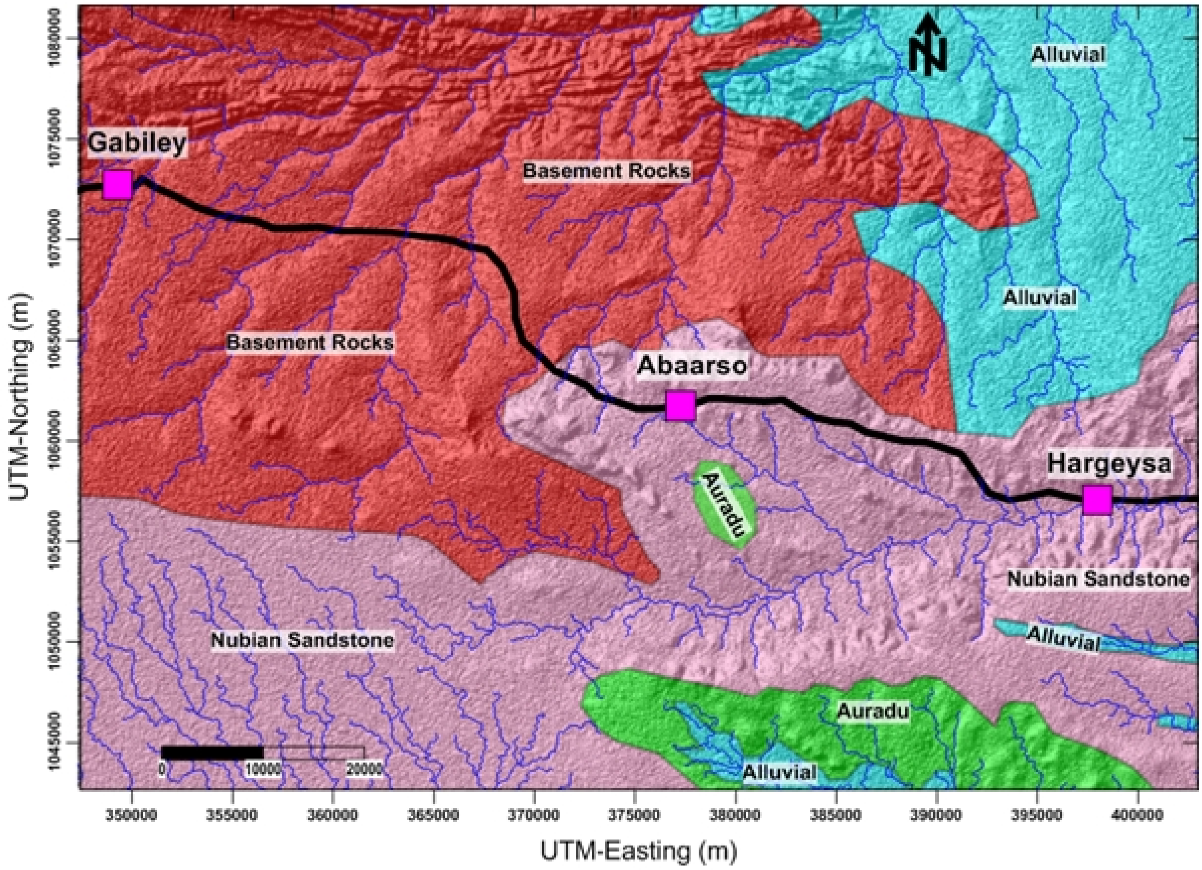
Abaarso Area Hydrogeological and Geophysical Investigation

Final Report



Client: National Drilling Company

July, 2015

SHAAC
Engineering Consulting PLC
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EXECUTIVE SUMMARY

This report summarizes the results of the Hydrogeological and Geophysical survey carried out by SHAAC Consulting Company to assess the groundwater potential of Abaarso area located at about 20 km Northwest from Hargeysa town for National Drilling Company. The details of the investigated site are reported below table and the current report will cover the findings of the site.

Table 1. Details of the investigated site (Abaarso area).

Region	District	Investigated Site	Geographic Datum:WGS84		UTM Datum: WGS84		UTM Zone
			Longitude	Latitude	Easting (m)	Northing (m)	
Gabiley	**Hargeysa**	Abaarso	43.902518^0	9.583885^0	379564	1059598	38 P

In Abaarso area, deep borehole was previously drilled to a depth of 180 m in the past but was abandoned due to encountering technical drilling difficulties and we were told that the drilling could not precede due to encountering massive collapse.

For the current water investigation in Abaarso area, detailed Geological, Hydrogeological and Geophysical survey were carried out and every effort was made to identify the best suitable site to be drilled in order to provide fresh drinking water to Abaarso village and its surrounding communities.

Based on the findings of the investigation, borehole drilling is recommended at the location of VES3.

Table 2. Details of the recommended drilling site

S/No	Investigated Site	Recommended VES Site	Geographic Coordinates in Degrees		UTM		Recommended Depth (m)
			Longitude	Latitude	Easting (m)	Northing (m)	
1	Abaarso	VES3	43.902518^0	9.583885^0	379564	1059598	250

The water bearing unit is found to be within the Nubian Sandstone formation composed of Sandy clay, sand and gravel and water quality is determined to be fresh but slightly salty. Since, the aquifer zone is predominated loose alluvial sediments, technical drilling difficulties such as caving and collapse are expected to be encountered during drilling. Therefore, rotary drilling with mud drilling system is recommended to be used for the drilling.

1. Introduction

1.1. Background

SHAAC consulting company has entered into an agreement with National Drilling Company to conduct detailed hydrogeological and geophysical investigation in and around Abaarso area situated at about 20 km Northwest of Hargeysa town. The purpose of the survey was to identify suitable location for a borehole drilling within the surrounding areas of the town and it was intended to improve the availability of water and sanitation in the area that was identified as high priority and have acute shortages of water supply source.

1.2. Objectives of the Study

Water supply situation in many parts of Somaliland are known to be exceptionally severe and this is due to its very low effective annual rainfall. Hence, groundwater development may be the main water supply source in the country as a whole. Several deep drilling projects were undertaken in Somaliland, however, due to lack of prior hydrogeological knowledge, the success rate of groundwater development or drilling of successful wells has been very low.

The overall objective of the Project is to improve the availability of water and sanitation in Abaarso area in which previous investigations have determined to be one of high priority for groundwater development intervention area since it has an acute shortages of fresh water supply source.

The broader objectives of this detailed hydrogeological site investigations are to select the appropriate water source for the studied locality and to submit detailed report outlining the best way to develop the water sources. In addition of above stated objectives of the investigation, the precise aims are as follows: -

(a) To conduct a baseline survey with particular emphases on hydrogeological and geophysical investigations.
(b) To select with high degree of accuracy, reliable and sustainable water source site.
(c) As a result of this investigation, some type of water sources will be developed for the communities and as a result of this will improve the health of Abaarso community and its surrounding areas.
(d) One of the most important aims of this water investigation is to reduce the burden of women and children who culturally bear the burden of fetching water for domestic purposes from distant sources. The study has concentrated of finding water source close to the community, so as to reduce the burden of women and children of fetching water from distant sources and water trucking.

1.3. Methodology of the Survey

The feasibility of water supply source, identification and design activities have been made through the application of standard socio economic, Environmental Impact Assessment, geological, hydrological, geophysical and engineering techniques. Basic data required for the design of the water supply were acquired from different sources as shown below.

1.3.1. Existing Data and Materials Collected

Existing data and materials has been collected from different sources and used for the surveying and analysis.

A) **Digital Topographic and Geological Maps**

- Digital Topographic maps covering the entire of Somaliland were collected and analyzed and used to prepare the base-map of Abaarso area. The TOPOMAPS are at 1:2500,000 scale
- SPOT satellite image and, Landsat image covering large areas of Somaliland including the investigated site were collected and analyzed.
- Digital Elevation Model (DEM) at 30 m resolution covering the entire Somaliland were obtained and used to model the topography and local physiographic and drainage systems of the interested area.
- Geological Map of Somaliland at digital format prepared by SWALIM Somalia was re-digitized and prepared the modified geology of the investigated site.

B) **Reports and Maps Reviewed**

- Geed Abeera Area Hydrogeological and Geophysical survey for Concern Worldwide, by SHAAC Consulting Company, April 2015.
- 18 Sites hydrogeological, geophysical, socio-economic and EIA in Somaliland for Islamic Relief Somalia, by SHAAC Consulting Company, 2015.
- Site Hydrogeological and geophysical investigation of Alleybadey town, Somaliland, by SHAAC Consulting PLC. 2014.
- Hydrogeological and Geophysical Survey in Boorama District by SHAAC Consulting PLC, 2013.
- Hydrogeological Survey and Assessment of Selected Areas in Somaliland and Puntland, Somalia Water and Land Information Management (SWLIM), December 2012.
- Water Sources Inventory for Northern Somalia, SWALIM, 2009.
- 13 Sites Hydrogeological site investigations in Somaliland by SHAAC Consulting Company, 2006.

