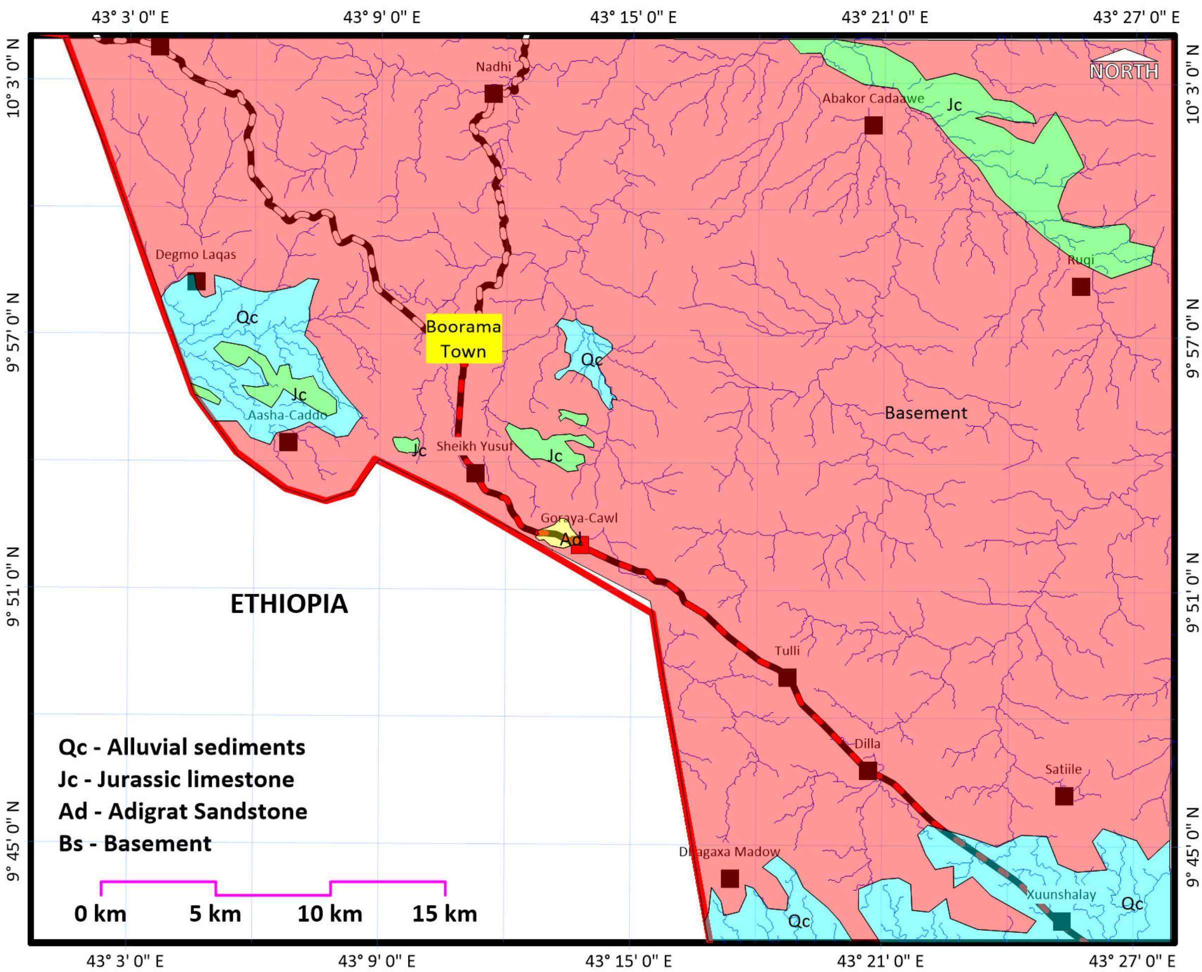
Site Hydrogeological and Geophysical Survey of Goraya Cawl and Amoud Sites

Final Report



Client: SHABA

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Prepared By:

SHAAC
Engineering/Geoscieces & Water Works Consulting Company

EXECUTIVE SUMMARY

This report summarizes the result of the Hydrogeological and Geophysical survey carried out by SHAAC Consulting Company to assess the groundwater potential of Goraya Cawl and Amoud Sites that to be drilled for three borehole for SHABA, Boorama District of Awdal Region of Somaliland. Detailed Geological, Hydrogeological and Geophysical survey were carried in Goraya-Cawl and Amoud sites and every effort was made to identify the best suitable sites to be drilled in both sites in order to be incorporated the water supply sources for Boorama town.

Most of the boreholes which supply water to Boorama town were drilled in Amoud area and based on the previous water investigation and consequent borehole drilling in Amoud area have clearly shown the presence of tectonically preserved full graben at the center of Amoud area. Based on aquifer modeling as well as geological cross sections, at the central part of Amoud area, the basement rocks could be reached below 230 to 250 m depth, while close to the fault delimited areas, the depth of the basement rocks were found to be shallow. For the current investigated points, were selected were the basement rocks are expected to be deep below 160 m depth.

For Goraya-Cawl area, the area, were found to outcrop Adigrat sandstone formation, however, the expected aquifer extension were found to be small, because the sandstone outcrops were found to be surrounded by the basement rocks. However, within the Adigrat sandstone outcrop area, the basement rocks were determined to be slightly shallow to deep with an average depth of 140 t0 180 m depth.

In Boorama area, especially in Amoud, Afraaga, Saw and Goraya-Cawl areas, due to tectonic activities that caused of faulting and the formation of Grabens, The Jurassic sediments as well as the underlying Adigrat sandstone were preserved from the erosion. The Jurassic limestone and the Adigrat sandstone formations are preserved in down-faulted blocks delimited by the basement, thus forming relatively good aquifers. It seems the Jurassic limestone and the underlying sandstone is preserved in Amoud area, hence, one of the thickest water bearing unit in Amoud area could found at the center of the area, therefore, any borehole drilled in Amoud area shall be drilled within the center in order to get deep borehole depth below 180 m depth.

Based on the findings of the investigation, deep borehole drillings were recommended in both area and below table is reported the details of the recommended sites:

Table 1. Recommended Drilling Sites

Site	Longitude	Latitude	UTM-X	UTM-Y	UTM-Zone	Recommended VES	Recommended depth (m)
Goraya-Cawl	43.22556°	9.87120°	305423	1091688	38 P	VES-5	160-180 m
Amoud 1st Priority	43.22597°	9.94964°	1100364	1100364	38 P	Site-1	>200 m
Amoud 2nd Priority	43.23114°	9.94481°	306079	1099828	38 P	Site-2	>200 m
Replacement for BH4	43.21973°	9.94686°	304829	1100061	38 P	VES-1 BH4	220-230 m

1. Based on drilling history in Boorama area, technical drilling difficulties such as caving and circulation losses are expected; hence drilling could only proceed by installing surface casing.
2. This type of drilling can be done only by using a Rig equipped with MUD ROTARY DRILLING SYSTEM capable of reaching the recommended depth. Therefore, the drilling should be awarded only those drilling rigs with Mud Drilling System capable of using large diameter drilling pits.
3. Due to above mention technical drilling difficulties, competent Hydrogeologist has to supervise the drilling activities in order to have a successful borehole drilling.

- After installation of minimum 13 inch steel casing for the upper unconsolidated sediments, the remaining part the minimum open hole diameter shall be not less than 12 ¼" in diameter
- Casing and screen materials shall be Steel Casing and screens or uPVC casings and screens.
- Screen slots shall be determined by the material but as a recommendation 3 mm may be used.
- Gravel Pack should be at least 95% silicic (quartz gravel) well rounded.
- Observation pipe shall be installed between the casing and the wall for monitoring purpose.

This report will present the findings and the recommendations made as result of this hydrogeological and geophysical investigation.

1. Introduction

1.1. Background

In October, 2020, SHAAC Consulting Company PLC. was commissioned by the representatives of SHABA, to undertake detailed hydrogeological, geological and geophysical site investigations in Amoud area. The investigated sites are Amoud area situated at about 5 east of Boorama town while Goraya-Cawl village is situated 11 km southeast of Boorama town on along the road to Hargeisa.

The purpose of the study was to identify suitable locations for successful borehole drilling within the Goraya-Cawl village in order to identify good borehole drilling sites that to be used as new water supply sources for Boorama town.

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. Similarly, the quality of groundwater was found to be saline especially areas covered by the Taleex Gypsum Formation and other evaporate geological units.

The overall objective of the project is to improve the availability of water and sanitation in Boorama town and to provide clean drinking water supply to the Boorama community. The overall broader objectives of this detailed hydrogeological geophysical site investigation is to select the appropriate water sources for Boorama area in both Goraya-Cawl and Amoud areas and to submit detailed report outlining the best ways to develop the water source. 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 sites.
(c) As a result of this investigation, some type of water sources will be developed for the community and as a result of this will improve the health of the community.

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 Boorama area including Amoud and Goraya-Cawl areas. 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**

- Weeraar Area Hydrogeological and Geophysical Investigation for Concern Worldwide, August, 2017 by SHAAC Consulting Co.
- Habaas area hydrogeological survey for Islamic Relief by SHAAC Consulting Company, January, 2017.
- Amoud and Degma-Laqas areas hydrogeological modeling for aquifer delineation for Ministry of Water Resources, Somaliland, 2017.
- Qolojeed Area water investigation by SHAAC Consulting Company for Private Farm owner, 2016.
- Geed Abeera Area Hydrogeological and Geophysical Investigation and Socio-economic and EIA by SHAAC Consulting Company for Concern Worldwide, 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. <u>Borehole Logs</u>

Available existing Water borehole logs were collected such as boreholes located in Geed Balaadh, Arabsiyo, Alleybadey, Magalo'ad, Tog-Wachale and Amoud and Degma-Laqas areas (Boorama area).

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 Amoud area and other sites close by 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.
- Five Vertical Electrical Soundings (VES) was undertaken in Goraya-Cawl area, while two VES measurements were made in Amoud area.
- 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 sources for Goraya-Cawl and Amoud areas. Other major outcomes of this water investigation are to gather information regarding on the sub-surface geology of the study areas.

