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Original Research

Groundwater Potential Assessment Using Electrical Resistivity Method: A Case of Hereto *Sub-Catchment*, Enderta Woreda, Mekelle Town, Ethiopia

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Abstract

Research for ground water today has become essential to obtain quality water from the bedrock. Therefore, the application of geophysics to the successful exploration of ground water in sedimentary terrain requires a proper understanding of its hydro-geological characteristics. This study was conducted to assess groundwater potential of Arato sub-catchment of Eastern Mekelle city Using Electrical Resistivity Method. Vertical Electrical Sounding was conducted at the study area within the area coverage of about 2km^2. The data obtained were interpreted by IPI2WIN, IPI-res3 computer iteration process and the geological parts were done by comparing and evaluating the interpreted VES data's with the lithologic log from existing borehole indicating different layered formation. The geological profile sequence in the study area included the top clay soil, marly shale intercalation, highly fractured limestone, fractured limestone and dolerite. From the interpreted geological and geophysical data's there existed low resistivity zones showed highly fractured limestone and were concluded as good groundwater aquifer zones. Also it was concluded that highly aquifer zones were identified. Lastly borehole investigations were recommended at VES 1, VES 6 and VES 9 with depth from 120 m to 130 m.

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INTRODUCTION

Water is one of the fundamental natural resources for all living things to exist on the earth and it plays a vital role to bring significant socioeconomic development. It is essential to the existence of human and all living things. Most human generally requires about 2.5 liters per day, when an average amount of water used by every person justified; it is around 190 liters (Lateef, 2012)]. Groundwater, on the other hand accounts for about ninety-eight percent of the world's reasonably constant supply, which is not likely to dry up under natural conditions in crust to the surface sources. Groundwater occurs almost everywhere beneath the earth surface not only in a single widespread aquifer, but also in thousands of local aquifer systems. It is the safest and most reliable water source, for domestic, irrigation, industries, and municipality purposes. The finite water resources are being explored to quench the thirst of millions of the populace. Although it is widely distributed, nature does not provide groundwater at the places of our choice.

Groundwater exploration in past years has reached a place of importance to the world and supplying it to the needy is most precious of all. It is important natural resource for living things to exist on the earth and it is a backbone of civilization. It is also one of major source, which contributed a lot to the world water demand. Groundwater is most widely distributed resource of earth and nearly all the water in the ground comes from precipitation that has infiltrated into the earth. The occurrence and distribution of groundwater resources are confined to certain geological formations and structures. The occurrence of groundwater is not uniform because of its dependence on various environmental and geological factors, that is the groundwater recharge and occurrence is mainly governed by geology degree of fracturing, topography and also by amount and distribution of rainfall.

The groundwater resource play an important role in Ethiopia used for irrigation, industries, and domestic purpose and is available in sediments, sandstone, alluvial and karstic limestone. Because of an increasing population growth and urbanization it is leading to abstraction of the groundwater. The short age of fresh drinking water for human and livestock population and for agriculture asses is known in lowland; in some highland areas of Ethiopia found essential to explore water; resource for sustainable water supply and food self-sufficient (Mowr, 1998). Lack of professional awareness in Ethiopia about the sustainable use of groundwater resource made gaps in exploring the water. Most of water supply for Mekelle city and the village around the city are from the groundwater of Aynalem and Chinfers well fields that faces rapid water table lowering due to increased abstraction for domestic and industrial water demand.

Research for groundwater today has become essential, due to its chance of obtaining quality water from the bedrock. Therefore, the application of geophysics to the successful exploration of groundwater in sedimentary terrain requires a proper understanding of its hydro-geological characteristics. Evidence has shown that geophysical methods are the most reliable means of all surveying method of subsurface structural investigations and rock variation (Carruthers, 1985; Emenike, 2001). Several methods employed in groundwater exploration include electrical resistivity, gravity, seismic, magnetic, remote sensing and electromagnetic methods. Out of which the resistivity method is the most effective for locating productive well and the vertical electrical sounding (VES) technique can provide information on the vertical variation in the resistivity of the ground with depth. In this research the vertical electrical sounding (VES) technique was used for assessing the groundwater potential in Arato case study, eastern Mekelle, Northern Ethiopia. Mekelle city water is mainly supplied by ground water of Aynalem catchment. This part of Mekelle outlier has been subject to geological, hydro geological and geophysical investigations for the last decades (Teklay, 2006). The groundwater table lowering of the well field creates a great concern in the region and shortage of drinking water is one of the critical issues in the city. As the result different geological and hydro geological studies has been conducted by different consultancy and researchers, but there is no research conducted around Arato catchment which need to be considered as one source of drinking water.

MATERIALS AND METHODS

Description of Study Area

Hereto sub-catchment is located on the north-eastern part of the central plateau west of the rift valley of Ethiopia and is part of Illal basin which then flows in to Giba basin. It is particularity located about 20 km eastern of Mekelle city which is situated in the northern Ethiopia. The Geographical location of the area is between 39o32’30” to 39o40’0East and 13o26’30”to 13o36’30”North .The study area covers about 8.46km2 with mean altitude 2209 meter above sea level. As the area is near to the capital city of Tigray, Mekelle it is accessible by the main asphalt road joining Quiha with the Ethiopian petroleum supplier Mekelle branch and all weathered Gravel road give access to the study area (Figure 1).

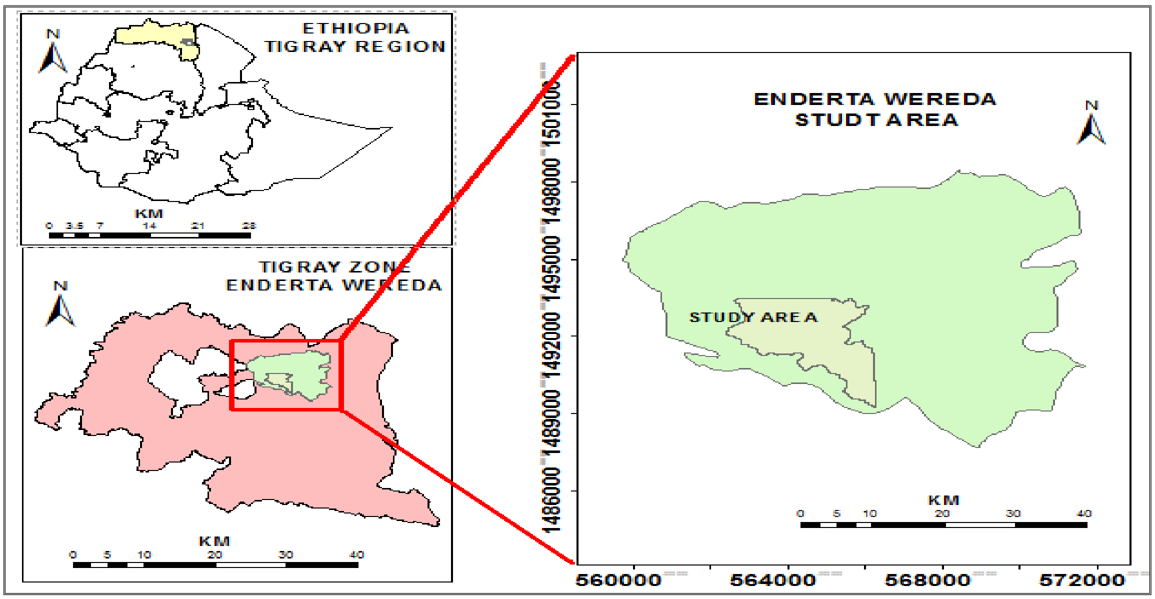


Figure 1 Location map of the study area.

Geomorphology and Drainage

The Arato sub catchment is topographically bounded to North and South by dolerite ridges and the valley is characterized by almost a gently rolling to flat topography. The elevation in the central part ranges from 2163m to 2416m above sea level. The river is part of the Tekeze river basin and it crosses the catchment dividing the areas almost in to two equal halves. The river drains from east to west direction in which the river coming along west flows forming the Giba River. As the result, the area is underlain by two prominent topographic features, namely; steep gradient along the river valleys, and undulating between the river valleys.