C. Borehole Logs

Available existing Water borehole logs were collected such as boreholes located in Geed Balaadh, Arabsiyo, Alleybadey, Magalo'ad and Tog-Wachale.

1.3.2. Field Data Collection

After, the reconnaissance deskwork, the fieldwork was arranged and the consultant mobilized the survey team to the site. During the field, the consultant has undertaken the following activities:

- Traverses has been made in different direction of the study areas to identify the rock types, strategic set up and geological structures in order to identify the possible aquifer system and estimate their aquifer parameter which are the key issues of defining the occurrence & movement of ground water.
- Hydrological and water supply information of the study site were gathered in the field.
- The geology, geomorphology, topography and hydrology of the study area have been reasonably studied in the field to understand the local and regional ground water occurrence.
- Furthermore, water sources namely existing boreholes available in the study area were assessed and inventoried.
- Similarly, specific & general problems relating to existing water supply were collected during the field.
- Three Vertical Electrical Soundings (VES) were conducted.
- Topographic data and locations of suited localities, water points, geological contacts and other relevant data were captured by using GPS.

1.4. Data Analysis and Reporting

Primary data collected from the field and secondary data acquired from different sources were integrated. All information on geological, hydrological and geophysical inventory gathered in the fields as well as from different sources has been used to produce preliminary hydrological map of the study area. The most important outcome as a result of this hydrogeological study is to locate and select the appropriate type of water source for Abaarso area. Other major outcomes of this water investigation are to gather information regarding on the sub-surface geology of the study area.

All information regarding on geological, hydrological, geophysical gathered in the field as well as from different sources have been used to produce this report.

2. General Background

2.1. Location and Accessibility

Abaarso is small town situated at about 20 km northwest of Hargeysa town. The town can be reached by taking the asphalt road connecting from Hargeysa town to Gabiley town.

Figure 1. Location Map of the investigated site

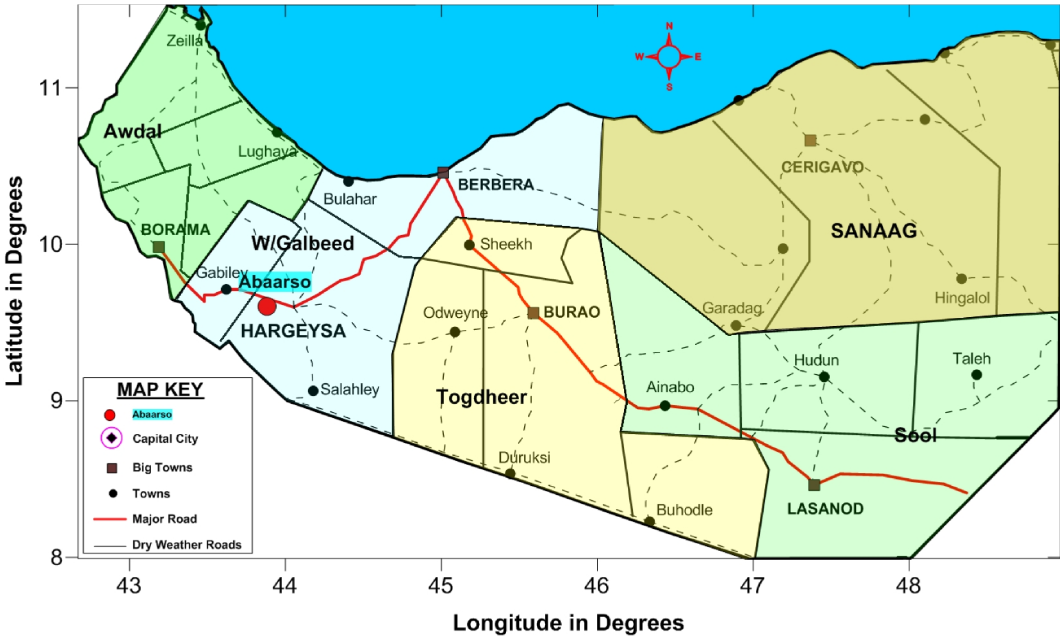
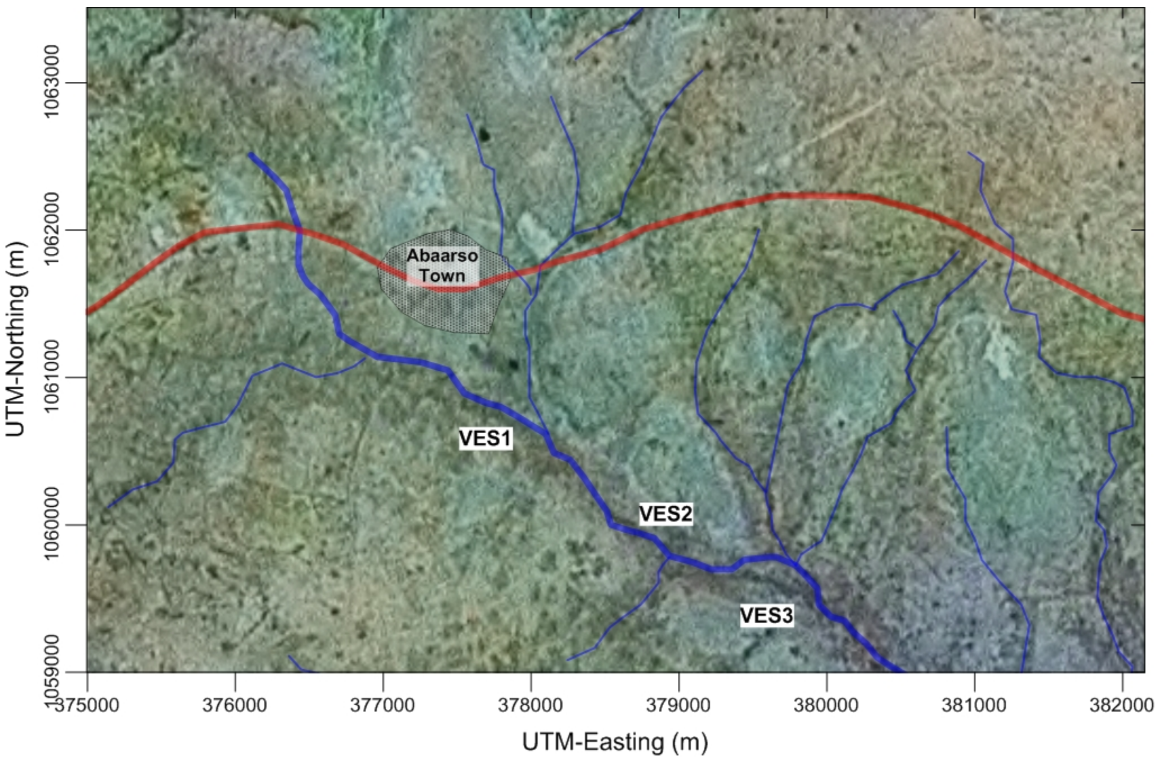


Figure 2. Map of Abaarso



2.2. Existing Water Supply Source

Abaarso is small town under the jurisdiction of Hargeysa District of Maroodi Jeex Region of Somaliland. Previously one borehole was drilled in Abaarso area by an NGO and according to the information obtained from the community, the borehole was drilled to a depth of 180 m depth, but was abandoned to encountering technical drilling difficulties. Currently, Abaarso community relies on its water supply sources from water trucking.