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

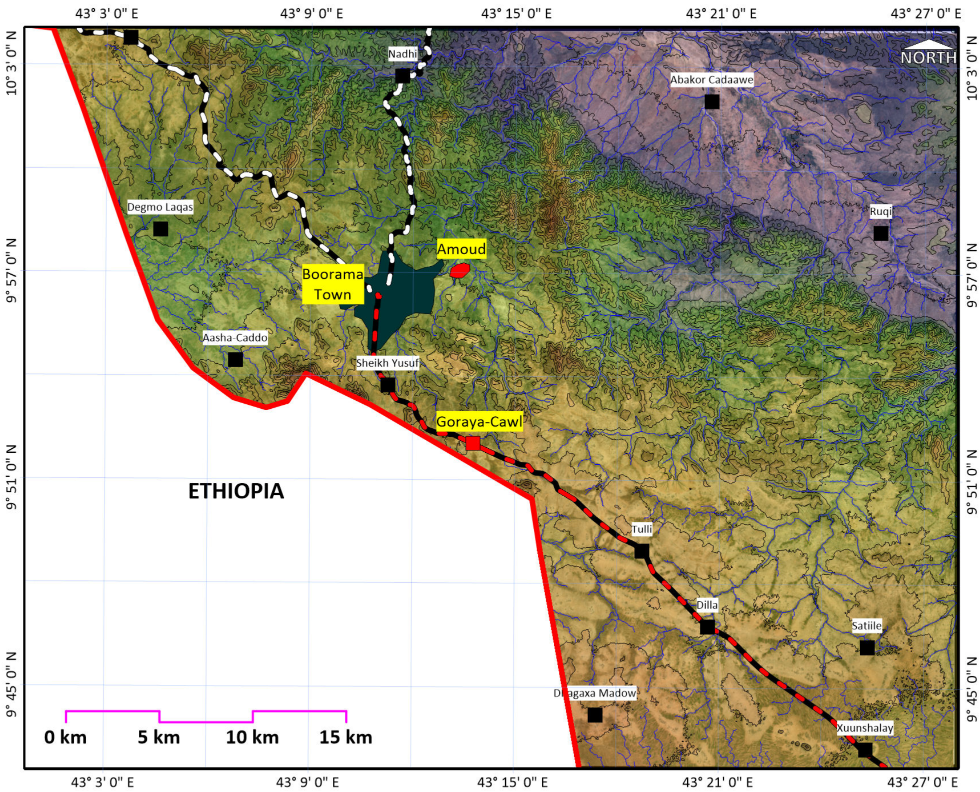
2. General Background

2.1. Location and Accessibility

Two sites were investigated namely Amoud area situated at about 5 km east of Boorama town and Goraya-Cawl village situated at about 11 km south of Boorama town along the road to Hargeisa town.

Figure 1. Location Map of Investigated Sites

Figure 2. Detailed Location Map of Investigated Sites



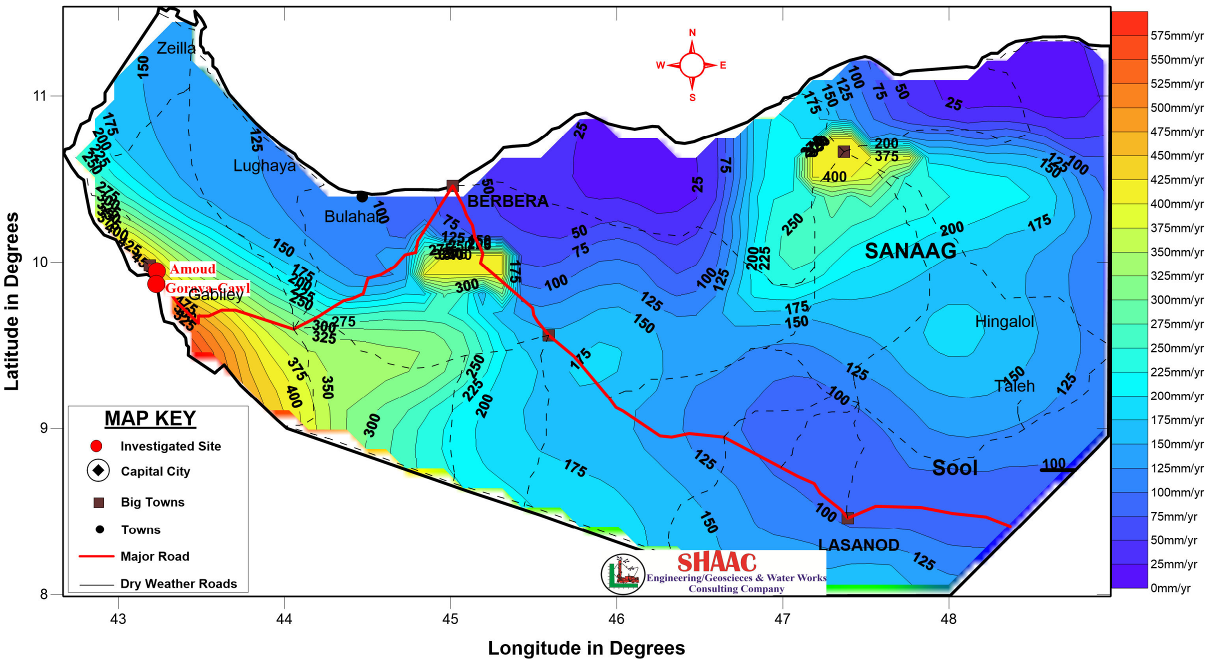
2.2. Climate and Seasons

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 Boorama, 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 the study site, receives an average annual rainfall of 400 to 300 mm/year

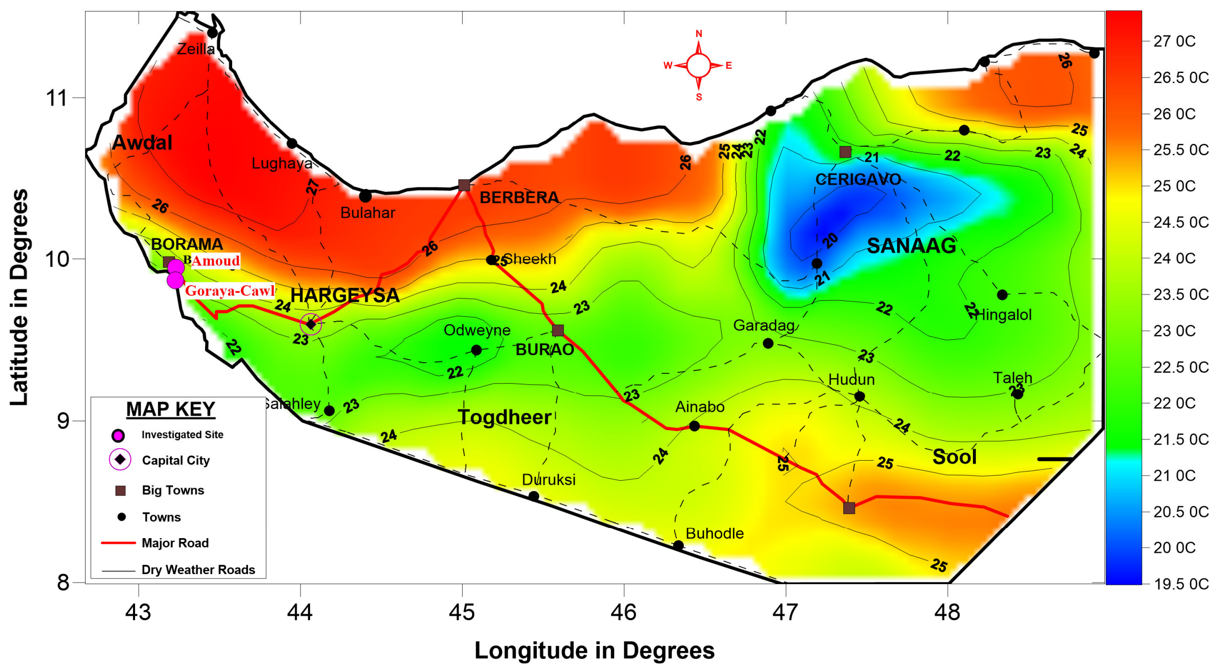
Figure 2. Annual Rainfall Map of Somaliland



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. As it can be seen on the above depicted rainfall map of Somaliland, Boorama area receives the highest annual rainfall of about 500 to 600 mm/year.

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.

Figure 3. Temperature distribution map in Degree Celsius (March)



2.4. Physiographic and Vegetation Cover

2.4.1. General Physiographic of Somaliland

Northern Somalia of Somaliland can be subdivided into three major physiographic provinces 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 Dharoor 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 gypseferous 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. Gypseferous 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

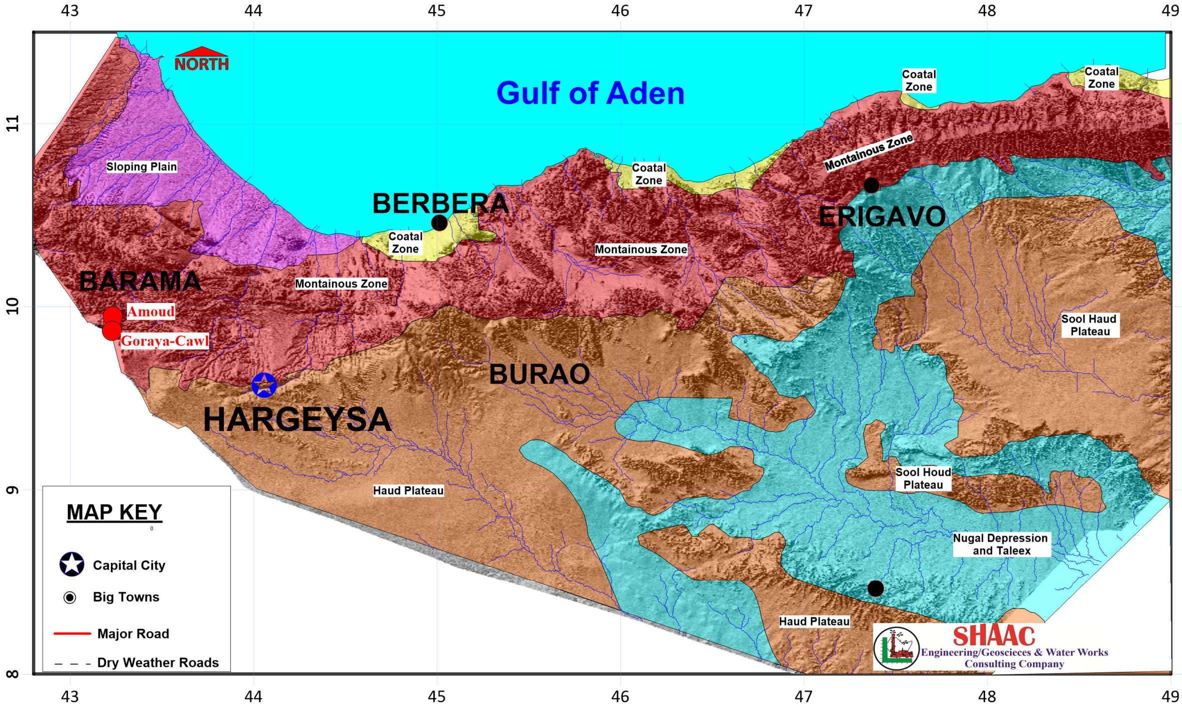
The Sool Haud Plateau extends between Jidali and Hadaaftimo near the edge of Gulf of Aden and extends as far as the northern part of Nugaal valley south of Xingalool village.

The Mountain Zone

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 Jurassic Limestone and 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. Amoud and Goraya-Cawl area belong to this mountainous physiographic zone. The study area is covered by Precambrian Basement rocks, Adigrat sandstone and Jurassic Limestone formation.

