GROUNDWATER PROSPECTING IN PUNTLAND - SOMALIA

Project Owner: **LIONS CLUBS MD 101 SWEDEN**

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Executive Summary

Despite groundwater being the main source of water for humans, agriculture and livestock, there is neither a hydrogeological map nor a sound policy for groundwater management and exploration in Somalia especially Puntland. The state of knowledge about hydrogeology, quality and quantity of groundwater resources is very poor.

Information on hydrogeology to facilitate drilling and development of strategic water sources is limited, scattered and in some cases non-existent. In many cases, groundwater drilling projects are unguided and exploration takes place without investigations leading to low success rates, thus wastage of financial resources. It requires huge resources to get accurate information on potential drilling sites. Hence, knowledge of groundwater resources is essential for strategic long-term planning.

Some previously conducted studies, created a good base for further hydrogeological works. Numerous works of drilling water wells or conducting geophysical surveys are available to support water supply of urban centres and local rural and semi-urban communities. There is however no capacity on hydrogeology and geophysics for borehole site selection and aquifer assessment. Weak water institutions have also contributed to un-regulated water exploration and drilling. Intervening agencies generally opt for water trucking to fulfil the needs of rural people and pastoralists during severe droughts.

The overall objective of the conducted Hydrogeological Survey and Assessment of Selected Areas in Puntland-Somalia by Lions International Club in Somalia in collaboration with Terra Geo AB was the creation of a base for more efficient and sustainable groundwater use in Puntland, while the specific objectives included: update of hydrogeological knowledge of groundwater distribution and availability in the study area and protection in order to improve sanitary and livelihood conditions in urban and rural areas; identification of certain promising areas for groundwater development and detailed hydrogeological, geophysical studies and drilling; improvement of local technical capacities for groundwater surveys.

1. Introduction

1.1. Previous studies and investigations

The geology of Puntland has been surveyed more actively since the end of WW II. The geology of the area was first described by Macfadyen (1949) and several reports compiled by the Geological Survey of the Former Somaliland Protectorate in the 1950's.

Geological maps covering a good part of the area of former British Somaliland were published by Macfadyen and MacKay in 1949 and 1953, respectively. This was the result of interest of several companies in exploring oil possibilities in the northern regions.

In the 1980s the Faculty of Geology of the Somali National University showed great interest in the geology of northern regions and published several papers based on the work carried out in selected localities and on general geological aspects. Geoelectric sounding surveys were also applied in groundwater investigations (UNDP, AFRICA70, COOPI, UNPOS-IFAD, SHAAC and CEFA).

In recent years some updated information about water sources and points resulted from surveys conducted by UNICEF (1999) and FAO/SWALIM (2008/09). UNICEF undertook a number of inventories in 1999 on the water sources in Bay Bakool, Hiraan, Sool and Sanaag. FAO/SWALIM, with the help of partner agencies, also collected data on the water sources for a database called the Somalia Water Source Information Management System (SWIMS).

In 2008, a field study was conducted in the northern part of Somalia. Swedish education organisation with name ABF (Arbetarnas Bildningsförbund) supported fact-finding mission. The aim was to study the living condition for the people in Bari region Somalia. The result was terrifying. People lack the basic need of the human being namely drinking water, health care and education. These areas hardly have any form of water wells. People drink principally rainwater stored in handmade water reservoirs. It is impurified and this can cause many diseases. A Swedish volunteer and a lion member visited first visited the north-eastern part of Somalia 2008. The villages that were visited were Bossaso and Qandala districts in Bari Region of Somalia. The estimated people in Bari Region are 720.000 (2014). The field studies paid attention to the villages in remote areas. The fact-finding mission showed that there is no clean water in the large part of the area were about 150 000 inhabitants' lives.

People residing in villages never had water with its original/natural colour, because they always have got the brown, green or black tinged water to drink in their daily lives mainly from rain. The project's other main objective was to transfer the knowledge and resources and encourage people to actively try to solve their problems and instead of being a standing recipient of charity to be participants in a long-term initiative to help their country. This fact-finding documentary film was funded by ABF, a Swedish organization local. The problems that existed in the area were categorized, and the need of water came into the highest priority. ABF in Sweden and other key individuals have agreed to implement water prospecting in the area in order to identify if there is enough useful water available in the area, before drilling.

1.2. Geological survey 2011

After the first field study was conducted, a more reliable geologic water prospecting study was planned to be conducted to find the best suitable site for drilling deep water source. Terra Company conducted the prospection. Terra is specialized in prospecting groundwater in sedimentary and crystalline rocks in Africa, Asia and Europe.

The geophysical equipment used for the prospection was Swedish geophysical designed WADI-VLF equipment. An indication of groundwater was found in 40 places in nine villages and two cities.

Terra Company– specialized in groundwater

Terra is a Swedish company, with its office in the city of Uppsala, Sweden, with chief executive Birger Fogdestam, Senior Hydrogeologist, who during most of his active years has been employed by the Geological Survey of Sweden. B. Fogdestam has been working at the Geological Survey of Sweden during more than 30 years. Most of the tasks during the employment has been dealing with groundwater mapping and groundwater investigation in Sweden.