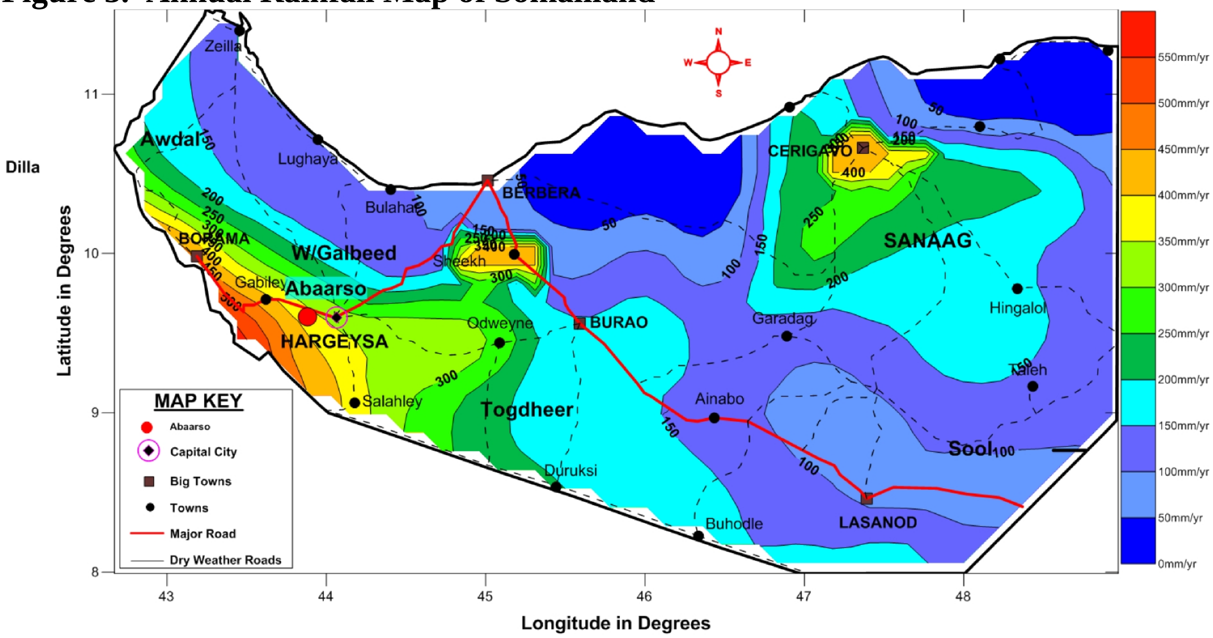
2.3. Climate and Seasons

In general the climate of Somaliland can be classified as arid and Semi-arid type climate, with an average annual rainfall ranging from 500 – 600 mm/year in mountain regions near Hargeysa, Sheekh and Erigavo and it decreases as far inland in the flatter area of Sool Region and in the coastal areas parallel to the Gulf of Aden and the amount decreases to less than 100 mm/year.

The rainfall distribution is bi-modal type pattern and the rain tends to fall in isolated storms. The climate of Somaliland is determined by the occurrence of the seasonal monsoon systems and change of the monsoon winds is responsible change of seasons. The directions of the winds are controlled by sequential movement of inter-tropical convergence Zone (Faillace & Faillace 1986).

During wet seasons, humid maritime air is swept inland by westward winds, while during dry seasons; dry northeast and southeast monsoons are swept into Somaliland which delivers dry continental air masses. There are two rainy seasons, locally known as the Gu' (April to June) and the Deyr (October to November). The rainy seasons are alternated by two dry seasons locally known as Jilaal (December to March) and Haggaa (from July to September). In Abaarso area, receives an average annual rainfall of 400-450 mm/year

Figure 3. Annual Rainfall Map of Somaliland



Somaliland has been recorded as one of the most drought prone regions in the Horn of Africa. Rain falls torrentially and for short duration. The low rainfall regions in the area have a higher intensity of rainfall than those areas which have relatively higher amount of mean annual rainfall. The region is characterized by strong wind circulation, which causes moisture loss in both plants and soils. The mean annual speed of the wind is 2.9 km/sec in relatively high altitude areas, whereas in the low altitude areas attain 5.8 km/sec. Mean monthly temperature ranges from 15 – 25 ^{0}C in the mountain regions to 25 – 35 ^{0}C in inland areas.

2.4. Physiographic and Vegetation Cover

Somaliland can be subdivided into three major physiographic provinces (Figure 4) and these are as follows:-

a) The coastal belt and slopping plain.
b) The Plateaux and valleys
c) The mountain Zone.

The Coastal Belt and Slopping Plain

The coastal Belt is a narrow strip which stretches along the Gulf of Aden, north of the mountain range and it comprises the flat coastal belt and inland rising plain. The coastal belt is a flat narrow strip ranging in width from few hundred meters to about 10 kilometers. The coastal belts under lies by Recent beach sand, coral reef deposits and marine terraces. Small sand dunes of 10 to 12 meter high are common in this Coastal Belt.

The sloping plain which is located between the coastal plain and mountain areas and it has triangular shape and could reach more than 90 kilometers in width. The predominant lithology of the sloping plain is alluvial deposits consisting of clay, sand and gravel.

The Plateaux and Valleys

The Plateaux and Valleys cover extensive area south of the mountain range. This physiographic region can be sub-divided into three Plateaux and large structural depressions which are as follows:

1. The Haud Plateau
2. The Taleex Plateau and Nugaal Valley
3. The Sool-Haud and Sool Plateaux
4. The Daroor Valley

The Haud Plateau

The Haud Plateau is a large undulating plain covering the northwestern part south of the mountain zone. The elevation rises from south to north from 900 m to 1300 m. The mountain area is hilly and drained by several streams, whereas, the southern part is gently flat. The Haud Plateau is covered by the Nubian Sandstone which overlies the Basement Complex.

The Auradu limestone outcrops along the northern border from Hargeysa towards east and southeast, forming a succession of gently elongated ridges with broad alluvial valleys.

The Taleex Plateau and Nugaal Valley

The Taleex Plateau and Nugaal Valley is a large area in Central part of North Somalia and covers parts of Sool, Sanaag and Nugaal regions. The Nugaal valley is large, flat bottomed valley flanked by the Taleex, Sool Haud and Sool Plateau. Togga Nugaal drains to Eyl and Indian Ocean. The Taleex Plateau rises gently towards the edge of the escarpment which constitutes the uppermost part of the Togga (stream) Nugaal catchment. Most of the area is covered by gypsum and gypsiferous soil and to a lesser extent, by limestone.

The areas covered by the gypsum are completely bare. Karstic depressions and sink-holes are wide spread in this zone. Sink-holes in the area of Ceerigabo and Caynabo are often indicated by the presence of a tree called locally Berda.

Gypsiferous alluvial soils cover depressions and in areas with outcrops with Taleex evaporitic sequence, vegetation is absent. Areas covered by thin red soil and underlain by Karkar Formation have consistent vegetation.

Vegetation therefore helps to trace the approximate boundary between Taleex gypsum formation and Karkar limestone formation.

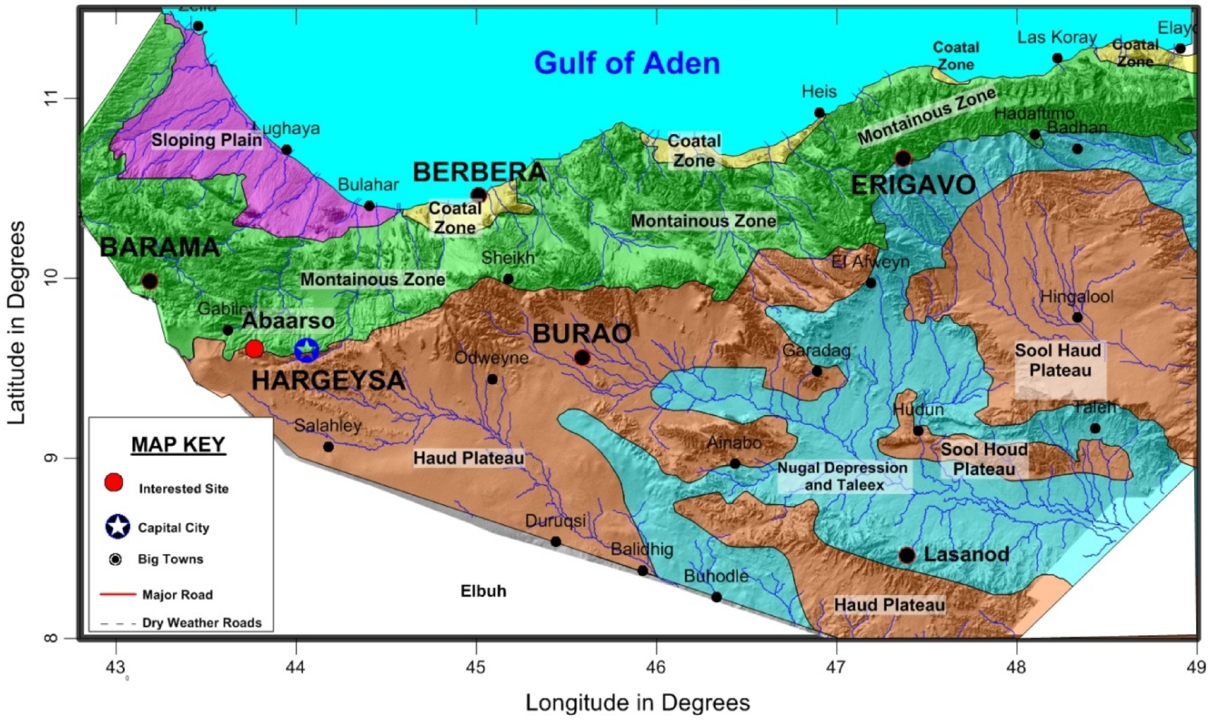
Sool Haud and Sool Plateaux

The Sool Haud Plateau extends between Jidali and Hadaaftimo near the edge of Gulf of Aden and extends as far as the northern part of Nugaal valley south of Xingalool village.

