SWALIM

Hydrogeological Survey and Assessment of Selected Areas in Somaliland and Puntland

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Hydrogeological Survey and Assessment of Selected Areas in Somaliland and Puntland

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Disclaimer

The Hydrogeological Survey and Assessment of Selected Areas in Somaliland and Puntland (HASP) was conducted by a team comprising of international consultants and staff from FAO SWALIM and the Somaliland and Puntland water authorities under the overall supervison of **Zoltan Balint, Chief Technical Advisor and Hussein Gadain, Water Coordinator; FAO-SWALIM** and the guidance of the **Team Leader, Dr Zoran Stevanovic**, Prof. of the University of Belgrade, Faculty of Mining and Geology, Department of Hydrogeology, Belgrade, Serbia.

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Executive Summary

Groundwater situation and demand for survey

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 Somaliland and 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 in the two regions 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.

To date there no systematic data collection has been carried out on wells' exploitation, capacity and especially on groundwater level fluctuations. Finally, before this study no accurate and adequate hydrogeological maps that are essential for planning any groundwater exploration and exploitation were available for Somaliland and Puntland. This is why the FAO-managed Somalia Water and Land Information Management (SWALIM) project under Phase-IV undertook a quantitative and updated assessment of the groundwater resources of Somaliland and Puntland and the set-up of a system for groundwater level monitoring.

The overall objective of the conducted Hydrogeological Survey and Assessment of Selected Areas in Somaliland and Puntland (HASP) was creation of a base for more efficient and sustainable groundwater use in Somaliland and Puntland, while the specific objectives included: update of hydrogeological knowledge of groundwater distribution and availability in the study area; preparation of GIS database as a basis for further works in groundwater utilization 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.

Collected information

To reach the objectives of the HASP, an extensive one-year field survey and desk analysis were carried out by a team of international experts of hydrogeology, remote sensing application in geology and geophysics along with SWALIM staff and relevant Puntland and Somaliland water authorities staff. The study comprised of four parts. Remotes sensing analysis of satellite images, desk study and review of previous investigations, field survey and analysis of collected hydrogeological and geophysical data including water quality testing and finally collation of all results into maps and reports.

Utilizing remote sensing it is possible to acquire information about an object on the earth's surface without physical contact using satellites. In the process of HASP remote sensing, analysis of multispectral satellite images was conducted to obtain the land surface parameters and more accurate information on the geological conditions, existing geo-morphological forms and fractures pattern. The information was interpreted in relation to the characteristics of rocks and their differences, mineralogical and geological composition of the studied areas. Remote sensing was performed at two levels: at a regional scale (for regional map at 1:750 000 scale – Figure-A) and at more detailed scales (1:250 000) for four selected promising sites covering an area of approximately 46 000 km^2. The 4 areas were selected by the water authorities and are shown in Figure-A:

i. First area of interest (AOI-1) located southeast of Hargeysa and southwest of Oodweyne in Somaliland.
ii. Second area of interest (AOI-2) located between Xudun and Taleex in the North and Laas Caanood and Garoowe in the South. This terrain belongs mostly to the Nugaal Valley.
iii. Third area of interest (AOI-3) situated between Burtiinle in the north and Galdogob to the south.
iv. Fourth area of interest (AOI-4) falls in the area east of the village Qardho.

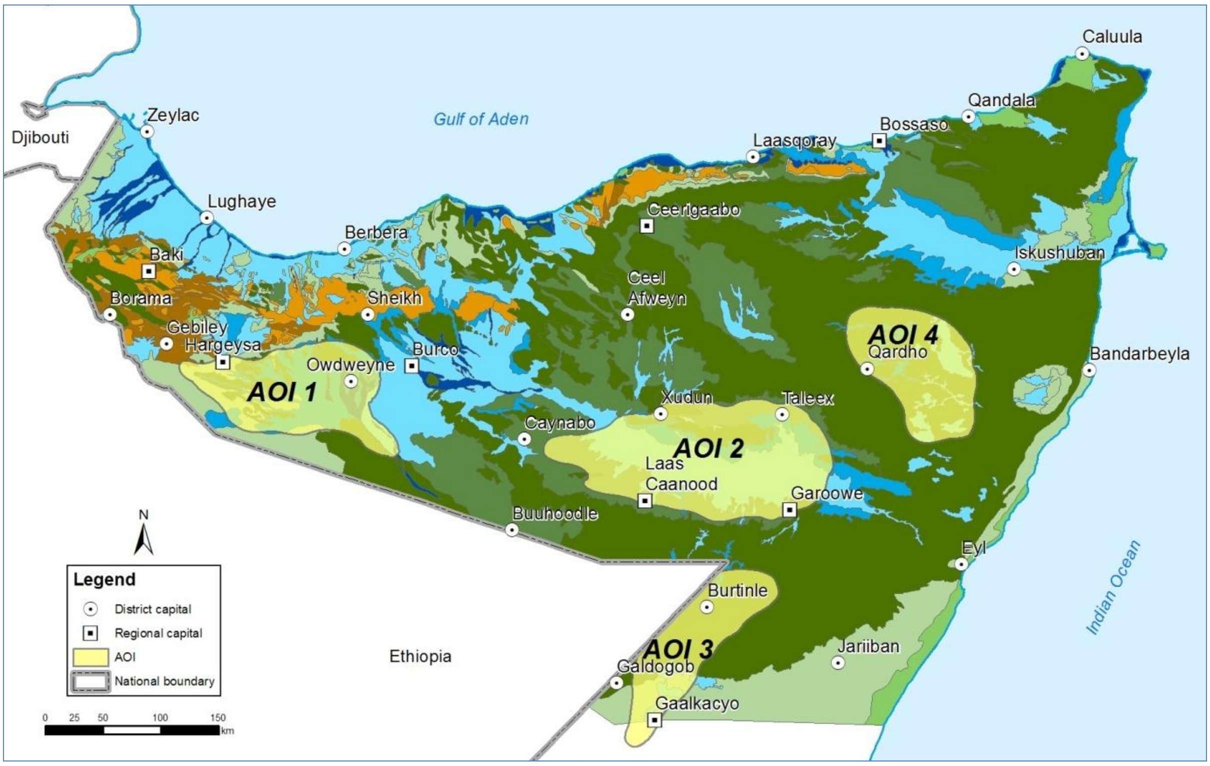

Figure-A: Coverage of the HASP with location of the four areas of interest in Somaliland and Puntland

The hydrogeology survey studied rocks forming water-bearing levels, complexes, and zones, the persistence in area and thickness of water-storing and water resistant rocks, as well as the amount of pressure and the types, quality, and regime of underground water. The values of basic hydrogeological parameters are given, and evaluations are made of the geological, geo-morphological, hydrological, climatic, and other factors affecting the recharge and formation of underground water.

The field survey enabled visiting a total of 1 270 sites; 720 water sources and 550 villages. Out of which 442 were in Somaliland and 278 in Puntland. More than half of the water sources are shallow wells. The information captured include technical hydrogeological information and socioeconomic information about population, water use and demand by both human and livestock. Basic physical water quality characteristics of acidity and alkalinity, salinity and dissolved solids (minerals) were analysed in the field (pH, EC, TDS, Temperature), while thorough chemical and mineralogical analyses were conducted using standard procedures in a specialised laboratory. In total, 511 water samples were analyzed on 30 basic chemical parameters and some important micro constituents. This enabled understanding the spatial water quality characterisation in terms of suitability for different uses - drinking, domestic, agricultural and industrial purposes. In general, the study found that, the quality of the groundwater of Somaliland and Puntland is low to moderate (with only 40-50% suitable for drinking water) with the majority of the water sources having excessive levels of salinity (70%) when compared to the United Nations, World Health Organization (WHO) standards for drinking water (1 500 µS/cm) and, hence it needs special attention as it is the only source for domestic consumption.

Through use of geophysics it is possible to investigate the subsurface conditions of the earth (geology, geological structure, groundwater bearing layers, etc.) using suitable geophysical instruments and equipments. Based on recommendations by the hydro geologists Geophysical surveys using the vertical electrical sounding-VES method were conducted for selected sites in Somaliland and Puntland. The results of VES data analysis and interpretation enabled identification of the potentiality of groundwater occurrence. More than 200 geophysical sites (87%) have shown potentiality of groundwater occurrence in the investigated depth. The recommendations from geo-electrical study may therefore be considered as basis for making decisions on where to further investigate and drill water wells. The upgraded knowledge on rock characteristics (lithology), rock fractures and infiltration capacity obtained from remote sensing and geophysical data analysis have supported hydrogeological assessment in and aquifer characterization.

A state of the art groundwater monitoring network was installed using new technology water level data loggers or divers (reliable instruments to automatically measure and store groundwater level and the groundwater temperature), in order to understand the behaviour of aquifers under natural variations in terms of the relationship between rainfall and the recharge of the aquifers in one hand and water excessive withdrawal on the other hand. Currently 8 divers for groundwater level monitoring are installed in Hargeisa, Borama, Berbera and Burco in Somaliland; and Garoowe, Boosaaso, Gaalkacyo and Qardho in Puntland. This information is expected to help prevent any future depletion of aquifers due to the high risk of groundwater over-exploitation in major towns caused by the rapidly increasing demand of water for domestic use and watering livestock.

Due to budget limitations, the short time-frame for the project implementation, and the problem of performing pumping tests in the field, the data which is used in the HASP project are from previous field investigations and tests that were conducted mostly from 2005 to 2010. Data from 28 wells which represent different geological units have been analysed and the hydraulic parameters used to define the aquifers' properties were recalculated and used in the study.

All information collected during the hydrogeological and geophysical field surveys, remote sensing, chemical analyses and other parameters determined *in situ* was posted into Geographical Information System (GIS) database. The main outputs of the HASP are the Regional Hydrogeological Map of Somaliland and Puntland adapted to the scale 1:750 000. The Map presents a general regional visualization of the distribution of groundwater and aquifers in a convenient format (Annex I), the Regional Groundwater quality Map of Somaliland and Puntland (Annex II) and the 4 Hydrogeological Maps for the Areas Of Interest (Annex III). However, considering the regional nature (large area) of the hydrogeological survey conducted and the scale of the prepared maps it is not realistic to expect to get a proper and detailed assessment of hydrogeology in certain areas and a definition of their prospect for further development. Such an attempt without additional detailed hydrogeological survey could even lead to an improper definition of drilling sites or drilling technology.

Along with these maps, several other thematic maps and GIS layers, which support the individual requirements of users such as water managers and professionals who intend to conduct further surveys in the designated areas were also developed.

Aquifer systems and groundwater resources

Groundwater is stored in a wide range of rock types, from crystalline basement rocks that store small quantities of water in fractures and faults, to alluvial sediments with variable depths that may contain huge volumes of water. Potentially productive aquifers occur extensively throughout Somaliland and Puntland with varying characteristics. Areas with groundwater potential considering their water quality and aquifer depth are classified as below:

1. Areas with fair to good water quality and well depths ranging from shallow to moderate located in the sand dunes in the central coastal belt, northern coastal regions, along the streams in the mountainous areas and sloping escarpment of Somaliland and Puntland and the coastal belt along the Gulf of Aden.
2. Areas with wells often drilled very deep and with very poor water quality occur in plateaus and valleys in Togdheer/Nugaal basins, plateaus in Hawd and Sool plateaus and valleys, plateaus and valleys in Dharoor basin and deep aquifers in the Mudug – Galgaduud plateau.

Shallow perched aquifers are often found in the alluvial sediments within the dry river beds and adjacent flood plains. The water table configuration varies between 2 – 20 m. Shallow dug wells are developed within these perched aquifers and used by a majority of both the rural and urban populations in Somaliland and Puntland.

Deep water aquifers are often found in alluvial deposits within the old river bed channels, the Karkaar, Taleh (Taleex), and Auradu formations. Drilled wells are the permanent source of water for almost all the populated places in Somaliland and Puntland. The depth of boreholes varies from 20 up to 400 m and their yield is in the range of 0.5 -17 l/s, while static water level (SWL) ranges from 2 - 270 m. However, aquifers are limited, mostly deep and often highly saline or low yielding compared to the rising demand that is driven by population growth.

The majority of wells drilled within these materials from later geologic times produce hard water often with a high content of sulphates, bicarbonates, carbonates, chlorides, etc. Nonetheless, these aquifers serve as the main sources of water in the two regions. The many productive water wells which have been drilled over the years attest to this fact.

One of the main HASP outputs include the first ever classification of local aquifer systems and groundwater resources assessment (both quantity and quality) of selected areas of interest.

Out of the nine hydrogeological units which belong to the major six aquifer systems classified in the study area, four are most promising for further development and groundwater utilization. They are: Major Togga'a alluviums (inter-granular aquifer of Quaternary age), Jurassic lime-stones (karstic aquifer), Auradu lime-stones (karstic aquifer of Lower Eocene age), and Karkar lime-stones (karstic aquifer of Upper Eocene). The best transmissivity values were obtained from pumping tests of the wells drilled in alluviums and lime-stones.

By estimating actual recharge and permeability of four major aquifers, it was roughly concluded that an equivalent average flow from these major aquifer systems (dynamic reserves) could be equal to 139 m^3/s.

Considering the size of Somaliland and Puntland, the specific groundwater yield is less than 0.5 l/s/km^2, which classifies the region as extremely poor in groundwater reserves. In accordance with UN World Health Organization (WHO) and certain other standards for water availability per capita, the region can be categorized between extremely poor and poor: replenished dynamic reserves provide approximately 900 – 1 000 m^3/per capita/year. However, their full utilization is far from the needs of the current situation or even reality.

Five major hydrogeological systems are classified as weak or poor for groundwater development. Groundwater reserves are restricted to certain zones and locally are of higher permeability of fissure and inter-granular aquifers. In these hydrogeological units, discharge of the wells higher than 1.0 l/s is very rare. However, such or similar flow can be sufficient to satisfy drinking water demands for local villagers and their animals. Drilling of "humanitarian" wells should be extended, but only after a feasibility assessment and under professional supervision.

Distribution of both aquifers of good productivity and hydrogeological units with limited reserves is presented on the regional hydrogeological map 1:750 000 scale and hydrogeological maps of the four areas of interest.

In order to assess the water situation in major towns which have around 2.5 million inhabitants or about half of the total population, a survey of fourteen water utilities in Somaliland and Puntland was conducted. Considering the fact that the current extraction rate for these towns is 0.74 m^3/s (according to information provided by the utilities) there is a shortage of around 1.5 m^3/s, or, in other words, almost 70% of actual water needs are not being met. It was confirmed that not more than 25% of the population is connected to the surveyed water distribution systems. The most problematic area is Hargeysa city where over 750 000 residents mostly in suburban areas have no proper access to tap water.

Considering the regional character of the hydrogeological research conducted in this stage, to expect to get a proper and detailed assessment of hydrogeology in certain areas and a definition of their prospects for further development is not realistic. However, based on remote sensing findings and hydrogeological information obtained from selected areas of interest some more promising (potential) areas for groundwater development are delineated. These promising areas comprise a surface of some 2 400 km^2 or nearly 1% of the entire study area. Although estimated GW reserves in these areas theoretically enable extraction of 2 - 3 m^3/s, the pumping rates should be strictly at least 3 - 4 times less due to the limited recharge of the aquifers. Otherwise, an over-exploitation and depletion of existing reserves will take place.

Groundwater quality and pollution

Groundwater quality and chemical composition is a result of soil and geological formations through which the water has residence time, effective recharge, groundwater depth as well as pollutants if they are presented in the catchment area. Physical properties and concentrations of chemical components in groundwater vary widely within Somaliland and Puntland areas, depending on the location and type of water sources (spring, dug well, drilled well).

Measurements conducted in the field show variations of acidity and alkalinity levels (pH) in tested waters between 6 and 10, water temperatures in the range of 19 – 38 ^{0}C, and electrical conductivity values from 160 to 11 000 µS/cm. The latter confirms that salinity of groundwater from certain formations can be very high.

Based on the chemical analyses of 511 samples hardness, levels of calcium, magnesium, sodium, potassium and other components are usually above the recommended WHO standards for drinking water, but acceptance of these waters is a necessity, as there is usually no alternative. However, consumption of waters with concentrations above the standard limits is not necessarily harmful and appropriate water treatment must be considered in areas where adverse types of water are likely to have hazardous effects on man and livestock.
Groundwater in the study area can also be contaminated by various chemical pollutants. The consequence of the civil war has led to presence of explosives and different dangerous materials in certain areas. Their presence in highly permeable karstic aquifer is extremely dangerous.

According to bacteriological analyses, shallow aquifers are quite commonly contaminated and may cause widespread water related epidemics, which is often the case in Somaliland and Puntland.

Major threats to the sustainable use and development of groundwater

- *Pollution of groundwater* can be considered the major threat for humans and livestock in Somaliland and 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 use or storage of harmful material, seepage of waste water and establishment of uncontrolled landfills, all registered during the SWALIM field survey, have negative impacts on groundwater quality and must be restricted, especially in populated areas and close to the water sources.

- *Inappropriate drilling* (selection of sites, drilling depth, poor construction of wells) in Somaliland and Puntland often results from the water shortage and urgency to provide water to vulnerable groups. One of the major problems for proper and sustainable development of groundwater is its unequal distribution. 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. In many cases, unfortunately, promising areas of water tapping do not coincide with settlements, and proper hydrogeological assessment and feasibility studies are required before any drilling occurs.
- *Over-exploitation of the existing sources is also under way.* Although Borama was the only one water utility where over-exploitation was clearly reported during the SWALIM inquiry (2.6 m/year), the majority of wells in the study area are pumped over their normal capacities. In fact, their over-exploitation has not been largely evidenced either due to lack of monitoring network or because a small number of consumers is currently connected to the water supply systems.

Next steps

Groundwater in Somaliland and 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 to raising the knowledge on groundwater distribution and reserves in Somaliland and 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, it would be necessary to conduct further field hydrogeological and geophysical surveys.
- *Test aquifer and groundwater before tapping.* Additional field survey are 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

supply. The Governments and donors should provide sufficient laboratory equipment and other logistical facilities.

- *Establish mobile teams for in-field checking of sanitary conditions and mapping of the pollutants* close to the utilized water sources (landfills, sewage waters, large septic tanks, hazardous materials). Support of local and international institutions is expected.
- *Complete and maintain groundwater monitoring network*. The initial groundwater network established under this survey should be completed and the rest of the monitoring equipment (divers) installed, and data on pumping rates, groundwater table fluctuations and physical parameters regularly collected and evaluated.
- *Maintain established GIS Geo database.* In order to improve the quality and adequacy of this important managerial and decision-making tool, it is necessary to continue with the collection and interpretation of data from various sources (field survey, laboratory analyses, monitoring data on climate, hydrology, hydrogeology, reports, maps).
- *Involve the available already-trained staff*. The hydrogeological survey was successful in the capacity building of the personnel from ministries involved in groundwater exploitation in Somaliland and Puntland. Their capacity has to be further improved through concrete projects execution and additional practical trainings in collaboration with universities or agencies involved in groundwater studies and development. The above activities should be implemented jointly by local and SWALIM staff, supported by international experts and specialized companies when necessary.

Medium and long term measures

- *Establish sanitary protection zones* around the existing utilized water sources. Following the general recommendations from this report, other references and broad experiences for different aquifer systems, delineation of sanitary protection zones, fencing of first sanitary zone and implementation of appropriate preventive measures to protect groundwater from pollution are required.
- *Extend groundwater monitoring network*. The expanded network should comprise some important natural springs and wells in selected villages and remote areas. They have to represent different aquifers and zones away from the main water utilities and regional cones of depression. Guidelines from the Water Framework Directive of European Union could be used as a base for establishing the surveillance and operational monitoring in the study area.
- *Design and construct groundwater control and conservation structures.* Control of aquifer pumping supported by some new solutions and intakes is a necessary precautionary measure for the sustainable aquifer development. Detailed hydrogeology survey and feasibility study of discovered suitable sites mostly located along major dry river beds (toggas) should result in final designs and civil works on subsurface dams, water storage structures or specific water intakes.
- *Prepare and adapt to the local circumstances Water Master Plans* for Somaliland and Puntland. Their integral parts should be: the establishment of a regulatory framework of provision of drilling licences and permissions, a

regulatory system for agencies responsible for water use and development and water quality control (on regional or municipality level). The regulation of work of water users associations or individual operators should also be included in these plans.

- *Remove existing major pollutants and remediate their previous locations.* Based on a conducted survey and mapping of hot pollution spots, cleaning and remediation of contaminated soil and water should be systematically carried out upon defined priorities. Along with their removal of new sanitary proper landfills, waste and drinking water treatment plants and chlorination stations should be designed and constructed. Depending on the density of the population, their size will rank from very small to large.
- *Strengthen sanitary education in schools*. It is an essential prerequisite for a progressively improved sanitary situation in the region. NGOs and donors should support the local authorities in creation and introduction of educational programmes for awareness raising of the local population regarding the importance of sustainable use and protection of water sources.
- *Train the local authorities, users and stakeholders in the use of hydrogeological information and products*. Additional educational and promotional programmes should facilitate an understanding of the groundwater existence, movement and appearance in order to ensure sustainability of this invisible but vital resource.

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Note: The maps in annex I - VI are available in the attached CD or on request from SWALIM (swalim@fao.org)

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Acronyms

AOI	Area of Interest
bgl	Below Ground Level
CEFA	Comitato Europeo di Formazione Agraria (European Committe for Agricultural Training)
CMI	Clay Mineral Index
COOPI	Cooperazione Internazionale
DEM	Digital Elevation Model
EC	Electrical Conductivity
FAO	Food and Agriculture Organization of the United Nations
FC	Field Coordinator (for survey) from SWALIM Office, Nairobi
GAA	German Agro-Action
GCS	Geographic Coordinate System
GF	Geophysics
GIS	Geographic Information System
GKW	Gesellschaft für Kläranlagen und Wasserversorgung (German Institution)
GPS	Global Positioning System
GTZ	Gesellschaft für Technische Zusammenarbeit (German Technical Aid)
GUMCO	Golden Utility Management Company
GW	Groundwater
HASP	Hydrogeological Assessment of Somaliland and Puntland
HG	Hydrogeology
hr	Hour
IDP	Internally Displaced Persons
IFAD	International Fund for Agricultural Development
K	Hydraulic conductivity (m/day;)
MDG	Millennium Development Goals
MIR	Mid-infrared
MMEWR	Ministry of Mining, Energy and Water Resource - Somaliland
MNF	Minimum Noise Fraction
MVI	Moisture Vegetation Index
NDVI	Normalized Difference Vegetation Index
NGO	Non-Government Organization
NIR	Near-infrared
PET	Potential Evapotranspiration
pH	Concentration of Hydrogen ions in water
PSAWEN	Puntland State Agency for Water, Energy and Natural Resources
PPI	Pixel Purity Index
Q	Yield, discharge
Q/s	Specific capacity (discharge - drawdown ratio; in m^3/hr/m)
RGB	Red Green Blue
RS	Remote Sensing
SHAAC	Somali Water Consulting Company
SOGREAH	Consulting group specialising in development and the environment

SWALIM	Somalia Water and Land Information Management
SWIMS	Somalia Water sources Information Management System
T	Transmissivity (values in m^2/day or m^2/s)
TDS	Total Dissolved Solids
UAE	United Arab Emirates
UNDP	United Nations Development Programme
UNICEF	United Nations Children’s Fund
UNPOS	United Nations Political Office for Somalia
UTM	Universal Transverse Mercator
VES	Vertical Electrical Soundings
WASH	Water, Sanitation and Hygiene
WGS	World Geodetic System
WHO	World Health Organization
µS/cm	micro-Siemens per centimetre: unit for electrical conductivity

Chapter 1. Introduction

1.1 Background

The investigated area covers 288,400 square km and comprise of Somaliland and Puntland. The area is generally hot, arid to semi-arid with annual rainfall of between 50 - 150 mm along the coast and up to 500 mm in the highlands. The land forms comprise flat plateaus and coastal plains. Highlands are only found to the north, and are characterised by mist forests. There are no permanent rivers in the region; only flashy streams exist which have surface water only after high rainfall events and normally drain into either the Indian Ocean, or the Gulf of Aden. These ephemeral water courses are important for water sources (wells dug at the river banks / beds), and for their relatively rich vegetation.

The water supply situation in Somaliland and Puntland is poor, particularly in rural areas where women and children travel long distances to a water source in the dry season to collect water for domestic and livestock use. Surface water resources are generally scarce because of their dependency on seasonal climatic variations that leave traditional surface water storage facilities either partially filled or empty. The majority of the Somali population have no access to an improved source of water and access to improved sanitation facilities. The country is far from realising the Millennium Development Goals (MDG) by 2015.

Despite groundwater being the main sources of water for human, agriculture and livestock, there is neither a hydrogeological map nor sound policy for groundwater management and exploration in Somaliland and Puntland. Information on hydrogeology to facilitate drilling and development of strategic water sources is limited, scattered and in some cases do not exist. It requires huge resources to get accurate information on potential drilling sites. Hence, knowledge of groundwater resources is essential for strategic long-term planning. To achieve sustainable water supply for vulnerable groups and help Somali reach the MDG targets, there is high need for hydrogeological information to guide successful borehole drilling and establishment of strategic boreholes for use during drought periods in order to reduce or eliminate water trucking costs.

Demand for groundwater in Somaliland and Puntland has doubled in the recent past due to an increase in population as a result of the relative stable political situation and, growing wealth from the diaspora. While a large proportion of the population lives in rural areas, urban needs increasingly dominate the development agenda. There are already evidence and cases of decline in groundwater levels in some cities like Boroma in Somaliland due to over pumping after the stability seen in the region.

Hydrogeological information will help spell out the status of groundwater resources and allow for sound water resources planning and management policies.

Data on strategic water sources were collected in 2009 by FAO under the Somalia Water and Land Information Management (SWALIM) project. The condition of many of these sources has deteriorated from wear and tear and lack of proper maintenance, prompting need for new sources. Information on status of the strategic point water sources needs to be regularly updated in terms of spatial distribution and functionality.

Despite the wealth of available information, the state of knowledge about hydrogeology, quality and quantity of groundwater resources is very poor. In many cases, groundwater drilling projects in the region are unguided and exploration takes place without investigations leading to low success rates, thus wastage of financial resources. There is 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 fill the needs of IDPs and pastoralists during severe droughts. According to the Somali WASH cluster, water trucking as a common method for providing drinking water is extremely expensive with the quality of water supplied often questionable.

This study addressed these and other issues. The information generated by the project is expected to benefit WASH agencies to locate areas of potential groundwater resources that can be used in development of sustainable water sources for the communities.

The study on hydrogeological survey and assessment of selected areas in Somaliland and Puntland made use of availaible resources held in different archives, e.g. UNDP 2006 survey, and on the data that was created during previous phases of SWALIM and that include geological maps, borehole and spring data from water sources survey, some satellite images, land use maps, soil type map, geoelectric surveys that were carried out by different actors, digital terrain model, etc.

1.2 Previous studies and investigations

The geology of Somaliland and 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. Macfadyen's report "Water Supply and Geology of Part of British Somaliland" (1951), made a valuable contribution to the knowledge of the geological and hydrogeological conditions. The report includes data on meteorology, stream flows, surface geology, borehole logs of the shallow aquifer in the Hargeysa, Ceerigabo and Burco. Records of the 46 boreholes (3,200 meters were drilled) for water supply of Hargeysa during 1931-1939 are also reported by Macfadyen.

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.

Considerable comprehensive information on previous works could also be found in Faillace and Faillace "Hydrogeology and Water Quality Report" (1986). This work is a result of a large GTZ project and is widely used as a main reference on the hydrogeology of the region. More detailed description of the aquifer systems and the potential groundwater development areas across Somalia is presented. The report is divided into three sections covering the northern, central and southern regions.

In their report Faillace & Faillace (1986) stated that the northeastern area has not been investigated on a regional scale. Because of the rather limited agriculture potential, the low rainfall, the scanty vegetation, and the limited natural resources of the area, only very localized zones have been studied. The GTZ programs for the water supply development in Burco, Ceerigabo, Garoowe, and Qardho (1981) have been very useful in defining the geological and hydrogeological conditions existing in these towns.

The Chinese program for the development of water resources in rural areas was completed in 1986, with the drilling of 43 boreholes. About 30 of them were completed as production wells: 24 were drilled for the water supply of towns and villages and in grazing areas for watering livestock; 6 were drilled for the Hargeysa water supply in Geed Deeble (later on 7 more wells were drilled).

The report of Popov et al. (UNDP, 1973) divides the northern area into seven hydrogeological provinces identified according to their general characteristics and their water resource conditions. The report includes the results of a large number of chemical analyses.

In the 1980s, the northwest region was investigated by the French consulting firm SOGREAH that made a comprehensive study evaluating the overall groundwater potential of the catchments of four major toggas. The study contains numerous geologic and hydrogeological data, over 400 electrical conductivity measurements and 30 chemical analyses. While date palm cultivation is the primary agricultural activity along the coast, SOGREAH studied the groundwater conditions in selected areas with the purpose of promoting programs aimed at expanding the areas presently cultivated (1982).

A description of the hydrogeological basins is also provided by Johnson (1978). While the report presents a general description of the groundwater system, quantitative figures on the recharge and the yields of these aquifers are missing.

A study of selected areas of the basement complex and the possibility of finding water in its fissures was carried out by the American consulting firm BCI Geonetics as part of an investigation into the possibilities of selecting suitable sites to drill boreholes for the purpose of alleviating the water supply problem of the refugees. BCI Geonetics inventoried and carried out about 30 water quality field tests limited to EC, pH, chloride, and total hardness measurements.

Pozzi and Benvenuti made a study of the Nugaal Region, with a special interest in the area between Garoowe to Sinujiif and to Eyl.

After 1986 and the Faillace & Faillace study, there was a gap in geological survey caused by regional war, internal conflicts, and the very unstable political situation. From the year 2000 some drilling and surveying activities restarted and intensified. Groundwater survey for the Dur Dur (Durdur) watershed in the Awdal region was a part of a water management plan prepared by the German Agro-Action (2005). Petrucci (2006) prepared a geophysical study for some areas of NW Galbeed and the Awdal regions of the Hawd Plateau. In 2007 two reports were made by Basnyat and Buggianai; the former wrote “Water resources of Somalia” while Buggianai continued the work of Petrucci in the Awdal region. Van der Plac conducted a wide research programme for the Burco (Burao) water supply project in 2001.

Azzaroli and Merla produced the first geological map on the scale 1:500,000 for Somalia and Ogaden. Beydoun in 1970 and Popov in 1972 also prepared geological maps for the study area in their studies and reports. The compilation geological map of Ethiopia and Somalia on the scale 1:2,000,000 was then produced and published by geologists from the University of Florence (Merla et al. 1973). This map was compiled from various sources. The eastern part, including the Bari and Nugal regions, was adopted from the aforementioned "Carta Geologica della Somalia e dell'Ogaden" on a scale of 1:500,000 published by Azzaroli and Merla in 1959. The geology of the remaining area was adopted from the "Geological Map of Northern Somalia and Socotra-Gulf of Aden", by Beydoun Z. R. (1970), and from the 1:125,000 scale geological maps included in the seven geological reports compiled by several geologists of the former Geological Survey, Somaliland Protectorate, during the 1950s. The next compilation map on the scale of 1:1,500,000 was the result of work by the University of Florence, University of Padua and Somali National University (1987-1991). It was published in 1994 (authors Abbate, Sagri and Sassi) and is used for this survey as the main information source on distribution of geological units.

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, Puntland and Somaliland. 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). Based on information collected through partners implementing water projects in the field during SWALIM II, data from only 750 water sources was received for a period of more than a year, and in many cases the data covered only a small section of the essential information. As a result it became necessary for SWALIM to move to the field and do an inventory of all water sources points in Somalia. A countrywide survey was launched for the strategic water points: boreholes, springs, dams and shallow wells which last long into the dry season.

Extensive field survey was conducted by FAO/SWALIM in Somaliland and Puntland in the spring of 2008. A total of 1,609 sources was assessed, with dug wells recording the highest number, 864.

The results were matched with the number of different users utilizing the sources. The users of these sources were categorized as urban, rural and nomadic. The rural users of all sources surveyed amounted to 71.41%. Some sources are used by both nomadic and rural users. The information collected during this survey was posted in the SWIMS database.

1.3 Purpose and scope of the study

1.3.1 Overview of the current hydrogeological status

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. Finally, before this study no accurate and adequate hydrogeological maps that are essential for planning any groundwater exploration and exploitation were available for Somaliland and Puntland.

The water supply situation in many parts of the study area is known to be exceptionally severe. This is due to its very low effective rainfall. Hence, groundwater development may be the main water supply source in the country. A large proportion of Somali people still do not have access to this basic and life-saving commodity. Several deep drilling projects were undertaken; however, due to lack of prior hydrogeological knowledge, the success rate of groundwater development or drilling of successful wells has been very low.

There is an urgent need for a quantitative and updated assessment of the hydrogeological resources of Somaliland and Puntland. A full hydrogeological investigation is out of reach due to time constraints and costs. One of the main activities of the FAO-managed Somalia Water and Land Information Management (SWALIM) project under Phase-IV is the preparation of a hydrogeological assessment, and the set-up of a monitoring system for hydro-geological monitoring, including relevant ministry staff and public utilities in Puntland and Somaliland.

1.3.2 Objectives: overall and specific

One of the main objectives of Phase IV is groundwater assessment of Somaliland and Puntland and the creation of a base for its sustainable use and development.

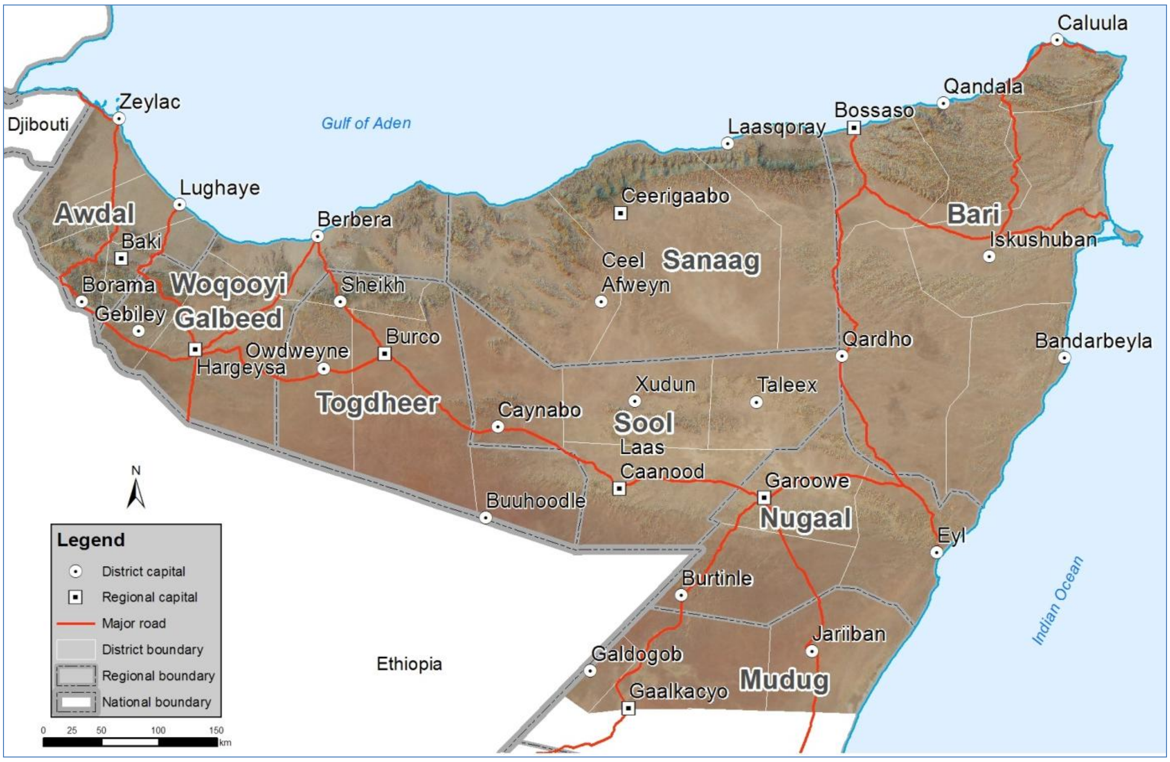


Figure 1.1 Study area in Somaliland and Puntland (HASP)

Therefore, the overall and specific objectives of the Hydrogeological Assessment of Somaliland and Puntland (HASP) are as follows:

Overall Objective:

Create a base for more efficient and sustainable groundwater use in Somaliland and Puntland.

