regional Geology

The general geology of the main Ethiopia rift can be broadly classified as pre-rift, rifting, and post-rift geological process. The pre-rift geology is predominantly volcanic and the resulting stratigraphic formations are Alaje group (Mid-tertiary period) The second formation of pre-rift volcanic is Anchar basalt(mildly alkaline transitional basalt).This basalt is overlain by late silicic volcanic Nazret group which is further overlain by fissural flood basalt of Bofa basalt. The rifting resulted on the Quaternary formations of volcanic complexes of the Wonji group. The three major volcanic complexes of the Wonji group are the Dino formation, central volcanic complexes, and the fissural Basalts of the rift floor. The post-rift activity in the rift is the sedimentation of the late Pleistocene-Holocene age lacustrne sediments of the rift floor.

1. Pre-rift volcanics

In this group the wider area regional setting of the central part of the rift the Alajie formation and Anchar basalt are the pre rift materials. The Alaje formation mainly consists of Aphyric flood basalt associated with rhyolites (ignimbrites) and subordinate trachytes This formation ranges in age between 36-13Ma.(Mengesh,etal,). Anchar basalt on the other hand is phyric to plagioclase and pyroxene phyric basalts and trachy basalt intermixed with rhyolitic tuffs (Tesgaye et,al,2005). The age of this group is 11.5to 8,3Ma.

2. Late Tertiary Volcanics

The Nazret group is a thick succession of welded ignimbrites with fiamme, pumice, ash and rhyolite flows and domes with rare intercalation of basalts flows. In composition the ignimbrites of are sub-alkaline ryolitic and trachytes with pre alkaline verities The age range of this group is 9to3 Ma. The volcanic formations Bofa basalt, Chilalao volcanic, Dino formation all belong to the Nazret Group. (Meyer,et.al 1978).

3 Quaternary volcanic and sedimentary rocks

The ignimbrite and unwelded pyroclastic material is named as Dino formation. The age of this formation is dated to be 1.5Ma (Kazmin and Berehe; 1978). This formation covers considerable part of the rift floor. Quaternary sediments of lacustrine origin make up the sedimentary formation in the rift.

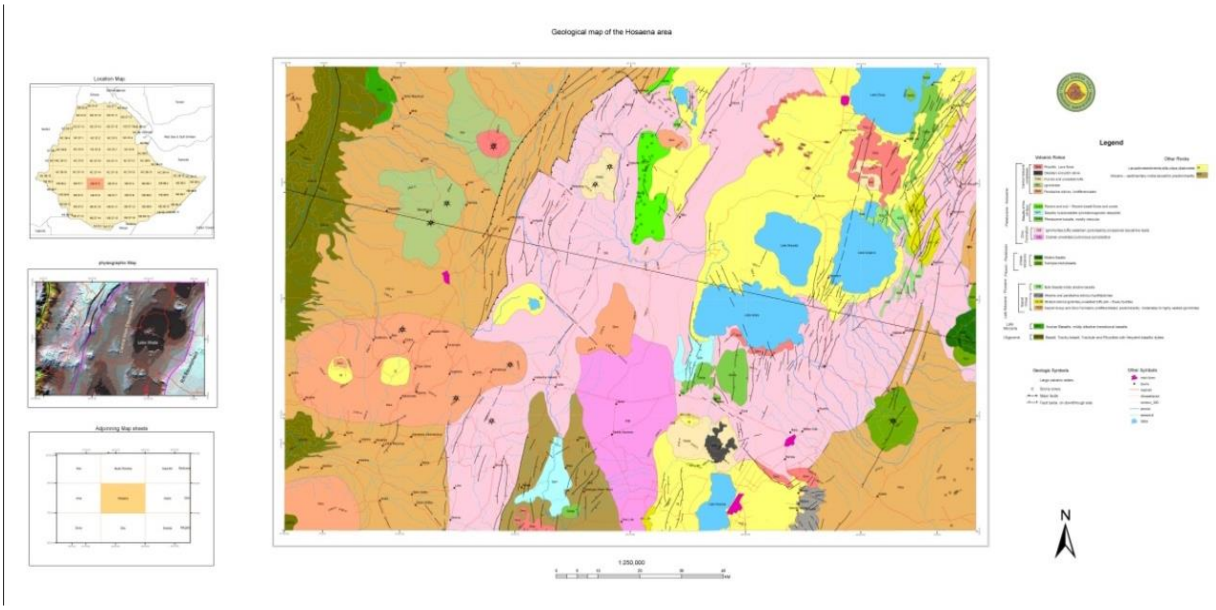


Fig. Geological map-of Hosaena-map sheet GSE

2.1.2 Local Geology

The geology of the study area was conducted by different organizations UNDP geothermal, prospect, JICA rift valley basin project; and hydrogeological study of the GSE. The different geological maps below may also show the detailed geological set-up of the area.

2.1.2.1 Dino Formation

Dino formation covers a considerable part of the rift floor it is made of ignimbrites intercalated with aphyric basalt unwelded pyroclastics (Kazimin and Seife M. 1978, Kazmin etal., 1980). The ignimbrites tuffs are water lain pyroclastics with occasional lacustrine beds. The coarse pumicious pyroclastics also makes up the geology of the study area.

2.1.2.2 Basalts of the Rift Floor

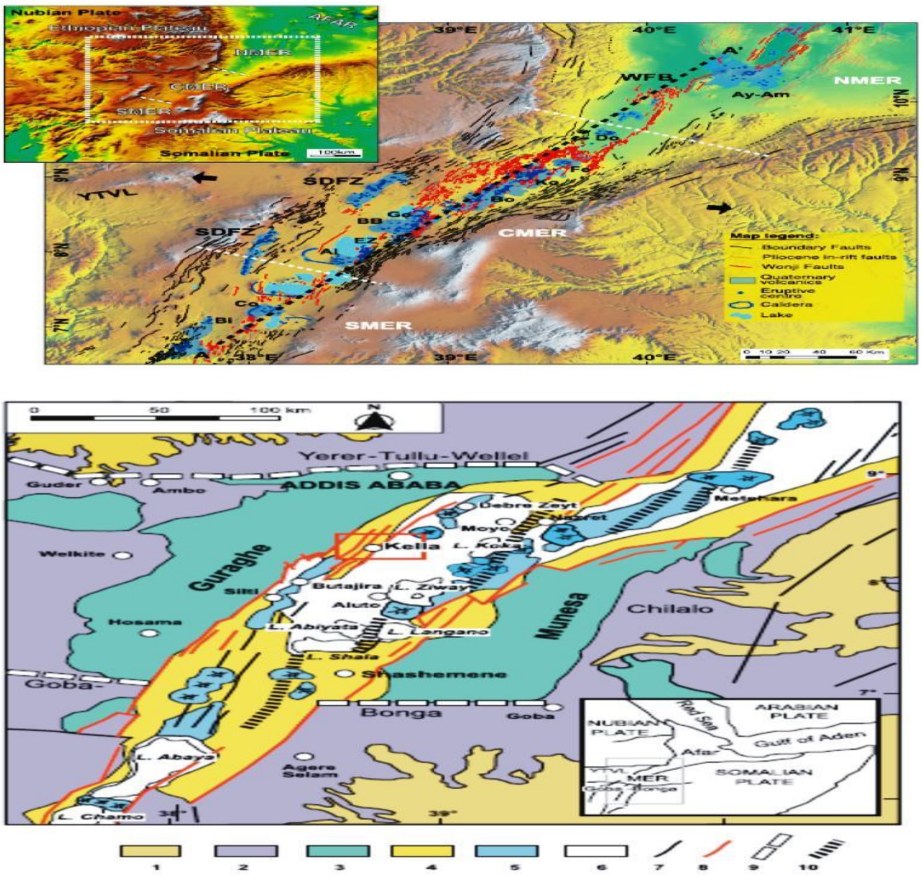
The basalts of the rift floor are in Wonji group with basaltic phertomagmatic tuffs. The bulk of this basalt is concentrated on the Wonji fault belt (WFB). However; the basalts of the Aje area has basalts of the rift floor.

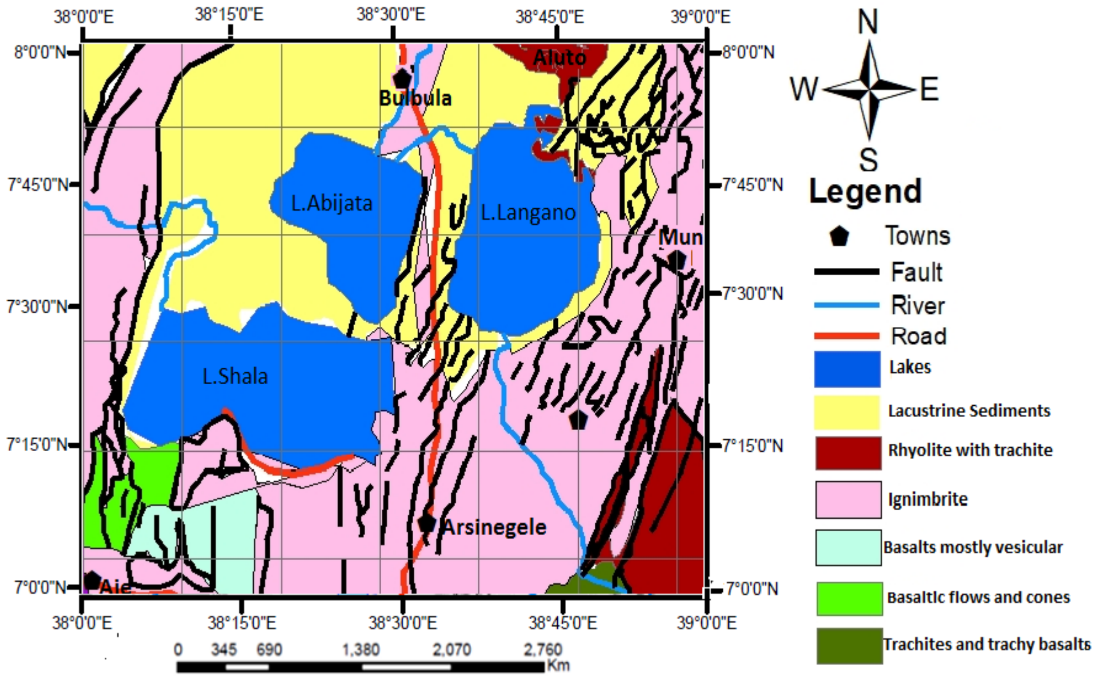
2.1.2.3 Nazreth group

The Nazret series is a thick succession of welded ignimbrites with fiamme pumice ,ash and rhyolite flows making dome with rare intercalation of basalt flows which occur in the MER rift margin and adjacent plateaus(Meyer etal;1978).

2.2 Tectonic Setting

The Ethiopian rift system is part of the east African rift system. The rift is divided into three parts in the main Ethiopian rift (MER) the north part, the central part and the southern part (Wolfenden etal, .2004; Mackinez etal. 2005 Keir etal. 2006). The study area is located in the central part of the rift system. This section of the rift is strongly affected by the NNE-SSW oriented active normal fault of the Wonji fault belt WFB (Mohr1962, Di paloa1972, Woldegabriel etal., 1990). The other interesting feature in the central part of the rift system is the effect of the Yere-Tulu-Wellel structure. The volcano- tectonic-lineament (YTVL) is related to the development of the MER which can be seen seriously affecting the central part of the rift (Kim, et.al., 2012).





2.3 Hydrogeology of the Study Area

The rift valley is a basin where water is drained by small rivers in to lakes and marshes which form the drainage for collected water. . The lakes Awassa and Shalla are fed by rivers like Bilate. However; the flow of water is controlled by faults which act as barriers or conduits.

The study area Aje is on the western side of Shashemene where scarcity of water in towns is serious where the geology and the controlling factors play a vital role.

Different researches were conducted by different authors .The rift area is covered by volcanic rocks like Basalts ignimbrites trachyte ,rhyolite and pumicious pyroclstics (Tesfaye1982) Furthermore Tesfaye (1982)had divided the rocks in the rift valley in to five main groups according to their hydrogeological behavior:

- Alkaline basalts, trachyte , and trachy-basalts of high lands
- Ignimbrites and tuffs with low permeability and yield of wells with 0 to 6l/sec
- Recent basalts with moderate to high permeability to fissured permeability.
- Pumice falls and acidic volcanic rocks with variable porous and fissure permeability.
- Lacustrine sediments with moderately to high permeability and yield wells with 1 to 5 l/sec.

Tenalem(1998) also classified the study area's hydrogeological condition by dividing the region into six zones of which two of them describe the study area preferably.

Zone 1 (10-20m/day) –these are recent basaltic fields and highly fractured rift floor ignimbrites with thin permeable volcanoclastic sediments and local lacustrine soils.

Zone 4(1-25m/day) –these are rhyolite, pumice, tuff and ignimbrites with low secondary permeability. They are covered with dominantly silt soil and black cotton soils with occasional lacusrine sediments.

On the other hand groundwater studies by Harclaw and JICA (2012) show the geological and hydro geological conditions of the rift valley lakes basin.

According to the above studies the hydrogeological classification/characterization of rock types in the study area are divided in to:

Rock units with porous permeability are rock types where ground water is stored in and flows through pores of unconsolidated or semi-consolidated material. Porous materials of quaternary age are sediments of lacustrine origin with additional fluvial, colluvial, and eluvial sediments.

