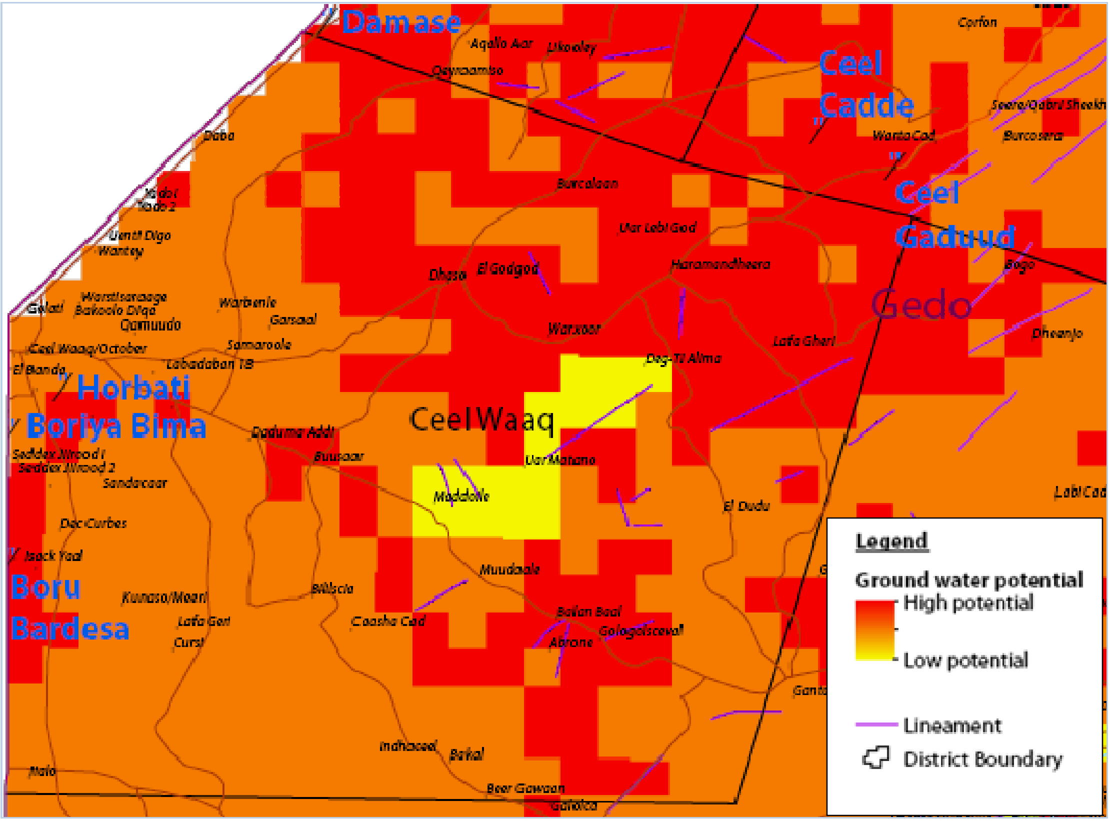
Hydrogeological Study in Ceel Waaq District, Gedo Region, Somalia



Project Report Nº W-26

September 2015

Somalia Water and Land Information Management
Ngecha Road, Lake View. P.O Box 30470-00100, Nairobi, Kenya.
Tel +254 020 4000300 - Fax +254 020 4000333,
Email: swalim@fao.org Website: http//www.faoswalim.org

Funded by the European Union and implemented by the Food and Agriculture Organization of the United Nations

Disclaimer

The Hydrogeological Study in Ceel Waaq District, Gedo Region, Somalia was carried out by FAO SWALIM through a contracting company, SWAS Water Surveys.

The document should be cited as follows:

SWALIM (2015) Hydrogeological Study in Ceel Waaq District, Gedo Region, Somalia. Technical Report No W-26, FAO-SWALIM (GCP/SOM/050/MUL) Project, Nairobi, Kenya

Executive Summary

This report presents the results of the Ceel Waaq hydrogeological study and recommendations for approaches to groundwater management in order to make effective investments in the marginal groundwater resources available in the district.

The study is spearheaded by FAO within its mandate to provide reliable water information for the WASH Cluster in Somalia and the general public. The information provided herein will be found especially useful the WASH Cluster programmes, giving direction on what ways to invest in future projects. The study for example recommends water use prioritization and conjunctive water resources application, so that marginal groundwater can be developed for stock use while using treated surface water and purified groundwater for domestic applications. This calls for new thinking about transfer of appropriate technology, especially using solar purification for desalination. For immediate investment by the WASH Cluster, the study recommends drilling at 5 sites; a number of the surveyed sites were found to have saline water.

The study demonstrates the validity of using Landsat imagery to delineate fracture zones, hence areas of relatively higher groundwater potential. Recharge water is channeled along regional fractures that enhance hydraulic connectivity hence higher fluxes along these lineaments. The identification of the nearest lineaments to each village was done with the help of automatically generated lineaments and manual tracing on satellite imagery, to select potential geophysical survey sites within a 2-kilometer radius of each village.

Water quality data from sampled water points show that, although some compounds and elements occur in elevated concentrations, they cause mainly aesthetic problems of taste and odour, but have no strict WHO guideline values because they are not associated with specific health problems. Parameters found in elevated levels include:-

- Electrical conductivity, which is dominantly in excess of 3000 μS/cm except at Dhamasa, Dhaba and Likoley where EC ranges between 1000 and 3000 μS/cm;
- Fluoride, which exceeds 1.5 mg/l except at Dhamasa, Dhaba and Likoley boreholes; however the fluoride risk is minimal because even in excess it is typically between 2 mg/l and 4 mg/l;
- The elements calcium, magnesium, sodium and potassium that exceed guideline value, with a few exceptions.

- Chloride and sulphate are characteristically high and can be attributed to rock-water interaction, the latter due to local pockets of gypsum.

Shallow wells particularly have poor water quality because most shallow aquifers occur in gypsite.

In consideration of the yield potential and expected water quality at various villages, the following sites have been recommended for drilling:

	Village	**VES ID**	**Grid Reference (WGS84)**	**Max. depth (m)**
1	Yado	VES 1	41.13886E, 2.96278N Alt 390m	100
2	Tulo Adde	VES 2	41.04556E, 2.81702N Alt 389m	130
3	Orre Dimtu	VES 1	40.99427E, 2.70783N alt. 390m	100
4	Jimbile	VES 2	41.04109E, 2.64268N Alt 448m	120
5	Boco	VES 1	41.08016E, 2.68140N alt. 396m	60

The study was acutely limited by insecurity in most of the areas proposed for the survey. As a result the local authorities proposed different survey villages than those initially proposed by the Technical Working Group (TWG). It was not feasible to verify the technical viability of all the new sites for groundwater development before field visit since their geographical locations were unknown.

Abbreviations

FAO	(UN) Food and Agriculture Organization
ORP	Oxidation Reduction Potential
SWALIM	Somalia Water and Land Information Management
TWG	Technical Working Group
VES	Vertical Electrical Sounding
WASH	Water, Sanitation and Hygiene
WHO	World Health Organization

Table of Contents

List of Figures

List of Tables

Chapter 1. Introduction

1.1 Background

Somalia is located at the Horn of Africa, covering an area of 637,600 km². It is bordered by Ethiopia to the West, Djibouti to the northwest, the Gulf of Aden to the north, the Indian Ocean to the east and Kenya to the southwest. The Juba and Shabelle River basins are located in Southern Somalia (**Error! Reference source not found.**). It is also called the 'breadbasket' of the country (Basnyat, 2007) as it is the centre of agricultural and livestock production and home to a majority of the Somali population (EC, 2004).

The Food and Agriculture Organisation (FAO) – Somalia has been implementing the Somalia Water and Land Information Management project (SWALIM), whose purpose is to provide timely and relevant water and land information to inform emergency response, early warning and preparedness in Somalia.

FAO also systematically provides, information needed for water projects by the Somalia WASH Cluster through carrying out assessment of rural and urban water supplies, strategic water sources survey and recently hydrogeological surveys in Somaliland and Puntland.

FAO is extending the same programme into the Gedo Region of Somalia, where the anticipated output of this project is water point mapping and hydrogeological survey for 10 borehole sites in Ceel Waaq district.

Gedo is one of the regions with very poor access to safe water. According FAO, a recent WASH cluster review in Ceel Waaq and Bardere districts indicated that about 30% of all boreholes drilled are not functioning, reportedly due to poor water quality, low - medium yield or un-successful drilling due to lack of comprehensive hydrogeological information. Furthermore, assessments indicate that 54.8% of the residents do not have access to water sources. FAO has determined that an intervention of this type will go a long way in improving the precarious water situation in this most vulnerable district.

1.2 Previous Studies and Investigations

The International Committee of the Red Cross (ICRC) Somalia Delegation conducted water resources assessment, water supply planning and rehabilitation surveys in Gedo Region in 2002, and included hydrogeology and geophysical investigations for shallow wells, rain water catchments and boreholes at selected villages within the Region (Gajsek & Gicheruh, 2002).

COSV (Mirobe, 2008) conducted assessment and hydrogeological surveys in Ceel Waaq. The report recognized that groundwater from sandstone aquifers is potable and water from limestone aquifers is of a quality only suitable for livestock at best. The study recommended drilling at 16 sites including Likoley, Akalaar, Dhaso, Warxoor, Horbati, Yado, Nustariq, Ilalo, Dibayu, Meri, Gof, Wantey, Sadajirod, Mudale and Shebow. Boreholes have since been drilled in some of these villages; it is now known that Likoley has potable water while Horbati has saline water.

Umikaltuma and Mutua (2014, research publication) conducted lineament extraction from Landsat 8 (OLI) because of its better spectral discrimination. This followed previous lineament extraction studies using Landsat TM, ETM ETM+ sensors.

What comes out from these studies is that good groundwater potential in Gedo is strongly linked with lineaments and that the older Jurassic limestone formations yield poor quality water while the sandstones host potable to marginal waters.

1.3 Purpose and Scope of the Study

The objective of the project is to increase water availability in Ceel Waaq district in Gedo Region of Somalia through guided borehole drilling using up to date hydrogeological information. Specifically, the study should:-

- Collect, collate and synthesise information from previous studies in order to provide a basic understanding of groundwater resource situation in the district;
- Carry out hydrogeological survey at 10 sites;
- Provide water quality information by collecting and analysing 25 water samples;
- Compile a comprehensive survey report.

The study is expected to provide consolidated groundwater information that can be used for quick interventions in Ceel Waaq district. The information should include distribution of groundwater potential showing areas in which it is viable to invest in groundwater schemes and areas that are not suitable. As a result, future donor funding will therefore be more targeted to yield results. For the immediate assignment, key outputs from the study are expected to be:

- Inventory of water sources (boreholes, shallow wells, springs and dams) in Ceel Waaq district;
- Preliminary classification of aquifers systems in Ceel Waaq district;
- Location of 10 drilling sites, with estimations of their potential, sustainable yield, water quality and recommendations for depth of drilling.

1.4 Organization of the Report

The report begins with a background and justification for the project, sets up the geographical environment of the district before describing the groundwater context in Chapter 2. Chapter 3 is dedicated to the approach used to deliver the services, beginning with data collection and desk analyses followed by fieldwork.

In Chapter 4 the results are presented and discussed; a synthesis of water quality data and what this means for the groundwater potential in the district is provided. Chapter 5 discusses groundwater management, starting by reviewing the demand versus resource availability and then looks at the options for meeting the various use demands given the limited resources. Recommendations are given at the end of the chapter for the way forward, using the results of this study.

References and appendices describe the sources of information cited, people met, and data collected.

Chapter 2. Description of the Study Area

2.1 Geography

The study area is in Ceel Waaq district of Gedo Region, Somalia (Figure 1). The district is bounded by Kenya in the western side, Belet Xawo and Grabaharey districts in the north and Bardheere district in the south and east. There are 10 proposed villages for geophysical surveys.

The villages of interest include the following in no particular order of preference:-

1. Muudaale
2. Balan Baal
3. Beer Gawaan
4. Abrone
5. Lafa Gheri
6. Buusaar
7. Warxoor
8. Haramandheera
9. Burcalaan
10. Dhaso
11. Dibayo
12. Indaceel
13. Yado
14. Tulo Addey

Out of these locations, 10 villages were selected for the final geophysical surveys, which were all the above except Dibayo, Indaceel, Beer Gawan and Buursar. However, due to poor security situation the District Commissioner Ceel Waaq provided a separate list of secure villages that could be surveyed, including:

1. Yado
2. Tulo Adde
3. Horbati (later Abdallah Balla)
4. Qorbeso
5. Jimbile
6. Boco
7. Goof
8. Wante
9. Shebow
10. Qamuudo

Notwithstanding, during the field survey the situation in Qamuudo and Shebow changed and the survey team was advised to avoid these (Figure 1). Horbati was replaced with Abdallah Balla due to salinity of a previously drilled well that was found at the village during the assessment. On inquiry it was indicated that it had been implemented through Oxfam.

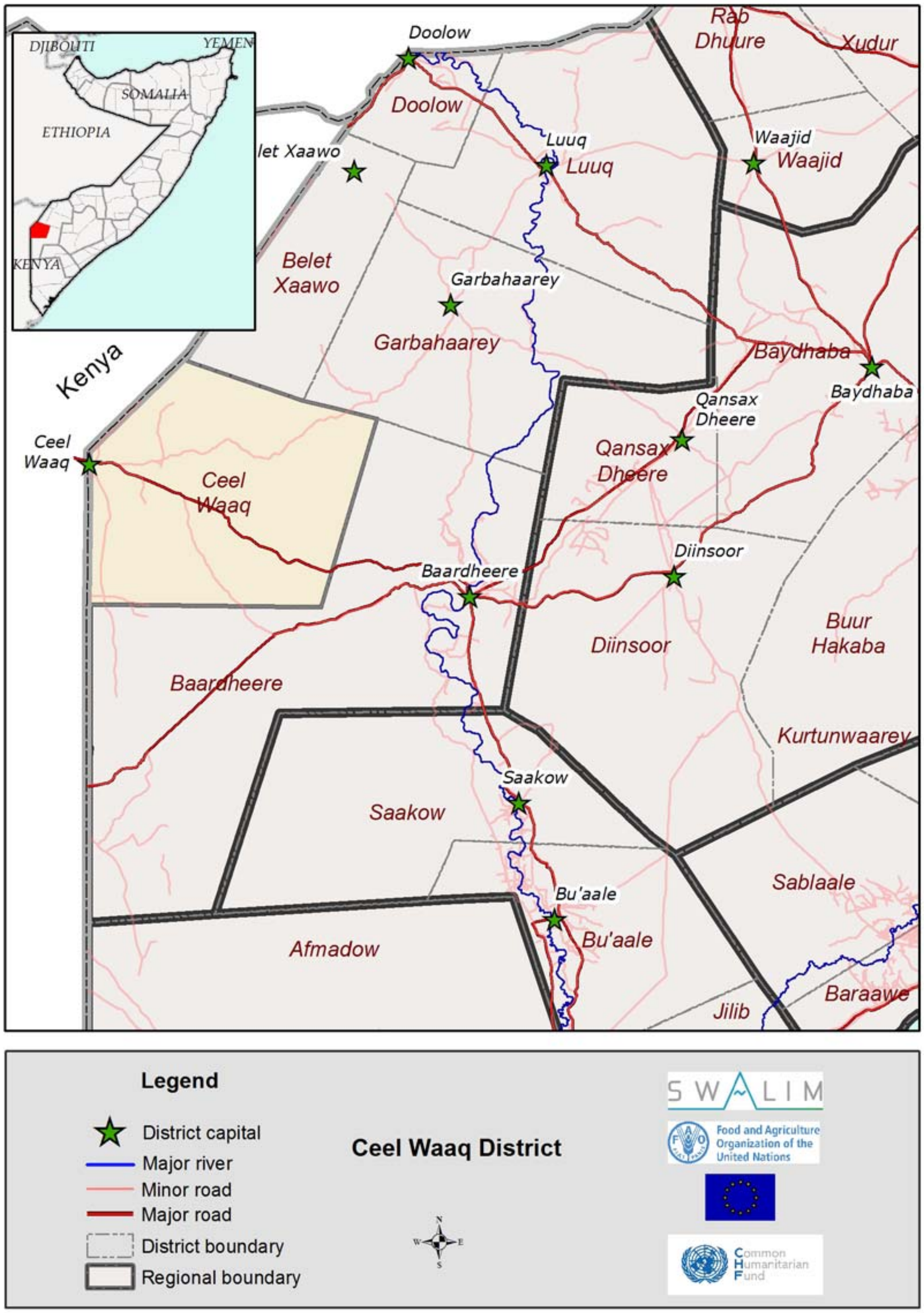


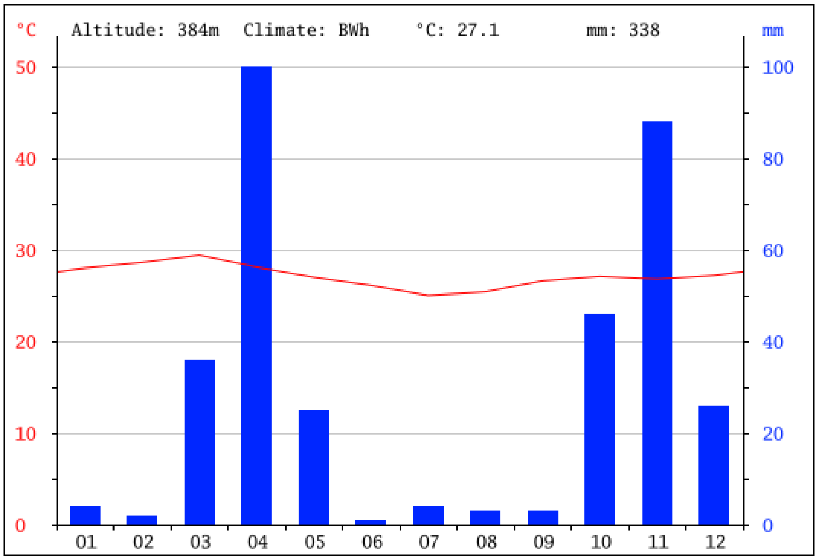
Figure 1. Location map of the study area

2.2 Population

Ceel Waaq district had an estimated population of 30,958 (UNICEF, 2014). Most of this population – up to 71% do not have access to safe water. According to available information from humanitarian agencies in the WASH cluster, about 30% of boreholes drilled are not functioning. The common causes of borehole failure are poor water quality, low - medium yield or un-successful drilling due to lack of comprehensive hydrogeological information.

2.3 Climate

Ceel Waaq according to the Koppen classification is climatically BWh and FAO very arid. Precipitation usually does not exceed 300mm throughout the district. Ceel Waaq town itself has a long term average of 338mm.



(Source: climatedata.org)

Figure 2. Rainfall hydrograph, Ceel Waaq

The annual distribution of rainfall has April (100mm) with the highest rainfall – the Gu rains. Other months with significant rainfall are November (88mm) and October (46mm) (Figure 2).

2.4 Geology

The Ceel Waaq district geology is dominated by the Ambar Sandstones Formation, with a smaller area covered by the older dolomitic and oolitic limestones (Figure 3). The stratigraphic relationships of these units are as follows:

i.	*Sands, silts and gravels*	*Pleistocene to Recent*
ii.	*Sandstones*	*Ambar Formation, Cretaceous*
iii.	*Dolomitic limestones*	*Garbaharey Formation, Jurassic*
iv.	*Marls and calcareous sandstones*	*Anoole Formation, Jurassic*

Detailed description of each unit follows in the next sub-sections.

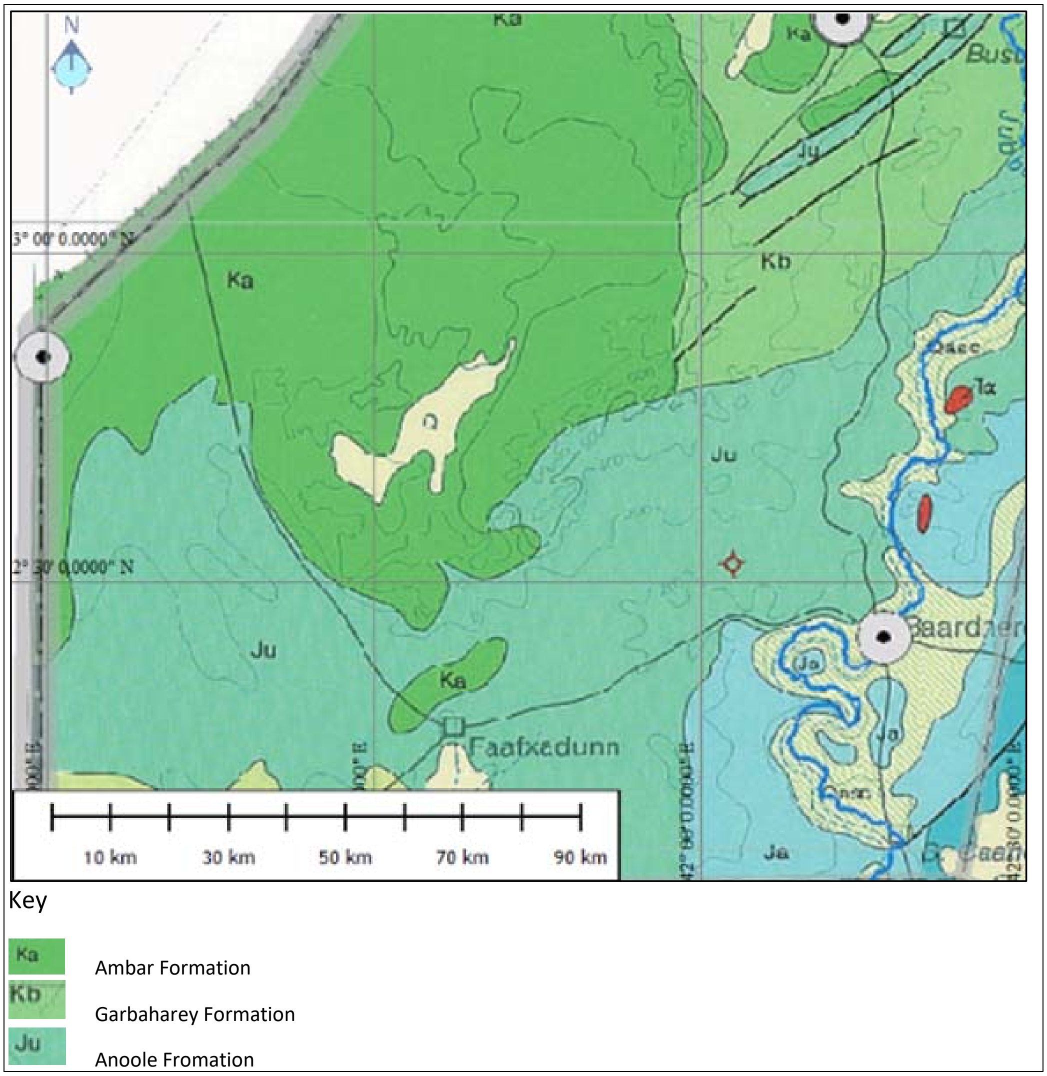


Figure 3. Geological map of the project area (courtesy Abatte et al)

2.4.1 Sandy surface sediments

These are the youngest lithological units and comprise sands, silts and gravels of alluvial, colluvial or aeolian origin. Their ages range from Pleistocene to Recent. These sediments vary in character according to origin and mode of placement. In the southern and northern part of Ceel Waaq they are mainly reddish-brown in colour; in the central areas and around Ceel Waaq town they are buff-white to grey. Where they overlie the Anoole Formation, these soils and alluvium bear groundwater of unacceptable quality.