Climate and hydrology

The rainfall pattern of the catchment is mono-modal type with 83% of rainfall occurring in wet season (i.e. June-September). The rest 17% occurs in the dry season from October to May (Teklebirhan *et al*., 2012). Climatically, the area is classified as "Woina Dega" (temperate) with an effective temperature between 14^0C and 20^0C [8], which for most of the time is comfortable. It has a moisture index (P/ET) ranging in between 0.25 and 0.5, which indicates moderately dry area and precipitation almost 250 mm. The mean annual temperature ranges between 16^0C and 20^0C (Gebremedhin, 2002).

Soil Type

The soils around the study area are litho logically grouped into clay, silt, sandy clay/silt and clayey/silty sand soils. There is more clay in the valleys and flat areas. The clayey/silty sand soils have very limited area coverage. During the field observation the exposed soil thickness within the catchment ranges around 3m along the main stream of the river which shows the area has little soil cover.

Vegetation

The area around Mekelle town generally belongs to the little or no vegetation class. Today it can be said that most part of the area is completely devoid of its forest cover [10].

1.5. Land Cover

The land cover around Arato area is mainly used for cultivation, grazing land. The main land use of the study area is highly agricultural lands whereas there is no left land that covers reforestation and are mostly villages and devoid of lands except some shrub lands.

Geological setup

Regional geology

Following the Pan-African Orogeny, the Nubian shield remained remarkably stable for more than four hundred million years until the end of the Mesozoic. During the Mesozoic, the long succession of gentle wrapping and sporadic volcanic outbreaks that preceded and followed the opening of the Red Sea rift began. Hence, the formation of the East African Rift System and the associated volcanicity are related to the same forces causing the opening of the Red Sea.

During the late Paleozoic to early Mesozoic, the northern and eastern parts of East Africa acted as depositional basins for sediments coming from the higher cratons. This period is particularly represented by the deposition of the Enticho sandstone and Edaga arbi glacials in Tigray (Kazmin, 1972).

Two major transgression-regression cycles took place during the Mesozoic (Kazmin V., 1972). It is believed that these cycles are related to major regional tectonic events that have affected the entire East African region. The Mesozoic sedimentary succession of the Mekelle outlier is the product of these cycles, and rocks representing a range of sedimentary environments have been recognised by various authors. The first cycle began during the early Jurassic or Late Triassic and resulted in the deposition of the Adigrat sandstone, consisting mainly of sandstone and minor lenses of siltstone, and the Antalo formation, consisting mainly of fossiliferous limestones in the Tigray Region (Mengesha et al., 1996). The regression phase of the first phase caused the deposition of the Agula formation, which is composed of black shale, marl, and claystone with some beds of black limestone in the Mekelle area.

The transgression of the second cycle took place in Aptian to Turonian but is said to have no consequences in causing major deposition in the Mekelle area. However, regression of the second phase during the Late Cretaceous resulted in the deposition of the Amba Aradom formation, which is composed of siltstone, sandstone, and conglomerates. The formation was named after the type locality south of Mekelle town. Hence, the stratigraphy of the rock units constituting the study area is, from the oldest to the youngest: Adigrat sandstone, Antalo formation, Agula formation, and Ambaradom formation. Rocks of the Antalo formation and Agula formation are grouped together as the Antalo super sequence (Bosellini et al., 1997).

The structure consists of four normal fault belts, running in NW-SE directions that cross the Mekelle outlier (Beyth, 1972). This consists of the Wukro fault belt, the Mekelle fault belt, the Chelekot fault belt, and the Fuicea Mariam fault belt. The bedding and primary layers of the rocks in the area are generally flat-lying or moderately tilted. According to Beyth, the Agula shale is mainly exposed along the axis, and the main movement along these faults could be post-Agula shale and pre-Amba Aradom formation.

Local geology

The sub-catchment area is surrounded by plateaus and ridges of bedded limestone's and marly shale's in which physically the river comes across and meets with the adjacent catchments of Ilala then to Giba River. The dominant units outcropping in the study area are the sediment deposits, fractured limestone, marly shale with thin beds of limestone intercalation and dolerite. The study area is structurally affected by faults, fractures and joints. The existence of these faults is recognized from the alignment of the dolerite ridges having the same trend to the Mekelle fault belts and from the sharp contact of different lithologic units, older and younger units (Teklay, 2006).

The Limestone rock unit (Jte) is found exposed on some side part of the study area. In this study area the limestone unit contains marl interbedded with coquina and fine grained limestone, which has two main units: the yellow marl interbedded with coquina containing silicified lenses and the white limestone, finely crystalline to lithographic very well bedded and containing rare fossil fragments, forms a distinct cliff. As cited in (Gebregziabher, 2003) according to Abdelwasie Hussein (2000), no porosity and permeability is seen in the thin section. This implies that the porosity and permeability of this rock unit is due to the intense fracturing.

The Shale- marl with thin beds of limestone intercalation unit (Jg) is highly exposed on the central part of the study area. This rock unit is marl and shale with minor coquina and black limestone characterized by thin gypsum and dolerite beds and are also called Agula shale. And their color is grey, green and black shale, marl and clay: inter-laminated with finely crystalline black limestone containing disseminated pyrite, some gastropods and brachiopods. Some thin beds of gypsum and dolomite. Sequence contains a few beds of yellow coquina, near Antalo 200m of red and greenish silty marl.

The Dolerite rock unit (Tlm) is called Andesine dolerite or Mekelle dolerite, is found exposed in the Agula shale as a network of dykes, sills and irregular bodies within the sedimentary successions in all parts of the study area as well as around Mekelle, which is characterized on weathering by rounded, exfoliated boulders. It is black and brown in color and medium grained.

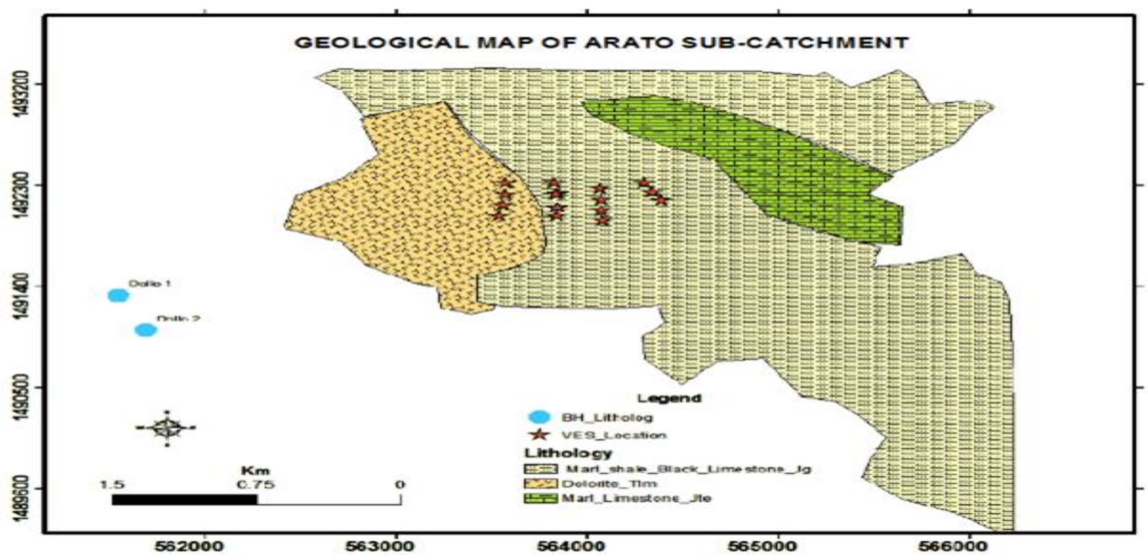


Figure 2 *Geological map of Arato sub-catchment.*

VES Data Acquisition

Vertical electrical sounding (VES) method was carried out at the study area within the area coverage of about $2km^2$ by using Schulumberger electrode configuration. In this survey, electrical current was sent into the ground through two current electrodes and the resulting potentials were measured with the help of two other potential electrodes. The measured apparent resistivity (ρ_a) for each half-electrode separation 'a' is computed from the following formula:

$\rho_a = 2\pi K(V/I)$, Where, ρ_a is apparent resistivity, K is the factor depending on the geometry of electrode configuration, V is the voltage measured across potential electrodes and I is the current sent into the ground. The apparent resistivity for a given electrode separation may vary within wide limits depending upon the nature of surface material.

