GROUNDWATER POTENTIAL ASSESSMENT USING ELECTRICAL RESISTIVITY METHOD: A CASE OF ARATO SUB-CATCHMENT, ENDERTA WOREDA, MEKELLE CITY, ETHIOPIA

Abstract

Nowadays, groundwater research has become critical in order to acquire fresh and clean water from the bedrock. Consequently, using various geophysics methods to successfully explore freshwater in sedimentary province necessitates understanding of its distribution and movement of water with in rocks. Utilizing the Electrical Resistivity Technique, this research was performed to assess the groundwater potential of the Arato sub-catchment of Eastern Mekelle city. Vertical electrical sounding was performed at the location within a 2km2 area coverage. The acquired data were interpreted using computer software through a reiteration process , and the geological sections were completed by comparing and evaluating the interpreted VES data with the characterized rock and soil materials from existing boreholes showing different layered formations. From the survey it showed that marl-shale intercalation, fractured limestone and dolerite are dominant rock types ascending with depth. 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 showing highly fractured limestone and were concluded as good groundwater aquifer zones. As well as highly aquifer zones were identified. This showed that the occurrence of groundwater was highly influenced by the geologic forms, such as fracturing and contacts. Lastly borehole investigations were recommended at VES 1, VES 6 and VES 9 with depth from 120 m up to 130 m.

Keywords: *Resistivity,Dolerite, Groundwater potential, Limestone, Lithological log*

1. Introduction

Water is among the most important raw materials for all living soul of the planet, also is critical for significant socioeconomic growth [Dhinsa et al., 2022]. Most people require around 2.5 liters of water each day, and the average quantity of water used by each individual is approximately 190 liters.

Groundwater, on the other hand, is estimated to account for around 98% of the world's relatively consistent supply [Lateef, 2012]. Groundwater may be found practically wherever under the earth's crust, in a sole extensive water aquifer and hundreds of local aquifer systems [Dhinsa et al., 2022].

Water resources are being explored in order to quench the thirst of millions of people. Despite its widespread availability, nature does not give groundwater in the locations of our choosing. Groundwater exploration has grown in importance in recent years, and delivering it to the needy is the most valuable of all. It is a vital natural resource for all humanity and the backbone of civilization. It is also a large source that contributes significantly to global water demand [Alabi et al., 2010]. Groundwater is the extremely widely distributed resource on the planet, with virtually all of the water in the ground originating from precipitation that has penetrated into the soil [Ali et al., 2017]. Groundwater resources occur and are distributed in certain geological formations and structures [Ayenew et al., 2008]. Groundwater occurrence is not uniform due to its dependency on numerous environmental and geological factors, that is, groundwater recharge and occurrence are primarily regulated by geology, degree of fracture, topography, and the quantity and distribution of rainfall [Tesfa and Girum, 2019].

Groundwater has an important role in Ethiopia, where it is utilized for irrigation, industry, and residential purposes, also it is found in sediments, sandstone, alluvial, and karstic limestone [Ali and Goshu, 2017]. The disruption of groundwater is being caused by increased population expansion and urbanization. The limited supply of pure drinking water for human and cattle populations, as well as agricultural needs, is known in the lowlands. Whereas water started to be a crucial reserve for long-term fresh water contribution and nourishment of each individuals in several upland areas of the country[Ali and Goshu, 2017]. In Ethiopia, a lack of understanding about the sustainable use of groundwater resources created gaps in water exploration. The majority of Mekelle's water supply comes from the groundwater of the Aynalem and Chinfers well fields, which are experiencing fast water table lowering owing to rising household and industrial water demand [Abdelwassie et al., 2021].

Because of the possibility of accessing fresh water from the bedrock, groundwater research has become critical nowadays. As a result, using applications of geophysics to successfully explore water-table aquifer in sedimentary province necessitates a thorough comprehension of its groundwater hydrology features. Geophysical methods have been proved to be the most reliable surveying approach for belowground systematic studies and various rock forms [Carruthers, 1985; Emenike, 2001].Various approaches are used in groundwater research, with the resistivity method being extremely successful for discovering adequate wells [Olaseeni et al., 2019]. And the sounding approach could give valuable details on the perpendicular fluctuation in resistivity of the subsurface with depth. The vertical electrical sounding (VES) technique was employed in this work to assess water-table capacity in the Arato case study, eastern Mekelle, Northern Ethiopia. Mekelle's city water is mostly supplied from groundwater of the Aynalem catchment. For decades geological, hydrogeological, and geophysical research have been conducted in the area of the Mekelle outlier [Teklay, 2006].

The lowering of the groundwater table in the well field causes tremendous concern in the region, and a lack of drinking water is one of the city's crucial issues. As a result, many geological and hydrogeological studies have been undertaken by various consultants and researchers, but no research has been conducted around the Arato catchment, which should be viewed as a one source of drinking water.

