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Investigating Groundwater Resources in Somaliland's Sool and Gebiley Regions Using the Vertical Electrical Sounding (VES) Method

Somaliland'ın Sool ve Gebiley Bölgelerinde Düşey Elektrik Sondaj Yöntemi (DES) ile Yeraltısuyu Kaynaklarının Araştırılması

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ABSTRACT

In this research, geological and geophysical investigations were conducted to assess the groundwater potential of Somaliland. The primary objective was to identify suitable aquifer areas for groundwater drilling in selected towns. The research covered geophysical studies conducted in the towns of Godalo, Gambadho, Qoryale, and Magalo'ad, situated in the Sool, Togdheer, and Awdal regions of Somaliland. The Vertical Electrical Sounding (VES) method was employed for groundwater exploration in this study. Measurements were taken at a total of 19 VES points in four different regions using the Schlumberger electrode array. The total expansion distance of the electrodes in the working area (AB) has been determined to be a maximum of 1400 meters.

The IPI2Win computer program was used to analyze the VES data obtained from the study area. The assessment revealed that the true resistivity values of underground layers ranged from a minimum of 0.24 ohm-m to a maximum of 5574 ohm-m. The thickness of these layers was determined to vary between a minimum of 0.14 m and a maximum of 342 m.

Information about the subsurface geoelectric structure was obtained using the acquired resistivity and thickness values. These data were correlated with regional geology to identify potential groundwater sources within the study area. Areas with identified groundwater potential include measurement points DES2 in the Godalo region, DES2 in the Gambadho region, DES1 in the Qoryale region, and DES4 in the Magalo'ad region. The maximum drilling depth in the study area was determined to be 350 meters.

Subsequent drilling at the recommended measurement points successfully obtained a sufficient amount of groundwater to meet the regions' drinking water needs. By enhancing the comprehension and exploration of groundwater resources in Somaliland, this study underscores the significance and value of sustainable water resource management.
Anahtar Kelimeler: Resistivity, Groundwater exploration, Vertical Electrical Sounding (VES), IPI2Win

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ÖZ

Bu çalışmada, Somaliland'ın yeraltısuyu potansiyelini değerlendirmek amacıyla jeolojik ve jeofizik çalışmalar gerçekleştirilmiştir. Bu çalışmanın temel amacı, seçilen kasabalarda yeraltısuyu sondajı için uygun akifer alanlarını belirlemektir. Araştırma, Somaliland'ın Sool, Togdheer ve Awdal bölgelerinde yer alan Godalo, Gambadho, Qoryale, Magalo'ad kasabalarında gerçekleştirilen jeofizik çalışmaları içermektedir. Bu çalışmada yeraltısuyu araştırması için Düşey Elektrik Sondaj (VES) yöntemi kullanılmıştır. Dört farklı bölgede, Schlumberger elektrot aralığı kullanılarak toplam 19 VES ölçüm noktasında ölçümler gerçekleştirilmiştir. Çalışma alanındaki elektrotların toplam açılım uzaklığı (AB), maksimum 1400 metre olarak belirlenmiştir.

Çalışma alanından elde edilen VES verilerini değerlendirmek için IPI2Win bilgisayar programı kullanılmıştır. Değerlendirme sonucunda yeraltındaki tabakaların gerçek özdirenç değerlerinin minimum 0.24 ohm-m ile maksimum 5574 ohm-m arasında değiştiği ve tabakaların kalınlığının minimum 0.14 m ile maksimum 342 m arasında değiştiği belirlenmiştir.

Elde edilen özdirenç ve kalınlık değerleri kullanılarak yeraltının jeoelektrik yapısı hakkında bilgi elde edildi. Bu veriler, bölgesel jeoloji ile ilişkilendirilerek çalışma alanı içindeki olası potansiyel su kaynakları belirlendi. Su potansiyeli tespit edilen alanlar arasında Godalo bölgesindeki DES2 ölçüm noktası, Gambadho bölgesindeki DES2, Qoryale bölgesindeki DES1 ve Magalo'ad bölgesindeki DES4 bulunmaktadır. Çalışma alanındaki maksimum sondaj derinliği 350 metre olarak belirlendi. Önerilen ölçüm noktalarında gerçekleştirilen sonraki sondajlar, bölgenin içme suyu ihtiyaçlarını karşılamak için yeterli miktarda yeraltı suyu elde etmeyi başarıyla sağladı. Somaliland'daki yeraltı su kaynaklarının anlaşılması ve keşfi konusunda katkıda bulunan bu çalışma, sürdürülebilir su kaynakları yönetiminin önemini ve değerini vurgulamaktadır.

Keywords: *Özdirenç, Yeraltısuyu araştırması, Düşey Elektrik Sondaj (DES), IPI2Win*

1.INTRODUCTION

Water is a fundamental requirement for the continuation of life for all living organisms, playing a critical role in agriculture, irrigation, and various industries. Groundwater, especially during periods of drought and in areas where surface water sources are limited, serves as a significant water source. However, sustainable use and management are crucial to mitigate risks such as overexploitation and contamination of groundwater resources. Effectively preserving and managing water resources is a critical factor that influences the quality of life and sustainability of communities. The preference between groundwater and surface water for water supply varies significantly based on the accessibility of aquifers relative to demand levels. In densely populated urban areas with high water demands, groundwater utilization becomes feasible when aquifers, typically found in sedimentary rock formations, exhibit favorable storage and distribution properties. Conversely, in sparsely populated rural regions, relying on weaker aquifers, especially those in weathered basement rock exposed to challenging climatic conditions, becomes crucial for providing modest yet indispensable water sources. In such areas, groundwater can play a critical role in ensuring sustainable water supply, particularly when surface water sources are limited or inaccessible due to seasonal fluctuations (Niemann, 2007; Muchingami et al., 2012; Mohamaden et al., 2016; Sikah et al., 2016; Kasidi, 2017; Hasan et al., 2018; Wahab et al., 2021; Riwayat et al., 2022; Getenet, 2023). Groundwater proves to be a significant strategy for effectively preserving and managing water resources, contributing to sustainable water supply and addressing the unique challenges faced by both urban and rural areas.