2.4.2 Ambar sandstones

The Ambar sandstones consist of fluvial to deltaic sandstones with marly and calcareous variants; they were apparently deposited in the latter stages of the transgression of the sea. The Ambar sandstones represent the last stages of sedimentation within a structural depression. In Jurassic time a trench opened with the axis of the trench trending northeastward and is called the Luugh-Mandera basin and was filled first with sandstones and shales, and later with mainly limestone. The sedimentation stopped during the Cretaceous period and the sediments were uplifted above present sea level. They are therefore likely to host groundwater of better quality than those deposited in evaporitic environments. It is the main outcrop in the high areas of the district.

The Dhamasa, Likoley, Dhaba and Boru Badesa boreholes are al drilled in the Ambar Formation and yield relatively fresh water at depths up to 180 metres.

2.4.3 Garbaharey Formation

This consists of Cretaceous to Tertiary sediments with clastic sequences, evaporites and marine successions. Large areas of this evaporate limestone formation are covered by residual clayey soils. Clay swelling after the first rainfall creates an impervious layer causing ponding in small depressions on the plateau. These ponds are frequently sites for the construction of wars. Groundwater recharge from these clay soil areas remains uncertain.

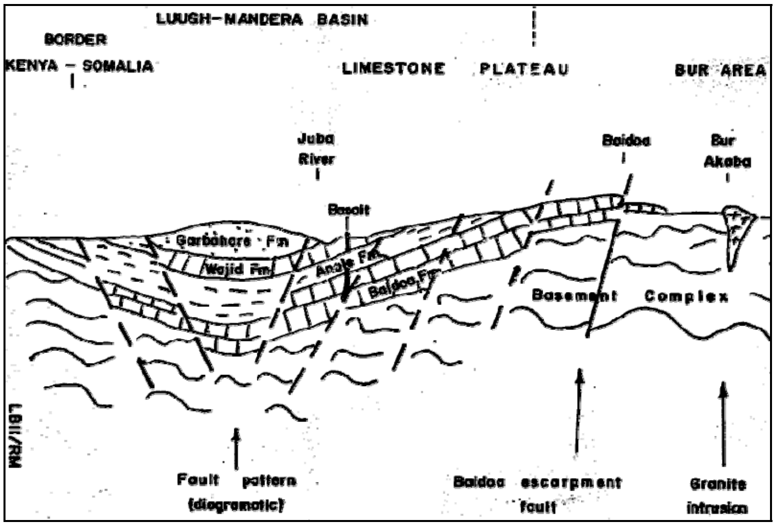


Figure 4. Generalised cross-section from Baidoa to Kenya-Somalia border (after Louis Berger Group, 1985)

The cross section in Figure 4 shows that there is higher potential near the fringes of the Garbaharey Formation where it comes into contact with other formations.

2.4.4 Anoole Formation

The Anoole Formation overlies the Iscia Baidoa Formation conformably; the Anoole is up to 300 meters in thickness, although in Ceel Waaq its maximum thickness measures much less (likely to be 200m). It consists mainly of black marl and shale with interlayers of blue compact limestone. The softer marl and shale layers do not occur as outcrops as they weather to light-brown clay. The limestone layers show few signs of karstification but may be weathered to caliche.

Groundwater with high degrees of mineralization is encountered in interlayered marls, shales, and limestone of the Anole Formation. These have poor quality of the groundwater whose conductivities may reach higher than 20,000 micromhos. There are high (>1000 mg/l) chloride concentration in the wells from the Anole Formation. Single layers of limestone, deeply weathered and forming a caliche surface may contain groundwater of acceptable quality, but the wells in this material have low yields.

The Horbati borehole drilled through OXFAM assistance was found to be saline because it taps an aquifer in the Anoole Formation.

2.5 Hydrogeology

2.5.1 Groundwater occurrence

It is indicated that groundwater in Ceel Waaq occurs in three different ways:

- Alluvial deposits (saline water when overlying Anoole Formation);
- Karstified limestone recharged by sink-holes;
- In caliche formed from deeply weathered limestone;
- In interlayered marls within the limestone beds;
- In the gypsite beds of Ceel Waaq;
- Fracture aquifers in fault zones widened by karstification to provide increased groundwater storage.

Aquifers in alluvial deposits and in the gypsite beds are the shallowest, being generally up to 30 meters deep. Aquifers in karst terrain tend to be of medium depth, with geological reports indicating occurrence of karst up to 50 meters deep.

Lenses of marl tend to host aquifers from over 50 meters and deeper, generally occurring at same depths as fracture aquifers. Fracture aquifers in Ambar sandstone are more likely to have fresh water than marl and caliche aquifers which have highly mineralized waters.

From the cross section in Figure 3, groundwater in the Garbaharey Formation is inferred to be limited in the formation proper, with better prospects on the fringes near the contact with the underlying Wajid Formation.

The yields of boreholes in the limestone areas vary according to the density of fractures in the rock and to the degree of fracture width through karst solution processes. Since other parts of the limestone are solid and generally impervious, the aquifers are not homogeneous with isotropic aquifer conditions in all directions. Since transmissivity formulas were originally developed for unconsolidated isotropic aquifers, it is not useful to generalize these hydraulic parameters.

2.5.2 Groundwater recharge

The second important determinant of groundwater potential after the geology is annual renewable recharge. This depends on the precipitation and evapotranspiration.

According to Khroda (1989) quotes studies in Wajir Kenya that have shown that in these arid environments, groundwater recharge does occur when rainfall episodes record at least 32.5mm. It can therefore be assumed that recharge is most likely to occur only in April and November in a normal year.

Further, according to Irungu (1997) the estimated recharge percentage for sandy sediments and sandstone in arid environments is 5%. Combining these two study results it is possible to estimate the annual renewable recharge over the sandstone covered areas of Ceel Waaq. Using GIS analysis, the surface area under sandstone is approximately 4,900 square kilometers. Assuming that a single rainfall event of 32mm occurs twice a year over this area, the annual recharge is estimated thus:

Recharge = Rainfall x % recharge x area
= 0.065 x 0.05 x 4900 x 106
= 15.9 MCM/ year

This may seem a significant volume of water, but other factors work to minimize its significance. For example, the sheer size of the area over which this recharge is collected reduces the flux per unit area of aquifer. The flux across the sandstone unit globally is estimated thus:-

Flux = Transmissivity x hydraulic gradient x width of aquifer

In this aspect, the yields of boreholes are generally less than 10 m3/ hr hence transmissivity is expected to be low, in the range of less than 10 m2/day. The cross section of the sandstone across the generalized flow direction is 70 kilometers.

Flux = 10 x 0.0025 x 70,000 = 1,750 m3/ day, or 25 m3 per day per kilometer width.

This is unusually low: what it implies is that groundwater potential will be better only where flux is concentrated along channelized flow paths, i.e. along faults and regional fractures. Yield improves where these fractures are hydraulically connected, thus increasing the flux. To locate such areas structural study must be done.

2.5.3 Structural influence on hydrogeology

Structural analysis was also aided by the results of an automatic lineament extraction done through the Geomatica 2014 software (Mutua and Umikaltuma, 2012). The manual extraction was compared with the automatic lineament sets. It emerges that there are two strong lineament directions in Gedo Region – NW-SE and NE-SW. The lineaments are composed of short lineaments and longer ones. In some cases the shorter lineaments are aligned so as to form longer ones. Figure 4 shows the automatically generated lineaments for the whole of Gedo Region.

Faults with northwest strikes on the Limestone Plateau are commonly widened by karstification. Such faults provide paths for groundwater movement and thus offer good locations for siting wells (Figure 5).

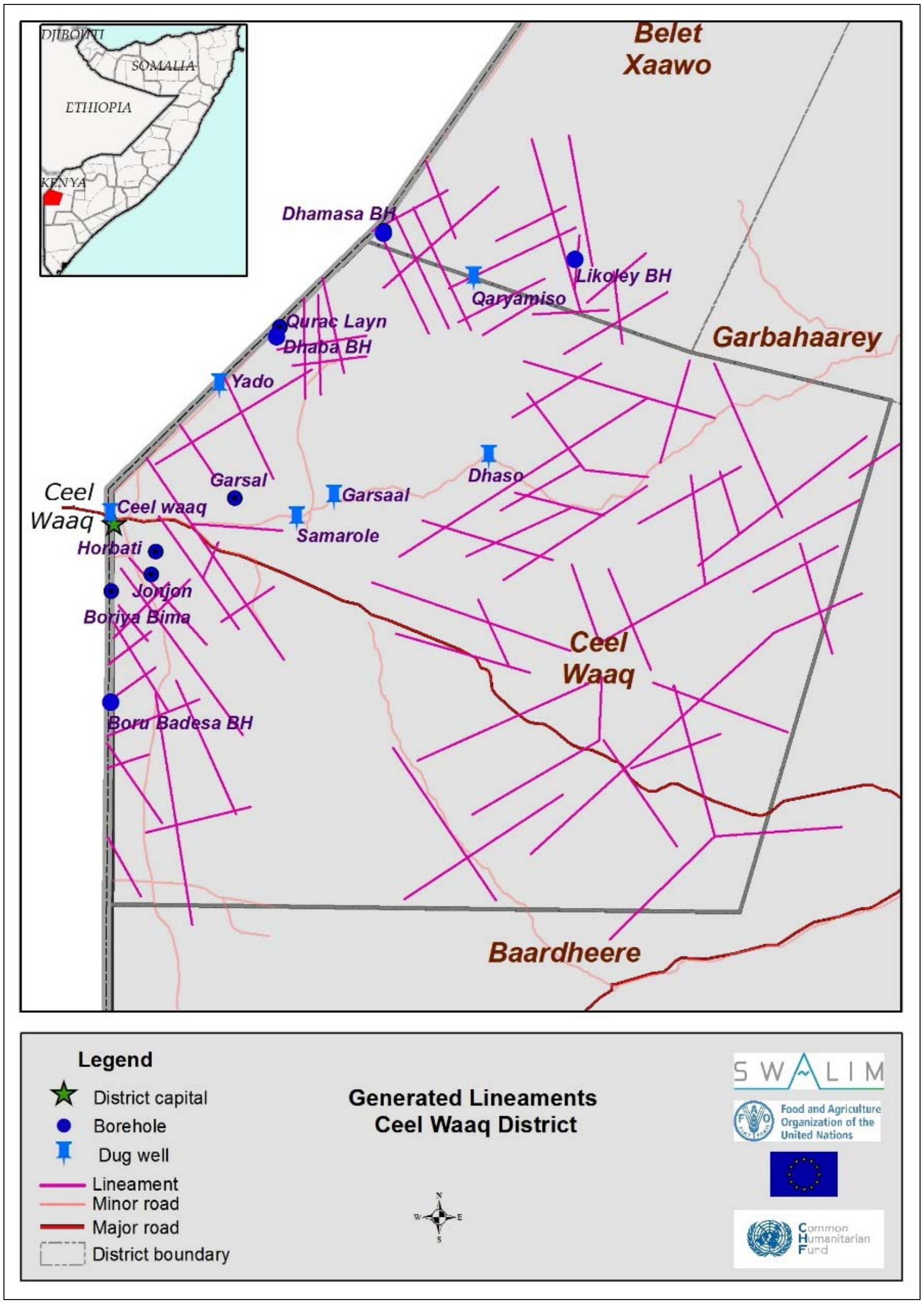


Figure 5. Manually generated lineaments in Ceel Waaq district, with existing borehole locations

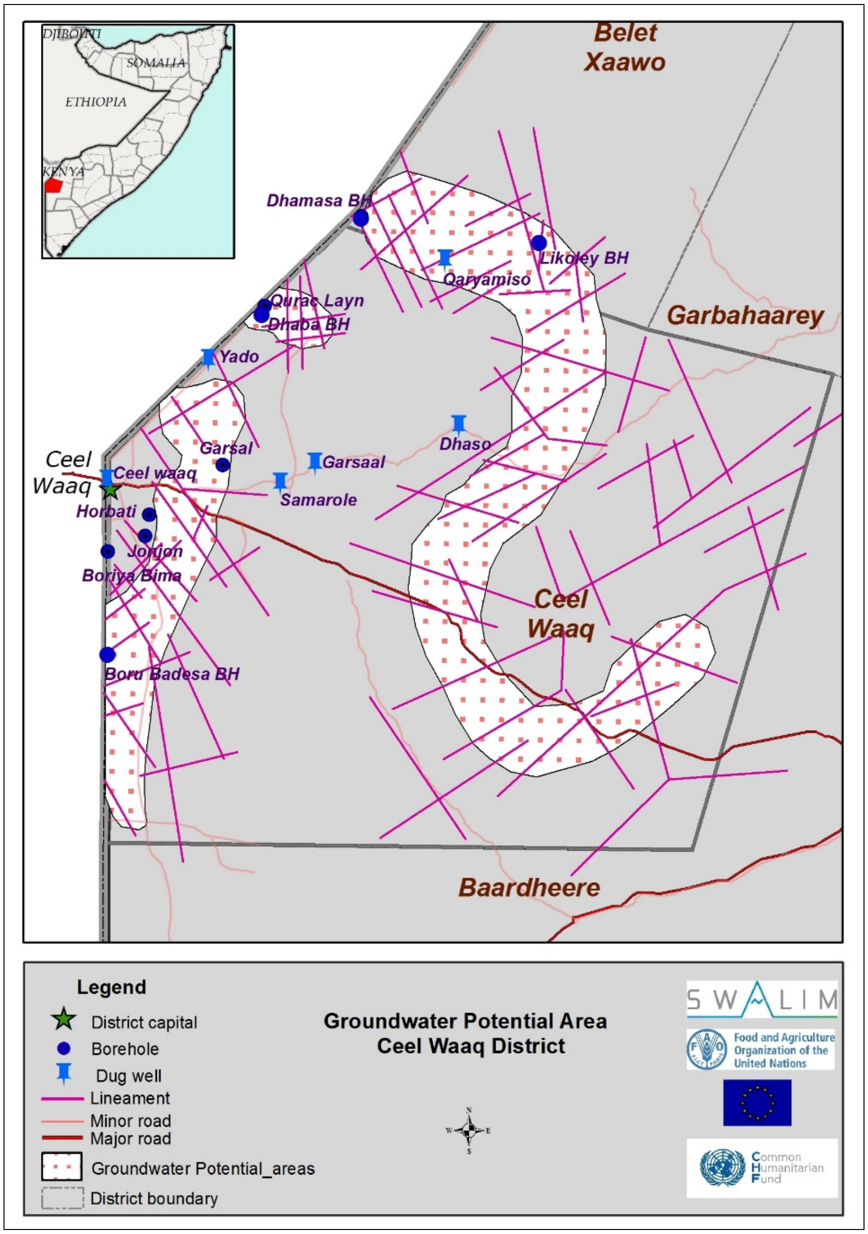


Figure 6. Areas likely to have high groundwater potential in Ceel Waaq

Based on this information, the areas with the highest groundwater potential in Ceel Waaq can be preliminarily mapped by tracing the intensity of fracturing and length of fractures. There are two corridors in Ceel Waaq district which have the highest groundwater potential, shown in Figure 6.

This compares well with the information generated by the TWG through a GIS-based groundwater potential evaluation (Figure 7).

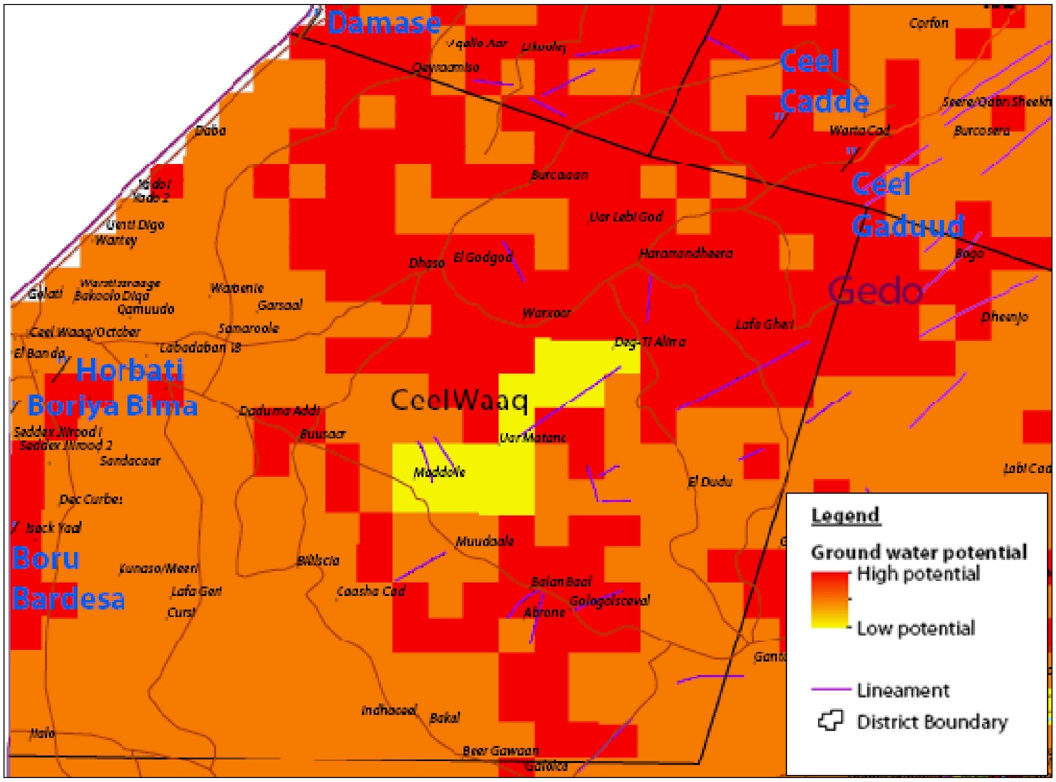


Figure 7. Groundwater potential as determined by the TWG

2.6 Hydrology

The historical weather monitoring network in the southern areas of Somalia is concentrated along the Juba and Shabelle river valleys (Figure 8). Consequently, there is limited hydrological data in Gedo region which is located outside these basins. All streams in Ceel Waaq are ephemeral, flowing only as flash floods following sporadic rainfall and leaving behind pools in areas with valley soils (*balley and warr*).

The district is covered by two drainage areas – the Lagh Dera and Juba basins (Figure 9). Surface runoff from these areas contribute to the seasonal peak flows of the Juba

River. Communities utilize the surface run-off by constructing warr and berkads in addition to the natural pools.

