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Research Article

Electrical Resistivity Method for Groundwater Exploration in Bure Industrial Park, Ethiopia

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ABSTRACT

The geophysical survey was conducted at the industrial park of Bure and the surrounding area, West Gojam, Ethiopia using vertical electrical sounding. The study aims to map groundwater potential aquifers and to identify and differentiate different geological structures that play a role in groundwater occurrence and movement. Furthermore, the study aimed in determining the groundwater horizons and identification of potential site selection to know the drilling point by interpreting the integration of geological, geophysical, and borehole data. For these, a total of 12 VES points were distributed on 3 Parallel profile lines. The VES data are processed Ip2win, Winreisit, and Surfer and Auto-CAD softwares. The results of the interpretation show that the study area is composed of two aquifers, shallow and deep aquifers. The shallow aquifer is exposed on the Northeast parts of the area within the gravel and highly fractured basalt rock units at a depth of 25 m. The lowest aquifer is found on the Southwest pars of the study area below a depth of 90 m within highly fractured vesicular and scoriaceous basalt. In the study area, the water table ranges from 10 m to 55 m and good groundwater potential gradually increases as the depth of investigation increases especially in the North West regions of the study area. Geological structure found in the study area that controls the movement and occurrences of groundwater and that trends NE-SW and NW-SE directions.

Keywords: Sounding points; VES locations; Magnetic data reduction; Magnetic anomaly pseudo sections; Geo-electric sections; Water table

INTRODUCTION

For years, various geophysical techniques have been employed either singly or in combination in the search for groundwater [1]. Geophysics is a nondestructive science that anyone can delineate the nature of the subsurface of the earth by using different methods along with different parameters [2]. In recent times, however, technology advancements have brought about the use of state of the art of geophysical techniques in groundwater exploration in complex terrains such as the use of magnetic and DC resistivity surveys in semiarid or arid terrains [3]. Other modern geophysical techniques for groundwater exploration include the use of airborne electromagnetic inductions and seismic refraction surveys in conjunction with Vertical Electrical Sounding (VES) resistivity methods [4].

In electrical resistivity method, many arrays can be used. These include Schlumberger, Dipole-Dipole, Winner, and Pole-Pole. Among others, the Schlumberger array takes the first section Vertical Electrical Sounding (VES), which has a symmetrical layout with electrodes spread on either side of the array spread and which requires large spacing at both ends for deeper information [5]. The Schlumberger arrays enable vertical electrical sounding with the movement of a current electrode (c1) while the other current electrode (c2) is fixed perpendicular (90°) to the line of spread, while the potential electrode remains temporarily fixed [6].

The use of geophysics for both groundwater resource mapping and water quality evaluations have increased dramatically over the last 10 years in large part due to the rapid advances in microprocessors and associated numerical modeling solutions that facilitated the rapid acquisition and processing of data and their presentation in a useful form [7].

The use of geophysics for groundwater studies has also been stimulated in part by a desire to reduce the risk of drilling dry holes and also a desire to offset the costs associated with poor groundwater production [8]. Today, the geophysicist also provides useful parameters for hydrogeological modeling of both new groundwater supplies and the evaluation of existing groundwater contamination [9]. In this respect, the major objectives of this study are to identify potential areas for extraction of groundwater

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resources in the study area and minimize the risk of sinking boreholes at inappropriate areas through the use of geophysical techniques. Specifically, the technique that will employ involves an electrical resistivity survey to get a general assessment of its groundwater resource.

The study area that lies on a Plate form topography in which there is an agroindustry park is building that requires a large supply of groundwater. The region around the study area is also widely used for agricultural purposes and thus putting further demand on water supply. Regarding the industries that have come into existence, the industries have yet to be connected to a municipal water source and could rely on groundwater resources of the area. Moreover, with the increase in the population near the study area, there is also a need for an increased volume of water resources for different purposes. All these demands combined and it becomes very necessary to map the area into hydrogeological zones to increase the number of potentially productive boreholes.

Finally, this research work is expected to give awareness to the government, organization the people livening near the area for groundwater development as well as to use the selected potentially productive aquifer sustainably and wisely.

Study area

The study area as shown in Figure 1, is found in the northwestern parts of Ethiopia, Amhara National Regional State, in the West Gojam zone. The town is located 411 km northwest of Addis Ababa and about 152 km southeast of Bahirdar town. The study area is accessed by an asphalt road that runs from Addis Ababa-Bure and a gravel road that runs from the main asphalt road to that of the industrial park. More specifically the town is geographically bounded between 10045’00” to 10046’00” N latitude and 37015’00” to 37016’00” E longitudes and the Geographical coordinates of Bure town where the study area is located are 288898 m east and 1184374 m north.