Specific Objectives

- *Update hydrogeological knowledge of groundwater distribution and availability in study area.*
- *Prepare GIS, Database and reports as a base for further works in groundwater utilization and protection in order to improve sanitary and livelihood conditions in urban and rural areas.*
- *Identify certain promising areas for groundwater development and make proposals for detailed hydrogeological, geophysical studies and drilling.*
- *Build local technical capacities for groundwater surveys.*

1.3.3 Outcomes of the study

To reach the objectives of HASP, an extensive 1-year survey was planned to be conducted by the team of international experts for hydrogeology, remote sensing application in geology and geophysics along with the SWALIM staff and the employed local staff.

The HASP outcomes defined in the Concept Note are to be results of the following major activities:

- Collection of scattered geological, geophysical, hydrological and hydrogeological information and review of existing studies, reports and surveys carried out in the two regions,
- Assessment of all existing information on geology and groundwater and input in a dedicated GIS.
- Remote Sensing analysis of multispectral satellite images (ASTER, LANDSAT, etc.), with field verification for updating of the geological conditions and a definition of the fractures pattern; and the knowledge of lithology, rock fractures and infiltration.
- Field surveys that include a geological and geophysical survey. Update of selected SWALIM inventoried permanent water sources and execution of a few pumping tests in selected aquifers.
- Training of local authorities, users and stakeholders in the use of hydrogeological information and products.

1.4. Organization of the report

1.4.1 Chapters of the book

The Hydrogeological Survey and Assessment of Selected Areas in Somaliland and Puntland (HASP) report is divided into six main chapters:

Chapter 1 gives a general background of the study, with details about the current hydrogeology status in Somaliland and Puntland. Previous hydrogeological studies and investigations in the study area are also summarised in this chapter including the study objectives and outcomes.

Chapter 2 presents description of the study area in terms of administrative units and population (geography), climate variability, hydrology and geomorphology. The geological and hydrogeological features of the study area are also discussed in this chapter.

In ***Chapter 3***, the methodology used for the HASP is described. This includes the methodology for remote sensing analysis of satellite data; field survey procedures for both hydrogeological and geophysics data collection; pumping test data collection and analysis; groundwater quality assessment; database creation (SWIMS and Geodatabase); and development of hydrogeology maps in GIS.

Chapter 4 presents the final study results and their discussions, where the findings of the remote sensing analysis in terms of tectonic patterns, geomorphological features, fracture lineaments and groundwater aquifer zoning are presented. The results of geophysics investigations and hydrogeology survey and groundwater chemistry are also presented in this chapter. The chapter gives details on classification and distribution of aquifer systems in Somaliland and Puntland, groundwater recharge, and variability of groundwater quality in the different geological formations.

Groundwater Management in Somaliland and Puntland is described in ***Chapter 5***. This includes groundwater utilization and demand, promising areas for groundwater tapping, aquifer control and regulations.

Chapter 6 gives a summary of the study and recommendations for further hydrogeological investigations in the studied areas.

1.4.2 Links with other reports, maps and databases

The Hydrogeology Survey and Assessment of Selected Areas in Somaliland and Puntland (HASP) summarises an elaborate process of field survey, data collection and analysis. The study involved acquiring and analysing remote sensing data; field surveys for the collection of geophysical and hydrogeological data; analysis of the data; creation of databases and development of final products in the form of maps and reports. Details of the processes involved in the assessment are provided in 4 appendices to this main report. These are:

Hydrogeology Survey and Assessment of Selected Areas in Somaliland and Puntland - Appendix I: Field Survey Report

Hydrogeology Survey and Assessment of Selected Areas in Somaliland and Puntland - Appendix II: Geoelectrical Survey Analysis Report

Hydrogeology Survey and Assessment of Selected Areas in Somaliland and Puntland - Appendix III: Remote Sensing Analysis Report

Hydrogeology Survey and Assessment of Selected Areas in Somaliland and Puntland - Appendix IV: Database Creation Report

While this report presents the HASP results, each of these appendices is a complete report on its own presenting the detailed methodology, findings and results of the respective processes.

Data collected during the HASP were analysed and managed into two databases: the Somalia Water Sources Information Management System (SWIMS) and the Geospatial Database (Geo-database). The data was processed and presented in the form of tables and maps for visualization, query and other operations. Besides these databases, the final results of the HASP is presented in six maps attached at the end of this report. The maps are well explained and referenced in the report. The regional hydrogeological and groundwater quality maps are produced at a sacle of 1:750,000, while the maps for the 4 selected areas of interests (AOI) as recommended by the water authorities in Somaliland and Puntland are produced at a scale of 1:250,000 – 1:350,000. For clarity and design purposes it is recommended the maps should be printed in A0 size paper. These maps are:

Annex I: Regional Hydrogeological Map of Somaliland and Puntland
Annex II: Regional Groundwater Qauality Map of Somaliland and Puntland
Annex III: Hydrogeological Map of Area of Interest 1 (AOI-1)
Annex IV: Hydrogeological Map of Area of Interest 2 (AOI-2)
Annex V: Hydrogeological Map of Area of Interest 3 (AOI-3)
Annex VI: Hydrogeological Map of Area of Interest 4 (AOI-4)

Chapter 2: Description of the Study Area

2.1 Geography

The study covers the areas of Somaliland and Puntland, which were formed following the fragmentation into states of the Somalia Republic after the break of civil war in 1991. Somaliland declared independence from the rest of Somalia on 18th May 1991, using the borders of the former British Somaliland which existed before independence. Similarly, Puntland state declared itself an autonomous state of Somalia in August 1998 and its territory consisted of the northeastern regions of Somalia.

2.1.1 Administrative units

The study area covers 8 administrative regions shown on the map in Figure 1.1. These are Awdal, Woqooyi Galbeed, Togdheer, Sool, Sanaag, Bari, Nugaal and Mudug. Each of these regions consists of several districts as indicated in the map.

Some of the cities and big towns in the study area are Hargeysa, Garoowe, Boosaaso, Berbera, Burco, Borama, Gaalkacyo, Ceerigaabo and Laas Caanood.

2.1.2 Population of study area

The population of Somaliland in 2009 was estimated at 3.85 million according to the Ministry of National Planning and Development (Somaliland in Figures, 2011). About 55% of the people are nomadic pastoralists and 45% are urban and rural dwellers. Somaliland is predominantly a nomadic pastoral community and traditionally the major livelihood is livestock husbandry, which is the main source of food and income for 70% of the population including rural pastoral and urban communities. Crop production ranks second to livestock, and is practised mainly in the districts of Hargeysa, Gabiley, Borama and Baki.

In Puntland, the population as at 2009 was estimated to be 2.4 million, 65% of which are nomadic pastoralist. Most of the Puntland territory is arid rangelands and is best suited for livestock grazing and not for crop production due to the general scarcity of water and the saline soils with high content of salt deposits. However, small scale oasis farming systems are found scattered along dry river basins and places with good quality soil near shallow hand dug wells.

2.2 Climate

The climate in Somaliland and Puntland varies from desert in the northeastern parts of the coastal areas of the Gulf of Aden basin and some areas in the Dharoor basin in the north-east to arid and semi-arid in much of the Gulf of Aden and Nugaal basin. Moist semi-arid climate prevails in the mountainous areas.

The hydrometeorological network as well as all major water resource infrastructures were totally destroyed during the civil war in the 1990s. Consequently, data on the water resources of the country for a period of many years is scattered and missing. As little climatological and hydrological data are available after 1990, most of the analysis was carried out using the pre-war data (before 1990). However, it is assumed that data on the hydrometeorological regime can be considered as still valid (Basnyat, 2007).

Rainfall in the study area drainage basins is low and erratic. There are wide spatial and temporal variations in the rainfall patterns over most of the areas. There are both seasonal and inter-annual variations in the amount of rainfall in the areas.

The long-term mean annual rainfall varies from 93 mm in the Dharoor basin to 549 mm in the Lag Badana basins (Basnyat, 2007). The minimum annual rainfall is around 20 mm in parts of the northern coastal locations in the Gulf of Aden. In some parts of the Dharoor and Nugaal basins it is as low as 66 and 80 mm, respectively.

There is a significant spatial variation in rainfall in the catchment areas of the study area. According to Basnyat (2007) the mountain region in the western part of the Gulf of Aden basin receives more than 500 mm of annual rainfall e.g. Borama (543 mm) and in Sheekh (515 mm). However, the coastal areas in the northern part of the Gulf of Aden receive very little annual rainfall (less than 20 mm in Berbera, Alula and Boosaaso). The catchment areas in the Dharoor basin also receive little water (e.g. Scusciuban 72 mm). The western part of the Nugaal basin near the mountains receives about 240 mm (e.g. Burco) and further east it decreases to about 110 mm (e.g. Qardho).

The distribution of rainfall is linked to the four seasons:

- *Jilal,* the northeast monsoon, a dry and hot season from December to March
- *Gu,* a transition period, an important rainy season from April to May
- *Hagaa,* the southwest monsoon, a dry and hot season from June to September
- *Deyr,* the second transition period, an important rainy season from October to November.

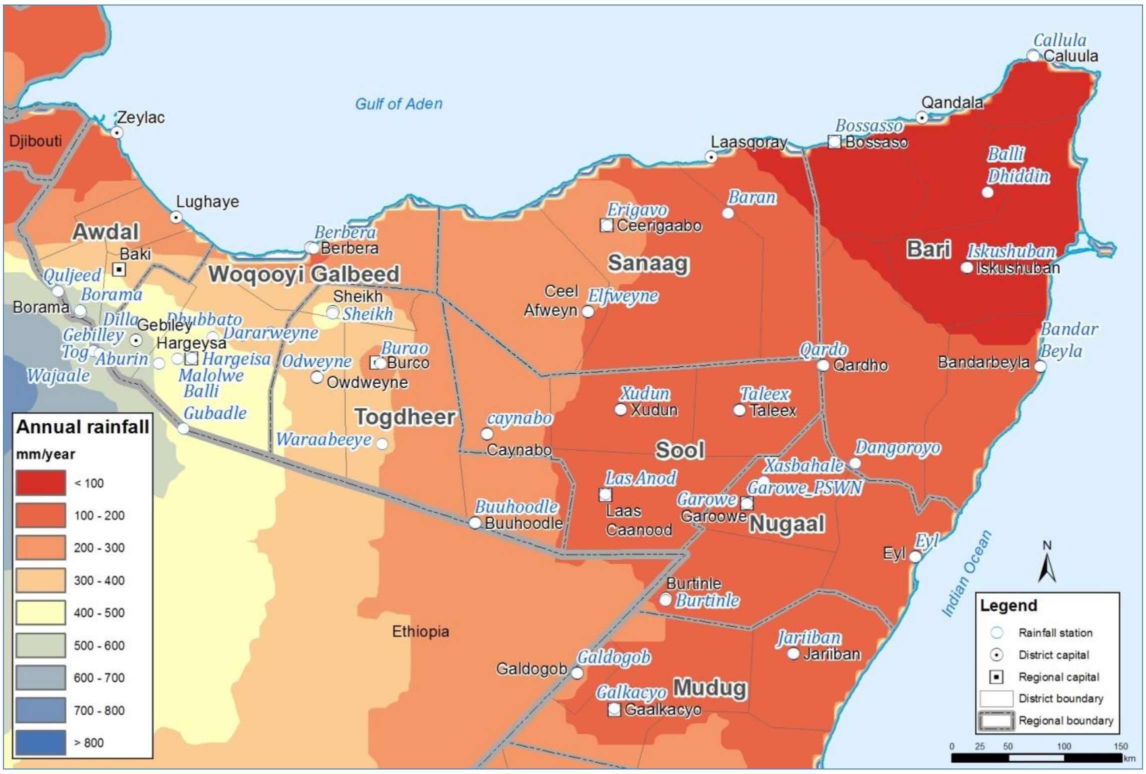


Figure 2.1 Operational monitoring network and rainfall distribution map of the study area

The climate shifts towards a very hot and very arid regime during the Jilaal and Hagaa seasons and at the beginning of rainy seasons, particularly the Gu season. Despite the wet character of Deyr, the areal percentage of rainfall can be quite low, as in the Gulf of Aden. The mountainous western region e.g Borama, receives a good amount of rainfall in Hagaa compared to Deyr and other seasons. Rainfall in the Gu and Hagaa seasons is good for rain-fed agriculture. The locations in the coastal regions (Boosaaso and Berbera) receive very little rain.

Basnyat (2007) noticed that in the case of basins away from the coast, about 50% and 30% of the annual rainfall occurs in the Gu and Deyr seasons, respectively. He also noticed that in terms of the seasonal variations of the rainfall, there is an exponential correlation between elevations and Hagaa rainfall and an inverse-exponential correlation between elevation and Deyr rainfall. At higher elevations especially in the north-western regions there is more Hagaa rainfall than in other reqions and less Deyr rainfall. However, no correlation was seen in the percentage of rainfall falling in the Jilaal and Gu seasons.

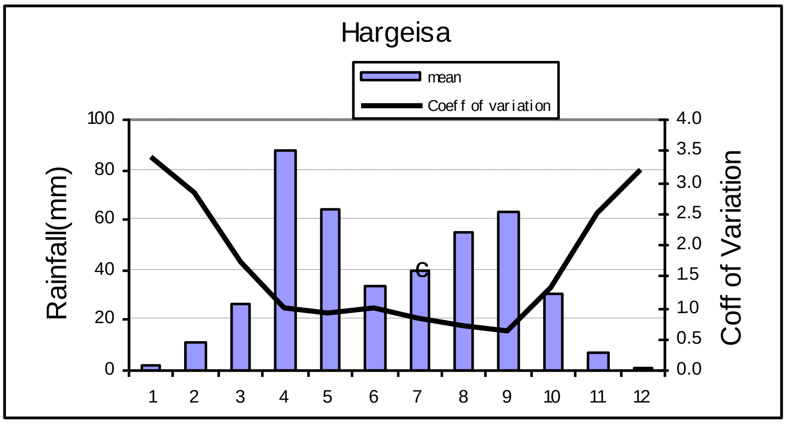


Figure 2.2 Average mean monthly rainfall distribution in Hargeysa

The annual Potential Evapotranspiration (PET) exceeds 2,000 mm in the Somaliland and Puntland, and is even as high as 3,000 mm in the Gulf of Aden. In most locations, PET exceeds rainfall in all months of the year. Except in a few locations in the extreme northwest regions, even 0.5 PET exceeds rainfall in all months, giving zero values for the longest vegetation growing period in most of the areas. This is why most areas in the northern basins are not suitable for agriculture (Basnyat, 2007).

The mean air temperatures are generally high, in the range of about 25^{o}C to more than 35^{o}C in the northern coastal regions (e.g. Berbera and Boosaaso) while it is cooler in the north-western mountain region (e.g. Shiekh) where it varies from about 15^{o}C to about 23^{o}C. In the inland areas of the Darror and Nugal basins, it varies between 22^{o}C and about 33^{o}C. The mean temperature is highest from June to August in the Gulf of Aden basin areas whereas the peak temperature occurs from May to September in the inland areas.

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

The Precambrian era was followed by uplift and erosion and the peneplained basement rocks were covered by conglomerate and sandstone during the Lower Jurassic which marks the sea transgression. Marine sediments were deposited during the Middle Jurassic over the regions. These sediments are predominantly fossiliferous limestone, marl and shale. Towards the end of the Jurassic, gradual uplift of the shield resulted in sea regression and subsequent erosion of part of the Jurassic sediments. With the formation of tectonic scarps and grabens caused by faulting, the Jurassic sediments were preserved from erosion in some areas.

This retreat of the sea was followed by the deposition of sandstone, sand and sandy clay of the Nubian Sandstone formation. From west to east the Cretaceous sediments range from continental through lagoonal to marine.

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

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

Further marine ingression during the Upper Eocene resulted in the Karkar Formation of shales formation which was deposited in a shallow sea and extends into the highlands of the eastern area and the Sool Plateau.

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

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.[1]

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)

[1] Cited from SHAAC Co.: 13 sites, Hydrogeological site investigation report (2006)

2. Jurassic: Limestone, shale and sandstone
3. Cretaceous: Nubian sandstones (sandstones and limestones)
4. Tertiary (Eocene): Limestone, evaporitic rocks
    4.1. Auradu Formation (limestones)
    4.2. Taleex Formation (evaporitic rocks)
    4.3. Karkar Formation (limestones)
5. Tertiary (Oligocene to Miocene): Thick extensive series of sedimentary rocks
    5.1. Daban series
    5.2. Hafun Series and Iskushuban Formation
6. Pleistocene to Recent Alluvium
    6.1. Basaltic rocks
    6.2. Recent alluviums, terraces and coastal beaches

Basement Complex

In the study area, the Basement complex outcrops in Somaliland mostly in its northwest part (Awdal, Hargeysa), in Berbera and Sheekh (also known as Shiikh or Sheikh) areas and along a narrow belt of the Ceerigabo-Ahl Madow escarpment. It is mostly composed of schists, ortogneiss, quartzites and paragneiss intruded by granite, diorite and gabro.

Faillace & Faillace (1986) stated that the predominant rock type is ortogneiss. The gneissic rocks are often crossed by numerous dykes generally of an acid nature. They also noticed that in the northwestern part of the Inda Ad Series there is a suite of younger, low-grade metamorphic rocks consisting mainly of folded sandstone, shales with intercalations of conglomerate, quartzite, and crystalline limestone overlying the Pre-Cambrian crystalline rock; their age, according to Abbate et al. (1985) is Cambrian.

Figure 2.3 Ortogneiss rocks of Basement complex near Beeyo Doofar (Hargeysa area, Photo Z.Stevanovic)

Jurassic rocks

Detailed description of Jurassic Fm. can be found in the Faillace & Faillace report (1986).“The Jurassic is constituted by a thick sequence of continental deposits (basal sandstone) followed by marine beds. The basal sandstone includes thinly bedded limestone in its upper section marking the transition between continental and marine environments. The thickness varies from place to place and is mainly due to the lateral change of facies; the thickest sequence was measured at Gowan (220 m). The basal sandstone has been dated as Liassic. A 1,000 m-thick sequence of marine Jurassic sediments outcrops in Bixinduule, between Sheekh and Berbera...

Sa Wer limestone outcrops in the Borama district. It comprises the Wanderer, the Gahodleh, and the Bihen suites, with thin-bedded limestone and marls followed by well stratified and massive coral limestone. The series is completed by calcareous and marly beds.

The Jurassic formations are preserved in down-faulted blocks delimited by the basement. Towards the northeastern part the Jurassic limestone is represented by a few outcrops which are generally sandy at the base. The correlation between these outcrops and the extensive western outcrops located in the Zeylac-Borama area is not easy due to the lateral variation of facies.[2]

Nubian Sandstone

The Nubian Sandstone is a typical continental and/or lagoonal formation deposited in a humid and hot environment. The Nubian sandstone unconformably overlies on the Basement Complex along the plateau escarpment or Jurassic rocks, and from Hargeysa to the north and the east is conformably underlain by the Auradu limestone. The formation consists of fine to coarse grained white to red-brown quartz sandstone sporadically with conglomerate beds. The sandstone is often cross-bedded, soft and friable. In some localities siltstones, shales, and calcareous sandstone were encountered as well as the hard sandstone forming rocky barriers across togga beds.

The sandstone outcrops in the southern part of the Hargeysa and Gabiley districts. Numerous investigations were carried out in areas occupied by the sandstone along the Ethiopian border, especially near Wajaale, Gee-Balaadh, Alleybadey, Salaxlay, and Baligubadle. The thickness of the sandstone increases toward the south and southeast. The thickness is only a few meters thick at Jifo Urey near Gabiley (Hargeysa-Borama road). In the Wajaale area the thickness is about 100 m while southeast toward Baligubadle,the thickness could be more than 500 m.

[2] Cited from Faillace & Faillace (1986)

Figure 2.4 Yesomma sandstones near Borama (Photo Somaliland team 2)

Faillace & Faillace (1986) estimated that in the north-central part of the study area the Cretaceous thickness of sandstone, sand, and sandy clay sequences can be 1,000-1,700 m. Further west, towards the border with Ethiopia, the thickness of these sediments decreases to 200-400 m. The nature of the Cretaceous sediments suggests that in the western part of the area deposition occurred under continental conditions. Proceeding eastwards from Ceerigabo the alternation of sand and limestone indicates that sediments were deposited during various regressions and transgressions. More stable sea conditions prevailed in the area north of Qandala, with the deposition of fossiliferous limestone.

Auradu Series

The Auradu series consists of grey to white, hard and massive limestone which is often unbedded. The Auradu limestone outcrops in a large, discontinuous and fault-dissected belt bordering the edge of the plateau escarpment where it overlies the Nubian Sandstone. It extends from the vicinity of Hargeysa to the area of Burco, Ceerigabo, and Qandala, with numerous outcrops covering large areas between Berbera and Ceerigabo. The thickest sequence, 380 m, was measured near Ceerigabo. Auradu limestone is also widely exposed in the Nugaal valley where limestone underlies the Taleex gypsum formation.

The upper part of the Auradu Formation consists of massive limestone alternated with thinly bedded limestone layers, at times chalky and gypsiferous, with calcareous shales. The thickness measured at Allahkajid was 345 m, but varies in other places.

Taleex Formation

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

Lateral changes of facies from gypsum and anhydrite to limestone is known in some places. Changes from anhydrite through gypsiferous limestone to dense limestone occur frequently and can easily be tracked for a comparatively short distance. A greater succession of anhydrite Series occurs in the Nugaal Valley, where it covers a large part of the Sool and Nugaal Regions.

Figure 2.5 Cavern carved in Taalex's karstified gypsum (Sool Plateau near Xudun)

Karkar Formation

The Karkar Formation 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.

Figure 2.6 Recording data on spring issued from Karkar Fm. (near Buhoodle; Photo Puntland team 2)

The Karkar Formation is penetrated for 230 m by the well in Rako Raaxo, 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 Rako Raaxo 260 m (Faillace & Faillace, 1986).

Oligocene to Miocene

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

Oligocene/Miocene sediments are irregularly distributed in scattered outcrops located along the Gulf of Aden coast between Berbera and Guardafuey and along the Indian Ocean coast. Those outcropping along the Gulf of Aden coast are subdivided into the Middle and Upper Daban Series. After Faillace & Faillace (1986) the Middle Daban Series is constituted by a thick sequence of red-brown, green sand and silts, gypsiferous sandstone, and gypsum in the lower part. "The succession of fine to medium quartz sandstone is frequently cross-bedded. Grey shales, concretionary chert, and sandy limestone are present in the middle part of this series. The upper part is more consolidated and consists of frequently cross-bedded brown to green, soft to massive sandstone, with intercalations of limestone associated with chert and fibrous gypsum. All these sediments are transgressive over the Lower Daban Series. The thickness of the Middle Daban Series was estimated at 2,310-2,450 m.

The uppermost part of the Daban Series is represented by sandstones and conglomerates of the Upper Daban Series. These coarse conglomerates and associated boulder beds predominantly derive from the Auradu limestone and form a sequence up to 125 m thick.

The Upper and Middle Daban Series are correlated to the Hafun Series and Iskushuban Formation outcropping along the coast of the Indian Ocean. The Hafun Series is constituted by coarse sandstone followed by marly and sandy limestone (lower section), biogenetic limestone (middle section), biogenetic limestone alternated with clay, marls, and sandstone layers (upper section). The upper part of the Hafun Series grades laterally into the "upper conglomerate".

The marine limestones and sandstones of the Hafun Series are replaced laterally towards the interior of the Dharoor Valley by the gypsiferous clay and conglomerate of the Iskushuban Formation. This formation fills the upper part of the Dharoor Valley, where a lagoonal environment was established."[3]

Basalt outcrops and other volcanic rocks are scattered along the coastal belt from the border with Djibouti to nearly as far as Qandala. The volcanic rocks belong to the Aden Series; generally dense and vescicular pyroclastic materials are found locally. Several lava flows have tuff intercalations in some localities (Faillace & Faillace, 1986).

Volcanic cones are preserved in various areas. In the north central part of the coastal belt near Bullaxaar, Mt.Jabel Elmis rises to an elevation of 571 m and is formed by stratified tuffs of basaltic lava (extends southward and eastward for 60-70 km). The lava, deposited during different periods, followed existing depressions and other uneven floors; it is over 50 m thick in several places.

Figure 2.7 Basaltic volcanic rocks cover recent deposits near Jalelo (Hargeysa area, Photo Z.Stevanovic)

[3] Cited from Faillace & Faillace (1986)

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

Pleistocene to Recent Alluvium

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

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

Recent alluvial deposits fill the numerous togga beds in the mountain range from Bari to Sanaag and westwards towards Awdal. They spread out in alluvial cones as toggas leave the mountain chain, covering extensive areas towards the coastal plain.

Figure 2.8 Shallow well dug on the terrace alongside main togga stream (Nugaal valley; Photo Puntland team 2)

Sand dunes constituted by reddish to yellow to grey sand are found in several areas along the coast as well as in the hinterland. Coastal sand dunes are particularly developed in the area east of Berbera. Inland, sand dunes are well developed along depressions and small valleys of the Sool and Hawd plateaus. Raised beaches have been observed in various localities along the Gulf of Aden as well as along the Indian Ocean.

Red soil is widespread over large areas of the Hawd and Sool plateaus, covering depressions and ancient valleys, and prevents a direct observation of the underlying rocks. After Faillace & Faillace (1986) red soil consists mainly of slightly clayey fine quartz sand. In some areas, according to Macfadyen "the deposit is recorded as an ancient reddish soil, derived mainly from denudation of Nubian sandstone." Red soil and other soft materials of alluvial origin, constituted by isolated lenses of coarse sand, gravel, and conglomerate, have an average thickness of 20-30 m; their thickness may reach up to 70-80 m, as was found in water wells drilled in Burco.

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

Figure 2.9 Anhydrite of Taalex Fm. covered by recent red soils (Laasqoray Xudun - Sool Plateau, Puntland team 2)

Hydrogeological setting and relationship between major lithostratigraphic units and aquifer systems are presented in chapter 4.3.1. of this report.

2.4 Geomorphology

Somaliland and Puntland areas are characterized by the major physiographic areas from the Red Sea coast to the south:

- The coastal plain and the adjacent escarpment zone sloping towards the Red Sea,
- The Mountain range traversed by many rivers from the west of the Ethiopian border to the east horn of Raas Casayr,
- The Plateaus and Valleys covering extensive areas south of the mountain range.
- The gently undulating plain towards the coast of the Indian Ocean.

Faillace & Faillace (1986) stated that the study area can be divided into three major physiographic provinces:

a) The coastal belt and sloping plain,

b) The mountainous zone incised by the numerous toggas,

c) The plateaus and valleys which include the large undulated Hawd and Sool plateaus and the Nugal and Darror valleys.

Within these three major subdivisions it is possible to recognize several hydrogeological provinces having, to a certain extent, similar hydrogeological characteristics."[4]

Figure 2.10 The escarpment of the high Golis Mountain sloping towards the Gulf of Aden (photo Somaliland team 2)

[4] Cited from Faillace & Faillace (1986)

Based on findings of some previous surveys Awise (2009) stated that "area generally slopes in a southeastern direction towards the Indian Ocean. The highest elevations occur along the Golis Mountains in the Gulf of Aden. The remainder of the area can be classified as gently sloping, undulating to flat topography with average slopes of less than approximately 1 - 2% (Kammer, 1989). Almost half the area is below 500 m above mean sea level (msl)."[5]

The Western part of the study area is characterized by four main geomorphological features. "A large, gently undulated plateau, with an elevation ranging from 1400 to 1600 m, extends south of Hargeysa and is covered mainly by sedimentary rocks. A lower plateau extending further north has an elevation between 1000 and 1400 m; it is crossed by numerous streams which have incised sedimentary and metamorphic rocks. North of this plateau, a mountain range extends from Lafaruug to Agabar and Borama. The highest peaks are located in the western part of this range, north of Borama, with heights of 1300 to about 1800 m. This area is covered mainly by crystalline basement rocks and by Mesozoic limestone where streams have incised narrow valleys. The northernmost part is constituted by the sloping plain and coastal strip, which extend along a large belt ranging in elevation from 600 m to sea level."[6]

The Central area is marked by the high Golis mountain range running parallel to the shore of the Gulf of Aden. The highest peak is Mt. Surud, with an elevation of 2408 m. The mountain range is mostly constituted by crystalline rocks which are deeply incised by numerous toggas. With the exception of the coastal belt, the remaining area forms a large plain sloping gently southwards where it meets the Bokh and the Nuugal valleys. The area between these two valleys is covered by large plains crossed by toggas: the Haded plain, south of Ceerigabo, the Karman plain south of Ceel Afweyn, the Barrado plain north of Ceerigabo and the Gubato plain to the northeast of Burco. These plains are covered by sandy soils and alluvial formations.

The Golis mountain range extends in **the Eastern area** while the northernmost part of the Horn of Africa is constituted by Mt. Bahaja, which is 2135 m a.s.l. high. The most remarkable morphologic feature is Togga Nugaal which formed a very large valley extending over 600 km in length, with draining areas from 1200 m a.s.l. down to sea level.

The remote sensing analyses followed by evaluation of previous data, 3-D model and GIS maps, as well as data sporadically collected from the field hydrogeological survey enable assessment of different active geomorphological processes and types of relief. Throughout the youngest geological history the geomorphological

[5] Awise: Puntland/Somaliland Hydrogeology, Report, 2009
[6] Cited from Faillace & Faillace (1986)

processes were mutually interchanging, and almost all of them are still active with different intensities creating recent relief.

The most important active geomorphological processes are karstic, aeolian, fluvial and slope (delluvial, prolluvial and colluvial) processes. Structural relief forms caused by inner, endogenic forces, and exposed by the activity of different exogenic forces are also abundant. The important role in relief formation is played by a strong weathering due to the specific climatic conditions such as fast alternation of high and low temperature, temporary strong rains, and partly by human activities. This process is not producing specific morphological forms, but it prepares a great amount of loose material that can be easily removed by any exogenic force (running water, wind, gravity) thus reinforcing their activity.

Figure 2.11 The typical piedmont deposits resulted from delluvial and prolluvial processes (Photo Somaliland team 2)

Karstic process. During the long geological history, especially in the Mesozoic and Tertiary periods, a lot of soluble rocks like limestone and evaporites were deposited. This enabled the development of strong karstification and the formation of surface as well as underground karstic morphology.

The first sedimentary cycle of carbonate rocks deposition started in the Early Jurassic and ended in Late Jurassic. A thick limestone deposit, partly separated by marls and other “impure” components were deposited along the Borama area (SW part, Awdal Region). During Maastrichtian and especially Eocene a new cycle of sedimentation of carbonate rocks was repeated, forming thick deposits of Auradu limestone, covered by evaporitic Taalex rocks (anchydrite, gypsum, dolostones). The uppermost part of Eocene rocks consists of Karkar limestone. In the central and eastern part of the study area Eocene formations prevail.

The carbonate and evaporitic rocks in most of Somaliland and Puntland territories were not exposed to intensive orogenic movements and uplifting during and after Tertiary. These processes were mostly took place in the northern parts and the Golis Mountain range where the presence of Eocene formations is limited to the southern slopes. However, folding and faulting, repeated in several phases, caused the creation of complex systems of faults and fractures as privileged ways for the water circulation.

The main cycle of karstification took place during and after Oligocene-Miocene and is active nowadays. The initial stream network created numerous valley and even small canyons in soluble Eocene rocks, but soon after (in geological terms) with the sinking of surface water underground the conditions for intensification of the karst process were initiated. The karstification was stimulated also by specific climatic conditions, especially with the exchange of periods of high humidity and very dry seasons.

Surface karstic small forms, dimensions from cm to dm, occur practically throughout the area of Jurassic limestone. The typical larger surface forms, such as sinkholes or dolines, are not as frequent in this region as in some other classical karst areas (Dinarides, Caribbean karst). Some large closed depressions resemble the polje forms, but have been strongly modified by surface fluvial process (e.g. Dharoor valley). However, a good number of collapsed sinkholes are locally used (or additionally excavated) for groundwater utilization. Although not a primary target of this survey a number of caverns, potholes and small caves were also visited and recorded by the SWALIM surveyors.

Figure 2.12 Collapsed roof of the cavern is creating a sinkhole (left, photo Puntland team) The cave carved in Karkar limestones (right, Buuhoodle area)

Aeolian process. It is especially intensive along the coast of Gulf of Aden and the Indian Ocean where thick sand deposits and dunes are created.

Even in the continental part the traces of aeolian process, or wind activity, can be seen in many places, especially where evaporitic rocks of Taalex or Quaternary carbonate crust are developed. As a rule wind blows out already weathered material and separated grains and forms specific morpho structures whose dimensions vary from a few cm to few dm.

Figure 2.13 "Classical" dunes near the coast (Berbera area, Photo Somaliland team 2)

Fluvial process. From observing the density of the drainage network it could be concluded that Somaliland and Puntland are abundant in water courses yielding to the area a very good discharge. However, such a network comprehends only toggas as temporary water courses. Their width in some cases could even surpass 1 km. The thickness of the deposited alluvial material, depending on the catchment size and water availability, varies greatly, and could often extend to 50 m. During the dry periods the water table lowers and circulation of the groundwater follows the main togga's orientation.

Figure 2.14 One of the typical toggas near Jalelo (Somaliland, Photo Z.Stevanovic)

After abundant rainfall the alluvium becomes completely saturated and then the surface flow appears. Along with nearby fossil terrace deposits, the toggas' alluvial fans are the most prosperous aquifer system in Somaliland and Puntland and are already utilized by many shallow or deep wells (e.g. for Hargeysa water supply).