Fogdestam has also been employed by other organisations, consultants and aid organisations during the past years, mostly working on the continent of Africa, i.e., Libya, Namibia, Botswana, Malawi and South Africa. During the last year (2011) works has also taken place in Puntland, Somalia. Most of the field works abroad has been dealing with VLF-investigation (Very Low Frequency).

Fogdestam has during a period of 5 years been Head of the National Well Record Section and during more than 10 years Head of the Division of Hydrogeology at the Geological Survey of Sweden

As a result, it became necessary for LIONS to move to the field and do an inventory of all possible water sources points in Bari, Karkaar, Sanaag & Nugaal Regions of Puntland following the same groundwater exploration survey conducted on 2011 with Mursal Isse being the initiator and Birger F. being the Hydrogeologist.

1.3. Purpose and scope of the study

Groundwater is very important and, in fact, even the sole water resource in most territories of Somaliland and Puntland. A number of previously conducted studies, created a good base for further hydrogeological works.

Numerous NGO's have also worked in the region and supported urban centres and local rural and semi-urban communities by drilling water wells or conducting geophysical surveys. However, although many water projects implemented or supported in the region, water-well drilling was commonly conducted without adequate project feasibility study. To date no systematic data collection has been carried on wells' exploitation, capacity and especially on groundwater level fluctuations.

Figure 1 Study area

There is an urgent need for a quantitative and updated assessment of the hydrogeological resources of Puntland. A full hydrogeological investigation is out of reach due to time constraints and costs.

1.4. Overall objective

- improve the population's living conditions by supporting clean drinking water, which is the living key to every human being.

1.5. Collected information

To reach the objectives of LIONS, an extensive one-week field survey using ABEM WADI VLF and desk analysis were carried out by a team of international experts of hydrogeologist and relevant water staff.

Most suitable points for water drilling have been selected on site and marked as GPS coordinates of each point with respect to its value from the VLF recorded and cemented on spot as well. Listed below are areas in which hydrogeologic prospecting was conducted upon:

- First area of interest located at Bari & Karkaar Region at the disticts of Iskushuban, Banderbayla and Xumbays area (Reebi Caris, Xiriiro, Mareer, Xumbabays, Kobriyaad, Caleemaley, Ceelmareere, Ceellahelay, Sarmaan Sare, Sarmaan Hoose).
- Second area of interest located at sanaag region at the city of Baran.

2. Methodology

2.1. Field work

Very Low Frequency Electromagnetic (VLF) were carried out Puntland region for the first time Mid 2011 by Birger F. & Mursal Isse Team and the second time at November 2022 at Bari, Karkaar, Nugaal and Sanaag regions.

The effectiveness of these methods is in mapping variations of subsurface geological structures, faults/fractures disposition, extent of the dykes and contact between different rock types.

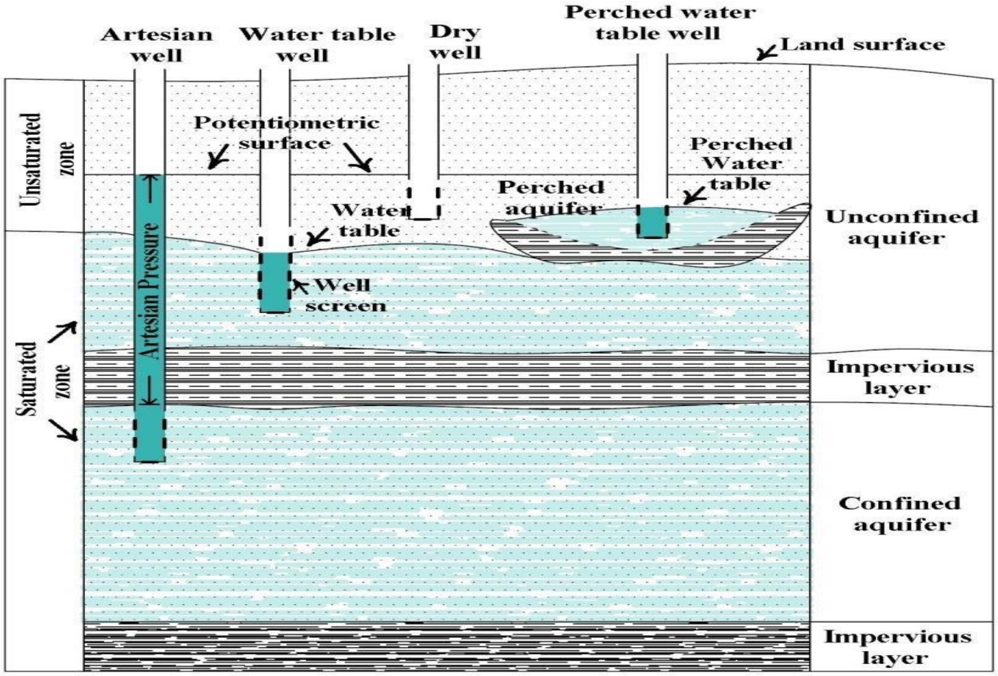


Figure 2 Aquifer Types

The VLF measurements were performed along thirty-five profiles. The results revealed the location of conductive bodies, geological boundaries, dykes, faults/fractures and shear zones are delineated along contact between dykes and granitic rocks. Highly productive water wells are obtained by drilling in rocks that are broken along joints and fractures, enabling drillers to select the most promising sites for water well drilling.