This study aimed to identify groundwater in various regions of Somaliland. Somaliland, located in the Horn of Africa, is acknowledged as one of the most drought-prone regions in the area. The drinking water situation in Somaliland poses significant challenges, particularly in rural areas where women and children are compelled to cover extensive distances in search of water for both household and livestock use. In these regions, surface water sources are often inaccessible due to their dependence on seasonal climatic fluctuations, which can result in conventional surface water storage tanks being either partially filled or completely empty.

Additionally, the water scarcity problem in Somaliland worsens in many regions, mainly due to the extremely low annual rainfall. As a result, increasing groundwater resources becomes a

vital solution to meet the country's water supply demands. Despite numerous deep drilling initiatives in Somaliland, the success rate in expanding groundwater access or drilling more productive wells has regrettably stayed low. This situation is largely attributed to the insufficient comprehensive hydrogeological studies in the region.

One of the most widely applied methods in groundwater investigations worldwide is the Vertical Electrical Sounding (VES) method. This method is recognized for its high sensitivity to variations in earth resistivity. Consequently, it proves to be a valuable technique for distinguishing between different lithological units and detecting variations within those units (Abdulkadir et al., 2017). Therefore, it holds significant importance, particularly in delineating aquifer areas (Owen et al., 2006). As a result, researchers worldwide, including many notable experts (Anechana, 2013; Haile and Atsbaha, 2014; Jayeoba and Oladunjoye, 2015; Badrinarayanan et al., 2018), employ the electrical resistivity method in their efforts to explore groundwater resources.

The primary aim of this research is to determine the groundwater potential of four different towns in Somaliland. In this context, the resistivity values obtained by applying the Vertical Electrical Sounding (VES) method at a total of 19 measurement points identified in these regions will be evaluated by correlating them with the lithological characteristics of the area. The main objective is on identifying areas with drinkable freshwater aquifers, especially in regions of high priority. In addressing this issue, four towns located in three distinct regions with the highest demand for groundwater have been identified. These locations include Godalo town in the Sool region, Gambadho and Qoryale towns in the Togdheer region, as well as Magalo'ad town in the Awdal region (fig. 1).

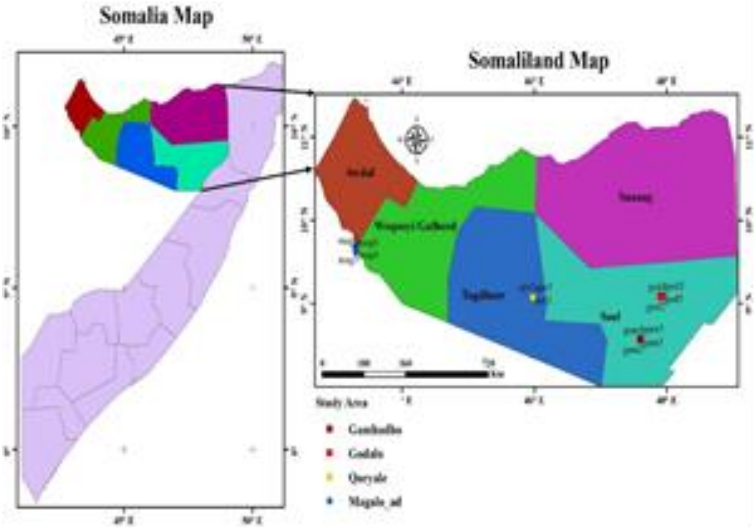


Figure 1.Location map of the study area (Hussein, 2020).

2. METEOROLOGICAL and GEOGRAPHIC FEATURES of the STUDY AREA

The study area has different meteorological and geographical characteristics. Somaliland is known for its extreme arid climate, and it's considered one of the most drought-prone areas in the Horn of Africa. Rainfall in this region is characterized by sporadic, torrential downpours that occur for short durations. The level of precipitation varies across the country, with some areas receiving significantly less rainfall compared to others. In the regions with low precipitation, the mean annual rainfall is notably lower than in areas with relatively higher rainfall levels. However, the overall return from precipitation to groundwater is minimal due to the region's high evapotranspiration rates. The average annual evapotranspiration capacity ranges from 1800 to 2500 mm, which is primarily influenced by the high temperatures experienced in the area, as illustrated in figure 2. The climate in Somaliland is marked by strong wind circulation, contributing to moisture loss in both plants and soils. The mean annual wind speed varies across different elevations, with relatively high altitude areas having an average wind speed of 2.9 km/sec, while lower altitude areas can experience wind speeds of up to 5.8 km/sec.Temperature in the region also varies significantly. The mean monthly temperatures range from 15°C to 25°C in mountainous regions, while in inland areas, temperatures can range from 25°C to 35°C. In these mentioned study sites:

- Magalo'ad town, close to Tog Wajaale, is expected to receive the highest precipitation, with an average annual rainfall projection of 500 mm/year.