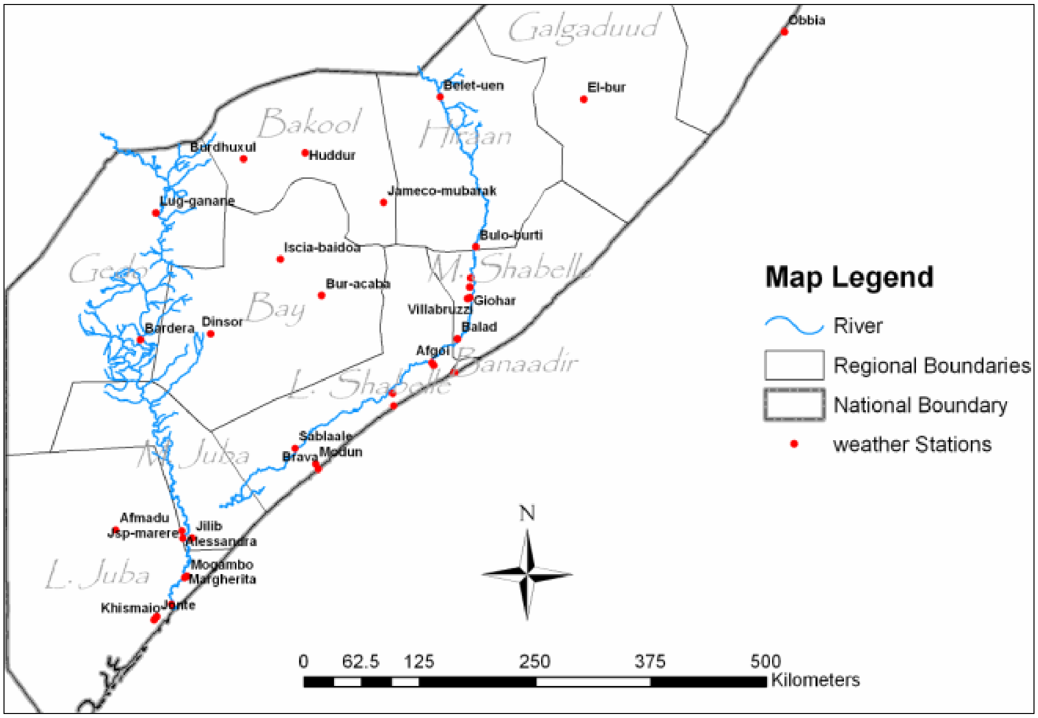


Figure 8. Weather monitoring stations (FAO SWALIM)

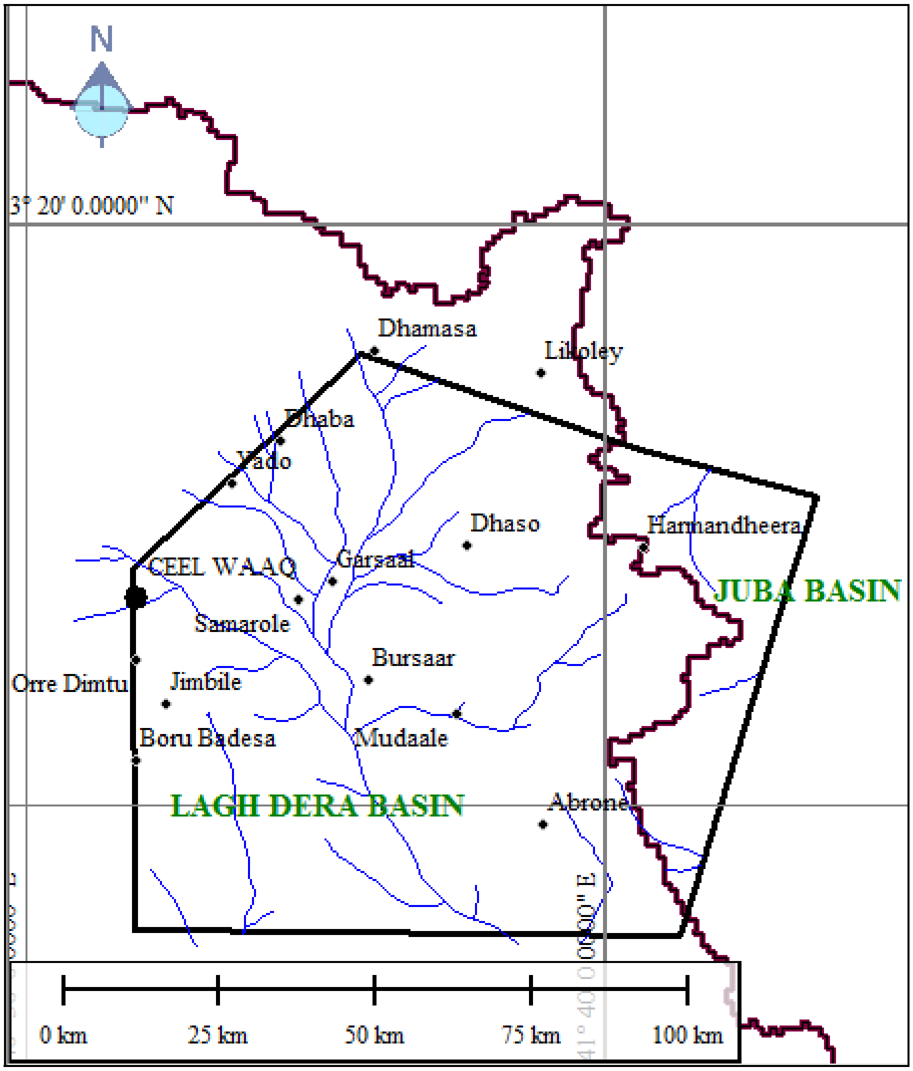


Figure 9. Hydrological basins of Ceel Waaq

Chapter 3. Methodology

3.1 Desk Review

Geological structural studies have been conducted with assistance of Landsat scenes supplied by FAO. Occurrence of structural lineaments was studied by enhancing spectral aspects using the software MultiSpec. A radius of 2 kilometers around each village is considered for the study, this being the assumed furthest distance from the village that a borehole source may be located. The following images present a village-by-village analysis.

3.1.1 Warxoor

Warxoor is the most structurally influenced location; there are two sets of lineaments – NW-SE and NE-SW (Figure 10). This is a good indicator of enhanced storage and hydraulic connectivity. Combined with the fact that it is situated on the path of surface run-off, the village has a comparatively higher groundwater potential; than many others.

3.1.2 Abrone

Abrone is situated at the surface contact between the sandstone and the limestone. It too has several lineaments, two of which interconnect to provide a sizeable catchment area (Figure 11). Its elevation is almost 100 meters lower that surrounding territory which makes it a discharge area and another area to expect significant groundwater potential. Since it is located toward the terminus of the sandstone, the water quality will most likely be poorer than at Muudale, another village to its northwest.

Figure 10. Lineaments around Warxoor

Figure 11. Lineaments at Abrone

3.1.3 Muudale

Muudale is located at the junction of two major sets of lineaments, with a third minor set dissecting the other two (Figure 12). Consequently, it is at a good location for a fractured aquifer. Muudale is therefore one of the villages with good potential for locating a successful borehole site.

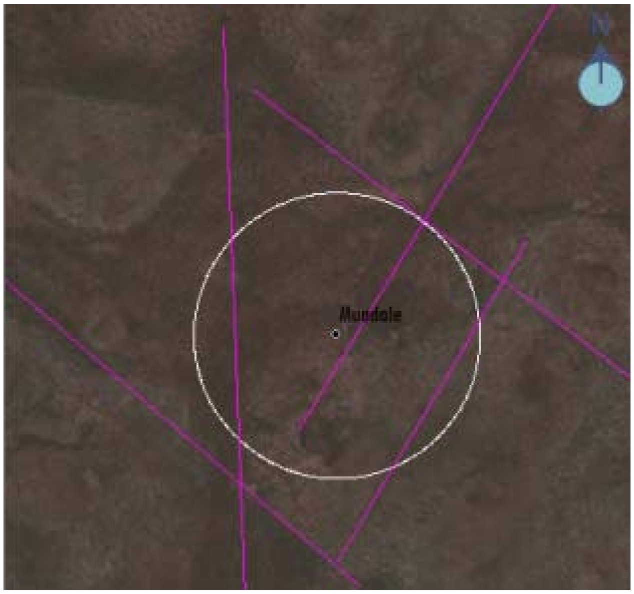


Figure 12. Muudale area structural lineations

3.1.4 Burcalaan

The village is located in the northern part of Ceel Waaq; on the sandstone proper. Here the rock is apparently more massive and less fractured (Figure 13). However, at least one regional fracture can be found, with a number of localized ones.

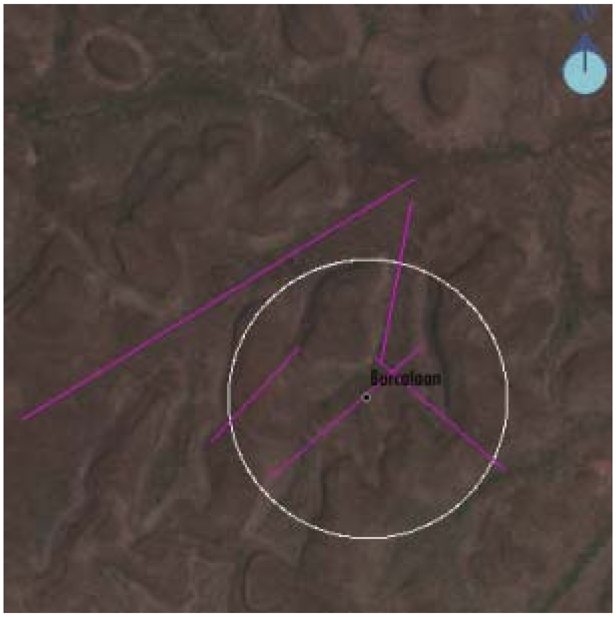


Figure 13. Fracture traces around Burcalaan

3.1.5 Harmandheera

Harmandheera is situated southeast of Burcalaan; it has a large recharge area hence is likely to have greater potential than Burcalaan (Figure 14). Additionally, several sets of fractures constellate 1.5 km south of the village to form the best possible investigation area.

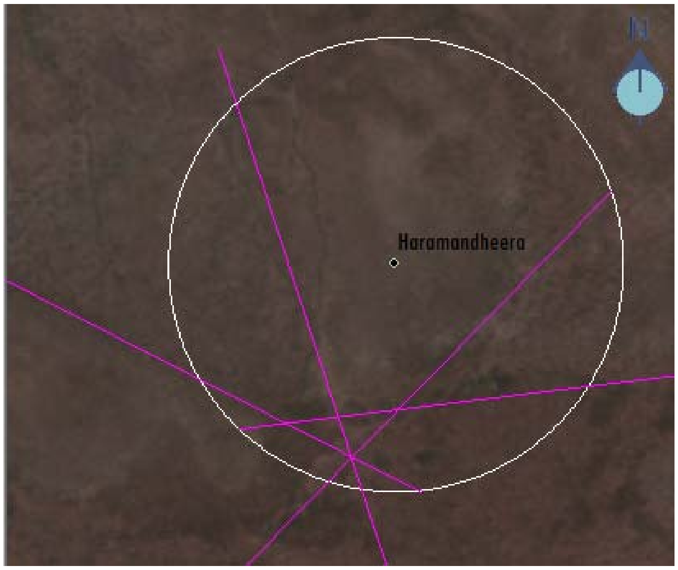


Figure 14.Harmandheera structural lineation

3.1.6 Lafa Gheri

Apparently there are no regional fractures within a 2-killometer radius of the village (Figure 15). The two lineaments that could be regional in extent are found some distance on either side west and east of the village. It has limited potential.

Figure 15. Lafa Gheri area lineaments

3.1.7 Balan Baal

Balan Baal is situated some 5 kilometers north of Abrone; it has fewer lineaments than the former, but has a couple of intersecting fractures that offer potential for limited groundwater occurrence (Figure 16).

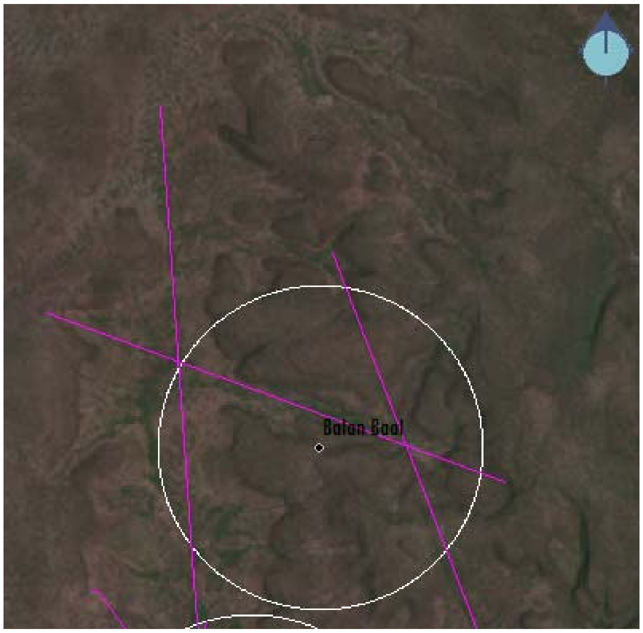


Figure 16. The Balan Baal area showing its set of lineaments

3.1.8 Buusaar

Buursaar is located on a watershed and possible groundwater divide. This makes it a particularly disadvantaged area in terms of groundwater potential. It has a set of NNW-SSE fractures intersected by a single NW-SE lineament; thus providing two possible survey sites (Figure 17).

Figure 17. Bursaar area lineaments

Figure 18. Lineaments around Dhaso

3.1.9 Dhaso

The village is situated at the end of a long regional weak zone. Consequently it is expected to have moderate groundwater potential. However drilling may be comparatively deeper than in the other villages (Figure 18).

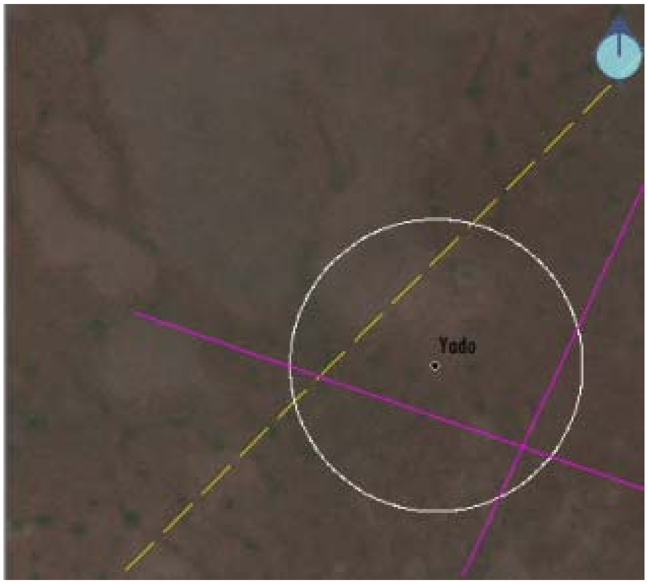


Figure 19. Lineaments at Yado; the dashed line is the international border

3.1.10 Yado

Yado has no discernable lineaments and its groundwater resource could depend more on weathering and sediment accumulation rather than fracture storage (Figure 19). It has limited groundwater potential.

3.1.11 Indhaceel

This village is one of the two located on limestones and although these rocks have low primary porosity, fracturing introduces secondary permeability that is enhanced through widening of the fractures by chemical dissolution. This process enhances mineralization hence poor quality is the problem that limits the groundwater potential (Figure 20).

Figure 20. Indhaceel village lineaments

3.1.12 Beer Gawan

Beer Gawan is at the extreme south of Ceel Waaq and also sits on limestone. The rock is fairly fractured and has some groundwater storage but water quality is expected to be poor (Figure 21).

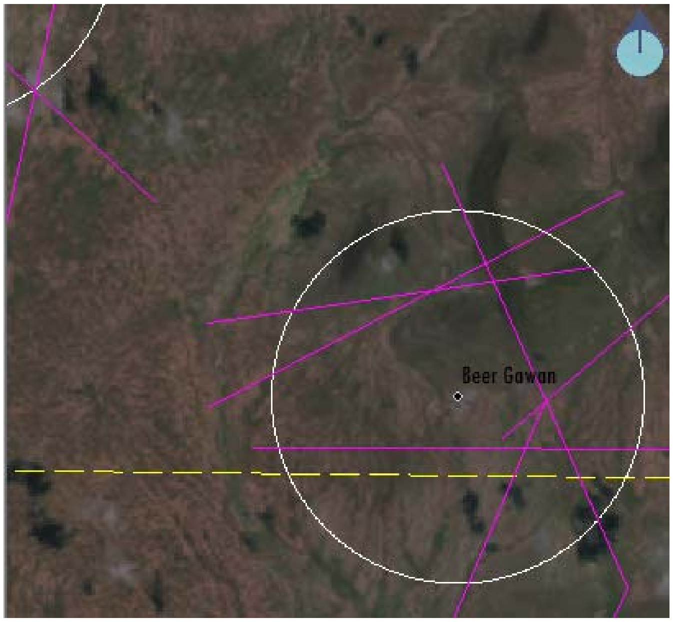


Figure 21. Lineaments around Beer Gawan

3.1.13 Tulo Adde

The village is located 4 kilometers northeast of Ceel Waaq town. It is situated at the edge of the gypsite unit of the Ceel Waaq Beds. Lineaments in the area are principally oriented NE and tend to draw groundwater from the higher areas northeast to the lower areas southwest and south (Figure 22).

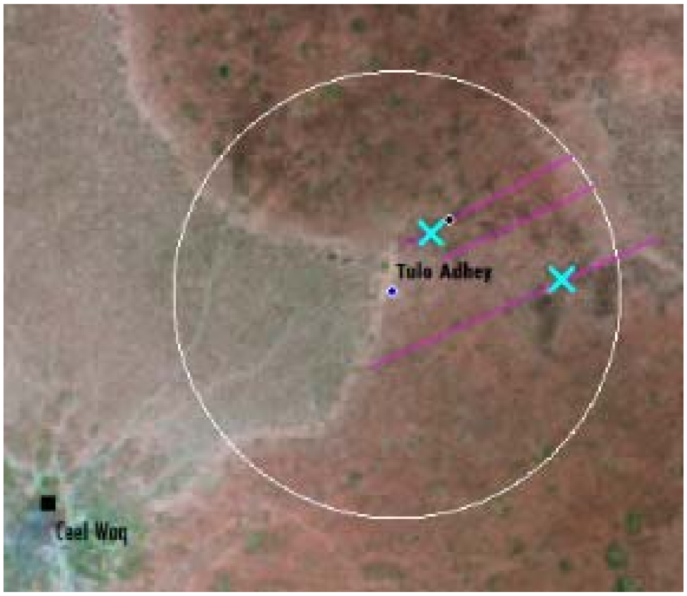


Figure 22. Lineaments, Tulo Adde

3.1.14 Orre Dimtu

The village is located on the southern part of Ceel Waaq district, about 10 kilometers from Ceel Waaq town. It has a population of 180 households within it and immediate catchment. The current source of water is a warr that is reported to last only one month after the rains.

There are at least two structural lineaments nearby the village (Figure 23). The main one is situated quite close and was therefore the preferred investigation area. It runs approximately N-S and exerts some influence on the drainage pattern in the locality.

3.1.15 Abdala Balla

This village is located only 4 kilometers from Orre Dimtu and nine kilometers from Ceel Waaq. It is much smaller and has a population of only about 60 households, but with a catchment population of another 120 households. Its existing water source is a water pan located some 3 kilometers from the village (Figure 24). An abandoned well is found at the village – its digging was abandoned at 15 meters due to encounter of a hard formation.

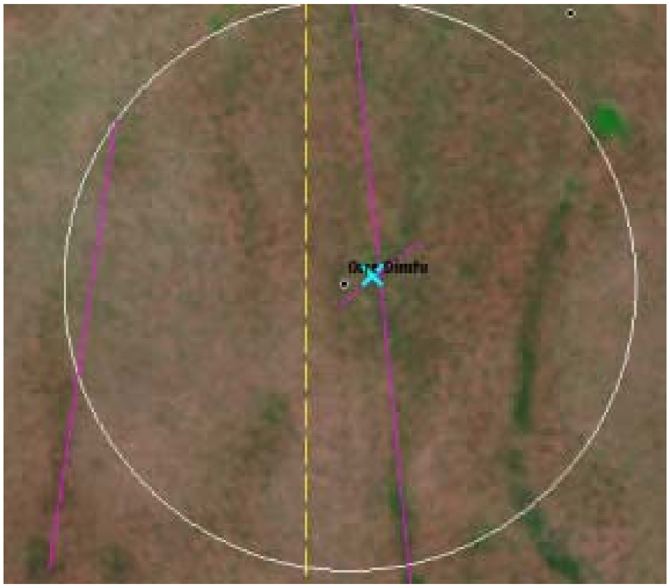


Figure 23. Orre Dimtu lineaments

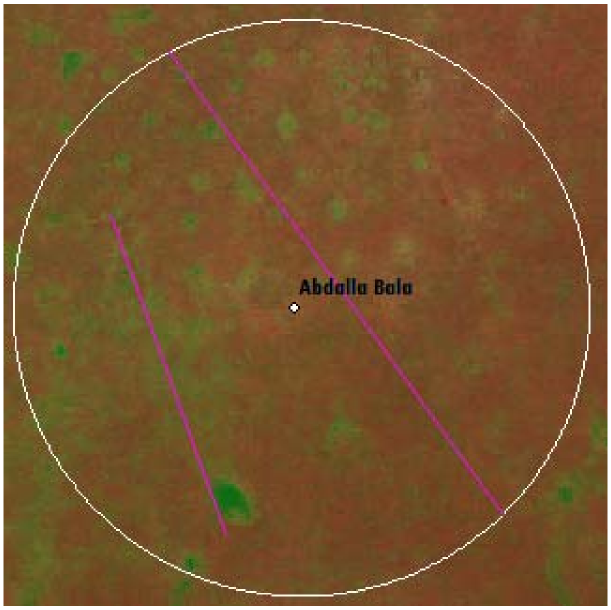


Figure 24. Fracture lines around Abdallah Bala

The Abdallah Bala lineaments are not prominent hence are considered either non-existent (wrong inference) or poorly defined, closed fracture systems with very little influence on groundwater flow and storage. If this is the case then the area is bound to have limited groundwater potential and the quality would be poor due to longer rock-water interaction resulting from slow movement in closed fracture systems.

3.1.16 Qorbeso

Qorbeso village is located 24 kilometers south east of Ceel Waaq. It has a sizeable population of some 100 households and a wide catchment area with another reported 250 households. The village depends on a warr for its water source, located a few hundred meters from the main settlement.

The village has no definite lineaments, but some are inferred as shown in Figure 25. Due to the sparse structural control on drainage, it is anticipated that groundwater movement is slow hence the likelihood of highly mineralized aquifers of low yield.

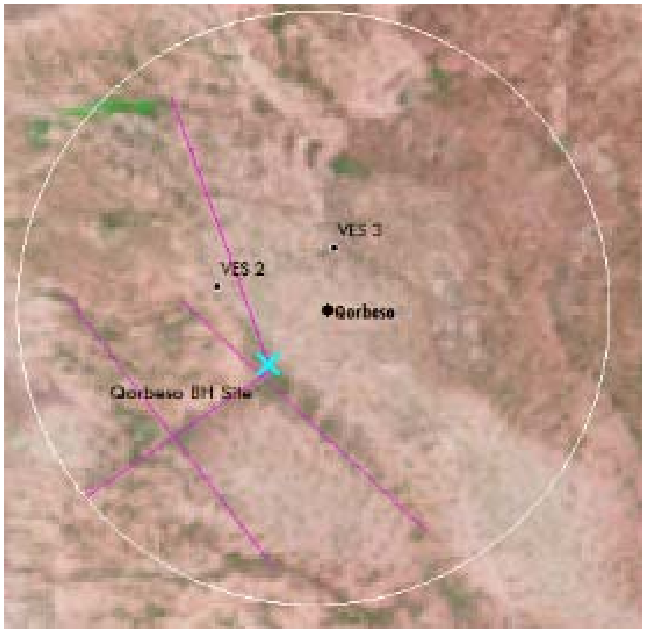


Figure 25. Qorbeso structures

3.1.17 Jimbile

Jimbile village is found 17 kilometers south or Ceel Waaq. It is a small village with population of 50 families; in addition it is reported there are up to 150 families in the surrounding rangeland. The village depends on a warr within it for water supply. This source also supports the smaller neighboring hamlets of Hawlwadag and Bula Ramata.

Jimbile has strong NW-SE linear structures that suggest strong groundwater flux; recharge is therefore likely to be regular thereby improving the prospects for groundwater of fair quality.