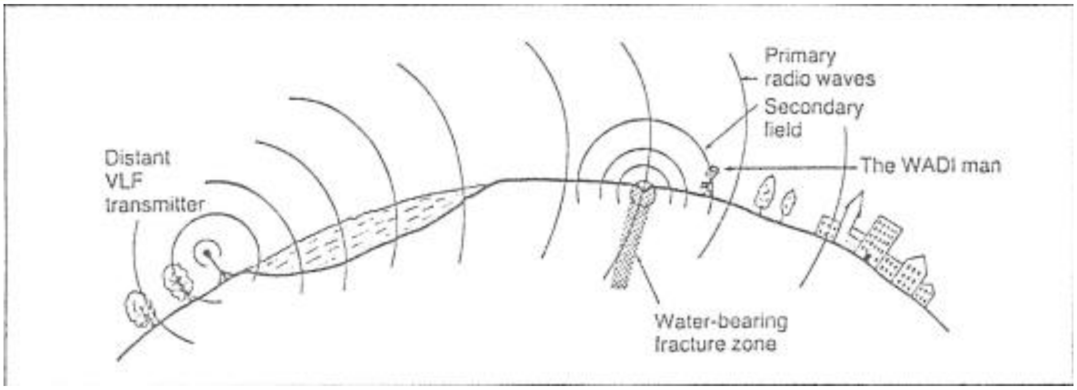


Figure 3 VLF outline

For VLF-measurements, use is made of a distant radio transmitter station, which transmits on the VLF-waveband (Very Low Frequency: i.e., 15 – 30 kHz and a long wavelength). Such radio waves are capable of penetrating deep into the ground (or water) and are in fact used for military communications and navigations. These radio waves are disturbed by extensive electrically conducting formations in bedrock, which may be electrically conductive types of rock or concentrations of certain minerals. They may also be steeply dipping, water-bearing fracture zones. These disturbances, or anomalies, may be recorded by means of VLF measurements and utilized to find the optimum location from where drilling can be done for best quantities of groundwater.

The WADI – VLF (used in Puntland 2011 & 2022) is a state-of-the-art geophysical instrument designed for easy use. A built-in program makes it possible to interpret measurements immediately, right on the site. However, like other geophysical instruments the WADI simply finds physical structures in the ground and bedrock and cannot guarantee water supply in the fractures. The sites were located using built in GPS and coordinates were given in longitude and latitude and UTM as well.

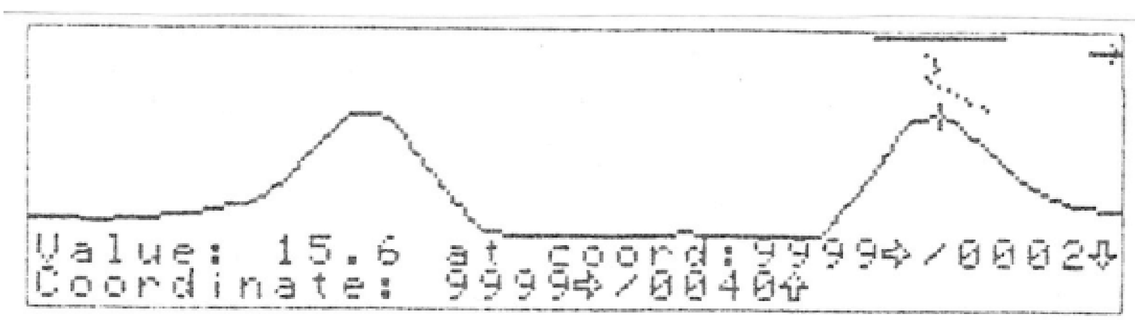


Figure 4 Example of the anomalies shown on the display of the WADI-VLF equipment.

2.2. Geology and Hydrogeology

Among several descriptions of geological history of Somaliland and Puntland, one of the best can found in the SHAAC report (2007) which in fact represents a synthesis of previous geological studies of the region. During the Precambrian era, vast sediments accumulated and at the end of the era, a period of regional folding and metamorphism has occurred. Along the Gulf of Aden coast coral limestone reefs which are topped by coarse conglomerates and boulders were deposited. The uplifting of this area and consequent sea regression together with the onset of the rifting of the Gulf of Aden during the Miocene has resulted in sedimentation being restricted to only a narrow coastal belt.