In the Schulumberger configuration, four electrodes were placed symmetrically along a common line with the outer two serving as current electrodes and the inner two as potential electrodes. The inner pair of potential electrodes (CD) was located at the centre of the array and the separation between them was small compared to the current electrode distance (AB), usually less than one-fifth of the current electrode distance as shown in Figure-2, and was carried out with half current electrode spacing (AB/2) of maximum 500m.

Electrodes were inserted in to the ground properly by dragging them with hammer in order for the currents to penetrate deeply so that the data will be recorded.

The secondary data related to geological and hydro geological were collected from all drilled bore hole around and near the study area. So that the depth and elevation of the bedrock surface, thickness of aquifers and elevations of identifiable geological units from the well logs data were evaluated. Beside the geological approach, the geophysical survey was done with the objective of identifying potentially aquifer zones of the area.

MATERIALS

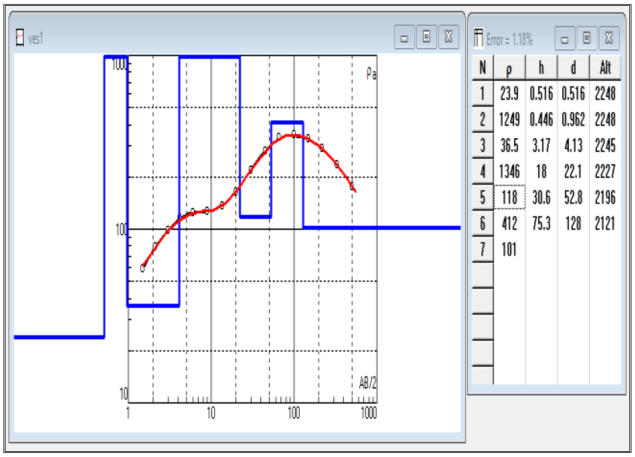
The instrument used during the survey was ABEM TERRAMETER SAS4000 with an external battery adapter with its DC input cable of using an external 12V battery. This instrument displays the apparent resistivity of subsurface layers. SAS stands for signal averaging systems in which means readings are taken automatically and the results are averaged. Other accessories used during this study included laptop , photo camera, Metal electrodes, labeled tag (used in locating station position), hammer (used in driving the electrodes into the ground), compass and GPS (to measure elevation, longitude and latitude), external battery, and connecting cables (crocodile cables).

VES Data Processing and interpretation

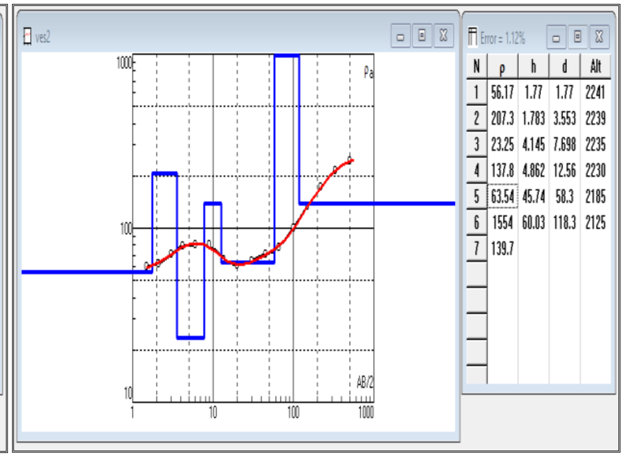
Different software and computer codes such as Microsoft Excel, IPI2WIN, IPI-res3 and Surfer 10(32-bit) were used to develop cross-sections and analyze data. In which Microsoft Excel was used to arrange field data and plot graphs whereas IPI2WIN software was performed to determine number of layers and their thickness based on their resistivity inputs while Surfer 10 was used to obtain geo-electric sections. The field results of the study were then presented in both qualitative and quantitative interpretations. When the data was interpreted qualitatively the shape of the field curves were observed to get an idea about the number of layers and resistivity of layers. The results of this method of interpretation involved pseudo and geo-electric sections. The VES data collected in the field were plotted on a bi-log paper and then curve matching was performed using IPI2WIN software to find out initial model parameters of possible layers. In the quantitative method geo-electrical parameter, i.e. true resistivity and layer thickness were obtained to make geo-electrical section using Surfer 10 software.