<u>The Mountain Zone</u>

The Mountain Zone is characterized by undulated plateau, with an elevation ranging from 1400 to 1600 m, extends south of Hargeysa and is covered mainly by sedimentary rocks. A lower plateau extending further north has an elevation between 1000 and 1400 m; it is crossed by numerous streams which have incised sedimentary and metamorphic rocks. North of this plateau, a mountain range extends from Lafaruug to Agabar and Boorama. The highest peaks are located in the western part of this range, north of Boorama, with heights of 1300 to about 1800 m. This area is covered mainly by crystalline basement rocks and by Mesozoic limestone where streams have incised narrow valleys. The northernmost part is constituted by the sloping plain and coastal strip, which extend along a large belt ranging in elevation from 600 m to sea level. In Sanaag area there is the high Golis mountain range running parallel to the shore of the Gulf of Aden. The highest peak is Mt. Surud, with an elevation of 2408 m. The mountain range is mostly constituted by crystalline rocks which are deeply incised by numerous streams.

Figure 4. Physiographic Region of Somaliland



As it can be seen on the above illustrated physiographic Region of Somaliland, Abaarso is situated in Mountainous Zone and also is situated on water divide area. South of the town it drains towards the Maroodijeex Stream, while the northern part directly it drains toward the Red Sea.

3. General Geology and Hydrogeology

3.1. General Geology

The geology of Northern Somalia has been described by Macfadyen (1949), and several reports compiled by the Geological Survey of the Former Somaliland Protectorate in the 50's. Faillace and Faillace Hydrogeology and Water Quality Report of 1986 were based on the above mentioned works. There are also several geological maps by the University of Florence (1973). The classifications of different geological formations that do exist in the study are will follow the above mention reports. The geological successions of the region (in order of succession) can be broadly divided into:

a) Polio-Pleistocene to Recent deposits: Consist of alluvial, colluvial, sand-dunes and Coral limestone.

b) Tertiary: Consists of Limestone, evaporitic rocks and thick extensive series of sedimentary rocks.
c) Cretaceous: Sandstone and Limestone.
d) Jurassic: Limestone, shale and sandstone.
e) Precambrian: Basement rocks.

The geological history of the region can be followed from the Precambrian Era which is represented metamorphic and igneous rocks of the basement system. The regional metamorphism was followed by various cycles of regression and transgression, and localized volcanism.

During the Precambrian era, vast sediments accumulated and at the end of the era, a period of regional folding and metamorphism has occurred. As a consequence of this large scale tectonic activity, the original sediments were subjected to high temperature and pressure, which caused partial melting and subsequent re-crystallization and growth of new minerals. Depending on the parent material and the prevailing temperature and pressure, different types of gneisses, schists and granites were formed. The Precambrian Basement complex outcrops extensively along the Plateau escarpments.

The Precambrian era was followed of uplift and erosion and the peneplained basement rocks were covered by conglomerate and sandstone during the Lower Jurassic which marks the sea transgression. Marine sediments were deposited during the Middle Jurassic over the regions. These sediments are predominantly fossiliferous limestone, marl and shale.

Towards the end of the Jurassic, gradual uplift of the shield resulted in sea regression and subsequent erosion of part of the Jurassic sediments. With the formation of tectonic scarps and grabens caused by faulting, the Jurassic sediments were preserved from erosion in some areas. This retreat of the sea was followed by the deposition of sandstone, sand and sandy clay of the Nubian Sandstone formation. From west to east the Cretaceous sediments range from continental through lagoonal to marine.

As a consequence of this early faulting the Cretaceous sediments are thicker and in stratigraphic continuity with the Jurassic in the east whereas to the west they tend to be thinner and lie directly over the basement. The continental deposits dated as Upper Cretaceous to Lower Paleocene are known as the Nubian Sandstone.

The exposed land covered by the Nubian Sandstone was flooded by a deep sea incursion during the Lower Eocene when the Auradu limestone was deposited. The sea gradually retreated during the Middle Eocene and an evaporitic environment prevailed with anhydrite, gypsum and marls of the Taleex Formation being deposited.

Further marine ingression during the Upper Eocene resulted in the Karkar Formation of shales topped by calcarenites, marine cherty limestone with intercalations of marls. This Karkar formation was deposited in a shallow sea and extends in the highlands of the eastern area and the Sool Plateau.

During the Oligocene and Miocene marine sediments were deposited in a narrow belt along the Indian Ocean coast and are replaced inland by lagoonal and continental deposits in the Daroor Valley.

Along the Gulf of Aden coast coral limestone reefs were deposited which are topped by coarse conglomerates and boulders. The uplifting of this area and consequent sea regression together with the onset of the rifting of the Gulf of Aden during the Miocene has resulted in sedimentation being restricted to only a narrow coastal belt. The breaking of the continental shield resulted in intense volcanic activity especially towards the Djibouti border.

3.2. Stratigraphy of Somaliland.

The above illustrated geological history of the region caused the following succession and creation of geological formations which can be broadly divided into the following major units:

1. Precambrian: Basement Complex (metamorphic and volcanic rocks)
2. Jurassic: Limestone, shale and sandstone
3. Cretaceous: Nubian sandstones (sandstones and limestone's)
4. Tertiary (Eocene): Limestone, evaporitic rocks
    - 4.1. Auradu Formation (limestones)
    - 4.2. Taleex Formation (evaporitic rocks)
    - 4.3. Karkar Formation (limestones)
5. Pleistocene to Recent Alluvium
    - 5.1. Basaltic rocks
    - 5.2. Recent alluviums, terraces and coastal beaches

3.2.1. Basement Rocks

the Basement complex outcrops in Somaliland mostly in its northwest part (Awdal, Hargeysa and Gabiley areas), in Berbera and Sheekh areas and along a narrow belt of the Ceerigabo-Ahl Madow escarpment. The Basement is mostly composed of schists, ortogneiss, quartzites and paragneiss intruded by granite, diorite and gabro. The gneissic rocks are often crossed by numerous dykes generally of an acid nature. In the study area, hills of Basement rocks are observed north of Arabsiyo area.

3.2.2. Jurassic

The Jurassic is constituted by a thick sequence of continental deposits (basal sandstone) followed by marine beds. The basal sandstone is known as Adigrat sandstone. This is the basal sandstone is present throughout East Africa, and was named by W. T. Blanford in 1870. In southern Somalia it is composed of varicolored quartz sands with intercalations of gypsum and dark-red shale with a maximum thickness of 130 m. In northern Somalia, the Adigrat consists of fine to coarse-grained, varicolored quartzitic, micaceous, cross-bedded, un-fossiliferous sandstones, locally grading upward into sandy Limestones. The thickness varies from place to place and is mainly due to the lateral change of facies.

Jurassic limestone outcrops in the Boorama district. It comprises the Wanderer, the Gahodleh, and the Bihen suites, with thin-bedded limestone and marls followed by well stratified and massive coral limestone. The series is completed by calcareous and marly beds. The Jurassic formations are preserved in down-faulted blocks delimited by the basement. In the study area, remnant of Jurassic limestone was observed along the road from Arabsiyo town to Abaarso area.

3.2.3. Nubian *Sandstone*:

The Nubian Sandstone is deposited under continental or lagoonal condition and consists of fine to coarse grained white to red-brown quartz sandstone. Some conglomerate beds are also present. The sandstone is often cross-bedded, soft and friable. The Nubian sandstone unconformably overlies on the Basement Complex along the plateau escarpment and is conformably underlies by the Auradu limestone.

The sandstone occupies the southern part of Hargeysa and Gabiley districts in areas such as Geed-Balaadh, Faroweyne, Alleybadey, Salaxlay and Baligubadle and Xaaji-Saalax. In these areas the sandstone is presumed to overlie the Basement complex. No outcrops are apparent in the area, as the sandstone is covered by thick sandy clay deposits in most parts.