Most of the small toggas come from the high mountains, oriented either to the coastal area as the main regional erosional base, or to the close depressions, such as the Nugaal or Dharoor valleys. As even today this is a neotectonically active zone, mountains are uplifting and rivers are reinforcing their incising, forming deeper valleys and even canyons with larger slopes.

By definition, togga's material is of heterogeneous lithological composition sorted in size from source to togga's mouth. Therefore, sediments in source area are composed of the coarse-grained gravel and along the water course change the size and roundness and in the mouth area turns generally into a fine sand and clay. However, size of alluvial cover predominantly depends of energy of water course and in some cases sorting process could even be inverse. It is due to presence of number of closed depressions from which downstream parts of togga could cut up small gorge and left coarse material behind.

Slope processes. Slope processes regularly comprise three different processes: delluvial, prolluvial and colluvial, acting mostly at the same place and the same time. These processes gradually pass one into another, but their mechanisms are different.

The delluvial process washes loose material down the slope by waters resulting from strong rains. No granular classification takes place. Transported material is deposited at the base of the slopes making foothills (piedmonts) and pediments, decreasing the slope of hill or river valley sides, and increasing its instability. The delluvium as material formed in this process could makes good soil, but is regularly covered with many stone boulders.

The prolluvial process is restricted to the strong temporary waters running down slope through a distinguished channel. Strong but short-lasting kinetic energy of water removes both loose material and bedrocks.

The colluvial process develops under the direct influence of gravity force. It manifests in occurrences of landslides, rockfall and rock slumps. Mainly bigger blocks are removed by this process. Smaller material moves down slope by the mixed influence of washing water (delluvial process), linear water running through gullies (prolluvial process), and gravity (colluvial process).

2.5 Hydrology

The surface waters of Somaliland and Puntland belong to three major river basins:

1. Gulf of Aden basin
2. Dharoor basin
3. Nugaal basin

"The surface drainage closely follows the general geomorphology. Much of the area drains in a southeasterly direction towards the Indian Ocean; the extreme north discharges its runoff into the Gulf of Aden.

The drainage network, which is influenced by local topography, rainfall, and geology, is dense to very dense in the northern mountains. It is very thin or virtually non – existent in large parts of the central basin. Runoff in Somaliland and Puntland basins generally takes place in seasonal streams (toggas) and in addition to infiltration, it replenishes stream bed and flood plain aquifers. Runoff only occurs after heavy rainfalls in the form of spate flows, which may last from a few hours to a several days. In sandy fans and in valley bottoms in the gently rolling topography large quantities of water are infiltrated into the aquifers. Evaporation and overland flows are also high in these plains. It could be said that little runoff reaches the seas."[7]

There are no perennial streams in the study area. The rivers and drainages have surface water only after periods of heavy rainfall. There are, however, many small streams called *toggas (wadis)* originating from the plateaus and mountains in the north that have perennial flows in some stretches and at other stretches have a

[7] Awise: Puntland/Somaliland Hydrogeology, Report, 2009

complex surface-water groundwater interaction (subsurface flow) where there is groundwater recharge. After intense rainfall, most of these small streams can carry high floods and debris. Even some river training and control structures can be destroyed as happened, for instance, on several occasions in Togga Hargeysa. The surface runoff lasts from a few hours to a few days. The subsurface flow of toggas is often tapped by many shallow wells, being an important source of water for people and livestock in the region.

In the **Western part** of the study area in the Awdal and Woqooyi Galbeed regions the largest are Togga Waheen, T. Durdur, T. Biji, and T.Silil comprising respective catchments of 3,000 km^2, 3,850 km^2, 3,560 km^2, 1,930 km^2 (Faillace & Faillace, 1986). All of them drain towards the Gulf of Aden.

In the **Central part** of the study area the major toggas are the T. Jangarra, T. Hodmo, and the T. Belgeabili, with catchments of 3,700, 3,800, and 4,800 km^2, respectively (Faillace & Faillace, 1986). They all also flow towards the Gulf of Aden. With the exception of the coastal belt, the remaining area forms a large plain sloping gently southwards where it meets the Bokh and the Nugal valleys.

Finally, **in the Eastern part** three main toggas reach the Indian Ocean. “The northernmost one is the Wadi Jaceyl, with a catchment of over 3,800 km^2. It has a deep valley carved into limestone and marls. T. Dhut, also named T. Jaceyl, downstream from Iskushuban, drains the Dharoor Valley and its western extension as far as Hadaaftimo. The Dharoor Valley is located south of the northernmost mountainous area and extends from west to east over a length of 350 km covering an area of over 25,000 km^2 which ranges in elevation from 1,500 m to about sea level. The T. Nugal has a catchment of 70,000 km^2 and drains the Nugaal Region and parts of the Togdheer and Sool regions.[8]

Dams, ponds and dug outs (*Wars*) are commonly used in the Nugaal and Dharoor valleys to collect storm water from small catchments. The *Wars* are unlined with surface areas of hundreds to thousands of m^2 and a depth of 2 to 3 m. *Berkads* are major water storage infrastructure in Hawd Pleatau. There are many of them in the Galbeed, Sool and Togdheer regions. Recently, they have been introduced in the Sanaag and Awdal regions, too. They vary in their capacity: those in Togdheer, Sool and Sanaag are normally less than 300 m^3 while those in Awdal and Galbeed can have a larger capacity. The main problems with *berkads* are related to sanitary and hygienic conditions. More than 50% of the berkads are non-operational due to cracks developed mainly as a result of faulty design and construction. UNICEF survey results for Puntland showed that 30% of people used *berkads*, 35% used boreholes,

[8] cited from Faillace & Faillace (1986), p.4,5

10% used dug wells and 5% used springs as the main source of water supply for human and livestock needs.

Under FAO/SWALIM projects several automatic gauging remotely controlled stations were established and became fully operational. It is thus now possible to collect useful information about the streamflow regime as well as flood intensity and duration in certain areas.

Figure 2.15 Installed automatic gauging station in pilot study area of Togga Waheen (FAO SWALIM)

Chapter 3: Methodology

3.1 Remote sensing analyses

3.1.1 Introduction

The main purpose of the use of remote sensing methods was to obtain more accurate and complementary geomorphological, geological and tectonics data for Somaliland and Puntland. In general, application of a remote sensing procedure can provide information on geomorphological properties of geological units on the earth's surface. Geology is concerned with the physical properties of the same units. The second important task is the acquisition of additional information about different lithological compounds and changes in lithological composition in the wider area covered by the same geological unit within the regional scale of observation. Lastly, the third and perhaps most crucial task is to identify with a high degree of confidence all relevant tectonic features, especially fracture patterns (major and minor faults system of hydrogeological significance) important for hydrogeological assessment.

3.1.2 Remote sensing methodology

A satellite image represents a digital signature of reflected electromagnetic energy. Applied methods of remote sensing processing on satellite images tend to improve the quality and evaluate the visual presentation of a digital signature. Those procedures enable a higher level of sophisticated analyses and interpretation of geological information on improved satellite images.

For this project, Landsat 7 ETM+ satellite images are used. A full list of satellite images used for remote sensing analysis and interpretation is provided in Appendix III.

Processed satellite images cover the Somaliland and Puntland study area.. During remote sensing work, different sets of procedures are applied. For regional research (and provision of basic data for the Regional Hydrogeological map), procedures like image pre-processing, image enhancement (mainly spatial and partly spectral improvement techniques) and production of satellite assemblage are done. Those data are used as a fundamental information layer and embedded into a Hydrogeological (HG) map in scale of 1:750,000.

On other hand, detailed geological analysis for 4 specific Areas of Interests (AOI) demanded another set of procedures and a different, more detailed approach to RS research. An essential part of the procedure was certainly the application of preprocessing techniques and spatial image enhancement. But additional common procedures of spectral enhancement like Normalized Difference Vegetation Index (NDVI), moisture vegetation index (MVI), mineral mapping and others, as well as different algorithms for classification are also used.

The final results of remote sensing analysis represent a compilation of all relevant geological and hydrogeological data obtained by this method. Bearing in mind that remote sensing derives information about the earth's cover from satellite images acquired at a distance and that information about an object (like a geological unit, geological structure or any other geological or hydrogeological phenomena) is acquired without contacting it physically, these results need serious field verification and should be accepted with a certain level of uncertainity.

3.1.2.1 Satellite data used

The research area of Somaliland and Puntland is covered by 18 separate satellite images of Landsat 7 ETM+ (Figure 3.1). Images are lined up in 7 paths from west to east (path160-166) and from north to south in 4 rows (052-055), all in a WGS (World Geodetic System) reference frame. They are chosen primarily considering the time of year when they are collected. That includes: season of the year (for geology research the year of acquisition is not significant), degree of cloud coverage, and the most prominent quality - vegetation coverage. Satellite Images are delivered in GeoTIFF format, with a unique reference: WGS (World Geodetic System 1984), UTM zone 38. However, for the sake of uniformity with other SWALIM GIS datasets the final RS products were projected to Geographic Coordinate System: GCS_WGS_1984.

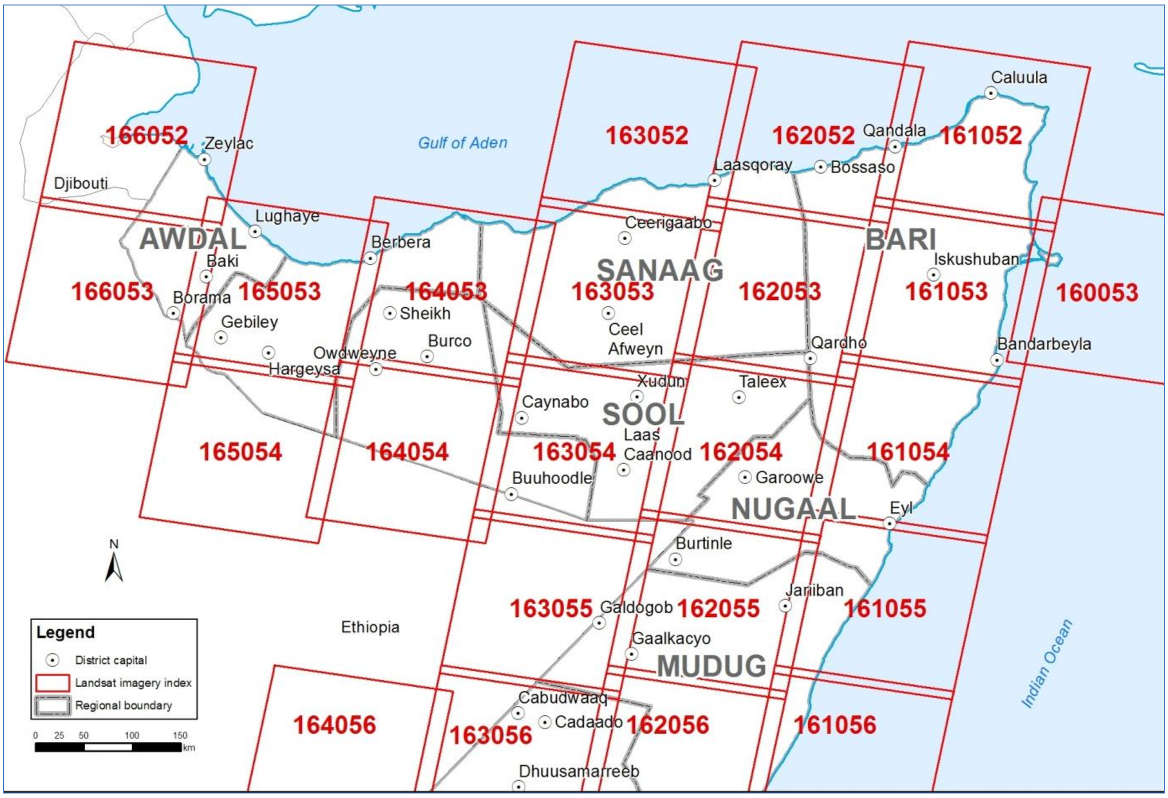


Figure 3.1 Landsat 7 ETM satellite images grid for the study area

3.1.2.2 Image processing, analysis and classification

Processing of satellite images in the study area includes some common RS procedures such as: image preprocessing (removing different kinds of noise from images), image enhancement (quality improvement and resolution enhancement) and image processing (formal and instrumental analysis and classification).

Satellite image analysis includes a methodology of standard combination of bands (as natural color), as well as other combinations (false color) designed to emphasize lithological properties at the investigated area.

The main purpose is to get more information related to lithological differences, mineralogical and geological composition. Because of that, a set of bands with different spectral characteristics has to be done. With that procedure, differences in reflection, because of morphological influence, can be removed. The results of this procedure will be treated in different RGB (Red, Green, and Blue) models which involved the combination of three different bands in order to obtain more geological information. It provides a complete series of highly useful parameters for analysis, especially in arid areas where the impact of water and vegetation is extremely low.

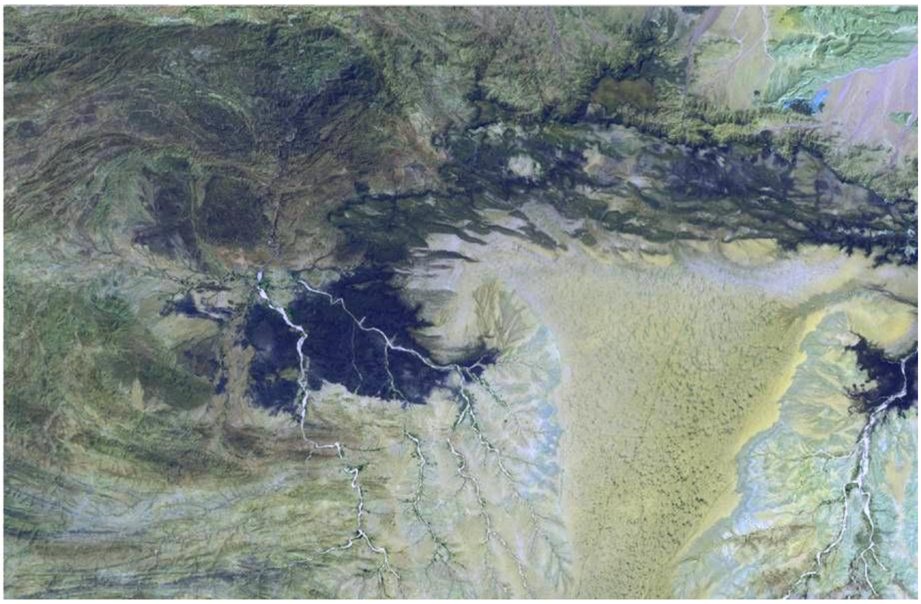


Figure 3.2 Area north of Hargeysa, RGB image without spectral enhancement

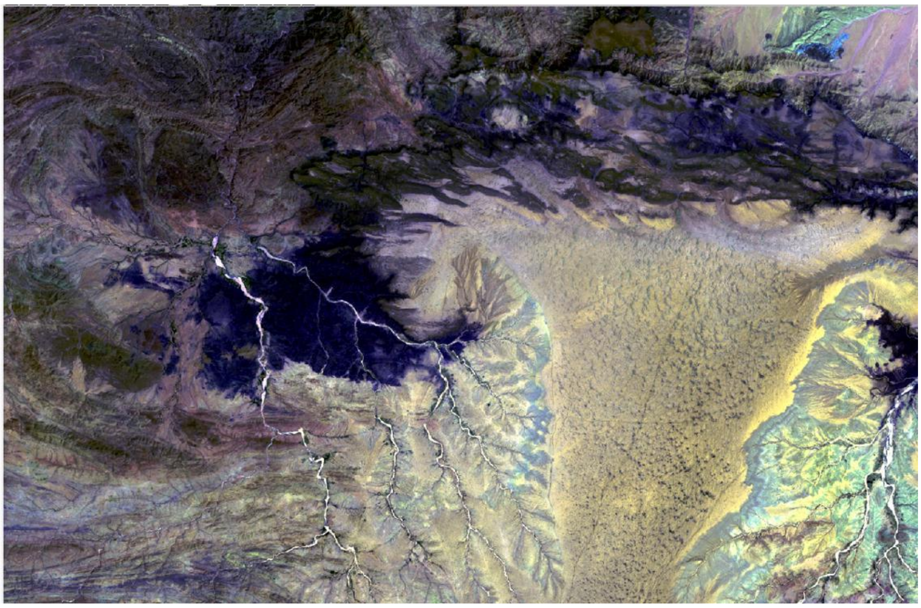


Figure 3.3 Area north of Hargeysa, RGB image enhancement by Brovey method

There are 15 possible correlations involving 6 multispectral bands, if we ignore inverse ratios. In general, the problem of selecting groups of three to display is related to a strategic approach and the main purpose of the research. Most effective and widely applicable are the band ratios which are embedded in vegetation, moisture or mineral mapping index.

The most commonly used indices are the Normalized Difference Vegetation Index (NDVI), Moisture Vegetation Index (MVI) and Tasseled Cap transformations which obtain useful information and measurements of vegetation calculated from remotely sensed data.

The Landsat 7 ETM+ sensor records information about the earth's surface in 6 spectral channels (bands). However, only 4 of these bands store data useful for the kind of analysis like NDVI and MVI. The near-infrared (NIR, band 4) and mid-infrared (MIR) bands (Landsat ETM+, bands 5 and 7) were selected because of the discrete absorption characteristic of water in these areas of the electromagnetic spectrum. Band 3 (RED) was also included.

The Normalized Difference Vegetation Index (NDVI) was used as an index for green vegetation cover. Higher values for NDVI (brighter tones) indicate a greater percentage of ground cover by green vegetation (Figure 3.4). NDVI is formed by combinations between the red band and near-infrared band, and is achieved by the following algorithm:

NDVI = (NIR -RED)/(NIR + RED)

NDVI = (band 4 – band 3) / (band 4 + band 3)

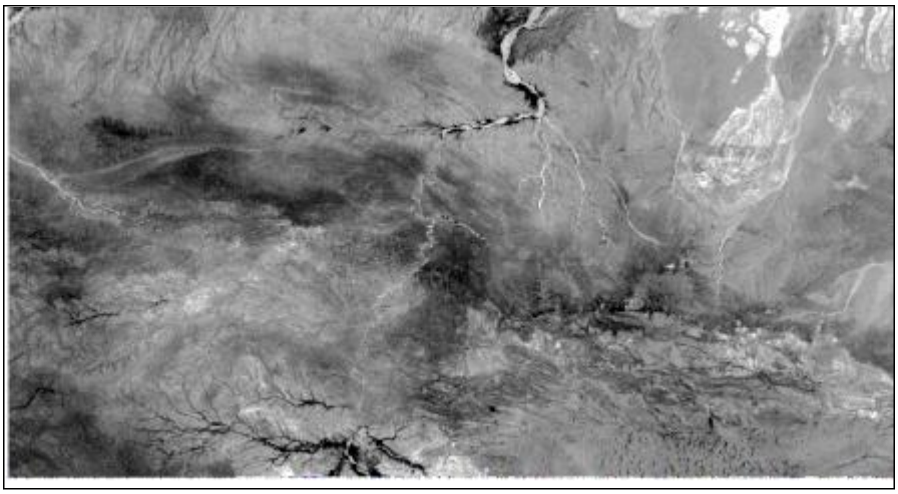


Figure 3.4 Image of NDVI index in area southeast of Quabri Baxar

In Figure 3.5 one example of moisture vegetation index is shown. The algorithm which produces results for this analysis is presented below:

MVI = (NIR - MIR)/(NIR + MIR),

where MVI is moisture vegetation index, NIR is a near-infrared band (band 4), MIR is a mid-infrared band (in this case band 7).

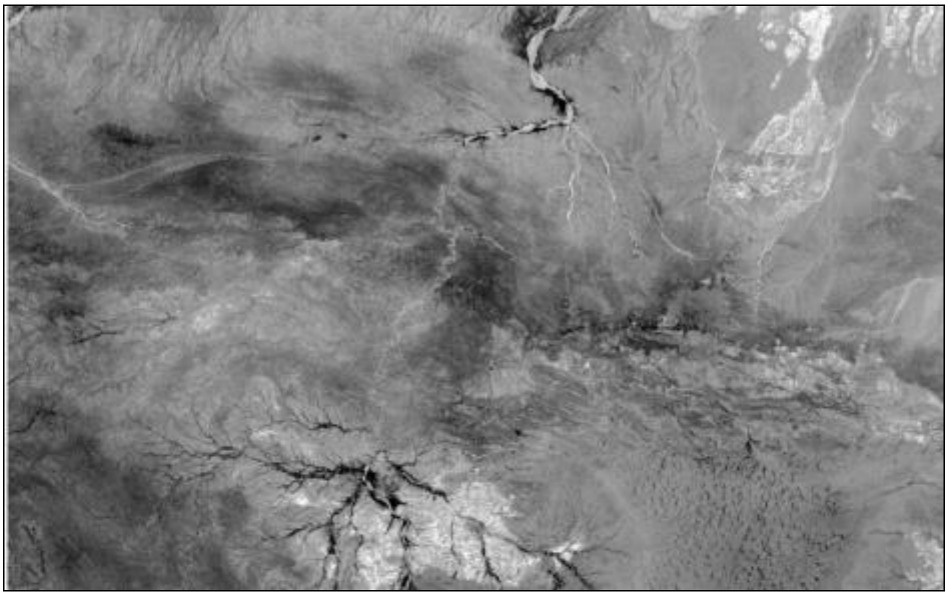


Figure 3.5 Image of MVI index in area southeast of Quabri Baxar

The mineral mapping ratio is used for determination of specific mineral deposits on the surface of the earth. But some minerals or groups of minerals can also be a good indicator for hydrogeological purposes like spatial distribution of vegetation or level of moisture in soil, etc.

Image algebra is a general term used to describe operations that combine the pixels of two or more raster layers in mathematical combinations. Index is a composite of three mineral ratios shown in Figure 3.6. Those indices are:

Clay minerals = band 5 / band 7 (Fig. 7b)

Ferrous minerals = band 5 / band 4 (Fig. 7c)

Iron oxide = band 3 / band 1 (Fig. 7a)

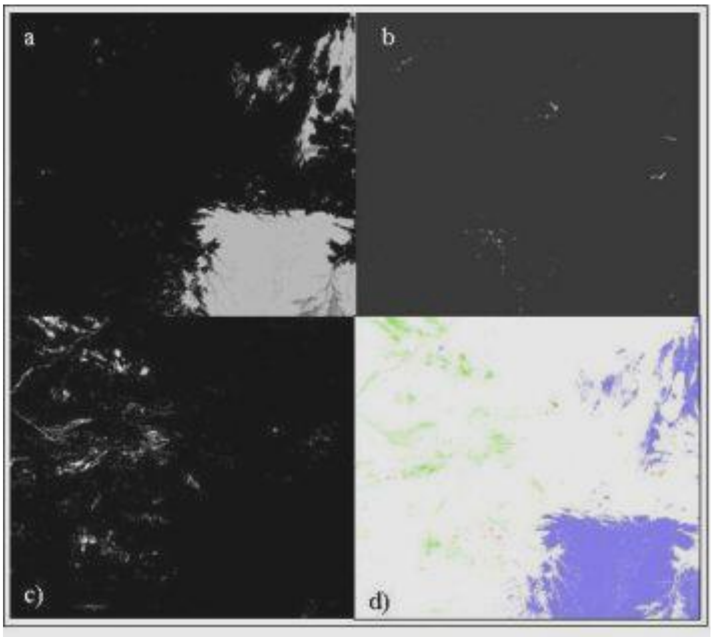


Figure 3.6; a) iron oxide (brighter tone), b) clay minerals (brighter tone), c) ferrous minerals (brighter tone), d) RGB combination (red-clay minerals, green-ferrous minerals, blue-iron oxide); some locality

Image processing

For particular areas, mostly in central and southern parts of the terrain, different procedures of classifications are applied. The best solution is achieved with techniques which are widely applied like unsupervised, supervised classification and classifications based on the algorithm for hyperspectral analysis.

Commonly, even automatic classifications give relatively good quality results for lithological composition. In that case, as the best algorithm, the isodata algorithm is applied. Much better qualitative results were achieved by using supervised classification. It was applied for one part of the image with recognizable geological units shown in Figure 3.7. In this case it is possible to make a “training site” as key for preliminary determination of geological units with different morphological and spectral characteristics. That increases the level of geological information and also the quality of the final results from remote sensing interpretation.

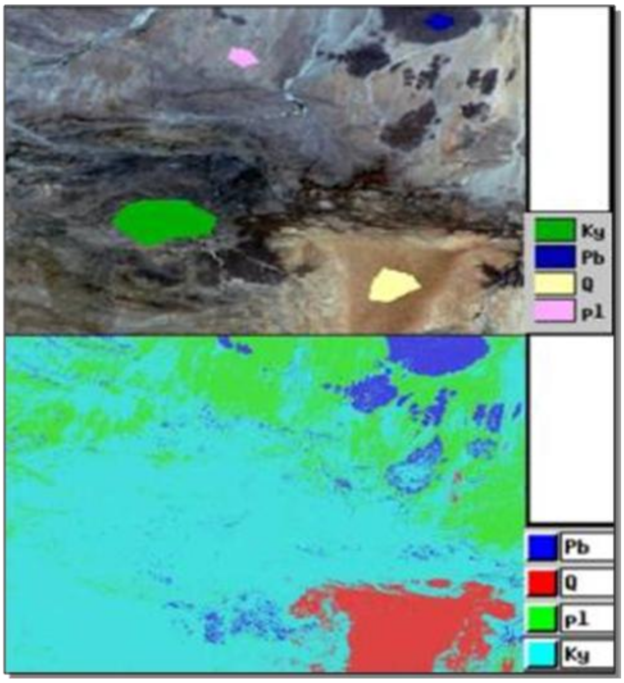


Figure 3.7 Set up of training area for determination of different geological units (upper part of figure), results of supervised automatic classification with legend (lower picture); some locality as at previous figs

Hyperspectral analysis algorithm is used only in the cases where previously described procedures do not produce satisfactory results. In that context, sequential procedures are applied:

• MNF transformation (Minimum Noise Fraction) which serves to isolate „impurities" in pixels, to divide data into two parts: first, with pixels with a high interval of eigenvalues, and another with constant values. In that way extraction of pixels with valuable information can be achieved.

• PPI (Pixel Purity Index) is the algorithm which finds the spectrally purest pixels i.e. extremum which are further classified in the PPI depending on the frequency of their occurrence,

• The selection of END members in n-dimensional space and their determination on the image through difference algorithms are used as the most reliable Spectral Angle Mapper.

3.1.2.3 Detailed analysis for selected Areas of Interest

For each band separately, six images for the whole research area are created (6 mosaics). To produce the final RGB model a combination of mosaics of bands 7, 5 and 2 is used (Figure 3.8). This model is taken as topographic background for RS data. Also, it is used for visual RS interpretation.

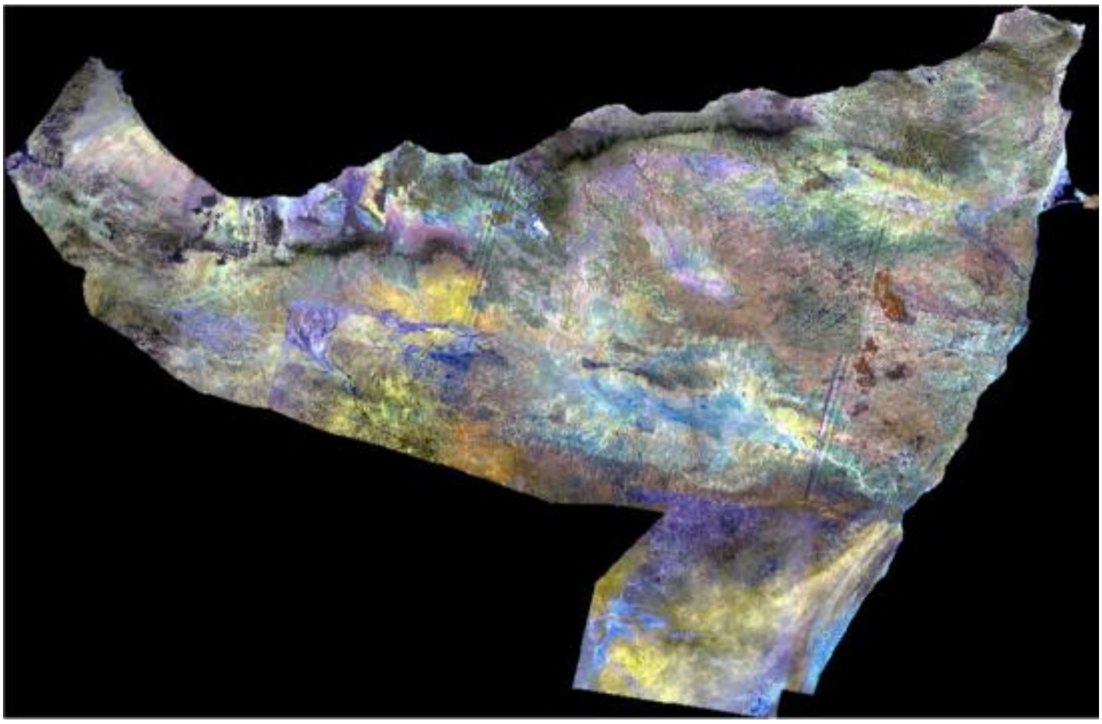


Figure 3.8 Study area assemblage (bands 7, 5 and 2)

As useful information from a hydrogeological point of view, all results of spectral analysis, especially that which provides stratigraphical boundaries and tectonic pattern, are presented as a separate layer in the final RS interpretation (Appendix III) and incorporated into the Regional Hydrogeological Map on a scale of 1:750,000 (Annex I) as well.

The previously described methodology is also applied to the processing of four areas of interest (4 AOI), two in Somaliland and two in Puntland. Those areas cover the west, central, east and south parts of the study area, approximately 46,000 square kilometers (Figure 3.9). They are all located near the larger populated places and considering the HG potential of the area.

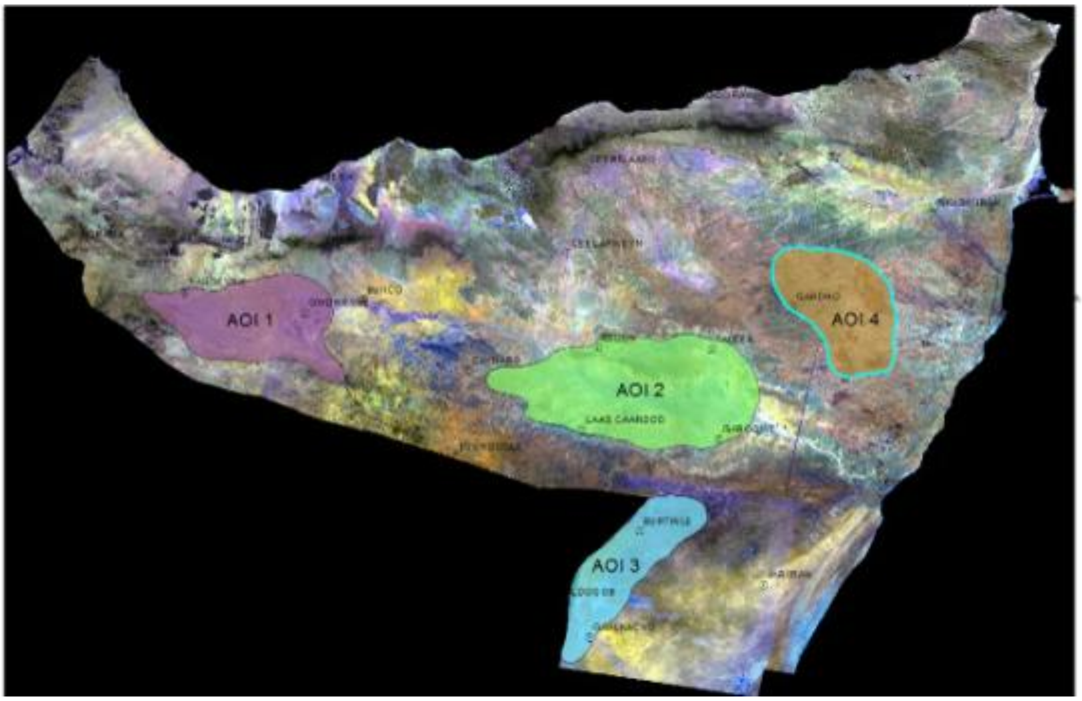


Figure 3.9 Four Areas of Interests (4 AOI) selected for detailed RS research

As for the regional investigation, a different combination of bands in the RGB raster models are used for the interpretation of detailed visual satellite images. Besides the usual combinations of bands like 7, 5 and 2, another RGB model which includes the 4th and 3rd bands are performed in order to outline the vegetation characteristics of AOIs. Also, a set of different spectral procedures of digital image processing are applied. Some of them give good possibility for indirect conclusions depending on the lithological composition of the host rocks, but only two give appropriate results to be widely used for analysis of HG properties in this study. The first is the algorithm designed to monitor and measure vegetation cover, called Normalized Difference Vegetation Index (NDVI). The second one is Clay Mineral Index (CMI) which provides a possibility to locate an area with a higher level of humidity.

3.2 Field survey methodology

a three month extensive field survey was carried out to collect data on hydrogeology and geophysics. the approach used and success of the survey depended on many factors among them the capacity of local professionals, available resources in terms of funds and time, security situation in some areas and access to remote areas. several mechanisms were put in place to ensure smooth running of the survey and quality data collection. these include:

(i) Good planning and preparations for the survey before kick off, including community sensitization.
(ii) Selection of qualified local staff, who can freely move to their respective survey areas.
(iii) Intensive training of the survey staff including field exercises before the start of the survey.
(iv) Close monitoring of the survey teams and giving technical and logistical support throughout the survey period.

3.2.1 Training of field Staff

3.2.1.1 Introduction

Training of the survey teams in hydrogeology and geophysics data collection procedures took place in Hargeysa, Somaliland during the period 17th – 24th September 2011. More than 20 local engineers, geologists, hydrogeologists and chemists participated in this training. The training started with theoretical lectures before extending to the field where the trainees participated in hands on exercises in handling the field equipment and filling the data forms. At the end of the training the survey teams had acquired sufficient knowledge to carry out the exercise with minimal supervision.


Figure 3.10, 3.11 Trainees in Hargeysa; Welcome note at the training opening session (left)

3.2.1.2 Team constitution and definition of tasks

Eighteen professionals in the fields of hydrogeology and geophysics were involved in this survey. The professionals from Somaliland were mostly employees at the Ministry of Mining, Energy and Water Resource (MMEWR), while those from Puntland included staff of Puntland State Agency for Water, Energy and Natural Resources (PSAWEN) and freelance consultants. The choice of ministry staff to participate in the survey was meant to build their capacity to enable them carry out similar surveys in the future.

The surveyors were divided into 4 hydrogeology and 2 geophysics teams, each consisting of three persons. The survey teams were further divided into 2 hydrogeology and 1 geophysics team for both Somaliland and Puntland. Each team was designated a certain area in which to carry out the survey for a period of 3 months.