RESULTS

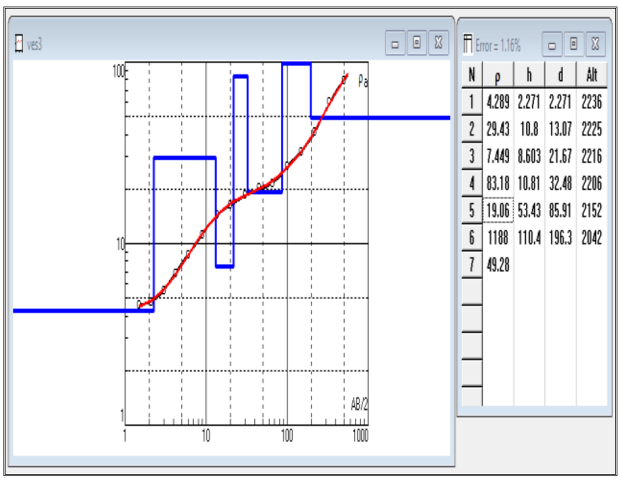
Interpreted VES Curves



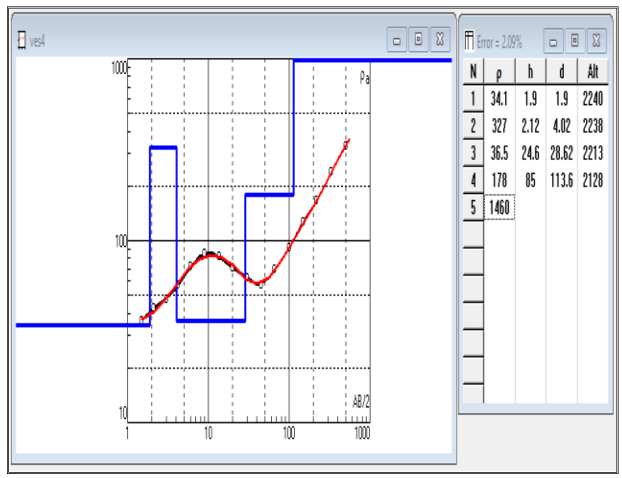
VES 1



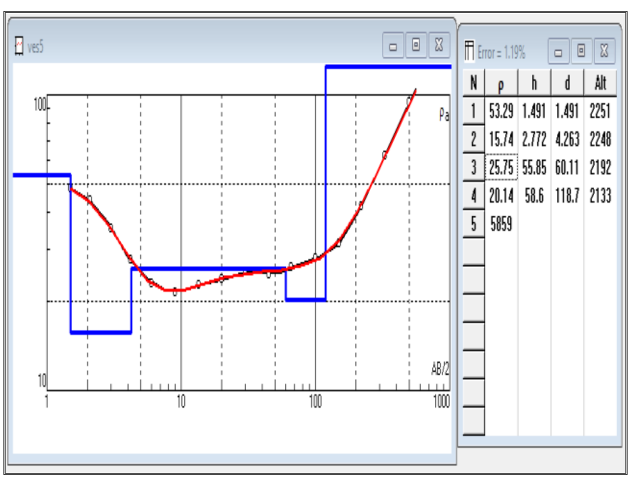
VES 2



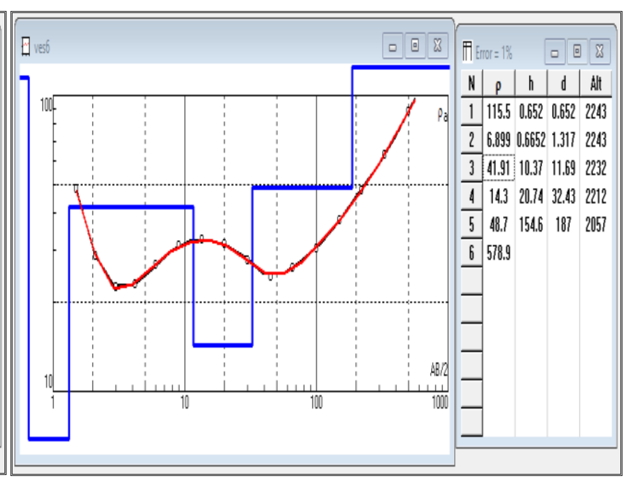
VES 3



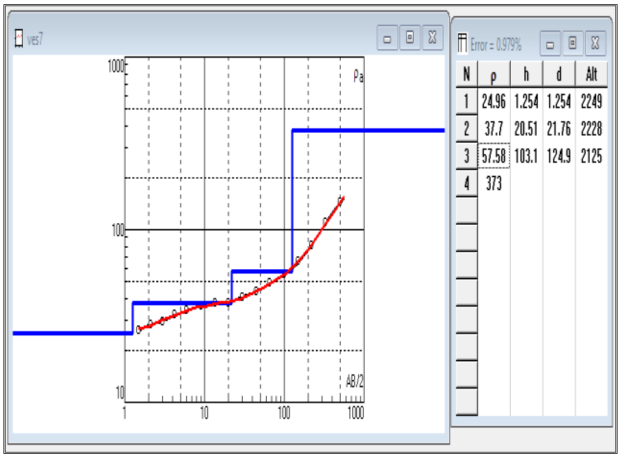
VES 4



VES 5

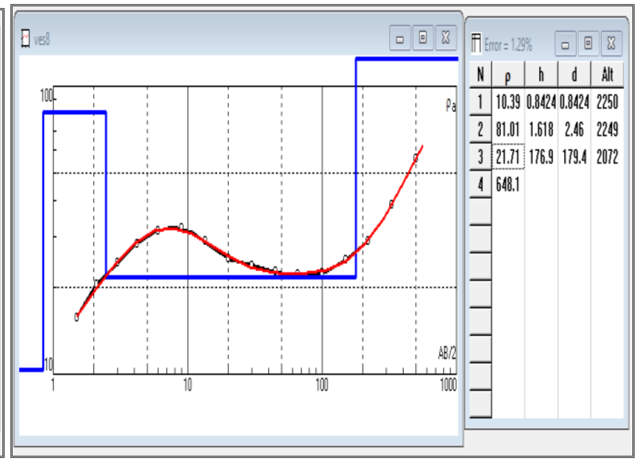


VES 6



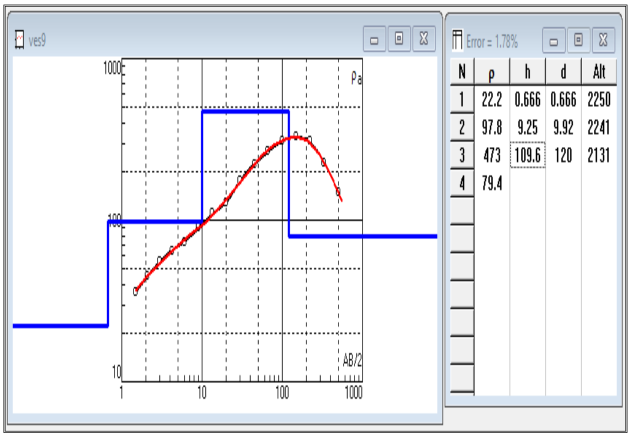
N	ρ	h	d	Alt
1	24.96	1.254	1.254	2249
2	37.7	20.51	21.76	2228
3	57.58	103.1	124.9	2125
4	373			

VES 7



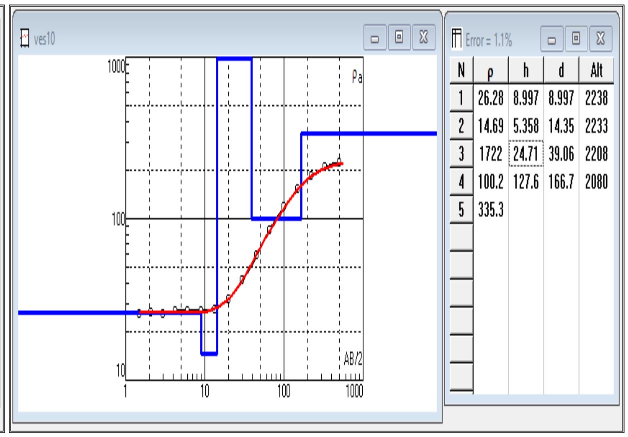
N	ρ	h	d	Alt
1	10.39	0.8424	0.8424	2250
2	81.01	1.618	2.46	2249
3	21.71	176.9	179.4	2072
4	648.1			

VES 8



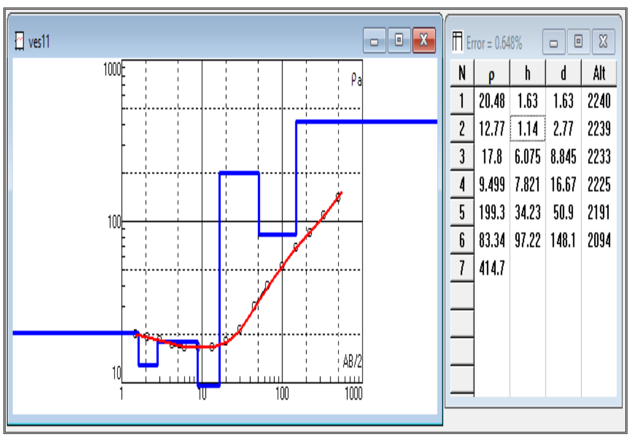
N	ρ	h	d	Alt
1	22.2	0.666	0.666	2250
2	97.8	9.25	9.92	2241
3	473	109.6	120	2131
4	79.4			

VES 9



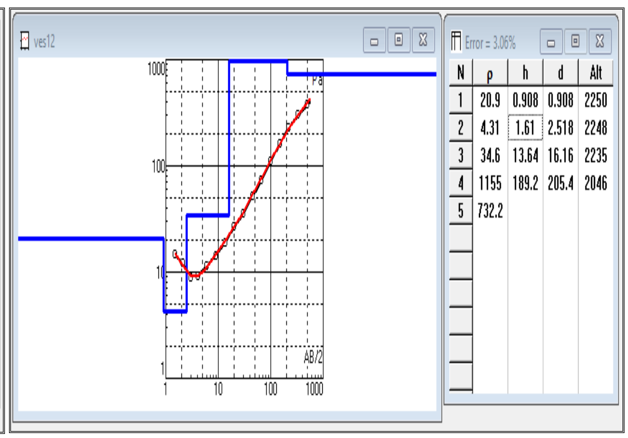
N	ρ	h	d	Alt
1	26.28	8.997	8.997	2238
2	14.69	5.358	14.35	2233
3	1722	24.71	39.06	2208
4	100.2	127.6	166.7	2080
5	335.3			

VES 10



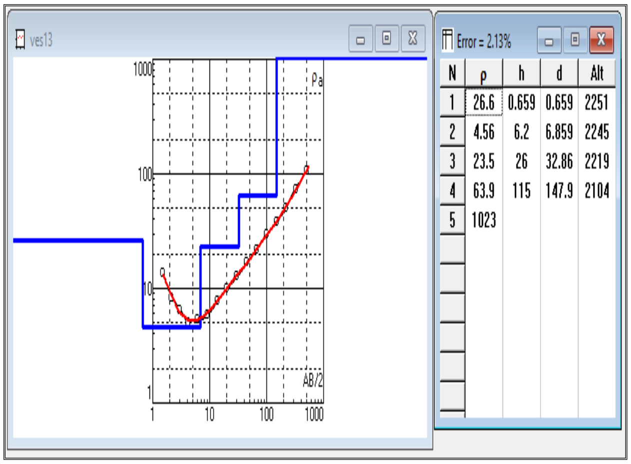
N	ρ	h	d	Alt
1	20.48	1.63	1.63	2240
2	12.77	1.14	2.77	2239
3	17.8	6.075	8.845	2233
4	9.499	7.821	16.67	2225
5	199.3	34.23	50.9	2191
6	83.34	97.22	148.1	2094
7	414.7			

VES 11

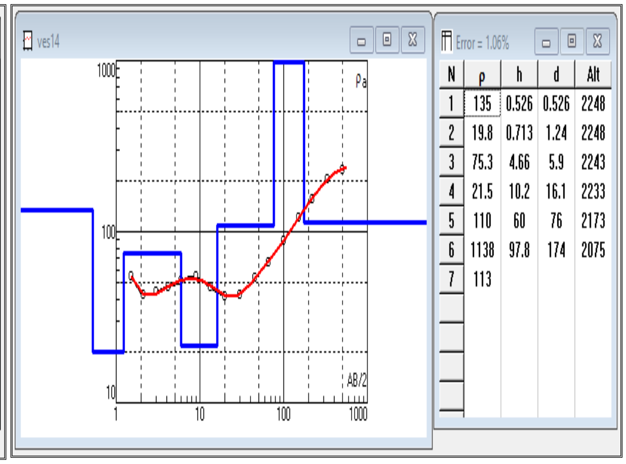


N	ρ	h	d	Alt
1	20.9	0.908	0.908	2250
2	4.31	1.61	2.518	2248
3	34.6	13.64	16.16	2235
4	1155	189.2	205.4	2046
5	732.2			