Figure 5. Physiographic Region of Somaliland



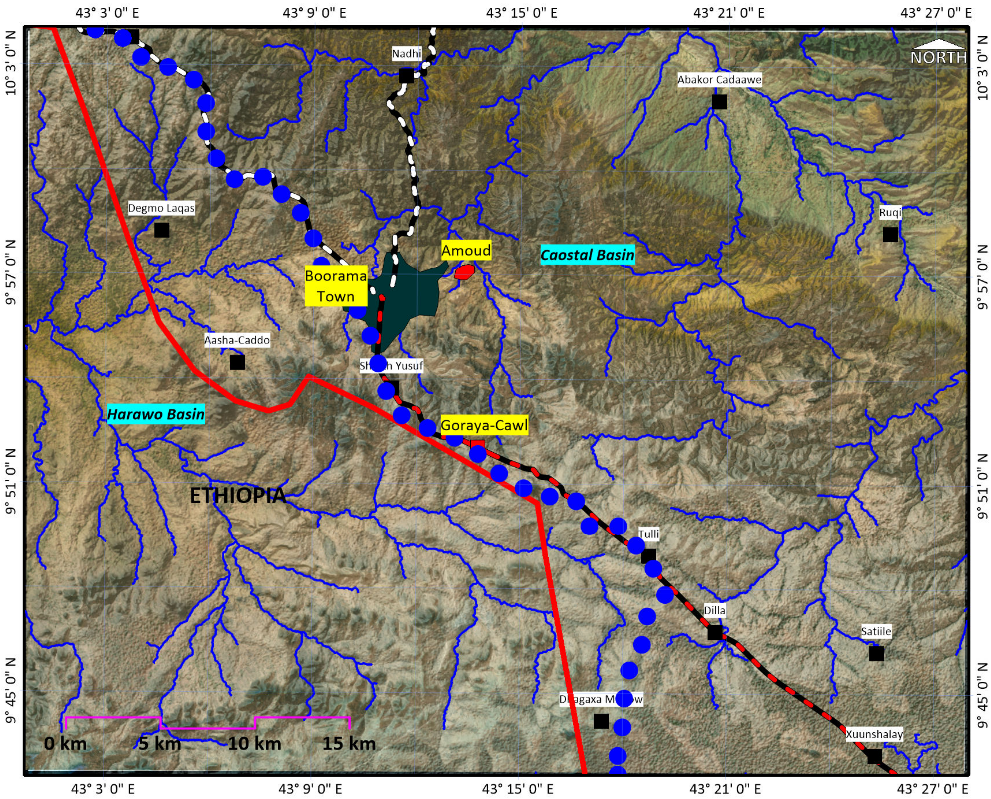
Adopted from SHAAC Consulting 2014

As it can be seen on the above illustrated physiographic Region of Somaliland, Amoud and Goraya-Cawl areas are situated in the Mountainous Zone of Awdal region and their drainage system is towards south-southwest towards Harawo stream and finally towards Awash Basin.

2.4.2. Local Geomorphology

Geomorphologically Amoud and Goraya-Cawl are situated in Mountainous Physiographic province of Somaliland. The area is found to be very rugged terrain with numerous crystalline basement rocks hills in the north of the study area.
The Mountain Zone is characterized by undulated plateau, with an elevation ranging from 1000 to 1450 m, and it is crossed by numerous streams which have incised sedimentary and metamorphic rocks. The study area is covered by thick alluvial sediments underlain by Jurassic Limestone formation, followed by Adigrat sandstone formation and most likely is underlain by basement rocks.

Figure 6. Local drainage Basins



As it can be seen on the above depicted local drainage basin map of the investigated sites, Amoud areas belongs to coastal drainage basin, while Goraya-Cawl area belongs to Harawo drainage basin and is very close to the surface water divide separating between these drainage basins.

The coastal drainage basin its drainage direction is towards the Gulf of Aden, while Harawo drainage basin belongs to Hawash drainage basin and its drainage direction is towards Afar Regional State of Ethiopia and finally is towards the Red Sea.

3. General Geology and Hydrogeology

3.1. General Geology

The geology of Somaliland 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:

- Polio-Pleistocene to Recent deposits: Consist of alluvial, colluvial, sand-dunes and Coral limestone.
- Tertiary: Consists of Limestone, evaporitic rocks and thick extensive series of sedimentary rocks.
- Cretaceous: Sandstone and Limestone.
- Jurassic: Limestone, shale and sandstone.
- 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 Dharoor 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 limestones)
4. Tertiary (Eocene): Limestone, evaporitic rocks
4.1. Auradu Formation (limestones)
4.2. Taleex Formation (evaporitic rocks)
4.3. Karkar Formation (limestones)
5. Tertiary (Oligocene to Miocene): Thick extensive series of sedimentary rocks
5.1. Daban series
5.2. Hafun Series and Iskushuban Formation
6. Pleistocene to Recent Alluvium
6.1. Basaltic rocks
6.2. Recent alluviums, terraces and coastal beaches

3.2.1. Basement Rocks

The Basement complex outcrops in Somaliland mostly in its northwest part (Awdal-Boorama, Hargeysa), Berbera and Sheekh areas and along a narrow belt of the Ceerigabo-Ahl Madow escarpment. The Basement is mostly composed of schists, orthogenesis, 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, basement rocks are widely outcropping. Boreholes drilled in Amoud area, basement rocks were reached from 100 m to 200 m depth.

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, unfossiliferous 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. Towards Boorama area and the Jurassic limestone is represented by a few outcrops which are generally sandy at the base.

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, Qaarar, and Maydh. 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 Idinka-Baligubadle, the thickness could reach more than 500 m. Faillace & Faillace (1986) estimated that in the north-central part of the study area the Cretaceous thickness of sandstone, sand, and sandy clay sequences can be 1,000-1,700 m. Further west, towards the border with Ethiopia, the thickness of these sediments decreases to 200-400 m.

The nature of the Cretaceous sediments suggests that in the western part of the area deposition occurred under continental conditions. Proceeding eastwards from Ceerigabo the alternation of sand and limestone indicates that sediments were deposited during various regressions and transgressions. Boreholes drilled in the Nubian sandstone along the Ethiopian border most of them yielded less than $10m^3/hr$.

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, El-Afweyn 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 gypseferous, 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 gypseferous 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 Taleex Series, groundwater 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. Oligocene to Miocene

In the northern part of the Daban Basin, located north of Sheekh, the Karkar Formation is replaced by the Lower Daban Series. The latter lies conformably over the Taleex Formation and consists of sediments deposited in littoral and lagoonal environments. The sediments include variegated sandstone, shales, clay with sandy limestone, and intercalations of anhydrite. The maximum thickness of the Lower Daban Series is 465 m.

Oligocene/Miocene sediments are irregularly distributed in scattered outcrops located along the Gulf of Aden coast between Berbera and Guardafuey and along the Indian Ocean coast. Those outcropping along the Gulf of Aden coast are subdivided into the Middle and Upper Daban Series. After Faillace & Faillace (1986) the Middle Daban Series is constituted by a thick sequence of red-brown, green sand and silts, gypseferous sandstone, and gypsum in the lower part. "The succession of fine to medium quartz sandstone is frequently cross-bedded. Grey shales, concretionary chert, and sandy limestone are present in the middle part of this series. The upper part is more consolidated and consists of frequently cross-bedded brown to green, soft to massive sandstone, with intercalations of limestone associated with chert and fibrous gypsum. All these sediments are transgressive over the Lower Daban Series. The uppermost part of the Daban Series is represented by sandstones and conglomerates of the Upper Daban Series. These coarse conglomerates and associated boulder beds predominantly derive from the Auradu limestone and form a sequence up to 125 m thick. The Upper and Middle Daban Series are correlated to the Hafun Series and Iskushuban Formation outcropping along the coast of the Indian Ocean. The Hafun Series is constituted by coarse sandstone followed by marly and sandy limestone (lower section), biogenetic limestone (middle section), biogenetic limestone alternated with clay, marls, and sandstone layers (upper section). The upper part of the Hafun Series grades laterally into the "upper conglomerate".

The marine limestones and sandstones of the Hafun Series are replaced laterally towards the interior of the Dharoor Valley by the gypseferous clay and conglomerate of the Iskushuban Formation. This formation fills the upper part of the Dharoor Valley, where a lagoonal environment was established.

Basalt outcrops and other volcanic rocks are scattered along the coastal belt from the border with Djibouti to nearly as far as Qandala. The volcanic rocks belong to the Aden Series; generally dense and vesicular pyroclastic materials are found locally. Several lava flows have tuff intercalations in some localities (Faillace & Faillace, 1986). Volcanic cones are preserved in various areas. In the north central part of the coastal belt near Bullaxaar, Mt.Jabel Elmis rises to an elevation of 571 m and is formed by stratified tuffs of basaltic lava (extends southward and eastward for 60-70 km). The lava, deposited during different periods, followed existing depressions and other uneven floors; it is over 50 m thick in several places.

The outburst of volcanic activity occurred as a consequence of the rift in the Gulf of Aden which started in the Lower Miocene and continued during the Pliocene. Intense volcanic activity developed during the Pleistocene, as is indicated by some well- preserved volcanic cones and lava flows interbedded in alluvial material of the Geed Deeble structural basin and in the piedmont alluvial area.

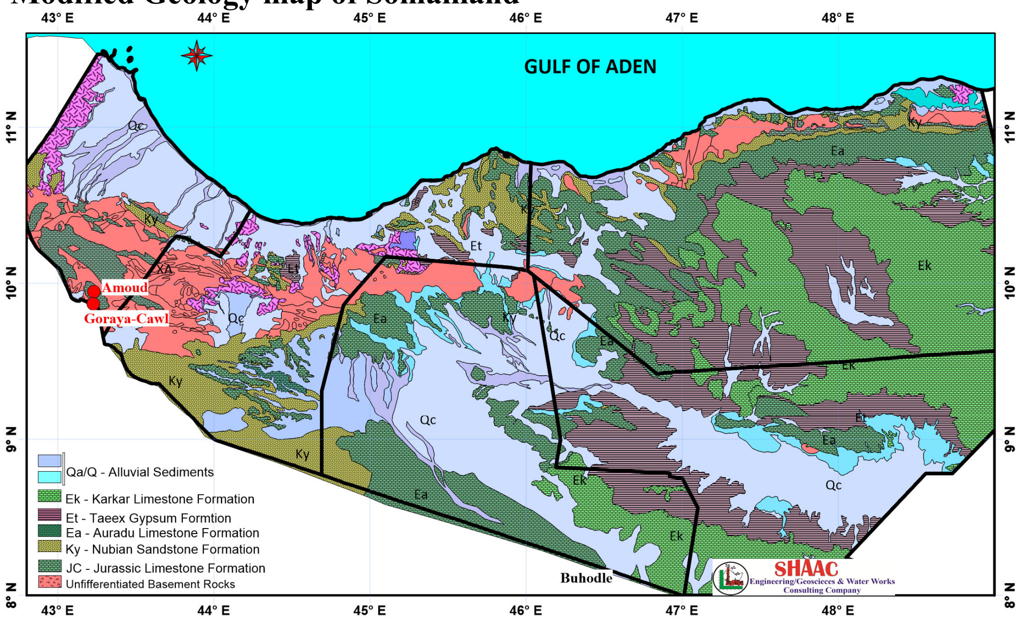
3.2.8. Pleistocene to Recent Alluvium

Thick layers of Pleistocene to Recent sediments were deposited within the plateau areas, between the foothills and the coastal strips. The sediments are of mixed texture and range from coarse gravel to heavy clays. Old alluvial sediments (terrace) filled some enclosed basins during the late Tertiary and early Quaternary. The largest of these basins is located in Geed Deeble, north of Hargeysa, where several streams converge. Water wells of Hargeysa Utility have penetrated the alluvial deposits of this basin for a thickness of 170 m, but their thickness may exceed 200 m. The deposits consist of red sandy clay materials with lenses of sand and fine gravel. Alluvial material was also deposited in the sloping plain, from the piedmont to near the coastal strip.