3.2.1.3 Selection of survey areas

The study area was divided into six parts, three in Somaliland and three in Puntland. Two hydrogeology teams and one geophysics teams worked in Somaliland and the other set in Puntland. The designated areas for field hydrogeological survey are shown in Figure 3.12. Clear distinction of the responsibilities between hydrogeology and geophysics teams, and ways of communicating between the teams was established during training.

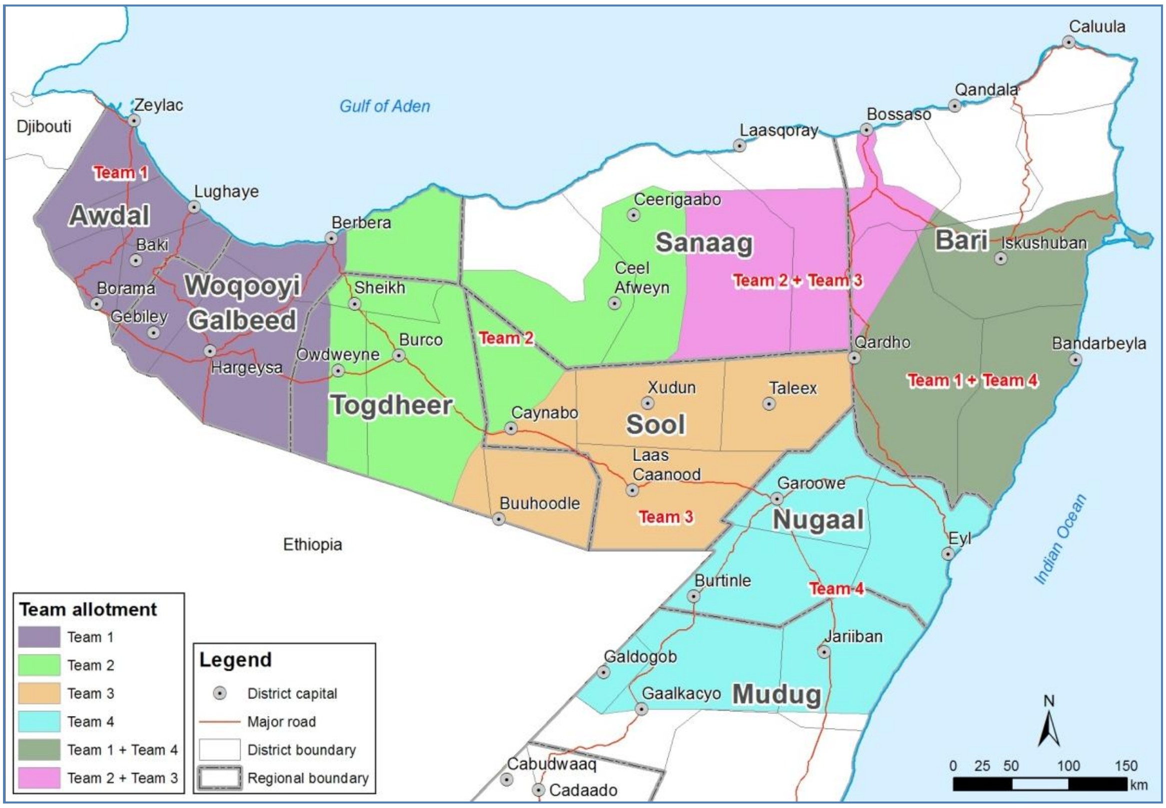


Figure 3.12 Designated areas for field hydrogeological survey

3.2.1.4 Survey methods and procedures

The survey procedures for both hydrogeology and geophysics teams were clearly explained and demonstrated during the week long training at the start of the survey. The hydrogeology teams followed some standard data collection methods for water points inventory (boreholes, dug wells, springs and togga). The geophysics teams collected geoelectrical (resistivity) measurements using terrameter instrument. Details about the specific procedures followed by the survey teams are available in Appendix I of this report.

3.2.1.5 Organization and coordination of survey teams

FAO SWALIM engaged Government Ministries / Water Authorities in Somaliland and Puntland in carrying out the hydrogeological survey. The institutions involved (MMEWR and PSAWEN) separately appointed two survey managers whose responsibility was to coordinate the survey teams in their respective regions. The managers also acted as a link between the survey teams and SWALIM. An organization structure presented in Figure 3.13 was agreed upon during training, and followed during the survey period.

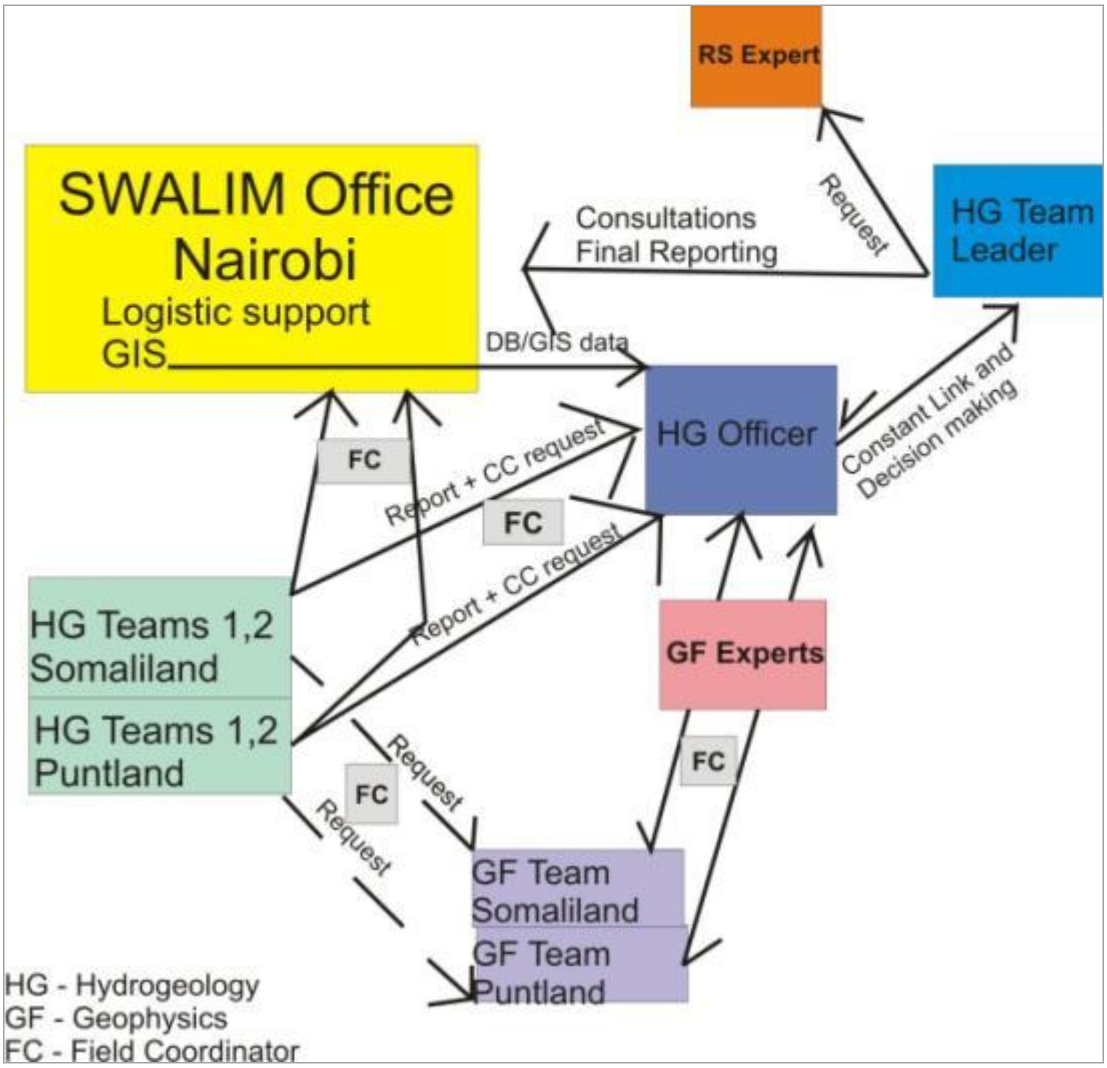


Figure 3.13 Organizational setup for field HG and GF surveys

3.2.2 Hydrogeology survey

3.2.2.1 Type of data collected

During the field survey and data collection the hydrogeological teams had to visit selected sites in the study areas, identify rock types and geological structures, assess water strategic set up, visit existing water points, measure the static water level, estimate groundwater flow direction in the locality and finally make field water quality tests and collect samples for the chemical laboratory. The teams also assessed the existing water sources and collected information related to specific and general water problems. They were asked to identify a number of sites for geophysical investigation, in principle not more than 20, and communicate to the geophysical team working in the area. Also they were expected to collect data on water utilities and other socio-economic data relevant to assess water demands and possible solutions.

At the same time, geophysics teams had the responsibility to conduct geophysical investigations in and around indicated sites through a number of vertical electrical soundings (VES) in different geological formations and topographies to identify the subsurface geological formations and estimate groundwater presence and potential.

3.2.2.2 Field investigation procedures

The procedure to be followed in the survey was agreed upon by the leading consultants and survey teams during training. The procedure covered the different aspects of the survey starting with community sensitization, interviews with water users / operators, measurements of specific water source parameters and filling of the field questionnaires. The surveyors were also expected to collect water samples for further analysis in the laboratory. Details about the survey procedures are available in Appendix I of this report.

3.2.2.3 Data transfer and reporting

The hydrogeology survey teams used to provide to SWALIM through the Field Coordinator (FC) a biweekly field summary report, GPS data of the visited sites, hard copies of filled forms during survey, photos taken from the visited sites, and water samples from visited water sources. The GPS data received was used to map the sources to determine the teams coverage and advice the teams accordingly.

The consultants followed closely the bi weekly reports, and advised the teams accordingly on gaps and areas of improvement. The hydrogeology survey teams visited a total of 1,270 sites: 550 villages and 720 water sources. The number of water sources visited in Somaliland was 442, while those of Puntland were 278. A summary of the water source types visited is given in the Table below:

Table 3.1 Summary of water source types visited

Source (water points) type	**No. of surveyed water points**
Boreholes	195
Dug Wells	397
Springs	61
Toggas	67
Total	**720**

For each of the water sources visited, the following data was collected: geographic location (X,Y,Z coordinates); physical characteristics of the source; type of aquifer and the geological formation; water yield and demand. Basic water characteristics were also measured in the field (pH, EC, TDS, temperature), and a water sample collected for further analysis in the laboratory. At least one photo was taken from each water source. These data were entered on the field data collection forms, and later transferred into SWIMS and the new Geodatabase.

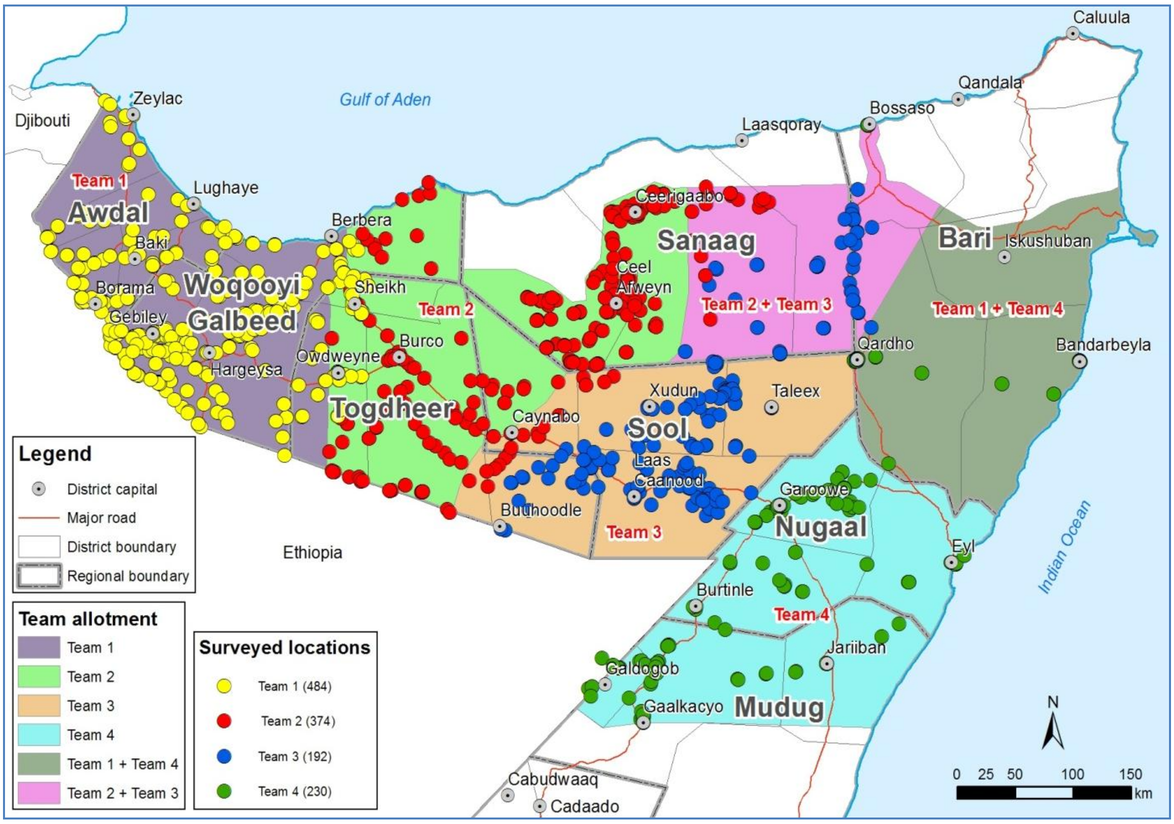


Figure 3.14 Map of surveyed water points in March, 2012

3.2.3 Geophysics

3.2.3.1 Type of data collected

The geophysical survey in Somaliland and Puntland involved conducting vertical electrical sounding in which the data collected was mainly the resistivity measured in the sounding mode and employing Schlumberger configuration.

3.2.3.2 Field investigation procedures

The geoelectrical surveys were conducted using ABEM TERRAMETER MODEL SAS1000 manufactured by ABEM Company of Sweden. The sounding was accomplished using the Schlumberger electrode configuration as shown in Figure 3.15 below where A and B are current electrodes, M and N are potential difference electrodes. The ABEM terrameters used in the surveys were capable of storing the survey parameters and measured values. The operator of the instrument enters the distance separations of both current and potential electrodes and after measuring the current and voltage, the values are then used to calculate the apparent resistivity at each measuring point and results displayed on the screen of which the operator may record the readings. Since the instruments had memory, all the parameters in a measured profile are stored in the data file in the memory of the instrument of which can be uploaded to the computer for processing and interpreation.

In this study considering the semi- arid to arid conditions, and the fact that the aquifers are deep seated, the current electrode separations of AB/2 ranging from 300 m to 600 m were used to investigate the potential aquifers. Such arrangement gave a depth of investigation of 200 m up to 400 m deep below the ground level.

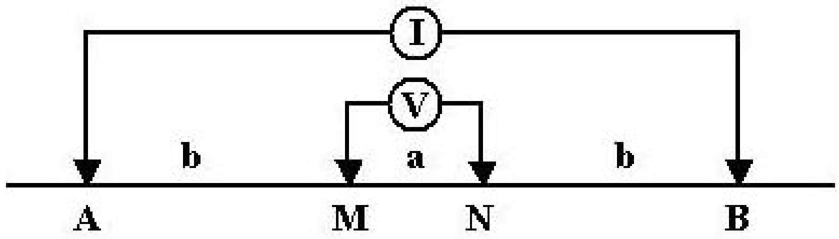


Figure 3.15 Schlumberger Electrode Configuration used in the survey

The apparent resistivity can be determined using equation 1.

$$\rho_a = \frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN}\pi R \qquad (1)$$

where, R is the resistance in ohms.

The apparent resistivity values obtained at each current electrode separation were then plotted on a log- log scale to get the apparent resistivity curves which were then inverted into layer parameters using resistivity inversion software called Interpex (IX1D v.3). Details about the geophysics survey procedures are available in Appendix II of this report.

3.2.3.3 Data transfer and reporting

The geophysical field work involved using field data forms that were collected and sent to the SWALIM office in Nairobi on a regular basis depending on their availability. Together with the field data forms, raw resistivity data in electronic format were sent as well to the international consultant for final processing and interpretation. Then the format for entry into the GIS database had to be designed in MS-excel format. Using the GPS coordinates for each data set, the Excel data file was then converted into a geo-database by converting the file into a .dbf format.

The Somaliland geophysical team was given a government vehicle to facilitate the transportation of the survey personnel as well as the geophysical equipment. In order to communicate with the survey manager at the ministry headquarters in Hargeysa, the VHF radio was used. The Somaliland geophysical team used mobile phones for communication as the network connectivity was available in most of the areas covered in the survey. However for data transfer from survey teams to SWALIM HQ E-mail communications was used. In cases where there were no possibility of going through the mobile phone or e-mails, the surveyors had to contact the Survey Manager through the VHF Radio, who would then pass the message on through the FAO-SWALIM liaison office manager. The Puntland geophysical team relied much on e-mail and in some cases on mobile phones to communicate with SWALIM offices, but while outside the town centre it was not possible to get connected and this resulted in information delays.

Both the hydrogeological and geophysical teams of Somaliland and Puntland relied on the use of VHF Radio, mobile phones, and e-mails for communications between them. The hydrogeological teams identified the sites that needed geophysical survey and hence called in the geophysical teams to do assessment and finally conduct the vertical electrical sounding (VES) at the identified sites. The sites were located using GPS and coordinates were given in longitude and latitude.

Resistivity data analysis and interpretation was carried out on each site and the results together with their recommendations are presented in section 4 within this report. Based on the resistivity results, about 87 % of all VES points have shown potentiality of groundwater occurrence. Since the sites investigated by the geophysics team were recommended by the hydrogeological team the favourable geophysical conditions do confirm the recommendations of the hydrogeological team. The recommendations from geoelectrical study may therefore be considered adequate in making decision to drill.

3.2.4. Groundwater monitoring

The monitoring activity was planned with the aim to verify the behavior of aquifers under natural variations, in terms of the relationship between rainfall and the recharge of the aquifers. The monitoring activity was supposed also to improve the degree of responsibility of the relevant Somaliland and Puntland Water Authorities.

The main target is the possibility of future depletion of aquifers. Due to the high risk of groundwater over-exploitation in major towns of Somaliland and Puntland where the demand for water is growing as the population increases, the towns prioritized for the monitoring of network installation included: Hargeysa, Borama, Berbera and Burco in Somaliland; and Garoowe, Boossaso, Galkacyo and Qardho in Puntland.

3.2.4.1. Training on groundwater monitoring

The training course was held in Hargeysa in the FAO Office from 19. 04. to 22. 04. 2012. The course was divided into three parts. The first was the theoretical approach to software installation together with equipment presentations (Figure 3.16). The second was an exercise with divers (gwl logging equipment) and software for collecting data. The third part of the course involved field training and establishing the first three monitoring points in Somaliland; this part was held at three locations: Borama, Hargeysa and Berbera towns.

After this course other major towns of Somaliland and Puntland were selected and prioritized for the diver installation. These towns included Burco in Somaliland, and Garoowe, Boossaso, Galkacyo and Qardho in Puntland. Divers for the first three towns (Borama, Hargeysa and Berbera) of Somaliland were installed during a course in April, 2012 and the others were installed in May of the same year.

Figure 3.16 Training course for monitoring equipment installation in FAO Office in Hargeysa

The methodology conducted on the training course for setting up a monitoring system in Somaliland and Puntland included four necessary steps.

The first step was:

- presentation of equipment to the local staff,
- demonstration of procedures for installation of monitoring equipment,
- installation of software for diver use in the computers,
- practical exercise in office: diver set up and downloading data.

The second step was to make the necessary agreement with the Ministries and local Waterworks according to diver installation in the wells, and maintenance and protection of the devices.

The third step dealt with field exercise and establishing the first three monitoring network points in Hargeysa, Borama and Berbera.

Lastly, the fourth step was the finalization of installations (12 at this stage available divers) in Somaliland and Puntland as well the installation of two baro divers in Somaliland and Puntland (for data calibration and correction).

3.2.4.2. Equipment used for groundwater monitoring

The Diver water level logger is the smallest instrument in the world for automatic measurement and registration of groundwater levels and groundwater temperatures; the CTD-Diver also measures conductivity. The Diver fits in the palm of your hand and is remarkably light. With its length of only 90 mm and a diameter of 22 mm, the Diver water level logger can be used in virtually any monitoring well (Figure 3.17).

The pressure, temperature sensor and battery are contained within a hermetically sealed stainless steel or ceramic housing. This ensures that the Diver water level logger is less sensitive to moisture or external electrical influences (*Faraday cage*). The Diver water level logger can be installed in the monitoring well simply suspended from a steel wire.

Once installed, no part of the monitoring system is left protruding above ground level, greatly reducing the risk of vandalism. The Diver water level logger can automatically measure the groundwater level and temperature and register these data in the internal memory. The internal memory is capable of storing 2 x 24,000 measurements. This means that a measurement can be executed and stored every ten minutes over a six-month period before the memory is full. The built-in battery has a life of approximately 10 years.

Programming the Diver water level logger, either in the field or in the office, is a matter of just a few seconds. Simply enter the location, (future) starting time, sample rate and select either a fixed measuring frequency, a fixed setup or an event-related frequency.

Figure 3.17 Diver water level loggers

3.2.4.3. Selection of sites and installation of monitoring equipment

The sites for the already installed 8 divers (4 in Somaliland and 4 in Puntland) were selected in consultation with the Water Authorities and Utility Companies in Somaliland and Puntland. One baro diver was installed at the FAO Offices in Hargeisa and Puntland to measure atmospheric pressure, which is used to compensate data from the regular divers.

Diver installations were done in the 8 selected sites in April - June 2012. Details about the diver installation sites and some photos taken during installation are given in Figure 3.18.

Region	District	Location	BH Name	Latitude	Longitude	Installation Date	BH Depth (m)	Diver Depth From Case (m)	Data Interval (Hrs)	Diver Responsibility
W/Galbeed	Hargeisa	Geed Deebleh	K2	9.77407	43.96468	22/04/2012	90	50	6	Hargeisa Water Supply
Awdal	Borama	Dhamuug	BH5	9.95014	43.21928	23/04/2012	55	50	6	SHABA Water Supply
W/Galbeed	Berbera	Fardero	BH6	10.24	45.08531	25/04/2012	57	40	6	Berbera Water Supply
Togdheer	Burco	Shacab, Burco	BH2	9.54155	45.52868	05/06/2012	160	70	6	Burco Water Supply
Mudug	Galkayo	Garsoor, Galkayo	BH4	6.79212	47.41398	26/05/2012	210	90	6	Galkayo Water Agency
Nugal	Garowe	Garowe	BH1	8.39348	48.46878	28/05/2012	52	45	6	Nugaal Water Agency
Bari	Qardho	Xingod, Qardho	BH4	9.49807	49.08278	29/05/2012	280	220	6	HODMAN Company
Bari	Bosaso	Aaran, Bosaso	BH	11.2419	49.20747	02/06/2012	41	38	6	GUMCO

Figure 3.18 Details about 8 diver installation sites and some photos taken during installation

By the end of the project, twelve divers remained uninstalled (6 in Somaliland and 6 in Puntland). The Ministry of Water in Somaliland and PSAWEN in Puntland would undertake the installation of the remaining divers in consultation with the Water Agencies at the respective towns where the installations will be done.

The groundwater monitoring system once complete would take the form presented in the schematic overview in Figure 3.19 below.

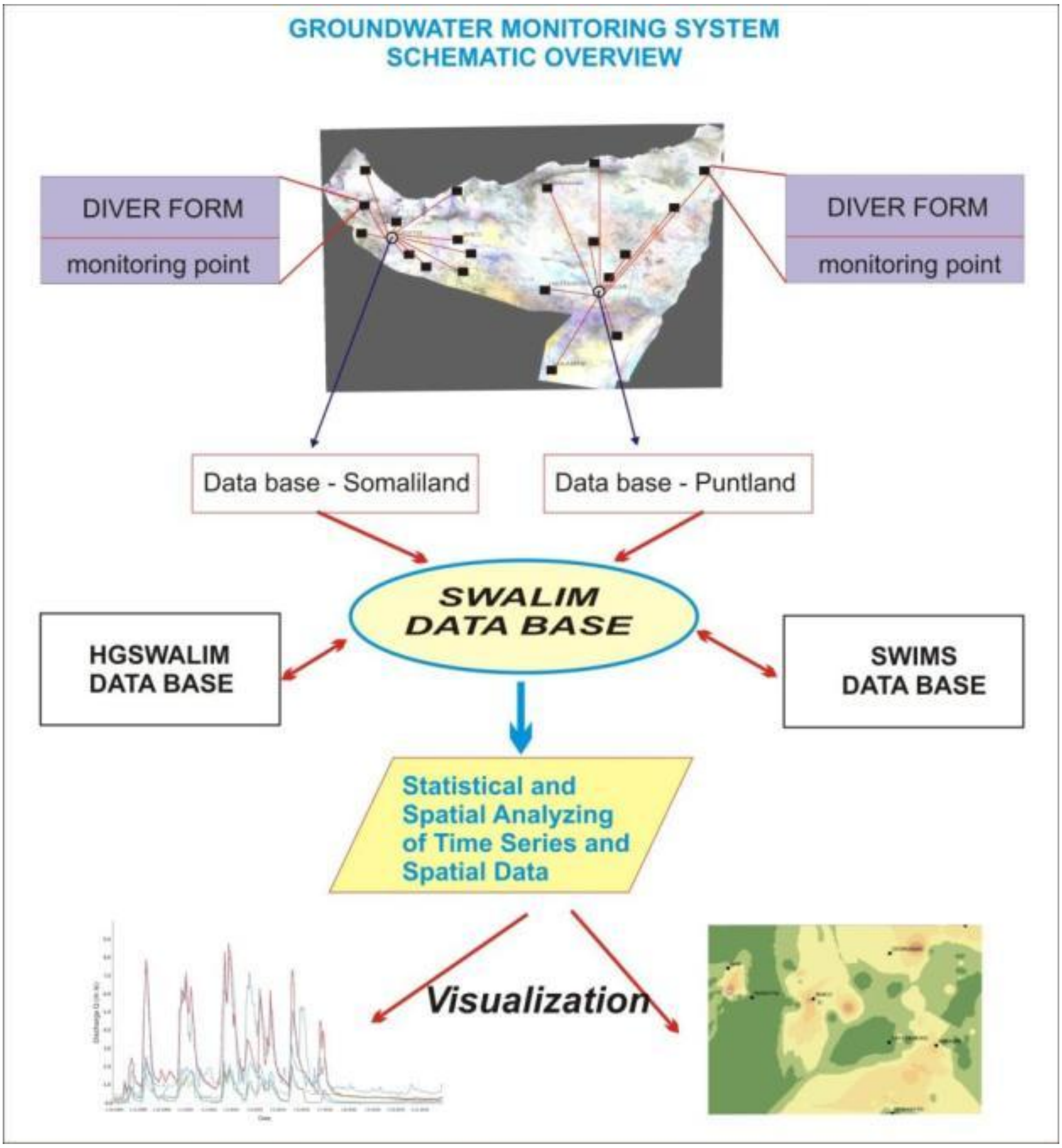


Figure 3.19 Schematic setup of monitoring network

The system is expected to be of great use in the long term groundwater monitoring in Somaliland and Puntland.

3.2.5. Pumping tests data evaluation

The primary purpose of aquifer testing is to provide data about aquifer properties, such as transmissivity and storage coefficient. Aquifer tests are also used to assess the impacts of boundaries on well production. The results of aquifer tests provide fundamental input data that can be used in calculations that predict drawdowns in an area.

Pumping a well lowers the water level in both the well and the surrounding geologic materials. The change (drop) in water level from the static or pre-pumping level is termed "drawdown." The greatest drawdown occurs at the pumping well and dissipates as distance from the well increases. Under ideal conditions, the distribution of drawdown around the pumping well assumes a conical shape often referred to as a cone of depression.

Within the framework of the SWALIM programme to support the sustainable improvement of supplying water in the Somaliland and Puntland, the main activities anticipated in this part of the project were:

- Collecting all data from pumping tests derived from previous hydrogeological surveys for different needs,
- Conducting hydrogeologic investigations aimed to find out the permeability distribution in different aquifers through evaluation of pumping tests,
- Interpretation of pumping tests as a base for the evolution of a hydrogeological map of Somaliland and Puntland.

During this project implementation the following activities were carried out:

- Collection of all data referring to the tested wells,
- Elaboration and interpretation of the data collected and calculation of transmissivity, hydraulic conductivity, specific yield and the proper pumping rate for each well

3.2.5.1. Pumping test data collection

All the data collected during the implementation of the project are prepared and shown in this report. The report summarises and updates the main boreholes and aquifer characteristics calculated from the pumping test. The wells in which pumping tests were carried out are shown in Figure 3.20.

Due to the short time for the project implementation and the real problem of performing pumping tests in the field, the data which is used in this project are from previous field investigations conducted mostly from 2005 to 2010.

The pumping tests achieved the following results:

- Calculation of the hydraulic parameters for different geological units,
- Good overlay between characteristics from pumping tests data and from the previous hydrogeological, geological and geophysical surveys,
- Suggestion of the proper pumping rate according to the new recalculations of pumping tests data in Aquifer Test Pro Software,
- Help in forming a new hydrogeological map according to aquifer characteristics.

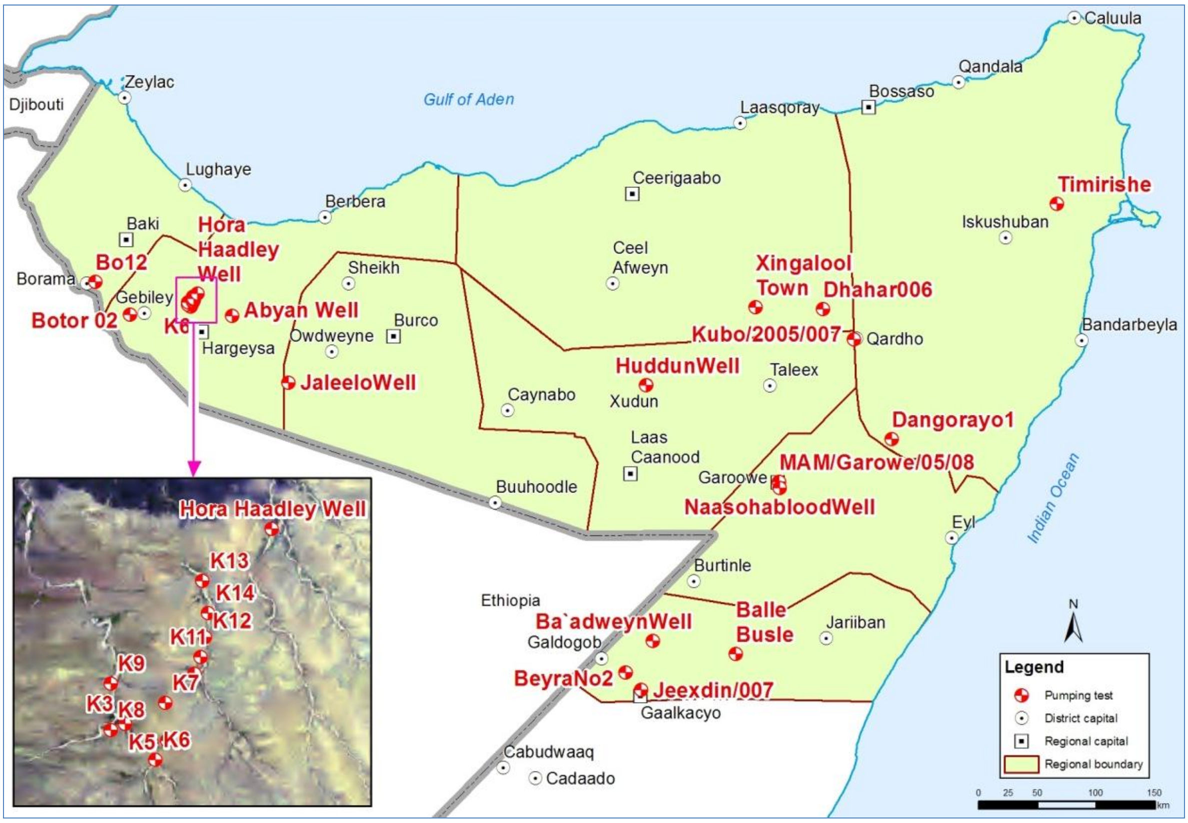


Figure 3.20 Position of wells with pumping tests data

3.2.5.2. Pumping test data analysis

The pumping tests of each well consisted mostly of a step test and a constant rate test. The purpose of the pumping test was to calculate some of the basic hydraulic parameters of the aquifer.

Transmissivity (T) and Hydraulic Conductivity (K) were calculated on the basis of drawdown curves of the constant rate tests, according to the *Aquifer Test Pro* software as well as previous data interpretation. The updated characteristics of the wells are listed in Table 3.2.