The second rock units are with fissured permeability where groundwater is accumulating in and flows through the weathered and fractured part of volcanic rocks. In this case the porosity of lava may have caused the development of secondary structures (or joints and fissures) within the rock. However, these units can be low in productivity.

The third rock types are mixed fissured and porous permeability volcanic rocks often mixed with sediments accumulated in between lava flows and or volcanic episodes in rivers and lakes and/or relatively thick layers of unwelded tuffs, ash flows and pumicious pyroclastics material. These inter-related porous materials do not act as independent aquifers but they form mixed fissured and porous multilayered aquifers together with the volcanic rocks.

Describing rock units and qualitative division of rock units with their topographical set up describes the hydrogeological condition of the area. This helps to develop a conceptual hydrogeological model of the area. The study area at a wider understanding can be divided in to three or four hydrogeological systems. The units can be: extensive and moderately productive porous aquifers, extensive and moderately productive fissured aquifers, and minor fissured aquifer with local and limited ground water (Aquiclude) After Kefale and Jiri Sima(2013).

2.3.1 Extensive and Moderately Productive Aquifers

The geological (hydrogeological) units of this classification are lacustrine sediments. This material with moderate and locally high productivity is widely developed in the rift valley lakes basin (RVB). This aquifers is very good source of groundwater depending on thickness, sorting and recharge condition.

2.3.2 Extensive and Moderately Productive Fissured Aquifers

In this case the lithological units are basalts; rhyolites; trachytes; ignimbrites and tuffs. These units are mostly found outside of the study area. In these units fissured flow through open faults and fault systems may provide considerable ground water flow.

2.3.3 Extensive and Moderately Productive Mixed Porous and Fissured Aquifers

The third units as a hydrogeological unit of the area consists of ignimbrites, rhyolites, trachyte lava flows mixed with pumice together with river and lake sediments. The geologic materials are: silicic central volcanic complexes, ignimbrites, unwedded tuffs, ash flows, rhyolites, trachyte basalts. The study area hyderogeological units are predominantly their materials. The aquifers consist of inter-granular and fractured permeability with ranging from extensive to moderate productivity. The study area geologic is ignimbrites (central volcanic complexes, the Nazareth group and part of the Dino formation) could be good aquifers at some places while the same unit may be limited productivity in the presence of tuff and sediments.

2.3.4. Geologic units of fissured aquifer with local and limited ground water

The last material to consider though not found in the study area are obsidian and pitch stone. These units show all developed fractures which may serve as ground water conduits. These units have low capacity to store groundwater therefore are considered as aquicludes.

CHAPTER THREE

3. Theory of Geophysical Methods

3.1 General

Geophysics uses the principles of physics to investigate materials beneath the surface of the earth. Groundwater is a natural resource which can be investigated by geophysical methods. These methods can be electrical, electromagnetic, gravity, magnetic; and seismic.

Groundwater as natural resource can be preferably studied by some geophysical means than others. The preferred methods more often are electrical and magnetic or electromagnetic. However, there may not be a particular preference over one than another. Instead a combination of the methods may be employed to get a better result of the investigation.

Geophysical methods are used to investigate water bearing horizons as well as shallow controlling structures. The DC-electrical method is used to identify the different strata of the earth while the magnetic method is used for the investigation of ground water hindering structures like dykes or sills or weak structures which can be conduits for groundwater flow.

3.2 Electrical Method

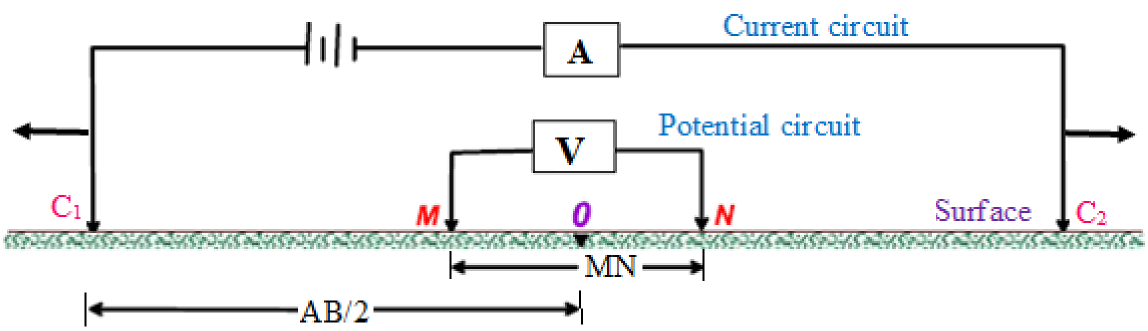
The electrical DC- method is often used for groundwater investigation. This is probably because of the availability of equipment, ease of operation, theoretical foundation, and interpretation of results. The other advantage of the electrical method is the operators (the equipment) control over the depth of investigation of water bearing horizons. The electrical resistivity method (in this controlled source low frequency AC and DC methods) are used to investigate the different subsurface layers (Keary etal, 2002).

The development of most of the geophysical methods has increased from the end of the Second World War for hydrogeological investigation although the method was developed in the early twenty century by the French Conard Schumberger,'s work on the method in the year 1912-1914 (Zohdy.R, 1992). There are two or three DC resistivity methods which are being used. These resistivity methods are vertical electrical sounding, resistivity profiling, and electrical resistivity tomography (ERT). The electrical sounding in most cases the vertical electrical sounding (VES) is used to investigate the vertical variation of the ground.

The electrical profiling on the other hand is used to investigate lateral variation of the ground. Furthermore; the method of electrical resistivity tomography can be taken as a method of combining the two for investigation of the depth of intermediate structures.

3.3 Principles of Vertical Electrical Sounding (VES) Survey

In the method of vertical electrical sounding (VES), the current electrodes are moved about the center of (ground point) investigation while the potential electrodes are seldom moved (Grifffths .H and King.F, 1998). This is to investigate the vertical variation in the resistivity. The method is extensively used in hydrogeological investigation to define horizontal zones of porous strata in geological structures, lithologies and, sub-surface resources of water (Keary, etal, 2002)



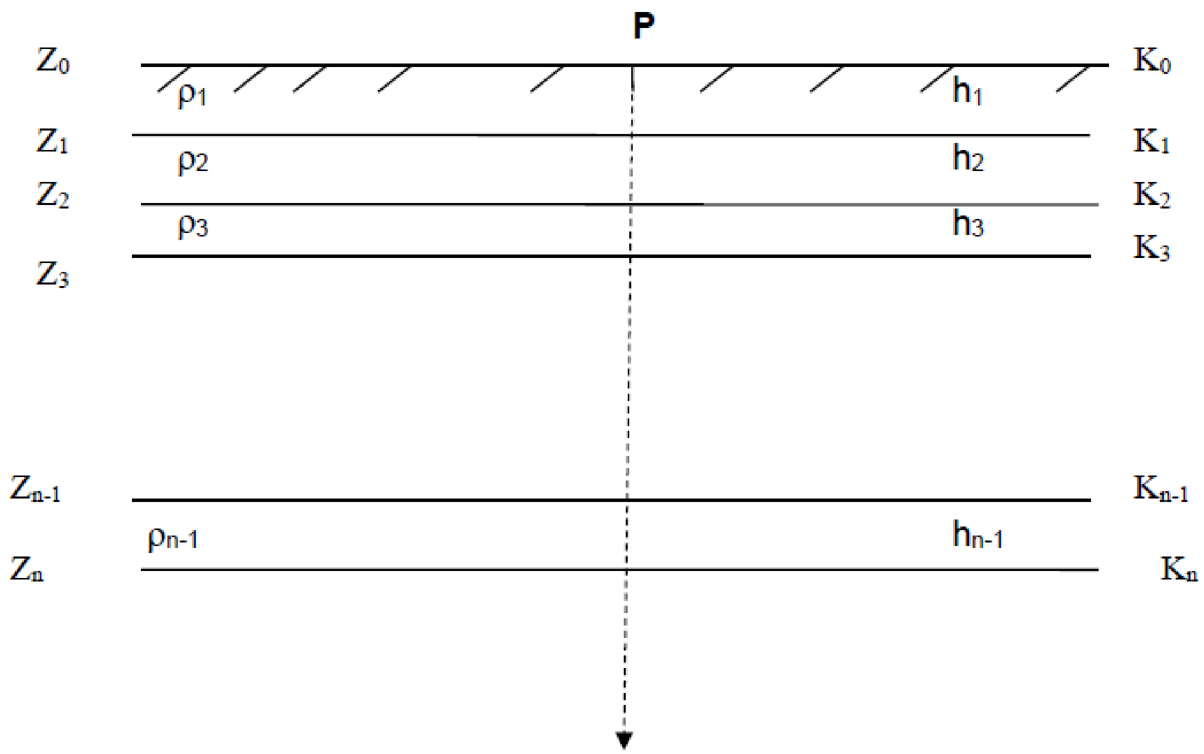
The method is also called electrical drilling as it is assumed to be investigating the vertical variation in resistivity. The procedure to be followed is the gradual increase in the Spacing of the current electrodes while seldom moving electrodes of the potential. The reading at the new spacing of the current electrodes is sketched on a bi-log paper. The sketch at each sounding shows the variation in resistivity with respect to current electrode spacing.

The often used arrays in electrical sounding are the Schlumberger and Wenner arrays. The resistivity method to collect raw data in this research work is the Schlumberger array. The spacing between the potential electrodes is not greater than one tenth of the current electrode spacing.

The increase in the separation of potential electrodes may produce different readings. These two readings taken at the two potential readings for a fixed current electrode separation is commonly taken as an overlap reading and the voltage is eventually become so small to be accurately measured(Milsom.J,1996). The galvanometer is not sensitive enough to take a reading at that particular separation than the other. Therefore it is common practice to take an overlap reading.

The theoretical (mathematical) foundation of investigating of the ground has been developed by different people. However, the basic assumption is that to assume the earth consisting of many (finite) layers bounded each other while the final layer is extending to a depth of infinity. If the depth of each layer is finite and each layer has a thickness of h the different layers will have thickness hi=h1, h2-----This assumption may require these layers to be homogeneous and isotropic (this may not be always the case in nature).

If a current electrode is placed as point source on the ground it produces an electric field the potential of which can be measured.



The potential foundation, rather the mathematical solution for this kind of problem is tedious. However with the above condition of isotropic and homogeneous earth and some boundary conditions for the differential (partial differential) equations the solution may be simplified. This was done by different mathematician Stefanescu et.al (1930) and Kofoed (1979).

The potential due to the single point source of electric field satisfies the Laplace equation. The potential due to this single source has a vertical cylindrical symmetry. As a result the

Laplace equation for cylindrical coordinates can be used for the solution of the potential field.

The assumption of solving the Laplace equation begins by the fundamental law of Ohm.

$\vec{J}=\sigma\,\vec{E}$

To arrive $\mathbf{V(r)} = \rho_1 \frac{I}{2\pi r} + \rho_2 \frac{I}{2\pi} \int_0^\infty 1(\lambda) J_0(\lambda r) d\lambda$ ....

However; to arrive on the above relationship an elementary model is taken and the only direction the resistivity varies is assumed to be downward. In this model there are n-layers which have parameters of resistivity and depth (thickness). The depth to the bottom of each boundary is $h_i = \sum_{j=1}^{\infty} dj$ and i=1.2,3….. The bottom layer has resistivity ρ_n and infinite thickness.

A current source placed at the surface of a half space with an intensity I into the earth once again the relation $\vec{J}=\sigma\vec{E}$ holds; where J is the current density, E-the electric field and σ the conductivity. According to Vermont (1989) the divergence of the current density in a given volume is equal to the amount of current in to and out that volume. This difference is equal to zero except at a current source and sink.

Div $\vec{J} = \nabla \vec{J}$

The electric field, $\vec{E}$ is defined as the negative gradient of the potential $\vec{E} = -\nabla V$

$\mathrm{div}\vec{J} = \nabla \vec{J} = \sigma(-\nabla V) = -\sigma \nabla^2 V$

$-\sigma \nabla^2 V = I\delta(x)$

Where the function Iδ(x) is the Dirac-delta function and as a result the above function is inhomogeneous differential equation of second order. The solution of this kind of equation is V= $\rho_1 \frac{I}{2\pi R}$ **where R=** $\sqrt{r^2+Z^2}$

Changing from Cartesian to cylindrical coordinates, $X = r\cos\theta$, $Y = r\sin\theta$, $Z=Z$ and using the identity $\cos^2\theta + \sin^2\theta = 1$ $R^2 = r^2\cos^2\theta + r^2\sin^2\theta + Z^2 = r^2 + Z^2$

The solution given by equation of the above equation can now be written as

$$\mathbf{V}=\frac{\rho_1}{2\pi r} \quad \frac{1}{\sqrt{r^2+Z^2}}$$

$\frac{1}{\sqrt{r^2+Z^2}}=\int_0^\infty e^{-\lambda z}\, J_0(\lambda r)\, d\lambda$ J_0 is the Bessel function of order zero the potential as a result is V= $\rho_1 \quad \frac{I}{2\pi}\int_0^\infty e^{-\lambda z} \quad J_0\ (\lambda r) d\lambda$

The above equation is valid for the upper most layer where div $\mathbf{J}=\mathbf{I}\delta(\underset{x}{\rightarrow})$ for all the other layers divJ=0 therefore; for $\mathbf{i=1}$ $-\sigma\nabla^2 V=0$

$$\nabla^2 V=0$$

This is the Laplace equation which can be written in Cartesian coordinates as

$$\frac{\partial^2 V}{\partial x^2}+\frac{\partial^2 V}{\partial y^2}+\frac{\partial^2 V}{\partial x^2}=0$$

The same Laplace equation in Cylindrical coordinates

$$\frac{\partial^2 V}{\partial r^2}+\frac{1}{r}\frac{\partial V}{\partial r}+\frac{\partial^2 V}{\partial z^2}+\frac{1}{r^2}\frac{\partial^2 V}{\partial \theta^2}=0$$

The layers are assumed to be homogeneous and isotropic the potential is symmetrical around the Z-axis therefore it is independent of θ the equation becomes

$$\frac{\partial^2 V}{\partial r^2}+\frac{\partial V}{\partial r}+\frac{\partial^2 V}{\partial z^2}=0$$

The solution to this second order homogeneous differential equation is found by separation of variables.