- The Togdheer area in Qoryale town is projected to have an estimated annual rainfall of 160 mm/year.

- Godalo town, situated in the high mountains of Sool, receives around 140 mm/year.

- Gambadho town, located in the Nugaal Depression, receives less than 100 mm/year

These figures emphasize the arid nature of the region, with notable variations in annual rainfall across different areas, making water resource management a crucial consideration in such an environment.

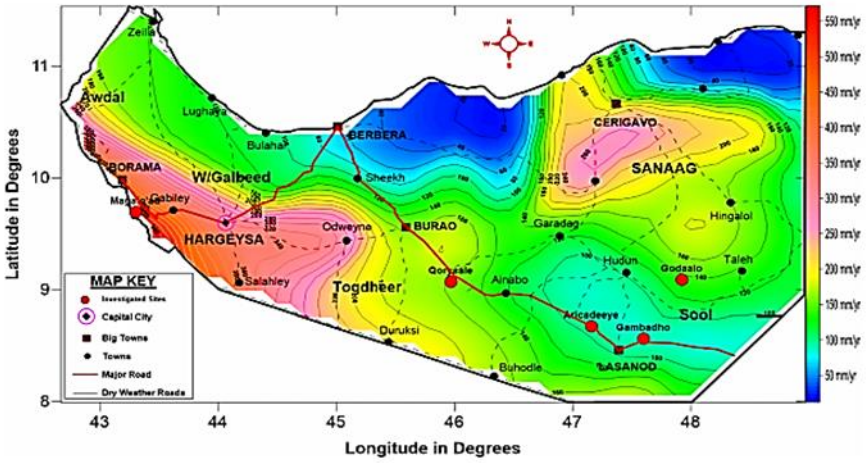


Figure 2. Annual rainfall map of Somaliland (SHAAC 2014)

3.MATERIAL and METHOD

The VES (Vertical Electrical Sounding) method involves measuring the ability of subsurface formations to conduct or exhibit resistance to electrical current in both horizontal and vertical directions, depending on changes in resistivity values. Electric current is applied to the ground,

and by measuring the potential difference, the resistivity values of subsurface units can be calculated. The resistivity of rocks varies according to factors such as the temperature, salinity, porosity, water content of the subsurface environment, and the resistivity values of the fluid in the formation. The study was carried out in four distinct towns in Somaliland with the primary objective of identifying groundwater sources through the utilization of the Vertical Electrical Sounding (VES) method (fig.3).

Figure 3. Obtaining data by applying the VES method in the study area

The ABEM Terrameter SAS 1000C equipment was employed for the resistivity survey. The ABEM Terrameter SAS 1000 is a highly advanced resistivity instrument designed to accommodate a wide range of applications (ABEM Instrument AB, 2018). The process of obtaining data from the research area was carried out using a resistivity device, four cable reels, an external 12-volt DC battery, and electrodes. In groundwater exploration research, the Schlumberger electrode configuration is widely preferred for Vertical Electrical Sounding (VES) measurements. This arrangement consists of symmetrically positioned two current and two potential electrodes with respect to the central point. The distance between potential electrodes is kept very small compared to the distance between the current electrodes. The objective is to measure the electric field precisely at the symmetry center. The Schlumberger electrode array is the most preferred arrangement in such studies due to its capability to enable

deep investigations and its practical advantages of being faster and easier to implement. A total of 19 VES measurement points were identified in four different research areas, as illustrated in Figures 4, 6, 8, and 10. These measurements were predominantly conducted in a north-south direction. The IPI2Win software, a geophysical program, was employed for the analysis and interpretation of the study data. The data was input into the VES notepad window, which functions similarly to an Excel spreadsheet, facilitating the automatic generation of logarithmic data curves. Subsequently, these curves were examined and compared against initial models. Utilizing the inversion function, the data was inverted, starting with user-defined models. The inverted data was saved in the format of a Bitmap Image, known as the sounding curve. This analytical process led to the determination of the actual resistivity and thickness values of the subsurface layers.

4. RESULTS and DISCUSSIONS

This study was conducted with the aim of assessing the groundwater potential and identifying suitable aquifers for drinking water in the towns of Godalo, Gambadho, Qoryale, and Magalo'ad located in Somaliland.

In general, the resistivity values of fresh water range between 10 and 100 Ωm, but depending on the aquifer's geology, resistivity values can vary between 50 and 2000 Ωm. In areas with hard rock formations, characterized by high resistance, the target is often a low-resistivity anomaly. Conversely, in environments with high clay or salt content, where conductivity is elevated, anomalies with high conductivity often indicate the presence of a freshwater aquifer. The thickness and resistivity of sedimentary layers can be employed as indicators of the aquifer's properties.

The interpretation of apparent resistivity data from VES measurement points in four different regions was conducted using the IPI2WIN computer software. The results of this computer modeling are presented in Figure 4b, 6b, 8b and 10b. In these figures, the black circles represent the measured data, the red line indicates the calculated data, and the blue line represents the interpreted resistivity sections. For this interpretation, parameters such as N (number of layers), ρ (apparent resistivity), h (thickness), and d (depth to the interface of each layer) were utilized. Upon evaluating the VES data, it has been determined that in deformed

regions, the resistivity varies between 10-80 Ωm, and the layer thicknesses range from 1-50 meters.