Numerous investigations were carried out in areas occupied by the sandstone along the Ethiopian border, especially near Wajaale, Gee-Balaadh, Alleybadey, Salaxlay, and Baligubadle. The thickness of the sandstone increases toward south and south east. The formation thickness is only a few meters thick at Jifo Urey near Gabiley (Hargeysa-Boorama road). At Wajaale area the thickness is about 100 m thick and as you go south-east toward Baligubadle, the thickness could reach more than 500 m

3.2.4. Auradu Formation

The Auradu series consists of grey to white, hard and massive limestone which is often unbedded. The Auradu limestone outcrops in a large, discontinuous and fault-dissected belt bordering the edge of the plateau escarpment where it overlies the Nubian Sandstone. It extends from the vicinity of Hargeysa to the area of Burco and Ceerigabo, with numerous outcrops covering large areas between Berbera and Ceerigabo. The thickest sequence, 380 m, was measured near Ceerigabo. Auradu limestone is also widely exposed in the Nugaal valley where limestone underlies the Taleex gypsum formation. The upper part of the Auradu Formation consists of massive limestone alternated with thinly bedded limestone layers, at times chalky and gypsiferous, with calcareous shales. The thickness measured at Allahkajid was 345 m, but varies in other places.

3.2.5. Taleex Formation

This formation is named after the town of Taleex in Sool Region where it outcrops for a section of 250 meters. It consists of a sequence of massive and dense anhydrite beds with intercalations of limestone and gypsum. Clay, sand and layers of gravel deposited by rivers in shallow lagoonal environment are also locally present in this sequence.

Lateral changes of facies from gypsum and anhydrite to limestone is known in some places. Changes from anhydrite through gypsiferous limestone to dense limestone are of frequent occurrence and can easily be followed in comparatively short distance. The greater succession of anhydrite Series occurs in Nugaal Valley, where it covers large part of Sool and Nugaal Regions.

Several boreholes were drilled in throughout the Taleex Series. Water from these wells is highly mineralized and most cases are of the Calcium or Sodium Sulphate type water. It was found the TDS (Total Dissolved Solidus) is usually greater than 3800 mg/l. Most of these boreholes were abandoned because of high salinity content which is not fit for human consumption.

Several boreholes drilled for Lasanod town water supply which has been drilled in Taleex formation have been abandoned. However, the Auradu limestone was struck at 140 m in a well drilled to a depth of 280 m in 1980. The Auradu limestone is very promising aquifer as it may yield water of good quality provided that the overlaying Taleex aquifer must be sealed off in order to secure the expected fresh water.

3.2.6. Karkar ***Formation:***

Karkar Formation is constituted by Fossiliferous, bedded limestone, marly limestone, and white marls. Limestone is often cavernous; its color ranges from white to yellow to brown. Thin layers of gypsum and occasionally thin shale also occur in some sections. The sequence is generally conformable on the Taleex Formation and its thickness various between 200 to 400 m. The contact between Karkar and the underlying Taleex Formation is marked by 2 meter of lateritic sand and weathered boulders. Water quality from Karkar springs and wells is good with EC value of 1490 to 1800 micromhos/cm.

3.2.7. Pleistocene ***to Recent Alluvium:***

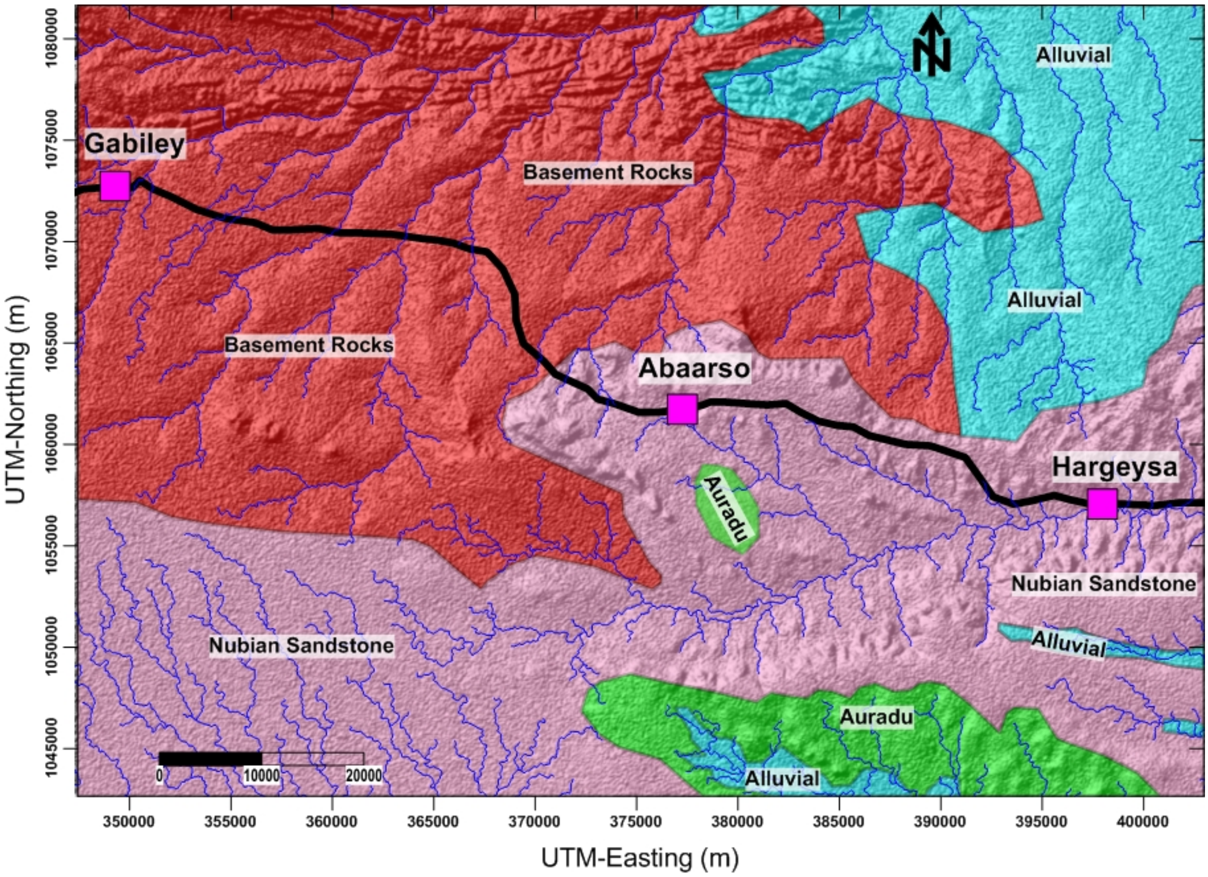
Thick layers of Pleistocene to Recent sediments were deposited within the plateau areas, between the foothills and the coastal strips. The sediments area of mixed texture and range from coarse gravel to heavy clays.

3.3. Geology and Stratigraphy of Abaarso Area

The geological Formations (Figure 5) that play a role of the investigated locality and its surrounding areas are as follows: Basement Complex, Nubian Sandstone Formation, and Pleistocene to Recent Alluvium.

Based on the borehole drilling logs in Arabsiyo area, the subsurface geology are composed of relatively thin alluvial sediments underlain by loose and less cemented sandstone which is most likely the Nubian Sandstone underlain by the Basement rocks. Most of the boreholes have reached the basement to an average depth of 90 to 120 m depth. However, the abandoned borehole in Abaarso area, basement rocks were not even reached at 180 m depth.

Figure 5. Local Geology of Abaarso area



As it can be seen on the above depicted geological map of Abaarso area, the area is underlain by the Nubian Sandstone Formation, while the western and northern parts are covered by the Basement rocks.

4. Geo-Electrical Survey Results

4.1. Principal and Objectives

Geophysical surveys can be useful in the study of most subsurface geologic problems. Geophysics also can contribute too many investigations that are concerned primarily with surface geology. However, geophysical surveys are not always the most effective method of obtaining the information needed. For example, in some areas auger or drill holes may be a more effective way of obtaining near-surface information than geophysical surveys. In some investigations a combination of drilling and geophysical measurements may provide the optimum cost benefit ratio. Geophysical surveys are not practical in all ground-water investigations, but this determination usually can be made only by someone with an understanding of the capabilities, limitations, and costs of geophysical surveys (Zohdy A.AR, et all, 1974).

A clear definition of the geologic or hydrologic problem and objectives of an investigation is important in determining whether exploration geophysics should be used and also in designing the geophysical survey. The lack of a clear definition of the problem can result in ineffective use of geophysical methods. The proper design of a geophysical survey is important not only in insuring that the needed data will be obtained but also in controlling costs, as the expense of making a geophysical survey is determined primarily by the detail and accuracy required.