V(r, z) = U(r)W(z)

Substituting

$$\mathbf{W\ (z)}\frac{d\,U(r)}{d\,r^2}+\frac{W(z)}{r}\frac{dU(r)}{dr}+\mathbf{U(r)}\frac{d^2W(z)}{dz^2}=0$$

Dividing the whole by U(r) W (z) gives

$$\frac{1}{U(r)}\frac{d^2U(r)}{dr^2}+\frac{1}{rU(r)}\frac{dU(r)}{dr}+\frac{1}{W(z)}\frac{d^2W(z)}{dz^2}=0$$

U is only a function of r and w is a function of z this can only be satisfied if

$$\frac{1}{U(r)}\frac{d^2U(r)}{dr^2}+\frac{1}{rU(r)}\frac{d\,U(r)}{dr} = -\lambda^2$$

And $\frac{1}{W(z)}\frac{d^2\,W(z)}{dz^2}=\lambda^2$ where λ is an arbitrary constant. The solution of W (z) is

W (z) = A$e^{\lambda z}$ +B$e^{-\lambda z}$ Here again A and Bare arbitrary constants

The solution of U(r) has a finite solution as **r→ 0** is

U(r) =DJ_0 (λr) in this case also d is an arbitrary constant.

However; **V (r, z) = U(r) W (z)** has special solution for the product

$$V= \Phi(\lambda)\, e^{\lambda z} J_0(\lambda r) + \Psi(\lambda) e^{-\lambda z} J_0(\lambda r)$$

λ,Φ(λ), and Ψ(λ) are constants

The general solution of the homogenous equation within each layer is a linear combination of the special solution as λ varies from 0 to ∞.

$$V_i = \int_0^\infty \left[\Phi_i(\lambda)e^{\lambda z} + \Psi_i\, e^{-\lambda z} \right] J_0(\lambda r)\, d\lambda$$

I=1.2.3….., n and the potential vanishes at infinity. The Bessel function of order zero J_0(λr) becomes zero if and only if λr is a real number(r→∞).

The general solution for the inhomogeneous differential equation of second order in the first layer can be written as the sum of the general solution for the homogeneous equation above and the special solution for the in homogeneous equation

$$V= \frac{I}{2\pi}\int_0^\infty \left[\theta_i e^{-\lambda z} + X_i(\lambda)e^{\lambda z}\right] J_0(\lambda r)\, d\lambda$$

Where $\theta_1(\lambda) = \frac{2\pi}{\rho_{1I}}\Psi_i(\lambda)$ **and** $X_1(\lambda) = \frac{2\pi}{I\rho_1}\Phi(\lambda)$

The solution to the other layers (i>1) can be written as from equation by defining the equation for i>1:

$$\boldsymbol{\theta_i}\ (\lambda) = \frac{2\pi}{I\rho_1}\quad \Psi_1(\lambda)\ \text{-1 and } X_i(\lambda) = \frac{2\pi}{I\rho_1}\ \ \Phi(\lambda)$$

The solution to these kinds of equations is found by setting boundary conditions for

$\boldsymbol{\theta_i}$ **(λ) and** X_i**(λ)**

These conditions are:

- The potential is constant across each boundary between the layers i.e.;

$$V_i\ (h_i) = V_{i+1}(h_i)$$

- The vertical component of the current density is constant

$$\frac{1}{\rho_1}\ \frac{\partial V_i}{\partial z} = \frac{1}{\rho_{1+1}}\ \frac{\partial V_{i+1}}{\partial z} \text{ at } z = h_i$$

- At the surface (z=0) the current density J_z is equal to zero very close to the source

- The potential is zero at infinity that is z→∞ ,V→0 ,and r→∞

In the lower most case (i=n) the condition becomes X_n(λ)=0 the solution for the lower most layer becomes :

$$V_n = \frac{\rho_{1I}}{2\pi} \int_0^\infty\ [1++\theta_1] e^{-\lambda z} J_0(\lambda r)\ d\lambda$$

The first and second conditions together with the case above after differentiating it gives with respect z produces system linear equations.

$$V_{i-1} = V_i$$

And $\frac{1}{\rho_{1-1}}\ \frac{\partial V_{i-1}}{\partial z} = \frac{1}{\rho_i}\ \frac{\partial V_i}{\partial z}$

Solving the linear equations Koefoed (1979)at least for two layered case gives

$$\boldsymbol{\theta_1}(\lambda) = \frac{k_1 e^{-2\lambda hA}}{1-e^{-2\lambda h}k_1}$$

Where $k_1 = \frac{\rho_{21-\rho_1}}{\rho_{2-\rho_2}}$

The potential at the surface is given by:

$$\mathbf{V(r)} = \frac{\rho_{1I}}{2\pi}\int_0^\infty [1 + 2\theta_1(\lambda)]J_0(\lambda r)d\lambda$$

$$\mathbf{V(r)} = \frac{I\rho_1}{2\pi}\int_0^\infty J_0(\lambda r)d\lambda + \frac{I\rho_1}{\pi}\int_0^\infty \theta_1(\lambda)J_0(\lambda r)$$

For the Bessel function of order zero

$$\int_0^\infty e^{-\lambda z} J_0(\lambda r)\, d\lambda = \frac{1}{\sqrt{r^2+z}}$$

For z=0 the integral becomes

$$\int_0^\infty J_0(\lambda r)\, d\lambda = \frac{1}{r}$$

$$\mathbf{V(r)} = \frac{I\rho_1}{2\pi r} + \frac{\rho_1}{\pi r}\int_0^\infty \theta_1(\lambda)J_0(\lambda r)d\lambda$$

Equation () is the fundamental equation describing the potential at the surface of a stratified medium generated by a single current source.

3.4 Resistivity of Earth Materials

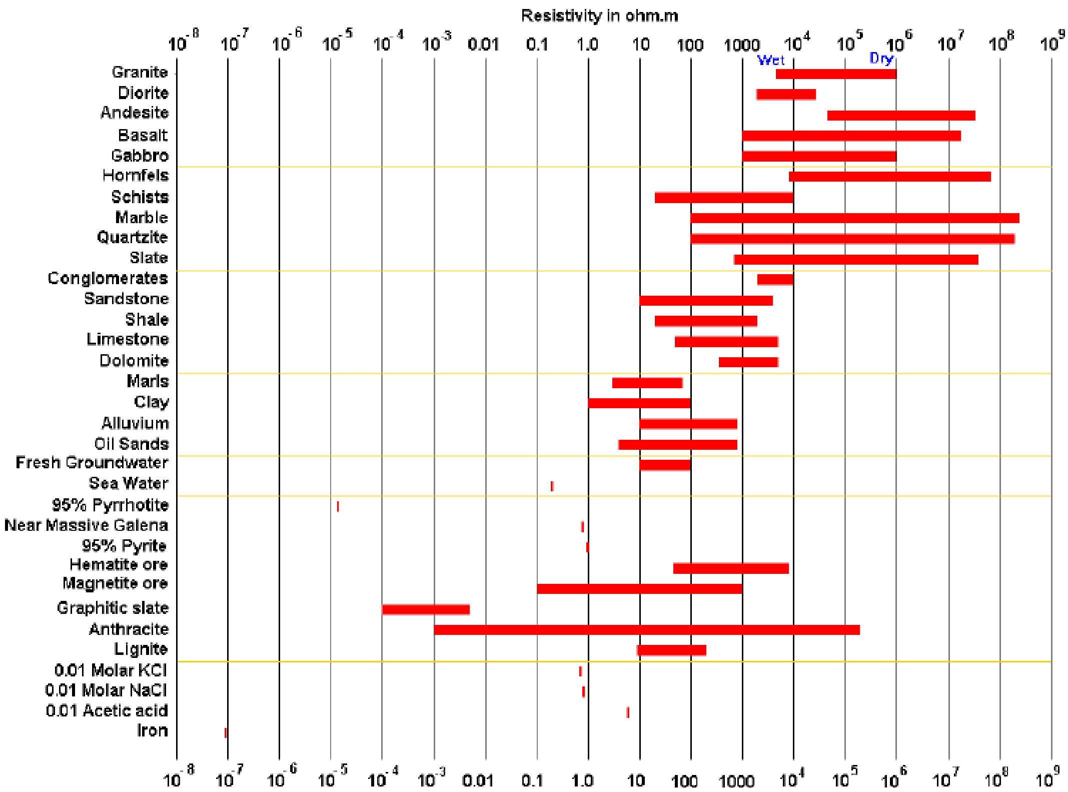
The resistivity of earth materials may depend on the pore spaces and fluid in these pore spaces. If the pore spaces are filled with water or some other fluid their resistivity varies.

Source

Volcanic rocks like that igneous rocks sedimentary materials of high compaction, and metamorphic rocks have in general high resistivity values. The resistivity of these rocks depends on the nature of fractures in these rocks and the percentage of open spaces filled with water. Sedimentary rocks which in most cases have more pore spaces and their pore spaces filled with water have lower resistivity.

The resistivity of these rocks largely depends on the porosity of the rocks and saturation of the contained water (Loke, 2013).

It may be quite useful to compare natural resistivity of rocks with their resistivity when they are fractured and filled with fluids (in this case water).



Resistivity of rocks and minerals after Loke

3.5 Magnetic Method

The earth's magnetic field throughout the earth and its different regions is more or less measured. These values are measured by different organizations. The daily, yearly and variations in decades can be found from these organizations. However, the earth's magnetic field may vary due to magnetic materials in the earth. These materials can be naturally occurring or manmade. The magnetic method measures the magnetic variation because of the presence of these materials. The magnetic method is also used for the investigation of ground water preferred paths or blocks which can control groundwater flow.

Rocks are very poor magnetic materials in their nature (source). However, some volcanic (igneous) rocks may contain enough magnetization to produce a variation in magnetic reading. The data interpretation of the variation in magnetic reading may record abundance of magnetization. This is useful in locating faults and geologic structures. (Blakely, 1995)

3.5.1 Basic Concepts of the Magnetic Method

A magnet suspended in air tends to seek one direction while the other moves away from it. The pole which seeks earth's magnetic north is known as the positive pole. This pole is balanced by a south seeking end which is known as a negative pole.

The force between two magnetic poles of strength m1 and m2 separated by a distance r is given by:

$$\mathbf{F}=\frac{\mu_0 m_1 m_2}{4\pi\mu_R\ r^2}$$

Where μ_0 and μ_r are constants as permeability of vacuum the relative permeability of materials separating the two poles.

The magnetic field due to a pole of strength m at any distance r from the pole is defined as the force exerted on a unit positive pole at that point.

$$\mathbf{B}=\frac{\mu_0\,\mathrm{m}}{4\pi\mu r^2}$$

For a single pole of strength m, the magnetic potential v at a distance r from the pole is given by:

$$\mathbf{V}=\frac{\mu_0\,\mathrm{m}}{4\pi\mu r}$$

The magnetic field can be defined in terms of magnetic potential in a similar manner as gravitational fields. For a single pole of strength m, the magnetic potential at a distance r from the pole is given by:

$$\mathrm{U}=\frac{\mu_0\,\mathrm{m}}{4\pi\mu r}$$

The magnetic field component in any direction is then given by the partial derivative of the potential in that direction.

3.5.2 Magnetic Property of Rock Materials and Susceptibility

Most rocks are not magnetic in nature. The property of rocks shows magnetic variations due to the presence of magnetic property in the rock. The basic physical property studied by geophysics is the susceptibility of rocks. However, magnetism of rocks is related with the magnetism of the rock forming minerals. The major rocks very roughly in their ascending order may be (k~0.0001)-sedimentary rocks, metamorphic rocks (0.001); acidic volcanic and plutonic rocks –basic plutonic rocks (0.01); and basic volcanic rocks (0.1) (Kirisch, 2009)

The magnetic moment between the two poles strength m separated by a distance l apart can be given by: M=ml

Whenever, a material (rocks) is exposed to earth's magnetization. It results in an induced magnetization in the rocks.

The intensity of the induced magnetization I- is equal to the dipole moment per unit volume.

$I=\frac{M}{LA}$ where L-the length of the sample and A-its cross sectional area and I the intensity is proportional to the strength of the magnetizing force H of the magnetic field.

I=kH Where the magnetic susceptibility is K.