- **Geology of the Godalo Region and Interpretation of VES Measurements**

Godalo is a newly established city situated on the Sool Haud Plateau in the Sool Region. In this region, Vertical Electrical Sounding (VES) measurements were conducted at various points around the town, resulting in a total of five VES measurements. There are no water wells in the study area or its vicinity. Therefore, the interpretation of VES curves was based solely on general geological information pertaining to the region. Within the study area, the total spread length (AB) for each Vertical Electrical Sounding (VES) measurement was established at 1400 meters.

At present, the residents of the region source water from extensive sinkholes, primarily to meet their drinking water needs. It has been reported that the region's water sources, primarily sourced from these sinkholes, exhibit high pollution levels. Consequently, there is a significant increase in mortality rates, notably among children and the elderly, as a result of the compromised water quality in the area. The geological characteristics of the study area in the Godalo region can be divided into two distinct litho-stratigraphic units. To the south of the city, you'll find the Auradu Limestone Formation, which is characterized by outcropping hills. In contrast, the Taleex Gypsum Formation is found within the city and to the north of it (fig. 4a). It appears that the region is intersected by multiple fault lines. To circumvent potential issues related to saline water within the Taleex Gypsum Formation, the focus of geophysical investigations was concentrated on the areas lying beneath the Auradu Limestone Formation.

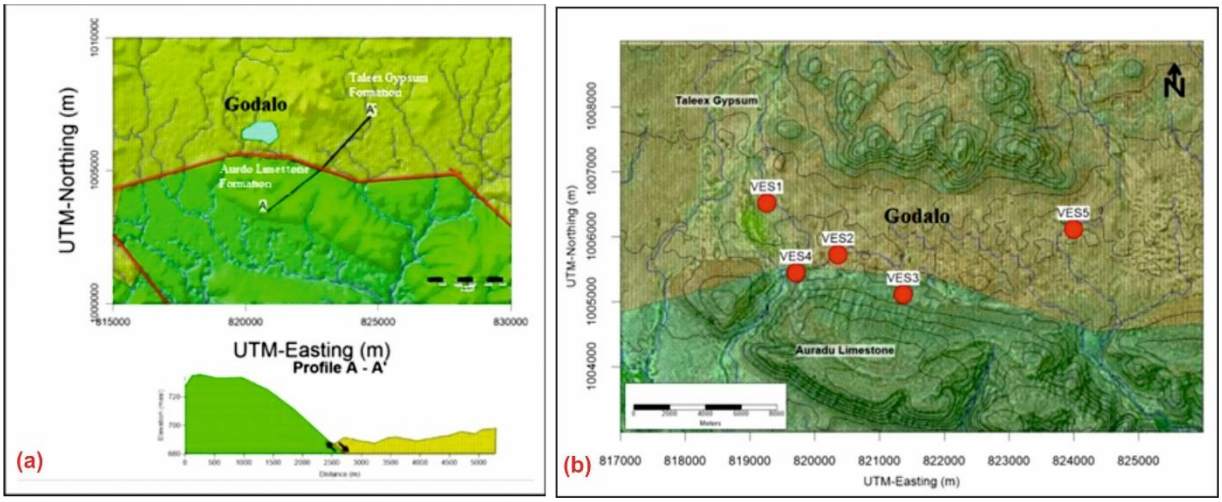


Figure 4. a) Geological map of the Godalo region. b) Location map showing VES (Vertical Electrical Sounding) measurement points in the Godalo region.

Upon evaluating the resistivity data obtained from the VES measurement points in the Godalo region, it was determined that the maximum depth to which the measurements reached is 250 meters. Several geoelectric layers ranging from 5 to 7 were identified, with resistivity values varying between a minimum of 2.7 Ωm and a maximum of 1234 Ωm (fig. 5).

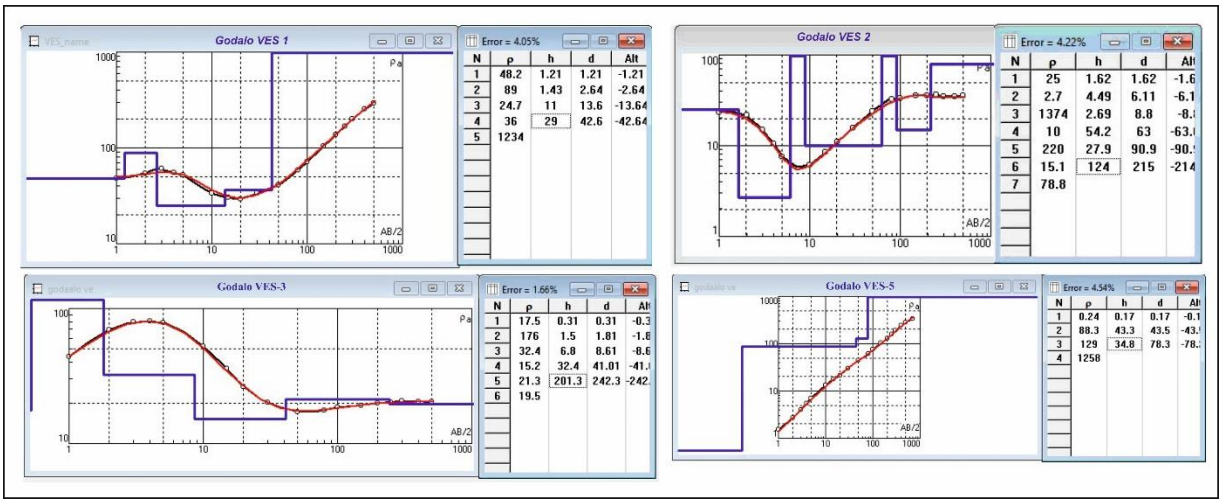


Figure 5. This figure presents the Vertical Electrical Sounding (VES) curves derived from resistivity measurements conducted in the regions of Godalo. These VES curves were analyzed using the IPI 2Win computer program, which aided in determining the thickness and resistivity characteristics of the subsurface layers in these areas