MATERIALS AND METHODS

To achieve the above objectives, several steps have been followed.

The First phase includes reviewing different previous works, not only geophysical works (groundwater exploration and identification of geological structures) but also geological and hydro-geological works of literature on the study area.

The second phase was geophysical data collection in which Fieldwork was carried out to collect primary data of Resistivity (R) data of subsurface layers as shown in the Figure 2 below. The Vertical Electrical-resistivity Sounding (VES) technique measures the variation of earth resistivity at depth by passing an electrical current into the ground and measuring the resulting potentials created at depth [10]. To acquire all the above-corrected data and information appropriate instruments were used.

The third phase was done after returning from the field in which different software’s have been used for processing and interpretation. The collected electrical resistivity raw data was interpreted and analyzed using appropriate software like RESIST, Ip2win, SURFER, AutoCAD 2007, and Microsoft.

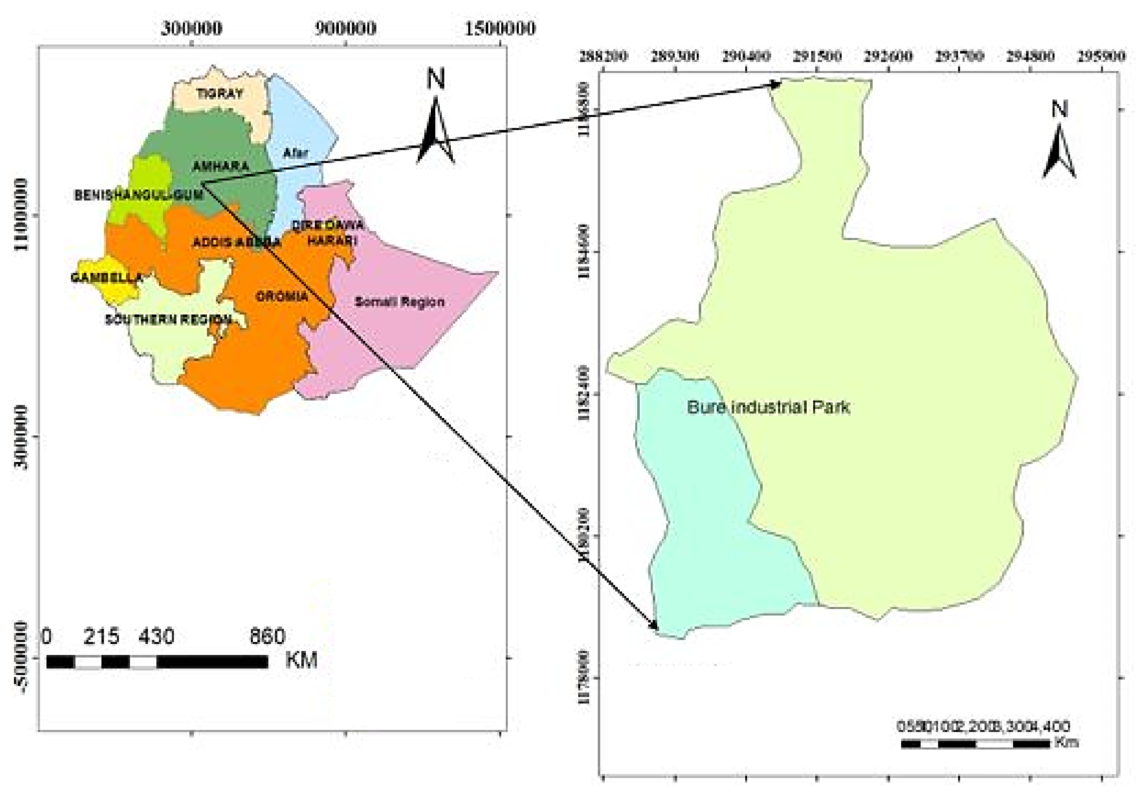

Figure 1: Location map of the study area. **Note:** ( ) Addis Ababa, ( ) Amhara, ( ) Afar, ( ) Benishangul-Gumuz, ( ) Dire Dawa, ( ) Gambela, ( ) Harari, ( ) Oromiya, ( ) Southern region, ( ) Somali region, ( ) Tigray, ( ) Tengha locality, ( ) Wangedam locality.

Figure 2: Electrical resistivity data acquisition on the field.

RESULTS

The apparent resistivity data versus the electrode spacing plotted on a bi log scale is interpreted using IP2win to have an initial model parameter of each sounding curve to be entered into inversion Win RESIST software. This is important to produce different anomaly curves which show contrast in the resistivity and depth of the subsurface rocks [11].