On the other hand the magnetic field strength B-is related to the magnetizing force by

$B=\mu_0 H$ μ_0 permeability of free space.

The magnetic material placed in this magnetic field experience additional magnetic field in the space which has magnetic field strength I μ_0 . The total (resultant) magnetic field in this

$B=\mu_0 H+\mu_0 I$

$B=\mu_0 H+\mu_0 (kH)$

$=\mu_0 H(K+1)$

$=\mu_0 H\mu_0$

Where μ_r is the relative magnetic permeability and μ_0 permeability of free space μ_0

$\mu_0 = 4\pi \text{ x} 10^{-7} \frac{T}{Am^{-1}}$

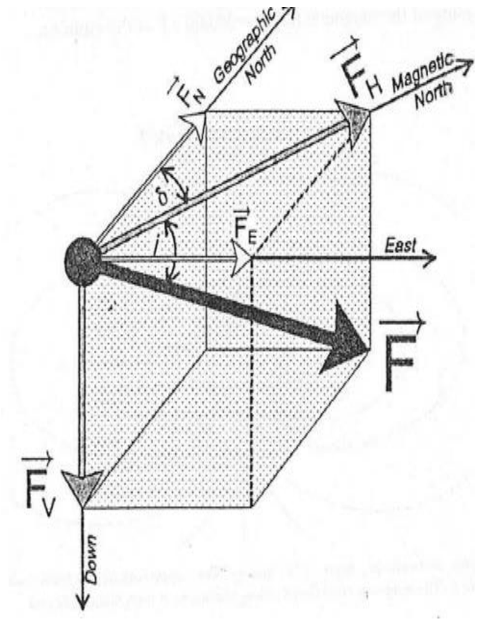
In practice the measured quantity is this field in units of Tesla (the Tesla is a very big unit therefore the Nano Tesla is used 10^{-9}Tesla).

Mineral or rock type	Susceptibility*
Sedimentary	
Dolomite (pure)	− 12.5 to + 44
Dolomite (impure)	20 000
Limestone	10 to 25 000
Sandstone	0 to 21 000
Shales	60 to 18 600
Average for various	**0 to 360**
Metamorphic	
Schist	315 to 3000
Slate	0 to 38 000
Gneiss	125 to 25 000
Serpentenite	3100 to 75 000
Average for various	**0 to 73 000**
Igneous	
Granite	10 to 65
Granite (m)	20 to 50 000
Rhyolite	250 to 37 700
Pegmatite	3000 to 75 000
Gabbro	800 to 76 000
Basalts	500 to 182 000
Oceanic basalts	300 to 36 000
Peridotite	95 500 to 196 000
Average for acid igneous	**40 to 82 000**
Average for basic igneous	**550 to 122 000**

Susceptibility of some rocks and materials (Renyolds .M, 1998)

3.5.3 The Geomagnetic Field

The vector nature that describes the magnetic field strength and direction from at a give position can be broken in to its components:



$\vec{F}$ = Total Magnetic Field Vector

$\vec{F_H}$ = Horizontal component of the total field vector

$\vec{F_V}$ = Vertical component of the field vector

$\vec{F_N}$ = North component of the horizontal vector

$\vec{F_E}$ = East component of the Horizontal vector

δ = Declination

i = Inclination

CHAPTER FOUR

4. DATA ACQUISITION, PROCESSING AND PRESENTATION

4.1 The Resistivity Method

4.1.1 Field Procedure and Data Acquisition

The Schlumberger array is used in vertical electrical sounding for its vertical drilling. The potential electrodes remain fixed during a number of successive measurements with expanding current electrodes.

For this study the Schlumberger array which is vertical electrical sounding (VES) among 3 lines are shown in Figure 4.1. The VES were carried out with maximum current electrode spacing (AB/2) of 500 to 750 m by injecting electrical current in to the ground by means of two outer electrodes, and the resulting potential difference were measured by a second pair of potential electrodes placed near the center of the outer electrodes.

Electrical resistivity survey using Supersting and PASI was used to collect the data within an average distance of 880 m. The current electrode spacing (AB/2): 1.5, 2.1, 3.0, 4.2, 6.0, 9.0, 13.5, 20.0, 30.0, 45.0, 66.0, 100.0, 150.0, 220.0, 330.0,500.0 and 750.0 meter and the potential electrodes spacing were (MN/2) 1.0, 12.0 and 90.0 were used to collect data during field work. The overlap readings AB/2: 20.0, 30.0, 150.0 and 220.0 m were taken in order to avoid the ambiguity of in homogeneity of the subsurface.

4.1.2 Data Reduction

The apparent resistivity values are plotted on bi- logarithmic data collection sheet. In processing of the collected data, the apparent resistivity values were written on the ordinate and the electrode separation (AB/2) on the abscissa. The resistivity measurements were made by progressively increasing the potential electrode distance (MN/2) relatively large increment of the current electrode distance (AB/2). The curve is smooth and at overlap measurement the average of shorter and longer spacing is taken. Two to three softwares were used to show the resistivity variation with depth. The IPI2WIN, Surfer 10, WinResist .

4.1.3 Data Processing and Presentation

The electrical sounding data collected in the field work were plotted on a bi- logarithmic paper and interpreted by using the Softwaers mentioned above for the thickness and electrical resistivity of the possible layers mapped in the survey area. These parameters obtained from curves is arranged and analyzed with rock units of the model in the WIN RESIST inversion software which resulted in possible electrical parameters under the area of investigation. The physical properties of these interpreted geoelectric parameters can be found. The depth, thickness and resistivity parameters acquired by the mentioned software program of vertical electrical sounding curves were used to construct geoelectric sections for a profile of VES line to show the distribution of different lithological unit in vertical direction using the software AutoCAD, 2011 programs

4.2 The Magnetic Methods

4.2.1 Field Procedures and Data Acquisition

Total magnetic field measurement with spacing interval 50 meter along traverse line 1, line 2, line 3 and line 4 were made. These traverses are on the same lines as that of the VES points as can be seen in the figure 3.1.During each measurement GPS location and time of measurements were taken. Total magnetic field measurements with magnetometer having a resolution 0.01 nT has been used. For each survey a base station was carefully selected and established in an area away from the magnetic noise like barbed wire fence, iron sheet buildings. At each station the location, time and reading were recorded, as well as any relevant topographic or geological information and details of any visible or suspected magnetic sources. Readings at the base stations were taken is used to correct the diurnal variation of the earth magnetic field.

The diurnal variation was removed from the observed magnetic field data using the Microsoft excel 2007. The main magnetic field at the base station is obtained from the International Geomagnetic Reference Field (IGRF). The IGRF value at the base station is subtracted from the diurnal corrected total magnetic field of each station. The magnetic field anomaly map was gridded and contoured using the Geosoft Oasis Montaj mapping software.

4.2.2 Data Processing and Presentation

The magnetic base readings were taken, so that diurnal corrections for total magnetic field readings along the profiles. The total magnetic field reading was corrected using Microsoft excel 2007(2011). Furthermore; by using Microsoft excel 2007 IGRF correction for each total magnetic reading along the profiles were taken by referring to online IGRF calculator.

The corrected magnetic data were processed using a standard Geosoft Oasis Montaj. The result is presented used program as: Total magnetic field intensity map, Residual map Magnetic analytic signal map. These maps are used to define qualitative interpretations in terms subsurface anomalous magnetic source that acts as controlling factor for ground water occurrences and movement.

4.2.3 Data Enhancement

The data was further enhanced by different enhancement techniques for residual magnetic anomaly, analytical methods were used for highlighting the contrast between magnetic anomalies generated by intermediate and shallow origin anomalous geologic bodies. The residual magnetic map was used to enhance the analytical signal magnetic map of the study area. These maps were interpreted for groundwater, and possible shallow or intermediate structures.

CHAPTER FIVE

5. RESULTS, DISCUSSION AND INTERPRETATION

A total of 15 vertical electrical soundings (VES) data are used to develop 3 survey lines. The survey lines are used to identify the major subsurface geological rocks together with the magnetic survey to identify and map possible water bearing horizons.

The interpreted individual VES curves, the results of geoelectrical surveys along the three lines are presented and discussed. The interpreted individual VES curves are further processed for apparent resistivity pseudodepth sections, and geoelectric sections. The apparent resistivity pseudodepth section along the selected lines are mapped from raw data using surfer 10 software and the resistivity sounding geoelectric sections are also processed by IPI2WIN and WinResist along the selected line are constructed from the interpreted layer parameters of each VES point. Some samples are shown below for clarity and purpose (while the others are attached at the appendix).

5.1.1 Interpreted VES Curves

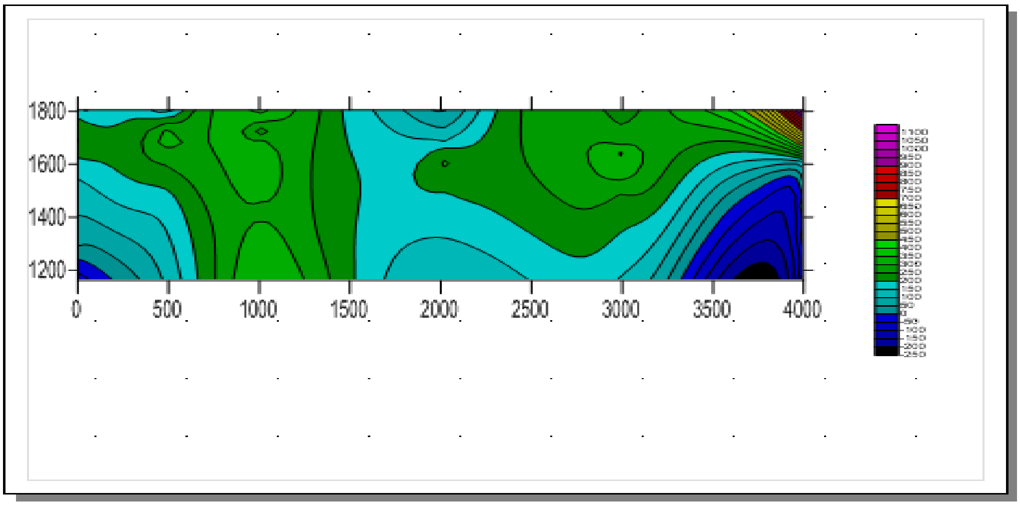
A typical interpreted sounding curve, for VES- of Line 1 is as shown in the . By plotting the apparent resistivity with electrode spacing on a bi-log scale the initial model of VES- with IPI2WIN and WinResist software. By using the inversion software WINRESIST and litho-logical description of the model parameters are defined in terms of geo-electric layers and its depth obtained by the resistivity survey.

The interpretation of the resistivity data revealed five layers with resistivity contrast between. The first tiny layer having a thickness 1m and resistivity value 100-300 Ohm-m is interpreted to be top dry soil (except in some cases). Below it two consecutive layers located at a depth of 6.8 m and 28.8 m having resistivity value 53.4 and 250 Ohm-m is characterized by highly resistive dry clay and boulder layers. In contrast beneath these layers, the fifth layer beneath VES 1 and 6 shows low resistivity response (27.9 Ohm-m).

Generally the interpreted VES points have represents 4 to 7 a five subsurface each of varying thickness and resistivity. A very good data quality and interpretation is obtained with RMS error of 2.4 %.

5.1.2 Pseudo Depth Section and Geoelectric Section of the Profiles

Using the 15 VES, Pseudodepth and geoelectric sections mapped along profile lines 1 to line 3 are constructed from software surfer 10 and Auto CAD, 2009 respectively. The VES points are placed 500m from each other and in some other case 1000m are used to represent the area. The GPS points of VES on each line and its location are given in the table below.