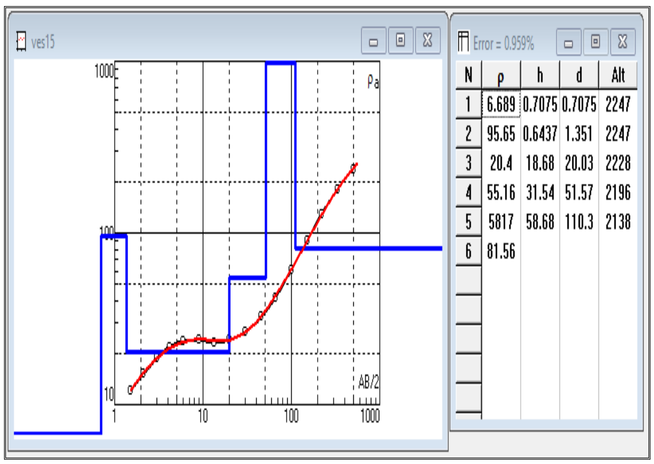
VES 12



VES 13



VES 14



VES 15

Figure 3 Interpreted Resistivity curves.

PSEUDOSECTION

Pseudo Section of Profile One

The pseudo section constructed for VES-1, 2, 3 and 4 that lie on the survey traverse line-1 are given in Figure-3. From the figure, there is lateral variation in resistivity of all the four VES points. There is low resistivity zone in VES-3 which is the black colored, then high resistivity zone in the blackish red left side of the section. The low resistivity value of VES-3 ranging from 4.3 ohm-m to 29.43 ohm-m is indicators of porous materials. On this profile VES-1 seems groundwater potential zone because the resistivity increases to 1346 ohm-m with depth of 22 m then decreases to 101 ohm-m with increasing depth up to 128 m.

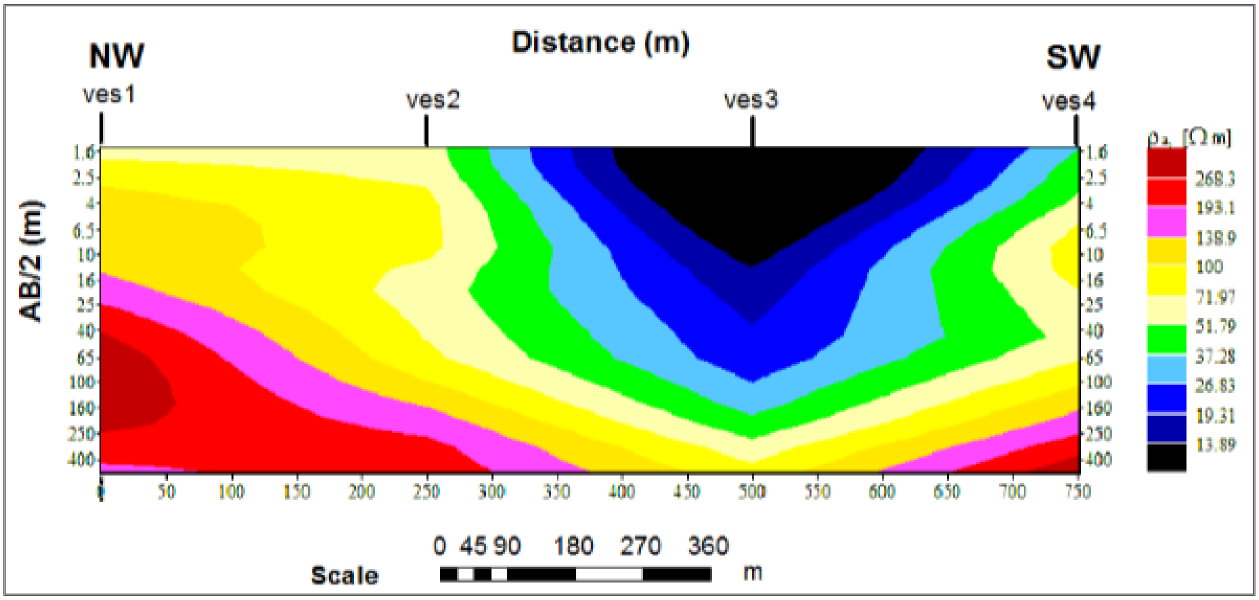


Figure 4 *Pseudo section of Profile one*

Pseudo Section of Profile Two

This profile is pseudo section of VES-5, 6, 7 and 8 given in Figure4. There is relatively small resistivity at the top of all VES points, this is not good indicator of groundwater, because are high porous with low permeability and are so shallow. According to the Figure 5, there is variation in resistivity extending to large depth. There is prominent high resistivity value away from the top at depth extending to 120 m for all the VES points. There is low resistivity zone which is below the top layer with resistivity ranging from 14 ohm-m to 81 ohm-m and depth up to 187 m and this is indicator of groundwater potential zone. These low resistive zones are located in between VES-5 and VES-6 also in VES-8.

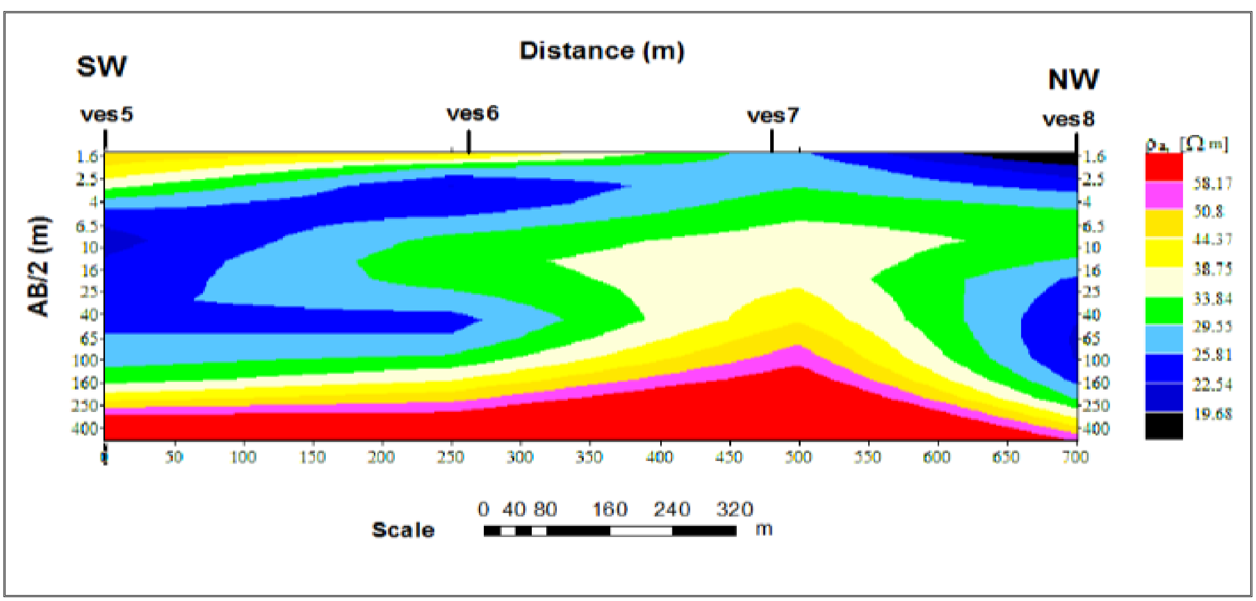


Figure 5 *Pseudo section of Profile two*

Pseudo Section of Profile Three

The pseudo depth section constructed for VES-9, 10, 11 and 12 is given in the Figure-6 below. There is a lateral variation in resistivity in the section with prominent high resistivity zone in the deep left side of the section near VES-9 greater than 268 ohm-m. The large area of the top section, especially VES-10, VES-11 and VES-12 has low resistivity. Whereas low resistive Zones between VES-10 and VES-11 are indicators of potential water saturation when going deeper from 38.7 m to 145 m with resistivity value of 100 ohm-m and 83 ohm-m to 199 ohm-m respectively. The high resistivity valued region that does not extend to large extent is mapped at VES-9 whereas there is low resistivity in this region when extending with depth in which this region may be good water potential zone.