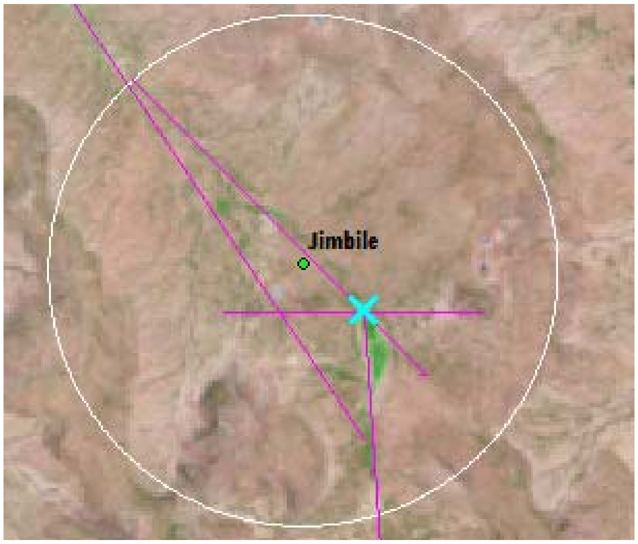


Figure 26. Lineaments around Jimbile

3.1.18 Boco

Like Jimbile, Boco is a small village of 51 households with an estimated 70 other households in the catchment. The settlement has no water source and relies on a warr approximately 4 kilometers away. The village has visible structural lineations with intersections that offer good locations for borehole siting.

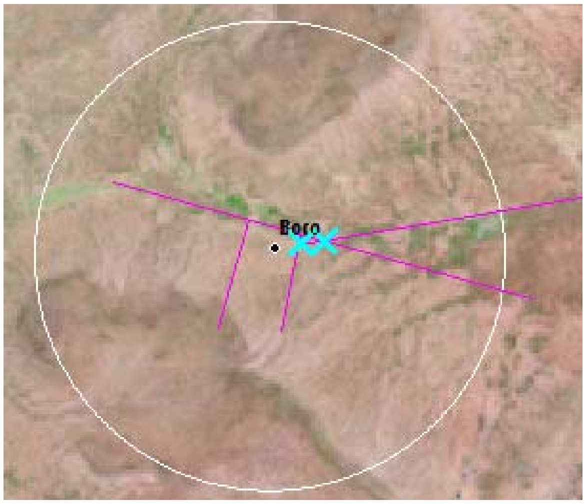


Figure 27. Boco lineaments

3.2 Field Survey

3.2.1 Hydrogeology: water point inventory

The inventory was conducted using modified standard SWIMS forms. Equipment deployed included a combined pH-EC-TDS-ORP-Temp stick-meter for wellhead physical chemistry, a 100m dipper tape, Garmin GPS and a Canon digital camera. Water sample bottles were prepared at the Crop Nutrition Laboratory in Nairobi, one set sterile and acidified, the other sterile but non-acidified in order to collect two samples at each site, one for cations and the other for anions.

Figure 28. Bottles prepared at the laboratory before packaging for delivery to the field

3.2.2 Training of enumerators

A team comprising two data collectors and a coordinator were inducted on field procedure for interview with water operators and filling in the SWIMS forms prior to mobilization. The team was thereafter mobilized and gathered data on the first day which was reviewed by the lead hydrogeologist and found to be filled in satisfactorily. Where there was need for adjustment the team was advised accordingly. Afterward the team went out for the remainder of the field period, carrying along a copy of the guideline on filling in the data fields.

The team was also shown how to collect water samples along the lines of BS ISO 5667-11 (Groundwater Sampling) which requires purging before sampling and collection of a representative sample. At well sites, water would be drawn with a bucket lowered on a rope poured back in the well. Alternatively the rope should be shaken once the bucket was half-filled to disturb the water then refilled again. It was not possible to do a complete purging of the wells due to their holding capacity. The first bucket was to be thrown out and the second collected. Sample water would be transferred from the bucket into the sample bottles.

Figure 29. Drawing a water sample

24 samples were delivered for analysis at the Crop Nutrition Laboratory in Nairobi for testing. The test results are included in Appendix 3.

For laboratory testing various methods to suit the analyzed parameter were used – colorimetry, turbidimetry, spectroscopy and potentiometric (i.e., pH and electrical conductivity)

3.2.3 Geophysical surveys

Geophysical investigations as stated in the Terms of Reference required execution of vertical electrical soundings (VES). However, VES alone without detailed hydrogeological/ structural geological studies to pinpoint investigation points can be a wild goose chase. The geophysical survey methodology therefore starts with the assumption that the right locations have been identified through the desk studies. The survey approach was as follows:-

1. Selection of prospective ground survey sites within reasonable distance from these settlements through use of LANDSAT 7 satellite data and geological maps. The maps and satellite images were georeferenced and processed using the Global Mapper GIS software. Issues considered were the

likelihood of groundwater occurrence at the target location and its anticipated quality.

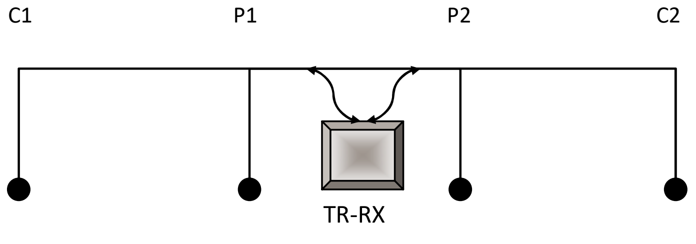
2. Discussions with community members about the proposed target sites.
3. Field walks and geophysics; vertical electrical sounding (VES) methods were employed for the survey.
4. Preliminary data analysis and site selection in the field.
5. Marking the surveyed sites.
6. Indication of the surveyed sites to the local elders and taking photographs.

The vertical electrical sounding method is based on electrical resistivity, using the principle of Ohm's Law and detects vertical or lateral changes in ground resistivity. Since resistivity is a function of the state of weathering of the rock strata and is proportional to occurrence of interstitial water, the observed variations are used to determine the occurrence of water-bearing layers below ground level.

In conventional resistance, a specified current is injected into the ground using probes connected to a DC power source (Figure 30). The resulting measured voltage is used to calculate the ground's resistance to current flow by Ohm's Law:

$$R = V/I,$$

where R = resistance, V = voltage, and I = current



Note: C1, C2 = Current electrodes; P1, P2 = Potential (voltage) electrodes; TR-RX = Transmitter-Receiver

Figure 30. Illustration of the electrical resistivity theory

Resistance will vary depending on the distance and geometry between the probes so it is normalized with the addition of a geometric factor that converts the measurement to apparent resistivity, ρa, (expressed in ohm-meters):

$\rho a = 2\pi a V/I$, for equally spaced galvanic electrodes (Wenner array)

For data acquisition, the vertical electrical depth probing technique was used. In this method, a selected point is investigated progressively deeper by systematically increasing the (I) and (V) electrode separation while keeping the point fixed. The Schlumberger array was the system adopted for increasing the electrode separation. For this array

$$\rho a= \pi an(n+1)\ V/I$$

An ABEM SAS1000 was deployed for the electrical transmitter/receiver instrument. It has a maximum power output of 100W, which is within the range for effective data acquisition in the local geological set-up. The data was acquired using the protocol for current and potential electrode separation presented in Table 1. At each village 2 sites were surveyed; due to the good site pin-pointing through the desk study the results were largely positive after two soundings. Due to the need to minimize field exposure a third was not found necessary.

Table 1. Resistivity acquisition protocol

MN/2 (m)	AB/2 (m)	MN/2 (m)	AB/2 (m)	MN/2 (m)	AB/2 (m)
0.5	1.6	5	10	25	50
0.5	2.0	5	13	25	63
0.5	2.5	5	16	25	80
0.5	3.2	5	20	25	100
0.5	4	10	20	25	130
0.5	5	10	25	25	160
0.5	6.3	10	32	25	200
0.5	8	10	40	25	250
0.5	10	10	50	25	320

The early increase of potential electrode separation was intended to get reliable data when the potential drop has not become too low and therefore liable to large deviations between individual measurement cycles.

As part of the data acquisition process each sheet had a record of the location and elevation of the sounding.

3.2.4 Data interpretation

Field geophysical data was plotted on a log-log sheet and used to do the initial analysis and decide the appropriate site before detailed layer-thickness to depth analyses. The field data is useful when the curve is smoothed freehand and the number of layers manually inserted. It provides the control for computer software interpretation.

Interpex IX1D developed by Golden Software Corporation was used for the inverse resistivity modelling.

Water quality data was analysed using GW_Chart software to draw piper diagrams for analyses.

Chapter 4. Results and Discussions

4.1 Geophysics

Geophysical surveys were conducted in 7 villages, namely Tulo Cadey, Yado, Qorbeeso, Gimbile, Abdalla Balla, Boco and Orre Dimtu. Data collected was analysed with Interpex 1D from Golden Software Corporation. The data collected was interpreted using Interpex IX1D software which is used for forward and inverse modeling of resistivity data. The software approximates the ground characteristics that would give the kind of resistivity signal delivered by the instrument during the data acquisition process. It relates ground strata resistivity and their thickness to derive a best-approximation model of the ground layering. The following tables illustrate the forward numerical models of the ground layer thickness-resistivity relationship from the sites. Detailed VES data are included in in Appendix 2.

4.1.1 Yado

The village sits atop a gentle hill that is hardly noticeable; the high ground was interpreted to comprise unsuitable geology for groundwater hence locations at the foot of the hill were selected, a few hundred meters from the village. Geophysical survey was conducted at two locations. Results of the geophysical survey are shown in Table 2.

Table 2. VES models Yado site

Depth (m)	**Resistivity (Ωm)**	**Interpretation**	**Remarks**
VES 1 41.13886E, 2.96278N Alt 390m			
0 - 0.6	185	Reddish-brown clay loam	Topsoil
0.6 - 2.3	416	Colluvium	Dry
2.3 - 5.7	135	Sandy sediments	Dry
5.7 – 13.0	224	Sandstone	Dry
13.0 - 33.7	33	Highly weathered sandstone	Possible aquifer
Over 33.7	229	Sandstone	Aquiclude
VES 2 41.1407E, 2.9603N Alt 393m			
0 - 1.0	1090	Stoney soil	Dry
1.0 - 4.9	132	Sandy sediments	Dry
4.9 - 10.9	57	Marl	Dry
10.9 - 43.8	43	Highly weathered sandstone	Possible aquifer at base
Over 43.8	569	Fresh sandstone	Aquiclude

Data interpretation: The data shows that there is possibility for an aquifer at the base of a horizon of weathered sandstone between 30 and 45 meters below ground level. Given the limitations of geophysical data acquisition and modelling, this means that the aquifer zone can even be as deep as 48 to 72 meters, because of equivalent curve models. From the two VES sites, VES 1 provided more steady and less noisy data than VES 2 and shows a better resistivity contrast between successive layers. It is therefore the preferred drilling site.

Recommendation: VES 1 site should be drilled to a minimum 80 meters and maximum of 100 meters below ground level. The site is known to the village elders and is marked with a wooden stake.

4.1.2 Tulo Adde

The survey targeted identified lineaments in close proximity to the village: the nearest spot to the village and another further off were selected for the survey. The Schlumberger array was used on this site as with all the others. Numerical model from the geophysical data collection is shown is Table 3.

Table 3. VES models for Tulo Adde

Depth (m)	Resistivity (Ωm)	Interpretation	Remarks
VES 1 41.061667E, 2.81316N alt. 390m			
0 - 0.6	77	Sandy soils	Dry
0.6 - 6.6	138	Limestone	Dry
6.6 - 24.1	19	Marl	Possible shallow aquifer
24.1 - 63.5	56	Highly weathered limestone	Aquitard
Over 63.5	28	Highly weathered limestone	Possible aquifer
VES 2 41.04556E, 2.81702N Alt 389m			
0 - 0.6	284	Sandy soil	Dry
0.6 - 2.4	866	Limestone	Dry
2.4 - 10.9	18	Marl	Possible shallow aquifer
10.9 - 30.1	147	Limestone, weathered	Aquitard
Over 30.1	25	Limestone, highly weathered	Possible aquifer

Data interpretation: Both sites show possibility of shallow and a deeper aquifer. There is however little resistivity contrast between the last 3 layers of VES 1 site which may suggest either presence of a clay matrix (mainly marl) in the system. VES 2 however has better resistivity contrast and has the chance for better aquifers overall. It is also nearer to the village (600 meters) compare to VES 1 that is 1.3 kilometers away.

In terms of water quality expected, the resistivity data and the VES curves show that the pore water is not salty hence water quality should be potable.

Recommendation: It is recommended that the proposed borehole be drilled at the VES 2 site. The main aquifer is in the last layer of the model, which due to limitations of modelling is only captured in Table 2 as “over 30.1 meters”. In consideration of the resistivity curve plot, the recommended minimum depth is 100 meters and maximum is 130 meters below ground level. The resistivity model is often misleading in terms of the maximum drilling depth because of the problems of suppression and aberrant values. Interpretation using the trend of the data plot often leads to more realistic conclusions. The site is marked and known to the village chairman.

4.1.3 Orre Dimtu

There are some seasonal watercourses running by the village but are more or less curvilinear, which means they follow lithological trends. Nonetheless, some rather subtle lineaments were identified and these used to locate the best possible VES sites. The results of the geophysical survey data analysis are shown in Table 4.

Table 4. VES models for Orre Dimtu

Depth (m)	Resistivity (Ωm)	Interpretation	Remarks
VES 1 40.99427E, 2.70783N alt. 390m			
0 - 0.6	172	Reddish-brown sandy soils	Dry
0.6 - 1.7	418	Kunkar	Dry
1.7 - 4.4	55	Weathered limestone	Dry
4.4 - 10.7	86	Weathered limestone	Aquitard
10.7 - 37.4	12	Marly limestone	Possible aquifer
Over 37.4	91	Limestone	Aquiclude
VES 2 40.99492E, 2.70493N Alt 389m			
0 - 3.6	88	Sandy colluvium	Dry
3.6 - 6.3	29	Marl	Dry
6.3 - 12.5	65	Weathered limestone	Dry
12.5 - 45.5	17	Marly limestone	Possible aquifer
Over 45.5	34	Weathered limestone	Aquitard

Data interpretation: The VES models indicate likelihood of ground water occurrence in the area. VES 2 does not seem to have a good aquifer base (aquiclude) hence the possible aquifer at about 45 meters may not store water due to lack of a confining base layer. On the other hand VES 1 has a high probability of an aquifer occurring circa 38 meters and it has a suitable aquifer base.

Recommendation: The proposed borehole should be drilled at VES 1 to a maximum depth of 100 meters and minimum 80 meters below ground level. It is known to the village elders.

4.1.4 Abdalla Balla

Two most suitable survey sites were located from the satellite image and investigated. The VES data collected displayed a trend similar to sites with saline water even after an attempt at the second site. It was therefore apparent that the area generally has saline water. The resistivity models developed are shown in Table 5.

Table 5. VES models for Abdalla Balla

Depth (m)	Resistivity (Ωm)	Interpretation	Remarks
VES 1 41.01554E, 2.72835N alt. 382m			
0 - 0.6	221	Reddish-brown sandy soils	Dry
0.6 – 2.0	632	Limestone	Dry
2.0 - 12.6	55	Weathered limestone	Dry
Over 12.6	3	Saline weathered limestone	Saline aquifer
VES 2 41.00689E, 2.72458N Alt 391m			
0 - 0.5	82	Reddish-brown sandy soils	Dry
0.5 - 4.2	188	Limestone	Dry
4.2 - 10.4	58	Weathered limestone	Dry
Over 10.4	3	Saline weathered limestone	Saline aquifer

Data interpretation: Both VES points return resistivity models that indicate the base layer which is within the depth for groundwater accumulation has very low resistivity of 3 ohm-meter or less. This is an indicator of salinity of the pore water. Further, a look at the resistivity data plot reveals a very steeply dropping curve in each instance, a clear pointer to saline conditions.

Recommendation: No drilling should take place at either site. The village should look for an alternative water source like a suitably designed berkad and a warr to supplement its water requirements.

4.1.5 Qorbeso

The sites judged suitable from the satellite image study were 600 meters and 800 meters from the village, respectively. The elders indicated they did not mind the distance as long as a suitable borehole site could be located for the village. Electrical resistivity survey was conducted at each site once located and the data processed using Interpex software. The obtained ground layer models are shown in Table 6.

Table 6. VES models for Qorbeso village

Depth (m)	Resistivity (Ωm)	Interpretation	Remarks
VES 1 41.09889E, 2.62125N alt. 362m			
0 - 0.8	933	Reddish-brown alluvium	Dry
0.8 - 5.4	165	Silty sediments	Dry
5.4 - 23.0	23	Weathered limestone	Dry
23.0 – 56.0	4	Marly limestone	Possible aquifer, may be brackish
Over 56.0	140	Limestone	Aquiclude
VES 2 41.095729E, 2.626054N Alt 361m			
0 - 0.6	1019	Reddish-brown sandy soils	Dry
0.6 - 4.6	774	Gravelly sediments	Dry
4.6 - 7.7	19	Marl	Dry
7.7 - 17.5	57	Weathered limestone	Dry
17.5 - 77.1	2.3	Marly limestone	Possible aquifer, saline
Over 77.1	130	Limestone	Aquiclude

Data interpretation: The electrical sounding data indicate there is groundwater potential in the area: however the data also show that salinity could be a problem. Nonetheless, the area is marginal hence it is possible that the pore water could be mineralized, but within acceptable limits for human consumption. VES 2 is definitely not a good site due to the high chance of striking saline water. VES 1 however offers the possibility of a marginally poor aquifer but that can still be put into use. This conclusion is arrived at especially by analyzing the field data curve that has all apparent resistivity is above not less than 9 ohm-m.

Recommendation: This site marginal and is not recommended for drilling for drilling for human consumption.

4.1.6 Jimbile

A few good lineaments were located relative to the village and the most suitable points selected for resistivity soundings to confirm the hypotheses from the desk study. The results are presented in Table 7.

Table 7. VES models, Jimbile village

Depth (m)	Resistivity (Ωm)	Interpretation	Remarks
VES 1 41.035848E, 2.64243N alt. 441m			
0 - 5.5	162	Reddish-brown colluvium	Dry
5.5 - 20.0	73	Weathered limestone	Dry
20.0 - 65.9	14	Marl	Possible aquifer
Over 65.9	107	Limestone	Aquiclude
VES 2 41.04109E, 2.64268N Alt 448m			
0 - 3.9	124	Reddish-brown colluvium	Dry
3.9 - 8.8	152	Gravelly sediments	Dry
8.8 - 80.8	17	Marl	Possible aquifer
Over 80.8	82	Limestone	Aquiclude

Data interpretation: The VES data indicate the occurrence of a single aquifer about 65-80 meters below ground level. For VES 1, the upturn of the resistivity curve into the base layer is quite sharp but smooth in contrast to VES 2, which has a broader aquifer layer but has noisier data. The nose in this instance is assumed to be a result of the presence of pore water in a geological environment of a mix of marly and more solid limestone material.

Recommendation: VES 2 is considered the technically more feasible drilling site. The proposed well shall be drilled to the minimum depth of 100 meters and maximum 120 meters below ground level. The limits on the depth recommendation are based on the modeling limitations of the manual nomogram or computer software algorithm. This maximum depth recommended is based on the sensible interpretation of the data plot to 160 meters AB/2. As a rule of thumb in practice the depth of the last layer is typically multiplied by 1.6 (hence this will be 80.8*1.6=129.3m).

4.1.7 Boco

A strong lineament was located near the village along with some less prominent ones; sites suitable for resistivity soundings were selected and 2 soundings executed. The forward resistivity models are presented in Table 8.

Table 8. VES models for Boco

Depth (m)	Resistivity (Ωm)	Interpretation	Remarks
VES 1 41.08016E, 2.68140N alt. 396m			
0 - 0.6	224	Reddish-brown sandy soil	Dry
0.6 - 2.0	674	Gravels	Dry
2.0 - 7.7	110	Sandy sediments	Dry
7.7 - 47.4	26	Marl	Possible aquifer above saline zone
Over 47.4	5	Highly weathered marl	Saline
VES 2 41.081827E, 2.68156N Alt 389m			
0 - 0.5	472	Reddish-brown sandy soil	Dry
0.5 - 6.2	137	Gravelly sediments	Dry
6.2 - 30.2	9	Marl	Possible saline aquifer near base
Over 30.2	0.1	Saline marl	Saline

Data interpretation: The resistivity data points to elevated pore water salinity in the aquifers in the Boco area. VES 2 site is especially a saline water area and is not suitable for further consideration. The VES 1 site offers a slim opportunity for groundwater development because there is a clear separation between the saline zone and the transitional zone above. This means however that the drilling has to be controlled so that the bore does not reach into the brine zone. Further, the pumping regime of a source developed must be regulated to mitigate water quality deterioration due to overabstraction.

Recommendation: Drilling at this site can proceed. However, the borehole has to be drilled to no more than 60 meters below ground level or as dictated by changes in water quality after the first water strike. An EC meter should be handy during the drilling to ensure close monitoring of water quality. Close supervision of the drilling works by a competent hydrogeologist is necessary.

4.2 Hydrogeology

The water sources inventory survey was conducted within accessible areas with a view to document as widely as possible the water points within Ceel Waaq district. Sources covered were principally shallow wells and boreholes but some water pans were also surveyed. 25 water points were assessed in total including 18 wells, 3 boreholes and 4 pans. Water quality and the operational characteristics of the sources were captured during the survey as well.

4.2.1 Hand dug wells

17 of the hand dug wells surveyed were operational; 1 was being deepened. In this respect, most of the wells have depths of 17 to 21 meters below ground level (bgl). The less deep reach between 12 and 17 meters bgl. This depth distribution is due to the occurrence of the aquifer in the Ceel Waaq gypsum beds that are horizontally layered hence the water table is rather flat.

The wells are protected with an apron and a raised wellhead to prevent surface water run-in.

4.2.2 Boreholes

The 3 boreholes surveyed were all operational. The Dhamasa borehole was reported to have a dynamic level of 80m during test pumping, and is 120m deep. The Likole borehole is the deepest at 210 meters bgl and Dhaba at 200 m bgl. The latter have static levels of 180 and 170m bgl, respectively. This makes the aquifers moderately deep, compared to Dhamasa. Table 1 summarizes the data availed by the operators.