By correlating the field curve with the existing borehole log data it is seen that there is a good correlation between them for all the VES points. This is attested by havening RMS error of 1.5-4.8% obtained for all VES point data. From all the sounding points two of the VES points having layers of 3-6 with AB/2 of 500 m represent the subsurface geologic formation for which two of interpreted VES curves are presented below.

According to the curve shown in the Figure 3, it has been correlated with the nearest borehole data and the first layer has a high resistivity of 99.1 due to compacted and dry soil and its resistivity value gradually decreases to 61.6 ohm-m is its moisture content gets maximum. The third and fourth layers have a resistivity value of about 31 and 37.6 Ohm-m supposed to be weathered and fractured basalt and are most likely the water-bearing horizon. The last layer that has a resistivity value of 120.1 ohm-m would be the response of slightly fractured basalt and scoriaceous basalt rock units.

The other interpreted VES curve which is shown in the Figure 4 is VES 10 with AB/2=500 m containing 6 geo-electric layers. According to the curve given below, it has been correlated with the nearest borehole data and the first two-layer clay soil with different moisture content. The third layer that has a resistivity value of 8.4 Ohm- m is supposed that clay is saturated by water and forms swamp-like horizons. The fourth layer with the highest resistivity represents slightly weathered and fractured basalt. The fifth layer is a highly fractured scoriaceous/Gravel deposit and is most likely the water-bearing horizon. The last layer that has a resistivity value of 181.8 ohm-m would be the response of slightly fractured basalt units.

Sliced-stacked maps

Figure 5 shows the slice stacked maps were constructed by superimposing the two-dimensional apparent resistivity plan maps for five different half current electrodes. The spacing chosen for these representations at different AB/2 values are 1.5, 45,100, 330, and 500 m and is believed to be adequate to represent the variation in apparent resistivity over the whole surveyed area with depth. These maps show the relative apparent resistivity of lateral vacations of the sub-surface over the horizontal plane at depths about 0.75, 22.5, 50, and 165 and, 250 meters respectively. More specifically the map shows the relative variation of the apparent resistivity values of the whole surveyed area varies both horizontally as well as vertically at different pseudo depths.

According to the figure given below, it is found that the apparent resistivity value considerably varies from 20-200 Ohm-m. From the given maps the most interesting feature of this sliced plot is the low resistivity zone less than 90 ohm-m that occupies the vast portion of the study area. The value of the high apparent resistivity value zone decreases as the investigation depth increases. The value of the low apparent resistivity zones observed in the North, Northwest, and Southwest parts of the area selected AB/2 of 330 m and 500 m. Another low resistivity zone is found at shallow depth in the northeast and southeast at a pseudo depth of AB/2 45 m and 100 m. On the other hand, the relatively very high resistivity response, (>90 ohm-m) that is found in the northeastern and southeastern part of the area for AB/2 AB/2=1.5 m, 45 m, and 330 m and in the North and northeast part at AB/2=330 m and 500 m and generally at AB/2=500 m the low resistivity zone dominates the wide area.

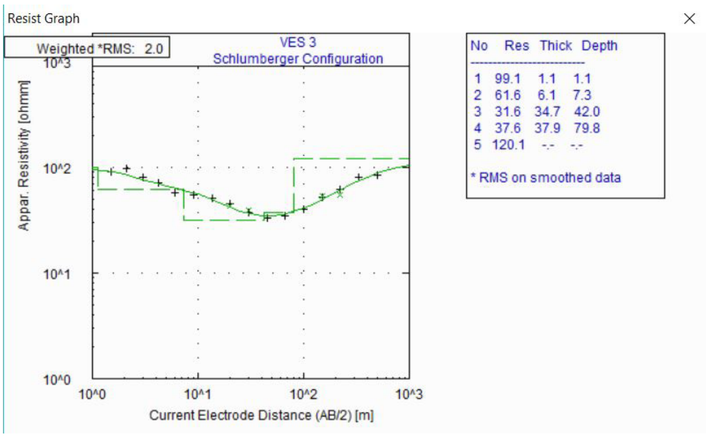

Figure 3: An interpreted VES three curves. **Note**: VES curve.

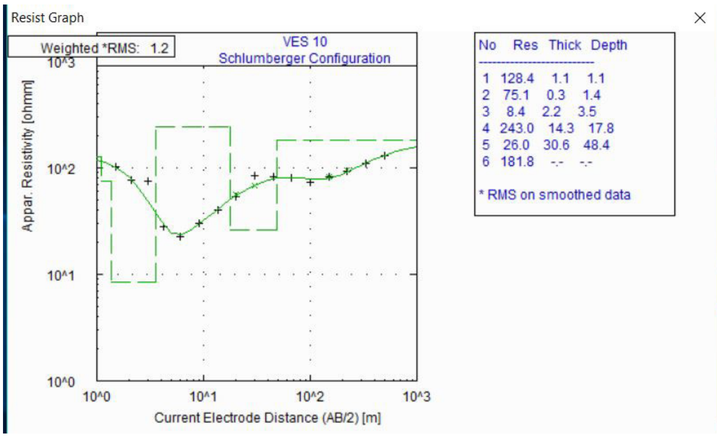

Figure 4: Interpreted VES ten curves. **Note**: VES curve.