Documents which are processed in this chapter according pumping tests are listed below:

1. Technical report - Ba`adveyn Water System, PPP (2010)
2. Pumping tests data for Gardo bore wells – WES section UNICEF (2002)
3. Beyra borehole report – Weirah Water Well Driling Company (2010)
4. Naasohablood well report – PSAWEN (2004)
5. Rehabilitation and Improvment of the Hargeysa Urban Water Supply System - Daniel Buggiani, Africa 70, (2007)
6. Technical Report Hoddun Borehole – UNICEF, MAM Brothers (2009)
7. Borehole Completion Report – UNICEF, MAM Brothers (2009)
8. Balle Busle Completion Report - MAM Brothers (2007)
9. Borehole Completion Report Garowe/ (west of GTZII) - MAM Brothers (2005)
10. Borehole Completion Report Weirah - Weirah drilling Co. (2006)
11. Borehole Completion Report Timirshe – CAFA COPI (2007)

Table 3.2 Updated characteristics of the aquifers according to pumping tests

Source	Location	Pumping Test Type	Depth (m)	SWL (m)	DWL (m)	Draw down (m)	Test duration (h)	Disch. Q l/s	T (m^2/s)	K (m/s)	Geo.symbol	Aquifer ID
K3	Geed Deeble	StepT./ConstantRateT./Recovery	91	15	31	16	48	18	0.00508	0.00023	al	I1
K4	Geed Deeble	StepT./ConstantRateT./Recovery	156	26	56	30	48	16	0.0042	0.0000288	al	I1
K5	Geed Deeble	StepT./ConstantRateT./Recovery	208	41	44	3	18	12	0.0033	0.000043	Qc	I3
K6	Geed Deeble	StepT./ConstantRateT./Recovery	143	33	38	6	48	16	0.00518	0.0000722	al	I1
K7	Geed Deeble	StepT./ConstantRateT./Recovery	203	37					0.000606	0.0000288	Qc	I3
K8	Geed Deeble	StepT./ConstantRateT./Recovery	108	17	23	6	48	20	0.0058	0.0000767	al	I1
K9	Geed Deeble	StepT./ConstantRateT./Recovery	144	44	49	6	20	14	0.0064	0.00014	al	I1
K10	Geed Deeble	StepT./ConstantRateT./Recovery	154	30	38	8	48	20	0.00953	0.000196	Qc	I3
K11	Geed Deeble	StepT./ConstantRateT./Recovery	145	23	36	13	48	20	0.0042	0.000083	Qc	I3
K12	Geed Deeble	StepT./ConstantRateT./Recovery	124	23	39	16	48	16	0.00286	0.0000684	γ	A
Botor 02	Botor Dam	ConstantRateT./Recovery	184	82	88	7	61	14	0.0033	0.0000494	Qc	I3
Hora Haadley	Geed Deeble	ConstantRateT./Recovery	94	2	31	28	48	15	0.0045		al	I1

Source	Location	Pumping Test Type	Depth (m)	SWL (m)	DWL (m)	Drawdown (m)	Test duration (h)	Disch. Q l/s	T (m^2/s)	K (m/s)	Geo.symbol	Aqui-fer ID
Well												
Abyan Well	Hargeysa	StepT.	160	6	95	81		4	0.0032	0.000055	γ	A
Balle Busle	Balle Busle	ConstantRateT./Recovery	170	102	138	36	24	6	0.00045	0.000064	OMmb	F
Dangorayo1	Dangorayo	ConstantRateT./Recovery	403	215	270	55	24	3	0.00023	0.0000437	Ek	K1
MAM/Garowe/05/08	Garowe	ConstantRateT./Recovery	166	23	158	136	9	4	0.00064	0.000034	d-pr	I2
Dhahar006	Dharar	ConstantRateT./Recovery	212	96	99	2	48	5	0.0033	0.00054	Ek	K1
Huddun Well	Xudun	ConstantRateT./Recovery		37	200	163	7	4	0.00023	0.0000124	Ea	K1
Jeexdin/007	Gaalakacyo	ConstantRateT./Recovery	210	69	92	24	24	5	0.00142	0.000341	OMmb	F
Kubo/2005/007	Kubo	ConstantRateT./Recovery	210	154	157	3	0	5	0.0055	0.000012	Qt	I2
Weirah/06/003	Beyra	ConstantRateT./Recovery	220	65	97	32	1	5	0.00029	0.0000175	OMmb	F
JaleeloWell	Jaleelo	ConstantRateT./Recovery	116	47	52	5	48	20	0.012	0.000255	Qt	I2
Timirishe	Timirishe	ConstantRateT./Recovery		22	74	52	2	5	0.00045	0.000032	Mi	F
Bo12	Borama	ConstantRateT./Recovery	114	48	51	3	48	12	0.0031	0.000055	Jc	K2
BeyraNo2	Beyra		180	89	91	2	48	3	0.0031	0.000421	OMmb	F
Ba`adweynWell	Bacaadweyn		235	128	130	2	7	5	0.0012	0.00023	Qc	I3
NaasohabloodWell	Naasohablod	ConstantRateT/Recovery	213	49	186	137	16	2	0.0001	0.000021	Et	K2
Xingalool Town	Xingalool	ConstantRate	127	56	58	2	10	7	0.0022	0.00041	Qc	I3

Pumping test - results from Awdal Region

Borehole Bo12 is located in the eastern basin of the town of Borama, and shows that the conditions of Jurassic karstic aquifer are excellent for the further supply of water. The location of borehole Bo12 is shown in Figure 3.21. A main characteristic of borehole Bo12 is that total drawdown in 48 hours of constant pumping at 12 l/s is 3 meters. With a constant yield the rate of drawdown remains constant. Its transmissivity is $3.1x10^{-3}$ m^2/s and its hydraulic conductivity is $5.5x10^{-5}$ m/s.

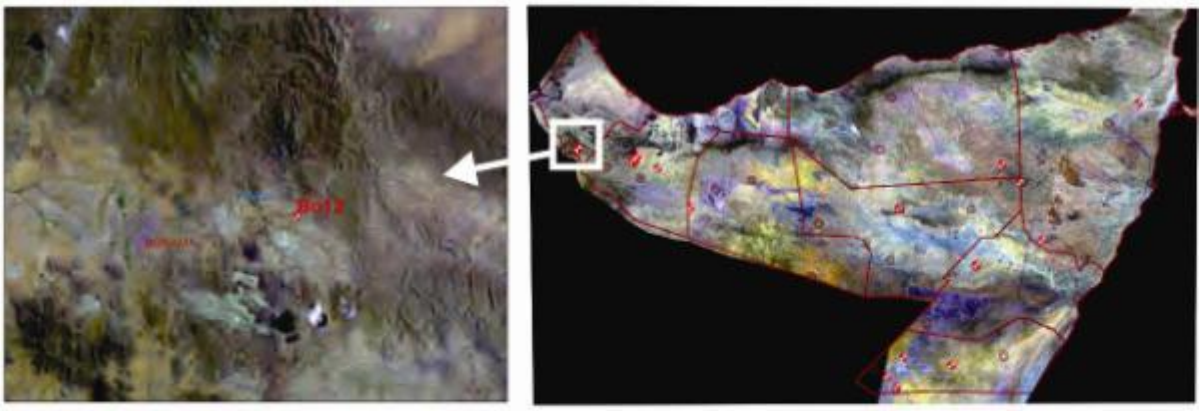


Figure 3.21 Location of borehole Bo12 in Awdal region.

The aquifer extends to the depth of 114 m, where the crystalline basement was met. Water was found in the Jurassic limestones at a depth of 65 m, after which it raise to a level of about 48 m.

Pumping test - results from Woqooi Galbeed region

On the basis of previous data from pumping tests carried in Woqooi Galbeed Region the following conclusions for wells and aquifer characteristics can be pointed out. The positions of wells are shown in Figure 3.22.

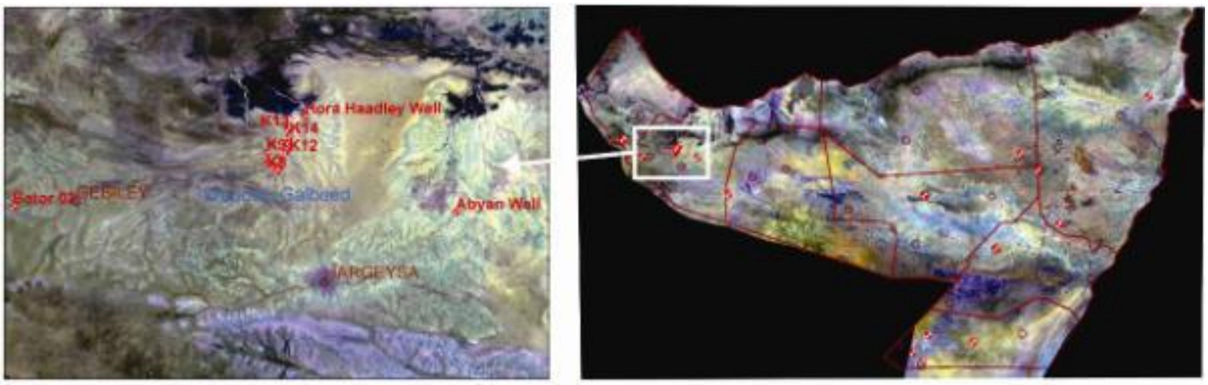


Figure 3.22 Position of wells with pumping test data in Woqooyi Galbeed region

Geed Deeble aquifer is up to 200 meters thick. According to the Hargeysa Water Agency, average production in 2012 is around 105-115 l/s. Still, according to the pumping test data (aquifer parameters) the capacity of Geed Deeble aquifer is higher than the current exploitation capacity. From the data available (concerning 11 wells) and later presented those wells can be considered as still non-fully exploited. Pumping tests also confirm this assertion.

A main characteristic of borehole K3 is that total drawdown in 72 hours of constant pumping at 17.5 l/s is 16 meters. With a constant yield the rate of drawdown remains constant (steady –state flow). Its transmissivity is calculated on 5.08 x 10^{-3} m^2/s and its hydraulic conductivity is 2.35 x 10^{-4} m/sec.

Borehole K4 was tested for 72 hours with constant pumping at 15.6 l/s and a drawdown of 30 meters. The drawdown is very fast and after 4 hours of constant pumping encounters a permeability limit that causes an increase in the rate of water table. Its transmissivity is 6.06 x 10^{-4} m^2/s and its hydraulic conductivity is 2.88 x 10^{-5} m/s.

The step test of the K5 well shows that its optimal yield is 12 l/s. During pumping, drawdown was only 3 meters.

The optimal yield of Well K6 is16.2 l/sec. The total drawdown in 72 hours of pumping at 16 l/s is very small at just 5.5 meters of drawdown and not encounter any significant variation. Its transmissivity is 5.18 x 10^{-3} m^2/s and its hydraulic conductivity is 7.22 x 10^{-5} m/s.

The step test carried out in Well K7 shows that pumping up to 17.8 l/s not reached the critical yield for this well. The main parameters revealed by the recovery test are: transmissivity 8.4 x 10^{-3} m^2/s and hydraulic conductivity 8.4 x 10^{-5} m/s.

The total drawdown in Well K8 in 48 hours of pumping at 20.38 l/s is also small, only 6 meters. After 24 hours of pumping the dynamic water level became stable and no additional drawdown was registered. This can also be related to the position of this well, which is near the joint of the two Togga Geed Deeble branches. Transmissivity is 5.8 x 10^{-3} m^2/s and its hydraulic conductivity is 7.67 x 10^{-5} m/s.

Well K9 has a constant rate at 19.8 l/sec with only 5,5 meters of drawdown. Its transmissivity is 5.69 x 10^{-3} m^2/s, while the hydraulic conductivity is 1.23 x 10^{-4} m/s.

The constant rate test in Well K10 was executed at 19.8 l/sec; the total drawdown in 48 hours was only 8 meters. The drawdown rate rises slightly in the first 7 hours of pumping, then between 7 and 18 hours the drawdown rate increases gradually until it stabilizes. The aquifer transmissivity is 9.53 x 10^{-3} m^2/s and hydraulic conductivity 1.96 x 10^{-4} m/s.

The subsequent constant rate test on well K11was executed at 20.3 l/sec; the total drawdown in 48 hours was 13 meters. As for the previous well (K10) the drawdown rate is small for up to 8 hours of pumping, then between 8 and 18 hours the drawdown rate increases gradually until it stabilizes. It is possible that the cone of depression reached lateral boundary or this well interfered with the surrounding wells. Transmissivity is calculated on 1.03 x 10^{-2} m^2/s and hydraulic conductivity is 2.2 x 10^{-4} m/s.

The step test shows that for Well K12 the critical yield is around 16.5 l/sec. Transmissivity is 2.86 x 10^{-3} m^2/s and hydraulic conductivity is 6.84 x 10^{-5} m/s.

Several wells were drilled around the town of Gebiley (population 21,000) for water supply.

The constant rate test of Hora Haadley well was executed at 15 l/s; the total drawdown in 48 hours was 28 meters. The transmissivity value is 4.53 x 10^{-3} m^2/s.

Another characteristic well which had a pumping test data is Botor 02. The constant rate test in this well was executed at 14 l/s, the total drawdown in 61 hours was only 7 meters. The transmissivity is 3.3 x 10^{-3} m^2/sec and its permeability is 4.96 x 10^{-5} m/s.

The step test shows that for the well in Abyan the critical yield is only 4 l/s. Transmissivity is 3.2 x 10^{-3} m^2/s and permeability expressed as hydraulic conductivity parameter is 5.5 x 10^{-5} m/s.

Pumping test - results from Togdheer Region

The pumping test of Jaleelo well in Togdheer region (Figure 3.23) was conducted with a constant discharge rate of 20 l/s. The dynamic water table reached the depth of 52 m while the initial static level was 47 m deep. Based on recovery measurements, the aquifer responded instantly and very fast. Transmissivity is 1.2 x 10^{-2} m^2/s and hydraulic conductivity is 2.5 x 10^{-4} m/s.

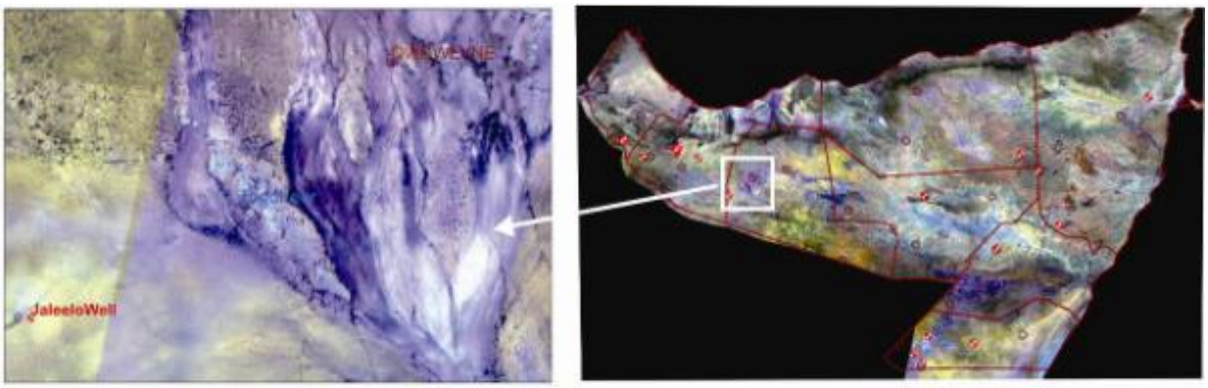


Figure 3.23 Position of well with pumping test data in Togdheer region

Pumping test - results from Sool Region

There is only one pumping test performed in the well located in the Sool region (Figure 3.25). Pumping test was conducted with constant discharge rate of 4 l/s, with dynamic water level of 208.5 m b.g.l. while initial static level was 36.6 m. In the first hours of the test, the well exhibited with a steep drawdown reaching 146.9 m, but it later stabilized. In the recovery measurements, the aquifer responded instantly from 199.08 m to 95.0 m after three hours, with an average recovery of 34.36 m per hour. Transmissivity is 2.3 x 10^{-4} m^2/s and hydraulic conductivity is 1.2 x 10^{-5} m/s.

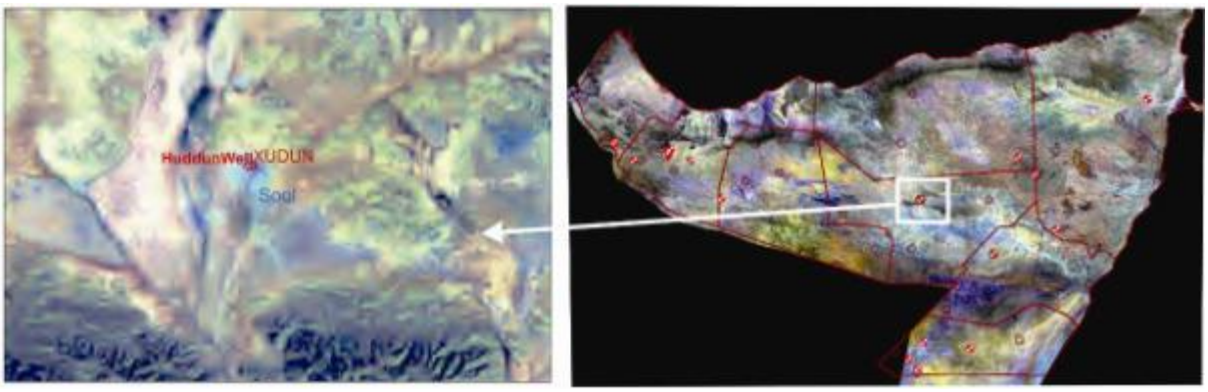


Figure 3.25 Position of wells with pumping test data in Sool region

Pumping test - results from Sanaag Region

There are only a few wells with data from pumping tests in the Sanaag region (Figure 3.26). The first is Dhahar 006 Well. A pumping test was conducted with 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} m^2/s and hydraulic conductivity 5,4 x 10^{-5} m/s.

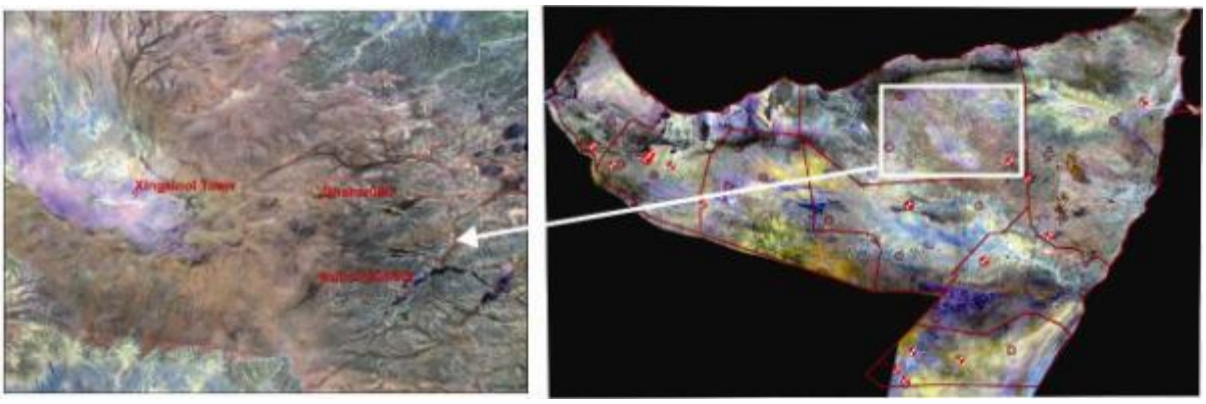


Figure 3.26 Position of wells with pumping test data in Sanaag region

The second examined is the well for Xingalool Town. A pumping test was conducted with a constant discharge rate of 7 l/s, and with a dynamic water level of 58 m b.g.l. while the initial static level was 56 m. Obtained transmissivity value is 2.2 x 10^{-3} m^2/s while the hydraulic conductivity is 4.1 x 10^{-5} m/s.

Pumping test - results from Bari Region

Data from three tested wells in the Bari region were collected and evaluated. All three pumping tests were conducted with a constant discharge rate and recovery.

The first is Timirishe Well 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} m^2/s and hydraulic conductivity is 3.2 x 10^{-5} m/s.

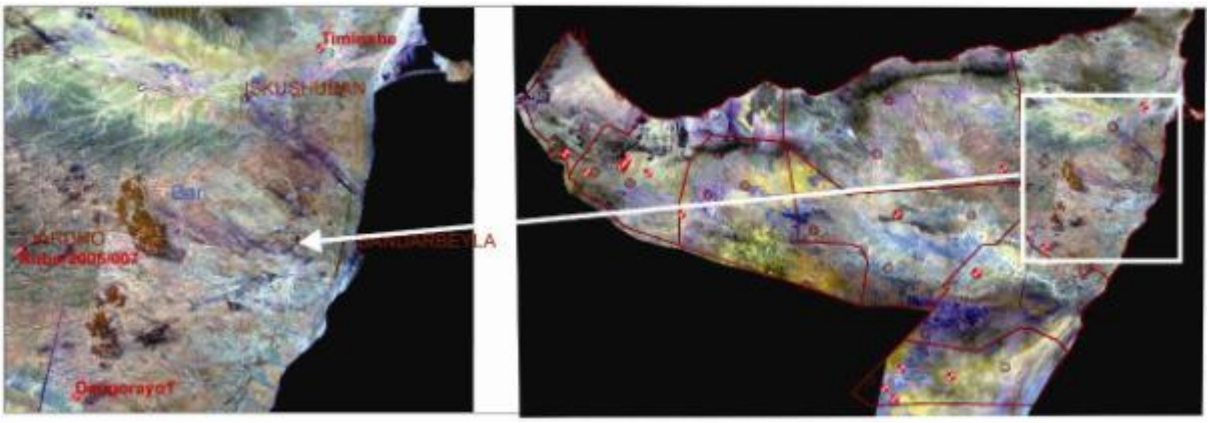


Figure 3.27 Position of wells with pumping test data in Bari region

The well Kubo/2005/007 is tested with a yield of 5 l/s. The dynamic water level was 157 m b.g.l. while the static level was only 3 meters above, 154 m. Transmissivity is 5.5 x 10^{-3} m^2/s and hydraulic conductivity is 1.2 x 10^{-4} m/s.

The next tested well is Dangorayo 1 with a yield of 3 l/s. The dynamic water level was at the depth of 270 m b.g.l. while the initial static level was also very deep, on 215 m. Transmissivity is 2.3 x 10^{-4} m^2/s and hydraulic conductivity is 4.4 x 10^{-5} m/s.

Pumping test - results from Nugaal Region

There are only two wells with pumping test results from a large Nugaal region (Figure 3.28).

The pumping test for Well MAM/Garowe/05/08 was 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} m^2/s and hydraulic conductivity is 3.4 x10^{-5} m/s.

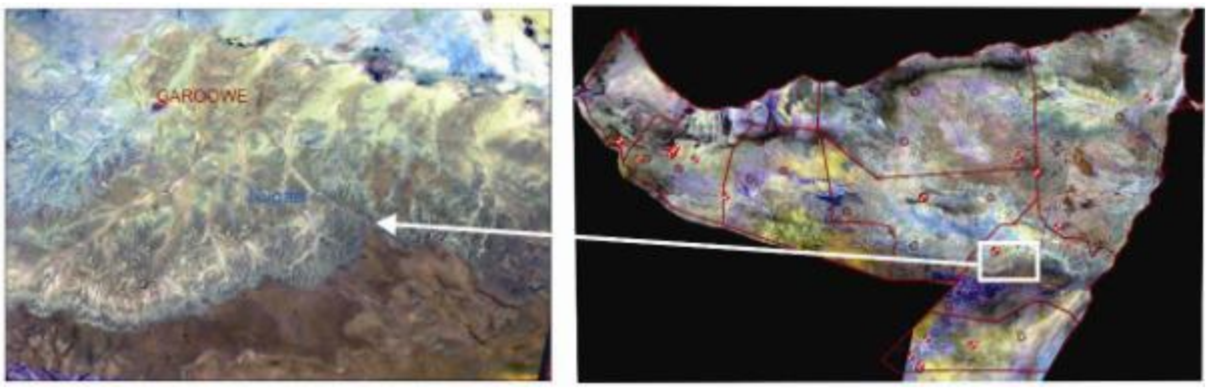


Figure 3.28 Position of wells with pumping test data in Nugaal region

The pumping test for Naasohablood well was conducted with a constant discharge rate of 2 l/s. The dynamic water level was reached 186 m b.g.l. while the initial static level was 49 m. Transmissivity is 1.1 x 10^{-4} m^2/s and hydraulic conductivity is 2.1 x 10^{-5} m/s.

Pumping test - results from Mudug Region

Several wells were drilled and tested in Mudug region. All these wells have a low yield, not higher than 6 l/s. Wells Beyra No2, Weirah/06/003 and Jexxdin/007 are in use for the water supply of Gaalkacyo, Beyra, Bacadveyn and BalliBusle (Figure 3.29). All tests were with a constant rate and recovery.

A pumping test for Well Beyra No2 was conducted with a constant discharge rate of 3 l/s, and with a dynamic water level of 91 m b.g.l. (initial static level was 89 m deep). Transmissivity is 3.1 x 10^{-4} m^2/s and hydraulic conductivity is 4.2 x10^{-5} m/s.

The test for Well Weirah/06/003 was conducted with a constant discharge rate of 5 l/s, with a static/dynamic/ water levels at 65 and 97 m b.g.l., respectively. Transmissivity is 2.9 x 10^{-4} m^2/s and hydraulic conductivity is 1.8 x10^{-5} m/s.

The well Jexxdin/007 near Gaalkacyo was tested with a constant discharge rate of 5 l/s. The dynamic water level was 92 m b.g.l. while the initial static level was 69 m deep. Transmissivity is 1.4 x 10^{-3} m^2/s and hydraulic conductivity is 3.4 x10^{-4} m/s.

The characteristics of the wells for Bacadveyn and BalliBusle are similar to previous wells in Mudug. The well in Bacadveyn was tested with a constant discharge rate of 5 l/s, with a dynamic water level of 130 m b.g.l. while the initial static level was 128 m b.g.l. Transmissivity is 1.2 x 10^{-3} m^2/s and hydraulic conductivity is 2.3 x10^{-4} m/s.

The well in BalliBusle was tested with a constant discharge rate of 6 l/s. The static/dynamic/ water levels were 102 m and 138 m b.g.l, respectively. Transmissivity is 4.5 x 10^{-4} m^2/s and hydraulic conductivity is 6.4 x10^{-5} m/s.

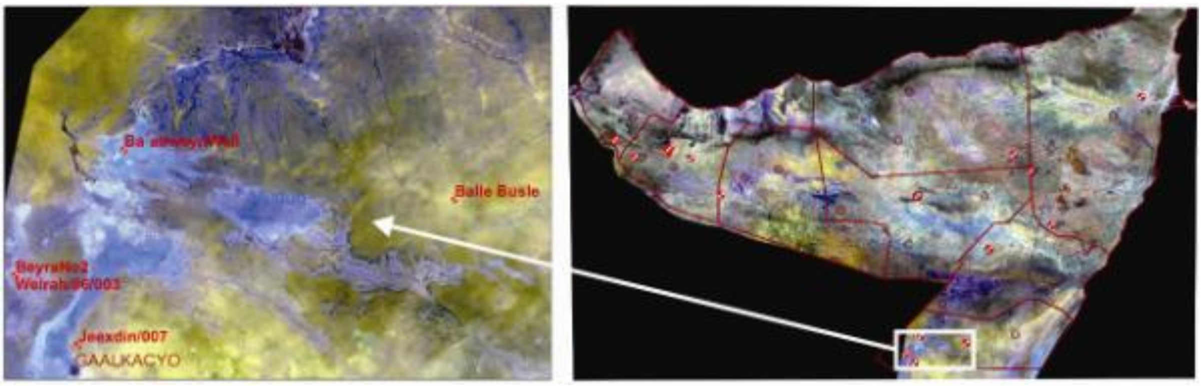


Figure 3.29 Position of wells with pumping test data in Mudug region

All the data acquired from different sources connected to the pumping tests and wells characteristics were integrated into the SWALIM Geo database.

The main outcomes from the results of the pumping tests are visually presented in Appendix IV.

3.2.6 Groundwater quality assessment

Groundwater quality is related to the chemical composition of geological formations through which the water has passed, as well as to the balance between recharge and discharge. Concentrations of chemical components in groundwater vary widely within the Somaliland and Puntland areas, depending on the location and type of hydrogeological objects (spring, dug well, drilled well).

Generally, groundwater quality in the study area is not high and usually does not meet all WHO guidelines for acceptable drinking water. Based on the chemical analyses of 511 samples hardness, calcium, magnesium, sodium, potassium and other components are usually above the WHO-standard.

Generally in Somaliland and Puntland, very few groundwater sources will conform to international standards. The salt content of the water commonly exceeds 1 g/l, which under normal circumstances is the upper limit for human consumption, but acceptance of water with relatively high ion concentrations is a necessity, as there is usually no alternative.

Consumption of waters with concentrations above the standard limits is not necessarily harmful. Still, water projects such as SWALIM should always target the best possible quality, and identify sources with chemical properties as close as possible to the WHO norms. Appropriate technological solutions must be considered in areas where adverse types of water are likely to have hazardous effects on man and livestock.

Tentative salinity limits, proposed by UNICEF, are as follows:

TDS (gr/l)	Suitability
0 – 1.0	Suitable for all normal purposes
1.1 – 3.0	Suitable for livestock, marginal for human consumption
3.1 – 5.0	Suitable for livestock, unsuitable for human consumption
5.1 – 7.0	Suitable for camels, marginal for other livestock
7.1 – 10.0	Suitable for camels, marginal for goats and sheep, unsuitable for cattle
10.0 – 15.0	Marginal for camels, only in emergencies for goats and sheep
> 15.0	Unsuitable for any domesticated animal life

According to previous bacteriological analyses, shallow aquifer is quite commonly contaminated and may cause widespread epidemics of cholera, diarrhoea and dysentery, which is often the case in Somaliland and Puntland and relatively easy to detect with a portable laboratory and incubator set. If the WHO limits are exceeded, the water is considered unfit for human consumption.

Several institutions have developed drinking water standards in order to define guideline values and highest admissible concentrations. Most of the international authorities more or less follow the recommendations by the World Health Organisation (WHO) given in Table 3.3, and the European Community (EC) drinking water standards which are given in Table 3.4.

Table 3.3 WHO's Guidelines for Drinking-water Quality, set up in Geneva, 1993, are the international reference point for standard setting and drinking-water safety

http://www.lenntech.com/applications/drinking/standards/who-s-drinking-water-standards.htm

Element/ substance	**Symbol/ formula**	**Normally found in fresh water/surface water/ground water**	**Health based guideline by the WHO**
Aluminium	Al		0.2 mg/l
Ammonia	NH_4	< 0.2 mg/l (up to 0.3 mg/l in anaerobic waters)	No guideline
Antimony	Sb	< 4 μg/l	0.005 mg/l
Arsenic	As		0.01 mg/l
Asbestos			No guideline

Element/ substance	Symbol/ formula	Normally found in fresh water/surface water/ground water	Health based guideline by the WHO
Barium	Ba		0.3 mg/l
Berillium	Be	< 1 μg/l	No guideline
Boron	B	< 1 mg/l	0.3 mg/l
Cadmium	Cd	< 1 μg/l	0.003 mg/l
Chloride	Cl		250 mg/l
Chromium	Cr^{+3}, Cr^{+6}	< 2 μg/l	0.05 mg/l
Colour			Not mentioned
Copper	Cu		2 mg/l
Cyanide	CN^-		0.07 mg/l
Dissolved oxygen	O_2		No guideline
Fluoride	F	< 1.5 mg/l (up to 10)	1.5 mg/l
Hardness	mg/l $CaCO_3$		No guideline
Hydrogen sulfide	H_2S		No guideline
Iron	Fe	0.5 - 50 mg/l	No guideline
Lead	Pb		0.01 mg/l
Manganese	Mn		0.5 mg/l
Mercury	Hg	< 0.5 μg/l	0.001 mg/l
Molybdenum	Mb	< 0.01 mg/l	0.07 mg/l
Nickel	Ni	< 0.02 mg/l	0.02 mg/l
Nitrate and nitrite	NO_3, NO_2		50 mg/l total nitrogen
Turbidity			Not mentioned
pH			No guideline
Selenium	Se	< < 0.01 mg/l	0.01 mg/l
Silver	Ag	5 – 50 μg/l	No guideline
Sodium	Na	< 20 mg/l	200 mg/l
Sulfate	SO_4		500 mg/l
Inorganic tin	Sn		No guideline
TDS			No guideline
Uranium	U		1.4 mg/l
Zinc	Zn		3 mg/l

Table 3.4 Council Directive 98/83/EC on the quality of water intented for human consumption. Adopted by the Council, on 3 November 1998:

http://www.lenntech.com/applications/drinking/standards/eu-s-drinking-water-standards.htm

Parameter	Symbol/formula	Parametric value (mg/l)
Acrylamide	C_3H_5NO	0.0001
Antimony	Sb	0.005
Arsenic	As	0.01
Benzene	C_6H_6	0.001
Benzo(a)pyrene	$C_{20}H_{12}$	0.00001
Boron	B	1.00
Bromate	Br	0.01
Cadmium	Cd	0.005

Parameter	Symbol/formula	Parametric value (mg/l)
Chromium	Cr	0.05
Copper	Cu	2.0
Cyanide	CN =	0.05
1,2-dichloroethane	$Cl\ CH_2\ CH_2\ Cl$	0.003
Epichlorohydrin	C_3H_5OCl	0.0001
Fluoride	F	1.5
Lead	Pb	0.01
Mercury	Hg	0.001
Nickel	Ni	0.02
Nitrate	NO_3	50
Nitrite	NO_2	0.50
Pesticides		0.0001
Pesticides - Total		0.0005
PAHs	$C_2\ H_3\ N_1\ O_5\ P_{1\ 3}$	0.0001
Selenium	Se	0.01
Tetrachloroethene and trichloroethene	C_2Cl_4/C_2HCl_3	0.01
Trihalomethanes - Total		0.1
Vinyl chloride	C_2H_3Cl	0.0005
Parameter	**Symbol/formula**	**Parametric value**
Aluminium	Al	0.2 mg/l
Ammonium	NH_4	0.50 mg/l
Chloride	Cl	250 mg/l
Clostridium perfringens (including spores)		0/100 ml
Colour		Acceptable to consumers and no abnormal change
Conductivity		2500 µS/cm @ 20°C
Hydrogen ion concentration	$[H^+]$	≥ 6.5 and ≤ 9.5
Iron	Fe	0.2 mg/l
Manganese	Mn	0.05 mg/l
Odour		Acceptable to consumers and no abnormal change
Oxidisability		5.0 mg/l O2
Sulfate	SO_4	250 mg/l
Sodium	Na	200 mg/l
Taste		Acceptable to consumers and no abnormal change
Colony count 22°		No abnormal change
Coliform bacteria		0/100 ml
Total organic carbon (TOC)		No abnormal change
Turbidity		Acceptable to consumers and no abnormal change
Tritium	H_3	100 Bq/l
Total indicative dose		0.10 mSv/year

Parameter	Parametric value
Escherichia coli (*E. coli*)	0 in 250 ml
Enterococci	0 in 250 ml
Pseudomonas aeruginosa	0 in 250 ml

Parameter	**Symbol/formula**	**Parametric value (mg/l)**
Colony count 22°C		100/ml
Colony count 37°C		20/ml

3.2.6.1. Collection of water samples from the field

During project implementation more than 511 samples of the groundwater are collected manually from the drilled wells, dug wells, springs and toggas which were approximately equally distributed all over study area.

Within the framework of the SWALIM programme to support the sustainable improvement of water quality in the Somaliland and Puntland, the main activities anticipated in this part of the project were:

- Collecting all data from previous hydrogeological surveys for different needs,
- Conducting hydrogeologic investigations on collecting samples for laboratory analysis.
- Interpretation of groundwater quality data for the evolution of a hydrocemical map of Somaliland and Puntland.

All samples were analyzed using standard procedures in the laboratory. The data base obtained from water quality testing is used as attribute data base for preparation of thematic maps showing distribution of various water quality parameters. The results of the water quality analysis work were presented in the form of maps, graphs and tables which can be used for better understanding of the present water quality of Somaliland and Puntland.

3.2.6.2. Basic water quality in the field

Analyses for some important physical and chemical elements during project implementation were carried out in the field by field teams. They used apparatus made specifically for field use. A significant advantage of field analysis is that tests are carried out on fresh samples whose characteristics have not been changed as a result of storage in a container - specially temperature. Field analysis which are provide by field teams as temperature, EC and pH are shown in Table 3.5 as well as in GIS data base. During field investigations more than 578 field analyses were collected on the field.