Recent alluvial deposits fill the numerous togga beds in the mountain range from Bari to Sanaag and westwards towards Awdal. They spread out in alluvial cones as toggas leave the mountain chain, covering extensive areas towards the coastal plain. Sand dunes constituted by reddish to yellow to grey sand are found in several areas along the coast as well as in the hinterland. Coastal sand dunes are particularly developed in the area east of Berbera. Inland, sand dunes are well developed along depressions and small valleys of the Sool and Haud plateaus. Raised beaches have been observed in various localities along the Gulf of Aden as well as along the Indian Ocean. Red soil is widespread over large areas of the Haud and Sool plateaus, covering depressions and ancient valleys, and prevents a direct observation of the underlying rocks. After Faillace & Faillace (1986) red soil consists mainly of slightly clayey fine quartz sand. In some areas, according to Macfadyen "the deposit is recorded as an ancient reddish soil, derived mainly from denudation of Nubian sandstone." Red soil and other soft materials of alluvial origin, constituted by isolated lenses of coarse sand, gravel, and conglomerate, have an average thickness of 20-30 m; their thickness may reach up to 70-80 m, as was found in water wells drilled in Burco.

Calcrete (carbonate) crusts are widespread over various rocks and alluvial and detritic subsoils of the Haud and Sool plateaus. They consist of secondary limestone with the appearance of a cemented whitish to dark-red concretionary breccias. Faillace & Faillace (1986) cited Stock: "A re-cemented form of calcrete occurs from the primary limestone and frequently extends as flat and isolated patches over wide areas where the limestones are covered by a thin layer of soil." Lateritic crusts and concretionary iron-bearing nodules are also found in various localities of the Haud Plateau.

Figure 7. Modified Geology map of Somaliland



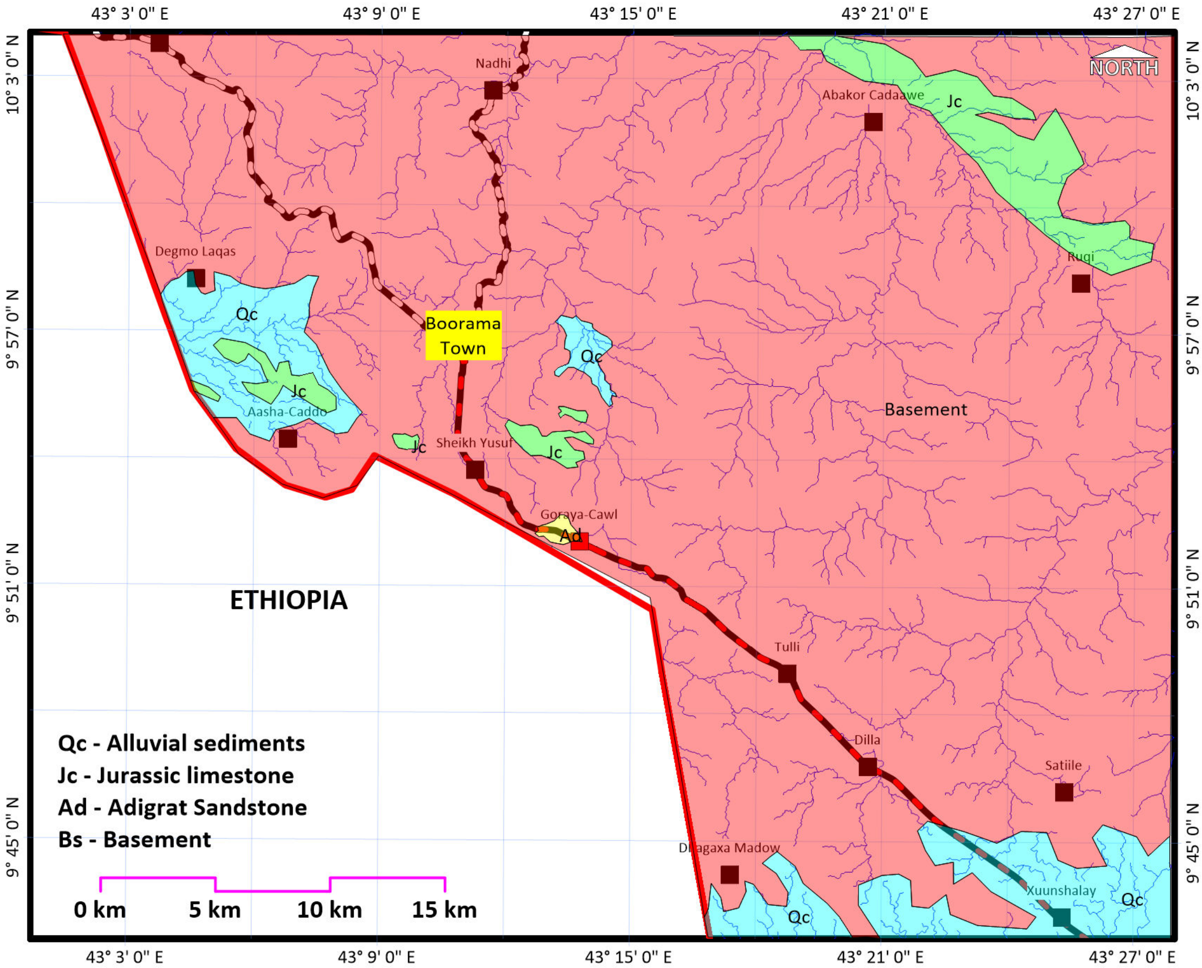
Modified from SWALIM, 2012

As it can be observed from the above depicted geological map of Somaliland, the study areas are covered by alluvial sediments underlain by the Jurassic limestone and Adigrat sandstone formations.

3.3. Local Geology and Stratigraphy

The geological formations that were mapped in Boorama area from the top to bottom are alluvial sediments underlain by the Jurassic limestone Formation, Adigrat sandstone formation and undifferentiated Crystalline Basement Rocks in Amoud area, while in Goraya Cawl area, the Jurassic limestone was found to be missing due to erosion and only Adigrat sandstone and Basement rocks were found to outcrop.

Figure 8. Local Geology



4. Geophysical Investigation

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. A great variety of geophysical methods are available in the assessment of geological subsurface conditions. In groundwater exploration, the most widely applied techniques are 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. Electrical soundings and horizontal profiling can also be used to delineate a fault zone.

In the present survey, resistivity sounding 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.

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 indirectly proportional to cross-sectional area (A), which can be expressed as:

$$\mathbf{R = \rho * L/A \qquad (\Omega) \qquad (1)}$$

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

$$\mathbf{R = \delta V/I \qquad (\Omega) \qquad (2)}$$

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:

$$\rho = (A/L) * (\delta V/I) \qquad (\Omega m) \qquad (3)$$

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.

4.2.2. 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:

$$\rho = F * \rho_w = F * 10{,}000/EC(\mu S/cm) \qquad (\Omega m) \qquad (4)$$

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 commonly encountered.
2. Large vertical and lateral variations are also common.

The resistivity contrasts are less pronounced for instant in Basement formation. When fresh the resistivity values are between 2,500 to 100,000 Ωm, which makes easier to distinguish from more conductive weathered zone or overlaying sedimentary formations.

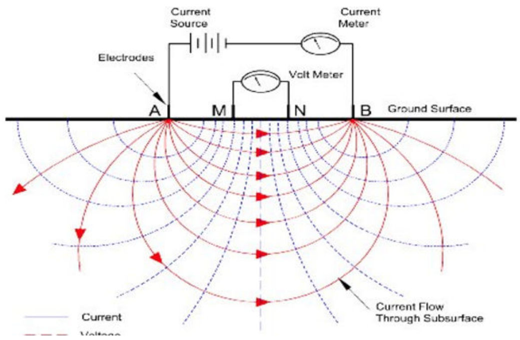
4.2.3. Resistivity Sounding Techniques

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 centre of the array. The ratio ($\delta V/I$) 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 centre. There are several electrical setups used for resistivity survey; however the most widely used is 'Schlumberger' array (Figure 8).

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.

Figure 9. Schlumberger array configuration



4.3. Geo-Electrical Survey Results

4.3.1. Field data Collection and interpretations

The electrical sounding survey was conducted by using **ABEM SAS 1000 Terrameter**, four cable reels and external 12 volt DC Battery. Since Schlumberger array configuration has a practical advantages 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 2. Electrode Configuration

Current Electrode Spacing (AB/2)	1-10	10-20	20-100	100-250	250-500
Potential Electrode Spacing (MN/2)	0.5	2.0	5.0	40.0	100

The field data was first interpreted manually by plotting the apparent Resistivity against current electrode separation (AB/2) on log-log papers 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.

4.3.2. Goraya-Cawl Area Geophysical Survey

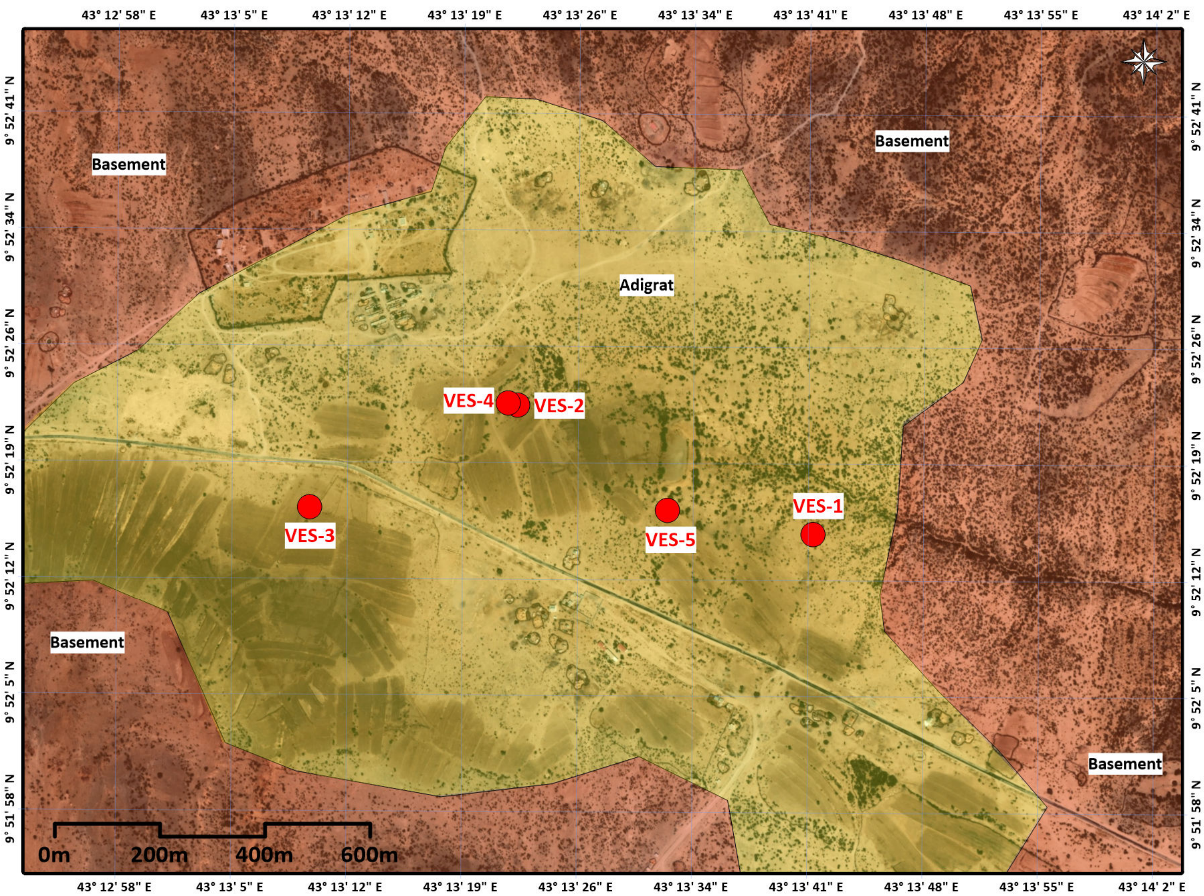
4.3.2.1 General Information

Goraya-Cawl area, basement rocks are outcropping, however, small area was found an outcrop of Adigrat sandstone formation, and hence, the geophysical investigation was concentrated within this outcrop. Five VES measurements were made in the area and the details of investigated VES sites are reported below table and VES location Map.