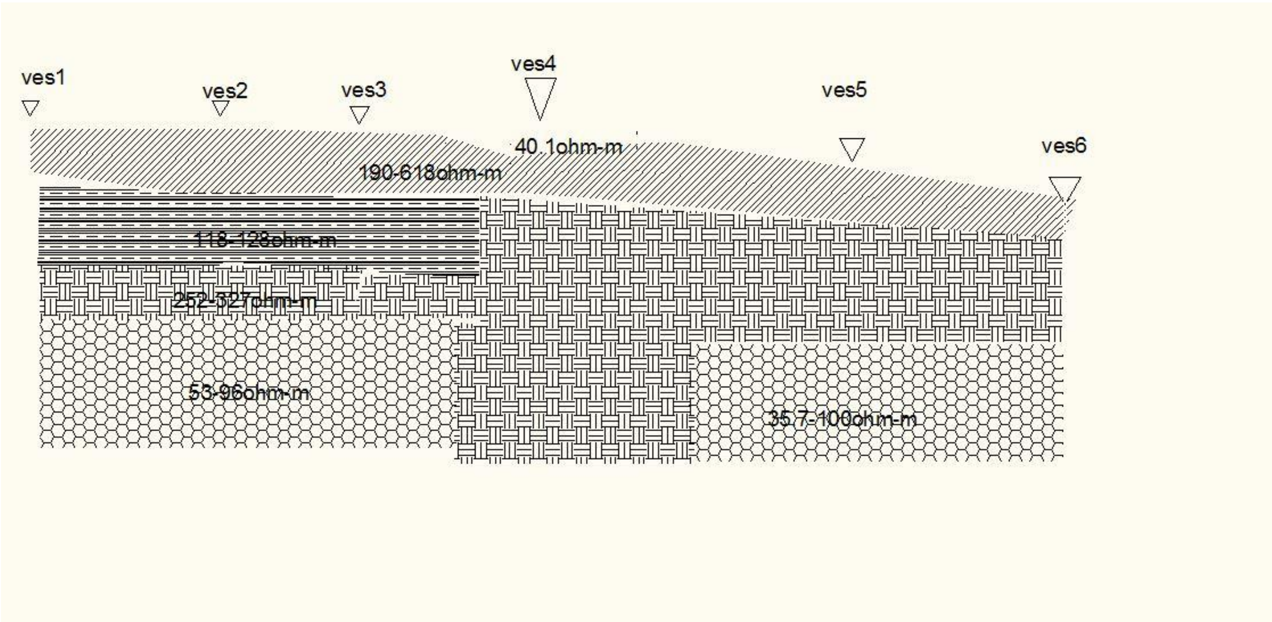
5.1.2.1 Traverse Line 1

Profile line-1 directed along W to E direction. This line with total length 4000 m consists of 6 VES points that lie on the profile line. Each VES with a spacing 500 m to1000m has an advantage to cross the widest part of the profile line

VES	X	Y	Elevation
Ves1	428285	813482	1806
Ves2	428790	813448	1793
Ves3	429269	813453	1770
Ves4	431500	813472	1701
Ves5	431513	813472	1690
Ves6	432659	813738	1661
Ves1p2	427566	811902	1795
Ves2p2	428560	811853	1775
Ves3p2	429550	811957	1744
Ves4p2	430611	811881	1701
Ves1p3	427654	810233	1785
Ves2p3	428563	810188	1774
Ves3p3	429044	810086	1763
Ves4p3	429638	810184	1745
Ves5p3	430502	810017	1708

B. Geoelectric section along profile Line 1

Geoelectric section profile1 constructed from the different layer parameters of six VES. Discussing one of the VES, by using the initial model of the curve interpreted initially using the above mentioned softwaers. The geoelectric section along profile line 1 produced using resistivity and thickness of soil deposit intermixed with of pumice, welded tuff and ignimbrite 135 m to 313 m depth .The geoelectric section developed along traverse line 1 are discussed as:



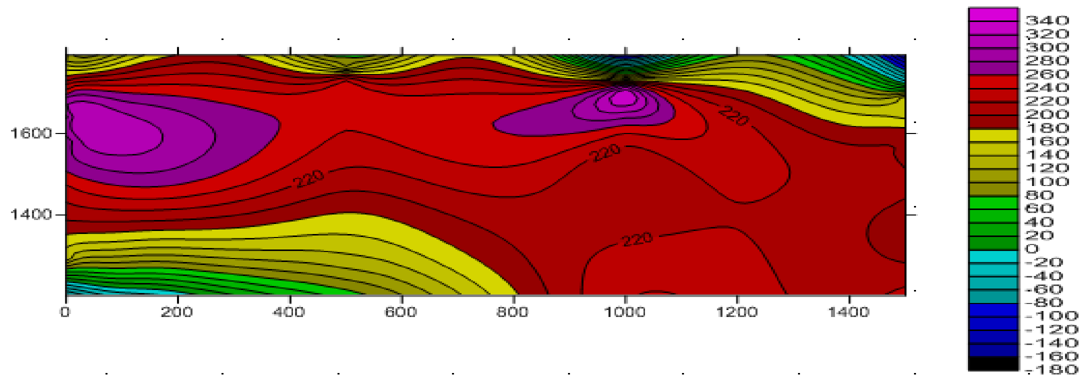
5.1.3 Profile Line 2

Profile 2 is oriented E to W direction has a total length of 2000 m. This line consists of 4 VES points spaced 500 m.

A. Pseudodepth section along Line 2

Four VES points shown aligning namely are used in defining the Pseudodepth section along the profile line 2.

Except the region at the top of VES4 and bottom of VES1, all regions are covered by high resistivity zone. This high resistivity region having soil combined with pyroclastic ash deposit is expected to have ground water potential in the region. In contrast, the high resistivity region beneath VES poin1 is expected to be weathered and fractured ignimbrite.



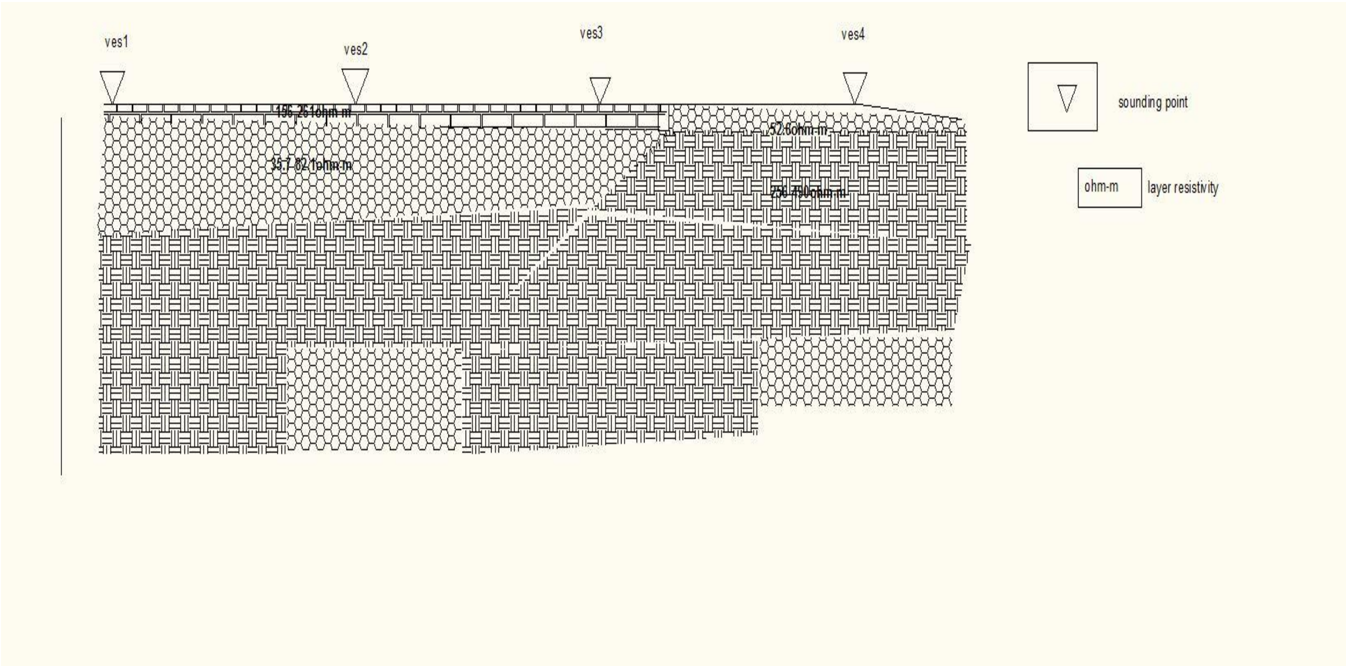
B. Geoelectric section along profile line 2

The geoelectric section along profile Line 2 shown reveals four main layers. In the first two VES points of the profile, the upper most layer is covered by high resistive dry top soil .This layer having an average thickness 1 m; is considered to be variable content of the sub soil changes within resistivity of range of 25to 240 Ohm-m.

Except at VES point V 4, the second layer having high resistive to 1000 Ohm-m is interpreted as fresh basalt. This layer increases its thickness towards the end the profile from VES3 to VES 4.

In contrast, the third and fourth layers located between VES point VES1 and VES 2 has relatively lower resistivity. This layer with resistivity range30-50 Ohm-m is probable source of ground water exploration.

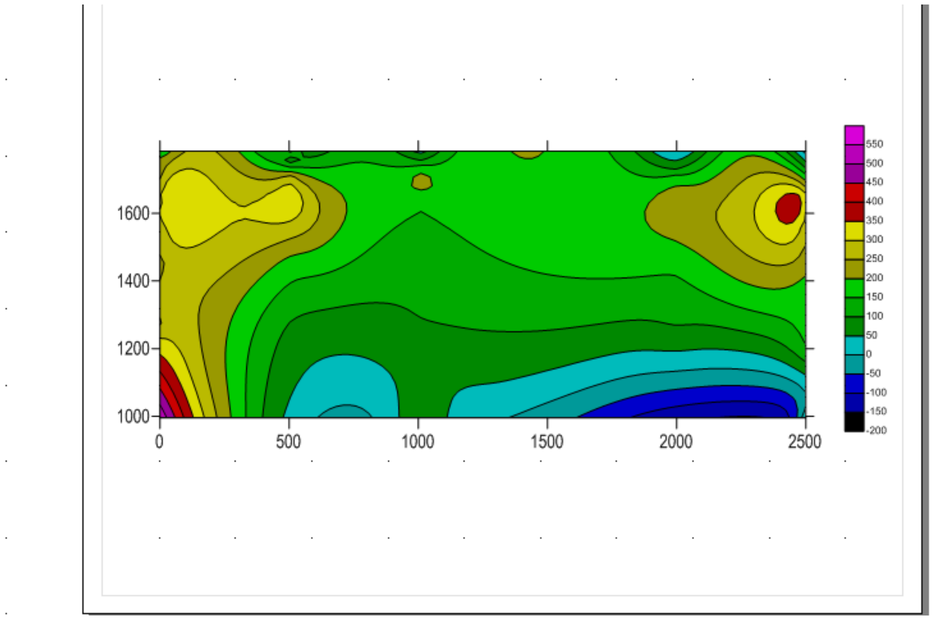
For ground water exploration purpose the third gravely clay layer which is located between the VES point V 1 and V 2 is the best position where ground water can be tapped.



5.1.4 Profile Line 3

This line shown in figure1.3 is oriented in W to E direction. This with a total length of 2500 m is identified by 5 VES points namely P3V1- P3V5.The average distance between each VES point is nearly equal to be 500 m.

Pseudodepth section along traverse line 3

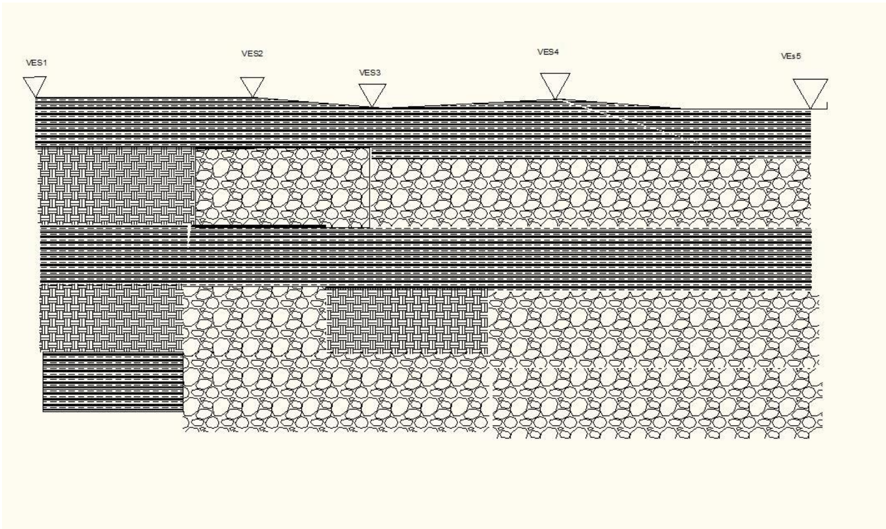


At the shallower depth level between VES point TAPV 7 and TAPV 3 (Figure 4.6.), the region are dominated by high resistivity value which corresponds to dry silt and clay.

At deeper depth point VES TBV14, it is covered by high resistivity value which corresponds to fresh basalt. In contrast the low resistivity region is related to geological formation having high yield aquifer.

B. Geoelectric section along profile Line 3

The geoelectric section along the traverse Line 3 (Figure 5.7.) is represented by three or four layers of simple structures which dip along the traverse. The first layer with resistivity ranges 7 to 28 Ohm-m is represented by dominantly top soil clay. This layer extends on the top of profile varies with thickness from 1.3 m to 6.4 m is considered to be so thin that its contribution for ground water distribution is inconsiderable.



CHAPTER FIVE

5. RESULTS, DISCUSION AND INTERPRETATION

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5.1.1 Interpreted VES Curves

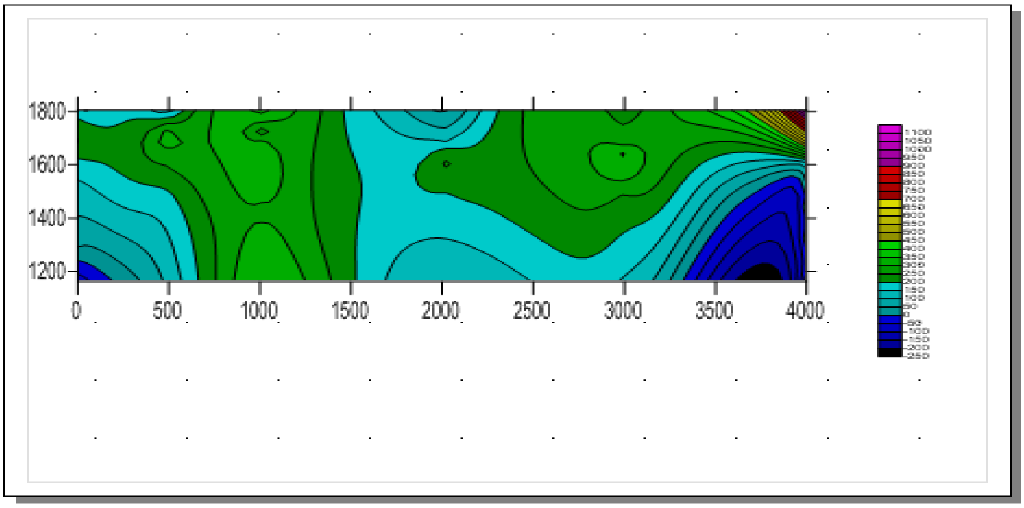
A typical interpreted sounding curve, for VES- of Line 1 is as shown in the . By plotting the apparent resistivity with electrode spacing on a bi-log scale the initial model of VES- with IPI2WIN and WinResist software. By using the inversion software WINRESIST and litho-logical description of the model parameters are defined in terms of geo-electric layers and its depth obtained by the resistivity survey.