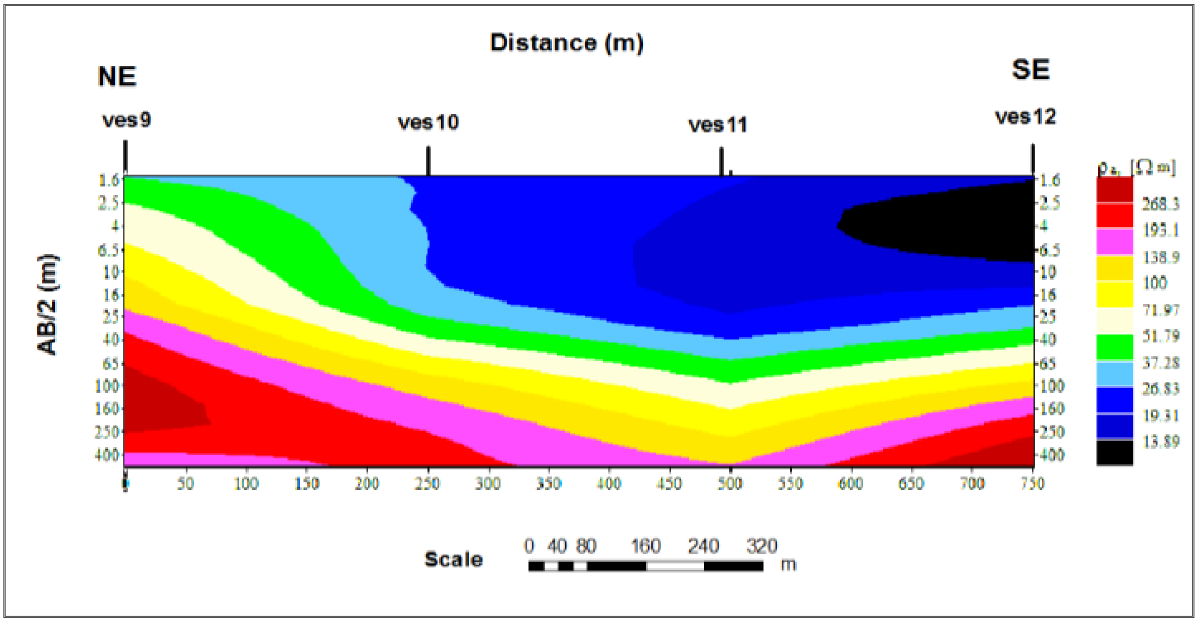


Figure 6 *Pseudo section of Profile three*

Pseudo Section and Geo-electric Section of Profile Four

This profile consist pseudo section of VES-13, 14 and 15 as shown in Figure-7. There is a lateral variation in resistivity in the section with prominent low resistivity zone in the top left side of the section near VES-13 with resistivity of 15 ohm-m and right side of the section near VES-15 with resistivity ranging 10 ohm-m to 13.9 ohm-m. In this profile VES-13 shows great water potential, as shown in the figure when going deeper there exist low resistivity value of 64 ohm-m with thickness of 44.1 m to 148 m. The large area of the medium of the section has small resistivity less than 120 ohm-m and the deep depth of VES-13 has small resistivity value of 64 ohm-m. And this region seems potential water saturation zone. The vast section of the bottom shows extensive coverage of the high resistivity zone.

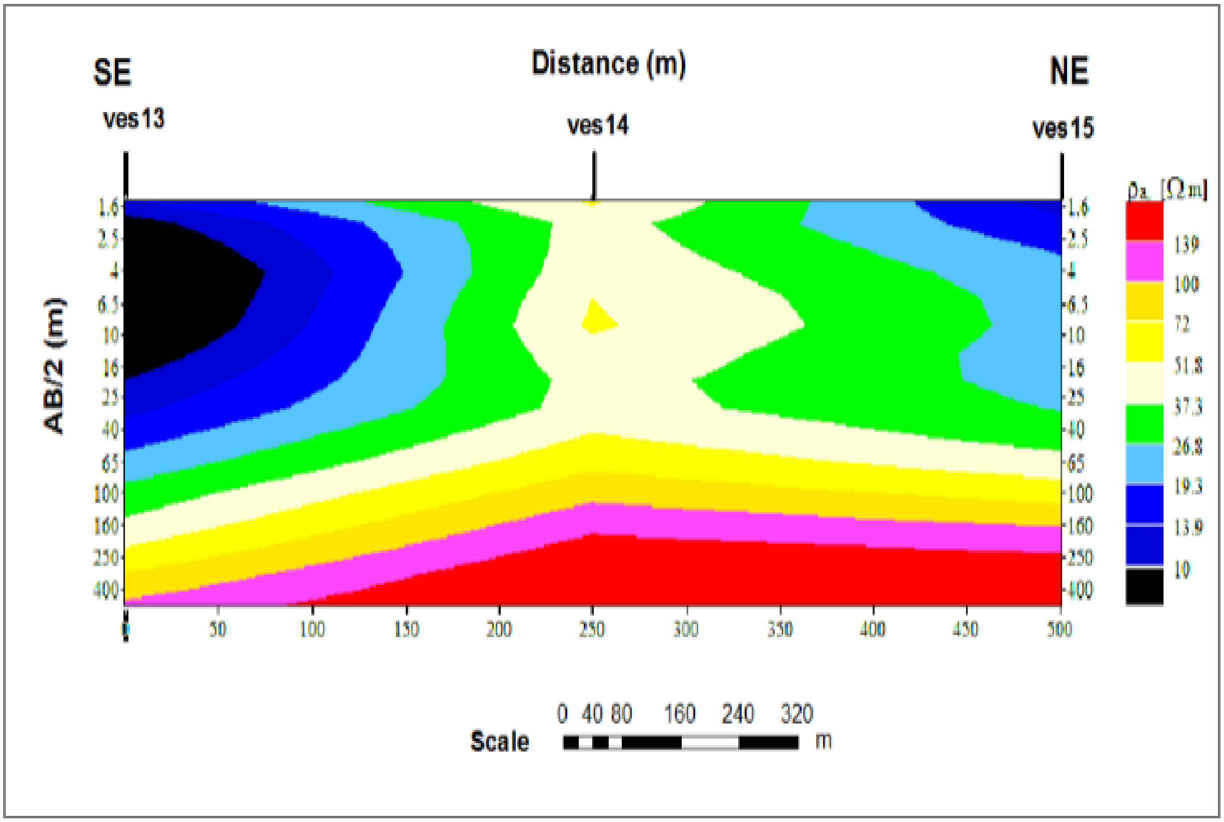


Figure 7 *Pseudo section of Profile four*

GEO-ELECTRIC SECTION

Geo-electric Section of Profile one

The resulting geo-electric section of profile one of VES-1, VES-2, VES-3 and VES-4 is given below in Figure 8. It consist different geo-electric layers and resistivity values. The first geo-electric section layer having resistivity of 24 ohm-m to 56 ohm-m with thickness from 0.51 m to 2.32 m interpreted as top soil. And this layer has relatively low resistivity value indicating the presence of clay intercalation. The second one is the marly-shale with limestone intercalation of resistivity value from 7.4 ohm-m to 327 ohm-m and thickness of 1.77 m to 29 m respectively and in VES-1 dolerite rock unit with 1249 ohm-m to 1346 ohm-m resistivity value and at depth up to 22 m. The third geo-electric layer with resistivity value ranging from 64 ohm-m to 178 ohm-m with thickness variation from 7.7 m to 114 m shows highly fractured limestone. The expected lithologic description of the fourth geo-electric layer manifested by VES-1 having resistivity value 411 ohm-m of depth from 53 m to 128 m is fractured limestone. Whereas the geo-electric section of the same layer marked by VES-2, VES-3 and VES-4 is assumed to be dolerite with resistivity value of 1188 ohm-m to 1554 ohm-m and thickness between 58 m to 196 m. The last geo-electric layer marked by VES-1, VES-2 and VES-3 with resistivity value of 49 m to 139 ohm-m found at 118 m deep may represent highly fractured limestone.