Figure 5 displays the Vertical Electrical Sounding (VES) curves obtained from resistivity measurements conducted in the regions of Godalo. Two distinct geological units were identified within the Godalo area. In the northern part of the town, the dominant formation is the Taleex Plaster formation, while the southern part is predominantly characterized by the Auradu limestone formation. An analysis of these formations revealed that massive anhydrite is prevalent in the areas under the Taleex Plaster formation, whereas in the regions under the Auradu limestone, highly weathered and fractured limestone with a relative resistivity value below 80 Ωm was observed. Importantly, relatively good water-bearing layers were identified within the Auradu limestone formation. The lithological units in the study area consist of alluvial and limestone formations. The water-bearing unit is primarily found within the highly weathered and fractured limestone, extending to depths beyond 215 meters. Based on the resistivity values of 15.1 and 78.8 Ωm, it has been determined that the limestone in the area is highly weathered, and the aquifer zone extends beyond the depth that has been reached. Therefore, at the location of VES2, it is advisable to drill a deep borehole with a recommended maximum drilling depth of 230 to 250 meters.

In the interpretation of resistivity data from VES sites in the Godalo area, two distinct geological units with contrasting resistivity values were identified. VES1 and VES5 were conducted in areas underlain by the Taleex Gypsum formation, while VES2, VES3, and VES4 were conducted in areas underlain by the Auradu limestone formation. The Taleex Gypsum formation is characterized by the presence of massive anhydrite, while the Auradu limestone formation primarily consists of highly weathered and fractured limestone, resulting in relatively low resistivity values below 80 Ωm.

- **Geology of the Gambadho Region and Interpretation of VES Measurements**

Gambadho is a relatively small town situated to the east of the town of Lasanod. Upon investigating the subsurface geology of the Gambadho region, it was established that there is a substantial thickness of alluvial deposits beneath the highly weathered Taleex Gypsum Formation (fig. 6a). This alluvial unit encompasses a shallow aquifer zone with freshwater, extending to an average depth of 80 meters.

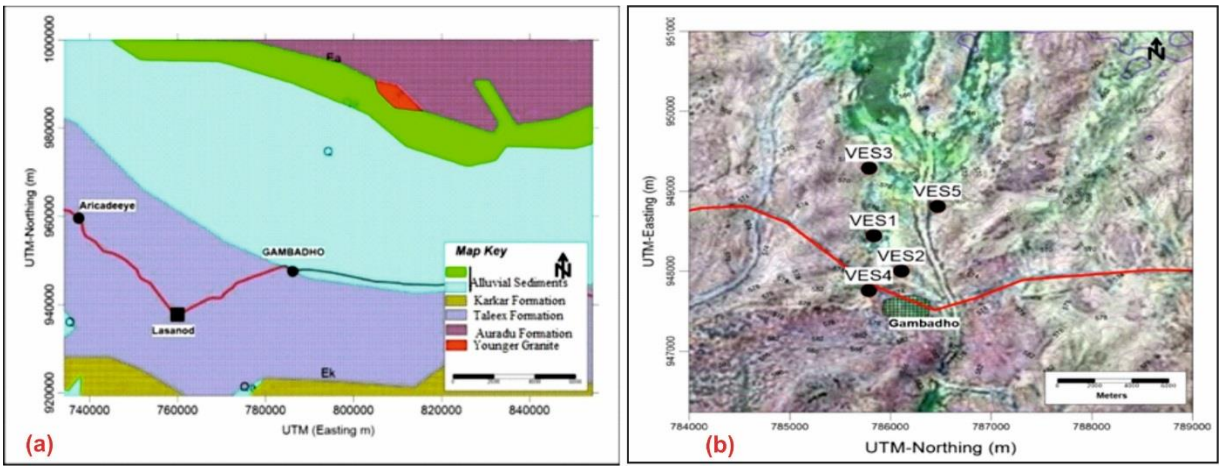


Figure 6. a) Geological map of the Gambado region. b) Location map showing VES (Vertical Electrical Sounding) measurement points in the Gambado region.

The interpretation of data from five VES measurement points in the Gambadho area revealed the presence of relatively thick alluvial units with varying grain sizes, covering the valley and underlain by highly weathered gypsum (fig. 6b). Although the thickness of the alluvial units varied from one region to another, these units were found to host shallow aquifers with groundwater of reasonable quality (fig. 7).