A great variety of geophysical methods are available in the assessment of geological subsurface conditions. In groundwater exploration, the most widely applied techniques geo-electrical resistivity, electro-magnetic (EM) profiling, seismic refraction and geophysical borehole logging. Other, less common investigation tools are induced polarization (IP) surveys, magnetometer surveys, gravity method and airborne geophysics. The most widely used geophysical survey for ground water investigation is the geo-electrical survey (USGS, 1974).

In ground-water studies, the resistivity method can furnish information on subsurface geology which might be unattainable by other geophysical methods. For example, electrical methods are unique in furnishing information concerning the depth of the fresh-salt water interface, whereas neither gravity, magnetic, nor seismic methods can supply such information. A thick clay layer separating two aquifers usually can be detected easily on a sounding curve but the same clay bed maybe a low velocity layer in seismic refraction surveys and cause erroneous depth estimates. Buried stream channels, often can be mapped accurately by the resistivity method.

In the present survey, due to lack of accessibility along the route for profiling, Resistivity and IP profile was not conducted, however, Vertical Resistivity Sounding (VES) techniques were applied. Geo-electrical survey or the Resistivity method is a method by which current is applied by conduction to the ground through electrodes. The electrical resistivity survey is to pass the current into the ground via two electrodes and that measure the potential drop between a second pair of electrodes placed in between the current electrodes. The use of Vertical Electrical Sounding is to provide addition subsurface data for the hydrogeological investigations. While, profiling measures lateral changes in apparent resistivity, which reflect variations in the lithology, the depth of weathering (if any) or the water content.

The applied geo-electrical method is briefly discussed in the following section.

4.2. Resistivity Method

4.2.1. Basic Principles

The resistance (R) of certain material is directly proportional to its length (L) and cross-sectional area (A), which can be expressed as:

R = ° * L/A	(t)	**(1)**

Where ρ is known as the specific resistivity, characteristic of material and independent of its shape or size. With Ohm's Law:

R = ¢V/I	(t)	**(2)**

Where δV is the potential difference across the resistor and (I) is the electric current through the resistor, the specific resistivity may be determined by:

° = (A/L) * (¢V/I)	(t **m)**	**(3)**

The electrical properties of rocks in the upper part of the earth's crust are determined by lithology, porosity, and the degree of pore space saturation and the salinity of pore water. These factors all contribute to the resistivity of a material which is the reciprocal of electrical conductivity. The resistivity of the earth materials can be studied by measuring the electrical potential distribution produced by earth's surface by an electric current that is passed through the earth. Vertical electrical soundings are point measurements that provide information on the vertical resistivity layering at certain location. Resistivity profiles, on the other hand, are carried out to obtain information on lateral changes in apparent resistivity along a cross-section.

3.2.2. Geo-electrical Layer Response

In principal, saturated and/or weathered rocks have low resistiveties than unsaturated (dry) and/or fresh rock. The higher of the porosity of the saturated rock, the lower its resistivity, and the higher the salinity of the saturating fluids, the lower the resistivity. In the presence of clay and conductive minerals the resistivity of the rock is also reduced. The relation between the formation resistivity (ρ) and the salinity is given by the Formation Factor (F), which can be expressed as:

° = F * °$_w$ = F * 10,000/EC(«S/cm)	(t **m)**	**(4)**

Where ρ_w is the resistivity of water and EC is electrical conductivity. The formation factor (F) varies between 1 (for sandy clay) and 7 (for coarse sand). If certain aquifer have an average formation factor of 3, and EC of 100 µS/cm, will have a formation resistivity of 300 Ωm. The same material, when containing water with an EC of 1,500 µS/cm, will have a resistivity of only 20 Ωm. Brackish water is marked by EC values of 2,000 to 15,000 µS/cm, which is equivalent to a ρ_w of 5 to 0.67 Ωm. Deposits containing brackish water will therefore in most cases adopt a formation resistivity of 10 Ωm. Clay formations with fresh water will respond similarly (equivalence). Coarse sand is usually marked by high resistivity, with common range from 60 to 500 Ωm. Weathered clay layers and layers with high portion of fine materials are less resistive, with typical range of 8 to 40 Ωm, depending on proportion of clay and the water content.

In sedimentary terrains, the greatest difficult is formed by:

1. Similar geophysical properties of layers with contrasting hydrogeological characteristics are encountered.
2. Large vertical and lateral variations are common.

4.2.3. Resistivity Sounding Techniques

When carrying out a resistivity sounding, also called Vertical Electrical Sounding (VES), an electrical current (I) is applied into the ground through two metal electrodes (Current electrodes). Subsurface variations in electrical conductivity determine the pattern of current flow in the ground and thus the distribution of electrical potential.

A measure of this is obtained in terms of voltage drop (δV) between a second pair of metal electrodes (Potential electrodes) which are placed near the center of the array. The ratio (δV/I) provides a direct measurement of the ground resistance and from this, and the electrode spacing, the apparent resistivity (ρ_a) of the ground is calculated.

The measuring setup consists of resistivity meter (usually placed in the middle of the array), connected to two current electrodes (AB), and two potential electrodes (MN) towards the center. There are several electrical setups used for resistivity survey; however the most widely used is ‘Schlumberger’ array for Vertical Electrical Sounding.

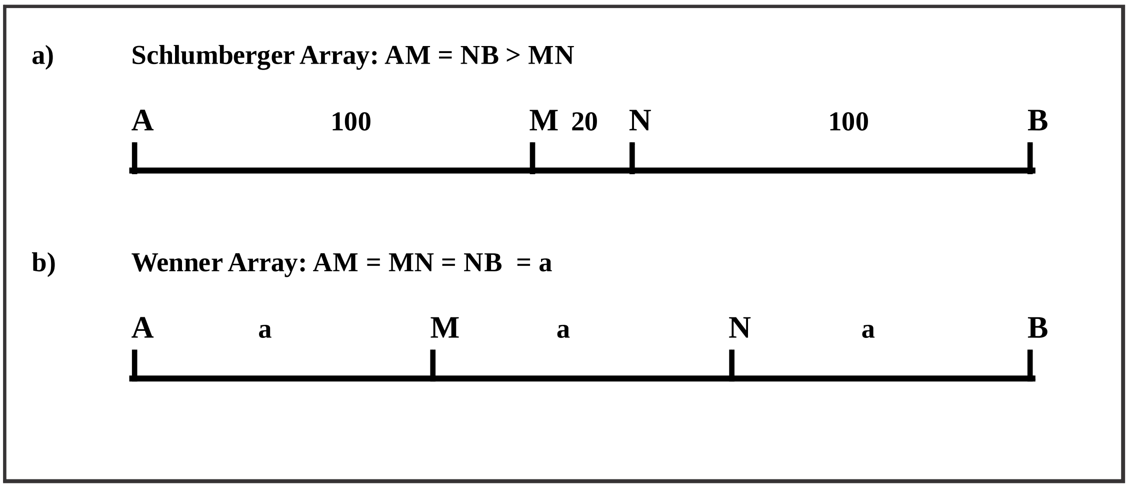
For Schlumberger array measurement is made with an expanding array of Current electrodes which allows the flow of current to penetrate progressively greater depths. The apparent resistivity as a function of the electrode separation AB provides information on the vertical variation in resistivity. Hence, the depth of penetration varies according to the electrode array. The point at which a change in earth layering is observed depends on the resistivity contrast, but is generally of the order of a quarter of the current electrode spacing AB.

Resistivity profiles are usually carried in Werner configuration, i.e. an electrode setup with a uniform distance between potential and current electrodes. The entire array is moved across the area of interest. By doing so, lateral changes in apparent resistivity are measured, which reflect variations in the lithology, the depth of weathering or the water content. The so-called "anomalies" may indicate the intersection of a fault (usually a negative anomaly), quartzite band (positive anomaly) or buried old river channels (anomaly depends on nature of surrounding deposits). Usually such lineaments, which may also be observed on aerial photographs, are associated with the occurrence of groundwater.

It must be noted that resistivity differences in a single profile array may largely reflect variations at the surface rather than underground. For this reason, it is usually not sufficient to carry out single-spaced profiles, particularly where litho-Stratigraphy is not well known. The depth of penetration increases at greater electrode spacing.

A series of profiles at variable electrode separations will provide an indication of vertical resistivity trends. Moreover, by repeating the same profile at a different configuration, it will become clear if the observed resistivity patterns are caused by surface phenomena or underground features.