The interpretation of the resistivity data revealed five layers with resistivity contrast between. The first tiny layer having a thickness 1m and resistivity value 100-300 Ohm-m is interpreted to be top dry soil (except in some cases). Below it two consecutive layers located at a depth of 6.8 m and 28.8 m having resistivity value 53.4 and 250 Ohm-m is characterized by highly resistive dry clay and boulder layers. In contrast beneath these layers, the fifth layer beneath VES 1 and 6 shows low resistivity response (27.9 Ohm-m).

Generally the interpreted VES points have represents 4 to 7 a five subsurface each of varying thickness and resistivity. A very good data quality and interpretation is obtained with RMS error of 2.4 %.

5.1.2 Pseudo Depth Section and Geoelectric Section of the Profiles

Using the 15 VES, Pseudodepth and geoelectric sections mapped along profile lines 1 to line 3 are constructed from software surfer 10 and Auto CAD, 2009 respectively. The VES points are placed 500m from each other and in some other case 1000m are used to represent the area. The GPS points of VES on each line and its location are given in the table below.



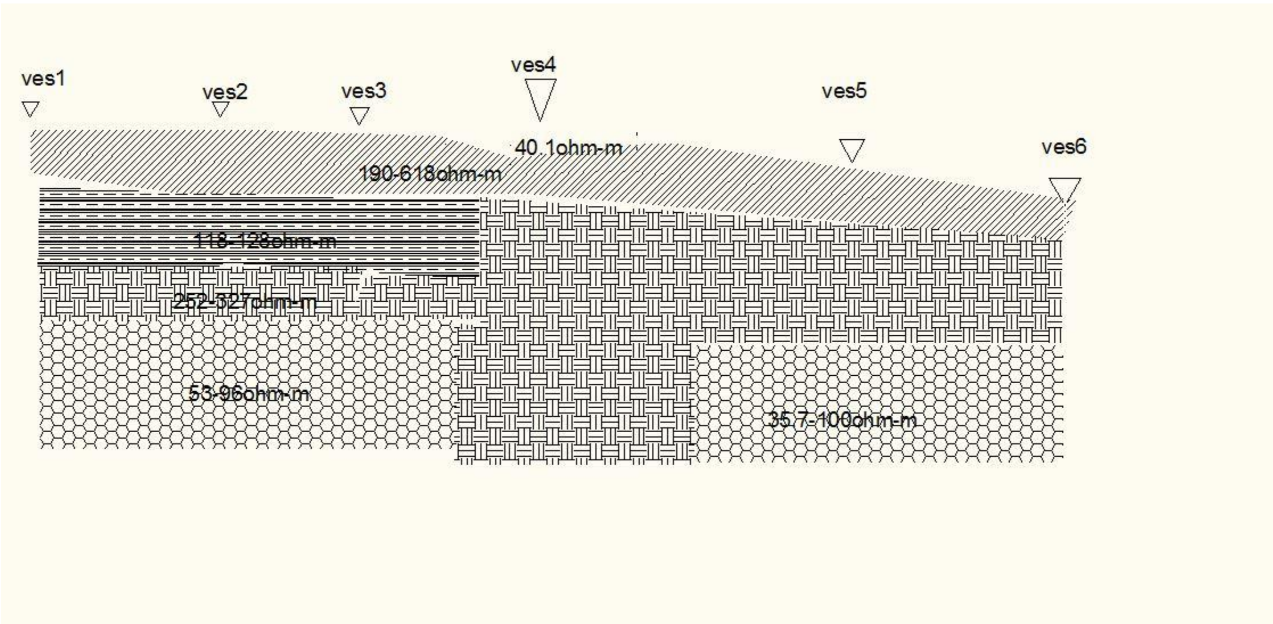
5.1.2.1 Traverse Line 1

Profile line-1 directed along W to E direction. This line with total length 4000 m consists of 6 VES points that lie on the profile line. Each VES with a spacing 500 m to1000m has an advantage to cross the widest part of the profile line

VES	X	Y	Elevation
Ves1	428285	813482	1806
Ves2	428790	813448	1793
Ves3	429269	813453	1770
Ves4	431500	813472	1701
Ves5	431513	813472	1690
Ves6	432659	813738	1661
Ves1p2	427566	811902	1795
Ves2p2	428560	811853	1775
Ves3p2	429550	811957	1744
Ves4p2	430611	811881	1701
Ves1p3	427654	810233	1785
Ves2p3	428563	810188	1774
Ves3p3	429044	810086	1763
Ves4p3	429638	810184	1745
Ves5p3	430502	810017	1708

B. Geoelectric section along profile Line 1

Geoelectric section profile1 constructed from the different layer parameters of six VES. Discussing one of the VES, by using the initial model of the curve interpreted initially using the above mentioned softwaers. The geoelectric section along profile line 1 produced using resistivity and thickness of soil deposit intermixed with of pumice, welded tuff and ignimbrite 135 m to 313 m depth .The geoelectric section developed along traverse line 1 are discussed as



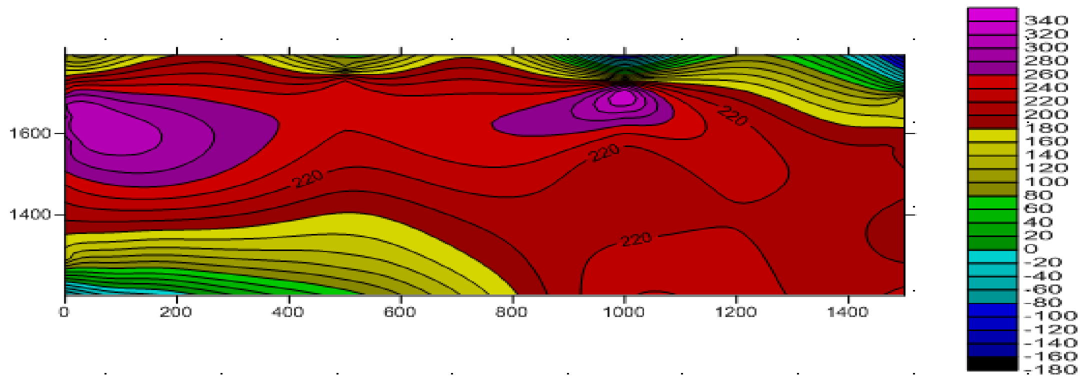
5.1.3profile Line 2

Profile 2 is oriented E to W direction has a total length of 2000 m. This line consists of 4 VES points spaced 500 m.

A. Pseudodepth section along Line 2

Four VES points shown aligning namely are used in defining the Pseudodepth section along the profile line 2.

Except the region at the top of VES4 and bottom of VES1, all regions are covered by high resistivity zone. This high resistivity region having soil combined with pyroclastic ash deposit is expected to have ground water potential in the region. In contrast, the high resistivity region beneath VES poin1 is expected to be weathered and fractured ignimbrite.



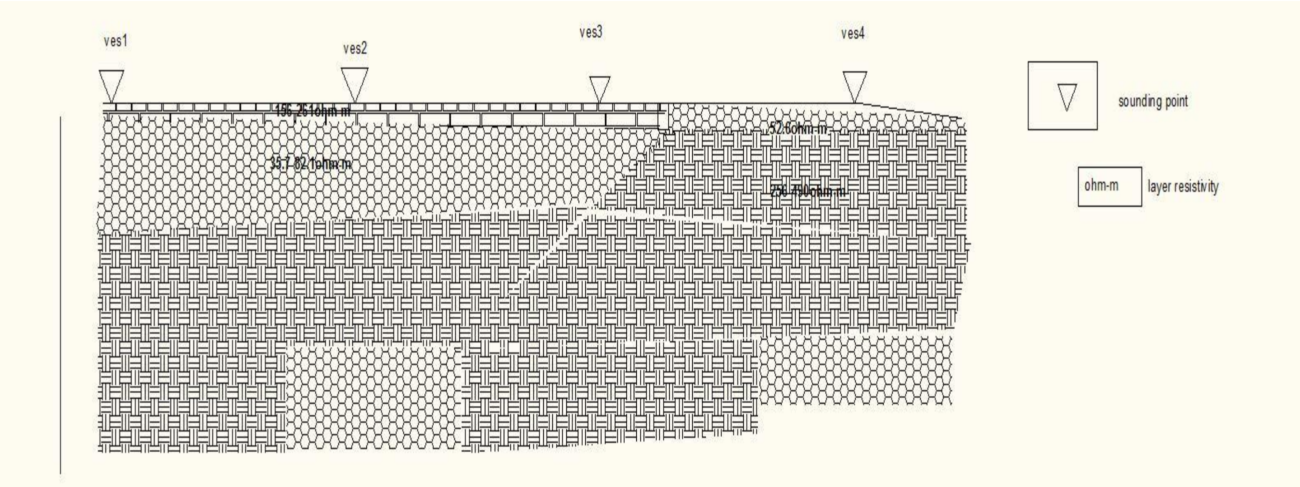
B. Geoelectric section along profile line 2

The geoelectric section along profile Line 2 shown reveals four main layers. In the first two VES points of the profile, the upper most layer is covered by high resistive dry top soil .This layer having an average thickness 1 m; is considered to be variable content of the sub soil changes within resistivity of range of 25to 240 Ohm-m.

Except at VES point V 4, the second layer having high resistive to 1000 Ohm-m is interpreted as fresh basalt. This layer increases its thickness towards the end the profile from VES3 to VES 4.

In contrast, the third and fourth layers located between VES point VES1 and VES 2 has relatively lower resistivity. This layer with resistivity range30-50 Ohm-m is probable source of ground water exploration.

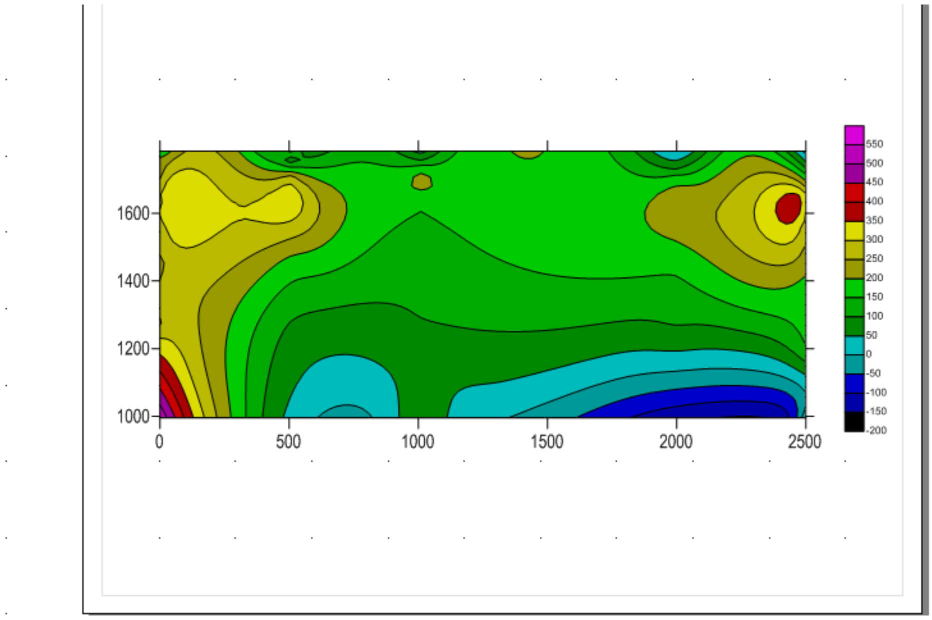
For ground water exploration purpose the third gravely clay layer which is located between the VES point V 1 and V 2 is the best position where ground water can be tapped.



5.1.4 Profile Line 3

This line shown in figure1.3 is oriented in W to E direction. This with a total length of 2500 m is identified by 5 VES points namely P3V1- P3V5.The average distance between each VES point is nearly equal to be 500 m.