Table 3.5 Values of analyzed groundwater quality parameters on the field

	Number of samples	*pH*		***EC (µS/cm)***		***T°C***	
Drilled well	147	6	10	160	11000	21	38
Dug well	370	7	10	271	11000	19	36
Spring	61	6	8	596	7840	22	37

3.2.6.3. Laboratory analysis of water samples

The obtained data from the laboratories are analyzed in terms of the spatial position and related quality, and on the other hand in terms of the relationship between the aquifer and the groundwater quality. The analyzed individual chemical parameters are discussed in the chapter 4.3.4.

Table 3.6 gives a summary of major characteristics and elements from more than 511 samples, and obtained minimal, maximal and average values or concentrations.

Table 3.6 Min. Max. and Average values of analyzed groundwater quality parameters

Parameter	***Minimum***	***Maximum***	***Average***
EC (µS/cm)	271	9 480	3 539.07
PH	6	10	7.68
TEMP (^{0}C)	19	38	26.40
Chloride (mg/l)	7.6	4 330	600.83
Sulfate (mg/l)	24	8 930	1 653.39
Nitrate (mg/l)	0.9	168	31.38
Nitrite (mg/l)	0.02	0.48	0.12
Ammonium (mg/l)	0.07	58	15.01
Fluoride (mg/l)	0.2	8.4	1.82
Hydrogen Carbonate (mg/l)	112	567	272.41
Carbonate (mg/l)	5	10	7.86
Aluminum (mg/l)	0.09	0.19	0.13
Arsenic (mg/l)	0.005	0.026	0.01
Barium (mg/l)	0.005	0.2	0.05
Lead (mg/l)	0.005	0.009	0.01
Boron (mg/l)	0.07	4.5	0.92
Cadmium (mg/l)	0.001	0.002	0.00
Calcium (mg/l)	21.6	825	305.03
Chromium (mg/l)	0.005	0.025	0.01
Iron (mg/l)	0.02	0.12	0.07
Potassium (mg/l)	1.7	111	21.54
Copper (mg/l)	0.005	0.012	0.01
Magnesium (mg/l)	8.41	2330	180.18
Manganese (mg/l)	0.006	4.2	0.89
Sodium (mg/l)	9.6	2530	353.28
Phosphorus total (mg/l)	0.05	0.11	0.07
Mercury (mg/l)	0	0	0.00
Silica (mg/l)	4.9	40	14.22
Strontium (mg/l)	0.51	21	7.05
Zinc (mg/l)	0.01	1.9	0.43
Iodine (mg/l)	0.006	2.6	0.27

All data of groundwater quality elements are presented in tables of Appendix IV.

3.2.7 Database creation

3.2.7.1 SWIMS

The Somalia Water-sources Information Management System (SWIMS) is a software developed by SWALIM for collecting and managing water sources data. Data collected by the hydrogeology teams using the field data forms were transferred into a water sources database using the SWIMS software. The SWIMS database was then exported into Ms Excel with all the source parameters linked to X,Y coordinates defining the location. The Excel data was further mapped in GIS applications using the X,Y coordinates to be part of the GIS database. (Details available in Appendix IV)

A total of 720 water sources (397 dug wells, 195 boreholes, 67 toggas and 61 springs) visted during the survey were incorporated into SWIMS.

3.2.7.2. Geo-Database

Geo-database is a common data storage and management framework for GIS. Hydrogeology geo-database is a GIS created tool which manages and maintains spatial data and associated attributes of groundwater sources. The tool allows easy translation of data collected in the field to a centralized database, and assists users in the future in managing water sources information in a systematic and standardized way.

The design of the geodatabase allows information from various sources to be assimilated together, viewed and analyzed based on spatial relationships. Digital Elevation Models (DEM) are common datasets in hydrogeological studies for describing the land surface terrain, and they are stored within the geo raster catalog. Atmospheric, surface waters, and groundwater datasets reference the land surface, thus the land surface can be thought of as the interface for linking the components of the hydrologic cycle

For this study, a geo-database was developed based on datasets generated from desktop studies, field reconnaissance, field hydrogeological exploration, examination of the local groundwater conditions at the sites, and analysis, evaluation and interpretation of the available data from the previous SWIMS data base. The various generated datasets were used for hydrogeological investigations with the aim of creating a hydrogeological map at a scale of 1:750,000 for Somaliland and Puntland.

Methodology and approach

Developing a hydrogeological geodatabase and related map involved a lot of initial field work, analysing the results and interpretation of data from a hydrogeological point of view. The entire process can be summarized into the following steps:

- Collection of available relevant information from libraries and document archives;
- Analysis of satellite images for upgrading the knowledge of lithology, rock fractures and infiltration as a base for a hydrogeological map;
- Field surveys to collect and compile data on boreholes, wells and springs. This data include locations, hydrogeology, geology, as well as information on specific characteristics of sites and technical data;
- Some specific ground verification of results of analysis of satellite images;
- Collection and analysis of pumping tests data;
- Geophysical investigations;
- Development of hydrogeological geodatabase and maps, and identification of sites with potential groundwater.

A geodatabase created from these various datasets contains information on various categories that allows statistical and spatial analysis in terms of water quantity and quality, management and utilization. Within the geodatabase, aquifers are represented as polygon features which outline the boundaries of aquifers and zones within them. Wells are represented as point features showing the well locations (x, y) in a map view and carrying associated attributes such as the well type, drill date, depth, static water level, yield etc. A set of relationships is defined to connect wells to the aquifers.

The number of water points used for the creation of ***Hydrogeology geo-database*** are presented in Table 3.7.

Table 3.7 Summary table of collected and analyzed data

No.	Source of data	Type of data	Number of data
1	SWIMS	Drilled well	379
2	SWIMS	Dug well	1,030
3	SWIMS	Spring	320
4	Hydrogeology geo-database	Drilled well	191
5	Hydrogeology geo-database	Dug well	394
6	Hydrogeology geo-database	Spring	61
7	Hydrogeology geo-database	Togas	67
8	Hydrogeology geo-database	Pumping test	30
9	Hydrogeology geo-database	Chemical analysis	511
10	Hydrogeology geo-database	Monitoring points	6

As shown in the table, almost 3,000 water points with more than 40,000 data attributes were analyzed and presented through a the geodatabase. Details about Geodatabase creation are available at Appendix IV.

3.2.8. The development of the hydrogeology map in GIS

Map design

The HG map design aims at collecting, and visualizing hydrogeological information on a regional scale, and conveying groundwater-related information in a way that facilitates discussion of water issues and gives recognition to groundwater resources.

The geological setting of the HG map is based on an existing regional geological map on the small scale of 1:1,500,000 (Abbate, Sagri, Sassi 1994) and on the remote sensing analysis conducted for the HASP (Appendix III).

The SWALIM consultants and experts agreed on an iterative approach. This consists in the first instance of providing data sets of geological, remote sensing, hydrogeological and topographical information; then collecting and capturing consolidated, up-to-date information supplied by field teams and from the previous SWIMS database; and finally, establishing and maintaining a comprehensive (Hydro) Geo-Information System (in this case Geo database) for data relevant to groundwater on a scale of 1:750,000.

The HG Geo database

The main focus of the map is the establishment of a SWALIM Geo database, in which a lot of data relevant to groundwater is stored together with its geographic reference. In its final form the HG map covers the following thematic layers, a selected number of which is shown in Annex I:

- hydrogeological units (aquifer systems)
  - hydrogeology provinces
  - intergranular aquifers
  - karst aquifers
  - complex, local and shallow aquifers
- aquifer properties
- groundwater flow directions
- surveyed water points

- groundwater potential
- accessibility and exploitability of groundwater resources
- hydrochemistry.

The process of map compilation can be summarized as follows:

- select topographic base map with borders of countries, regions and districts
- extract information from existing maps and data base
- develop legend and representation
- design and create GIS structure
- analyze obtained remote sensing data for establishing new geological boundaries
- compile old geological map with new boundaries established by RS
- compile old lithological data with collected field data
- reshape old boundaries and merge with new contours
- transform feature line to a feature polygon
- rename polygons according to established legend (aquifer systems)
- prepare first draft of the global groundwater map

The HG Map presents a general visualization of the distribution of groundwater and aquifers in a convenient format. From the HG MAP and GIS Geo database a variety of thematic maps of different scales and complexity can be derived to support the individual requirements of users such as water managers or professionals who intend to conduct further survey in the designated areas.

The step by step process of creating a hydrogeological map is presented below in Figures 3.30 to 3.34.

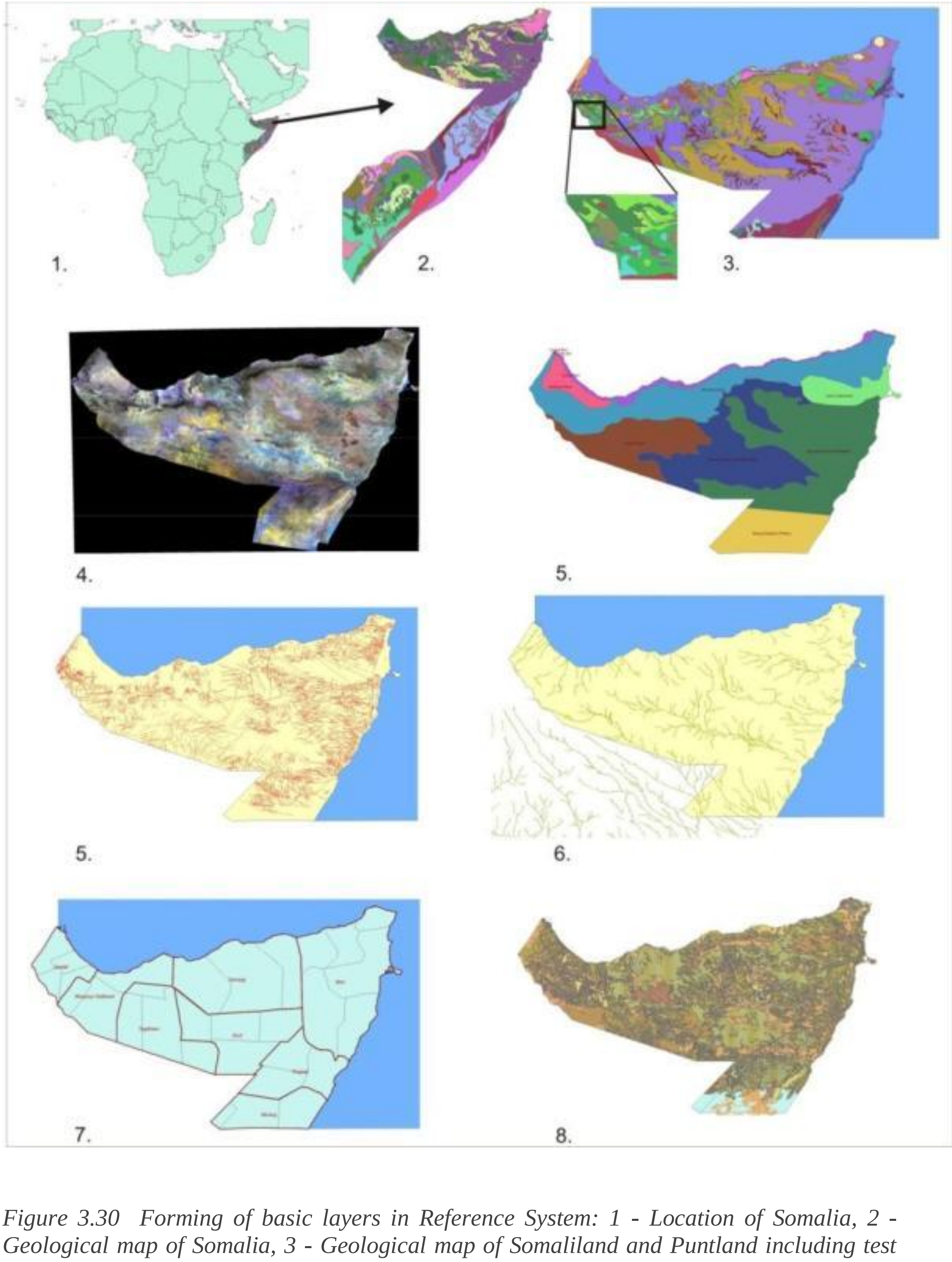


Figure 3.30 Forming of basic layers in Reference System: 1 - Location of Somalia, 2 - Geological map of Somalia, 3 - Geological map of Somaliland and Puntland including test areas, 4 - Satellite image, 4 - Hydrogeology Provinces, 5 - Tectonic pattern from RS, 6 - Drainage network, 7 - Districts and regions map, 8 – Land cover

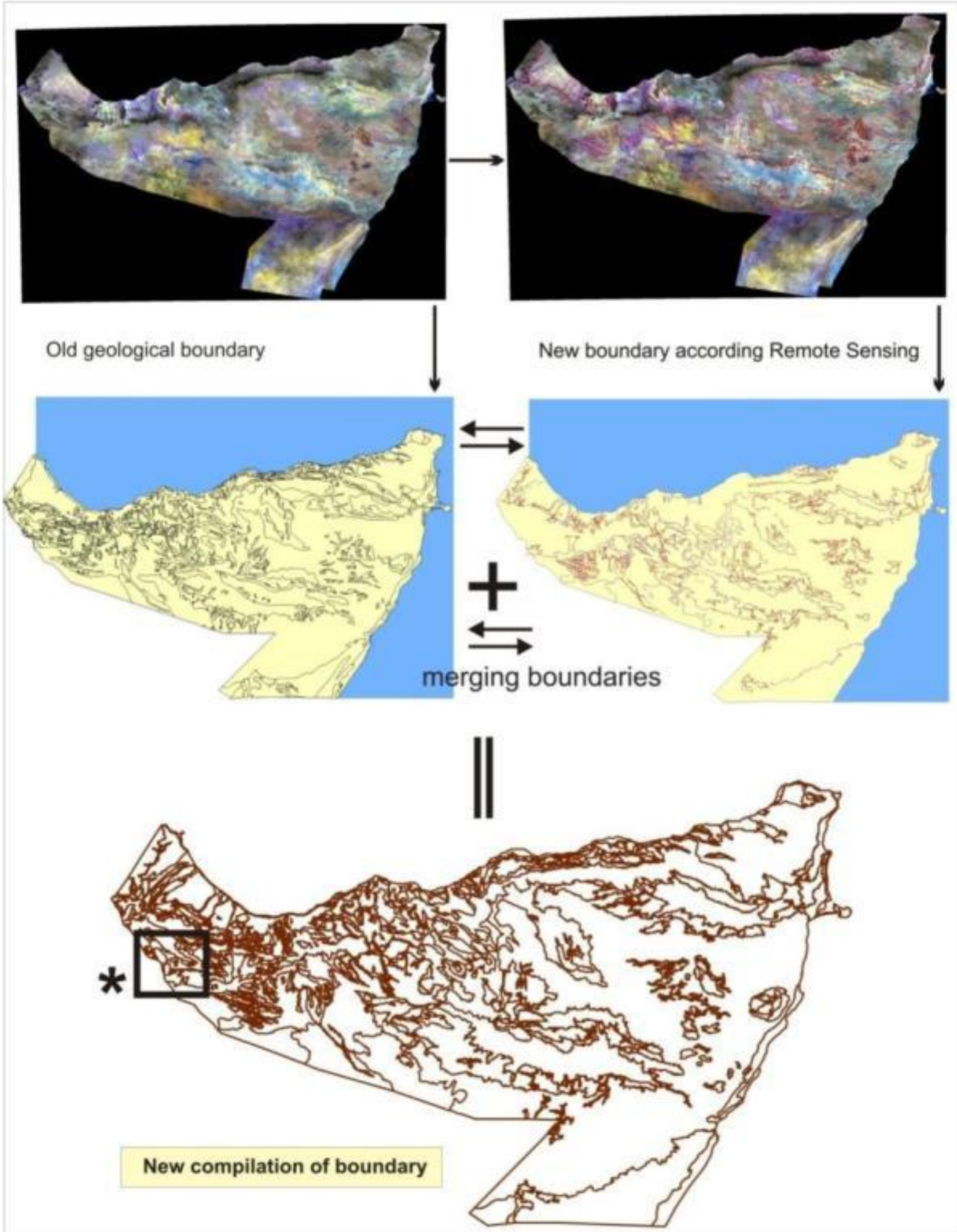


Figure 3.31 Steps of merging "old" geology boundaries with "new" boundaries according to remote sensing analyses and their findings

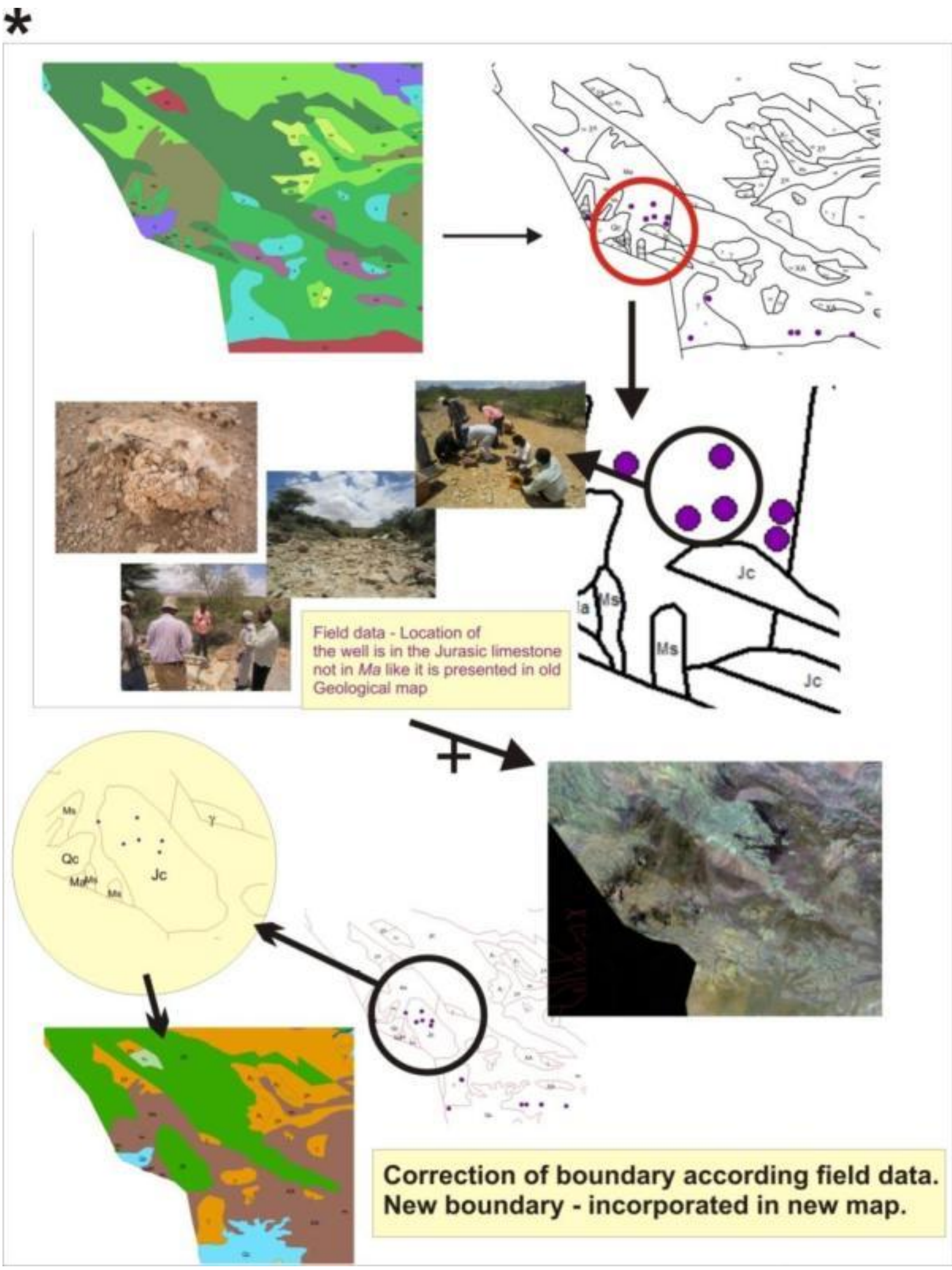


Figure 3.32 Correction of boundaries on the local scale according field data

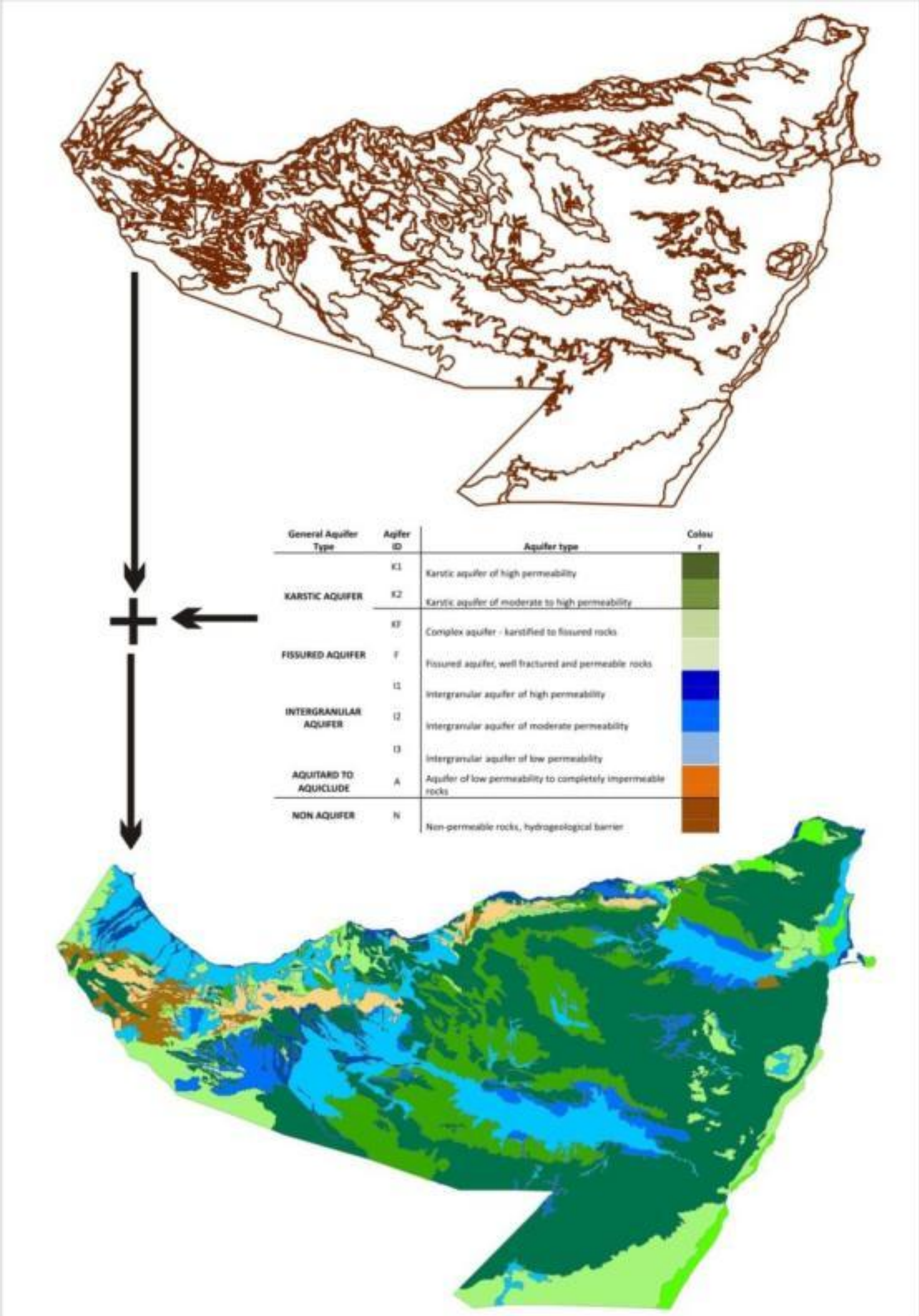


Figure 3.33 Transformation of boundary lines to polygons for established aquifer classification

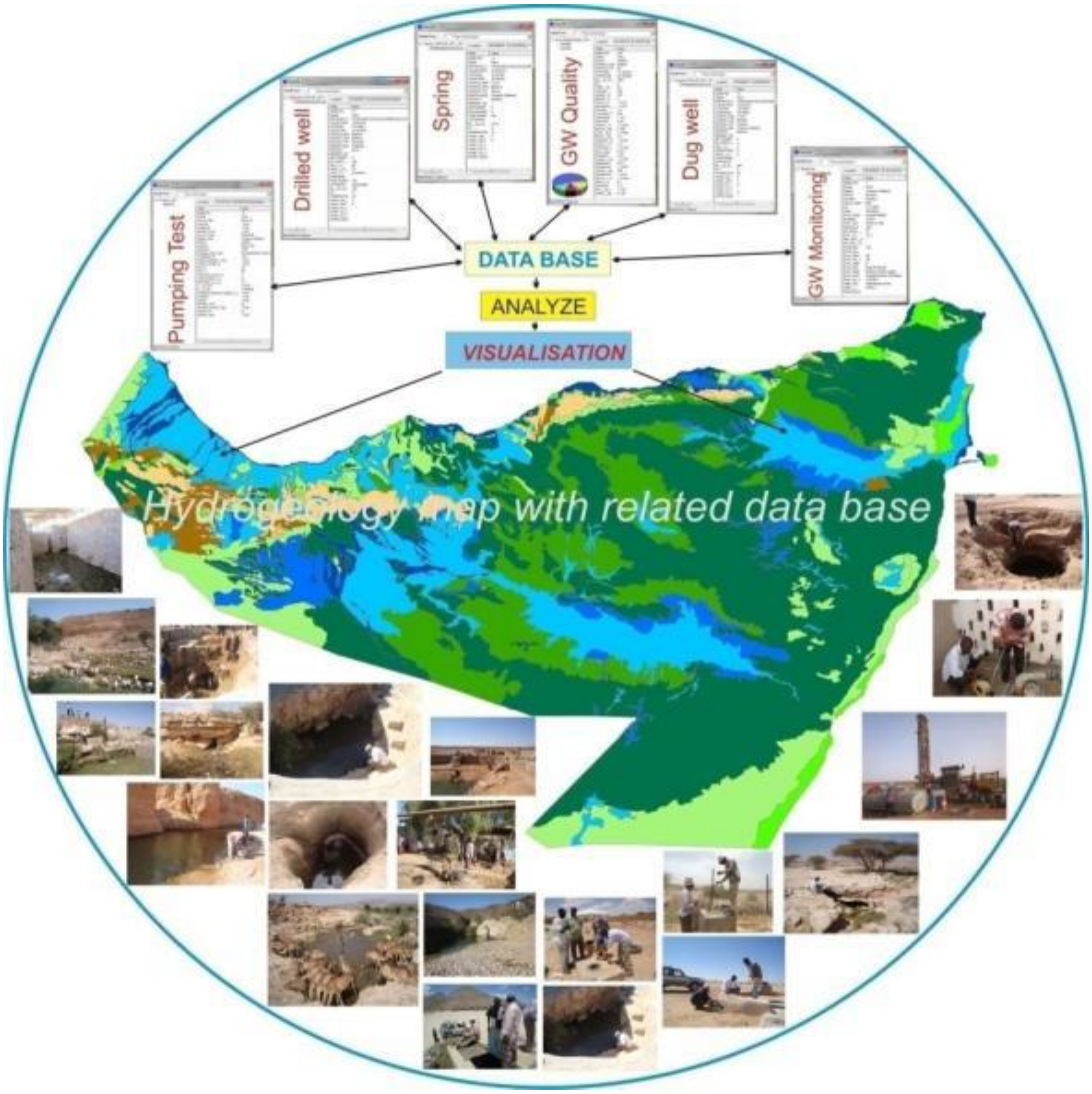


Figure 3.34 Overview of model of Hydrogeological Map

Chapter 4: Results and Discussions

4.1 Results of Remote Sensing analysis

Regional RS analysis

In this project use of RS techniques had two main benefits: First is a better precision and more accurate location of boundaries of geological units for the production of a Regional Hydrogeological map (more detailed explanation available *in Appendix III*). Prior to this assessment, the existing digital geological map at a scale of 1:1,500,000 was less accurate as it was digitalized from scanned map georeferenced with modest number of points and without any geodetic ground control point. Such a map becomes less precise especially if used at a scale of 1:750,000 or larger. The use of RS method allows much more detailed disjunction of geological units if they have clear morphological overprint on Earth surface. Using the RS techniques and formal analysis of enhanced satellite images, quite accurate boundaries of geological units are produced. This provides a better and much more accurate delineation of HG units and precise detection of the exact spatial position of HG indicators. At last, using RS techniques provide very detailed and precise differentiation between various types of Quaternary deposits which is also important for HG research.

The another important benefit of using RS method is the possibility to lineate all significant regional or local faults, faults systems and faults zones, which means that RS method in geological research provide possibility for sophisticated tectonic analysis in a relatively short time and for a large surface. That fault pattern is the most important indicator for water supply or water contained in aquifers. From HG point of view this is quite important and fundamental information.

All results of regional RS interpretation were put in ArcGIS format and delivered to FAO SWALIM as individual set of layers (polygon, line, point and annotation) and as Remote Sensing Interpretation map for Somaliland and Puntland at a scale of 1:750,000. (Appendix III). Remote sensing interpretation data were also used and fully incorporated in Regional Hydrogeological map in same scale.

Figure 4.1 presents part of interpretation results in RS lineation for Northern part of Nugaal basin. Full detailed analysis results are presented in Remote Sensing Interpretation map and Regional Hydrogeological map of Somaliland and Puntland (Annex I; Appendix III).

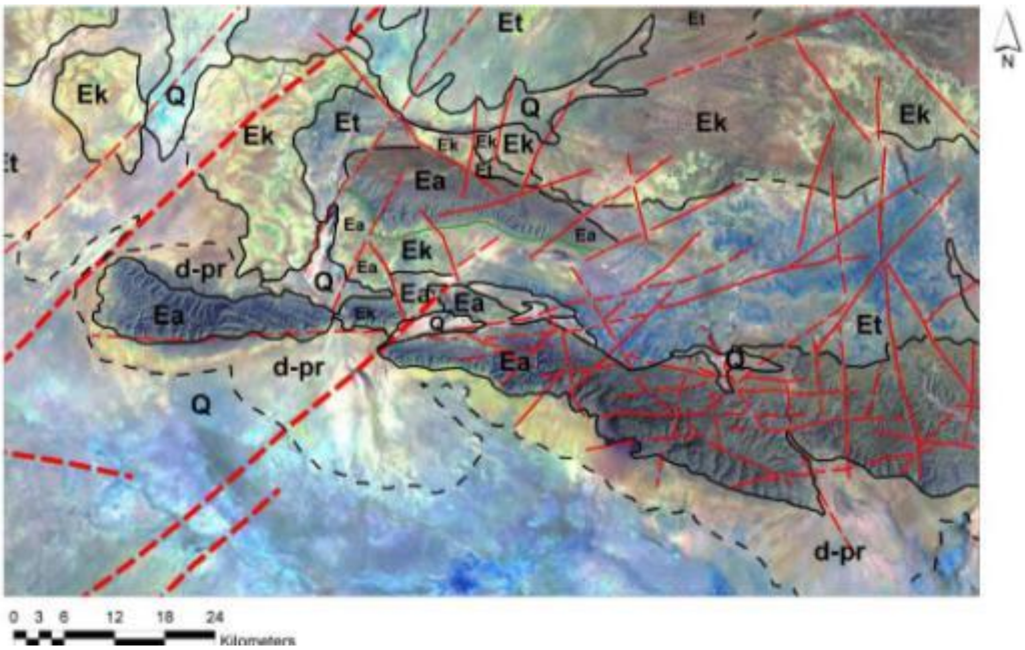


Figure 4.1 Part of RS interpretation (detail). Northern part of Nugaal basin

Results of image processing in 4 AOIs

To get better results, a set of various digital RS procedures are applied on satellite images. In this analysis, two procedures were applied to get the required information: The first was spectral index called Normalized Difference Vegetation Index (NDVI). This procedure was applied in all 4 AOI, but without uniform classification. In some cases it was possible to single out only the area in the zone with permanent or temporary water flows like in AOI 1. In other cases three or four different types of vegetation were distinguished. The second implemented procedure was Moisture Vegetation Index or Clay Mineral Index (CMI). Also different numbers of classes were separated, depending on the spectral response on satellite images in bands 5 and 7 related to different rock lithology.

The first area of interest (AOI 1) is located in the western part of the study area. This area covers catchment area southeast of Hargeysa and southwest of Owdweyne. The most spread-out type of vegetation in this area is the tiger bush, clearly recognizable on the images and shown in Figure 4.2 - left. In general a different genetic type of quaternary deposits covers most of the area with isolated, E-W elongated Auradu and Karkar limestone (see part of RS interpretation in Figure 4.2 - right).

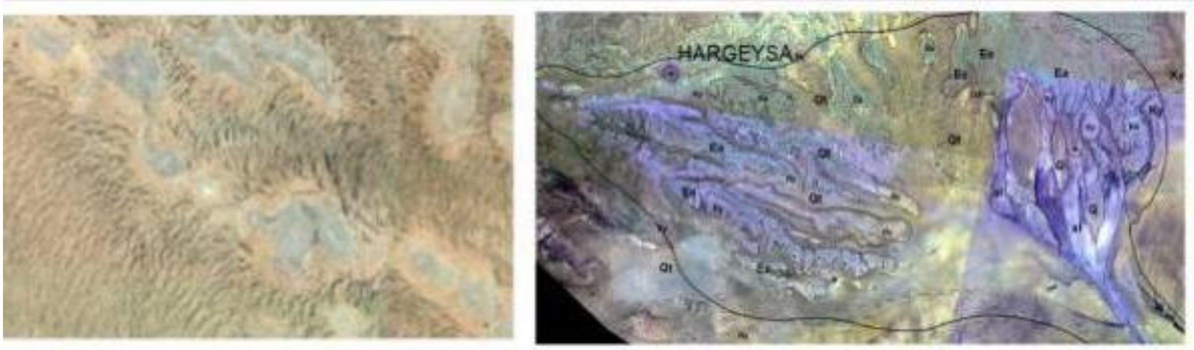


Figure 4.2 Detail in AOI 1: Left- tiger bush; Right- draft preview of RS lineament map

Results of digital processing are shown in Figure 4.3. Distribution of the most distinguished NDVI class in blue (left part of Figure 4.3) and CMI in dark blue (right part of Figure 4.3) indicates the areas and sometimes linear zones of increased humidity in AOI 1.