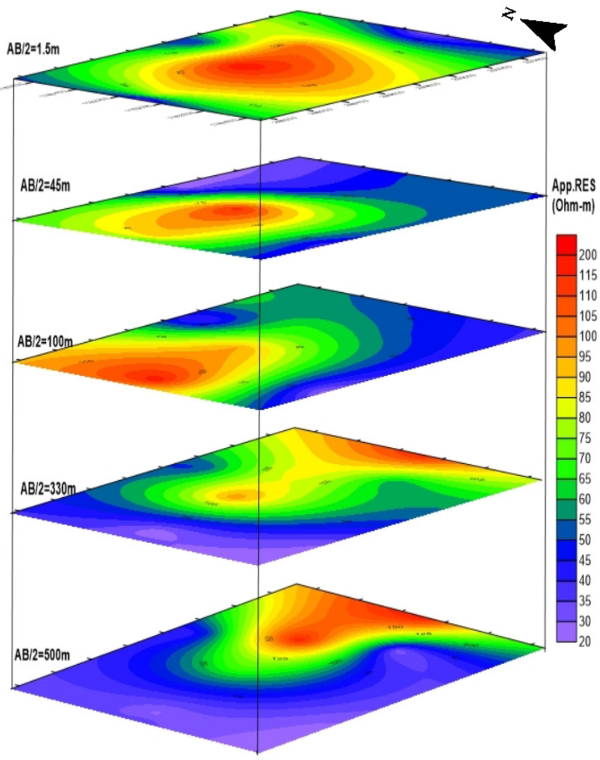

Figure 5: Sliced stacked map for different AB/2 showing low to high apparent resistivity zones.

Apparent resistivity pseudo-depth and geo-electric sections along with the selected profile

Pseudo depth section of profile one: The pseudo–depth section in this profile consists of 4 VES points VES 1, 2, 3, and 4 in which all these lie on survey line profile one as shown in the Figure 6. The map below shows that there is relatively variation in apparent resistivity both laterally and vertically especially in the direction of the northeast. The high resistivity zone extends at a pseud-depth of 300 ms below at VES 1 while the remaining low resistivity zones cover a wide area and are found at the top section of this profile. The resistivity value that ranges between 20-80 ohm-m is an indication for groundwater potential zones.

Geo-electric section of profile one: In Figure 7 which shows a geo-electric section that was constructed from the interpreted layer parameters of the 4 VES which lies on this profile as shown below. To model the geo-electric section of this profile Well logging data taken from boreholes located near to this traverse line especially close to VES one used to correlate and constrain the depth and to differentiate (identify) different rock units beneath these VES points. The total numbers of layers that are constructed in this profile are five in the first geo-electric layer has a resistivity value that varies from 62 to 69. And its thickness ranges from 4.5 to 10 meters. This layer is dominantly composed of soils, unconsolidated sediments, and rock fragments with variable moisture content. The second layer forms a resistivity range of 42-62 ohm-m and thickness varying 9-34 m beneath the VES points. This layer is inferred as highly fractured vesicular basalt with different degrees of fracturing and water content.

The third geo-electric layer corresponds to saturated layer manifests resistivity value varies highly, i.e., 19-38 ohm-m with thickness variation from 23-52 m and may be represented river gravel deposit that includes a varying rock units sand and salty, vesicular basalt with boulder sand slightly and highly weathered and fractured basalt that are eroded transported and deposited at this layer. At this layer especially at the location of VES2 potential groundwater is found compared to the layers discussed above.

The fourth geo-electric layer especially at the VES4 location is detected and has a depth of 38-71 meters and it extends to a certain depth for the remaining sounding points. It is characterized by slightly and moderately weathered and fractured basalt rock units. The bottom resistive layer is detected intermittently at the location of VES-4 (53 ohm-m) and represents scoria and a highly fractured and weathered scoriaceous Vesicular basalt bedrock. At this layer, the degree of fracturing is much higher and maximum compared to the other layer resistivity regions and it is the most promising layer that has the maximum amount of groundwater potential is expected to found.