Table 3. Amoud VES locations (WGS84 Datum)

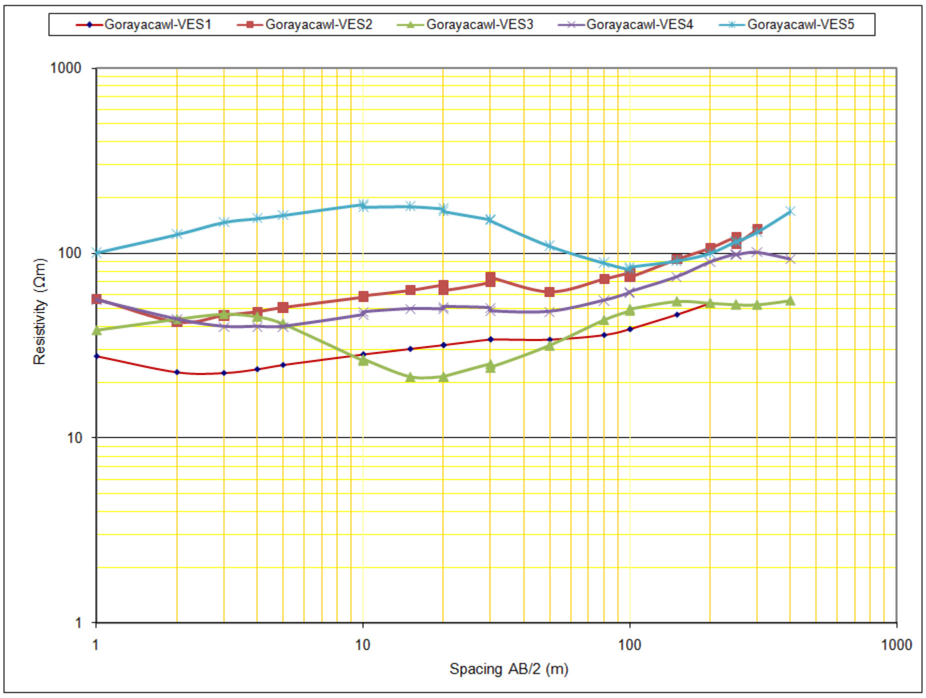
Coordinates in Degree Decimals		UTM Coordinates (m)			
Longitude	Latitude	UTM Zone	Easting	Northing	VES ID
43.22808°	9.87079°	38 P	305700	1091642	VES-1
43.22295°	9.87299°	38 P	305138	1091888	VES-2
43.21934°	9.87122°	38 P	304742	1091695	VES-3
43.22278°	9.87303°	38 P	305120	1091892	VES-4
43.22556°	9.87120°	38 P	305423	1091688	VES-5

Figure 10. Goraya-Cawl Area VES location Map



4.3.2.2. Goraya Cawl VES Results and interpretation

Figure 10. Goraya-Cawl Combined VES Graphs



<u>Goraya Cawl VES interpretations</u>

<u>VES-1</u>

Table 4 - Hydrogeological Interpretation of VES-1

Layer	Resistivity	Thickness	Depth	Interpretation	Acquiferous?
1	81.089	0.23474	0.23474	Top soil	No
2	21.46	2.8803	3.115	Sand	No
3	34.387	85.73	88.845	Highly weathered sandstone	No
4	89.901	74.293	163.14	Weathered sandstone	Yes
5	235.63	∞	>163.14	Fractured basement	Yes

Goraya Cawl VES1 was identified 5 geo-electric layer and maximum penetration of 163.14 m depth was reached. According to the interpretation, the area is covered by thin alluvial sediments underlain sandstone of different degrees of weathering extending up to 163 m depth. This unit is most likely the Adigrat sandstone and underlain by Basement rocks.

The water bearing strata is expected within the weathered sandstone and the underlying fractured basement rocks. Below the depth of 163.14 m depth was encountered high resistivity geo-electric layer that was interpreted as fractured basement rocks. If drilled at this site, the recommended drilling depth is 160-180 m depth.

VES-2

Table 5 - Hydrogeological Interpretation of VES-2

Layer	Resistivity	Thickness	Depth	Interpretation	Acquiferous?
1	590.16	0.18775	0.18775	Dry top soil	No
2	38.742	3.8407	4.0284	Sand	No
3	74.434	16.777	20.806	Weathered sandstone	No
4	27.696	16.267	37.073	Highly weathered sandstone	No
5	116.17	130.28	167.35	Less weathered sandstone	Yes
6	634.58	∞	>167.35	Basement rocks	No

Goraya Cawl VES2 six geo-electric layer and maximum penetration of 167.35 m depth was reached. According to the interpretation, the area is covered by thin alluvial sediments underlain sandstone of different degrees of weathering extending up to 167 m depth. This unit is most likely the Adigrat sandstone and underlain by Basement rocks.

The water bearing strata is expected within the weathered sandstone and the underlying fractured basement rocks. Below the depth of 167 m depth was encountered high resistivity geo-electric layer that was interpreted as fractured basement rocks. If drilled at this site, the recommended drilling depth is 160-180 m depth.

VES-3

Table 6 - Hydrogeological Interpretation of VES-3

Layer	Resistivity	Thickness	Depth	Interpretation	Acquiferous?
1	35.734	0.91229	0.91229	Top soil	No
2	75.924	1.5231	2.4354	Sand	No
3	16.902	19.265	21.701	Sand with clay	No
4	205.85	30.434	52.135	Less weathered sandstone	No
5	15.024	77.901	130.04	Highly weathered sandstone	Yes
6	172.59	∞	>130.04	Fractured basement	Yes

Goraya Cawl VES3 six geo-electric layer and maximum penetration of 130 m depth was reached. According to the interpretation, the area is covered by thin alluvial sediments underlain sandstone of different degrees of weathering extending up to 130 m depth. This unit is most likely the Adigrat sandstone and underlain by Basement rocks.

The water bearing strata is expected within the weathered sandstone and the underlying fractured basement rocks. Below the depth of 130 m depth was encountered high resistivity geo-electric layer that was interpreted as fractured basement rocks. If drilled at this site, the recommended drilling depth is 150-160 m depth.

VES-4

Table 7 - Hydrogeological Interpretation of VES-4

Layer	Resistivity	Thickness	Depth	Interpretation	Acquiferous?
1	67.021	0.59259	0.59259	Top soil	No
2	36.336	3.5802	4.1728	Sand	No
3	84.878	2.8727	7.0455	Sand with gravel	No
4	43.158	57.992	65.038	Highly weathered sandstone	No
5	458.91	71.027	136.06	Gravel	Yes
6	11.073	∞	>136.06	Highly weathered sandstone	Yes

Goraya Cawl VES4 six geo-electric layer and maximum penetration of 136 m depth was reached. According to the interpretation, the area is covered by thin alluvial sediments underlain sandstone of different degrees of weathering extending up to 136 m depth. This unit is most likely the Adigrat sandstone. No basement rocks were identified at this penetration rate

The water bearing strata is expected within the weathered sandstone and the underlying fractured basement rocks. Below the depth of 136 m depth was encountered low resistivity geo-electric layer that was interpreted as highly weathered sandstone. If drilled at this site, the recommended drilling depth is 150-180 m depth.

VES-5

Table 8 - Hydrogeological Interpretation of VES-5

Layer	Resistivity	Thickness	Depth	Interpretation	Acquiferous?
1	88.482	0.90488	0.90488	Top soil	No
2	190.51	16.862	17.766	Gravel with sand	No
3	72.118	158.51	176.27	Highly weathered sandstone	Yes
4	6844.2	∞	>176.27	Basement	No

Goraya Cawl VES5 four geo-electric layer and maximum penetration of 176 m depth was reached. According to the interpretation, the area is covered by thin alluvial sediments underlain sandstone of different degrees of weathering extending up to 176 m depth. This unit is most likely the Adigrat sandstone.

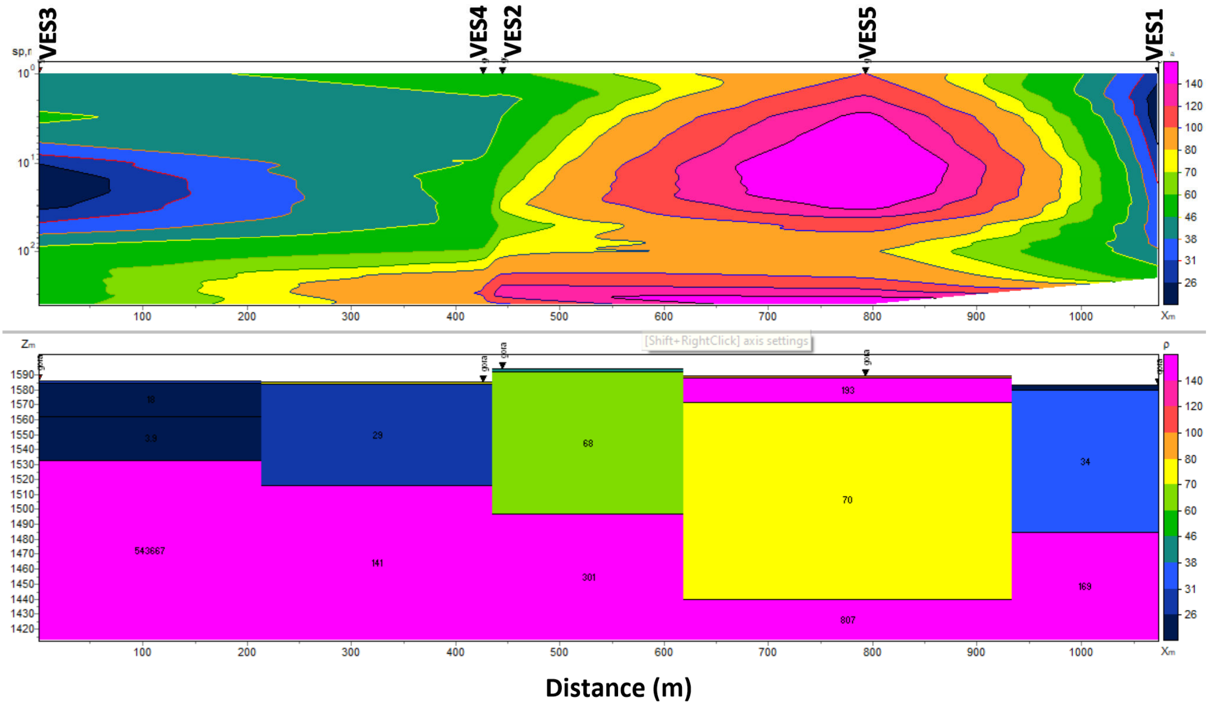
The water bearing strata is expected within the highly weathered sandstone unit. Below the depth of 136 m depth was encountered high resistivity geo-electric layer that was interpreted as Fresh basement rocks. If drilled at this site, the recommended drilling depth is 150-180 m depth.