2. Methodology

Secondary geological and hydrogeological data were obtained from all drilled boreholes in and around the research region, including the depth and height of the bedrock layer, thickness of aquifers, and elevations of identifiable geological units using well log data. Besides from the geology method, a geophysical study was carried out purposely to detect possible aquifer zones in the area.

2.1 VES Data Acquisition

The vertical electrical sounding (VES) approach was performed at the site with an area coverage of about 2km2 utilizing Schulumberger configuration. Two electrode wires were inserted in to the subsurface in order to record the electric current and associated potential difference respectively. The apparent resistivity (ρa) measured for each half-electrode spacing 'a' is calculated using the following equation:

$$\rho a = 2\pi K(V/I)$$

Where ρa is the apparent resistivity, K is the determinant that depends on the shape and form of the electrode arrangement, V is the voltage measured across potential electrodes, and I is the current injected to ground. The apparent resistivity for a particular electrode spacing might vary greatly depending on the nature of surface material [Zohdy et al., 1974].

Four electrodes were placed orderly across a common wire in this Schulumberger design, i.e., the exterior two operating as current electrodes and the inner two as potential electrodes. The interior pair of potential electrodes (CD) was located in the center of the array, and their separation was small in comparison to the current electrode distance (AB), typically below one-fifth of the current electrode distance as shown in fig-1, and was performed with half current electrode spacing (AB/2) of maximum 500m. The apparent resistivity values recorded with this array were connected to the midpoint of configuration, which is called as the observation point 'O'. The apparent resistivity for this setup over a completely uniform earth is given by the equation [Keller and Frischknecht, 1966]

ρa = 2π V/I ([1/AM - 1/BM - 1/AN + 1/BN])-1

Where, ρa= apparent resistivity, V = potential difference between potential electrodes, I = (electric charge)current flowing, AB= current electrodes, CD = potential electrodes.

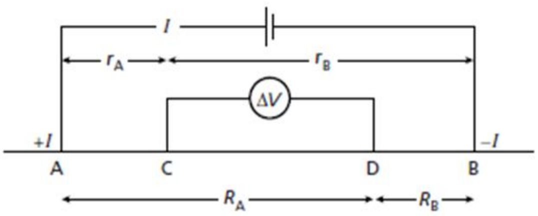


Fig 1.Schlumberger Electrode Configuration

Electrodes were appropriately inserted into the ground by pulling them with a hammer in order for the currents to penetrate deep enough to record data.

2.2 Materials

ABEM TERRAMETER SAS4000 with External battery adapter and DC input cable of an external 12V battery was utilized throughout this survey. The apparent resistivity of underlying strata was displayed by this equipment. SAS stands for signal averaging systems, which indicates that measurements are obtained automatically and averaged. Other equipment used in this study included a laptop, a photo camera, metal electrodes, a labeled tag (for locating study area), a hammer(for inserting the electrodes into the sub surface), a navigator (for measuring elevation, longitude, and latitude), an external battery, and connecting cables (crocodile cables).

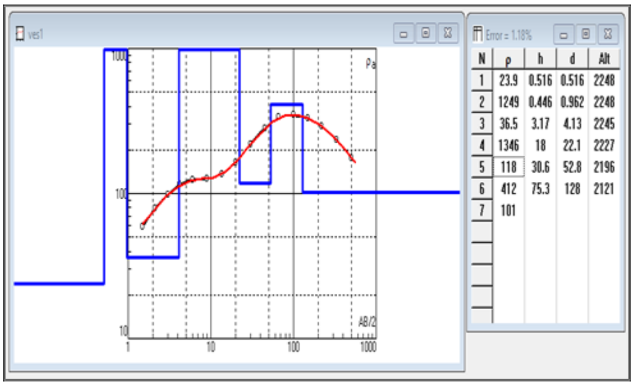
2.3 VES Data Processing and interpretation

To create cross-sections and analyze data, several software and computer programs were utilized, including Microsoft Excel, IPI2WIN, IPI-res3, and Surfer 10(32-bit). In which Microsoft Excel was used to organize field data and plot graphs, IPI2WIN software was utilized to calculate the number of layers and thickness based on resistivity inputs, and Surfer 10 was used to generate geo-electric sections. The study's field data were interpreted qualitatively as well as quantitatively. When the data was evaluated qualitatively, the form of the field curves was examined to determine the number of layers and their resistivity. This method of interpretation produced pseudo and geo-electric sections. The recorded field data were plotted on bi-log paper, and curve matching was conducted by IPI2WIN software to determine the initial model parameters of potential layers. In the quantitative technique, geo-electrical parameters such as actual resistivity and layer thickness were acquired using Surfer 10 software to create geo-electrical sections.