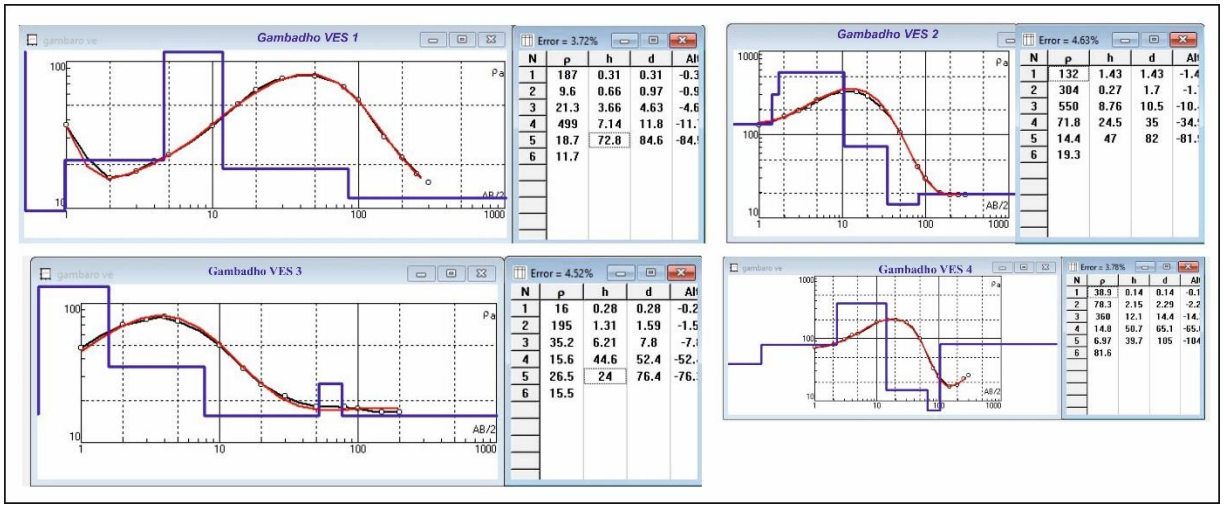


Figure 7. This figure presents the Vertical Electrical Sounding (VES) curves derived from resistivity measurements conducted in the regions of Gambadho. These VES curves were analyzed using the IPI 2Win computer program, which aided in determining the thickness and resistivity characteristics of the subsurface layers in these areas

The Gambadho region indicates the presence of a shallow alluvial aquifer zone. The variation in resistivity values in Figure 7 demonstrates that resistance decreases with depth. Therefore, any water well drilled in this region would only be able to access groundwater in the upper shallow alluvial unit. The VES2 measurement was conducted approximately 550 meters southeast of the abandoned well, in an area prone to flooding. VES2 is the closest measurement point to the town and is considered the area with the highest groundwater potential. It was determined that VES1 consists of alluvial units with varying thicknesses, extending to a depth of 82 meters, with the bottommost layers reaching gypsum-containing units. Therefore, it is recommended to drill a shallow well with a maximum depth of 80 meters at this location. As an important note, below 80 meters, there is a saline unit with relatively low resistivity values, measuring less than 10 Ωm. Therefore, to prevent unwanted penetration into the Taleex gypsum formation and entry into the saline unit during drilling, it is advisable to have a qualified field geologist closely monitor the drilling activities.

Geology of the Qoryale Region and Interpretation of VES Measurements

Qoryale serves as the newly established capital of the Qoryale district, situated approximately 60 kilometers south of Burco town. The Qoryale region is characterized by the presence of the Auradu limestone formation and the underlying alluvial units (fig. 8a).

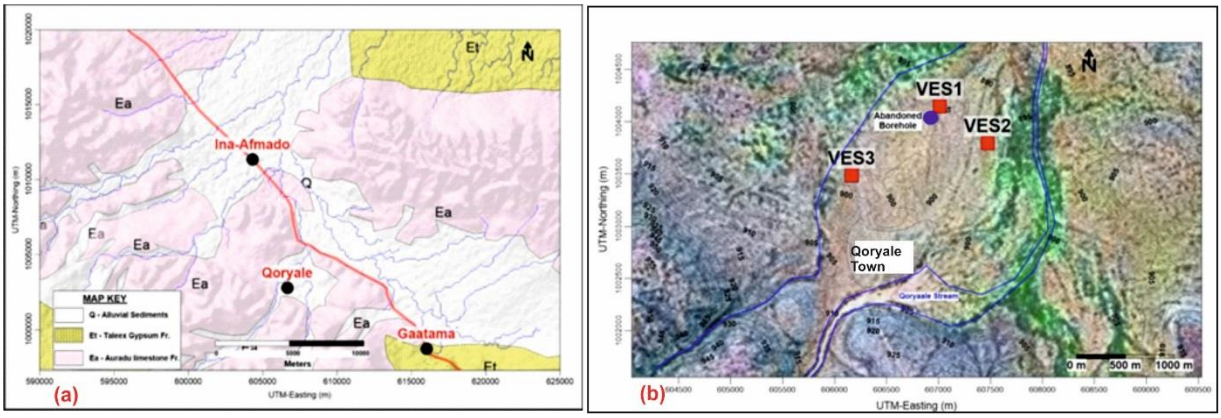


Figure 8. a) Geological map of the Qoryale region. b) Location map showing VES (Vertical Electrical Sounding) measurement points in the Qoryale region.

As a result of the evaluation of VES1, eight geoelectric layers were identified, and a maximum depth of 336 meters was reached (fig. 99). The upper five layers, extending from the surface to a depth of 17.6 meters, were interpreted as geological units consisting of clay, clay sand, sand, and gravel. Based on resistivity data, it was determined that the area where the VES1 measurement point is located has the highest potential for groundwater.