Table 9. Borehole information

Borehole	**Depth, m**	**Static level, m**	***Discharge, m^3/hr**	**EC, µS/cm**
Dhamasa	120	75	4.8	1,200
Dhaba	200	170	8	1,670
Likole	210	180	8	860

*Converted from equivalent drums per hour

The distribution of all the inventory water point locations is shown in Figure 31.

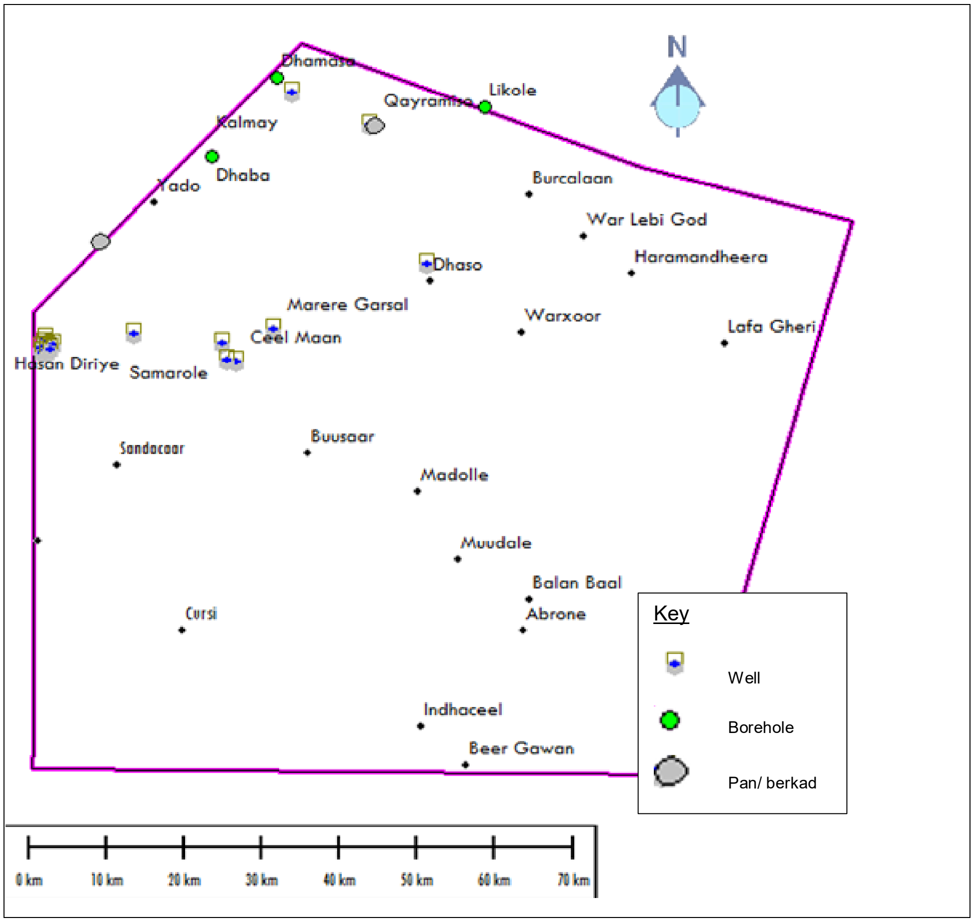


Figure 31. Distribution of assessed water points

4.2.3 Synthesis of water quality results

Following the water resources inventory, sampling and laboratory tests, the results indicate that the Ceel Waaq shallow groundwater from hand dug wells is a calcium-magnesium sulphate type. The water type is directly associated with the gypsite rock that forms the Ceel Waaq Beds, due to dissolution of these salts from the rock. Figure 32 shows the piper diagram plot for the Ceel Waaq area wells sampled. Highlights of water quality anomalies include:-

- Electrical conductivity: Is in excess of 3000 µS/cm except at Dhamasa, Dhaba and Likoley where EC ranges between 1000 and 3000 µS/cm;

- Fluoride exceeds 1.5 mg/l except at Dhamasa, Dhaba and Likoley; however the problem is not compounded because typical value is 2 mg/l and it hardly exceeds 4 mg/l;
- Calcium, magnesium, sodium and potassium generally exceeds guideline value, with a few exceptions.
- Chloride and sulphate is characteristically high, owing to the geology (gypsum-rich).

Heavy metals including copper, zinc, iron, manganese, are found within guideline limits. Others metals including boron, molybdenum are also within WHO guideline values.

The excessive compounds make the water unpleasant, but not necessarily unfit for human consumption. The following are noted:-

- The WHO has not set a guideline value for excess potassium ;
- Similarly, no guideline value is set for sodium; however, in excess of 200 mg/l will cause unpleasant taste and may cause irritation of stomach walls.
- No guideline for chloride, but in excess of 250 mg/l leads to detectable taste in water.
- The fluoride values though sometimes in excess of the guideline 1.5 mg/l are still within the WHO operational guidelines where higher values are acceptable depending on local conditions including amount of fluoride intake from other sources and high background fluoride levels.

Secondary effects of excessive constituents are also of concern. Water supply systems using metal pipes suffer corrosion due to excess chloride in the water; the corrosion could lead to high iron content. The high bicarbonate level even though not harmful, means chlorination of the source well is not very effective to sterilize the water because the bicarbonate reacts with chloride thus consuming its concentration in water.

In terms of water quality distribution, villages south of the Yado – Dhaso line are therefore expected to have aquifers with fresh to brackish water, tending to salty and finally saline further southeast. This trend in water quality changes is not purely because of geology. Rather, the increase is also attributed to longer residence time with movement from the recharge zones in the west to the discharge zones in the east. This result also supports the notion that there is some modern-day recharge taking place.

Figure 34 illustrates the approximate distribution of groundwater quality in Ceel Waaq district.

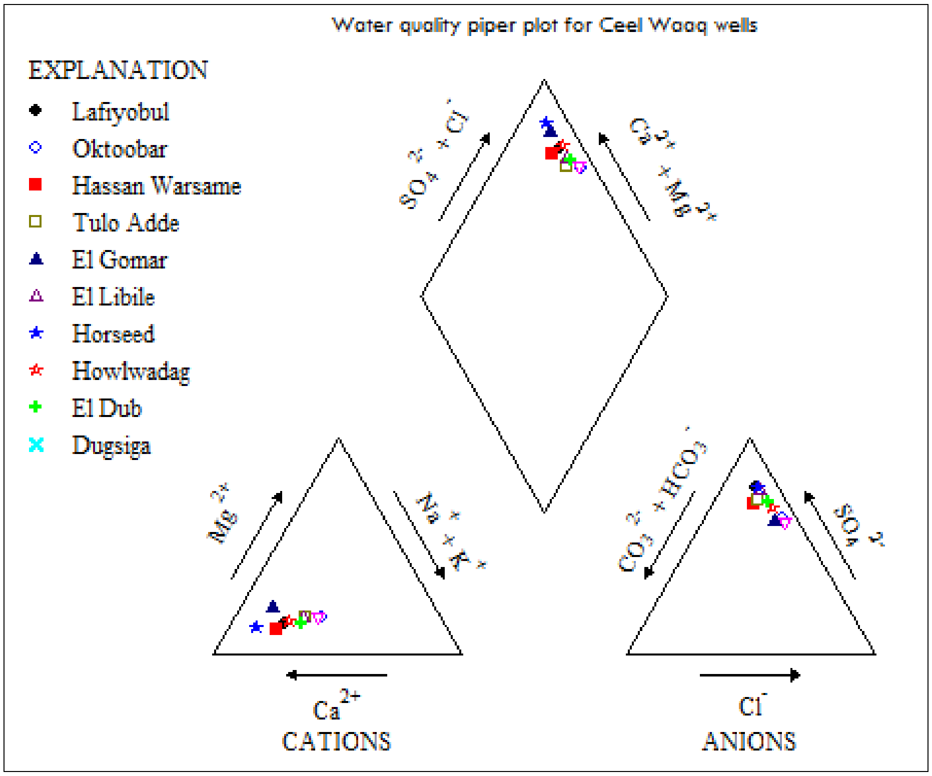


Figure 32. Piper diagram for Ceel Waaq wells – calcium-magnesium sulphate water

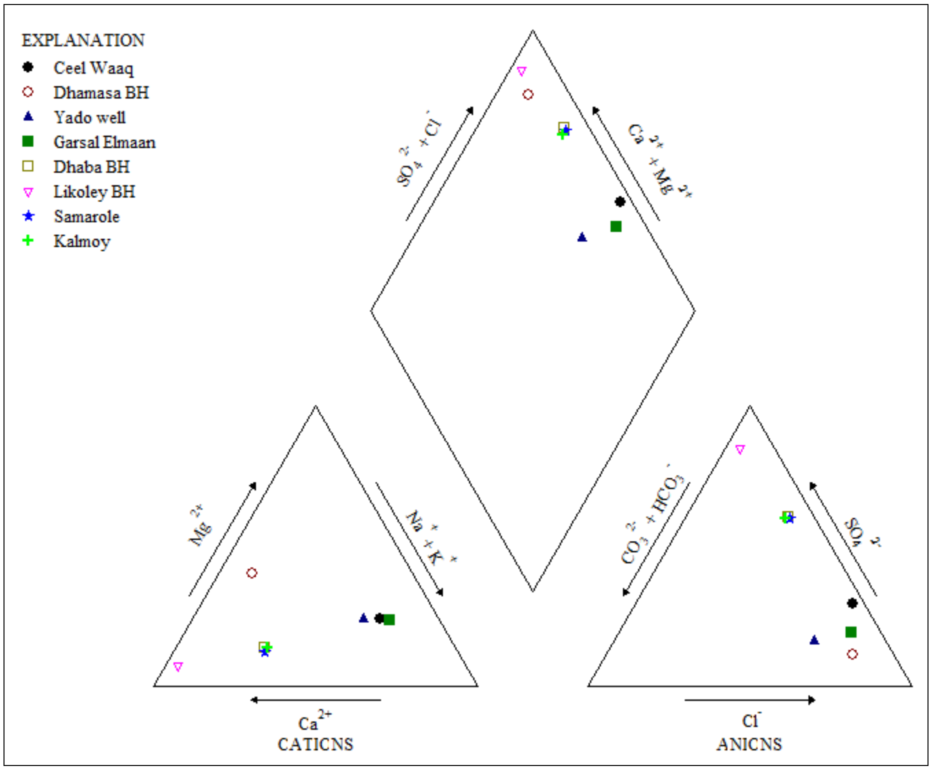


Figure 33. Piper diagram for other water points

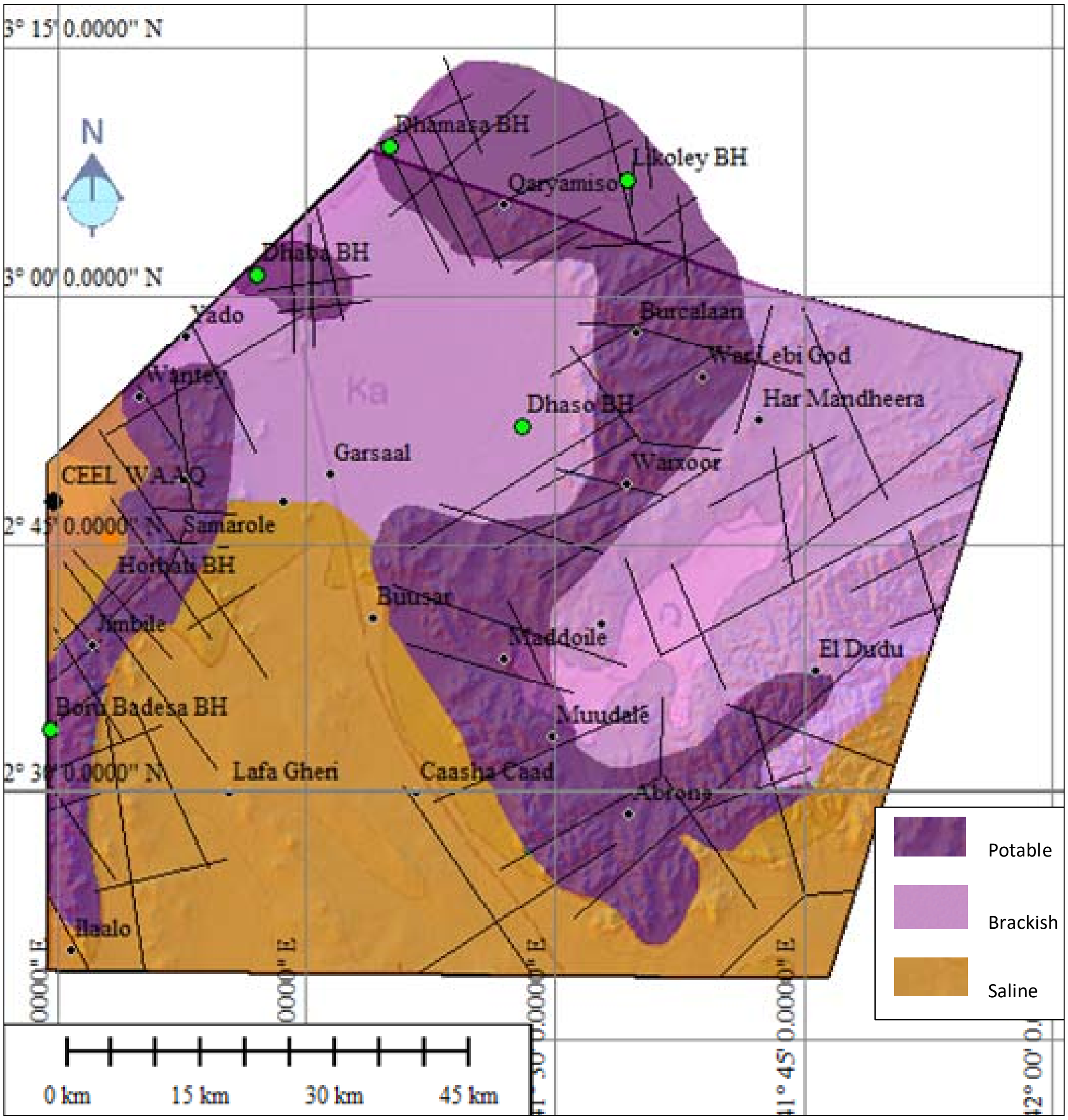


Figure 34. Expected groundwater quality

Chapter 5. Groundwater Management

5.1 Groundwater Utilization and Demands

Groundwater is an important resource in Somalia in general and Ceel Waaq in particular, because there is no perennial river system in the area. Surface runoff serves for only a few months (usually 1 to 3) after the short rainy seasons that do not last more than a month and a half. Communities therefore rely heavily on groundwater from wells and boreholes for both domestic and livestock use. There is negligible irrigation demand on groundwater because irrigation in southern Somalia is restricted to riverine regions. Further, most of the groundwater is unsuitable for irrigation due to quality demands for irrigation.

Because of scarcity and the poor quality potential of groundwater, salinity of up to 3000 µS/cm is tolerated for human consumption and up to 10,000 µS/cm for livestock, with camels able to withstand the more mineralized waters but cattle and shoat usually up to 5,000 µS/cm. Few projects have targeted specifically water for stock use, hence the more marginal aquifers are largely unutilized.

One of the challenges to groundwater management is how to restrict priority of use. In a normal situation, a community water system maintains its operation because of stock watering, which is the largest consumer with guaranteed revenue. As a result, the situation at water points is that livestock will often be given priority over domestic needs. Importantly, the quality of water should be suitable for domestic applications so that once the herder has watered livestock, his family can also take away water for domestic use.

The SPHERE standards for communities in distress specify average water use for drinking, cooking and personal hygiene in any household is at least 15 litres per person per day. WHO standards specify a minimum of 7.5 lpd and 15 lpd for persons in emergency situations, but recommends this value to be raised to 20 lpd to fully meet hygiene requirements. The Somalia WASH Cluster Strategic Operational Framework (SOF) adheres to the SPHERE standards. Most consumers in the district are categorized in service levels 1 and 2 of the WHO ranking (Table 10).

Based on these consumption recommendations, the Ceel Waaq population of approximately 31,000 has a minimum domestic water demand of 620 m3/ day. However, studies show that people who live near water points use significantly more water – up to 30 lcd. The actual demand is therefore higher, say 30% more or equivalent to 806 m3/day. Assuming 20% water losses the total domestic demand may reach 1000 m3/ day.
Based on the author's estimated groundwater flux of 1,750 m3/day through the district (see Section 2.5.2) the domestic demand is currently at 57% of the flux. Therefore, if all the annual renewable groundwater was potable, then it would meet the current demand. However, with an increasing population, groundwater is not going to be sufficient to meet the demand in the future. Therefore harvesting of surface run-off has to be pursued actively and hygienic ways of its use be explored and implemented. Finally, conjunctive use of surface and groundwater must be undertaken to reduce stress on the limited potable groundwater available in Ceel Waaq.

Presently, there is no groundwater management program in place hence this realization provides opportunity for projects in groundwater management, especially through conjunctive use.

Table 10. Summary of Summary of requirement for water service level to promote health (WHO, 2003)

Service level	**Access measure**	**Needs met**	**Level of health concern**
No access (quantity collected often below 5 l/c/d)	More than 1000m or 30 minutes total collection time	Consumption – cannot be assured Hygiene – not possible (unless practised at source)	Very high
Basic access (average quantity unlikely to exceed 20 l/c/d)	Between 100 and 1000m or 5 to 30 minutes total collection time	Consumption – should be assured Hygiene – hand washing and basic food hygiene possible; laundry/ bathing difficult to assure unless carried out at source	High
Intermediate access (average quantity about 50 l/c/d)	Water delivered through one tap on-plot (or within 100m or 5 minutes total collection time	Consumption – assured Hygiene – all basic personal and food hygiene assured; laundry and bathing should also be assured	Low
Optimal access (average quantity 100 l/c/d and above)	Water supplied through multiple taps continuously	Consumption – all needs met Hygiene – all needs should be met	Very low

5.2 Promising Areas for Groundwater Tapping

Areas with better groundwater potential are those where water is likely to be struck and of fair quality. The linear structural map was overlaid on the geological map to delineate areas that are structurally enhanced aquifers but at the same time have favorable geology – mainly the Ambar sandstone.

The following areas are therefore identified as having good potential for tapping groundwater:

- The winding axis between Wantey and Boru Badesa, terminating north of Ilalo;
- The area around Dhaba;
- The winding axis from Dhamasa, Qayramiso, Burcalaan, Warxoor, Maddoile, south to Abrone.
- Some shallow water is expected in the alluvial valley east of War Matano.

Exceptions of poor quality water are expected in these areas, as well as exception where groundwater of good quality is occasional found in the areas outside the selected zones. This means that site-specific groundwater surveys are still important and should not be ruled out.

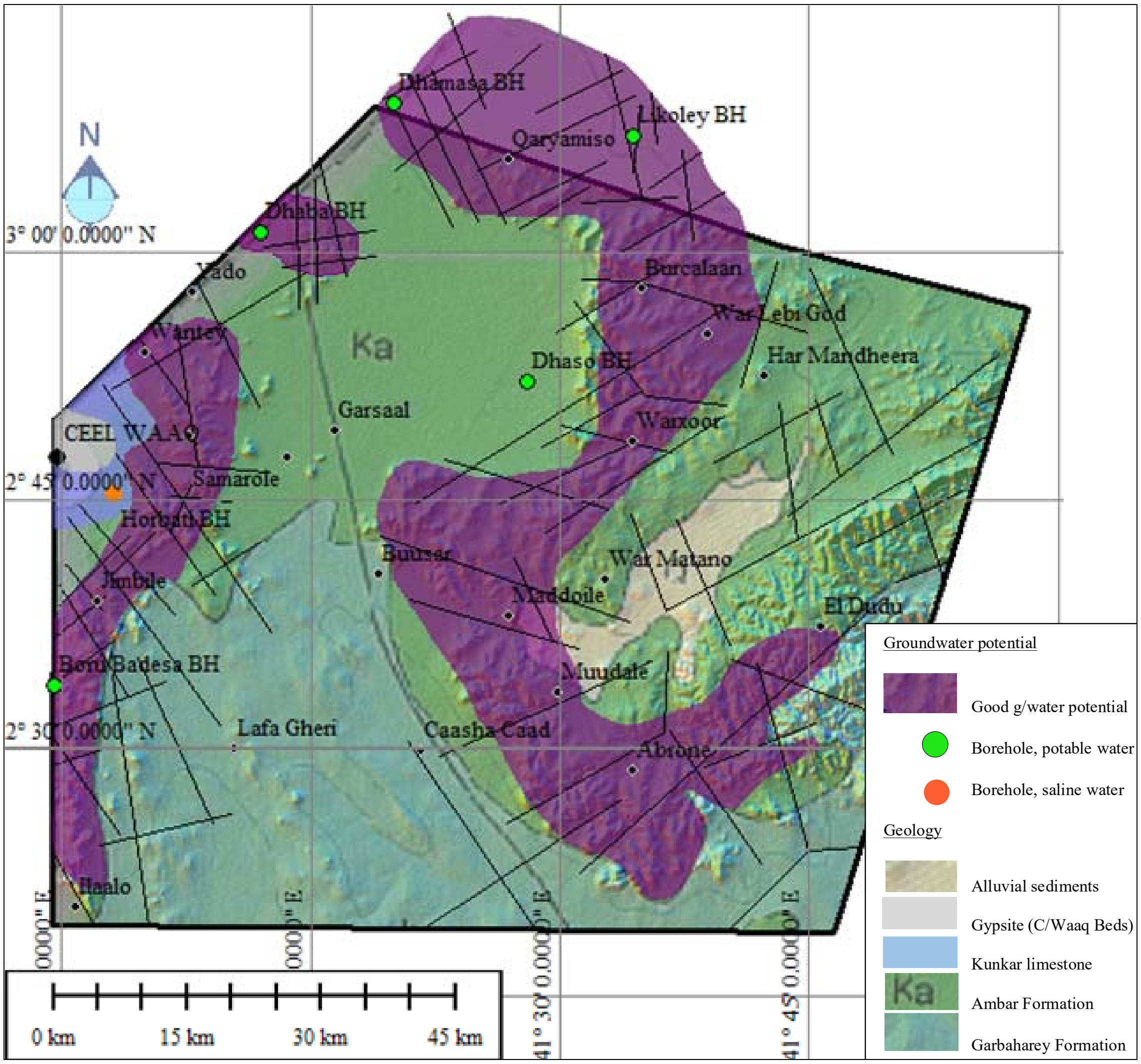


Figure 35. Areas with good groundwater potential

5.3 Recommendations

The study illustrates that there is limited suitable groundwater for abstraction in Ceel Waaq district. Greater resource allocation should therefore be directed towards improved understanding of the resources and their occurrence.