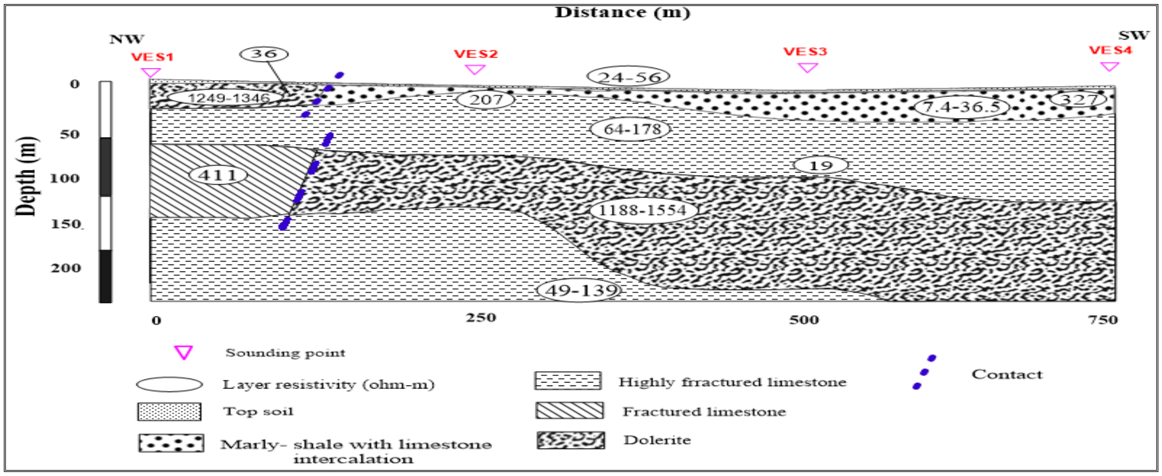


Figure 8 *Geo-electric section of Profile one*

Geo-electric Section of Profile two

The resulting geo-electric section constructed from the interpreted layer parameters of four VES lying along profile 2 is given in Figure 9. The first geo-electric layer is top clay soil with a resistivity ranging from 7 ohm-m to 115 ohm-m and a thickness variation of 0.6 m to 4.3 m, which may be saturated or dry top soil, respectively. The second geo-electric layer marked by VES-5, VES-6, and VES-7 indicates marly shale with limestone intercalation of resistivity values from 14 ohm-m to 42 ohm-m and 11 m to 120 m of depth variation. The third layer marked by VES-5 with a resistivity value of 5859 ohm-m and a depth greater than 120 m likely reflects massive dolerite. While the geo-electric section of the same layer, denoted by VES-6, VES-7, and VES-8, reveals the existence of severely fragmented limestone at depths between 2.5 m and 187 m with resistivity values between 49 ohm-m and 81 ohm-m, Limestone that has been fractured may be seen in the final geoelectric layer, which is designated by the numbers VES-6, VES-7, and VES-8 and has a resistivity range of 373 ohm-m to 648 ohm-m.

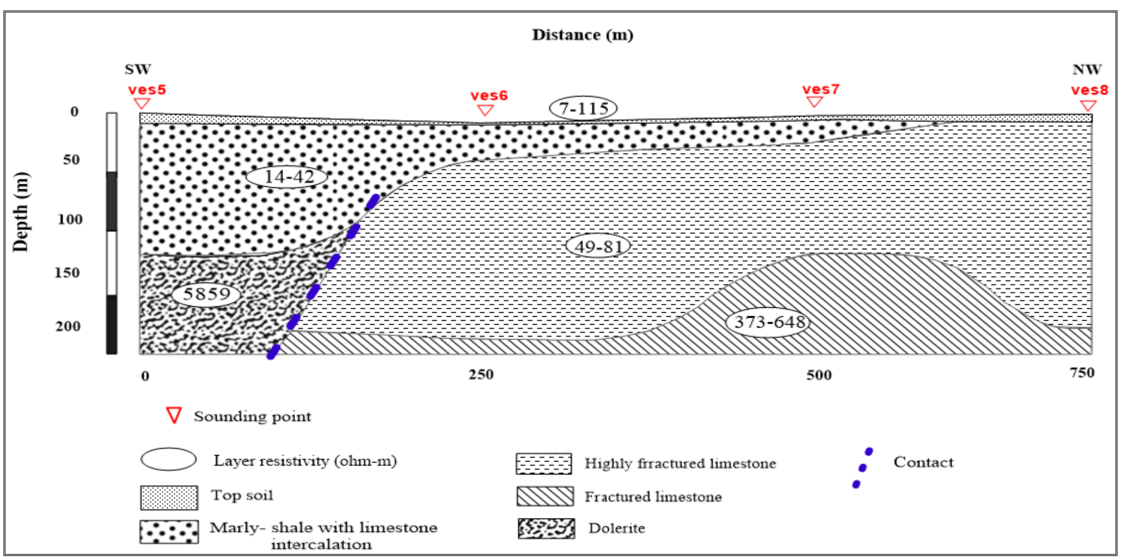


Figure 9 *Geo-electric section of Profile two*

Geo-electric section of Profile three

As shown in Figure 9, the first geo-electric layer is the top clay soil, whose resistivity ranges from 3 ohm-m to 20.2 ohm-m with a thickness between 0.6 m and 9 m. This layer is a good site for evapotranspiration and pipeline lying. In this layer, groundwater accumulation cannot be verified. The second geo-electric layer marked by VES-9, VES-10, and VES-11 shows marly shale with resistivity values of 9 ohm-m to 32 ohm-m and a thickness of 3 m to 17 m. The third layer marked by VES-9, VES-10, and VES-11 with a resistivity value of 83 ohm-m to 199 ohm-m and a depth of 0.6 m to 167 m likely reflects highly fractured limestone, whereas the geo-electric section of the same layer marked by VES-12 and some top parts of VES-10 with a resistivity value of 1121 ohm-m to 1722 ohm-m and a thickness of 14 m to 39 m and 17 m to 185 m, respectively, reflects the presence of dolerite. The fourth layer, with a resistivity value ranging from 335 ohm-m to 746 ohm-m, shows the presence of fractured limestone. Highly fragmented limestone with a resistivity value may be seen in the last geoelectric segment indicated by VES-9 of 79 ohm/m.