Pseudo depth section of profile two: The pseudo-depth section on this profile which is shown in the Figure 8 was constructed for VES 5, 6, 7, and 8 that lies on the same traverse line. According to this figure as shown below there are both lateral and vertical relative resistivity vitiations that range from 20-190 (ohm-m). In this section, relatively high resistivity values are associated with VES5 that extends at a pseudo-depth of 100 m to a large depth of investigation. The middle side of the section has relatively small apparent resistivity values especially near VES6. The other lowest resistivity anomaly is found at the location of VES8 that extends at the middle to last depth of investigation. The resistivity ranges 0 to 80 ohm-m of this low resistivity region are an indication for good groundwater potential saturation.

Geo-electric section of profile two: In the Figure 9 which is a geo-electric sections were constructed from the interpreted layer parameters of the 4 VES which lies on this profile as shown below. To model the geo-electric section of this profile Well logging data taken from boreholes located near this traverse line especially close to VES8 used to correlate and constrain the depth and to differentiate (identify) different rock units beneath these VES points. The total numbers of layers that are constructed in this profile are five. In the first geo-electric layer the resistivity value varies from 44 to 389 and its thickness ranges from 3 at VES5 and to 10 meters at VES6, VES7 and VES8. This layer is dominantly composed of top soil, unconsolidated sediments, and rock fragments with variable degrees of moisture content.

The second geoelectric layer is marked by form a resistivity range from 31-81 ohm-m and the thickness varying from 3-34 m beneath the VES points. This layer likely show highly fractured basalt, Gravel deposit silt, sand, and other rock fragments with different degree of fracturing and water content. This layer is dominated by low resistivity values for all VES points under this section and shallow groundwater is expected to be found.

The third geo-electric layer agrees to have a resistivity value that varies from 190-282 ohm-m with thickness ranges from 28-50 m and represents scoria and massive basaltic rock units. This layer especially at the location between VES6 and VES7 may indicate a good groundwater potential aquifer zone.

The fourth geo-electric layer is indicated by a resistivity value that varies from 73-146 Ohm-m with thickness ranges from 50-90 m and represents highly fractured and weathered scoriaceous basalt with a little sand and gravel deposits.

The last resistivity layer having an average resistivity value that ranges between from 41 to 65 is indicated and represented by highly fractured vesicular basalt. At this layer for all VEs locations may indicate the resemblance in water-bearing capacity and yield of the aquifer is to be found good groundwater potential.

Pseudo depth section profile three: This pseudo-depth section constructed containing VES 9, 10, 11, and 12 lies on the same profile line 3 as shown in the Figure 10 below. VES 9 and 10 found on the left side, that shows a small resistivity anomaly up to a few depths and it gradually increases and becomes highest at large depth. Otherwise, the vast area on the right side of the section has relatively small resistivity extends to dipper depth and is located at VES-11 and 12. At these VES regions, the large area of the bottom of the section has small resistivity with a resistivity value of less than 100 ohm-m. Generally, a half region under the section shows extensive coverage of the low resistivity zone and the resistivity values that range from 20 to 200 ohm-m of this low resistivity region are indicative of groundwater potential zones.

Geo-electric section profile three: A geo-electric section that is constructed from the interpreted layer parameters of the 4 VES which lies on this profile as shown below (Figure 11). To model the geo-electric section of this profile Well logging data taken from boreholes located near this traverse line especially close to VES12 used to correlate and constrain the depth and to differentiate (identify) different rock units beneath these VES points. The total numbers of layers that are constructed in this profile are five.

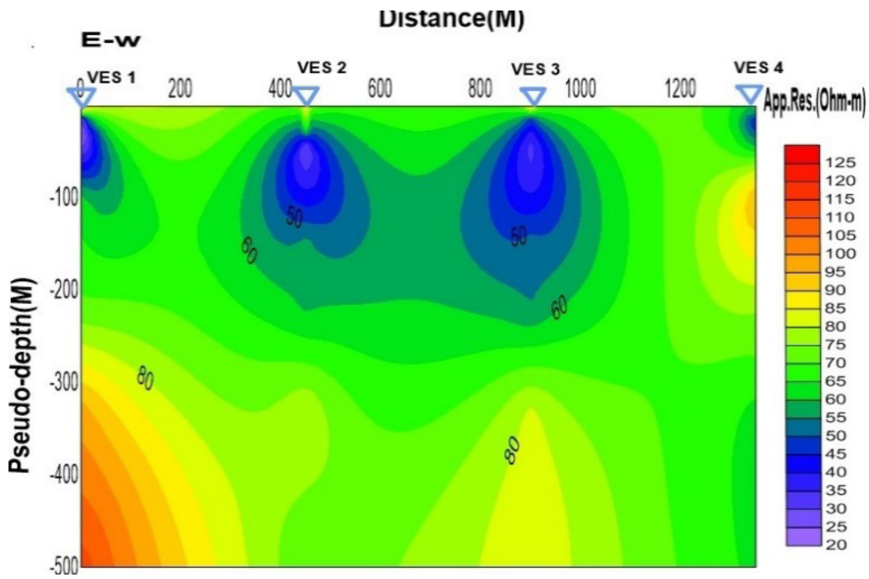

Figure 6: Pseudo depth section of profile one which shows the apparent resistivity value variations from 20 to 130 ohm-meter.