Due to increasing demand for water resources, it is recommended that future development incorporates water use prioritization in the allocation of groundwater resources. It will become increasingly necessary to identify use based on water quality.

Some sources could be developed so that the un purified water is used for stock watering and purification systems installed for domestic water. Because of the abundance of solar radiation in the district, more effort should be placed on pilot projects using solar powered purification systems. It has been argued that some of these technologies do not work well in rural settings and especially in re-emerging states like Somalia. Instead of abandoning these ideas altogether, this realization calls for improved methodologies in the implementation of such projects. The installation of water filters along Juba River in Bardheere is one such technology that could previously have been thought of us unsustainable but the project has proved that new technology can work, with the right approach.

The imperative to focus in this direction is provided by the fact that there are no perennial surface water sources from which future supplies could be tapped and surface run-off is sporadic hence a more permanent solution is required for Ceel Waaq district. FAO and other humanitarian agencies can provide the lead in this.

Finally, following the completion of hydrogeological assessments in 7 villages, the following 5 villages are recommended for borehole development:-

1. Yado
2. Tulo Adde
3. Orre Dimtu
4. Jimbile
5. Boco

Abdallah Balla and Qorbeso (Curbes) should not be drilled because of the high probability of striking saline water. Drilling should proceed at the following sites to the recommended depths below:

Table 11. Selected drilling sites

	Village	**VES ID**	**Grid Reference (WGS84)**	**Max. depth (m)**
1	Yado	VES 1	41.13886E, 2.96278N Alt 390m	100
2	Tulo Adde	VES 2	41.04556E, 2.81702N Alt 389m	130
3	Orre Dimtu	VES 1	40.99427E, 2.70783N alt. 390m	100
4	Jimbile	VES 2	41.04109E, 2.64268N Alt 448m	120
5	Boco	VES 1	41.08016E, 2.68140N alt. 396m	60

Mud-assisted rotary drilling is recommended; down the hole hammer will work for some sites but there will be challenges of loss of circulation in the karstified horizons. Monitoring of water quality during drilling is imperative to check against mixing of waters of poor quality from subsequent aquifers.

References

FAO SWALIM Somalia database: www.faoswalim.org

SOF, 2012: Guide to WASH Cluster Strategy and Standards Also known as Strategic Operational Framework

Irungu, C.N., 1997: National land degradation assessment and mapping in Kenya; 1997

Krhoda, G.O., 1989: Groundwater assessment in sedimentary basins of eastern Kenya, Africa, Regional Characterization of Water Quality, Proceedings of the Baltimore Symposium, May 1989). IAHSPubl.no.182, 1989

Mirobe, J, 2008: Water resources assessment and hydrogeological survey report, El-Waak district, Gedo region, Somalia, COSV unpublished report

Umikaltuma I., and Mutua, F, 2012: Lineament Extraction using Landsat 8 (OLI) in Gedo, Somalia, International Journal of Science and Research (IJSR)

Gicheruh, C. and Gajsek, 2002: Hydrogeological & Geophysical Surveys: Gedo Region

Appendix I: List of Contacts Made

Ceel Waaq

1. District Commissioner – Ibrahim Gulet
2. Deputy District Commissioner – Sahal Maalim

Korbeeso Village

1. Maxamed Yaqub Cali – Chairman
2. Guuliye Diis Abular
3. Maxamed Ahmed Hasan

Abdalla Balla

1. Adan Maxamud Maxamed – Chairman
2. Ali Hasan Ibrahim
3. Abdifatax Hussein Adan
4. Isaak Cabdi

Orre Dimtu

1. Osman Hassan Dubey – Chairman
2. Bishar Osman Cabdi
3. Hassan Cabdullah Cali

Yado

1. Bishar Cabdi Salat – Chairman
2. Maxamed Hassan Yarre
3. Warsame Abaile Elmi

Tulo Caddey

1. Cali Balow Ifow
2. Sehal Khalif
3. Adan Hilowle
4. Maalin Haret

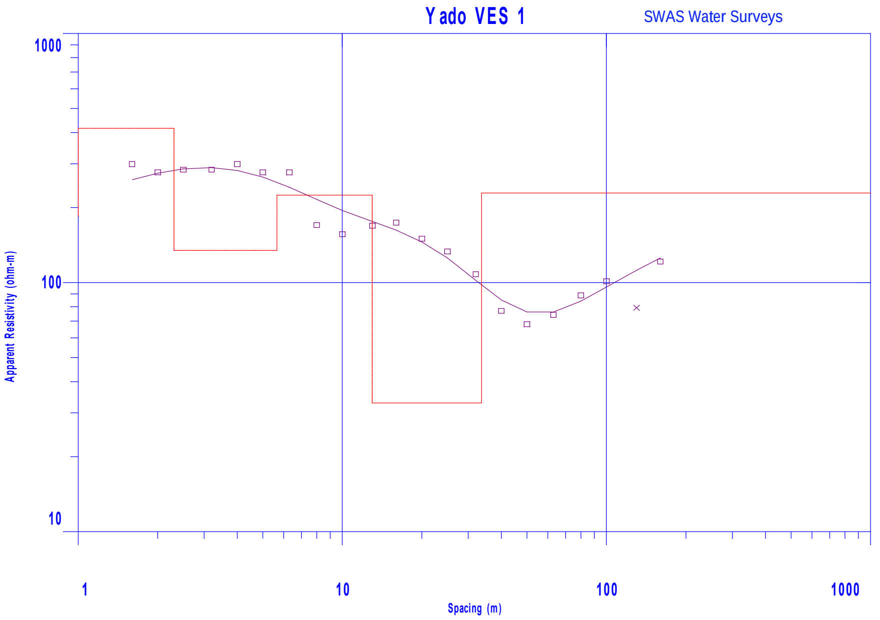
Gimbile

1. Adan Addow Isaak – Chairman
2. Cali Sheikh Dahir
3. Cabdullahi Hassan Cabdi
4. Adan Isaak Hassan
5. Adan Ahmed Maxamed

Boco

1. Cabdi Madoobe Maxmed – Chairman
2. Cali Maxamud Ibrahim
3. Dakane Warmooge
4. Hassan Yarrow

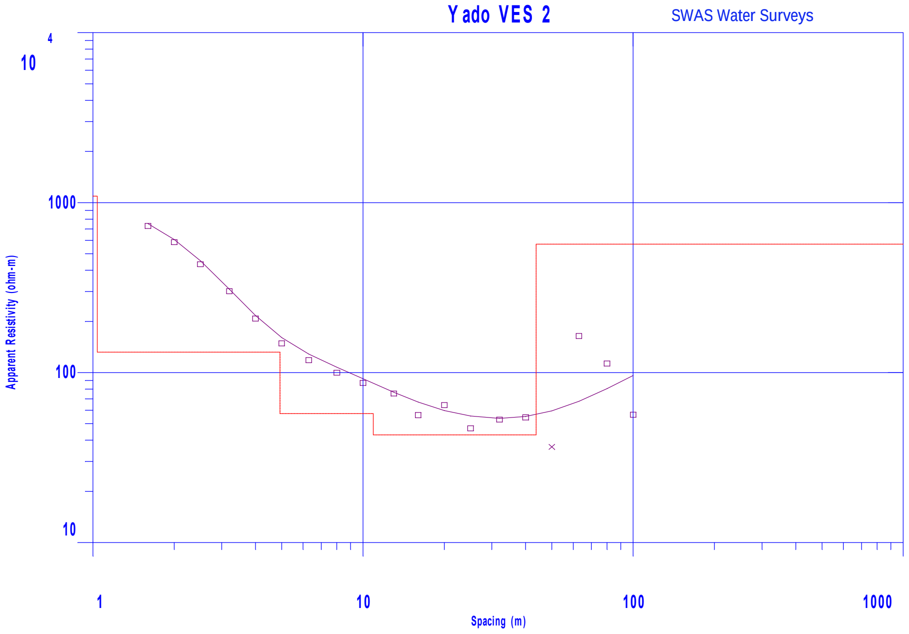
Appendix II: Geophysics Data



```
DATASET: Yado VES 1


NUMBER        AB/2          MN       RESISTIVITY
    1      1.600000      0.500000    299.000000
    2      2.000000      0.500000    277.000000
    3      2.500000      0.500000    284.000000
    4      3.200000      0.500000    284.000000
    5      4.000000      0.500000    299.000000
    6      5.000000      0.500000    277.000000
    7      6.300000      0.500000    277.000000
    8      8.000000      0.500000    170.000000
    9     10.000000      0.500000    156.300003
   10     13.000000      0.500000    169.100006
   11     16.000000      0.500000    174.000000
   12     20.000000      5.000000    150.000000
   13     25.000000      0.505000    133.300003
   14     32.000000     10.000000    108.000000
   15     40.000000     10.000000     76.946175
   16     50.000000     10.000000     68.073654
   17     63.000000     23.000000     74.192635
   18     80.000000     23.000000     88.878189
   19    100.000000     23.000000    101.269119
   20    130.000000     23.000000     79.240791
   21    160.000000     23.000000    121.461761
```

DATASET: Yado VES 1

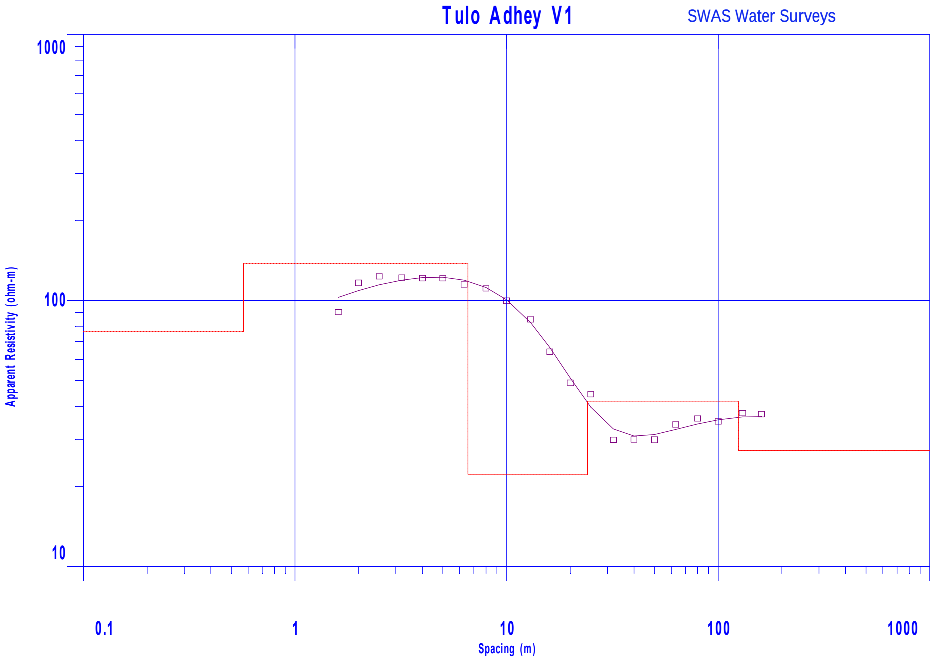
LAYER	RESISTIVITY	THICKNESS	DEPTH
1	185.0	0.6	0.6
2	416.0	1.7	2.3
3	134.5	3.3	5.7
4	224.3	7.3	13.0
5	32.9	20.7	33.6
6	228.7		



DATASET: Yado VES 2

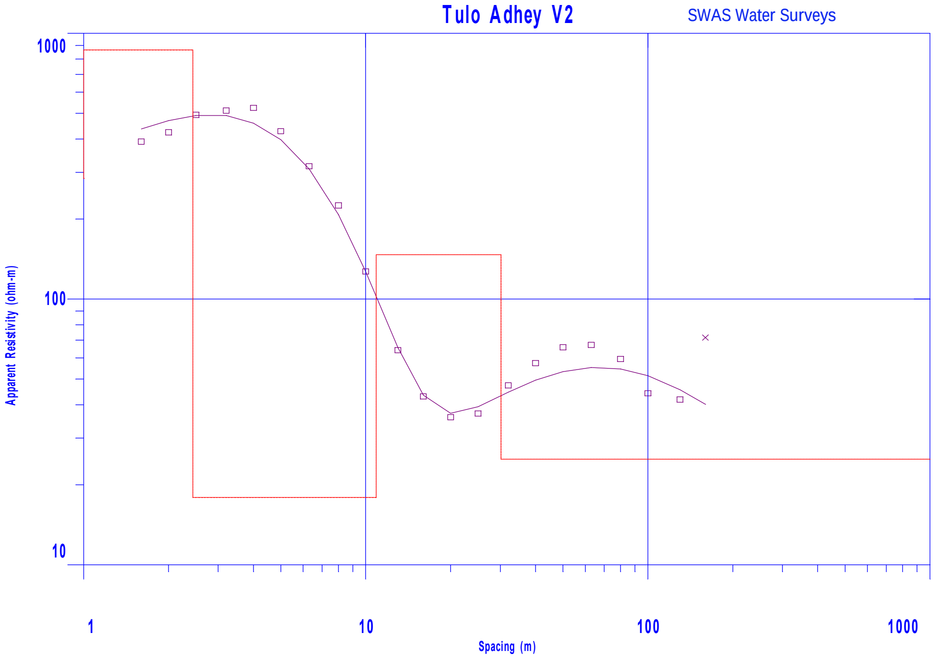
NUMBER	AB/2	MN	RESISTIVITY
1	1.600000	0.000000	729.000000
2	2.000000	0.000000	585.000000
3	2.500000	0.500000	434.000031
4	3.200000	0.500000	301.000031
5	4.000000	0.500000	208.000015
6	5.000000	0.500000	148.600006
7	6.300000	0.500000	118.200005
8	8.000000	0.500000	99.800003
9	10.000000	0.500000	87.000008
10	13.000000	0.500000	75.300003
11	16.000000	0.500000	56.200008
12	20.000000	0.500000	64.300003
13	25.000000	0.500000	47.000004
14	32.000000	0.500000	52.926086
15	40.000000	10.000000	54.492756
16	50.000000	10.000000	36.578262
17	63.000000	10.000000	164.159439
18	80.000000	10.000000	113.072472
19	100.000000	10.000000	56.479416

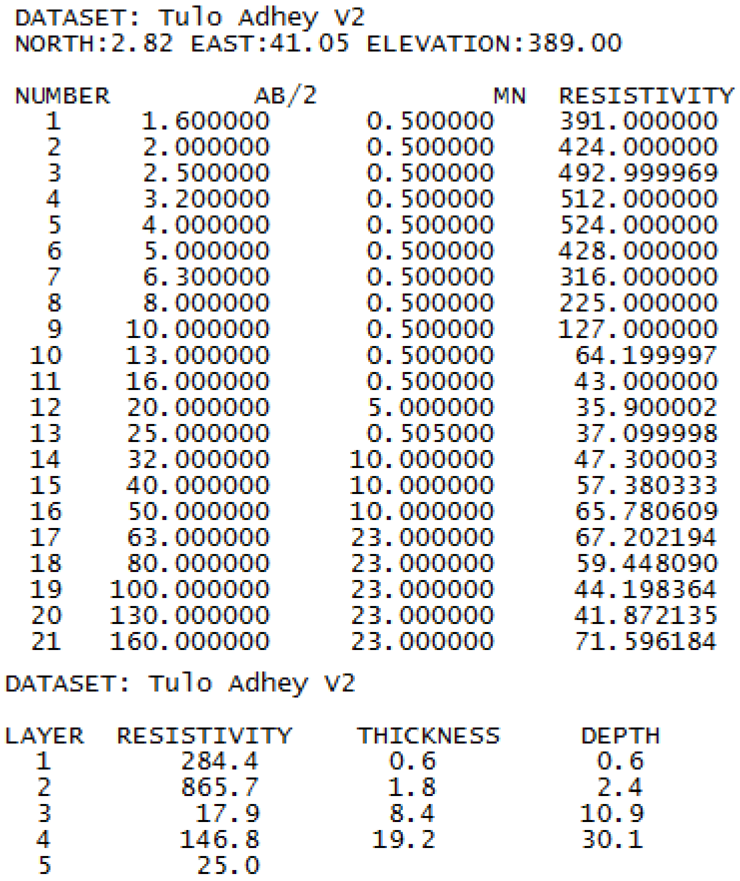
```
DATASET: Yado VES 2
LAYER  RESISTIVITY    THICKNESS        DEPTH
    1       1090.4          1.0          1.0
    2        131.9          3.9          4.9
    3         57.4          6.0         10.9
    4         43.0         32.8         43.7
    5        569.5
```



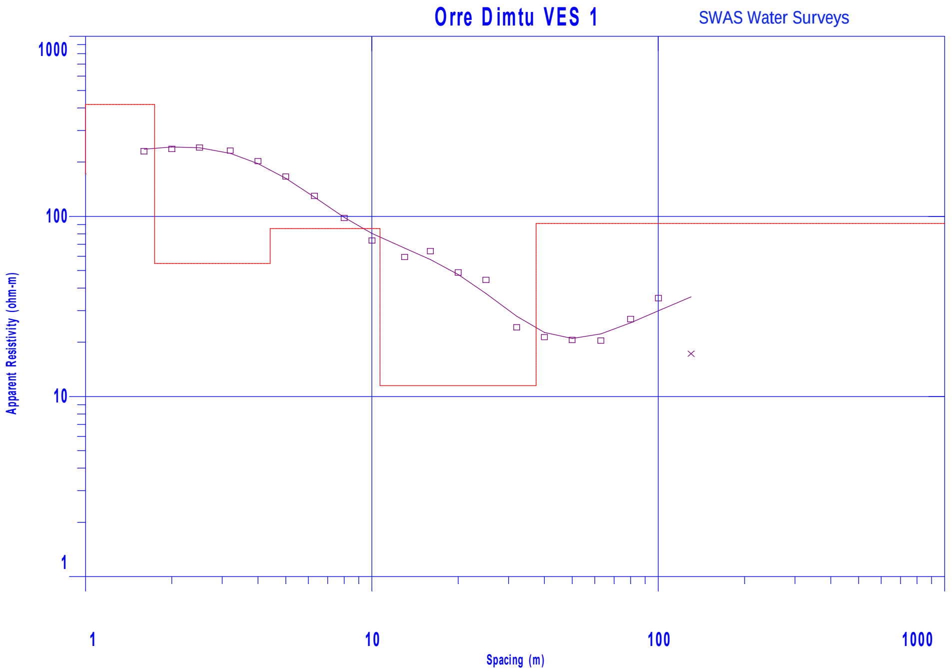
```
DATASET: Tulo Adhey V1
NUMBER        AB/2          MN     RESISTIVITY
   1      1.600000    0.500000      90.400002
   2      2.000000    0.500000     116.599998
   3      2.500000    0.500000     123.099998
   4      3.200000    0.500000     121.800003
   5      4.000000    0.500000     121.000000
   6      5.000000    0.500000     121.000000
   7      6.300000    0.500000     114.800003
   8      8.000000    0.500000     111.000000
   9     10.000000    0.500000      99.800003
  10     13.000000    0.500000      84.800003
  11     16.000000    0.500000      64.199997
  12     20.000000    0.500000      49.099998
  13     25.000000    0.500000      44.400002
  14     32.000000    0.500000      29.940001
  15     40.000000   10.000000      30.000000
  16     50.000000   10.000000      30.000000
  17     63.000000   10.000000      34.200001
  18     80.000000   10.000000      36.000000
  19    100.000000   10.000000      35.099998
  20    130.000000   10.000000      37.700001
  21    160.000000   10.000000      37.299999
```

```
DATASET: Tulo Adhey V1
LAYER   RESISTIVITY     THICKNESS      DEPTH
   1           76.6           0.6        0.6
   2          138.0           6.0        6.6
   3           18.9          17.6       24.1
   4           55.9          39.4       63.5
   5           27.9
```



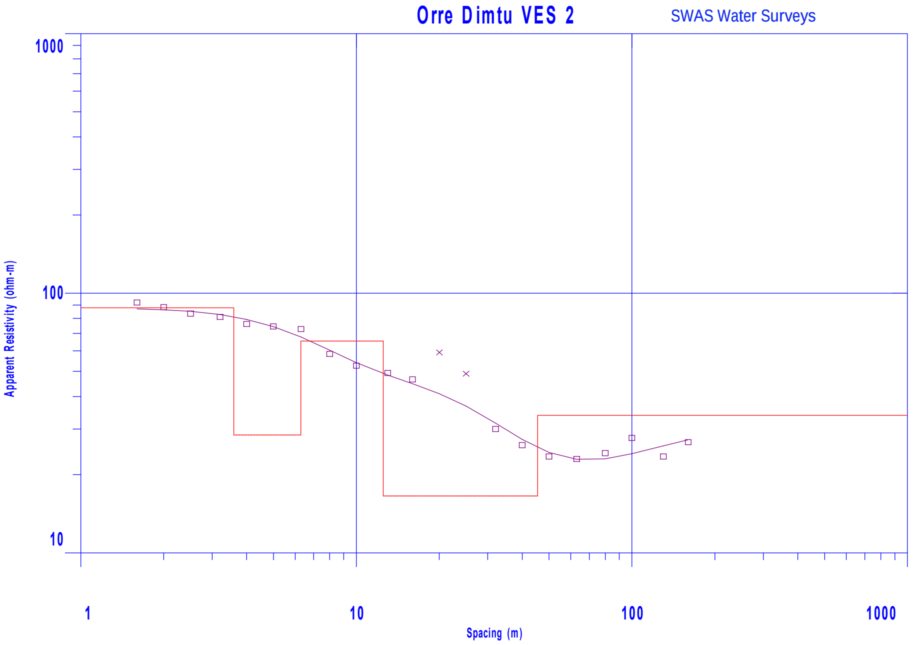


```
DATASET: Tulo Adhey V2
NORTH:2.82 EAST:41.05 ELEVATION:389.00

NUMBER          AB/2            MN  RESISTIVITY
   1      1.600000      0.500000   391.000000
   2      2.000000      0.500000   424.000000
   3      2.500000      0.500000   492.999969
   4      3.200000      0.500000   512.000000
   5      4.000000      0.500000   524.000000
   6      5.000000      0.500000   428.000000
   7      6.300000      0.500000   316.000000
   8      8.000000      0.500000   225.000000
   9     10.000000      0.500000   127.000000
  10     13.000000      0.500000    64.199997
  11     16.000000      0.500000    43.000000
  12     20.000000      5.000000    35.900002
  13     25.000000      0.505000    37.099998
  14     32.000000     10.000000    47.300003
  15     40.000000     10.000000    57.380333
  16     50.000000     10.000000    65.780609
  17     63.000000     23.000000    67.202194
  18     80.000000     23.000000    59.448090
  19    100.000000     23.000000    44.198364
  20    130.000000     23.000000    41.872135
  21    160.000000     23.000000    71.596184
DATASET: Tulo Adhey V2

LAYER  RESISTIVITY    THICKNESS     DEPTH
  1        284.4        0.6          0.6
  2        865.7        1.8          2.4
  3         17.9        8.4         10.9
  4        146.8       19.2         30.1
  5         25.0
```