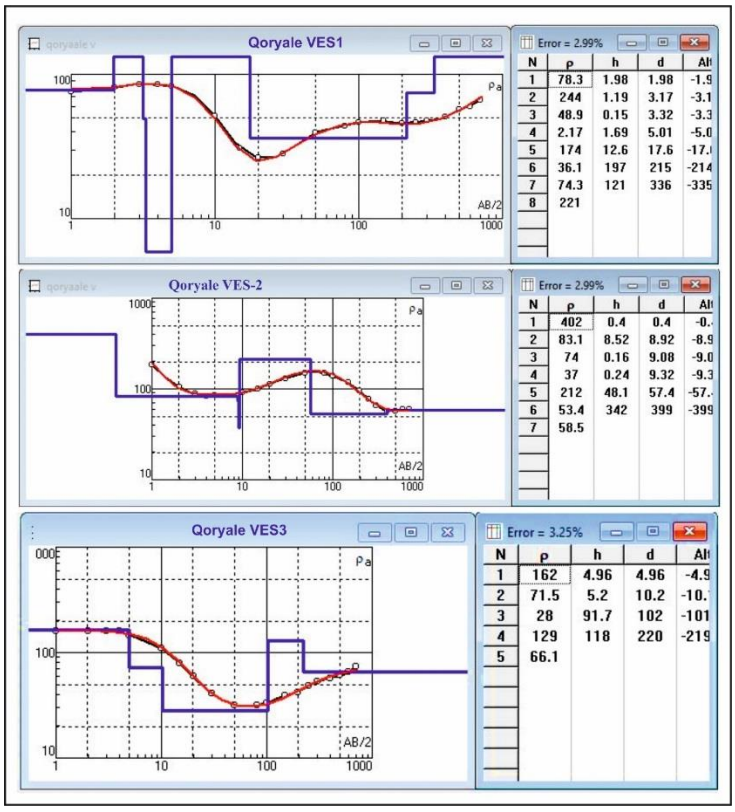


Figure 9. This figure presents the Vertical Electrical Sounding (VES) curves derived from resistivity measurements conducted in the regions of Qoryale. These VES curves were analyzed using the IPI 2Win computer program, which aided in determining the thickness and resistivity characteristics of the subsurface layers in these areas

As a result of the VES1 evaluation in the Qoryale region, three geo-electric layers extending up to a depth of 336 meters beneath the alluvial deposits were identified. These layers are believed to be composed of limestone, with the layers containing groundwater situated within this unit. The resistivity of this unit, possessing aquifer properties, was determined to be 74.3 Ωm. Therefore, it is recommended that the maximum drilling depth for a well in this area should not exceed 350 meters. Since all three VES measurement points in this region are

located within the Auradu limestone formation, all of them can be considered potential water-bearing units. However, the expected yield of any well drilled within this formation will be influenced by factors such as fracture density in the limestone unit. Therefore, the selection of the most suitable drilling site should consider this aspect. In the Qoryale region, the VES1 measurement point is recommended as the location with the highest groundwater potential.

- **Geology of the Magalo'ad Region and Interpretation of VES Measurements**

Magalo'ad is a relatively small town that hosts a large agricultural and pastoral community. Recently designated as the capital of the Magalo'ad District by the Somaliland Government, it shares its borders with Boorama district to the north, Gebiley district to the east, and the Somali Region of Ethiopia to the south and west. When examining Magalo'ad and its surrounding areas, it becomes apparent that the northern and southern regions exhibit different structural features (fig. 10a). While the northern part displays signs of faulting and graben formation, the southern part is characterized by a more stable geological structure. Additionally, the alluvial units present in the southern part appear to have a thicker and more well-bedded structure. In and around the Magalo'ad area, numerous boreholes, randomly drilled by the local inhabitants, have been abandoned due to issues such as drying up or low yield. To address this, VES measurements were conducted at specified points in this region to identify areas with groundwater potential. The result of these VES measurements led to the identification of areas with thick alluvial layers overlaying the bedrock, suggesting promising groundwater potential.

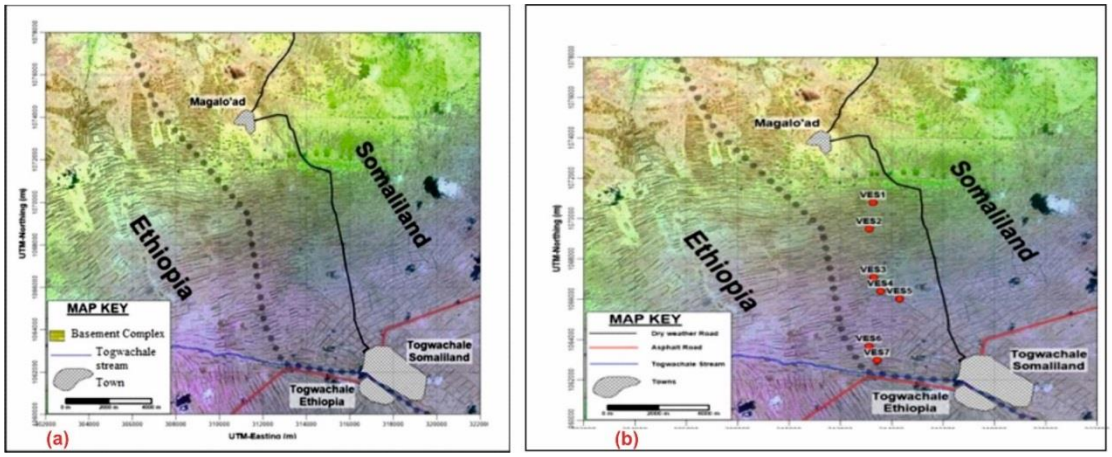
- 

Figure 10. a) Geological map of the Magalo'ad region. b) Location map showing VES (Vertical Electrical Sounding) measurement points in the Magalo'ad region.