The breaking of the continental shield resulted in intense volcanic activity especially towards the Djibouti border. Such geological history of the region caused the following succession and creation of geological formations which can be broadly divided into the following major units:

1. Precambrian: Basement Complex (metamorphic and volcanic rocks)
2. Jurassic: Limestone, shale and sandstone
3. Cretaceous: Nubian sandstones (sandstones and limestones)
4. Tertiary (Eocene): Limestone, evaporitic rocks
    - Auradu Formation (limestones)
    - Taleex Formation (evaporitic rocks)
    - Karkar Formation (limestones)
5. Tertiary (Oligocene to Miocene): Thick extensive series of sedimentary rocks
    - Daban series
    - Hafun Series and Iskushuban Formation
6. Pleistocene to Recent Alluvium
    - Basaltic rocks
    - Recent alluviums, terraces and coastal beaches

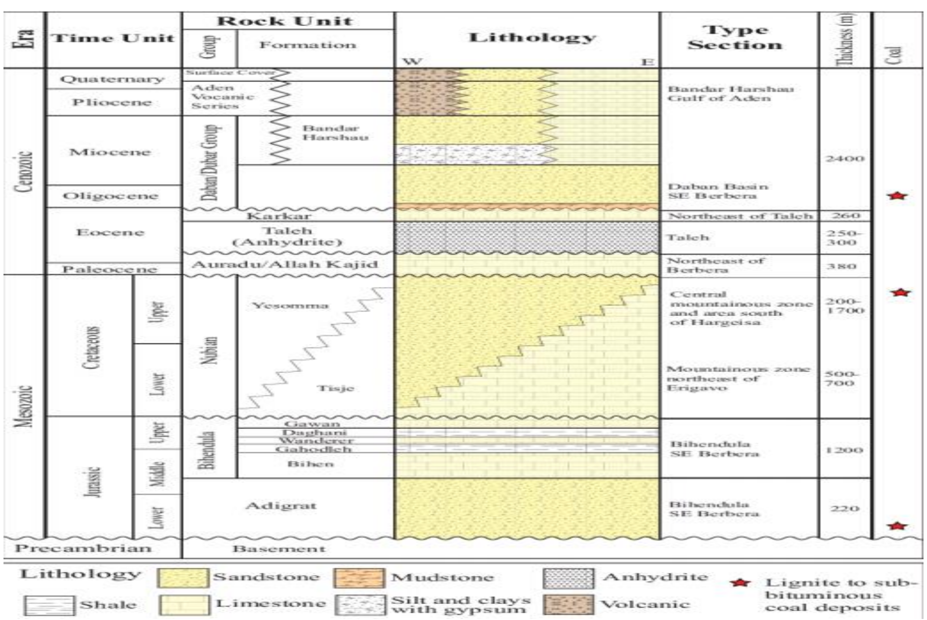


Figure 5 Geologic formation of surveyed area

The surveyed area is under the Karkar Formation and is constituted by fossiliferous, bedded limestone, marly limestone, and white marls. Limestone is often karstified containing a well-developed cavernous system. The color ranges from white to yellow to brown. Thin layers of gypsum and occasionally thin shale also occur in some sections. The sequence is generally conformable on the Taleex Formation and its thickness varies between 200 to 400 m. The contact between Karkar and the underlying Taleex Formation is often marked by 2-3 meters of lateritic sand and weathered boulders.

The Karkar Formation is penetrated for 230 m by the well in Xumbays, in the Sool Plateau. The well is located at the foot of a 30 m-high Karkar limestone hill making the total thickness of this formation in Xumbays 260 m.