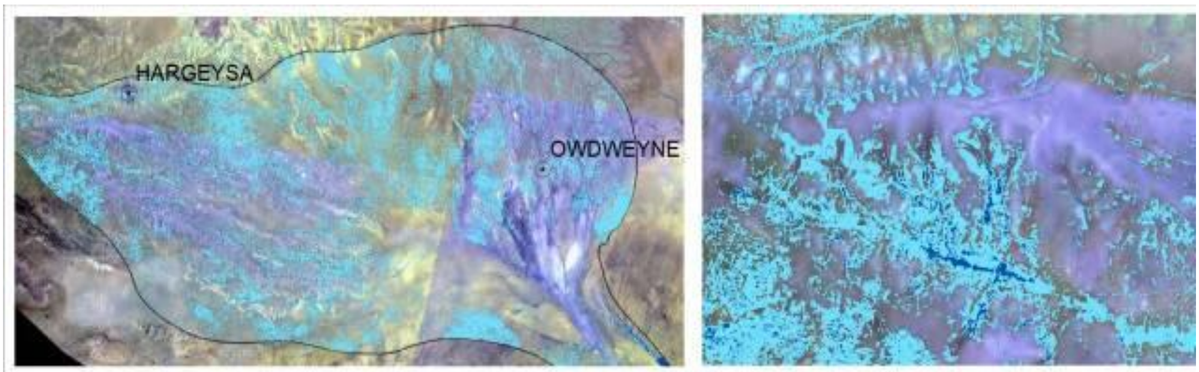


Figure 4.3 Results in AOI 1: Left – NDVI; Right - CMI

Similar results were obtained in AOI 2 between Xudun and Taleex in the North and Laas Caanood and Garoowe in the South. This terrain belongs mostly to the Nugaal Valley. Also, Quaternary deposits dominate in this widespread alluvial plane smoothly inclined to the east. Marginal parts of the area are composed of Auradu limestone and Taleh Evaporites. In this area, considering the hydrogeological aspect, the vegetation class marked with the color orange in the central part of AOI 2 is the most important (see Figure 4.4).

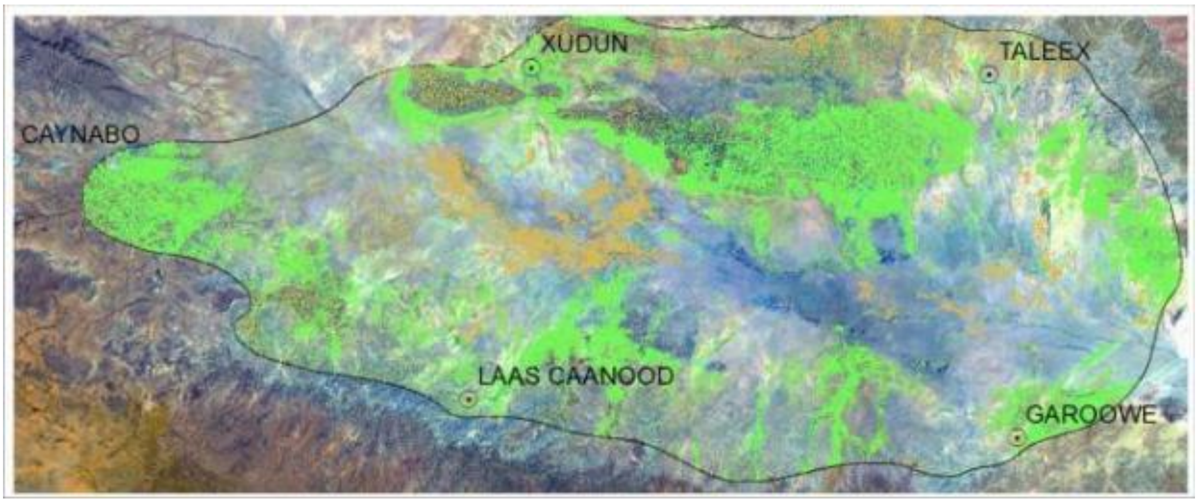


Figure 4.4 Distribution of NDVI index for AOI 2

In Figure 4.5 classification of the clay mineral index is shown. Five different types of clay mineral classes are distinguished in areas of mostly Quaternary deposits but strongly depended on the lithological composition of origin rocks. The area covered with dark blue and green is the most important indicator of a higher level of moisture in AOI 2.

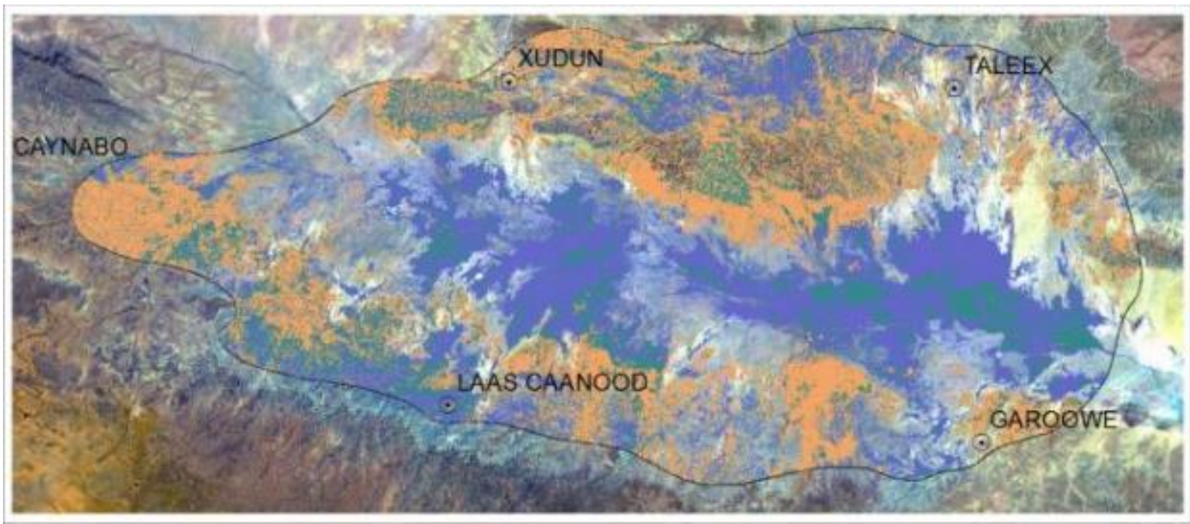


Figure 4.5 Distribution of classes of Clay mineral index for AOI 2

Results for most of the southern area of interest (AOI 3) between Burtinle in the north and Galdogob to the south are presented in Figure 4.6. Three classes of different types of vegetation, and two classes of clay minerals are separated.

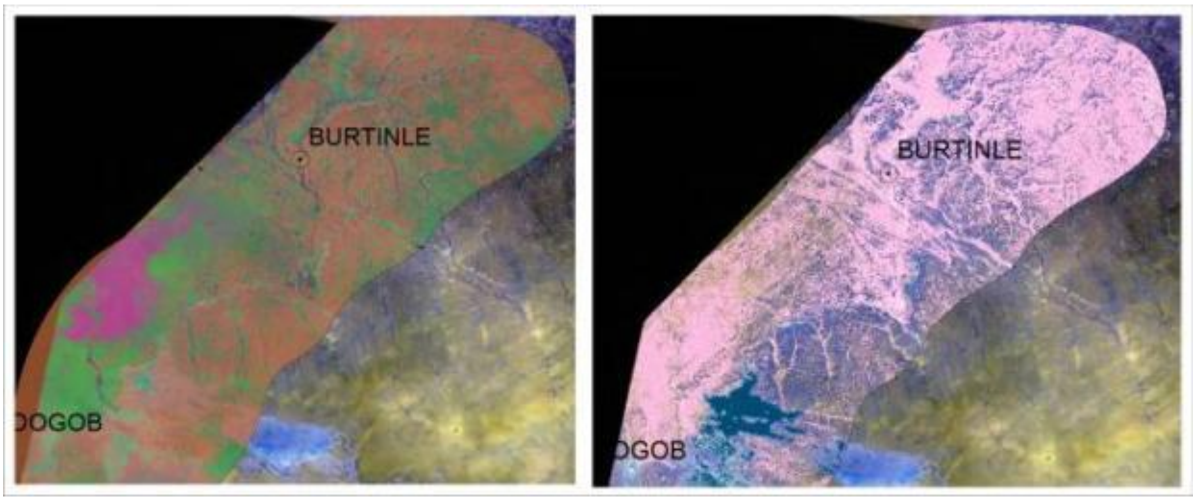


Figure 4.6: Vegetation index NDVI (left) and clay mineral index CMI (right) for AOI 3

Finally, for AOI 4, results of digital image processing are presented in Figure 4.7 for the area east of the village Qardho. Three vegetation classes provided by NDVI classification represent 3 different vegetation types as a good indicator of a smaller or greater level of humidity. Also, the classification and distribution of the clay mineral index CMI can more precisely point to the locations or areas saturated with moisture.

The complete results of the analyses of four AOIs are presented in Annexes III - VI.

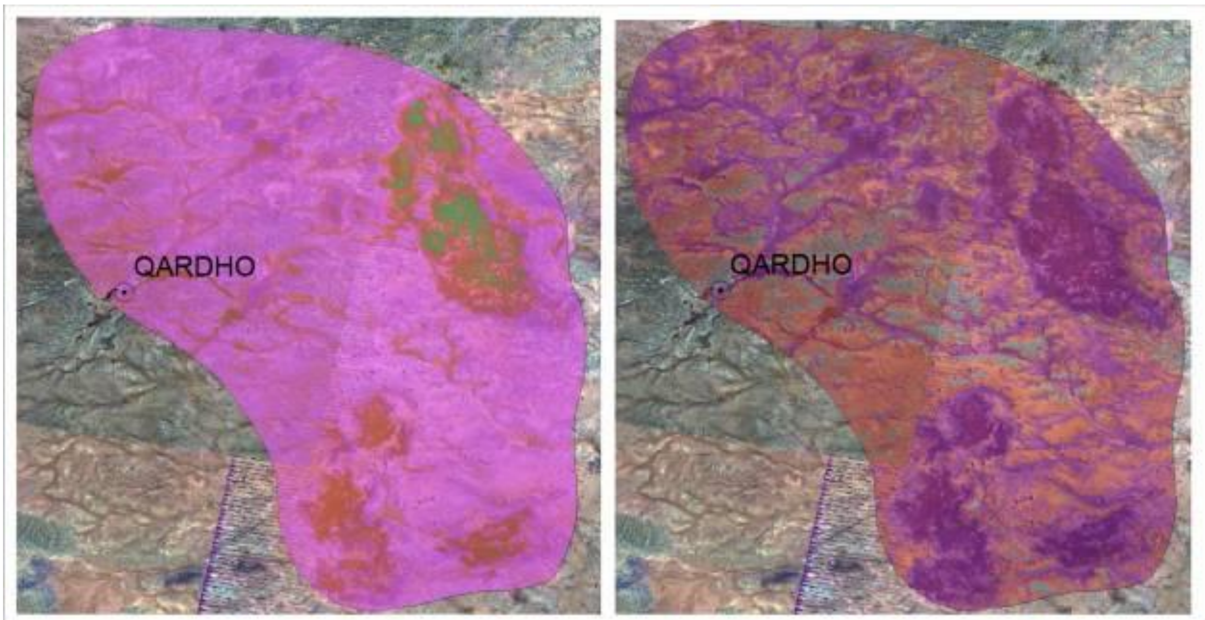


Figure 4.7 Result of processing in AOI 4; NDVI (left) and CMI (right)

4.1.1 Tectonic patterns for Somaliland and Puntland[9]

Regional fault pattern analysis

In the process of tectonic pattern analysis, the study area was divided into 4 sub-areas (north, mid, east and south). The criteria for this separation into smaller, in a structural sense relatively homogeneous areas, was based on the geomorphological characteristics and geological composition of terrain.

It is evident that the study area is divided by the E-W trending Golis (Karkar) Mountains, the dominating morphological structure, sub-parallel to the coast line. The highest peak of the Karkar Mountains, Shimbiris (2,416 meters), is located about 15 km NW of Ceerigaabo. The northern part of the mountain crest (highest peaks of mountain range) terrain is hilly, especially in the eastern part where the hills touch the sea. To the west the topography gently slopes down to the Gulf of Aden coastline. By contrast, the central and southern parts of the research area are characterized by a flat platform or slow dipping surface trending to the southeast and the east.

This mountain range represents a natural barrier for surface water, or a watershed which directs atmospheric water to the north and to the south, respectively. On other hand, the geological composition of the mountain area was also quite important criteria. In general most of the basement rocks located in the mountain range are built of metamorphic Proterozoic and Late Proterozoic to Cambrian magmatic and metamorphic rocks. Since they are impermeable rocks this natural barrier has a certain hydrogeological importance. Also, the discontinuity of rocks (faults and fracture) must have much more hydrogeological significance than lithological properties of rocks, especially for underground flow.

Taking into account all this criteria, the research area was divided into north, mid, east and south sub-areas (Figure 4.8). Fault pattern analysis was done first for whole study area, and in particular for the 4 separate sub-areas.

[9] This chapter is based on findings of IRSE presented in his interims and final report

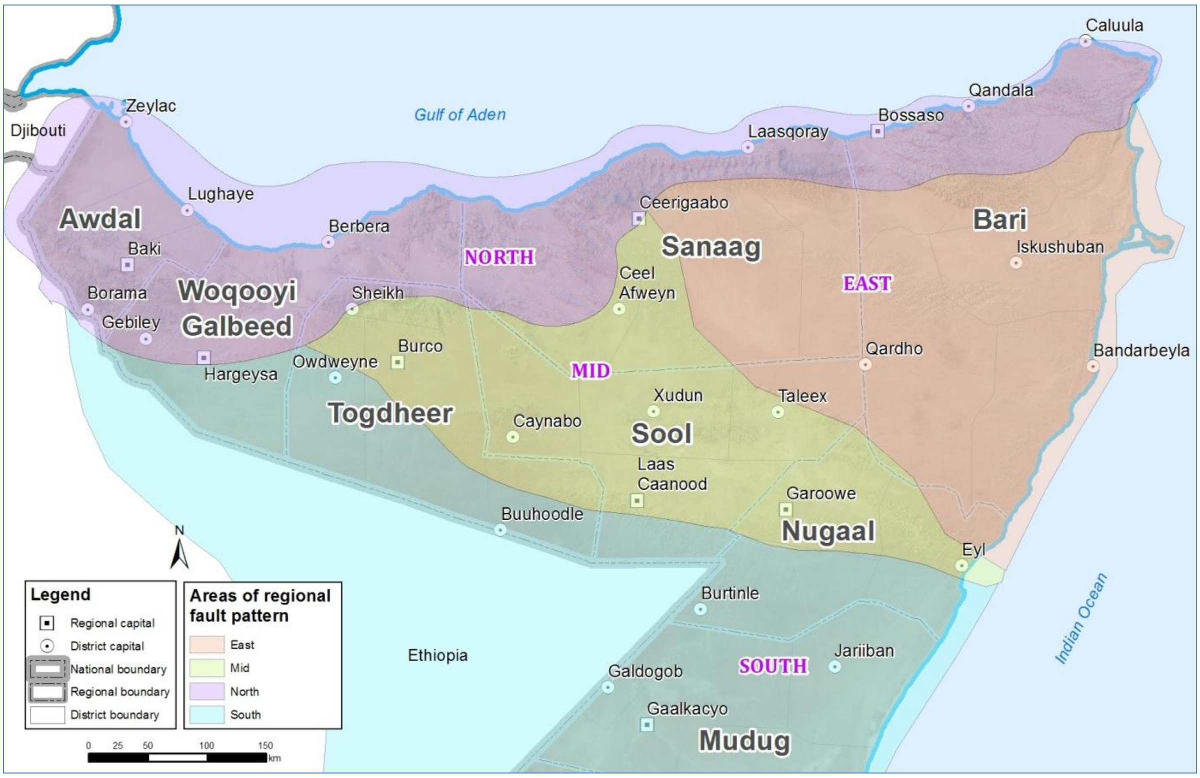


Figure 4.8 Division of study area in 4 sub-areas for statistical analysis of faults pattern

In this kind of analysis, also from a hydrogeological point of view, two main geological features were studied.

The first is fold structures which show a degree of ductile deformation and also a direction and intensity of endogenous (tectonics) forces. For hydrogeological research, not only is the attitude of stratification (or layering) important, but also the general trending and dipping angle of the fold axis.

The second tectonic feature is much more significant. It is faults and fractures, which show the main disruption to the continuity of the rock mass. These geological structures which were carefully treated and lined on a lineament RS map represent the most significant hydrogeological indicator for the direction of water supply or water loss.

Results of the statistical analysis of the stratification measured in sedimentary cover in the study areaare presented in Figure 4.9. It is obvious that stratification is sub-horizontal or gentle dipping in most cases; this shows poles of planes around the center of the plot. Open folds are identified in the area near Sheekh and Borama. These folds are characterized with gentle dipping axes to E and NE (statistical dip direction/dip is 102/007^{o} and 052/003^{o}) and also gentle dipping fold limbs to the south/southeast and northeast/northwest, respectively.

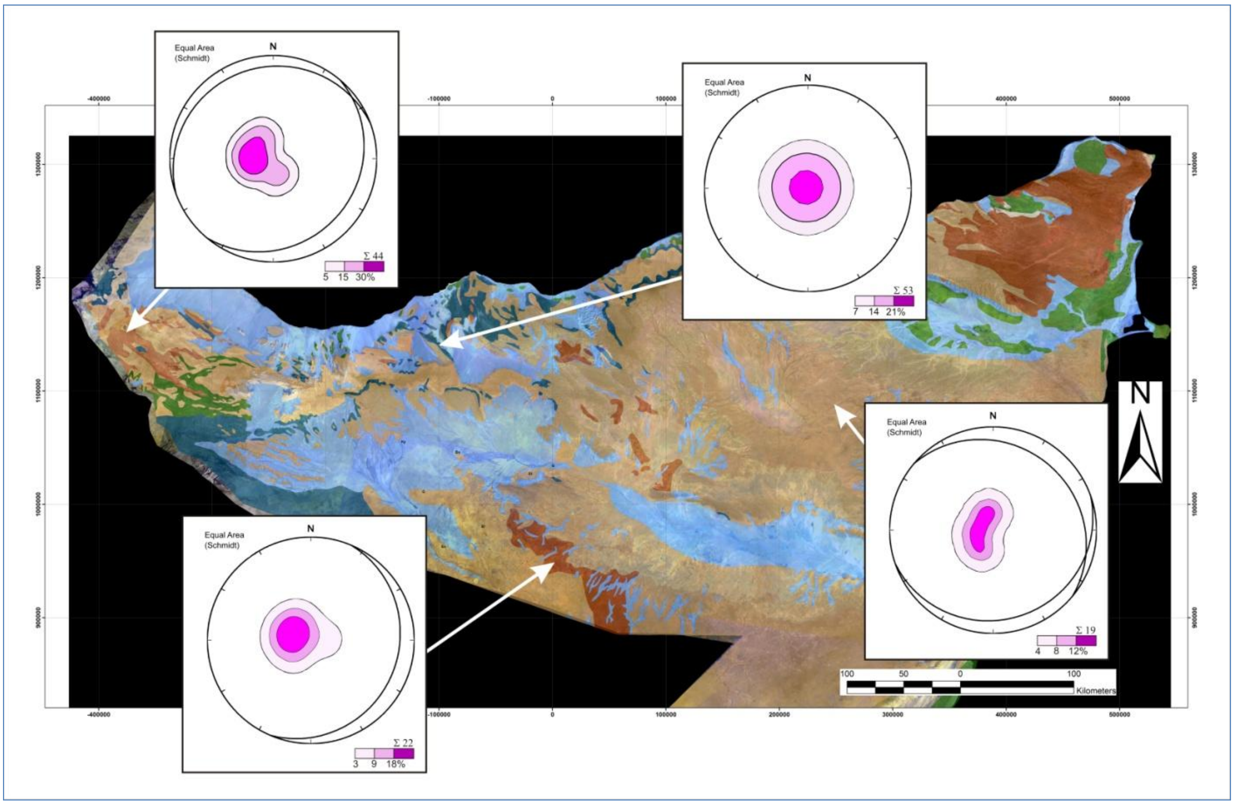


Figure 4.9 Stratification observed by visual RS analysis and calculated by using Digital Elevation Model (DEM). Key – Diagrams represents percentage of population (3 classes with diffferent color) and statistical plane of stratification (solid line trace)

Figure 4.10 presents the results of the analysis of the fault pattern for the entire research area. Based on the level of accuracy, faults are classified as certain and approximated (solid red line and dash red line respectively). On the other hand, different line thickness represents regional (thicker red line) or local faults. Also, different weight factors are embedded into statistical analysis. Depending on the fault length, the weight factor changes. Longer faults are divided into smaller segments (approximately 5 km per individual fault segment) that are counted as single fault data. This means that longer faults have more significance (higher weight factor) than smaller ones. The Figure 4.10 shows a low resolution preview of the orientation of regional and local fault systems in the research area. The original layer with detailed fault pattern analysis within the map scale limits and in ArcGIS format (as georeferenced polyline faults.shp layer) was prepared for use in future projects and delivered to FAO SWALIM as a layer of the database named RS interpretation.

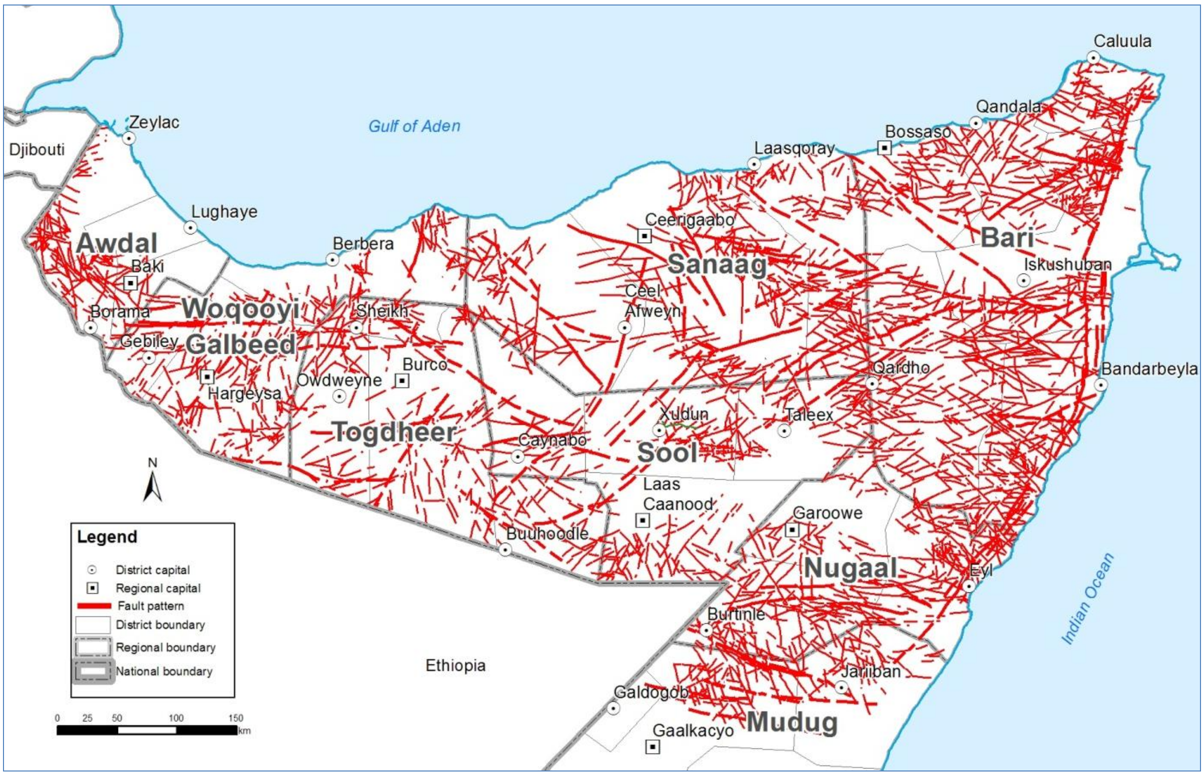


Figure 4.10 Preview of RS fault pattern interpretation

The statistical results of the total number of measured fault strikes are shown in Figure 4.11. On this rose chart 3411 data are processed. It is obvious that the achieved result is quite similar to the statistics about the local fault shown in Figure 4.11a. This is so because most of the processed data are related to the population of local faults (3115 data are provided), so the population of regional faults has little influence on the final statistical results. The collected population of regional faults numbers 296 single measurements. Results of the statistical analysis for regional faults are presented in Figure 4.11b.

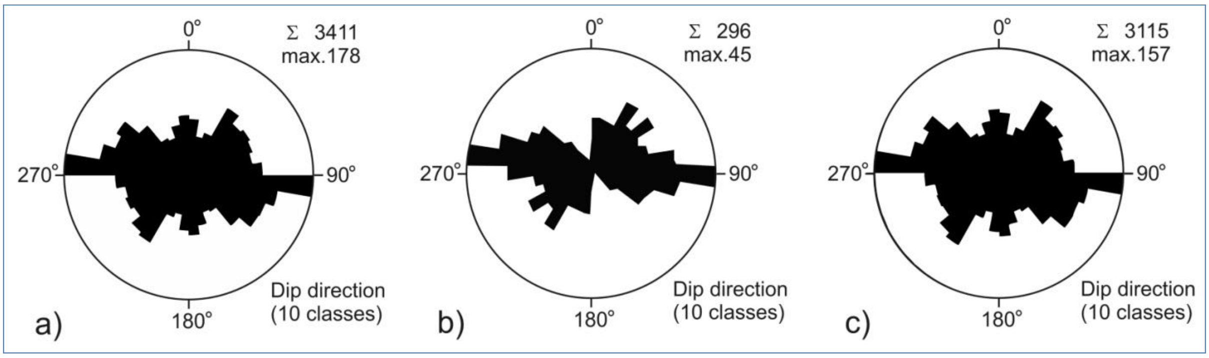


Figure 4.11 Results of statistical fault strike orientation for whole research area

The strike of the regional fault systems is presented in Figure 4.11b. On the rose chart one distinguished maximum oriented from E to W (095-275^o) and two submaximums generally striking from NE to SW (030-210^o and 050-230^o) dominate. E-W trending on the echelon regional faults pattern is shown in the central part of the research area from Borama to Sheekh and from Ceerigaabo to Iskushuban and also, in the south between Burtinle, Galdogob and Jariiban. Regional fault zones marked by sub maximum striking NE-SW are observed from Buuhoodle, through Xudun and Taleex to Qardho as well as the easternmost parts along the Indian Ocean coastline from Jariiban in the south through Eyl, Bandarbeyla to Iskushuban in the north.

Local fault systems are presented in Figure 4.11c. The same maximum as on the regional rose chart is dominant. Most prominent are the fault systems striking from east to west (095-275^o). In addition, three less dominant systems are observed. The first is trending NE-SW with azimuth direction 035-215^o, the second one is striking from north to south (355-175^o), and the third fault zones are oriented from WNW to ESE (305-125^o).

Fault system analysis in the northernmost part of the research area, sub-area 1 (North), are done on a population of 1013 fault data. Results of the statistical analysis are presented in Figure 4.12. On the rose chart three maximums are notable. The major fault system is oriented from east to west with azimuth direction 095-275^o. Two other maximum faults, striking N-S and NE-SW, have a direction of 355-175^o and 035-215^o, respectively.

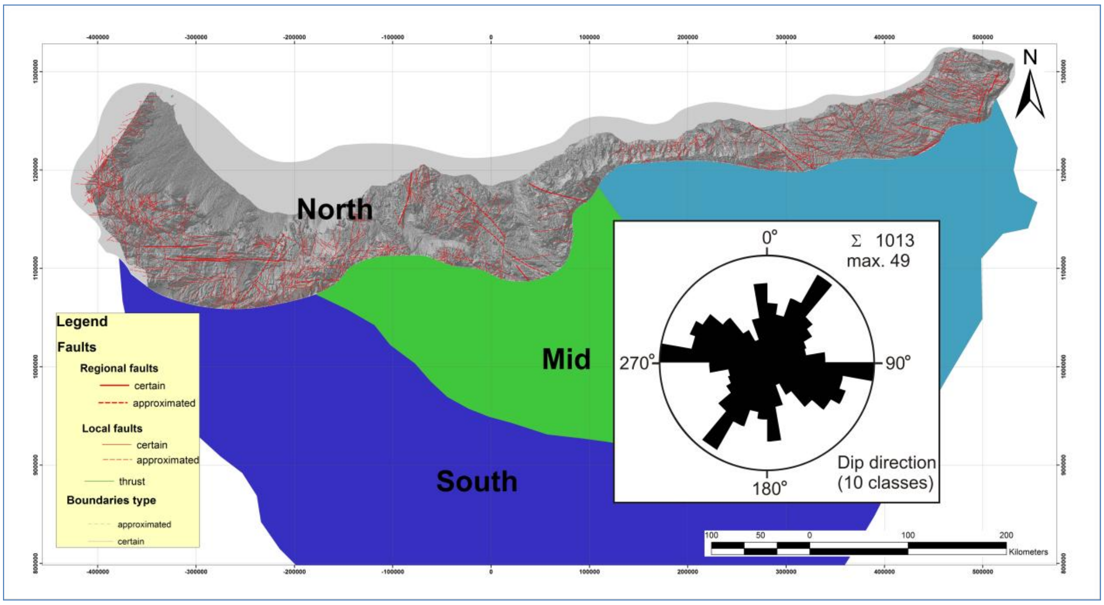


Figure 4.12 Rose chart presentation of major fault systems in North sub-area

Sub-area 2 (Mid) mostly includes terrain around the Nugaal Valley. Results of the statistical analysis (diagram in Figure 4.13) are similar to those concerning the orientation of the regional faults systems. The same maximum as that in Figure 4.11b, oriented from E to W (095-275°), is dominant. Also, the maximum with azimuth direction 035-215° striking from NE to SW is distinguishable.

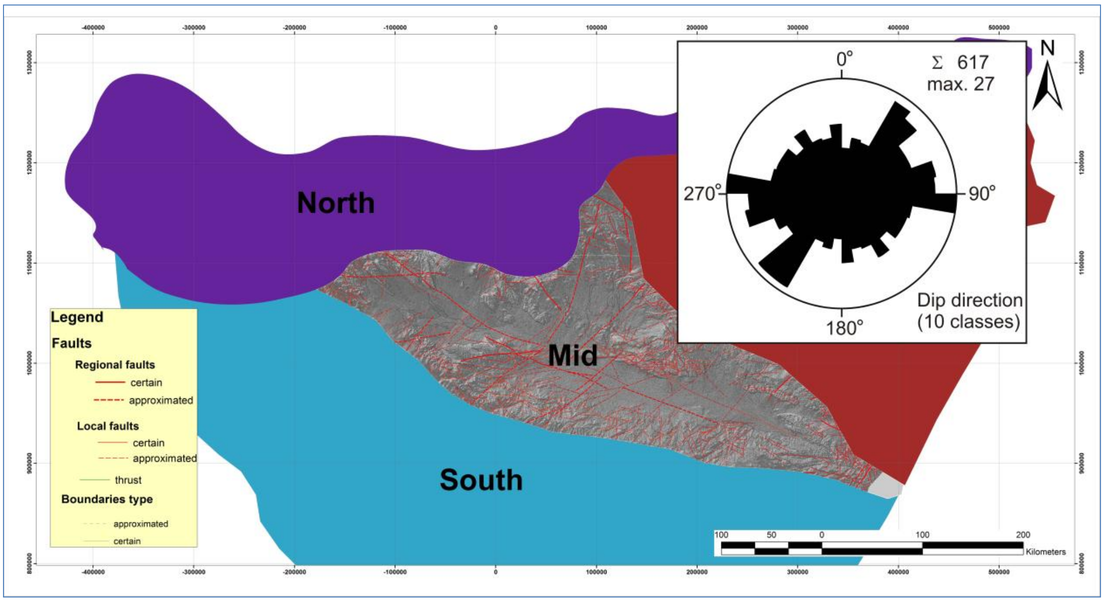


Figure 4.13 Rose chart presentation of fault systems in Mid sub-area

Results of the fault system analysis for Puntland and for part of the Somaliland region (Sub-area 3: East) are shown in Figure 4.14. As in previous cases, one major and three minor fault systems are observed. Dominating fault systems trending from east to west are marked with azimuth direction 095-275°.

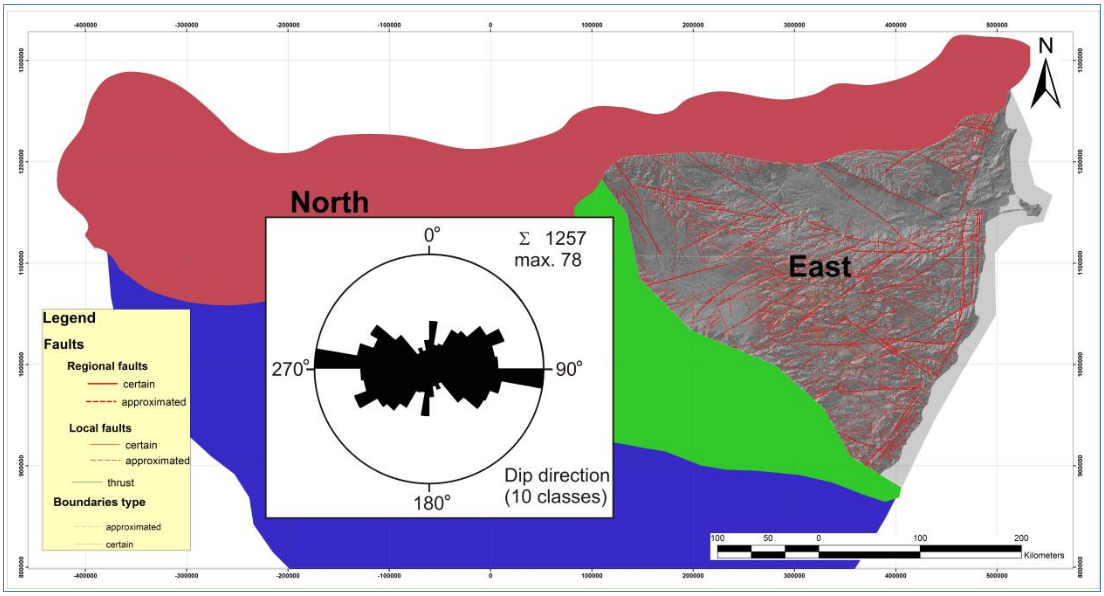


Figure 4.14 Results of statistical analysis in East sub-area

A little bit different is the orientation of the faults detected in the South sub-area. Two major fault systems dominate. The first system strikes from E-W with a statistical direction of 100-280°, and the second one with azimuth direction of 345-165°. Minor fault systems are marked with two submaximums oriented from NE to SW (045-225°) and NW-SE (305-125°).