Pseudodepth section along traverse line 3

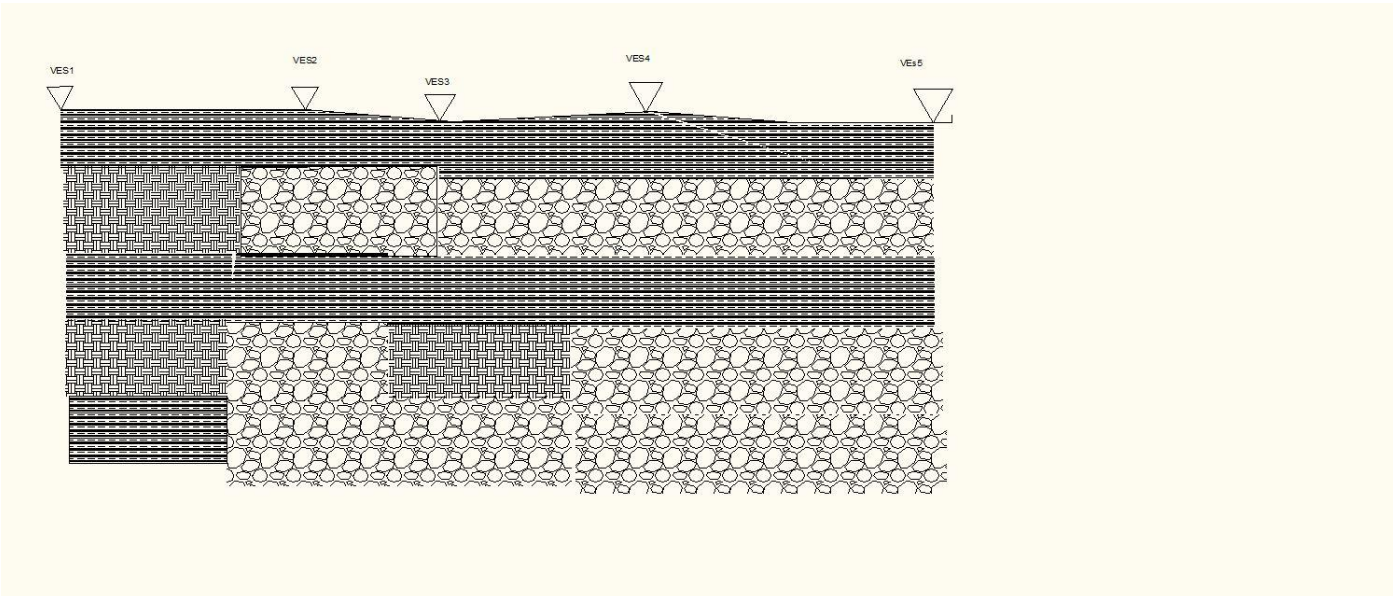


At the shallower depth level between VES point TAPV 7 and TAPV 3 (Figure 4.6.), the region are dominated by high resistivity value which corresponds to dry silt and clay.

At deeper depth point VES TBV14, it is covered by high resistivity value which corresponds to fresh basalt. In contrast the low resistivity region is related to geological formation having high yield aquifer.

B. Geoelectric section along profile Line 3

The geoelectric section along the traverse Line 3 (Figure 5.7.) is represented by three or four layers of simple structures which dip along the traverse. The first layer with resistivity ranges 7 to 28 Ohm-m is represented by dominantly top soil clay. This layer extends on the top of profile varies with thickness from 1.3 m to 6.4 m is considered to be so thin that its contribution for ground water distribution is inconsiderable.



5.2 Result and Interpretation of Magnetic Data

5.2.1 Total Magnetic Field Anomaly and Analytical Signal Maps

The total magnetic field intensity map plotted shown below indicates the variation for the total filed of rock magnetization at their different places. . The total magnetic field intensity map can be revealed within two or three magnetic anomaly patterns. The first pattern which is represented in region with blue dominating colored map shows low magnetic intensity 35053 nT to can be the is represented to be sediment pumice rich geological formation. There is a region in between with magnet intensity32148-32153nT which seems to be differentiating the relative high and low which is of the ignimbrite and welded tuff material. However there is a region with higher magnetic intensity (35154 nT to 35186 nT) located within a region related to volcanic rocks (basalt) .This region is dominated N to S by structures There seems also the rifts influence of SW-NE, SE-NW and E-W structures

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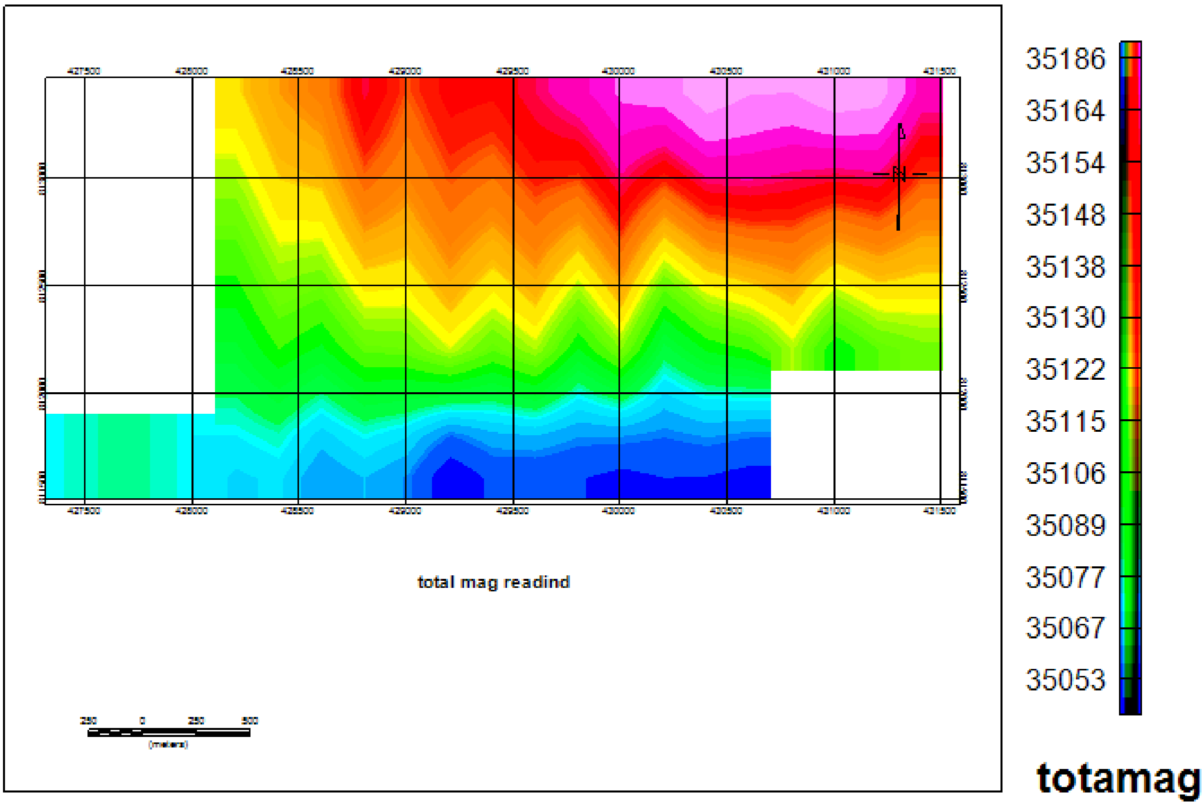
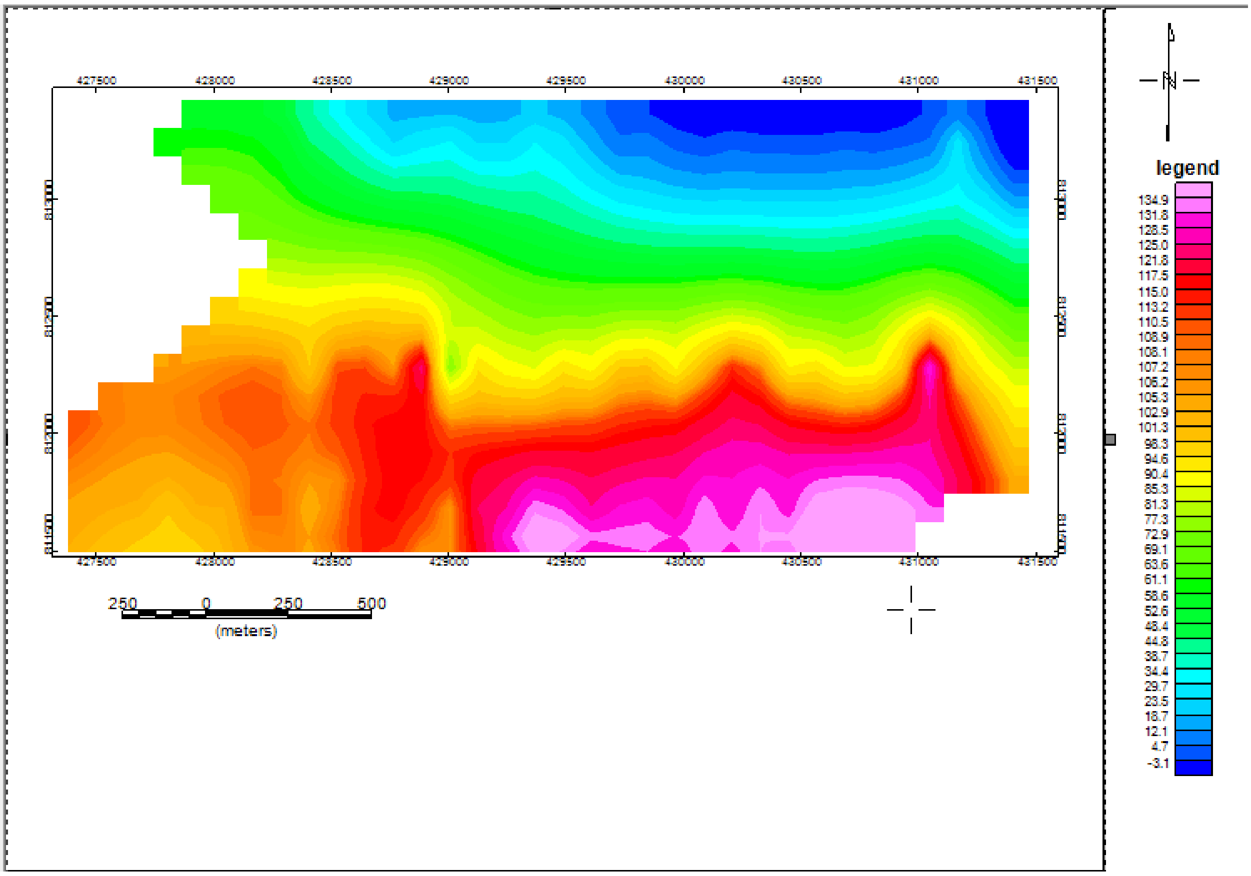


5.2.2 Residual Magnetic Field Anomaly Map

Magnetic anomalies, on the other hand, are a function of two variables: the subsurface distribution of susceptibility and the orientation of the Earth's main magnetic field. Changing one of these variables will change the resulting magnetic anomaly. This may be affected by the location for a rock located near the equator with one located near the North Pole. The geometry also affects the magnetic anomaly

Strong remnant magnetization is abundantly observed with young volcanic rocks, while in sedimentary and metamorphic rocks the remnant magnetization is in general much lower than the induced magnetization (Reinhard et al., 2009).



These map shows relatively high residual magnetic anomaly represented in the region blue This high magnetic response is could be magnetization of volcanic rocks basalt which is represented in the area. However the yellow pattern may show the sediment and volcanic ash which is dominant in the area.

5.2.3 Magnetic Analytical Signal Map

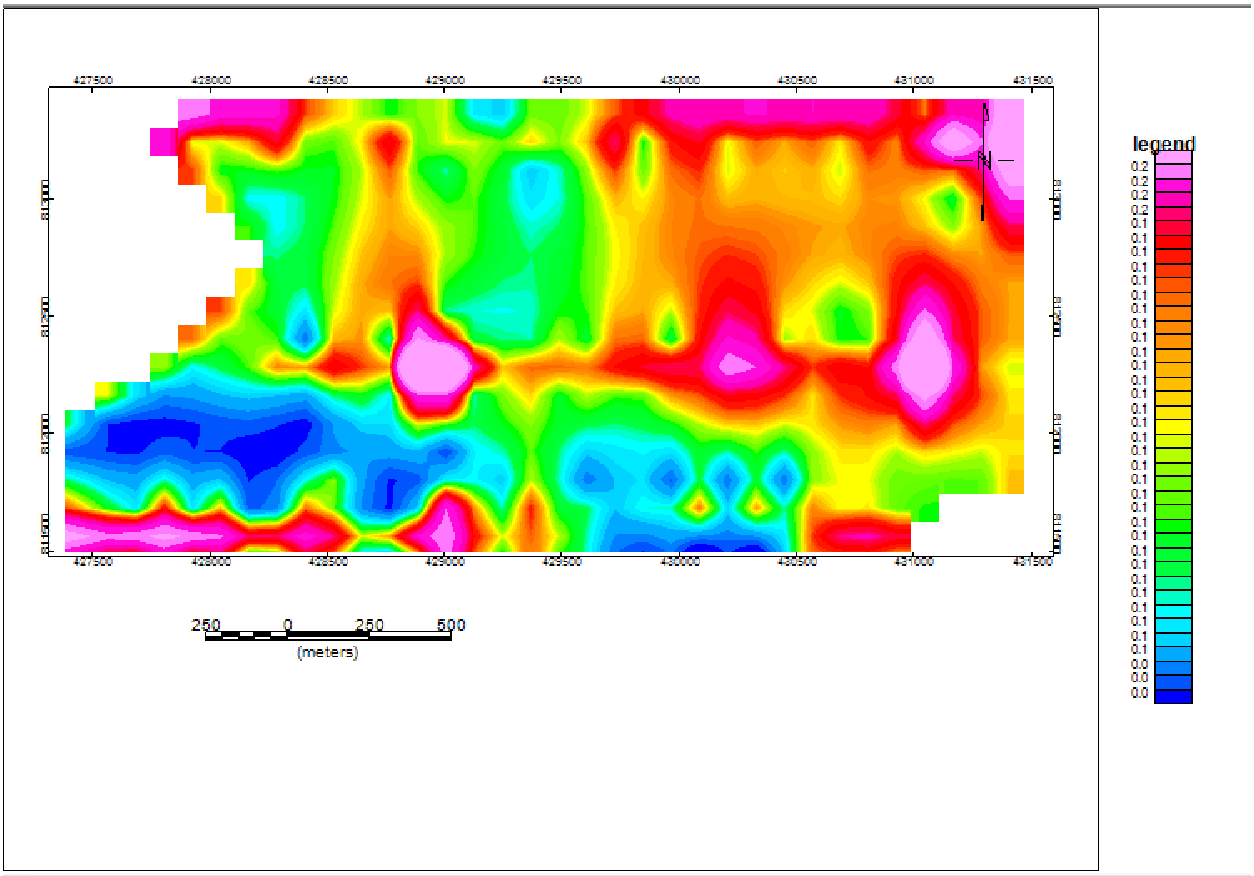
The analytical signal map is formed through a combination of horizontal and vertical gradients of a residual magnetic anomaly map. The analytic signal has a form over causing the magnetization which further depends on the locations of the bodies but not their orientation of magnetization.