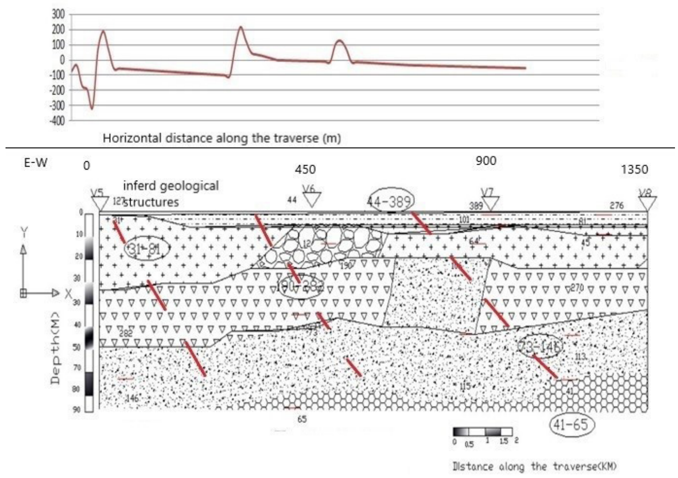

Figure 7: Geo-electric section of profile one that shows the rocks sequences up to depth of 100 m.
Note: (▽) Sounding points, (◍) Massive basalt, (◍) Top soil, (◍) Vesicular basalt, (◍) Fractured basalt, (◍) Gravel deposit, (◍) Highly fractured scoracious basalt, (◯) Layer resistivity interval value (ohm-m), (—)Infered geological structures, (—) Residual.

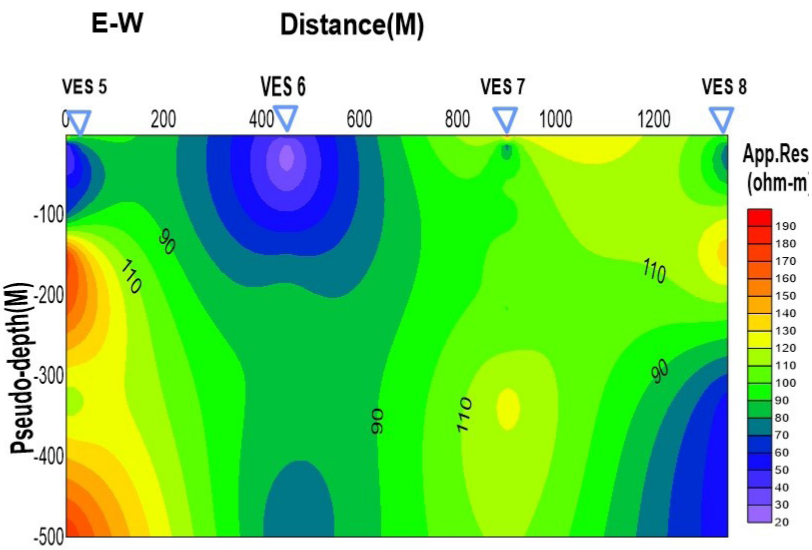

Figure 8: Pseudo depth section of profile two which shows the apparent resistivity value variations from 20 to 200 ohm-meter.