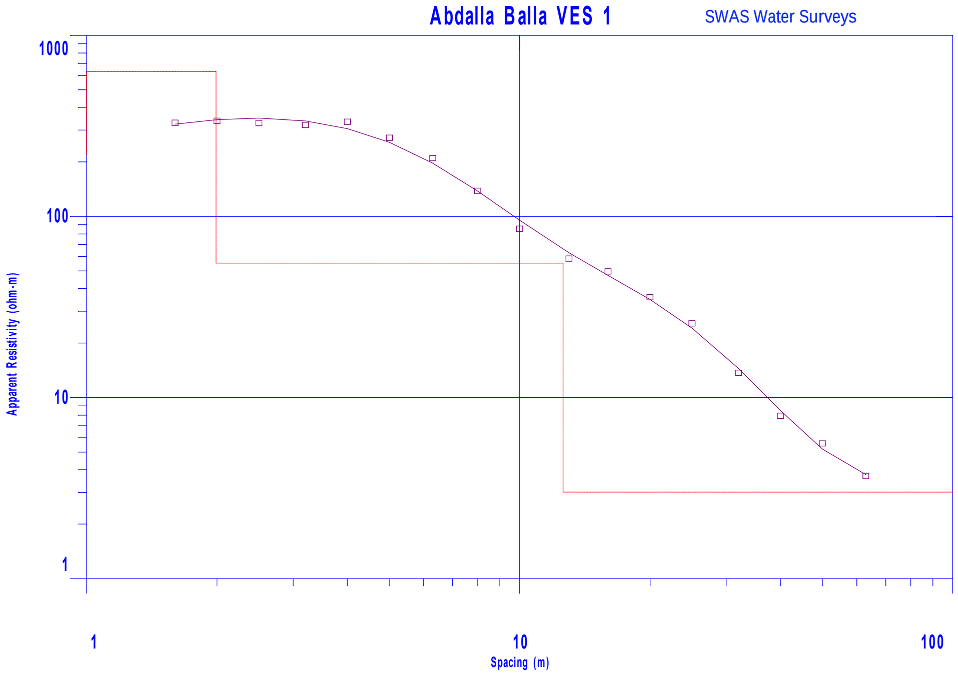
```
DATASET: Orre Dimtu VES 1
NORTH: 2.71 EAST: 40.99 ELEVATION:390.00

NUMBER          AB/2          MN   RESISTIVITY
   1        1.600000    0.500000    229.900009
   2        2.000000    0.500000    236.699982
   3        2.500000    0.500000    241.000000
   4        3.200000    0.500000    231.699982
   5        4.000000    0.500000    202.599991
   6        5.000000    0.500000    166.500000
   7        6.300000    0.500000    130.000000
   8        8.000000    0.500000     97.900009
   9       10.000000    0.500000     73.400002
  10       13.000000    0.500000     59.500000
  11       16.000000    0.500000     64.099998
  12       20.000000    5.000000     48.799999
  13       25.000000    0.505000     44.400002
  14       32.000000   10.000000     24.200001
  15       40.000000   10.000000     21.344099
  16       50.000000   10.000000     20.592546
  17       63.000000   23.000000     20.442238
  18       80.000000   23.000000     26.905590
  19      100.000000   23.000000     35.172672
  20      130.000000   23.000000     17.285715
```

```
DATASET: Orre Dimtu VES 1

LAYER  RESISTIVITY   THICKNESS    DEPTH
   1        172.1         0.6      0.6
   2        418.5         1.2      1.7
   3         54.7         2.7      4.4
   4         85.6         6.3     10.7
   5         11.5        26.8     37.4
   6         91.4
```

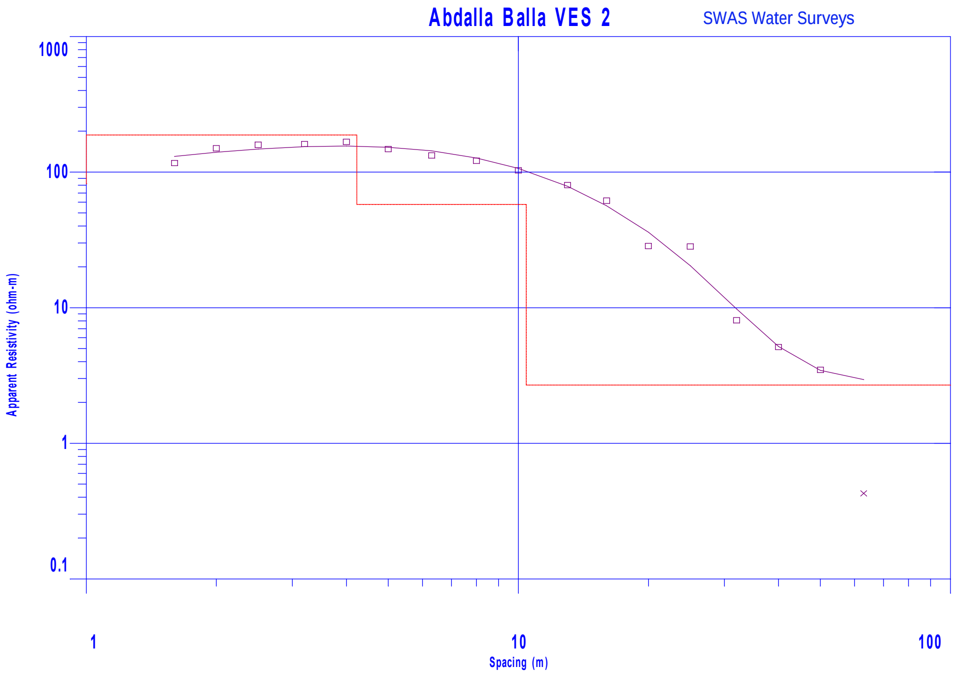


```
DATASET: Orre Dimtu VES 2

NUMBER        AB/2          MN       RESISTIVITY
   1       1.600000      0.500000    92.099998
   2       2.000000      0.500000    88.400002
   3       2.500000      0.500000    83.500000
   4       3.200000      0.500000    81.000000
   5       4.000000      0.500000    76.199997
   6       5.000000      0.500000    74.500000
   7       6.300000      0.500000    72.800003
   8       8.000000      0.500000    58.400002
   9      10.000000      0.500000    52.599998
  10      13.000000      0.500000    49.299999
  11      16.000000      0.500000    46.599998
  12      20.000000      0.500000    59.200001
  13      25.000000      0.500000    49.000000
  14      32.000000     10.000000    30.000000
  15      40.000000     10.000000    26.000000
  16      50.000000     10.000000    23.500000
  17      63.000000     10.000000    23.000000
  18      80.000000     10.000000    24.200001
  19     100.000000     10.000000    27.700001
  20     130.000000     10.000000    23.500000
  21     160.000000     10.000000    26.700001
```

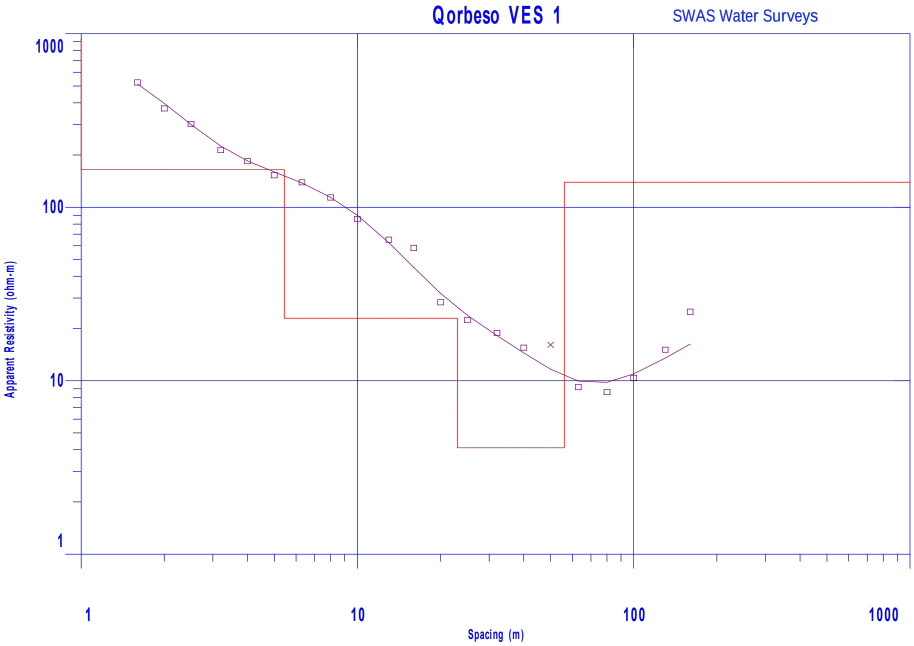
```
DATASET: Orre Dimtu VES 2

LAYER  RESISTIVITY    THICKNESS    DEPTH
  1        87.9          3.6        3.6
  2        28.4          2.7        6.3
  3        65.4          6.2       12.5
  4        16.6         33.0       45.5
  5        33.9
```



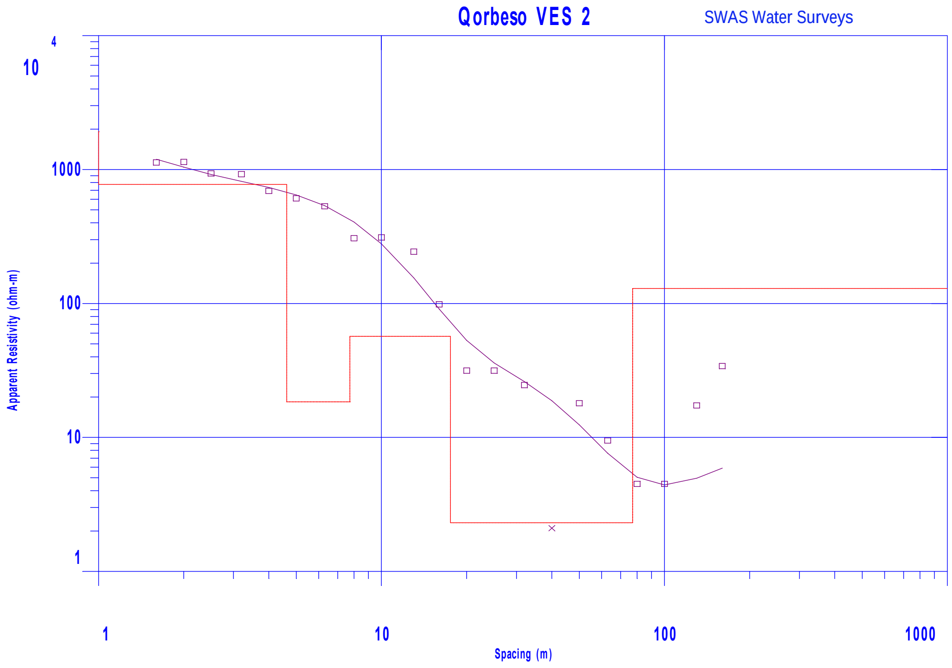
```
DATASET: Abdalla Balla VES 1
NORTH:2.73 EAST:41.02 ELEVATION:382.00

NUMBER        AB/2          MN      RESISTIVITY
     1    1.600000    0.500000    329.000000
     2    2.000000    0.500000    337.000000
     3    2.500000    0.500000    328.000000
     4    3.200000    0.500000    320.000000
     5    4.000000    0.500000    333.000000
     6    5.000000    0.500000    272.000000
     7    6.300000    0.500000    210.000000
     8    8.000000    0.500000    138.699997
     9   10.000000    0.500000     85.500000
    10   13.000000    0.500000     58.499996
    11   16.000000    0.500000     49.700001
    12   20.000000    0.500000     35.799999
    13   25.000000    5.000000     25.700001
    14   32.000000    0.505000     13.700000
    15   40.000000   10.000000      7.931579
    16   50.000000   10.000000      5.588158
    17   63.000000   10.000000      3.695395

DATASET: Abdalla Balla VES 1
LAYER  RESISTIVITY   THICKNESS    DEPTH
    1        220.5       0.6      0.6
    2        631.7       1.4      2.0
    3         55.2      10.6     12.6
    4          3.0
```



```
DATASET: Abdalla Balla VES 2
NORTH:2.72 EAST:41.01 ELEVATION:391.00

NUMBER     | AB/2          MN        RESISTIVITY
  1       1.600000      0.500000    116.500000
  2       2.000000      0.500000    149.800003
  3       2.500000      0.500000    159.000000
  4       3.200000      0.500000    161.000000
  5       4.000000      0.500000    167.000000
  6       5.000000      0.500000    147.800003
  7       6.300000      0.500000    132.500000
  8       8.000000      0.500000    121.199997
  9      10.000000      0.500000    103.099998
 10      13.000000      0.500000     80.199997
 11      16.000000      0.500000     61.599998
 12      20.000000      5.000000     28.500000
 13      25.000000      0.505000     28.299999
 14      32.000000     10.000000      8.076334
 15      40.000000     10.000000      5.121578
 16      50.000000     10.000000      3.480047
 17      63.000000     23.000000      0.426798

DATASET: Abdalla Balla VES 2

LAYER  RESISTIVITY   THICKNESS    DEPTH
    1        81.8       0.5       0.5
    2       187.8       3.8       4.2
    3        57.7       6.2       10.4
    4         2.7
```

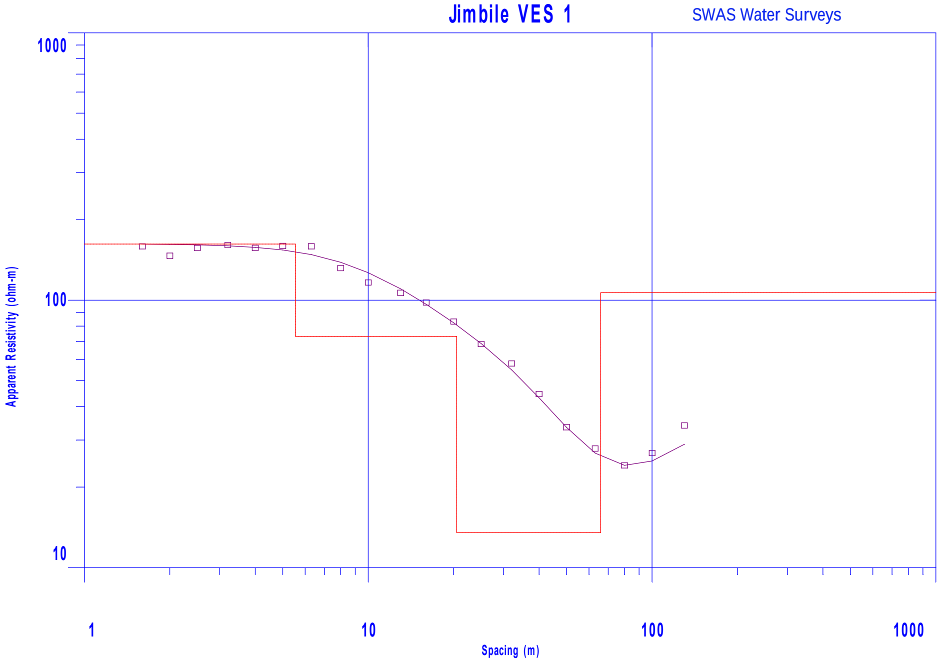


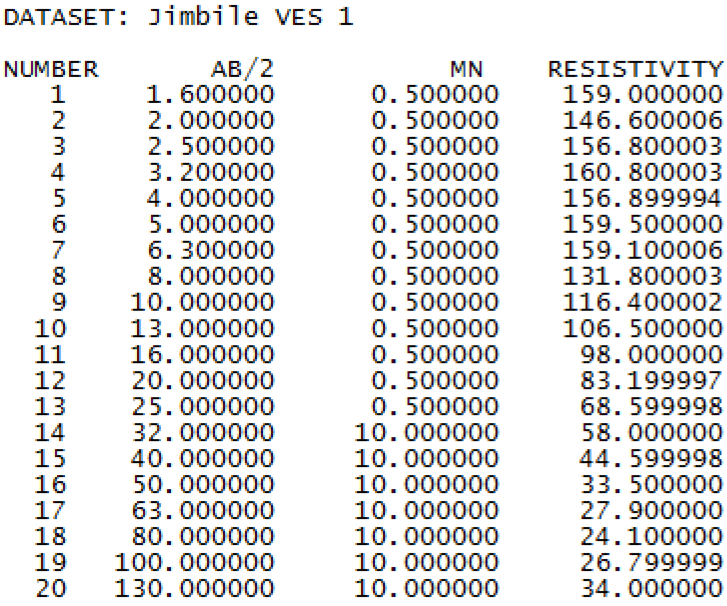
```
DATASET: Qorbeso VES 1

NUMBER          AB/2           MN        RESISTIVITY
   1       1.600000      0.500000      523.983276
   2       2.000000      0.500000      370.981323
   3       2.500000      0.500000      301.561157
   4       3.200000      0.500000      214.091751
   5       4.000000      0.500000      184.102249
   6       5.000000      0.500000      153.002029
   7       6.300000      0.500000      139.117996
   8       8.000000      0.500000      113.849052
   9      10.000000      0.500000       85.525635
  10      13.000000      0.500000       64.977264
  11      16.000000      0.500000       58.312931
  12      20.000000      5.000000       28.323425
  13      25.000000      0.505000       22.352541
  14      32.000000     10.000000       18.831251
  15      40.000000     10.000000       15.525000
  16      50.000000     10.000000       16.099998
  17      63.000000     23.000000        9.200000
  18      80.000000     23.000000        8.600000
  19     100.000000     23.000000       10.400000
  20     130.000000     23.000000       15.100000
  21     160.000000     23.000000       25.000000
DATASET: Qorbeso VES 1
LAYER  RESISTIVITY   THICKNESS     DEPTH
    1        933.0         0.8        0.8
    2        164.5         4.7        5.4
    3         22.9        17.6       23.0
    4          4.1        33.0       56.0
    5        139.5
```



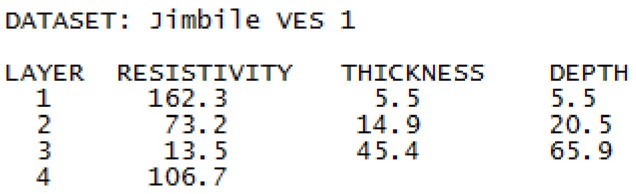
```
DATASET: Qorbeso VES 2          NORTH:
NUMBER      AB/2        MN      RESISTIVITY
 1       1.600000    0.500000  1130.062500
 2       2.000000    0.500000  1141.875000
 3       2.500000    0.500000   937.124939
 4       3.200000    0.500000   925.312500
 5       4.000000    0.500000   693.000000
 6       5.000000    0.500000   610.312500
 7       6.300000    0.500000   531.562500
 8       8.000000    0.500000   307.125000
 9      10.000000    0.500000   311.062500
10      13.000000    5.000000   244.124985
11      16.000000    5.000000    98.437500
12      20.000000    5.000000    31.500000
13      25.000000    5.000000    31.500000
14      32.000000   10.000000    24.600000
15      40.000000   10.000000     2.100000
16      50.000000   10.000000    18.000000
17      63.000000   10.000000     9.500000
18      80.000000   10.000000     4.500000
19     100.000000   10.000000     4.500000
20     130.000000   10.000000    17.299999
21     160.000000   10.000000    34.099998
```

```
DATASET: Qorbeso VES 2
LAYER  RESISTIVITY   THICKNESS   DEPTH
  1      1919.4         0.6       0.6
  2       774.3         4.0       4.6
  3        18.5         3.1       7.7
  4        56.9         9.8      17.5
  5         2.3        59.6      77.1
  6       129.5
```