3.3.2.2. VES Evaluation and Site Selection

In the investigated site, the subsurface geology as inferred from the resistivity interpretation shows the presence of thin alluvial sediments followed by reasonably thick sandstone of Adigrat formation and underlain by the Basement rocks.

The basement rocks were identified from 130 to 170 m depth, therefore, any borehole drilled in Goraya Cawl has to be selected where the basement rocks are deep, hence, the location of VES5 and VES4 could be selected for drilling with maximum recommended drilling depth of 150 to 180 m depth.

Figure 11. Goraya-Cawl Resistivity Cross Section



As its can be seen on the above depicted cross section, the location of VES5 was found to have the deepest basement rocks, hence, the location of VES5 is selected as 1st priority site to be drilled.

3.3.2.3. Conclusions and Recommendation for the Investigated Site

The major aim of this water investigation was to identify the best location to be drilled for a borehole in Goraya Cawl area and to identify if there is a possibility to identify new aquifer that to be used as water supply source for Boorama town. As a result of this detailed water investigation, the following conclusions and recommendations are made:

4. The geology of the area is predominated alluvial sediments underlain by sandstone and the basement.
5. The aquifer zone was found within the sandstone, just above the Basement.
6. The thickness of the aquifer zone was found to be thick and the basement rocks could reach at a depth of 130 to 160 m depth.
7. Therefore, the location of VES5 is recommended for drilling as 1st priority site to be

drilled.

8. The maximum recommended drilling depth is 160 to 180 m depth.
9. The details of the recommended drilling site are shown below:

Site Name	**Coordinates in Degree Decimals**		**Coordinates in UTM**			**VES ID**	Depth
	Longitude	**Latitude**	**Easting**	**Northing**	**UTM Zone**		
Goraya Cawl	43.22556°	9.87120°	305423	1091688	38 P	VES-5	160-180

4.3.3. Amoud Area Geophysical Survey

4.3.3.1 General Information

Previously the area was investigated by SHAAC Consulting Company and other organizations in order to identify the deepest aquifer zone in Amoud area. Based on the result of the investigation, the best and the deepest drilling area were delineated based on more than 80 VES data points that was modeled.

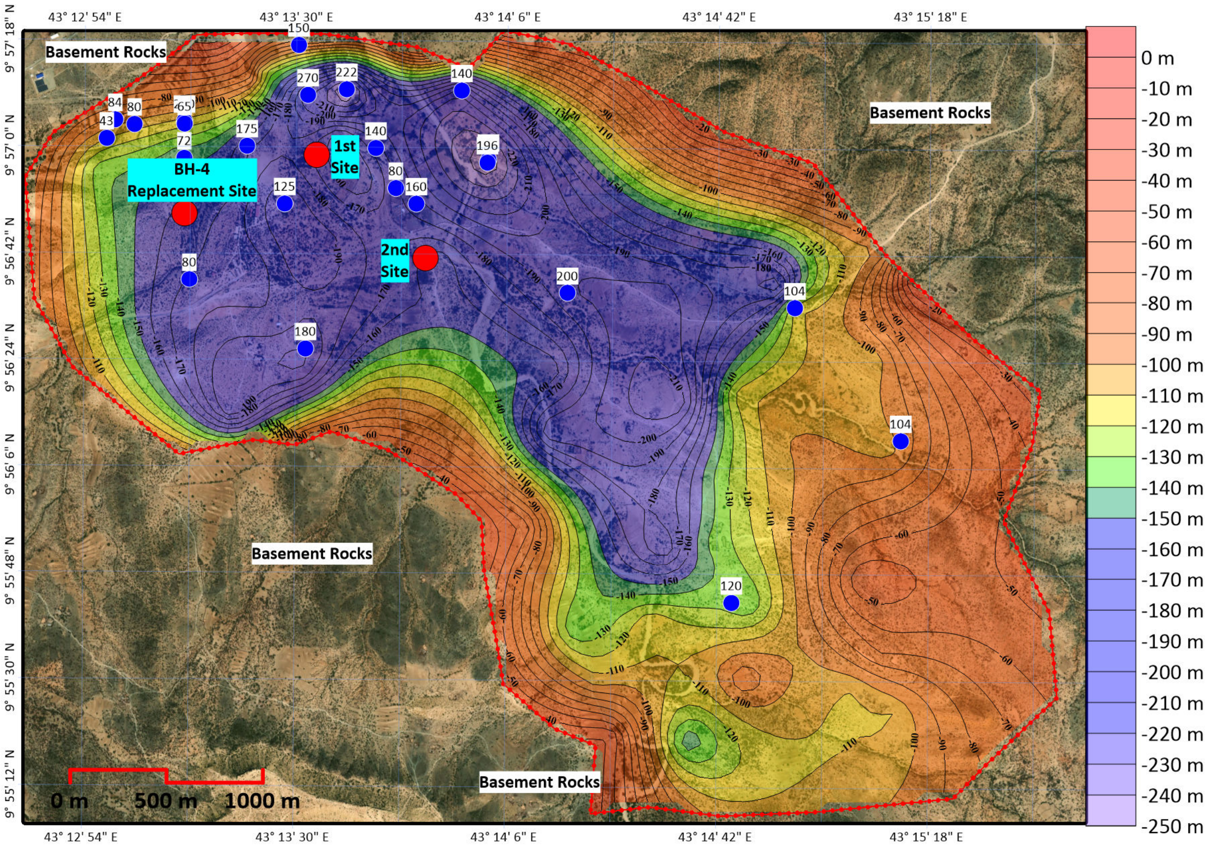
In Amoud area, SHABA required to be identified two new borehole drilling sites within the areas that was previously modeled and identified areas of that was expected the deepest basement depth. SHABA has selected two potential sites that to be drilled as 1st priority site and second priority site. The geographical coordinates of the selected sites by SHABA is reported below table:

Table 9. Sites selected for drilling by SHAABA

Coordinates in Degree Decimals		Coordinates in UTM			
Longitude	Latitude	Easting	Northing	UTM Zone	Priority for Drilling
43.22597°	9.94964°	1100364	1100364	38 P	1st Priority
43.23114°	9.94481°	306079	1099828	38 P	2nd Priority

By using the previously identified and modeled area, the two selected sites by SHABA was found to be located within the area that was expected to have the deepest basement rocks that was expected below 200 m depth. The location with modeled aquifer depth is reported below figure:

Figure 12. Amoud Aquifer Modeled Map



As it can be observed from the above depicted Amoud area aquifer depth modeled map, the two selected sites by SHABA fall within the blue area indicating that any borehole drilled within this area could be drilled with maximum depth of 200 m depth.

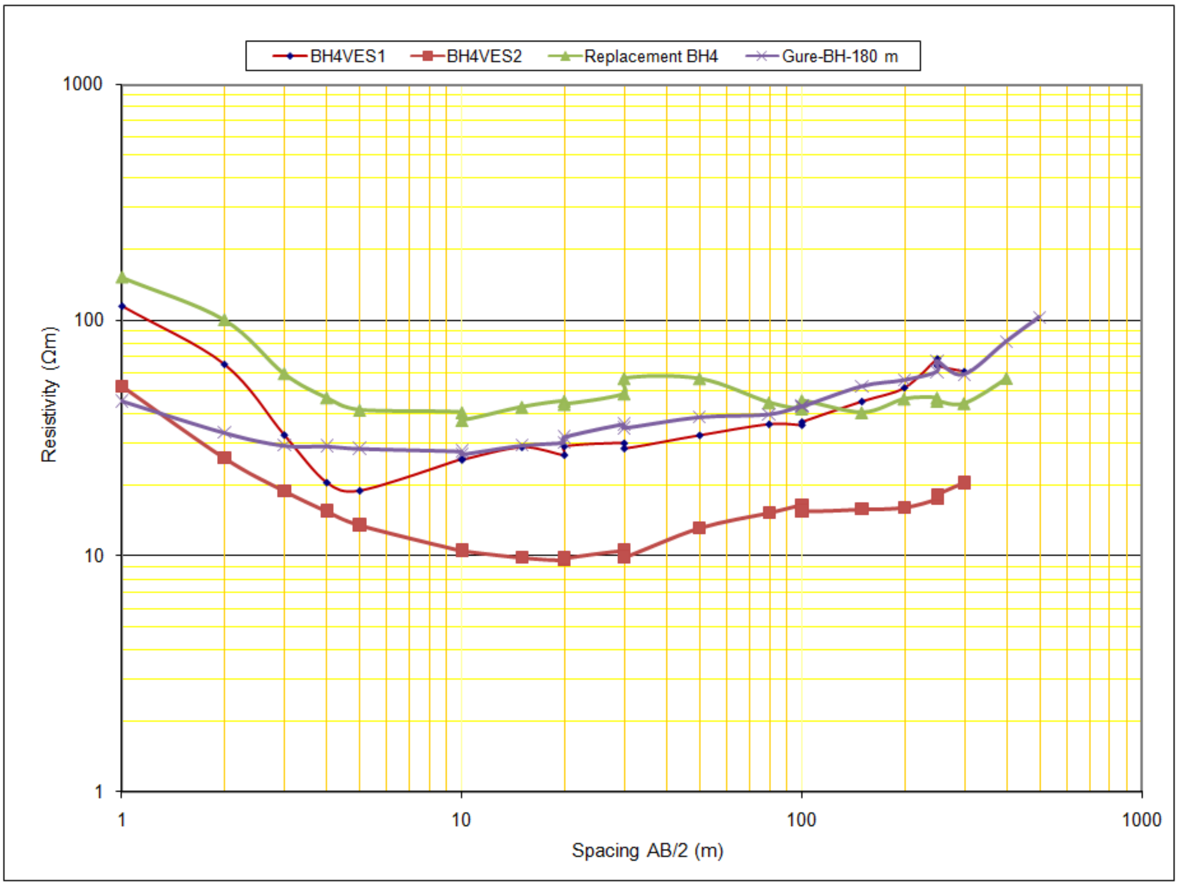
Therefore, the consultant is recommending that these two sites could be selected for drilling with maximum expected drilling depth of 200 m depth or the boreholes should reach the basement rocks.

4.3.3.2 Geophysical Survey Result In Amoud Area

In addition of the above selected two sites, SHABA required to be investigated a site situated close to the abandoned BH4 sites that was intended to be drilled as replacement of BH4. This site also is situated within the blue area in which the basement rocks is expected to be depth.

Since the selected site is situated between two limestone hills, the consultant has undertaken VES investigation. The VES survey was conducted by using **ABEM SAS 1000 Terameter**, four cable reels and external 12 volts DC Battery. Since Schlumberger array configuration has a practical advantages compared to other configurations, Schlumberger array configurations was used for this survey.

Figure 13. Amoud Area Combined VES Graphs



The VES from the investigated site was compared with other VES data that was already successfully drilled. Based on the resistivity pattern, all VES data was found to be very similar indicating the similarity of sub-surface geology. The interpreted result of VES soundings are summarized below 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.