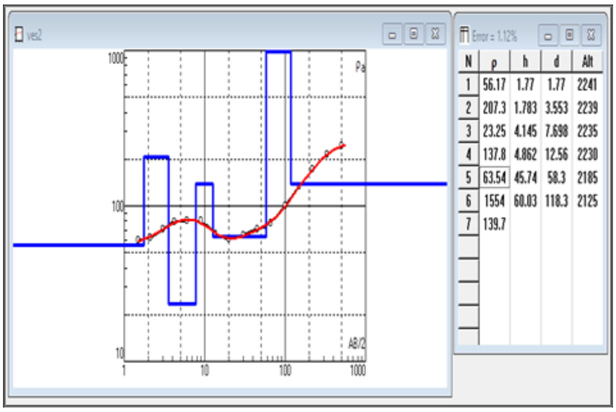
3. Results and Discussion

3.1 Interpreted VES Curves

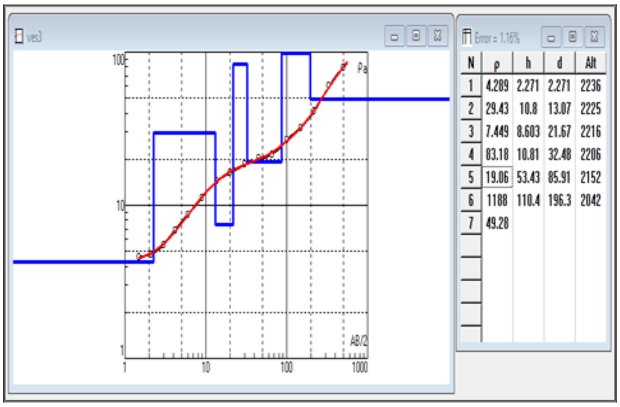
VES1



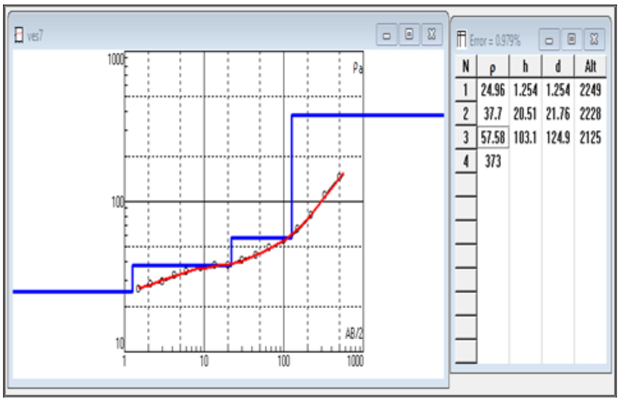
VES2



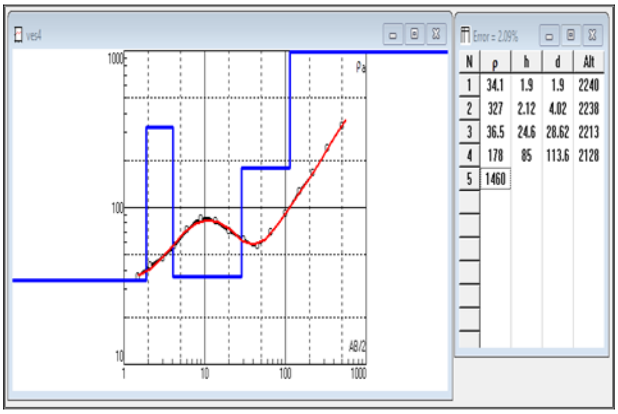
VES3



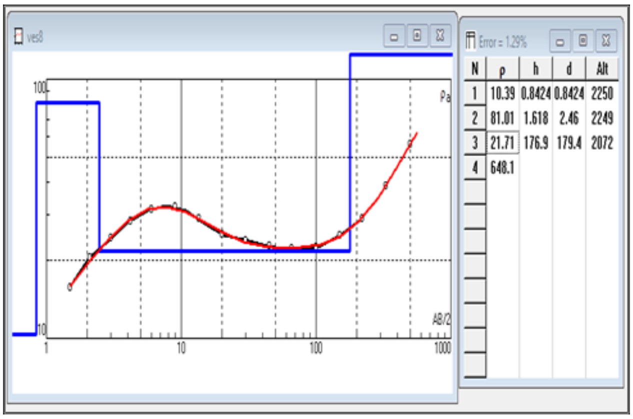
VES4



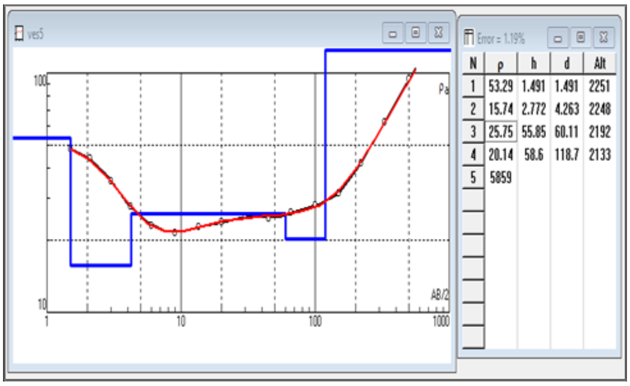
VES8



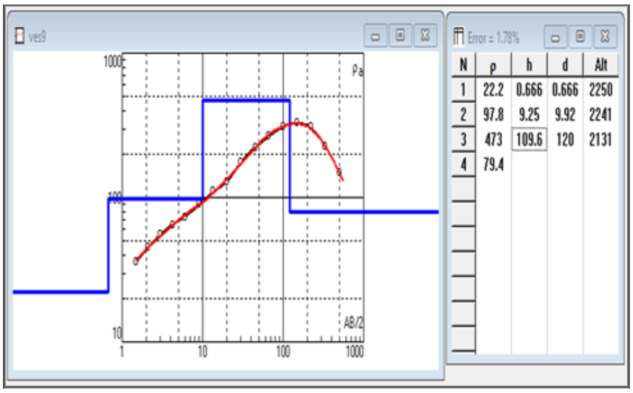
VES5



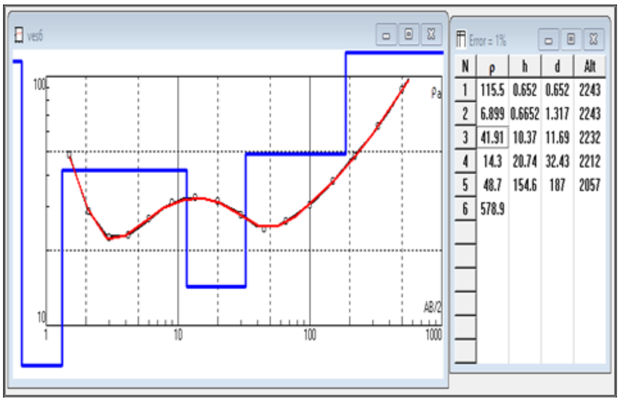
VES9



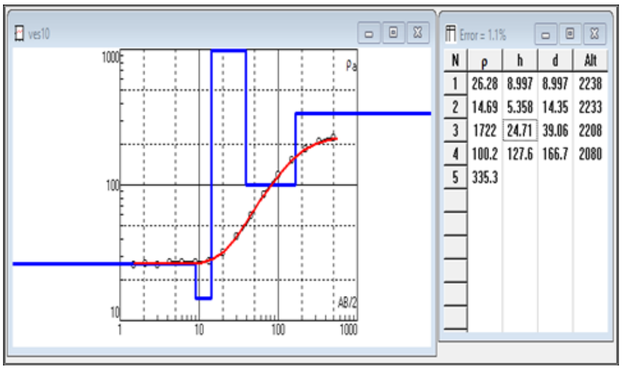
VES6