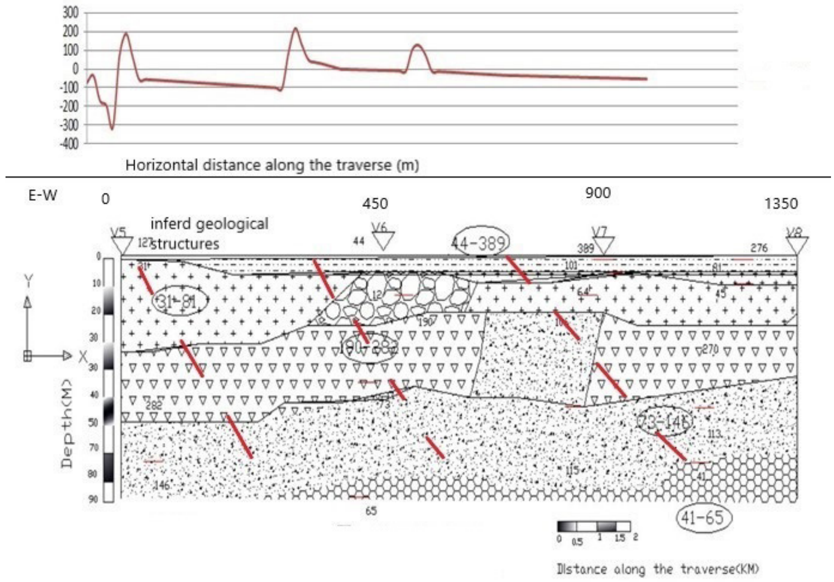

Figure 9: Geo-electric section of profile two that shows the vertical sequences rocks up to depth of 100 m.
Note: (▽) Sounding points, (◍) Massive basalt, (◎) Top soil, (◎) Vesicular basalt, (◎) Fractured basalt, (◎) Gravel deposit, (◎) Highly fractured scoracious basalt, (◯) Layer resistivity interval value (ohm-m), (▬)Infered geological structures, (▬) Residual.

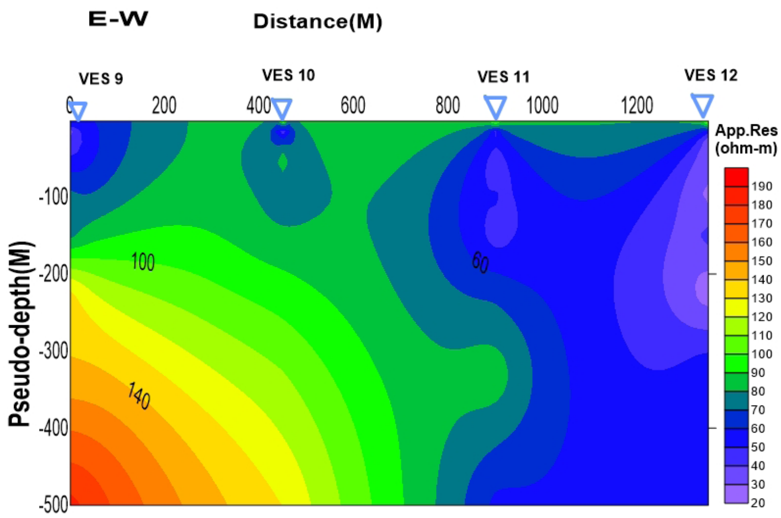

Figure 10: Pseudo depth section of profile three which shows the apparent resistivity value variations from 20 to 130 ohm-meter.

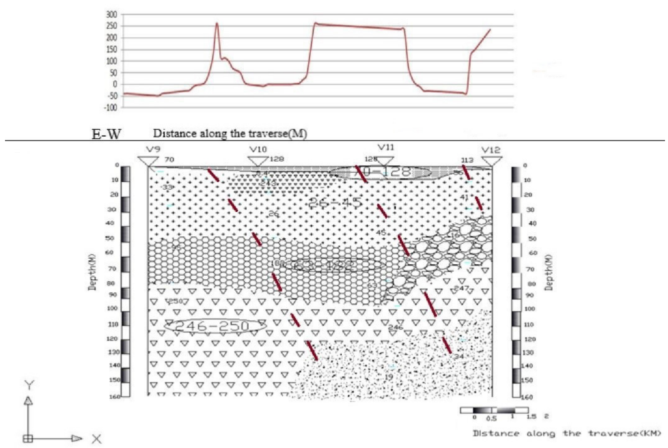

Figure 11: Geo-electric section of profile three that shows the vertical rocks sequences up to depth of 160 m.
Note: (▽) Sounding points, (◍) Massive basalt, (◎) Top soil, (◎) Vesicular basalt, (◎) Fractured basalt, (◎) Gravel deposit, (◎) Highly fractured scoracious basalt, (◯) Layer resistivity interval value (ohm-m), (▬)Infered geological structures, (▬) Residual.

In the first geo-electric layer the resistivity value varies from 70-128 ohm-m and its thickness ranges up to 9 meters. Similar to the above geoelectric layer this layer is dominantly composed of top soils, unconsolidated sediments, and rock fragments with variable degrees of moisture content.

The second geoelectric layer is marked by form a resistivity range from 26-45 Ohm-m and the thickness varying from 9-55 m. This layer likely show highly fractured basalt, Gravel deposit silt, sand, and other rock fragments and decomposed rocks with different degree of fracturing and water content. This layer is dominated by low resistivity values for all VES points under this section and shallow groundwater is expected to be found.

The third geo-electric layer agrees to have a resistivity value that varies from 68-188 ohm-m with thickness ranges from 52-80 m and represents river gravel and vesicular basaltic rock units. This layer especially between VES11 and VES12 may indicate a good groundwater potential aquifer zone.