Amoud Area VES for Replacement of BH4 interpretations

VES-1 Replacement for BH4 Site

Table 10 - Hydrogeological Interpretation of VES1-for Replacement BH4

Layer	Resistivity	Thickness	Depth	Interpretation	Acquiferous?
1	194.51	0.92	0.92	Dry top soil	No
2	37.72	7.69	8.61	Highly weathered Limestone	No
3	113.24	10.48	19.09	Fractured limestone	No
4	35.93	206.92	226.01	Highly weathered limestone with sandstone	Yes
5	226.48	∞	>226	Fractured basement rocks	Yes

VES1 as replacement site for borehole four (BH4), four geo-electrical layers were discriminated and maximum penetration of 226 m depth was reached. According to the interpretation, the area is covered by thin alluvial sediments underlain limestone of different degrees of weathering and fracturing and underlain by sandstone and basement rocks
The water bearing strata is expected within the highly weathered limestone with sandstone and the underlying fractured basement rocks.

This VES site can be drilled with minimum expected drilling depth of 220 to 230 m depth.

3.3.3.3. Conclusions and Recommendation for the Investigated Site

The major aim of this water investigation was to identify the best location to be drilled for a borehole to be drilled as replacement site for BH4. As a result of this detailed water investigation, the following conclusions and recommendations are made:

1. The geology of the area is predominated thin alluvial sediments underlain by limestone of different degrees of weathering and fracturing, underlain by sandstone and the basement.
2. The aquifer zone was found within the highly weathered limestone and the underlying sandstone, and the weathered part of the basement rocks.
3. The thickness of the aquifer zone was found to be thick and the basement rocks could reach at a depth of 226 m depth.
4. Therefore, the location of VES-1 for replacement of BH4 is recommended for drilling.
5. The maximum recommended drilling depth is 220 to 230 m depth.
6. The details of the recommended drilling site are shown below:

Site Name	Coordinates in Degree Decimals		Coordinates in UTM			VES ID	Depth
	Longitude	Latitude	Easting	Northing	UTM Zone		
Amoud Replacement BH	43.21973°	9.94686°	304829	1100061	38 P	VES-1	220-230

5. Conclusions and Recommendations

During the survey every effort was made to examine every potential water source for each studied site and based on the findings of the hydrogeological and geophysical investigation, the appropriate water source for Goraya Cawl and Amoud areas were selected. A lot of effort has been dedicated to groundwater sources, because groundwater is more reliable and sustainable than surface water. The following table summarizes the recommended water source for each site.

Table 20. Recommended Sites

Site	Longitude	Latitude	UTM-X	UTM-Y	UTM-Zone	Recommended VES	Recommended depth (m)
Goraya-Cawl	43.22556°	9.87120°	305423	1091688	38 P	VES-5	160-180 m
Amoud 1st Priority	43.22597°	9.94964°	1100364	1100364	38 P	Site-1	>200 m
Amoud 2nd Priority	43.23114°	9.94481°	306079	1099828	38 P	Site-2	>200 m
Replacement for BH4	43.21973°	9.94686°	304829	1100061	38 P	VES-1 BH4	220-230 m

Based on the drilling history in Boorama area, due to possible technical drilling difficulties that could be encountered during drilling such as circulation loss, caving and/or collapse, telescopic drilling could be expected, therefore, drilling rig with mud-rotary drilling system is recommended. Due to above mention technical drilling difficulties, competent Hydrogeologist has to supervise the drilling activities in order to have a successful borehole drilling.

APPENIX 1. TENDER DOCUMENT

DRILLING SPECIFICATIONS, CONTRUCT AGREEMENT

Tel:- +252 634-804-616, / +251915744495
Email: - shaac2003@yahoo.com
Website: www.shaacinternational.com

INSTRUCTION TO BIDDES

INSTRUCTION

Bidders are strictly advised to carefully look through all instructions and give special attention to those instructions, which, failure to fulfill them, will entail rejection of the bid submitted by any bidder.

1. **Drilling Site Details.**

Site	Longitude	Latitude	UTM-X	UTM-Y	UTM-Zone	Recommended VES	Recommended depth (m)
Goraya-Cawl	43.22556°	9.87120°	305423	1091688	38 P	VES-5	160-180 m
Amoud 1st Priority	43.22597°	9.94964°	1100364	1100364	38 P	Site-1	>200 m
Amoud 2nd Priority	43.23114°	9.94481°	306079	1099828	38 P	Site-2	>200 m
Replacement for BH4	43.21973°	9.94686°	304829	1100061	38 P	VES-1 BH4	220-230 m

2. Eligible Bidders

The invitations for the bids are open to all eligible Water Well Drilling Companies registered in the Ministry of Water Resources of Somaliland or Water Authority of Puntland, especially, those companies that have been engaged in water well drilling and construction of water supply schemes.

3. Services

All services to be done under the contract shall have their measurement.

4. Cost of Bidding

The bidder shall bear all costs associated with preparation and submission of its bid, and the Employer will in no case be responsible for those costs, regardless of the conduct or outcome of the bidding process.

5. Clarification of Bidding Documents

A prospective bidder requiring any clarification of the bidding documents may notify the Employer in writing or by telephone, and the Employer will respond in writing to any request prior to the deadline.

6. Amendment of Bidding Document

At any time prior to the deadline for submission of bids the Employer may, for any reason whether at its own initiative or in response to a clarification requested by a prospective bidder, modify the bidding documents, which modifications shall be binding on the bidder. The amendment will be notified in writing or by fax or telex or cable to all prospective bidders, which have received the bidding documents and the amendment shall be binding on the bidders. In order to allow prospective bidders responsive time in which to take the amendment into account in preparing their bids, the Employer may, at its discretion, extend the deadline for the submission of the bids.

7. Language of the Bid

The bid prepared by the bidder, as well as all correspondence and documents relating to the bid, supporting documents and printed literature furnished by the bidder shall be written in English language.

8. Documents comprising the bid.

The bid document prepared by the bidder shall comprise the following component:

- A bid form and price schedule
- Documentary evidence that bidder is registered with the Ministry of Water Resources of Somaliland, establishing that the bidder is eligible to bid and is qualified to perform the contract if its bid is accepted.
- Documentary evidence establishing the required technical capability and the experience needed aspect to perform the required tasks.
- Conform to the bidding document.

9. Bid Currencies

For Water Well drilling works that the bidder will accomplish, the prices shall be quoted in US Dollar (USD).

10. Bids prices

- The bidders shall indicate the unit price where possible and the total bid price of the Work separately (for each work).
- Prices quoted by the bidder shall be fixed during the bidders' performance of the contract and not subject to variation in any account.

11. Employer's right to vary quantities at the time of the award

The Employer reserve the right at the time of award of contract to increase or decrease by up to 10% the quantity of work specified in the technical specification without change of unit price or other term of condition.

12. Employer's right to accept any bid and reject any or all bids

The Employer reserves the right to accept any bid and to annul the bidding processes and rejects all bids at any time prior to award of contract, without, thereby incurring any liability to the affected bidder or bidders or any obligation to inform the affected bidder or bidders of the grounds of the Employer's action.

Sample Contract Agreement

ARTICLE 1: GENERAL PROVISIONS

a) **'EMPLOYER'** means **SHABA**
b) **'Contractor'** means the firm or individual whose partner(s)/Senior Representative(s) are appointed as set forth under the Agreement to this Contract.
c) **'Engineer'** means the technical officer from EMPLOYER who is authorized on behalf of EMPLOYER to provide technical supervision and monitoring of the Works undertaken by the Contractor for this contract.
d) **'Works'** means drilling of the borehole in this Agreement.
e) **'The Contract Documents'** means the documents consisting of: Specific terms and Conditions of Contract: Drilling of Borehole.
f) **'Contract'** means the Conditions of Contract, the Technical Specifications, and main construction procedures for boreholes The Schedule of Rates, Time Schedule/Works Program, Reporting formats, list of staff members and contract agreement.
g) **'Week'** means period of seven days.
h) **'Completed work'** means the works on the borehole completed as per the Specifications and Terms of Conditions.
i) **'Commencement date'** means the date on which the works as agreed in the contract are executed.

ARTICLE 2 - SCOPE OF WORKS

1. The objective of the work under this agreement is: borehole drilling of 12 sites

ARTICLE 3 - OBLIGATION OF THE CONTRACTOR

a) The Contractor shall execute and maintain the works, provide and pay for labor, materials, construction equipment and machinery required for such execution, maintenance and completion of the work.
b) The contractor warrants and guarantees the Employer that all materials and equipment shall be new unless and otherwise specified and that all works shall be of good quality and free from faults or defects.
c) The contractor shall take full responsibility for the stability and safety of all site operations and methods of construction.
d) The contractor shall be responsible to see that finished works comply accurately with the contract documents to the satisfaction of the Employer.
e) From the commencement of the works until the date of completion and acceptance of the same by the Employer, the contractor shall take full responsibility of the care thereof.
f) On the completion of the works, the contractor shall remove from the site all construction materials, surplus materials, and temporary works of every kind, leave the whole of the working site clean.
g) The contractor will not be liable for compensation for the death, disability or hazards, which may be suffered by employees of the other party / parties to this contract as a result of their employment on works, which is the subject matter of this contract.

ARTICLE 4 – OBLIGATION OF THE EMPLOYER

a) The Employer shall hand over the sites, which is designated for use by the contractor.
b) Shall make arrangements with the community for the contractor to have access to the site unconditionally until the work is completed.
c) The Employer shall appoint his representative who shall inspect the works and deal with the contractor's representative.
d) The Employer shall within 15 (Fifteen) days of presentation of an approved application for payment, pay the contractor the amount approved by the Employer's representative.
e) The Employer will not be liable to indemnify any third party / parties in respect of claim, debt damage or demand arising out of implementation of this contract.
f) The Employer will not be liable for compensation for the death, disability or hazards, which may be suffered by employees of the other party / parties to this contract as a result of their employment on works, which is the subject matter of this contract.

ARTICLE 5 - PAYMENT CONDITIONS

4.1. The Employer will affect the payment in USD currency, and payments can be made through cheque.
4.2. The Employer's will pay 30% Advance payment after signing the Contract agreement provided that the Contractor provides **bank-grantee** equivalent on the amount requested.
4.3. The Employer's will pay 50% for the executed work after Employer's engineer satisfied the progress of the work and the contractor implement more than 80% of the work.
4.4. Final payment (20% of the Contract Price) shall be made upon submission of an approved payment certificate (s) by the contractor. Payment requests can only be made for the actual work done and measured on the basis of units & lump sum prices agreed upon in the bill of quantities.

ARTICLE 6 - COMMENCEMENT DELAYS & LIQUIDATED DAMAGE

- The contractor shall start the work within 10 calendar days after signing of this agreement and receipt of advance payment and shall complete and handover the work to the employer within **10** calendar days after the commencement of the work. If the contractor suffers delays from failure on the part of the employer in handing over the site designated, the contractor shall be entitled to an extension of the contract time for the completion of the work.

ARTICLE 7 – ACCEPTANCE OF THE WORK

6.1. The contractor will give written notice to the employer or his representative for final acceptance of the work when the whole of the work has been satisfactorily completed.
6.2. Upon receiving notice of the completion of the work from the contractor, the employer shall inspect the work within 7 (Seven) days and will issue the acceptance within 5

(Five) days after the inspection.

6.3. It is agreed that the employer shall be solely responsible for all the consequences that may result from his own failure to make final acceptance as requested by the contractor.