Figure 6. Resistivity Arrays



4.3. Field data Collection and interpretations

The electrical sounding and Resistivity survey were conducted by using **ABEM SAS 1000 Terrameter**, four cable reels and external 12 volt DC Battery. For Vertical Electrical Sounding (VES), since Schlumberger array configuration has a practical an advantage compared to other configurations, Schlumberger array configurations was used for this survey. The selected current electrode spacing (AB/2) and the potential electrode spacing (MN/2) from the center of the spread are illustrated in the table below.

Table 3. Electrode Configuration

Current Electrode Spacing (AB/2)	1-10	10-20	20-50	50-100	100-500
Potential Electrode Spacing (MN/2)	0.5	2	5	20	50

For Vertical Electrical Sounding (VES) field data was first interpreted manually by plotting the apparent Resistivity against current electrode separation (AB/2) on log-log paper and curve matching using a 2-D master curve and four auxiliary curves available for Schulumberger spread. The initial model parameters were further processed by Interpex-1D Sounding Inversion computer software.

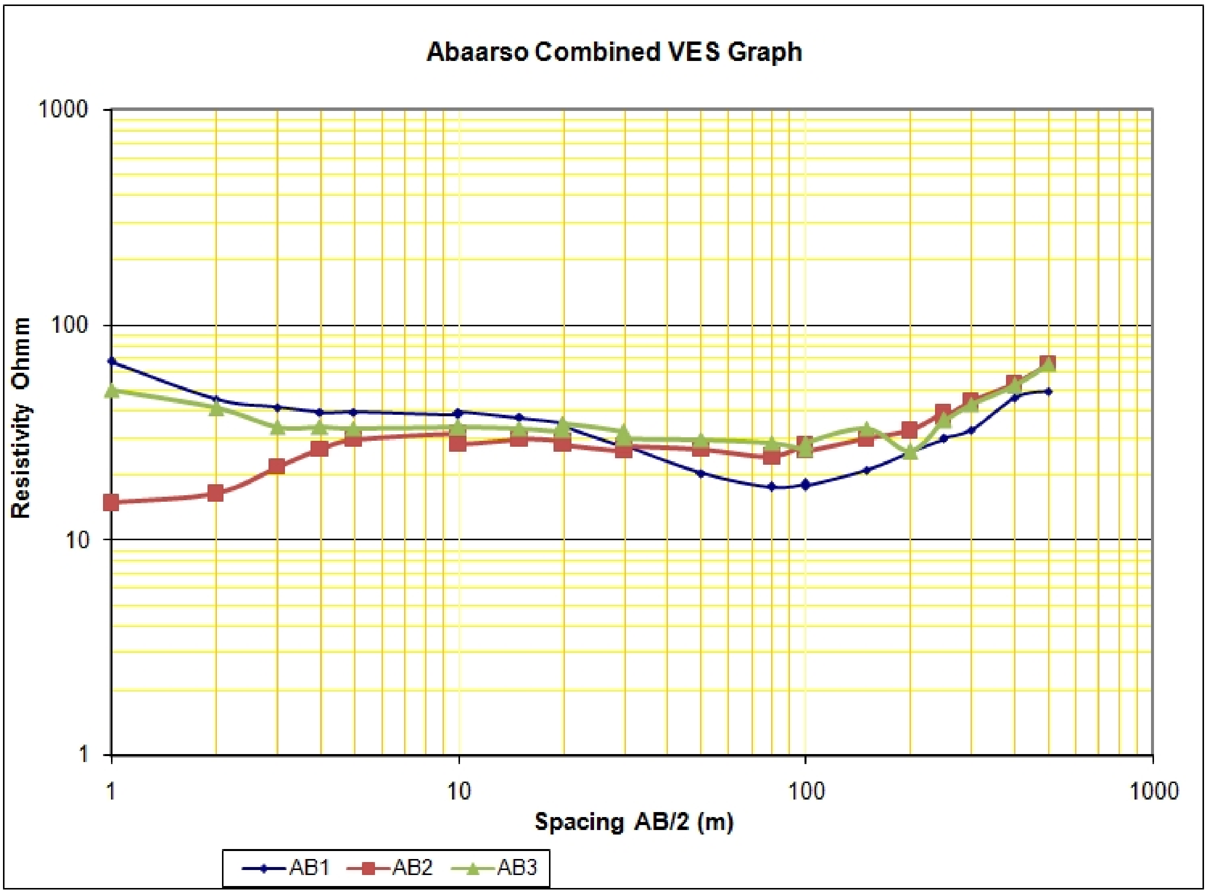
4.4. Geo-Electrical Survey Results of Abaarso Area

4.4.1. General

The morphology of the study area consist of rugged terrain deeply incised by streams, in addition the area that is not cultivated are predominated by acacia threes, hence, the accessibility was limited. Three VES measurements were taken along the stream which is one of tributaries of Maroodijeex stream. The VES Measurements were executed using the Schlumberger measuring array with the current electrode spacing expanded to 1000 m at each VES point (AB/2 = 500 m). The VES data has been interpreted both qualitatively and subsequently by means of recognized modelling softwares (Interpex ID sounding Inversion, Resist and IPI-Win) 1-D programs to provide quantitative 1-D depth-resistivity model interpretation of the probed locations of measurement and analysis of equivalent solutions.

4.4.2. Results and interpretation

Figure 7. Abaarso Combined VES Graphs



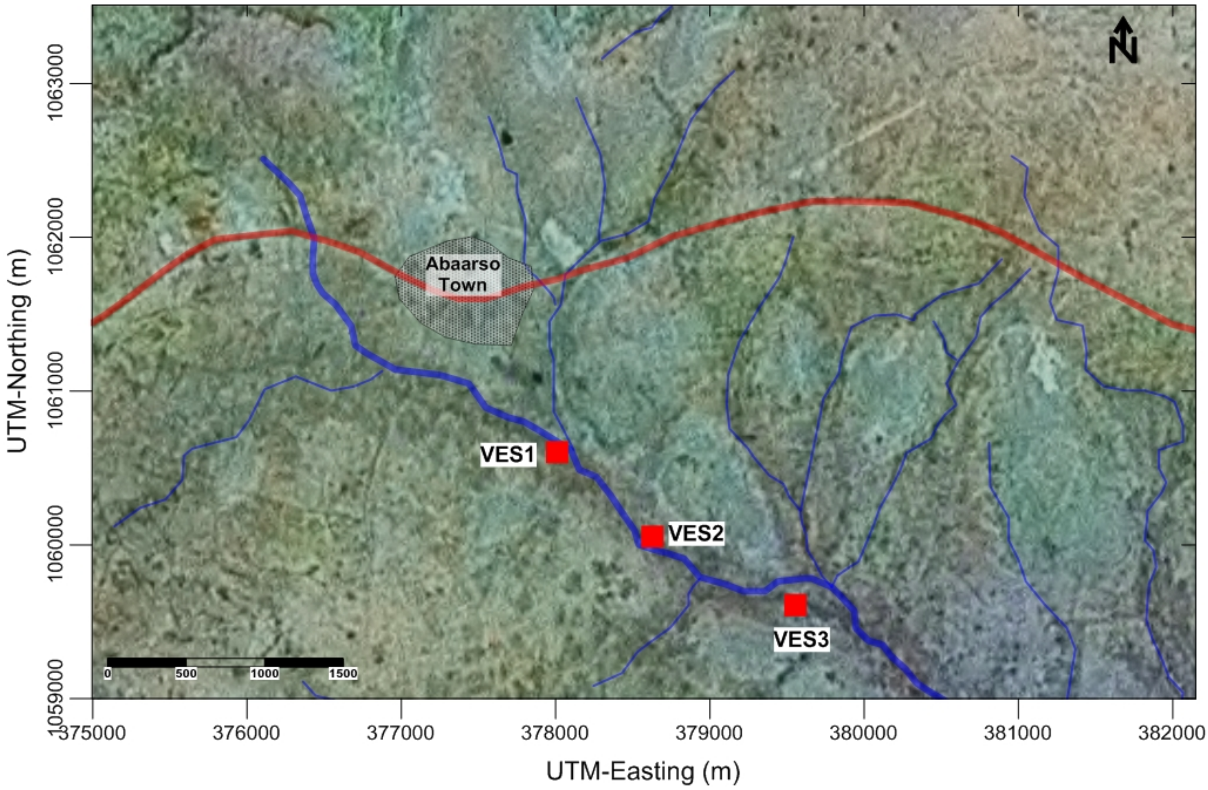
For visual interpretation, combined VES graph of Abaarso was created. As it can be seen from the above depicted graph, the resistivity values of all VES data rises gently and this is an indication that the basement rocks are relatively deep.