The analytic signal method, known also as the total gradient method, as defined here produces a particular type of calculated gravity or magnetic anomaly enhancement map used for defining in a map sense the edges (boundaries) of geologically anomalous density or magnetization distributions (e.g., basement fault block boundaries, basement lithology contacts, fault/shear zones, igneous).

The amplitude of analytic signal of the magnetic anomaly of a 3D source can be given by the following formula:

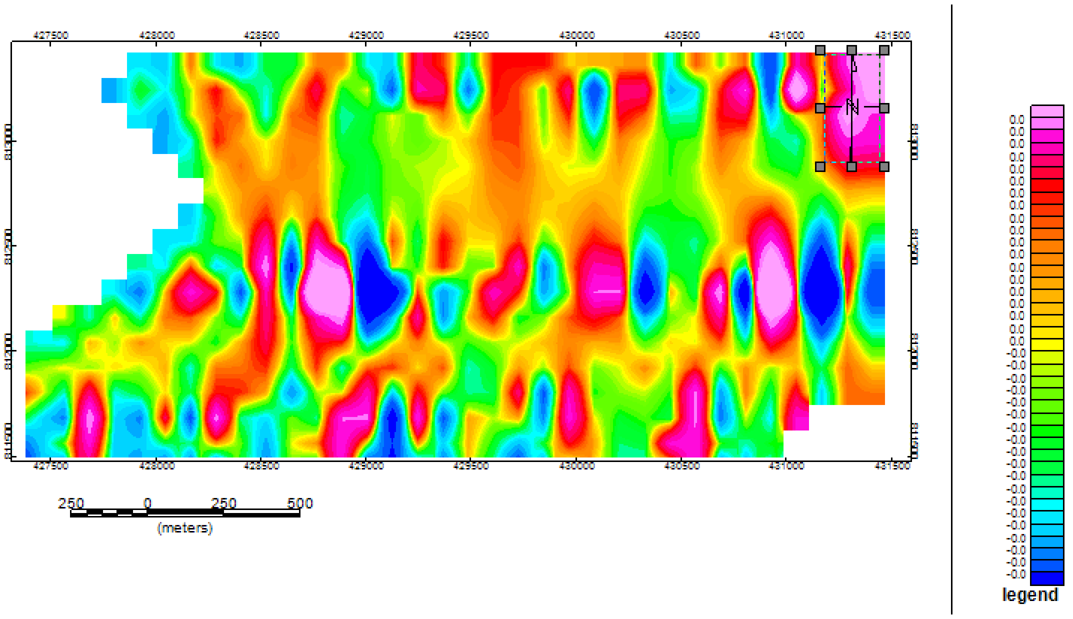
$$|AS(x,y,z)| = \sqrt{(\frac{\partial M}{\partial x})^2 + (\frac{\partial M}{\partial y})^2 + (\frac{\partial M}{\partial z})^2}$$

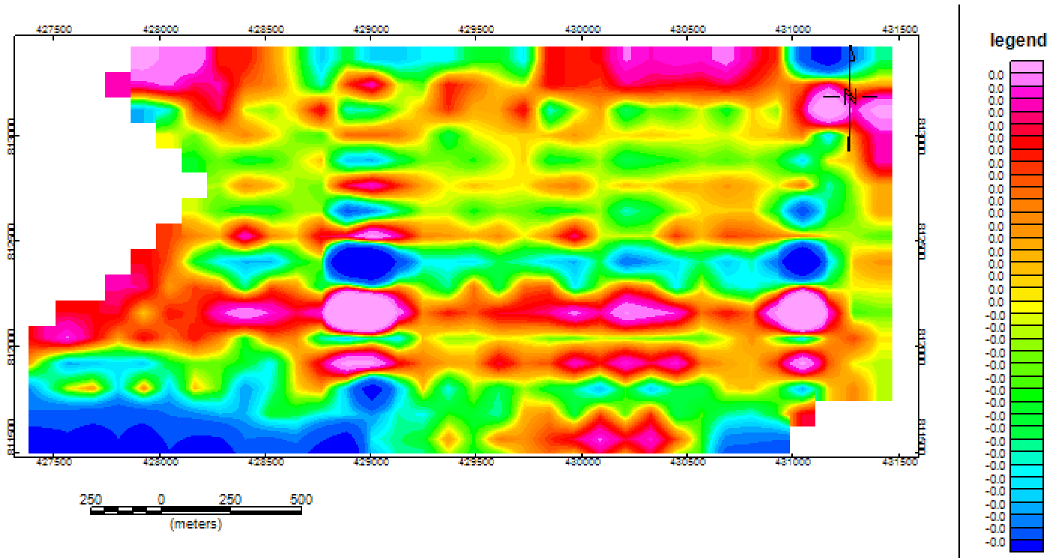
In contrast to the sediments deposited in the area, High analytical signal gradient oriented in a W-E is caused by High Susceptibility contrast of basalt. Whereas low magnetic anomalies values around region in residual anomaly map; shows contrasting high analytical signal values. This is believed to be a structure that oriented towards W-E direction can acts like a hidden structure which inhibits the flow of ground. on the other hand the low intensity direction may show the conduit for ground water.



5.2.5 Horizontal and Vertical Derivative Maps

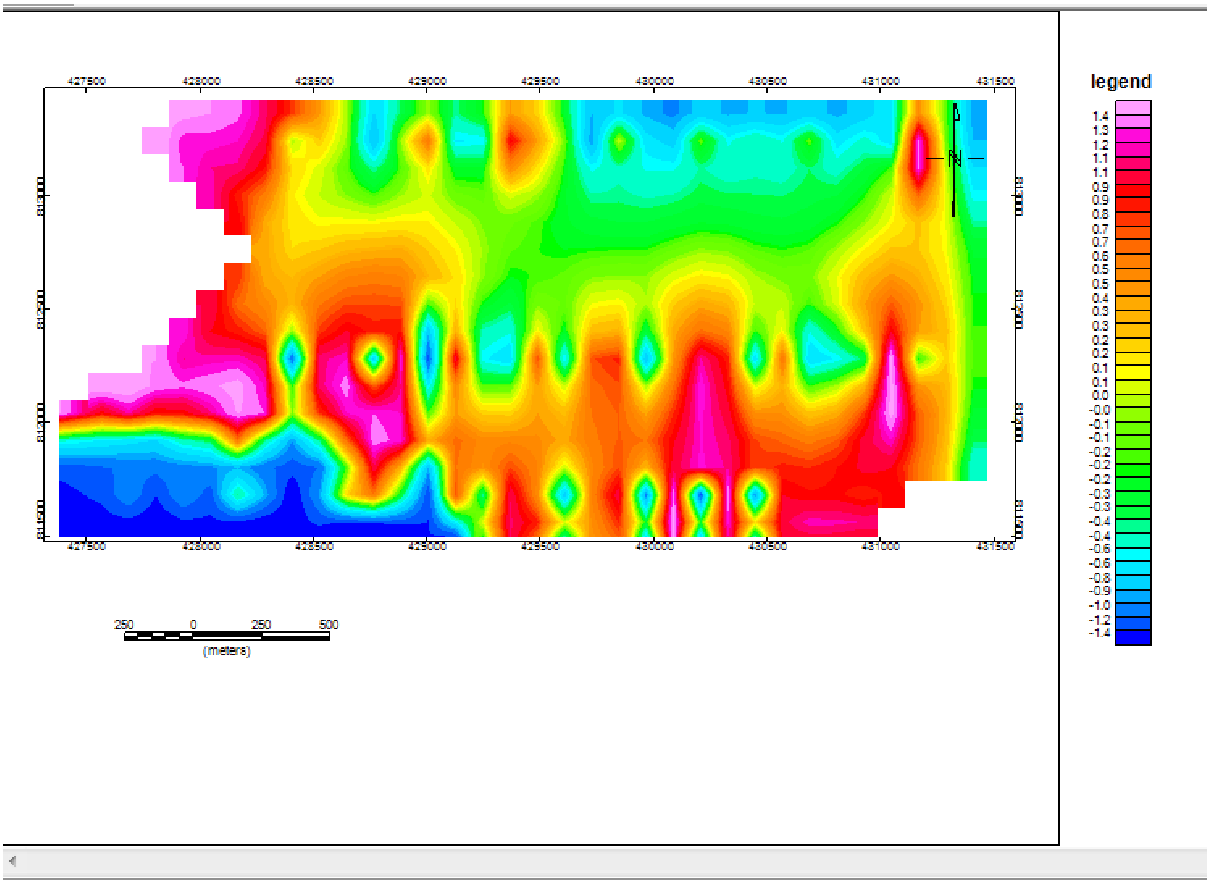
The purpose of doing the two derivatives is to indicate which the more dominant structures are playing ground water flow direction .The two derivative maps are put side by side to show the more important shallow or intermediate structures playing groundwater. The horizontal derivative map shows the north to sothe structuers in the area which is dominantely red. On the other hand the hand the vertical derivatives showing the east west structuers the coparision between the two shows the presence of east west structuers of stronger magnitued. These structuers are the main patterns controlloing ground water flow and natuer the bearing rocks.





5.2.4 Tilt Derivative Map

The Tilt Derivative Maps shows the maximum values in the map correspond to geological contact and geologic structures. It can see from the Tilt Derivative Map of the Analytical Signal map the study area is characterized by numerous structures delineated by contact/boundaries. The result may agree with the electrical response of rocks in the sub-surface results that may indicate the geologic history of the formation



CHAPTER SIX

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The following conclusions have been drawn using the combination of data presentation approaches:

The interpreted results of each VES point and correlating the values along the profile line, geoelectic sections reveal resistivity values:

- 150-600 Ohm-m: top soil mixed up with ignimbrite (weathered)
- 100s Ohm-m: ignimbrite
- 200-300Ohm-m pumice
- 50-90 Ohm-m pumice

The geoelectical sections over each profile line identify the major source of groundwater in the area to be weathered ignimbrite. These layers are mainly recharged with water through structures like faults beside it are also recharged by pumice pile which it acts as a good conduit but poorly holding it. Over all the potential sites for drillings has been identified within a depth interval of 120 m to 242 m are defined to be a water bearing horizon suggested to be more promising for groundwater exploration.

The two geophysical methods Geophysical results show the drilling of well log taken around the study is covered by thick ignimbrite pumice; and volcanic ash. The study area has highly resistive

The electrical and magnetic results correspond very well in mapping structural discontinuities of the study area. It is seen that the area is highly affected by tectonic events that trace NNE-SSW, NE-SW and W-E trending faults.

6.2 Recommendations

This study proves that the area has scarcity for ground water exploration. Along the profile lines one has to make care full selection be made with a reference of the geoelectric section:

- Geoelectical section profile line 1

The third layer within a depth of 100 to 240m is defined to be a water bearing horizon suggested to be more promising for ground water exploration. It is very difficult towards VES6 as the basalt is very near to the surface, drillings between VES 5 and VES6 is better situated position. This layer may contain promising material to some extent for water tapping as the structure is dividing the lithologies. Drillings in this area can face multiple confined aquifers.

- Geoelectical section Line 3

The spread in this case is 750m and it seems that third clayey gravel layer with resistivity range 8 to 16 Ohm-m reveals high ground water potential. Drillings in this layer can face multiple confined aquifers by clay; in this respect protection against subsidence of layers should have to be considered during drillings.

- Within all geoelectric sections along the Lines

The resistivity value which is less than 10 Ohm-m can be an indication that the groundwater in the study area can contain highly dissolved mineral. For an effective ground water exploration, further studies using integrated geophysical methods should have to be made in mapping the regional structural as well as for mapping the possible mineralized zone of the study areas.

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