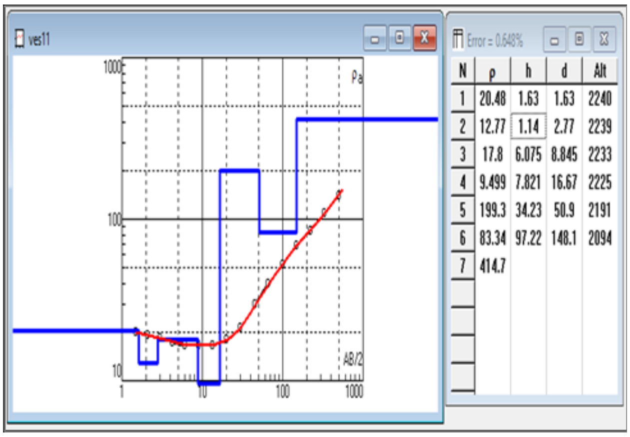
VES10



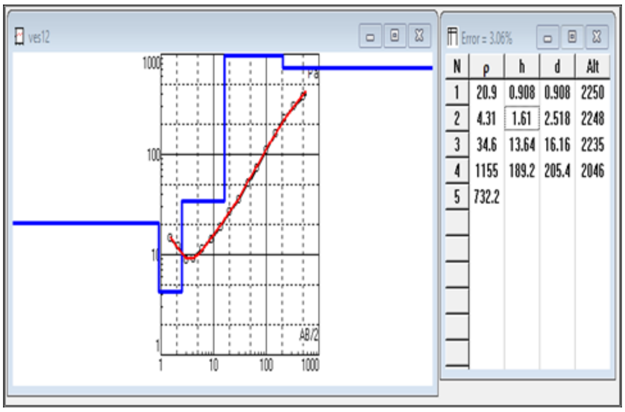
VES7



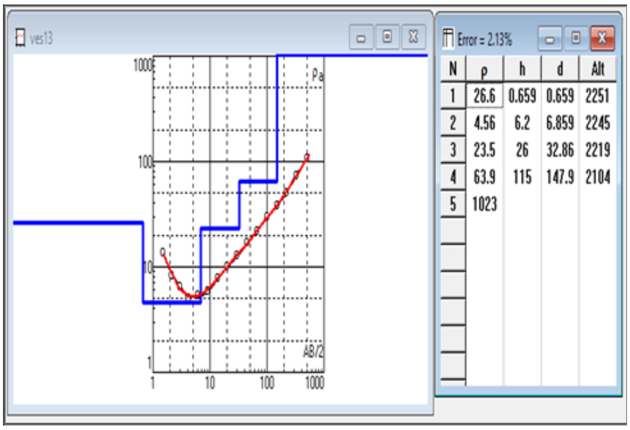
VES11



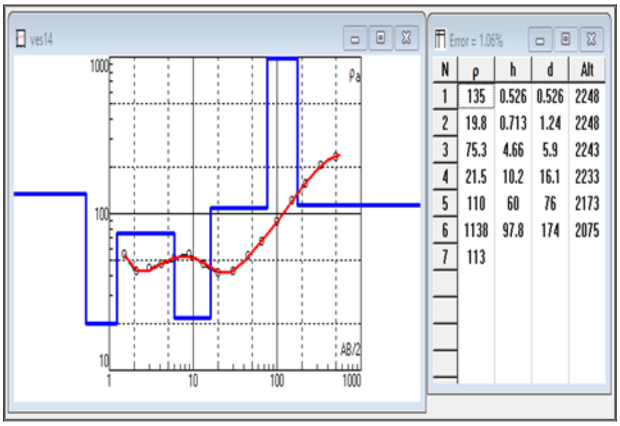
VES12



VES13



VES14



VES15

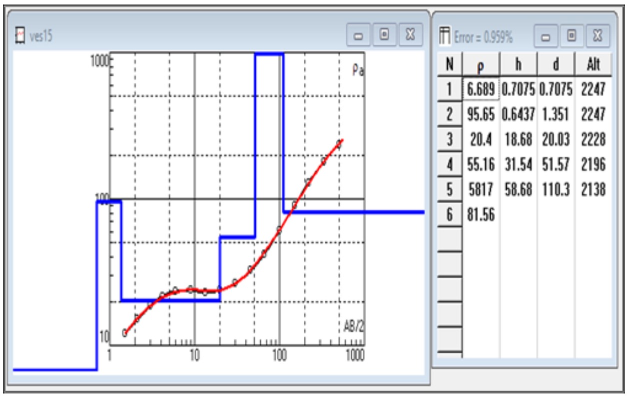


Fig 2. Interpreted Resistivity curves.

3.2. Pseudo Section

3.2.1. Pseudo Section of Profile One

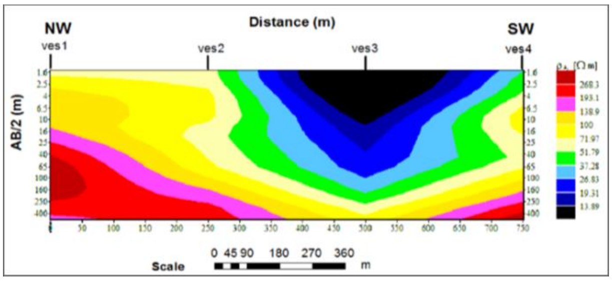


Fig 3. Pseudo section of Profile one

Fig-3 depicts the pseudo section built for VES-1, 2, 3, and 4 along the survey traverse line-1. The resistivity of all four VES locations varies laterally, as seen in the figure. In VES-3, the low resistivity zone is black, while the high resistivity zone is leftward of the section, which is blackish red. VES-3 resistivity values ranging from 4.3 ohm-m to 29.43 ohm-m indicates porous materials. In this profile, VES-1 appears to be a groundwater potential zone because resistivity climbs to 1346 ohm-m at 22 m and subsequently drops to 101 ohm-m at 128 m.