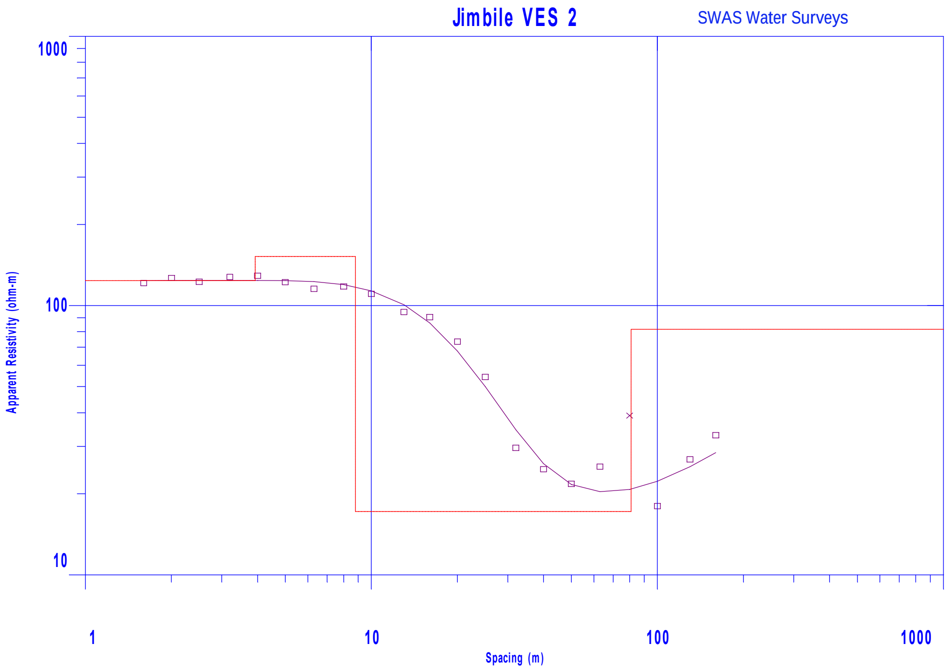


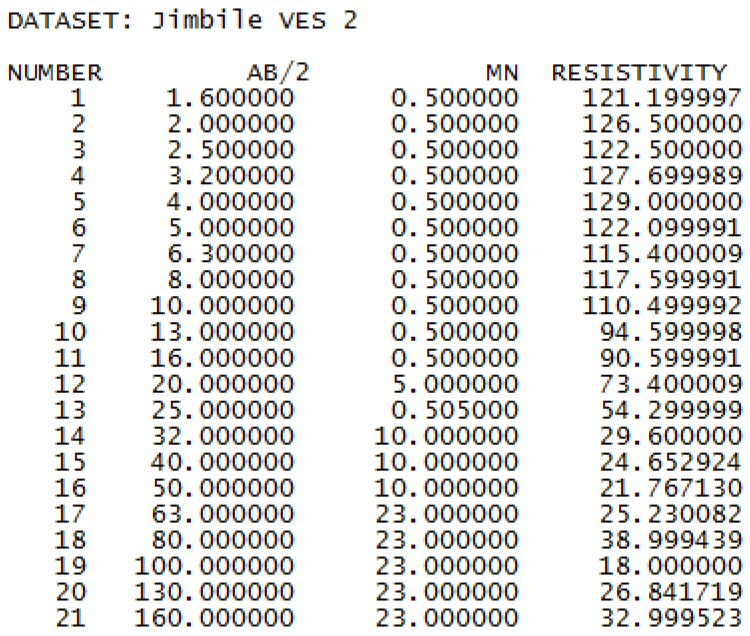


```
DATASET: Jimbile VES 1

NUMBER       AB/2            MN     RESISTIVITY
   1      1.600000      0.500000    159.000000
   2      2.000000      0.500000    146.600006
   3      2.500000      0.500000    156.800003
   4      3.200000      0.500000    160.800003
   5      4.000000      0.500000    156.899994
   6      5.000000      0.500000    159.500000
   7      6.300000      0.500000    159.100006
   8      8.000000      0.500000    131.800003
   9     10.000000      0.500000    116.400002
  10     13.000000      0.500000    106.500000
  11     16.000000      0.500000     98.000000
  12     20.000000      0.500000     83.199997
  13     25.000000      0.500000     68.599998
  14     32.000000     10.000000     58.000000
  15     40.000000     10.000000     44.599998
  16     50.000000     10.000000     33.500000
  17     63.000000     10.000000     27.900000
  18     80.000000     10.000000     24.100000
  19    100.000000     10.000000     26.799999
  20    130.000000     10.000000     34.000000
```

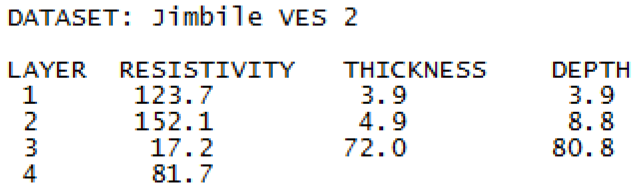


```
DATASET: Jimbile VES 1

LAYER   RESISTIVITY   THICKNESS    DEPTH
  1       162.3          5.5       5.5
  2        73.2         14.9       20.5
  3        13.5         45.4       65.9
  4       106.7
```

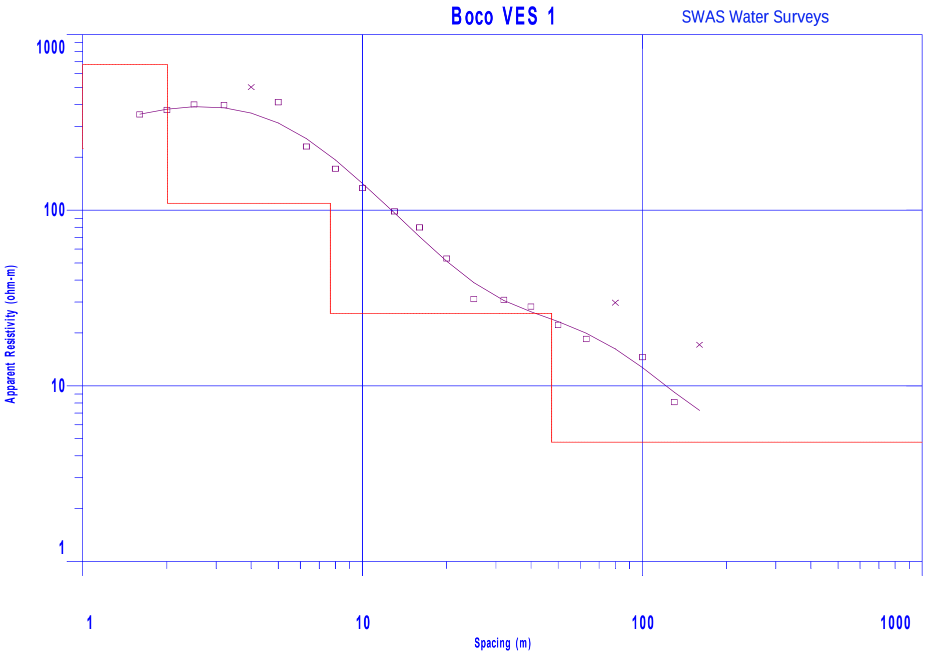


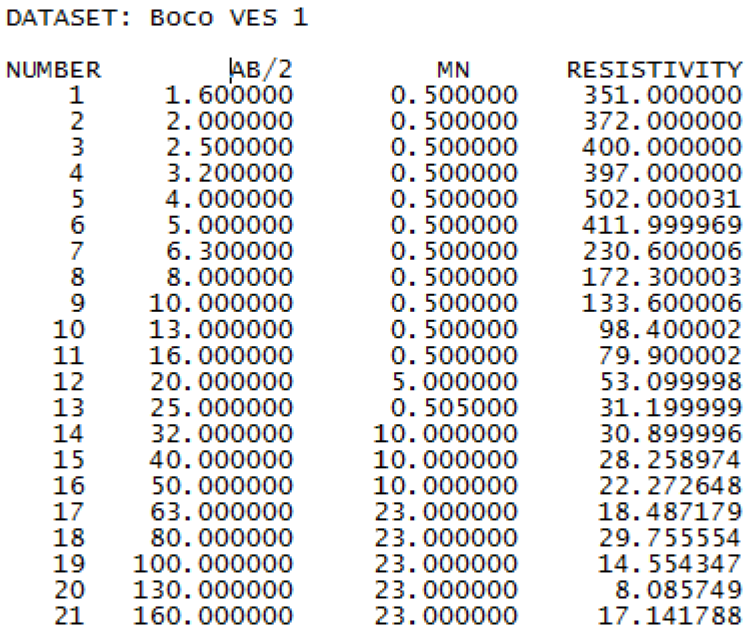


```
DATASET: Jimbile VES 2

NUMBER          AB/2          MN   RESISTIVITY
     1      1.600000      0.500000    121.199997
     2      2.000000      0.500000    126.500000
     3      2.500000      0.500000    122.500000
     4      3.200000      0.500000    127.699989
     5      4.000000      0.500000    129.000000
     6      5.000000      0.500000    122.099991
     7      6.300000      0.500000    115.400009
     8      8.000000      0.500000    117.599991
     9     10.000000      0.500000    110.499992
    10     13.000000      0.500000     94.599998
    11     16.000000      0.500000     90.599991
    12     20.000000      5.000000     73.400009
    13     25.000000      0.505000     54.299999
    14     32.000000     10.000000     29.600000
    15     40.000000     10.000000     24.652924
    16     50.000000     10.000000     21.767130
    17     63.000000     23.000000     25.230082
    18     80.000000     23.000000     38.999439
    19    100.000000     23.000000     18.000000
    20    130.000000     23.000000     26.841719
    21    160.000000     23.000000     32.999523
```



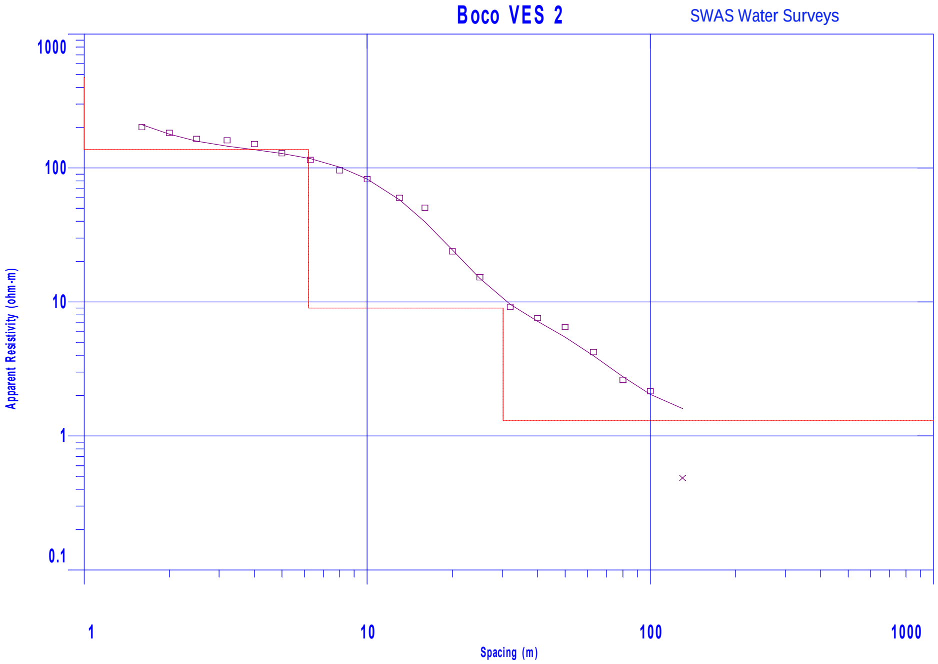
```
DATASET: Jimbile VES 2

LAYER  RESISTIVITY   THICKNESS    DEPTH
 1       123.7          3.9         3.9
 2       152.1          4.9         8.8
 3        17.2         72.0        80.8
 4        81.7
```



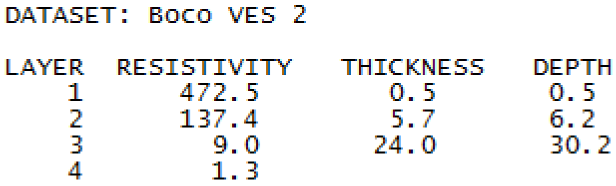


```
DATASET: Boco VES 1

NUMBER          AB/2           MN     RESISTIVITY
    1       1.600000     0.500000     351.000000
    2       2.000000     0.500000     372.000000
    3       2.500000     0.500000     400.000000
    4       3.200000     0.500000     397.000000
    5       4.000000     0.500000     502.000031
    6       5.000000     0.500000     411.999969
    7       6.300000     0.500000     230.600006
    8       8.000000     0.500000     172.300003
    9      10.000000     0.500000     133.600006
   10      13.000000     0.500000      98.400002
   11      16.000000     0.500000      79.900002
   12      20.000000     5.000000      53.099998
   13      25.000000     0.505000      31.199999
   14      32.000000    10.000000      30.899996
   15      40.000000    10.000000      28.258974
   16      50.000000    10.000000      22.272648
   17      63.000000    23.000000      18.487179
   18      80.000000    23.000000      29.755554
   19     100.000000    23.000000      14.554347
   20     130.000000    23.000000       8.085749
   21     160.000000    23.000000      17.141788
```

```
DATASET: Boco VES 1

LAYER  RESISTIVITY   THICKNESS    DEPTH
  1       224.0      0.6           0.6
  2       674.1      1.4           2.0
  3       109.5      5.7           7.7
  4        25.8      9.7          47.4
  5         4.8
```



```
DATASET: Boco VES 2

NUMBER       AB/2          | MN       RESISTIVITY
   1       1.600000      0.500000   202.000015
   2       2.000000      0.500000   183.000015
   3       2.500000      0.500000   165.000000
   4       3.200000      0.500000   161.000000
   5       4.000000      0.500000   151.000000
   6       5.000000      0.500000   129.000015
   7       6.300000      0.500000   115.000000
   8       8.000000      0.500000    96.200005
   9      10.000000      0.500000    82.599998
  10      13.000000      0.500000    59.900002
  11      16.000000      0.500000    50.599995
  12      20.000000      0.500000    23.900002
  13      25.000000      0.500000    15.267463
  14      32.000000      0.500000     9.203284
  15      40.000000      0.500000     7.592710
  16      50.000000      0.500000     6.499819
  17      63.000000      5.000000     4.224882
  18      80.000000      5.000000     2.621594
  19     100.000000     10.000000     2.160387
  20     130.000000     10.000000     0.485480
```



```
DATASET: Boco VES 2

LAYER  RESISTIVITY   THICKNESS   DEPTH
    1      472.5        0.5        0.5
    2      137.4        5.7        6.2
    3        9.0       24.0       30.2
    4        1.3
```

Appendix III: Water Quality Data

Parameter	Unit	Likoley	Dhamasa	Dhaba	Samarole	Ceel Maan	Hassan diriye	Dhoga	Owsqurun	Farasoley	Marere Garsal
pH		7.13	7.6	7.15	7.23	7.91	7.24	7.53	6.73	6.87	7.53
*Electrical Conductivi	mS cm -1	2.72	2.69	5.03	5	6.58	15.8	1.18	0.27	0.28	9.08
*Ammonium	ppm	**< 0.01**	0.1	0.18	0.033	0.025	0.67	**< 0.01**	**< 0.01**	**< 0.01**	0.88
Calcium	ppm	657	147	693	674	197	581	67.9	28.3	42.2	472
Magnesium	ppm	32.3	72	99.5	94.2	179	470	63.2	2.49	3.29	275
Potassium	ppm	22.3	22.6	82.7	86.9	75.5	122	25.5	22.6	5.46	53.1
Sodium	ppm	22.3	253	320	318	835	2060	83	23.6	12	984
*Nitrate N	ppm	6.34	6.67	13.4	14.5	45	2.14	45.7	**< 0.01**	1.26	269
*Nitrates	ppm	28.1	29.5	59.2	64.5	199	9.5	202	**< 0.01**	5.57	1190
Phosphorus	ppm	**< 0.01**	0.029	0.11	0.066	0.019	0.077	0.045	0.38	0.1	0.025
Sulphur	ppm	538	47.7	611	608	209	881	9.34	16.1	21	136
*Sulphate	ppm	1610	142	1830	1820	626	2630	28	48.5	62.8	407
Iron	ppm	0.027	0.04	0.093	0.056	0.092	0.11	0.027	0.46	0.13	0.25
Manganese	ppm	**< 0.01**	0.052	**< 0.01**	**< 0.01**	**< 0.01**	0.016	**< 0.01**	0.086	0.016	0.11
Zinc	ppm	0.017	1.29	0.064	0.035	0.011	0.24	0.32	0.31	0.52	5.73
Copper	ppm	0.06	0.01	0.019	0.055	0.011	0.02	**< 0.01**	**< 0.01**	**< 0.01**	**< 0.01**
Boron	ppm	0.21	0.7	1.29	1.29	2.02	5.73	0.54	0.054	0.061	2.56
*Chlorides	ppm	65.5	705	708	734	1750	4470	157	12.5	17.1	2340
*Bicarbonate	ppm	257	203	308	299	387	395	248	97.2	65.9	373
*Fluorides	ppm	1.86	0.26	1.83	2.04	1.27	3.37	1.82	0.31	0.053	0.85
*Hardness	ppm	1770	662	2140	2070	1220	3370	428	80.9	119	2300
Molybdenum	ppm	**< 0.01**	**< 0.01**	**< 0.01**	**< 0.01**	**< 0.01**	**< 0.01**	**< 0.01**	**< 0.01**	**< 0.01**	**< 0.01**
*Silicon	ppm	44.6	29	32.3	34.3	35.2	38.2	52.5	5.53	3.08	27.8
*Silica	ppm	95.4	62	69.2	73.5	75.2	81.9	112	11.8	6.61	59.3
*SAR		0.23	4.26	3	3.04	10.3	15.4	1.74	1.14	0.48	8.91
*Turbidity	NTU	0.76	1.25	0.78	0.95	0.79	0.72	0.74	6.08	1.37	1.37

Parameter	Unit	Laf iyo bul	Oktoobar	Hassan Warsame	Tulo Adde	El Gomar	El Libele	Horseed	Howlwadag	Ceel Dub	Dhugsiga
pH		7.62	6.56	7.38	7.36	7.47	7.38	7.35	7.3	7.54	7.62
*Electrical Conductivi	mS cm -1	3.78	5.41	3.73	3.25	4.79	4.35	3.39	4.55	4.59	5.58
*Ammonium	ppm	0.038	**< 0.01**	1.19	0.13	0.24	**< 0.01**	**< 0.01**	**< 0.01**	0.14	0.067
Calcium	ppm	566	508	565	297	506	614	714	723	638	607
Magnesium	ppm	78.4	114	56	58.6	102	118	67.4	106	98	129
Potassium	ppm	99.6	124	66.1	52.4	129	141	44.5	79.4	151	105
Sodium	ppm	165	359	150	148	50.5	276	93.5	257	275	413
*Nitrate N	ppm	5.58	36	0.92	20.7	7.18	6.48	8.12	14	8.19	8.13
*Nitrates	ppm	24.7	159	4.07	91.6	31.8	28.7	35.9	62	36.3	36
Phosphorus	ppm	0.069	**< 0.01**	0.98	0.044	0.024	0.026	0.03	0.06	0.083	0.043
Sulphur	ppm	611	570	521	343	524	707	572	702	677	656
*Sulphate	ppm	1830	1710	1560	1030	1570	2120	1710	2100	2030	1970
Iron	ppm	0.25	0.14	1.8	0.15	0.15	0.31	0.26	0.16	0.076	0.45
Manganese	ppm	0.034	0.014	0.98	0.02	0.025	0.044	0.048	0.027	0.013	0.053
Zinc	ppm	0.065	0.018	0.046	0.022	0.26	0.041	0.022	0.026	0.032	0.034
Copper	ppm	0.038	0.021	0.069	0.16	0.1	0.07	0.099	0.14	0.16	0.036
Boron	ppm	0.97	1.94	0.79	0.63	0.65	1.56	0.56	1.18	1.39	1.72
*Chlorides	ppm	236	630	262	180	540	325	241	572	442	800
*Bicarbonate	ppm	266	187	403	210	305	297	243	283	299	257
*Fluorides	ppm	1.91	4.33	1.8	3.41	3.98	2.81	3.77	2.85	2.45	3.52
*Hardness	ppm	1740	1740	1640	983	1680	2020	2060	2240	2000	2050
Molybdenum	ppm	0.016	**< 0.01**	**< 0.01**	0.016	**< 0.01**	0.016	**< 0.01**	0.012	0.018	0.019
*Silicon	ppm	26	25.5	26.4	16.3	49	28.2	45.6	45	26.6	31
*Silica	ppm	55.6	54.6	56.5	34.9	105	60.3	97.6	96.3	56.9	66.3
*SAR		1.72	3.74	1.61	2.05	0.54	2.67	0.9	2.36	2.68	3.97
*Turbidity	NTU	53.6	10.2	17.5	2.54	24.1	39.2	18.9	14.3	2.37	16.6

Appendix IV: Water Point Inventory Data

Boreholes

Borehole name	Village	Easting	Northing	Depth, m	Static level, m	Q, m^3/hr	Status
Dhamasa	Dhamasa	41° 20' 8"	3° 9' 3"	120	75	4.8	Operational
Dhaba	Dhaba	41°12'21"	3°11'57"	200	170	8	Operational
Likole	Likole	41°34' 29"	3° 7' 4.0"	210	180	8	Operational

Dug wells

Well name	Village	Easting	Northing	Depth, m	Static level, m	Dia, m	Status
Ceel Gumar	C/Waaq	41°00'54"	2°48'05"	19	17.0	1.5	Operational
Bulo Gomar	C/Waaq	41°01'13.6"	2°47'32.3"	17.5	15.0	1	Operational
Dhugsiga	C/Waaq	41°01' 24"	2°47'41"	17	15.0	1.1	Operational
Ceel Dub	C/Waaq	41°00'37"	2°47'33"	16.5	15.0	1.2	Operational
Ceel Libele	C/Waaq	41°00'47"	2°47'48"	17.0	14.0	1.2	Operational
C/Hassan Warsame	C/Waaq	41°00'30.4"	2°47'28.4"	13.5	13.0	1.4	Operational
Horseed	C/Waaq	41°00'56"	2°47'38"	18.0	16.0	1.5	Operational
Howlwadag	C/Waaq	41°00'39.2"	2°47'10.2"	18	16	1.2	Operational
Oktoobar	C/Waaq	41°01'14.2"	2°47'26.2"	16	14.5	1.3	Operational
Laf Iyo Bul	C/Waaq	41°01'11"	2°47'23"	18.0	15.1	1.2	Operational
Abdalla	Samaroole	41°13'37"	2°47'33"	20	-	1.2	Operational
Garsal Ceel Maan	Garsal	41°16'32"	2°49'34"	17.0	14.0	1.4	Operational
Marere Garsal	Garsal	41°16' 36"	2° 16'36"	18.0	-	1.5	Operational
Farasoley	Farasoley	41°0'13"	2°48'50"	12	11	1.0	Under rehab.
Owsqurun	Owsqurun	41°9'19"	2° 12'4"	21	18.0	1.5	Operational
Dharkeyn Dhoga	D/Dhoga	40°59'39"	2°48'6"	18	16.0	-	Operational
Hassan Diriye	C/Waaq	41°0'47"	2° 47'15"	18.0	-	1.5	Operational

Appendix V: Photographs of Borehole Sites

Yado drill site

Tulo Adde drill site

Orre Dimtu drill site

Qorbeso drill site

Boco