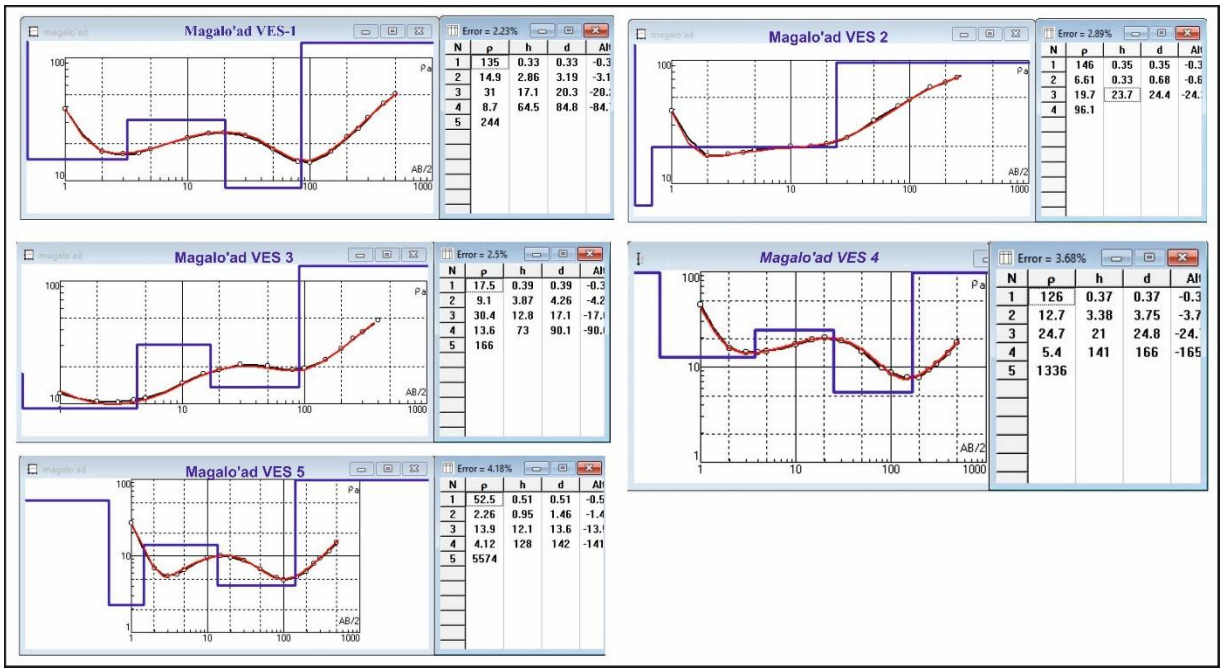


Figure 11. This figure presents the Vertical Electrical Sounding (VES) curves derived from resistivity measurements conducted in the regions of Magalo'ad. These VES curves were analyzed using the IPI 2Win computer program, which aided in determining the thickness and resistivity characteristics of the subsurface layers in these areas

In this region, there are four VES measurement points: VES1, VES2, VES3, and VES4, and the depth of exploration varies between 24.4 meters and 166.2 meters. It is assumed that the geological units from the surface down to this depth are primarily composed of alluvial units. Below this depth, there is a basement rock unit that allows drilling to proceed to a depth of approximately 170 meters in this area.

High resistivity values dominate in the northern areas where VES1, VES2, and VES3 are located (fig. 11). Conversely, in the southern region where VES4 is situated, a distinct vertical

contact is observed between low and high resistivity values. This significant variation may indicate the presence of a fault in this region.

A study was conducted to address the potable groundwater needs of the local residents in four different settlements in Somaliland. To achieve this goal, VES measurement studies were conducted in conjunction with geological surveys in the designated regions. In Table 1 below, the VES measurement points with the highest and most efficient potential for groundwater are identified. Due to the recorded low resistivity values increasing with depth, the mud drilling technique is recommended for borehole construction.

Table 1. Details of the recommended sources

No	Investigated Sites	Recommended VES Site	Recommended Depth (m)
1	Godalo	VES 2	230-250
2	Gambadho	VES 2	80
3	Qoryale	VES 1	350
4	Magalo'ad	VES 4	170

In this research conducted in Somaliland, the potential groundwater resources in the study areas were identified, and the thickness and depth of aquifer units were determined.

Drilling at the recommended measurement points revealed the presence of productive aquifer zones containing groundwater. As a result of this comprehensive groundwater investigation, optimal locations for water wells were determined, and due to the recorded low resistivity values throughout the study area, the mud drilling technique was deemed suitable.

The interpretation of VES data suggests that the groundwater potential within the identified aquifers is sufficient to support life in the region. The findings obtained from this study are of

great importance for the four regions comprising the study area and have contributed to the development of an effective water plan to ensure the well-being of the local population.

5. ACKNOWLEDGMENT

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