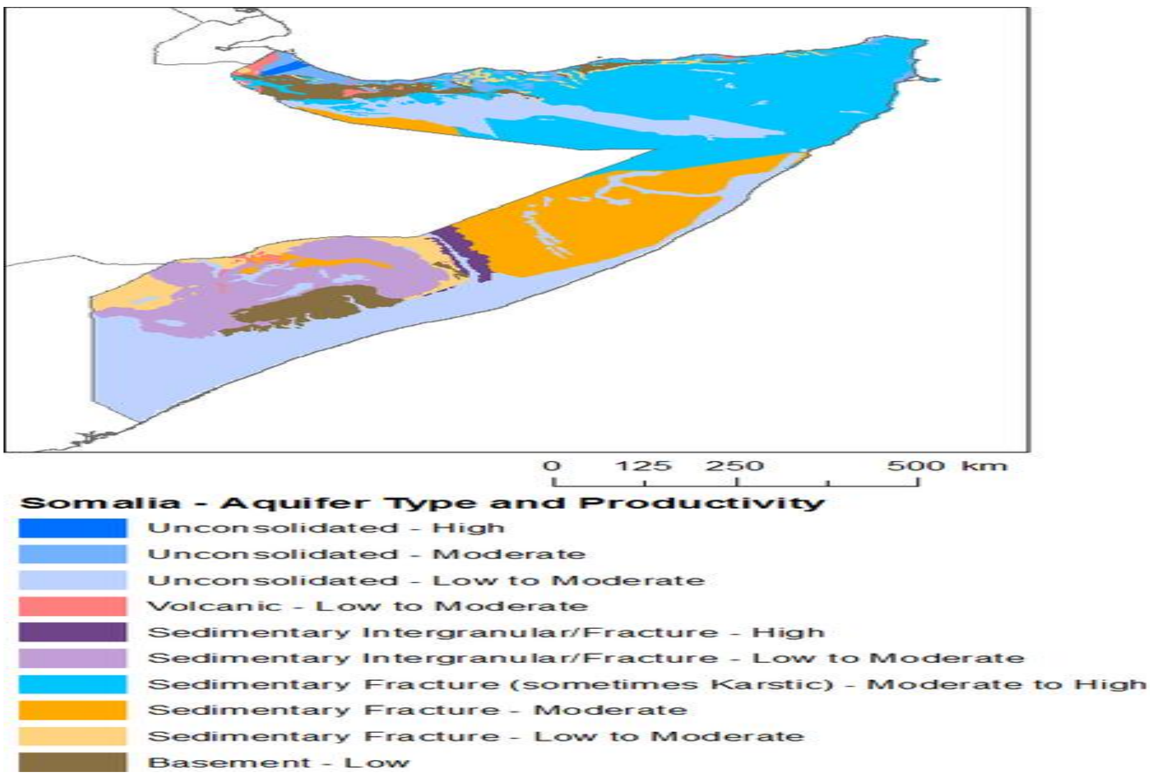


Figure 6 Aquifer Types and Productivity in Somalia

The first surveyed are can be represented by Timirishe Well - Bari region with 5 l/s, and with a dynamic water level of 74 m b.g.l. (initial static level was 22 m deep). Calculated transmissivity is 4.5 x 10-4 m2/s and hydraulic conductivity is 3.2 x 10-5 m/s.

There are only a few wells with data from pumping tests in the Sanaag region, The first is Dhahar Well. A pumping test conducted indicated a constant discharge rate of 5 l/s, with a dynamic water level of 99 m b.g.l. while the initial static level was 96 m. Transmissivity is 3.3 x 10-3 m2/s and hydraulic conductivity 5,4 x 10-5 m/s. The pumping test for Well Garowe conducted with a constant discharge rate of 4 l/s, and with a dynamic water level of 158 m b.g.l. The initial static level was 23 m deep. Transmissivity is 6.4 x 10-4 m2/s and hydraulic conductivity is 3.4 x10-5 m/s.

3. Recommendation & Conclusion

3.1. Data Acquisition & Interpretation

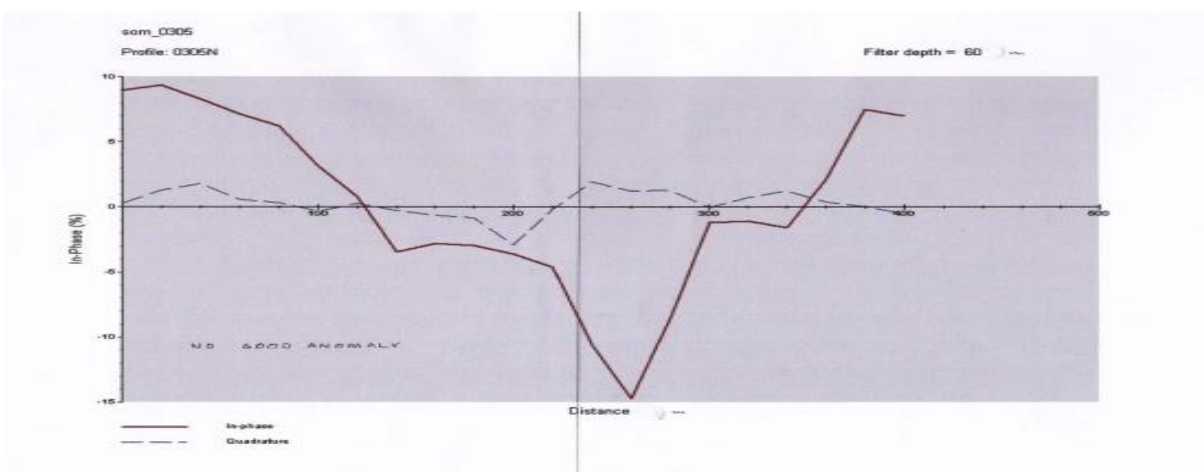
The WADI equipment shows a simple curve/anomality on the display of the data unit, it is easy to decide the best drilling point on spot at the site. When processing the profiles in the computer using the **Ramag 2** program you will get more sufficient anomalies, which is shown on the appendices below. It is very difficult to get information of the exact depth of groundwater table, but the Ramag 2 program is asked to show the anomalies of the fracture zones at a depth of 60 meters.

It's recommended to drill a depth of 150 – 250 meters in order to get sufficient volume of water standing in the borehole.

Symbols

✓ Surface, NOT SHOWING TOPOGRAPHY	//////////////////////////
✓ Fracture zone – STEEP DIRECTION	XXXXXXXX
✓ Marked drilling point on site (m)	↓↓↓↓

Investigations were made in 11 villages and 2 cities in Puntland in a period of less than two weeks, several profiles were measured at each village and the VLF frequency we worked with a reception of 18.2 kHz, bellow is a list of profiles of each survey conducted with the best value indicated in numeric form and selected points marked on site with GPS coordinates cemented with it.