3.2.2. Pseudo Section of Profile Two

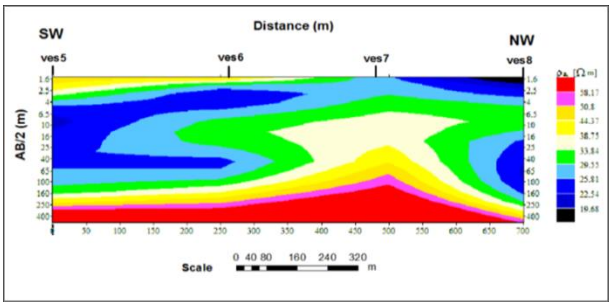


Fig 4. Pseudo section of Profile two

This profile is a pseudo section of the VES-5, 6, 7, and 8 profiles shown in fig-4. There is comparatively low resistivity at the top of all VES locations, suggesting high porosity with low permeability and are shallow. The image depicts resistivity variation that extends to great depth. At all VES sites, there is a noticeable high resistivity value away from the top at depths up to 120 m. Below the top layer, there is a low resistivity zone with resistivity varying from 14 ohm-m to 81 ohm-m and depths up to 187 m, indicating a groundwater potential zone. These low resistive zones are found between VES-5 and VES-6, as well as in VES-8.

3.2.3. Pseudo Section of Profile Three

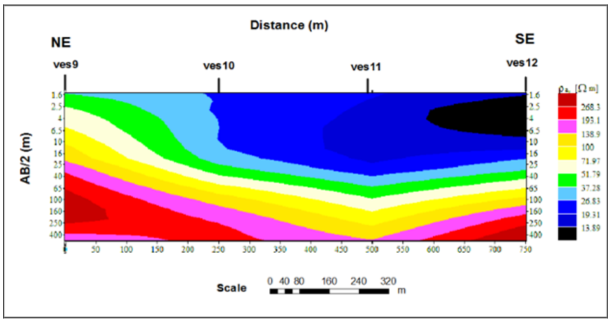


Fig 5. Pseudo section of Profile three

The pseudo depth section built for VES-9, 10, 11, and 12 is shown in fig-5 below. There is a sideward fluctuation of resistivity in the section, i.e., a noticeable high resistivity zone around VES-9 that is more than 268 ohm-m. The upper section's wide area, particularly VES-10, VES-11, and VES-12, has low resistivity. By moving deeper from 38.7 m to 145 m, low resistive zones between VES-10 and VES-11 indicate possible water potential with resistivity values of 100 ohm-m – 83 ohm-m to 199 ohm-m, respectively. The high resistivity valued region that does not extend to a significant extent is mapped at VES-9, yet when increasing with depth, there is low resistivity in this region, which may be a good water potential zone.

3.2.4. Pseudo Section of Profile Four

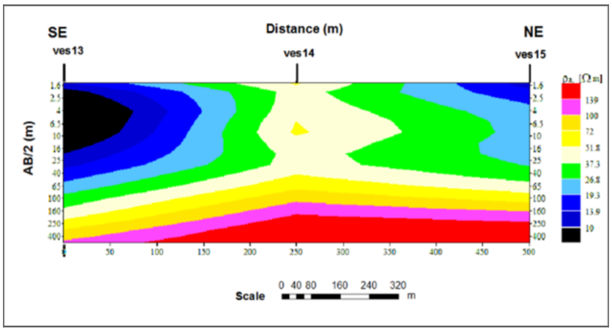


Fig 6. Pseudo section of Profile four

This profile is made up of VES-13, 14, and 15 pseudo sections, as seen in fig-6. There is a lateral fluctuation in resistivity in the section, with a significant low resistivity zone in the top left side of the section near VES-13 with resistivity of 15 ohm-m and a resistivity range of 10 ohm-m to 13.9 ohm-m in the right side of the section near VES-15. VES-13 has a high water potential in this profile, with a resistivity value of 64 ohm-m for thicknesses ranging from 44.1 m to 148 m. The broad area of the section's medium has a low resistivity of less than 120 ohm-m, while the deep depth of VES-13 has a low resistivity of 64 ohm-m. And this area appears to be a possible water saturation zone. The high resistivity zone is well covered throughout a large area of the bottom.