The fourth geo-electric layer is indicated by the relatively highest resistivity value that ranges from 246-250 ohm-m with a thickness range from 50-90 m and massive basalt

The bottom layer is identified at VES 11 and VES12 and the resistivity values abruptly decrease. This layer is marked with resistivity values of 19-34 ohm-m and represented by highly fractured and weathered scoriaceous basalt rocks with clay and sand-sized and gravel deposits. At this layer, the degree of fracturing is much higher and maximum compared to the other layer resistivity regions and it is the most promising layer that has the maximum amount of groundwater potential.

DISCUSSION

From the results obtained as it is interpreted and discussed in chapter five, the following conclusions have been drawn using the synthesis of data presentation approaches.

1. Volcanic rocks more specifically the basaltic rock units cover most parts of the study area it's surrounding. The groundwater flow and storage on this rock unit depends on weak zones or along its fracture openings. By correlating electrical resistivity with the borehole data; among the groups of igneous rocks, groundwater is stored in highly weathered and fractured scoriaceous basaltic rock units.

2. Relatively Bure Integrated Agroindustry Park is suited at lower topography it is a place where Yisir and Silala rivers decrease its speed. Therefore, it is an area where a variety of rock fragments materials transported by the rivers are deposited and accumulated. The grain size of the materials varies from silt size to gravels and boulders and its thickness reaches up to 40 m in some parts of the study area. Generally, from borehole data in the area gravel deposit is characterized by excellent groundwater potential aquifers.

3. The most important geologic rock units found over the survey area that is likely to bear groundwater (based on the degree of fracturing and weathering) are Gravel deposits and highly fractured scoriaceous basalts. The highly to moderately weathered and fractured basalts and sand layer supply more for the recharge and movement of the groundwater through the wake zones and faults.

4. In the study area geological structures have a great influence on the movement and occurrences and movement of groundwater. Moderately to highly weathered fractured rocks act as a conduit for the movement of groundwater.

5. Both the apparent resistivity pseudo section and the true geo-electric sections show the presence of shallow and deep groundwater potential aquifers. In the survey, the lowest resistivity larger thickness, and deeper depths are the most promising indicator for high potential groundwater aquifers.

6. Comparison of the geophysical interpretations with drilled borehole results shows that the results of the geophysical survey are a good correlation with the borehole lithological logging results.

7. As it is shown from the sliced stacked section the study area is composed of two Aquifers. Shallow aquifers were found on the northeast part and relatively deep aquifers were found on the southwest parts of the study area. These two aquifers are separated by geologic structures (faults, and contacts). Therefore, Geological structures play a powerful role in the occurrence and movement of the groundwater in the study area.

8. In the study area the water table ranges from 10 m to 55 m and good groundwater potential gradually increases as the depth of investigation increases especially in the North West regions of the study area.

9. The most important locations with their depth for water-bearing layers over the study area for each profile line are described as follows.

Profile one: As shown from the geo-Electric section in Figure 7, good groundwater potential is located at VES4 mapped at a depth of 90 m and shallow aquifers are also found at VES1, VES2, and VES3 below the depth of 25 m.

Profile two: At this traverse line boreholes drilled below 50 m at location VES7 have high and good groundwater potential zones.

Profile three: In this line as shown especially at the location of VES12 with a depth of 50 m and 115 m, two groundwater horizons are expected to be found.

CONCLUSION

Based on the results of the study the following thoughts are concluded:

1. The borehole site for drilling is given in the following order. The first borehole site is recommended to be at profile three VES 12, profile two VES 7and 8and profile one VES 4 with UTM coordinates (289311, 1182464), (289643, 1183154), (289071, 1183048), (288952, 1183429) respectively.

2. For an additional and further deep groundwater exploration the area has to be studied in detail by having maximum current electrode separation and survey by horizontal and perpendicular direction of the existing profiles for detail investigation for the extension of low resistivity zones.

3. From the regional point of view the water found in some parts of the town is saline and for the investigation of the quality of groundwater in the area, it is highly recommended to study and map the chemistry of groundwater in detail.

4. Similarly in some parts of the town during to a large depth drilling and becomes dry due to structural effect. Therefore, I highly recommended the area to study in detail structural geological investigations for mapping the orientation of fractures, faults, and weak zones as well as their natures like a strike, dip, and their extension.

5. Industrial, agricultural and domestic west disposal activities

are polluting the surface water and shallow groundwater tables to minimize this it has to be drained properly for better water chemistry with long-lived life.

6. Further geological and hydrogeological study has to be recommended to study the basin, amount of precipitation, and evaporation which are used to estimate the percolation of surface water to the groundwater.

7. And finally for the additional VES survey, it is recommended in the horizontal and perpendicular direction of the existing profiles for detailed investigation for the extension of low resistivity zones.

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