Dooxagaban

- 7th Nov. 2022

Profile 4			
Start	0 M		
E	438445		
N	1156010		
End	260 M		
E	438238		
N	1155906		
Best Value @ 199m (2.7 value)			
E	438291		
N	1155935		

Profile 5		
Start	0 M	
E	438340	
N	1155817	
End	220	
E	438337	
N	1156019	
Best value at 120 m from start (2.7 value)		
E	438342	
N	1155933	

Hiriro Village

- 8th November 2022

Profile 6			
Start			
E	497576		
N	1103259		
End			
E	417273		
N	1103420		
Best value (6.7) at 101 m from start			
E	417500		
N	1103302		

Profile 7			
Start	Altitude 533 m		
E	417485		
N	1102789		
End			
E	417204		
N	1102998		
Best value (5.4) at 61 m from start			
E	417434		
N	1102819		

Profile 8			
Start			
E	417712		
N	1102525		
End			
E	417466		
N	1102841		
Best value (6.1) at 143 m from start			
E	417643		
N	1102628		

Profile 9			
Start	Altitude 531 m		
E	418436		
N	1102960		
End	Altitude 529 m		
E	418156		
N	1103154		
Best value 1 = (7.2) at 45 m from start			
E	417500		
N	1103302		
Best value 2 = (5.4) at 220 m from start			
E	418286		
N	1103053		

Profile 10			
Start			
E	417846		
N	1103935		
End	Altitude 530 m		
E	417783		
N	1104137		
Best value (4.8) at 182 m from start			
E	417793		
N	1104072		

Kobriyaad Village

- 9th November 2022

Profile 12			
Start	Altitude 346 m		
E	457026		
N	1120605		
End			
E	456928		
N	1120936		
Best value (5.2) at 300 m from start			
E	456954		
N	1120852		

Profile 13			
Start	Altitude 346 m		
E	457431		
N	1120665		
End	Altitude 339 m		
E	457348		
N	1120980		
Best value (2.7) at 263 m from start			
E	457381		
N	1120884		

Profile 14					
Start	Altitude 349 m				
E	457850				
N	1120594				
End	Altitude 340 m				
E	457784				
N	1120970				
Best value (9.7) at 222 m from start				Altitude 342 m	
E	457809				
N	1120800				
Best value (7.2) at 121 m from start				Altitude 342 m	
E	457837				
N	1120706				

Xumbabays

- 9th November 2022

Profile 15			
Start	Altitude 425 m		
E	443739		
N	1107793		
End	Altitude 419 m		
E	443404		
N	1107793		
Best value (6.7) at 261 m from start			
E	443521		
N	1107897		

Profile 16			
Start	Altitude 430 m		
E	444139		
N	1108168		
End	Altitude 421 m		
E	443790		
N	1108451		
Best value (8.1) at 257 m from start			
E	443936		
N	1108317		

Mareer Village

- 9th November 2022

Profile 17			
Start	Altitude 454 m		
E	439410		
N	1101321		
End	Altitude 419 m		
E	439331		
N	1101696		
Best value (23.8) at 287 m from start			
E	439358		
N	1101592		
Best value (10.8) at 61 m from start			
E	439358		
N	1101592		

Profile 19			
Start	Altitude 448 m		
E	440047		
N	1101178		
End	Altitude 451 m		
E	439944		
N	1101672		
Best value (7.1) at 500 m from start			
E	439953		
N	1101653		

Profile 20			
Start	Altitude 488 m		
E	435027		
N	1101213		
End	Altitude 486 m		
E	435020		
N	1101591		
Best value (4.9) at 200 m from start			
E	435032		
N	1101401		

Caleemaley Village

- 10th November 2022

Profile 21			
Start	Altitude 478 m		
E	426962		
N	1089778		
End	Altitude 477 m		
E	426903		
N	1090130		
Best value (4.5 & 3.3) inside the village			

Profile 22 Parallel to 21			
Start	Altitude 488 m		
E	426991		
N	1090189		
End	Altitude 486 m		
E	426792		
N	1090600		
Best value (6.2) 400 m from start			
E	426786		
N	1090609		
Best value (6.9) at 383 m from start			
E	426821		
N	1090549		

Profile 23			
Start	Altitude 480 m		
E	426533		
N	1089799		
End	Altitude 478 m		
E	426515		
N	1090162		
Best value (10.4) 104 m from start			
E	426525		
N	1089899		

Ceelmareere Village

- 10th November 2022

Profile 24			
Start	Altitude 646 m		
E	402270		
N	1095151		
End	Altitude 478 m		
E	402395		
N	1095508		
Best value (6) 320 m from start			
E	402357		
N	1095441		