3.3. Geo-electric Sections

3.3.1. Geo-electric Section of Profile one

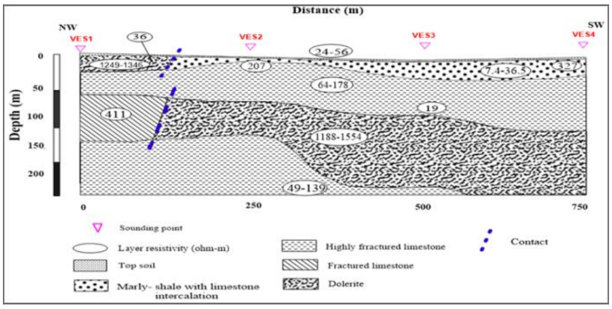


Fig 7. A diagrammatic illustration of stratified layers of Profile one

Figure 7 illustrates the resultant geo-electric section of VES-1, VES-2, VES-3, and VES-4 profile one. It includes of several geo-electric layers and resistivity levels. Topsoil is regarded as the initial geo-electric section layer, with resistivity varying from 24 ohm-m to 56 ohm-m and thickness ranging from 0.51 m to 2.32 m And this layer has relatively low resistivity value indicating the presence of clay intercalation. The second layer, marly-shale with limestone intercalation has resistivity values ranging from 7.4 ohm-m to 327 ohm-m and thicknesses ranging from 1.77 m to 29 m respectively, while at this similar layer the VES-1 dolerite rock unit of 1249 ohm-m to 1346 ohm-m resistivity with depth up to 22 m. Limestone with a high degree of fracture of 64 ohm-m to 178 ohm-m resistivity and thicknesses ranging from 7.7 m to 114 m is located in the third geoelectric section. Looking up on lithological setup of the fourth geo-electric layer manifested as VES-1 with resistivity value 411 ohm-m of depth from 53 m to 128 m is fractured limestone. Whereas the geo-electric section of the identical layer marked as VES-2, VES-3 and VES-4 is assumed to be dolerite with resistivity value of 1188 −1554 ohm-m with thickness of 58 m −196 m. The final layer marked by VES-1, VES-2 and VES-3 of resistivity 49 m−139 ohm-m found at 118 m deep may represent highly fractured limestone.

3.3.2. Geo-electric Section of Profile two

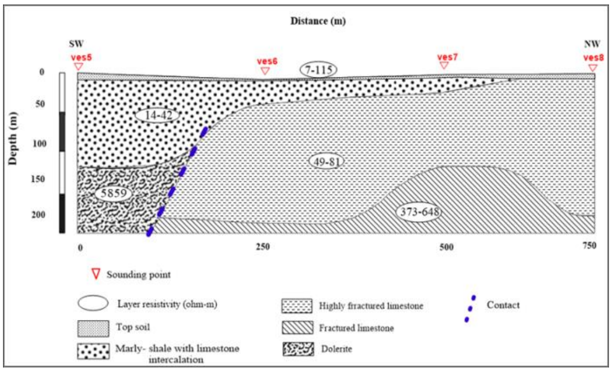


Fig 8. . A diagrammatic illustration of stratified layers of Profile two

The successive geo-electric stratification of four VES layers is formed creating profile two as illustrated in fig-8. The upper surface shows clay soil with resistivity ranging from 7 -115 ohm-m with depth variation of 0.6- 4.3 m which may be saturated and dry topsoil respectively. The second geo-electric layer marked by VES-5, VES-6 and VES-7 indicates marly shale with limestone intercalation of 14 - 42 ohm-m and 11 - 120 m of resistivity and depth variation respectively. The third surface noted by VES-5 of 5859 ohm-m with thickness of greater than 120 m likely reflects massive dolerite. While the same surface marked as VES-6, VES-7 and VES-8 with resistivity value 49 - 81 ohm-m and depth of 2.5 - 187 m gives back the existence of highly fractured limestone. At the last geo-electric surface given by VES-6, VES-7 and VES-8 with 373 - 648 ohm-m shows presence of fractured limestone.

3.3.3. Geo-electric section of Profile three

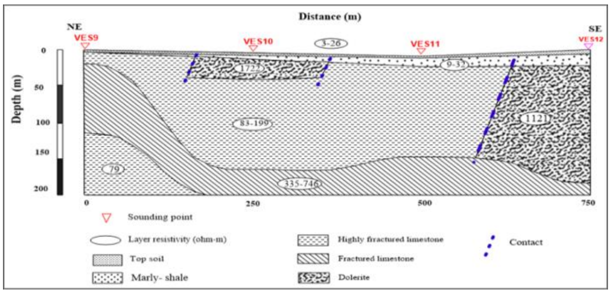


Fig 9. . A diagrammatic illustration of stratified layers of Profile three

As shown in fig-9, the first geo-electric stratum gives clay soil of resistivity 3 - 20.2 ohm-m and depth 0.6 m - 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 from VES 9-11 show marly shale with resistivity values of 9 - 32 ohm-m and thickness of 3 m to 17 m. The third stratum marked from VES 9 -11 with resistivity value of 83 - 199 ohm-m and depth from 0.6 - 167 m likely reflects highly fractured lime stone whereas the geo-electric section of the same layer marked by VES-12 and some top parts of VES-10 with resistivity value 1121 - 1722 ohm-m and depth of 14 - 39 m and 17 - 185 m respectively reflects the presence of dolerite. The fourth layer of the stratification value ranging from 335 ohm-m to 746 ohm-m shows presence of fractured limestone. The last geo-electric section marked by VES-9 shows highly fractured limestone with resistivity value of 79 ohm-m.