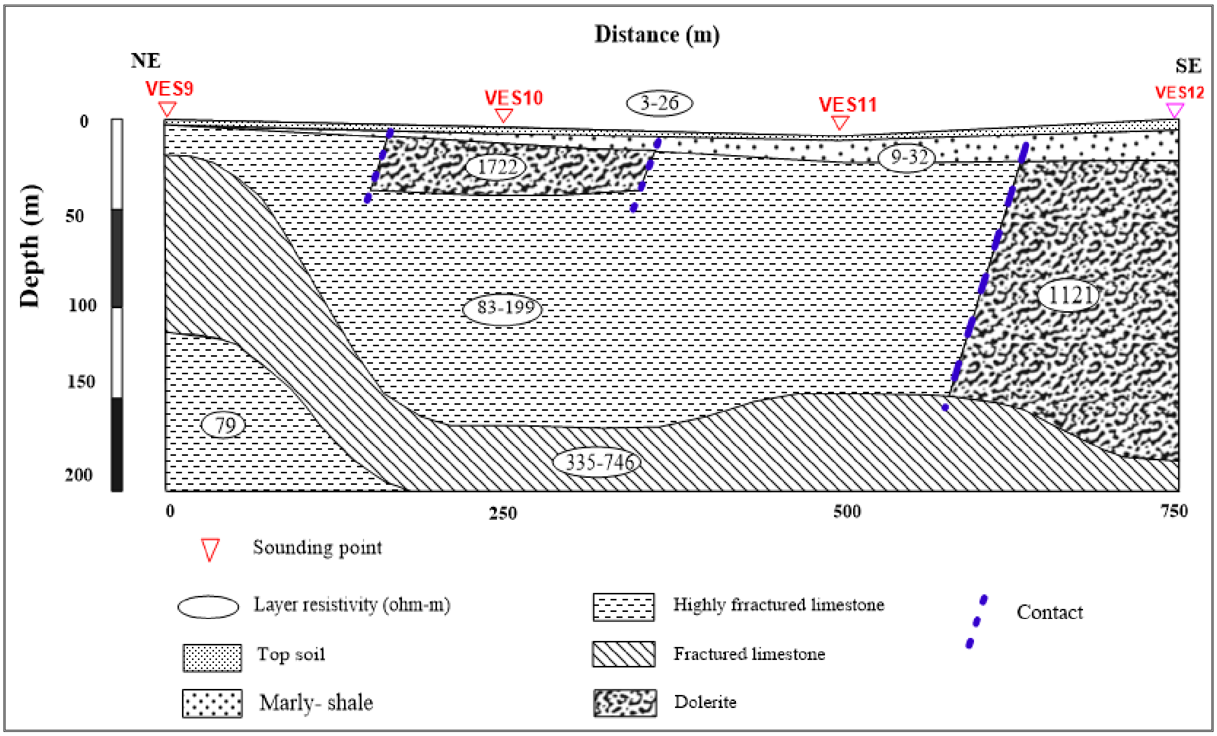


Figure 10 *Geo-electric section of Profile three*

Geo-electric section of Profile four

The geo-electric section of profile 4 consists VES-13, 14 and 15 as shown in Figure 10. The top layer is in generally combination saturated and dry clay soil with resistivity values of 7 to 135 ohm-m with thickness up to 1.5 m. The second layer shows marly shale with limestone intercalation of resistivity ranging from 5 ohm-m to 75 ohm-m and depth of 1.5 m to 52 m. The third layer marked by VES-13 and VES-14 clarifies highly fractured limestone with resistivity of 64 ohm-m to 110 ohm-m and thickness of 16 m to 148 m. While the geo-electric section of the same layer marked by VES-15 with resistivity value of 5817ohm-m and thickness from 52 m to 110 m reflects presence of massive dolerite. The last geo-electric layer marked by VES-13 and VES-14 shows dolerite with resistivity ranging from 1023 ohm-m to 1138 ohm-m, whereas highly fractured limestone appears in the same layer connected with the third geo-electric layer with resistivity value of 81 ohm-m (Figure 11).

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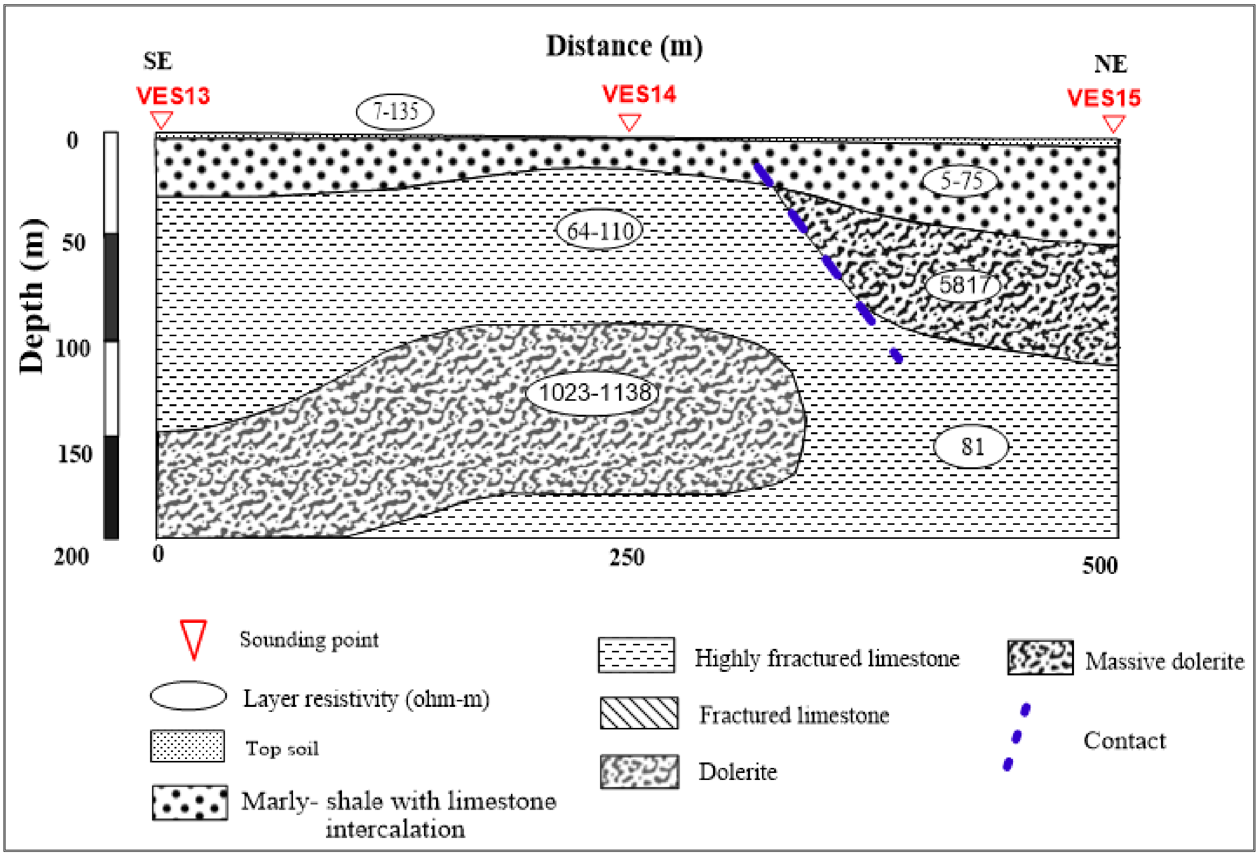

Figure 11 *Geo-electric section of Profile four*

CONCLUSIONS

The vertical electrical sounding (VES) survey of geophysical method was carried out in Arato sub-catchment, Eastern part of Mekelle city, Ethiopia. A total of 15 VES were collected in the Arato flat areas. From the survey it showed that marl-shale intercalation, fractured limestone and dolerite are dominant rock types with ascending of depth. After comparing the interpreted VES data's with the borehole data, the only difference showed was difference in thickness. The apparent resistivity pseudo-depth sections and the resistivity geo-electric sections showed the presence of shallow as well as deeper low resistivity horizons which showed potential zones of groundwater saturation. The low resistivity and high depth of these horizons may be an indicator of groundwater potential zone in the study area.

Generally geological profile sequence in the study area included the top clay soil, marly shale intercalation, fractured limestone and dolerite. And all profiles were interconnected with highly fractured limestone with an averaged maximum depth of 200 m. This showed that there exists fractured limestone rock type with large width and depth.

From the geo-electric section of profile one VES-1 and VES-2 with resistivity value of 101 ohm-m and 140 ohm-m at depth of greater than 128 m and 118 m respectively seems good aquifer zones. The geo-electric section of profile two showed low resistivity zone in VES-5 and VES-6 with the value of 20 ohm-m and 49 ohm-m with depth to 118 m and 187 m respectively, and geo-electric section of profile three displayed aquifer zone at VES-9 with resistivity of 79 ohm-m and depth of 120 m which is highly fractured zone. Whereas from the last profile four VES-14 seemed good potential zone of groundwater with resistivity value of 113 ohm-m at depth greater than 174 m. Comparing the potentially aquifer level of each geo-electric sections, VES-1 from profile one, VES-6 from profile two and VES-9 from profile three seemed good aquifer zones. There existed highly fractured limestone rock unit in VES-1, VES-6 and VES-9, and it is known that these rock units are layers of water bearing permeable fractured rocks. And from this result it was concluded that VES-1, VES-6 and VES-9 may be suitable zone of groundwater potential, as it had low resistivity with depth of 128 m, 187 m and 120 m respectively. Thus, borehole may be recommended in these VES points at depth of about 120 m to 130 m.

The occurrence of groundwater was highly influenced by the geologic forms, such as fracturing and contacts. These contacts may be due to the sedimentary rock deposited on an older rock or due to rocks intruded to another rock unit. The geology of the area especially topographically higher lands were mostly dolerite and limestone were affected by fracturing. This fracturing controlled the flow of groundwater in other words the recharge rate of the area increased due to fractured rocks of highly elevated areas. As understood from the result, observation and different research's done around the study area, the groundwater potential in the base of mountains and flat areas is high, due to high recharge rate of highlands, thick and small soil amount, ground flow and most of the water is drained in to the flat lands. Generally the study area can be graded as high aquifer level. Therefore this result is significant in alleviating the freshwater problems around the study area and Mekelle city.

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