Profile 25			
Start	Altitude 647 m		
E	403009		
N	1094430		
End	Altitude 644 m		
E	402969		
N	1094941		
Best value (7.1) 200 m from start			
E	402997		
N	1094614		
Best value (8.7) 479 m from start			
E	402983		
N	1094885		

Ceelahelay Village

- 11th November 2022

Profile 26 (Inside the village)			
Start	Altitude 570 m		
E	407351		
N	1076076		
End	Altitude 574 m		
E	407025		
N	1076063		
Best value (10.2) 181 m from start			
E	407175		
N	1076081		

Profile 27			
Start	Altitude 574 m		
E	407025		
N	1076063		
End	Altitude 574 m		
E	406850		
N	1076452		
Best value (4.7) 62 m from start			
E	407005		
N	1076115		

Profile 28			
Start	Altitude 574 m		
E	406850		
N	1076452		
End	Altitude 569 m		
E	407082		
N	1076657		
Best value (3) 120 m from start			
E	406937		
N	1046532		

Profile 29			
Start	Altitude 575 m		
E	407061		
N	1075895		
End	Altitude 570 m		
E	407479		
N	1075673		
Best value (10.8) 419 m from start			
E	407406		
N	1075697		
Best value (8.2) 72 m from start			
E	407123		
N	1075864		

Sarmaan Village

- 11th November 2022

Profile 30 (1Km Profile)			
Start	Altitude 508 m		
E	404949		
N	1057575		
End	Altitude 508 m		
E	404774		
N	1058508		
Best value (7.2) 837 m from start			
E	404797		
N	1058356		
Best value (6.7) 379 m from start			
E	404876		
N	1057933		
Best value (5.5) 640 m from start			
E	404819		
N	1058171		

Sarmaan Hoose Village

- 11th November 2022

Profile 31			
Start	Altitude 413 m		
E	414300		
N	1050235		
End	Altitude 411 m		
E	414694		
N	1050746		
Best value (5.6) 604 m from start			
E	414625		
N	1050666		
Best value (4.4) 380 m from start			
E	414502		
N	1050506		

Profile 32			
Start	Altitude 412 m		
E	414694		
N	1050746		
End	Altitude 412 m		
E	414372		
N	1050712		
Best value (3.7) 279 m from start			
E	414443		
N	10507177		

Xumbays District

- 11th November 2022

Profile 33 (1Km Profile)			
Start	Altitude 584 m		
E	377980		
N	1066345		
End	Altitude 574 m		
E	377976		
N	1065941		
Best value (9.6) 540 m from start			
E	377988		
N	1065993		
Best value (6.4) 439 m from start			
E	377987		
N	1066084		
Best value (5.8) 140 m from start			
E	377996		
N	1066354		

Baran - Sanaag

- 12th November 2022

Profile 34 **(800 m Profile)**		
Start	Altitude 1137m	
E	207291	
N	1184430	
End	Altitude 1127 m	
E	207667	
N	1185111	
Best value (9.5) 549 m from start		
E	207549	
N	1184884	
Best value (5.1) 383 m from start		
E	207463	
N	1184748	
Best value (4.7) 678 m from start		
E	207607	
N	1184991	

Profile 35 **(800 m Profile)**		
Start	Altitude 1124m	
E	207183	
N	1185862	
End	Altitude 1120 m	
E	207209	
N	1186405	
Best value (11.7) 334 m from start		
E	207190	
N	1186159	
Best value (7.4) 160 m from start		
E	207189	
N	1186006	
Best value (6.7) 503 m from start		
E	207195	
N	1186318	

3.2. Drilling and Well Design

Here are recommendation and general procedure to be followed while conducting drilling activities:

- **Drilling Technique:** Drilling should be carried out with an appropriate tool using – Hammer Rotary machines with good compressing capacity and considerably faster using drilling fluids. Geological rock samples collected at 2-meter intervals for proper decision, record of well log of drilling method, recording geology of the area for well design and decision if stability of walls is needed e.g., Bentonite Clay.
- **Well Design:** The design of the well should ensure that screens are placed against the optimum aquifer zones.
- **Casing and screen:** The well should be cased and screened with good quality material. Owing to the depth of the borehole, it is recommended to use PVC casings and screens of high open surface area (preferably slots of 1.5mm) and 8" in diameter.
- **Gravel Pack:** The use of a gravel pack is recommended within the aquifer zone, because the aquifer could contain sands or sandstone that is finer than the screen slot size and14"diameter borehole screened at 8" will leave an annular space of approximately 1", which should be sufficient. Should the slot size chosen be too large, the well will pump sand, thus damaging the pumping plant, and leading to gradual `siltation' of the well. The slot size should be in the order of 1.5 mm. The grain size of the gravel pack should be an average 2 - 4 mm which we finally managed to add the gravel pack smoothly.
- **Well construction:** Once the design has been agreed, construction can proceed. In installing screen and casing, centralizers at 6-meter intervals should be used to ensure centrality within the borehole. This is particularly important for correct insertion of artificial gravel pack all around the screen. After installation, gravel packed sections should be sealed off top and bottom with clay (2 m). The remaining annular space should be backfilled with an inert material, and the top two meters grouted with cement to ensure that no surface water at the wellhead can enter the well bore and cause contamination.