6.4. The contractor shall in no way be responsible for any damage that may occur to the works once the employer issues a written certificate of acceptance and performance of the obligation and completion of the works.

ARTICLE 8 - FORCE MAJEURE

7.1. Neither parties to this agreement shall be liable to each other for any loss or damage of any nature what so ever incurred or suffered by the other party due to delays or defaults in the performance under this agreement caused by circumstances beyond its control including but not limited to acts of nature, hostilities, war (whether declared or not), rebellion, sabotage, strikes or concerted sets of workmen, fires, explosions, floods, acts of enemies or restrains of any danger or de-facto government.

7.2. Force Majeure shall mean as defined in the civil code of Republic of Somaliland.

ARTICLE 9- CONTRACT DOCUMENTS

The following documents shall be an integral part of this contract agreement

- Letter of invitation.
- Terms of Reference
- Technical specifications
- Drawings.

ARTICLE 10- EFFECTIVE DATE

9.1. This agreement shall have binding effect on both parties as of the date it is signed by their dully-authorized representatives.

9.2. IN WITNESS THEREOF, the undersigned being duly authorized thereto, have signed this agreement on behalf of the parties hereunto on the day and year written below

FOR THE EMPLOYER	**FOR THE CONTRACTOR**
Signature: ______________________	Signature: ____________________
Name: _________________________	Name: ______________________
Title: __________________________	Title: ______________________

WITNESSES

FROM THE EMPLOYER

Name	**Signature**
Name: _________________________	___________________________
Name: __________________________	___________________________
Name: __________________________	___________________________

FROM THE CONTRACTOR

Name	Signature
Name: ____________________________	___________________________
Name: _____________________________	____________________________
Name: _____________________________	_____________________________

FORM OF TENDERS

To: SHABA, Boorama Town

Dear Sir/Madam:

Having examined the contract documents for the **-------------------- Borehole Drilling**, we the under signed, offer to implement and complete the whole of the said work in conformity with the said contract documents for the sum ________________________________ USD or such after sum as may be ascertained in accordance with the said documents.

We undertake if our tender is accepted to commence the works within ____________________ days of receipt of the order to commence, and to complete and deliver the whole of the works comprised in the contract within ________________ days calculated form the last day of the aforesaid prior in which the works are to be commenced.

We agree to abide by this bid for a period of ______________________ days from the date fixed for bid opening and it shall remain binding upon us and may be accepted at any time before the expiration of that period.

Unit a formal contract is prepared an executed that bid, together with your written acceptance, therefore, shall constituted abiding contract between us.

We understand that you are not bound to accept the lowest or any bid you may receive.

Dated on this day _______________ Month ______________ Year _________

Signature: ___________________Name: _______________________________

(In the capacity of authorized to sign bid for and a behalf of (____)

Borehole Drilling Technical Specifications

1. OBJECTIVES:

The main objective is to develop reliable production boreholes

Site	Longitude	Latitude	UTM-X	UTM-Y	UTM-Zone	Recommended VES	Recommended depth (m)
Goraya-Cawl	43.22556°	9.87120°	305423	1091688	38 P	VES-5	160-180 m
Amoud 1st Priority	43.22597°	9.94964°	1100364	1100364	38 P	Site-1	>200 m
Amoud 2nd Priority	43.23114°	9.94481°	306079	1099828	38 P	Site-2	>200 m
Replacement for BH4	43.21973°	9.94686°	304829	1100061	38 P	VES-1 BH4	220-230 m

2. MOBILISATION

1. Mobilization shall consist of all, necessary manpower, drilling rig and tools, and construction materials to different sites. Demobilization shall consist of clean-up work and operations including, but not limited to those necessary to the removal of personnel, equipment, and incidentals from the project site.
2. The Contractor shall also mobilize all the necessary materials such as water for drilling, drilling chemicals fuels etc, which are required during the progress of the works.

3. DRILLING

3.1. The Contractor shall clear the site during rigging up and excavation of mud pit and measurements shall be the net-in-site volume obtained from the difference between the lines and levels of the ground surface agreed with the Employer before excavation is commenced.
3.2. Where drawings do not indicate profiles, then these shall be held to be equal to the net plan area with the sides taken as vertical.
3.3. The Contractor shall only adopt mud system since collapse and circulation loss is expected in the area.
3.4. The Contractor shall use different drilling fluid Bentonite, drilling foam etc., with appropriate drilling technique.
3.5. Units of measurements for drilling shall be in meters and measurements are taken based on geological samples taken after drilling.
3.6. The rates of drilling shall be based on geological formations.
3.7. Geological logging shall be performed after the end of each drilling and drawings should be submitted accordingly.
3.8. Drilling up to the estimated depth shall not necessarily proceed and drilling can be ceased based on the hydrogeological and geological condition when approved by Employer Hydrogeologist (Engineer).
3.9. The upper unconsolidated shall be drilled 17 inch drill bit.
3.10. The remaining diameter of the wells shall not be less than 12 ¼ inch.
3.11. If the boreholes are drilled with rotary equipment and the following drilling fluid may be used,

- Drilling mud containing Bentonite or other clay minerals.

- Drilling mud composed of water and a thickening agent containing no solid particles. Examples are the starch based mud, revert, and polymer based mud such as quick thick.

3.12. The drilling equipment and methods used should be capable of drilling through both overburden and bedrock.

4. INSTALL CASINGS

4.1. Surface steel casing of minimum 14 inch might be needed for the upper unconsolidated sediments.
4.2. 8" uPVC production casing and screens shall be used.
4.3. The rates of casing (blind or screen) shall include installing up to desired depth.
4.4. Installations of casings and screens shall be up to required depth as per standards and the geological logs to meet the function of the aquifer and the type of pumps to be used.
4.5. Minimum wall thickness for all well casing shall be 10 mm.
4.6. Well screen shall be continuous slot wire wound screens as manufactured by Johnson screens or equivalent. For different sizes, the slot size should be specified by the Engineer after sieve analysis of the aquifer samples.

5. GRAVEL

5.1. Gravel for drilled wells shall be river gravel, round and having sufficient strength and proper sizes to meet the designed screen for proper filtration (the gravel should be siliceous in composition). Gravel should also be washed with water to remove weathered particles before packing.
5.2. Gravel shall be supplied and packed up to the required depth and shall be measured in meter cube.
5.3. Gravel size is selected based on the geological strata of the drilled well.

6. WELL CLEANING AND D EVELO PMENT

6.1. The well shall be cleaned and developed so as to arrange the positions of gavels for a good filter media so that clean water can be drawn while developing.
6.2. The time interval for cleaning and developing shall be of minimum twelve (12hrs) and the unit of measurement is in hours (hrs).
6.3. The well shall be grouted with mass concrete up to a maximum depth of 2m and a well head shall be constructed facilitating a good drainage that protect vertical seepage around the well

7. METHOD AND EQUIPMENT FOR PUMPING TESTS

The contractor shall provide the following equipment

- Submersible pump designed to pump water at the desired depth.
- Diesel generator to run the pump.
- Suitable devices to measure the discharge.
- Water level measurement device capable of measuring the desired depth.
- EC meter for electrical conductivity measurements during pumping tests.

7.1. Data collection

1) **Step draw-down test**:
Test pumping will comprise an extended step draw-down test of 3 hours duration for each step and minimum of five (5) steps is required.
2) **Continuous Draw-down (Constant rate Test)**
The duration of the test shall be 72 hours.
3) **Recovery test**
After 72 hours of continuous test, the pump should be turned off and measurement of water level recovery should be immediately be undertaken
4) **Field analysis**
During the pumping tests, pH, EC (electrical conductivity) and the temperature of the water should be measured.
5) **Chemical analysis**
Two samples of 5 liter each shall be collected at the end of the pumping test for further chemical analysis of the water in order to determine the portability of the water and should be compared with WHO guideline. The tests that should be performed are bacteriological and physio-chemical analysis. The parameters to be analyzed should include: PH, Alkalinity, Hardness, Electrical Conductivity, and major and minor Cations & Anions (Na^{+1}, K^{+1}, Ca^{+2}, Mg^{+2}, Fe^{+3}, HCO_3, CO_3^{-2}, Cl^{-1}, F^{-1}, NO_3, NO_2 and so on)

8. WELL HEAD CONSTRUCTION

The contractor shall construct a well-built well head in order to protect the well against pollution. The well head should be constructed with concrete mix of 1:2:2 ratios.

9. REPORTING

A final report shall be produced for well including but not limited to the following information:

- Location and reference number of the well
- Make and type of drilling rig and details of tools used
- Names of Foremen and Drillers
- The detailed log of drilling activities
- Well screen and casing arrangements
- Details of gravel pack sections, Bentonite seals and inert fillings
- Details of development operations carried out.
- Detailed diary of test pumping operations.
- Result of pumping test analysis
- A complete record to all water level readings time and discharge.
- Details of the pump and its installation depth.
- Complete chemical analysis of ground water

Goraya Cawl BH Drilling (180 m deep)

Work Description	Unit	QTY	Unit Price USD	Total Price USD
General Items				
Mobilization/De-mobilization	Ls	1		
Inter-site mobilization	Ls	1		
Site cleaning, rigging & excavation of mud pit	Ls	1		
Drilling				
Drilling with 17.5" bit in the unconsolidated Upper section	m	20		
Drilling in all types of formation @12 1/4 "	m	160		
Logging				
Lithological Logging	LS	1		
Supply and install of 14" surface casing	m	20		
Supply and install mild Steel 8" bland casing	m	144		
Supply and install Steel screen 8"	m	36		
Supply and installation 3/4 observation pipe	m	150		
Well Completion and Sanitary Protection Work				
Supply and install clean well rounded and sorted river gravel in to annular space and/or casing	m^3	15	ls	
Well cleaning and development	hrs	12	ls	
Grout with mass concrete to a depth of 2m	m^3	2	ls	
Construct well head	Ls	1	ls	
Pumping Tests including result analysis				
Constant discharge test	hrs	72		
Monitoring Recovery	hrs	24		
Step draw-down test (Variable discharge)	hrs	15		
Supply and install well cap	pcs	1		
Water quality analysis	Ls	1		
Total Cost for drilling				

Deep BH Drilling

Bill of Quantities for a Borehole 200 m depth

Work Description	Unit	QTY	Unit Price USD	Total Price Total Price USD
General Items				
Mobilization/	Ls	1		
Inter-site mobilization	Ls	1		
Site cleaning, rigging & excavation of mud pit	Ls	1		
Drilling				
Drilling with 17.5" bit in the unconsolidated Upper	m	6		
Drilling in all types of formation @12 ¼"	m	194		
Logging				
Lithological Logging	LS	1		
Supply and Installation of Material				
Supply and install of 14" surface casing	m	6		
Supply and install mild Steel 8" steel bland casing	m	160		
Supply and install steel Screen 8"	m	40		
Supply and installation 3/4 observation pipe	m	180		
Well Completion and Sanitary Protection Work				
Supply and install clean well rounded and sorted river gravel in to	m^3	16		
Well cleaning and development	hrs	12		
Construct well head	m^3	1		
Pumping Tests including result analysis				
Constant discharge test	hrs	72		
Monitoring Recovery	hrs	24		
Step draw-down test (Variable discharge)	hrs	12		
Supply and install well cap	pcs	1		
Water quality analysis	Ls	1		
Total				

Typical Well Design (BH of 200 m Depth)