Since, all VES data have similar patterns it implies that geologically are found to be within similar environment encountering similar rock types. Significant differences only arise in the lithological variations especially in texture of the rocks encountered at different places as well as thicknesses of geo-electric layers encountered. Table 4 below shows the geographical coordinates of Abaarso VES locations.

Table 4. Abaarso VES Locations (Datum is WGS84 for both projections)

Longitude	Latitude	UTM-X	UTM-Y	VES ID
43.888365^0	9.592992^0	378014	1060610	**VES1**
43.893949^0	9.587900^0	378625	1060045	**VES2**
43.902518^0	9.583885^0	379564	1059598	**VES3**

Figure 8. Abaarso VES Location Map



Interpreted results of VES soundings have been summarized and presented in the following tables. Layer-specific resistivity ranges (presented in the tables) are determined lithological and geological background of the area. The descriptions may therefore not necessarily represent the actual formations that will be encountered during drilling.

Abaarso VES-1 Interpretations.

Table 5. Hydrogeological Interpretation of Abaarso VES1 (Control VES)

Later No	Resistivity (Ωm)	Thickness (m)	Depth (m)	Interpretation	Acquiferous?
1	120.35	0.38	0.38	Dry top sandy top soil	No
2	39.93	14.27	14.66	Sand	No
3	14.40	93.32	107.98	Highly weathered sandstone	Yes
4	135.96	∞	>107.98	Basement Rocks	No

At this VES sites, four geo-electrical layers were identified and maximum penetration of 107.98 m depth was reached. According to the interpretation, the upper two geo-electric layers are alluvial sediment underlain by a geo-electric layer that was interpreted to be the Nubian sandstone and below the depth of 107.98 m depth hard rock was encountered which is most likely the upper weathered part of the Basement Complex. The water bearing unit is found within the highly weathered sandstone and the upper part of the weathered Basement rocks and extends beyond 107.98 m depth.

It seems that the basement rocks could be encountered at shallow depth, hence, borehole drilling is not recommended at this site.

Abaarso VES2 Interpretations.

Table 6. Hydrogeological Interpretation of Abaarso VES2

Later No	Resistivity (Ωm)	Thickness (m)	Depth (m)	Interpretation	Acquiferous?
1	11.74	1.30	1.30	Clay top soil	No
2	63.70	1.26	2.57	Sand	No
3	23.67	127.80	130.36	Wet and highly weathered sandstone	No
4	59.33	64.19	194.55	Weathered Sandstone	Yes
5	425.07	∞	>194.55	Basement Rocks	No

VES2 was conducted at about 2 km south of Abaarso town. At this location, the area is found to be underlain by thin alluvial sediments underlain by the Nubian sandstone and the Basement rocks was found to be encountered at 194.55 m depth. The water bearing strata is found with the weathered sandstone and extends up to 194.55 m depth.

If drilled t this site, the borehole will be shallow and the expected yield could be low, hence, borehole drilling is not recommended at this location.

Abaarso VES3 Interpretations.

Table 7. Hydrogeological Interpretation of VES3

Later No	Resistivity (Ωm)	Thickness (m)	Depth (m)	Interpretation	Acquiferous?
1	61.79	0.56	0.56	Dry top soil	No
2	33.13	26.73	27.29	Sand	No
3	23.89	107.96	135.25	Sandy clay	No
4	37.52	77.82	213.07	Weathered sandstone	Yes
5	2381.20	∞	>213.07	Basement rocks	No

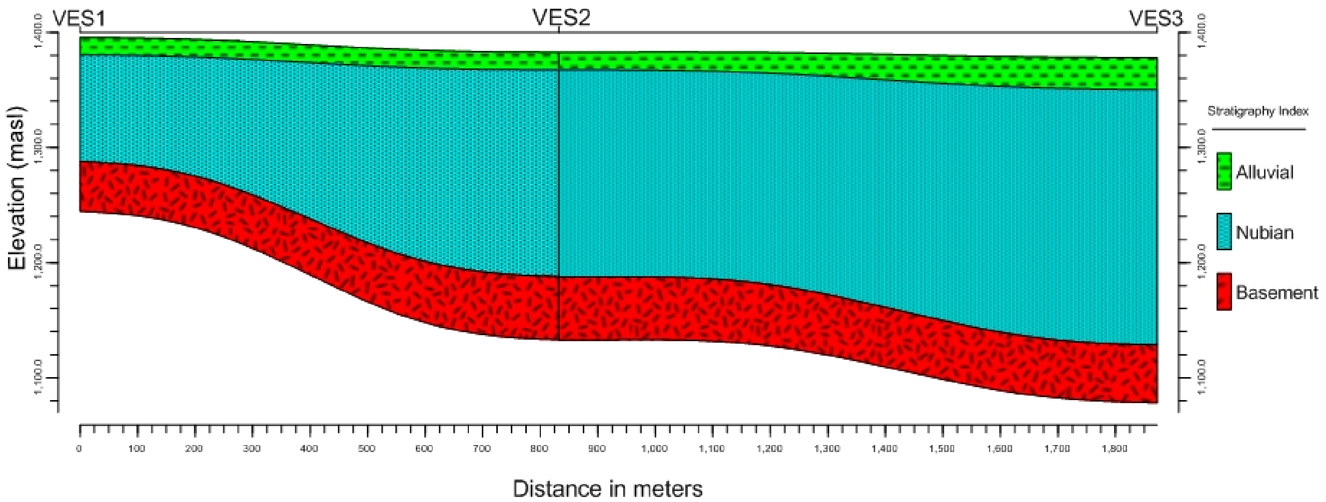
VES3 is conducted about 3 km south of Abaarso town along the western bank of the main stream. According to the interpretation, the area is underlain by relatively thick alluvial sediments extending up to 27.29 m depth, underlain by reasonably thick Nubian sandstone. The Nubian sandstone unit is underlain by fresh basement rocks and starts at the depth of 213 m depth. The water bearing strata was identified within the weathered Nubian sandstone and extends up to 213.14 m depth. The resistivity value (37.82 Ωm) of the water bearing strata indicates that the degree of weathering is relatively high and the groundwater quality is determined to be fresh. At this site, borehole can be drilled with maximum expected drilling depth of 250 m depth.

4.4.3. VES evaluation and site selection

Based on the resistivity interpretations of VES sites conducted around Abaarso area, the area is found to be underlain by alluvial sediments followed by the Nubian Sandstone formation underlain by the Basement Complex.

In order to understand the subsurface geology of the area such as the thickness of the Nubian Sandstone Formation as well as the depth of the basement along the profile connecting from VES1 to VES3 was prepared. The interpreted VES data for each site were converted into stratigraphy; hence stratigraphic cross section was prepared.

Figure 9. Interpreted litho-stratigraphy of Abaarso area



Based on the above depicted interpreted apparent resistivity cross section, at the location of VES1, the Basement Rocks are found to be shallow and becomes deeper as you go toward south and towards VES2 and VES3. In order to drill a borehole with reasonable good quantity of water, the well has to fully penetrate the entire thickness of the Nubian Sandstone, therefore any borehole that to be drilled in Abaarso area, should be drilled at the location of VES3 or even far away from VES3 in southern direction. If drilled at this site, the maximum expected drilling depths is 250 m depth.

Considering that the location of VES3 is situated only at about 3 km from Abaarso town, the location of VES3 is recommended for drilling and the maximum expected drilling depth is 250 m depth.

5. Conclusions and Recommendation

- In Abaarso area, three stratigraphic units were encountered namely the Alluvial sediments, the Nubian Sandstone and the underlying Basement rocks.
- The basement rocks were found shallow close to the town; however, it becomes deep as you go toward the location of VES3.
- For this reason, any borehole drilled in this area, shall be drilled at the away from VES, hence, the location of VES3 is the most appropriate site to be drilled.
- The maximum expected drilling depth is 250 m depth.
- The expected groundwater quality for the selected site is fresh water.
- The expected water bearing unit is composed highly weathered Nubian Sandstone composed of sandy clay, and gravel, hence, drilling difficulties could be encountered during drilling.
- For this reason, careful drilling is recommended and if it is possible, rotary mud drilling system is recommended to be used.
- The geographical coordinates for the selected site is shown below

Longitude	Latitude	UTM-X	UTM-Y	Recommended VES Site and depth
43.902518^0	9.583885^0	379564	1059598	VES3 (250 m)

APPENDIX 1.

Borehole Design

Abaarso Typical Borehole Design

250 m deep