- **Well development:** Once screen, pack, seals and backfill have been installed, the well is developed. Development aims at repairing the damage done to the aquifer during the course of drilling by removing clays and other additives from the borehole walls. Secondly, it alters the physical characteristics of the aquifer around the screen and removes fine particles. We do not advocate the use of over pumping as a means of development since it only increases permeability in zones that are already permeable. Instead, we would recommend the use of air or Water jetting, or the use of the mechanical plunger, which physically agitates the gravel pack and adjacent aquifer material. This is an extremely efficient method of developing and cleaning wells.

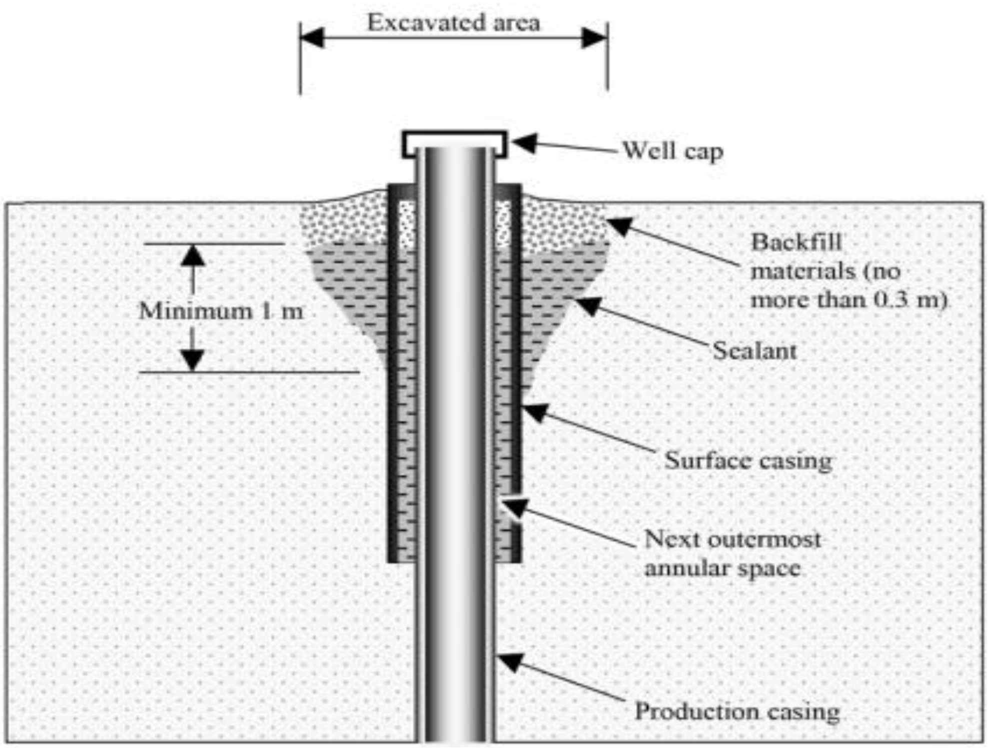


Figure 7 Well Design Layout

3.3. Major threats to the sustainable use and development of groundwater

- Pollution of groundwater can be considered the major threat for humans and livestock in Puntland. Although contamination of deep ground water is not easy and as fast as in the case of surface waters, their cleaning or remediation is much more complicated.
- Inappropriate drilling (selection of sites, drilling depth, poor construction of wells) in Puntland often results from the water shortage and urgency to provide water to vulnerable groups. Some existing sources or promising areas are far away from the consumers, forcing people to transport water from long distances or even to migrate close to the sources. Therefore, the chosen drilling sites are commonly situated near existing settlements.
- Over-exploitation of the existing sources is also under way.

3.4. Next steps

Groundwater in Puntland is a key issue in environment, health, agriculture and development as a whole. It is also a strategic resource for the alleviation of poverty and improvement of conditions in both urban and rural areas.

Planning of its efficient and sustainable use is therefore of crucial importance.

Short term measures

- **Continue the groundwater exploration,** The conducted survey represents the first yet very important step in raising the knowledge on groundwater distribution and reserves in Puntland. The present study produced a preliminary baseline document on a regional scale. In order to improve the knowledge of the most promising zones for groundwater abstraction.
- **Test aquifer and groundwater before tapping,** Additional field survey is needed and should primarily target suitable locations for drilling or construction of the aquifer to control intakes such as subsurface dams. In principle, exploratory test drilling with small diameter bits, rock sampling and air-lift testing should certify groundwater presence and suitability before any large diameter well can be drilled.
- **Control groundwater quality,** there is high need for regulatory frameworks and support to existing water utilities and medical centres to sample regularly and to conduct chemical and bacteriological analyses of the water tapped for centralized remediation is much more complicated. Inappropriate use or storage of harmful material, seepage of waste water and establishment of uncontrolled landfills, have negative impacts on groundwater quality and must be restricted, especially in populated areas and close to the water sources.

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