3.3.4. Geo-electric section of Profile four

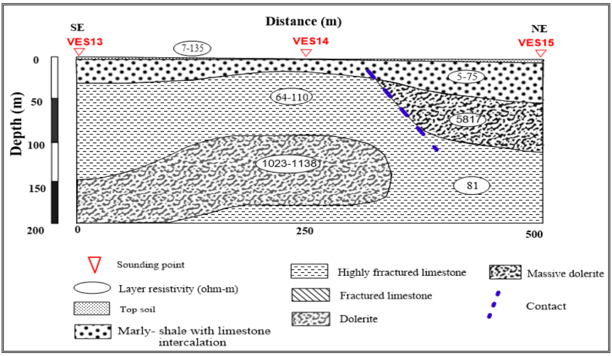


Fig 10. A diagrammatic illustration of stratified layers of Profile four

As illustrated in fig-10, the geo-electric portion of profile 4 comprises of VES-13, 14 and 15. The top layer is often a mix of saturated and dry clay material of 7 - 135 ohm-m and width variation of up to 1.5 m. The second stratum includeds marly shale and limestone intercalation of 5 - 75 ohm-m and depths of 1.5 - 52 m. The third surface, denoted by VES-13 and VES-14, contains severely fractured limestone with resistivities coverage 64 -110 ohm-m and thicknesses coverage of 16 -148 m. While on same surface identified by VES-15 reveals the existence of massive dolerite with a resistivity value of 5817ohm-m and depth covering from 52 m to 110 m. Dolerite with resistivity values coverage of 1023 - 1138 ohm-m appears in the final geo-electric layer denoted by VES-13 and VES-14, whereas severely fractured limestone appears in the same layer connected with the third section with a resistivity value of 81 ohm-m.

4. Conclusion

The electrical sounding (VES) of geophysical approach was implemented in Arato sub-catchment, Eastern part of Mekelle city, Ethiopia. In the Arato flat regions, 15 VES data's were gathered. According to the study, the dominating rock types with increasing depth include marl-shale intercalation, fractured limestone, and dolerite. When the interpreted VES data was compared to the borehole data, the sole variation was in thickness. The existence of shallow and deeper low resistivity horizons were revealed by pseudo-depth sections and geo electric sections, indicating probable groundwater saturation zones. These horizons' low resistivity and depth may indicate a aquifers capable zone of the investigation region.

The research area's geological profile succession includes top clay soil, marly shale intercalation, fractured limestone, and dolerite. Moreover, with an average maximum depth of 200 m, all profiles were interconnected with extensively fragmented limestone. This demonstrated the existence of a fractured limestone rock type with a significant width and depth.

According to the geo-electric section of profile one VES-1 and VES-2 with resistivity values of 101 ohm-m and 140 ohm-m at depths exceeding 128 m and 118 m, respectively, they appear to be good aquifer zones. The geo-electric section of profile two revealed a low resistivity zone in VES-5 and VES-6 with values of 20 ohm-m and 49 ohm-m, respectively, with depths of 118 m and 187 m, and the geo-electric section of profile three revealed an aquifer zone at VES-9 of 79 ohm-m and thickness of 120 m, indicating a highly fractured zone. Whereas from the last profile four VES-14 showed a good prospective zone of groundwater with a resistivity value of 113 ohm-m at depths more than 174 m. When the potential aquifer levels of the geo-electric sections were compared, VES-1 from profile one, VES-6 from profile two, and VES-9 from profile three appeared to be good aquifer zones. There were extremely fractured limestone rock units in VES-1, VES-6, and VES-9, and these rock units are known to represent layers of water-bearing permeable fractured rocks. As a consequence of this, it was concluded that VES-1, VES-6, and VES-9 may be acceptable zones of groundwater potential, since they have low resistivity and depths of 128 m, 187 m, and 120 m, respectively. Boreholes at depths of 120 m to 130 m may thus be recommended at these VES sites.

Groundwater occurrence was heavily impacted by geologic formations such as fracture and interactions. These contacts might be caused by sedimentary rock deposited on older rock or by rocks intruding into another geological unit. Fracturing had significant consequence on the geology of the study area, specifically the topographically higher areas, which were largely dolerite and limestone. This fracturing controlled the flow of groundwater, which increased the area's recharge rate due to fractured rocks in highly elevated places. According to the findings, observations, and various studies conducted in field of investigation, aquifers potential in the base of mountains also flat areas is high, owing to the high recharge rate of highlands, thick and small soil amount, ground flow, and most of the water is drained into the flat lands. In general, the studied region has a high aquifer level. As a result, this conclusion is crucial in terms of alleviating freshwater concerns in study area and Mekelle city.

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