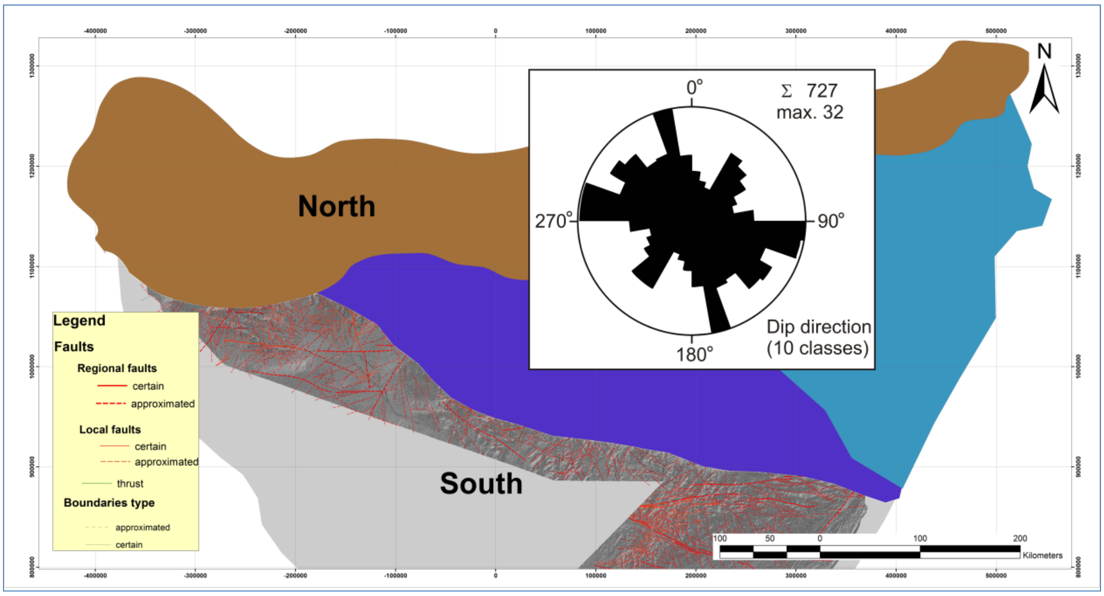


Figure 4.15 Rose chart presentation of fault systems in South sub-area

A common, unified, synoptic (partial) presentation on the fault patterns for all 4 sub-areas in the study area is shown in Figure 4.16.

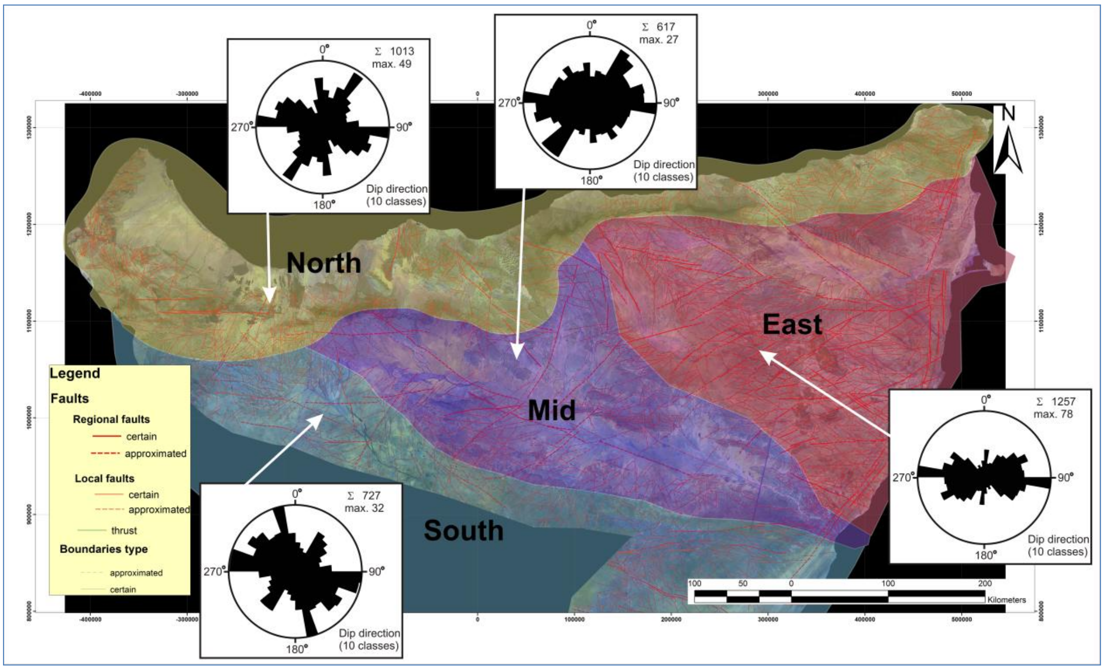


Figure 4.16 Presentation of fault pattern statistical analysis for the study area

Fault pattern analysis for 4 AOIs

Detailed remote sensing analysis was also done for 4 areas of interests chosen on the basis of HG potential and proposed by local government institutions. These areas cover approximately 46,000 square kilometres.

AOI 1 is located in westernmost part of research area. It covers the surface of about 10,000 square kilometres. Most of the terrain is covered by Quaternary deposits. Oldest rock in this area is Cretaceous in age, presented with Yesomma sandstones, located in west part of terrain. This unit is overlain by Auradu limestones Masstrichtian to Early Eocene in age. Those sediments are covered in some parts with thicker and in the other with thinner Quaternary deposits, mainly presented by tiger bush formation (Qt). Also other types of Quaternary deposits are presented such as alluvium or diluvial-proluvial sediments spread over in easternmost part of AOI 1. Geological cross-section of AOI 1 is presented in Figure 4.17.

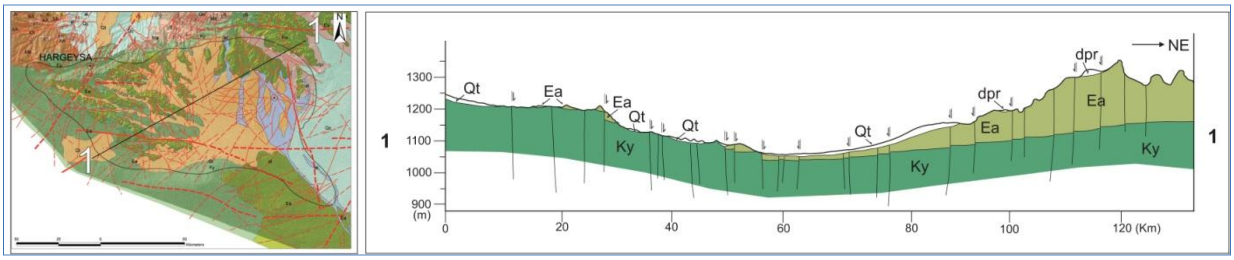


Figure 4.17 Geological cross-section for AOI 1 (left-position of cross-section line)

Statistical analysis of detected fault system was performed on regional and local faults. In case of regional feature one maximum dominates with two subordinate submaximums. The maximum strikes from north to south with azimuth of 355^o (175^o). Submaximums are generally striking WNW-ESE (275-95^o) and SW-NE (45-225^o). Local fault systems show quite different trend. Statistical result of total population of collected local faults, presented on rose chart (Figure 4.18) comprehends 365 measured data. From this chart it is obvious that faults with different orientation dominate in larger scale of observation. Faults and fault systems with striking from northeast to southwest and with azimuth in range from 30^o to 70^o dominate. All other subordinate local faults accompanied main regional faults directions.

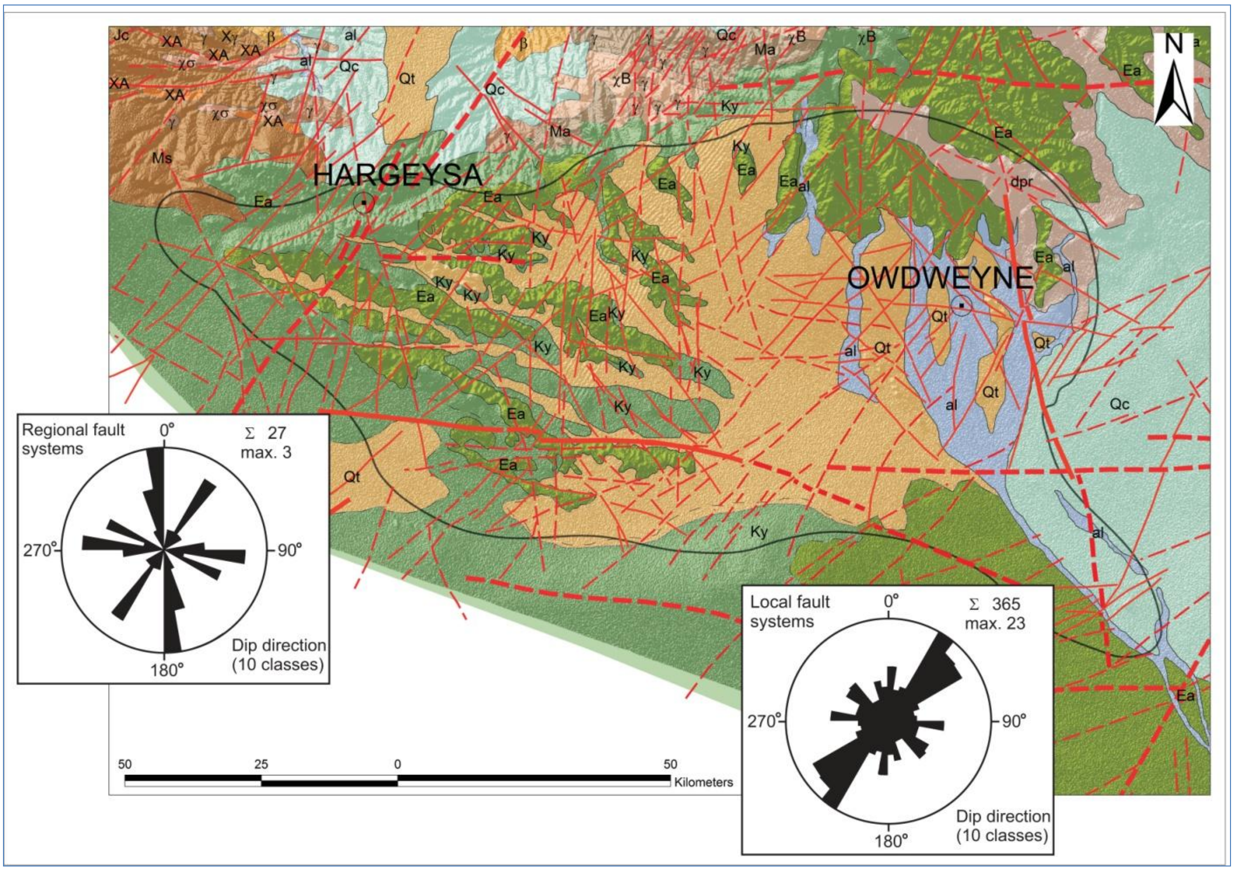


Figure 4.18 Geological map of AOI 1 with tectonic pattern analysis

Larger surface is covered by AOI 2. It is approximately 18,000 square kilometres. AOI 2 is located in mid part of the study area in Nugaal valley. Besides Auradu limestones, Taleh and partly Karkar limestones Early to Late Eocene in age, most of the area is covered by undefined Quaternary unit (Qc). Eocene sediments are located in north and southern part of the area, while Quaternary deposits cover central part of AOI 2. From HG point of view diluvial-proluvial sediments detected at the lower part of slopes at the north rim of Nugaal valley can be quite important. Geological cross-section of AOI 2 is presented in Figure 4.19.

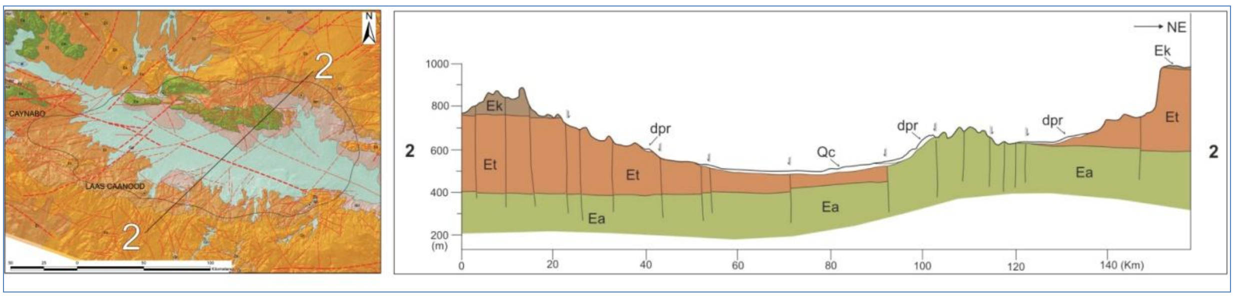


Figure 4.19 Geological cross-section for AOI 2 (left-position of cross-section line)

Results of statistical analysis for regional and local faults as well as geological map of the area are presented in Figure 4.20. Small population of regional faults was collected. The maximum is oriented from west northwest to east southeast with direction of 285° (105°). Trends of local faults dominate one maximum with similar orientation E-W (275-95°) like the rose chart of regional fault systems. Submaximum striking NE-SW with azimuth range of 30° has direction of 55° (235°).

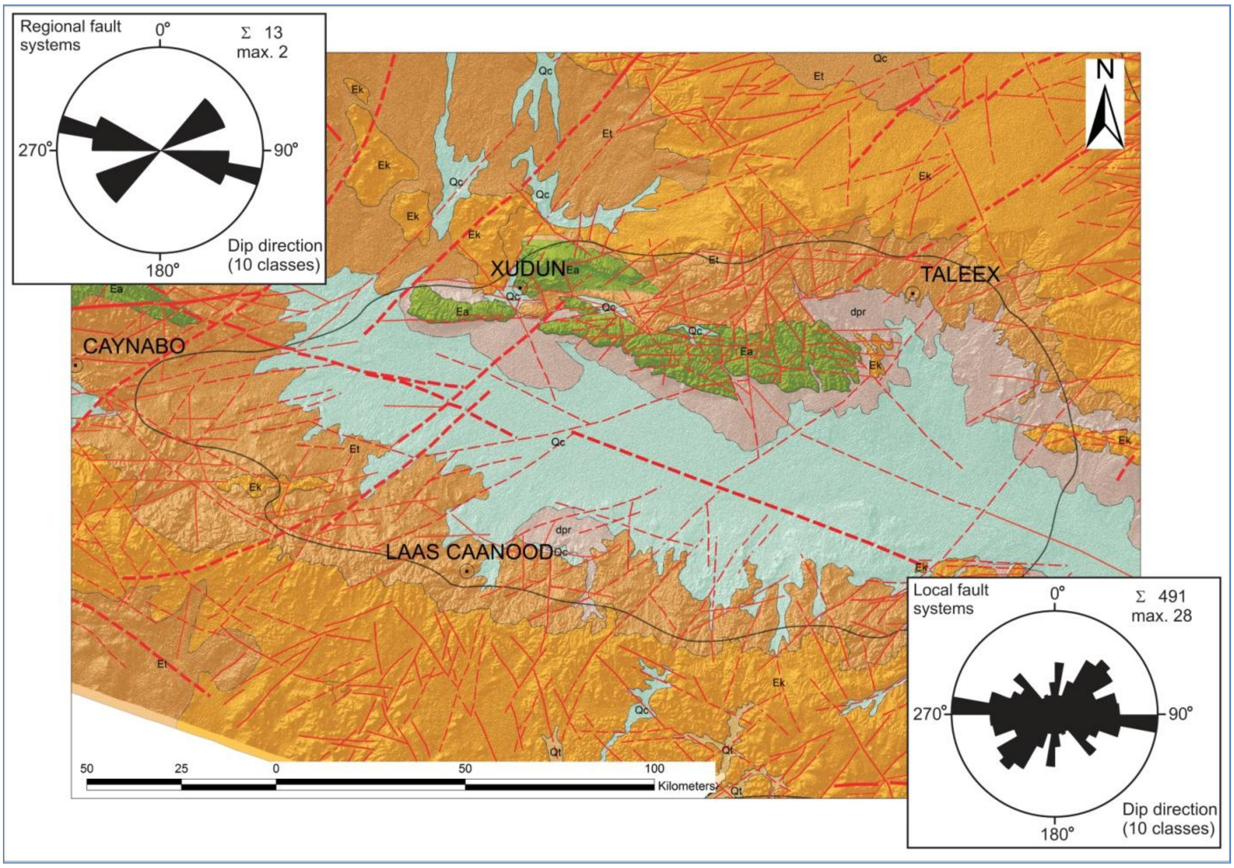


Figure 4.20 Geological map of AOI 2 with tectonic pattern analysis

AOI 3 is situated in southern part of Puntland. This area is spread over 8,000 square kilometers. Most of surface in AOI 3 is covered by Middle to Late Eocene Karkar limestones. Only in northern and most southern part of the area are detected Quaternary deposits: mostly tiger bush formation and disaggregated Quaternary sediments (Qs). Geological cross-section of AOI 3 is presented in Figure 4.21.

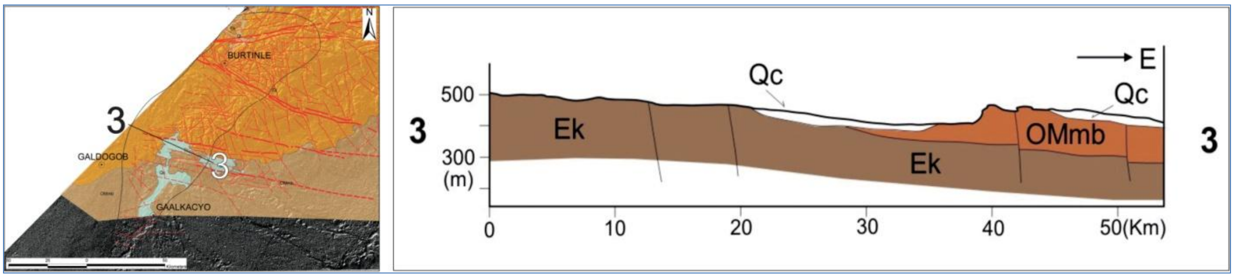


Figure 4.21 Geological cross-section for AOI 3 (left-position of cross-section line)

In Figure 4.22 geological map of this area and results of statistical analysis are presented. Similar results were obtained for orientation of regional and local faults systems. Concerning regional feature one system dominates and it is oriented from east to west. Azimuth of this fault system is 265^o (85^o). On rose chart which presents local faults one maximum and two submaximums are detected. Maximum has already mentioned orientation from east to west with azimuth of 275^o (95^o), and two maximums directed NW-SE has azimuths of 315^o (135^o) and 345^o (165^o).

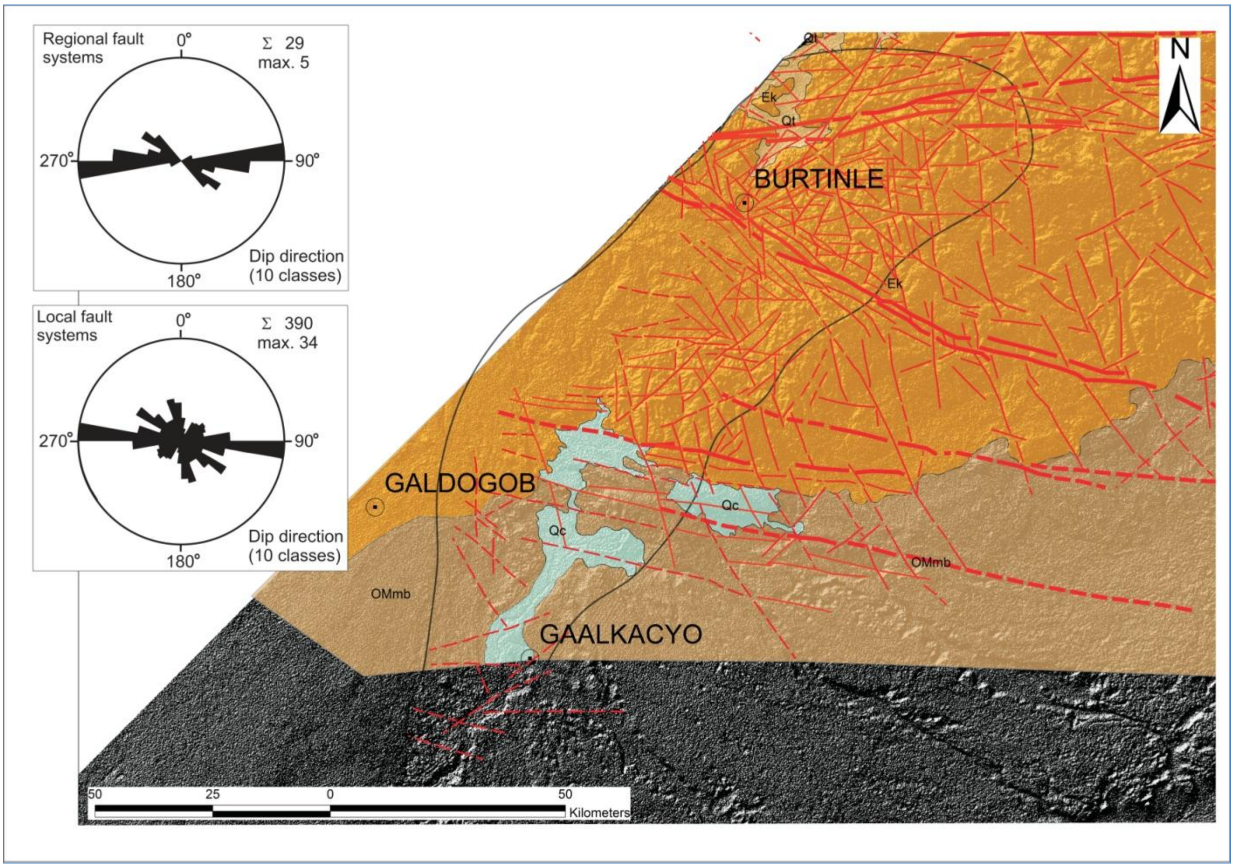


Figure 4.22 Geological map of AOI 3 with tectonic pattern analysis

Smallest area of interest (AOI 4) is located in eastern part of the study area (see Figure 5). Geological setting of this area is very similar as in AOI 3. Middle to Late Eocene Karkar limestones are overlain by Quaternary deposits. Most spreaded is disaggregated Quaternary sediments (Qs). Much less is widespread tiger bush unit and it is detected northeast and east of Qardho. Geological cross-section of AOI 4 is presented in Figure 4.23.

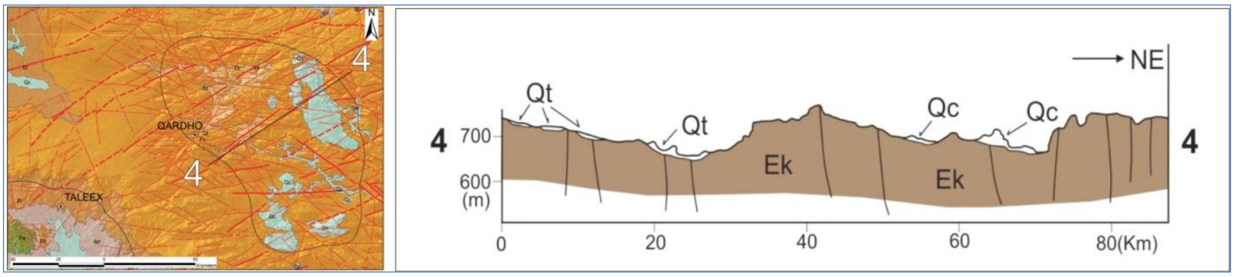


Figure 4.23 Geological cross-section for AOI 4 (left-position of cross-section line)

Results of statistical analysis are shown on Figure 4.24. Most prominent is regional system striking from northeast to southwest. This system has azimuth of 65^o(245^o) and it is accompanied with local faults system detected as submaximum on same figure. On rose chart where population of 342 collected data of local faults is statistically processed, one maximum dominate which indicate faults with E-W orientation 275^o(95^o).

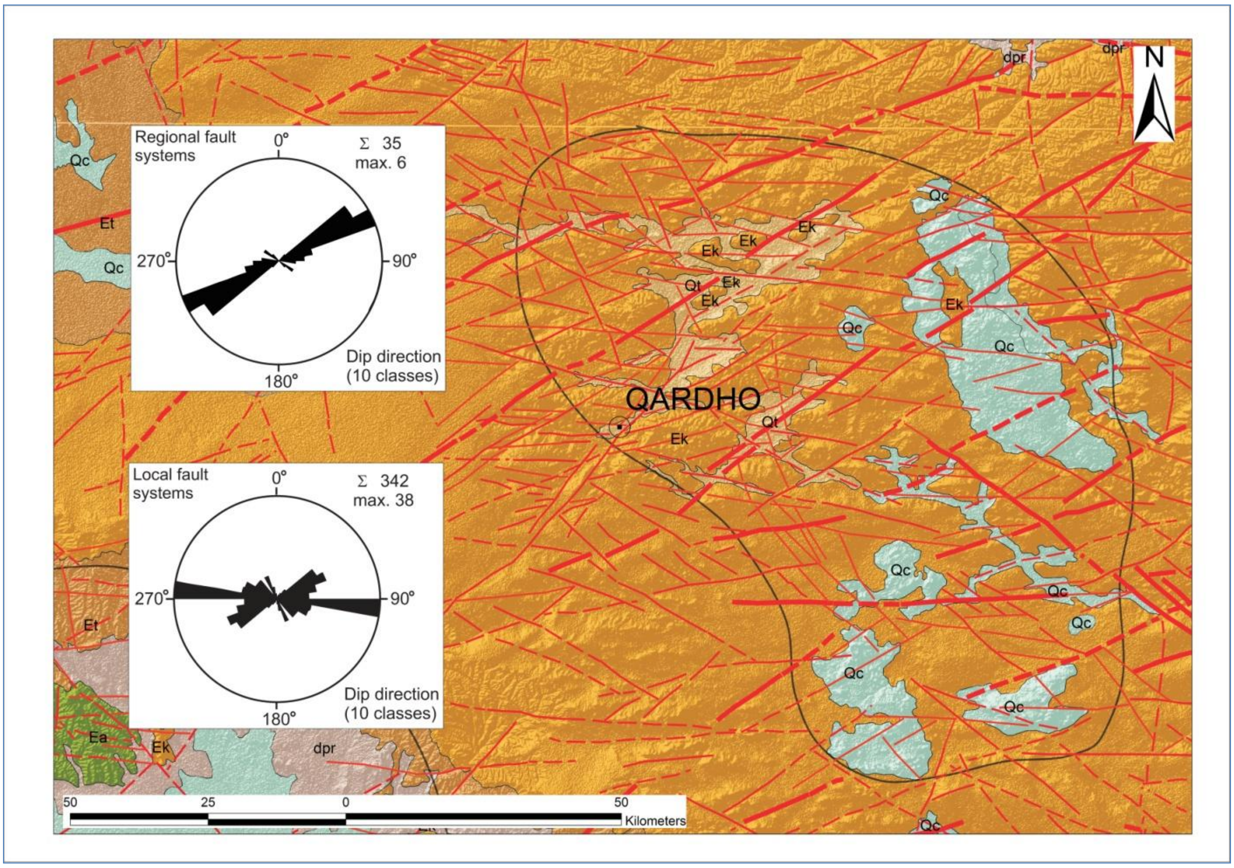


Figure 4.24 Geological map of AOI 4 with tectonic pattern analysis

4.1.2 Update of geological map, geomorphological features, fracture lineaments and groundwater aquifer zoning

Geological analyses of satellite images include a method of defining and extracting areas with different geological properties. Analysis was performed visually on images and is based on observation about clear differences between them. Using geological logic, areas with different spectral properties were singled out and linear geological elements like boundaries, layering or faults are located. Additional information is provided by applying different image processing techniques (classification, mineral mapping, indexes etc.). In that way, satellite images ensure better “visibility”, easier registration and locating of geological structures and units.

Primary task of remote sensing method is to emphasize morphological and lithological properties of geological units and peculiar position of main geological structure, for relatively short time and for large area. That information became useful background for any compiled thematic maps like small-scale (regional) geological or hydrogeological map.

Visual interpretation of satellite images comprehends geological study funded on three basic criteria: geomorphological, spectral characteristics of geological units (color/tone/hue) and vegetation criteria.

Results of geological analysis based on qualitative (visual) remote sensing interpretation are shown in this chapter. All observed properties of rock composition and tectonic pattern are analyzed in light of defined geological unit in regional geological map in scale of 1:1,500,000 (Abbate E. et al. 1994). Detail criteria used for geological analysis and interpretation of RS data are presented in *Appendix III*.

Basement unit is treated as unique geological unit with hardly distinguished parts of different lithology or various morphological patterns. Except in some area where gabbro-syenite dykes or youngest granites are spread out, all other lithological members of basement unit are hardly recognizable on satellite images. Also, significance of this unit in hydrogeological sense is minor and unimportant. This is the reason why in RS interpretation lithological members are not separated and whole unit is treated as unique. Tectonic features, mainly faults different in scale are analyzed and interpreted in detail.

Nogal Valley plutonic body and Ahl Madow succession covers a small percentage of the research area. Lithology of these formations is presented by medium to coarse-grained, pink to violet Neocomian syenite (Nogal Valley magmatic rocks) and limestone, marlstone, pebbly sandstone and gypsum (rare) in repeated cycles of a shallow shelf environment, as well as, limestone with micro and macro fossil remnants, locally marl with ammonites and in continental sandstones and conglomerates with interbedded coal (Ahl Madow succession). Members of Ahl Madow succession are Early Jurassic to Kimmeridgian and Aptian to Kampanian in age, respectively.

In general, those units accompany basement unit and often is very difficult (on satellite images) to distinguish this succession rocks from basement rocks. Because of the small distribution, a poorly visible and nonspecific morphological characteristic as well as not so important hydrogeological significant, Ahl Madow succession is treated in general (analyzed roughly in RS interpretation).

Other Mesozoic succession in northern regions sedimentary cover is partially processed better. Especially upper part of unit, built of Cretaceous sandstones.

Borama-Bihendula succession has two members. Older one is Middle to Late Jurassic in age shallow water and open sea fossiliferous limestone separated by dark and gray marls and shale, sometimes rich in organic matter underlain by fluvial quartzose sandstone with basalts and rare shallow-marine calcarenites. Cretaceous Yesomma sandstones built upper part of Borama-Bihendula succession. It’s represented by mostly variegated quartzose sandstone, siltstone (mainly fluvial) with sparse silicified woods and marine limestone with parts of carbon with a gradual transition.

Lower unit has small distribution and nonspecific morphological characteristics and can be set aside in RS interpretation. Contrary to fossiliferous limestone Yesomma sandstones has relatively large distribution in the research area. In this unit, sandy component is largely dominated. This lithological property of Yesomma sandstones is reflected in morphological sense by development of dendritic drainage pattern. In many places like in the area north of Hargeisa sandstone is covered with so-called tiger bush (Qt in RS interpretation), Quaternary sediments with its characteristic appearance.

Tertiary (mainly Eocene limestone) and Quaternary sediments are studied in detail. Those sediments are very good developed and wide spread over with recognizable morphological and RS characteristics.

The oldest Eocene unit is presented by Auradu limestones, Maastrichtian to Early Eocene in age. Shelf limestones are stratified and often nodular, with corals, foraminifera and pelecypods. Locally, limestones are interbedded by marls and cherts. In RS interpretation, Auradu limestones have been singled out as an independent unit and marked by symbol Ea (same symbol as at Geological map in scale of 1:1,500,000). On satellite images it characterized with intensively developed, deeply integrated drainage pattern, more than in other Eocene units. Lithological composition of this unit is a little bit problematic, because it's treated dominantly as limestone unit at geological maps. If we take into account the morphological criteria, especially drainage pattern, it seems that other lithological components (like marls) dominate. Mostly, Auradu limestones have subhorizontal stratification, except in the northern part where they are folded in open folds with axes orientation E-W. On the Southern border of Somalia this unit, as well as, Taleh evaporites (Et), and Yesomma sandstones (Ky) are very difficult to separate because of the shallow Quaternary cover.

Early to Middle Eocene Taleh evaporites (Et) is built of anhydrite, gypsum, dolomite, cherty limestone and shales. In RS interpretation they have very heterogeneous appearance in different parts of the terrain and obviously depend of lithology changes. In the basin Dharror clastic component is dominated and is marked by dense and dip stream cutting in a drainage network (pattern). In the village Barhana and Ceerigaabo carbonate component predominates and those areas are characterized with very weak and poor drainage. At the rim of Nugaal basin, this unit is observed as fine-grained clastic rocks, with dense drainage pattern.

The youngest Eocene formation is Middle to Late Eocene in age. It is called Karkar limestone (Ek) built of nodular nummulitic limestone and marl intercalations with rich shallow-marine fauna. This unit is widely spread out in the research area. It covers most of central, south and eastern parts of the study area.

On satellite assemblage Karkar limestone is easily recognizable unit and it occurs on the slopes in the lower parts, with well integrated drainage pattern. Morphological criteria indicate lithological compound of unit in the lower part, probably as fine-grained clastic sediments. Upper part (top most layering) is very good distinguished and easily detectable planar structure on images most likely developed like carbonate crust. It’s subhorizontal and sharply stands out in relief, so in the plateau area can be clearly separated, which is on RS interpretation mostly done. The basin Al Bahari is characterized by dense dendritic drainage pattern, also ending with crust in Dharror area. Drainage is controlled by fault/rupture features pattern in the whole area of Somaliland and Puntland. In this unit river stream are filled with Quaternary sediments so-called tiger bush (Qt).

Oligocene to Neogene units from regional geological map in RS interpretation is treated as unique unit. Basically it is because small spread of units in the research area and poor appearance on satellite images. In general, those units have a lot of carbonate components. They appear locally, as separate units with clear morphological criteria characteristic of carbonate formation which are: no associated drainage, sinkholes, etc. In the south part of the research area they are like tiny "patch" cover over Karkar limestone (Ek). They don’t have more important significance from hydrogeological point of view, so they are not specifically separated as different units.

The similar situation is with units in Golf of Aden coastal Areas. Daban succession (siltstones, sandstones, conglomerates, gypsum and limestone) is built of conglomerates, Dubar limestones and basalts. They are poorly distributed in investigated area and noticed only locally, in cases where they have a distinctive morphological expression like in Al Bahari area. Contrary to this, Pleistocene basalts as separated geological unit can be clearly and easy distinguish in the satellite images. They don’t have hydrogeological significance, except in the area where they are positioned on the edge of Quaternary sediments.

Different type of Quaternary deposits is separated on RS interpretation and analyzed in detail. Some of the units are treated as equivalent of units on Geological map in scale 1:1,500,000. Also, some new units were added.

Most spread out has Quaternary deposits marked by Q on Geological map in scale of 1:1,500 000. It consists of sands, gravels and silts of alluvial, colluvial, eluvial, eolian and beach deposits. In RS interpretation this unit includes genetically different but undivided Quaternary deposits. Usually, these are unconsolidated deposits generated from fluvial, proluvial, deluvial or coluvial process. Mixed with them, along the coast are marine sediments. They are heterogeneous in composition as well as in size. Locally, in some area those sediments are coarse-grained or fine-grained, depending on the length of their transport. It can be expected that in some places sediments are poorly rounded and poorly sorted. In basin Dharror it covers Ms. unit. In this area it is quite impossible to divide it from the other Quaternary sediments.

Sands and gravels which filling main permanent or temporary water flows (marked by Qa on the regional map and by al on RS interpretation) is quite easy noticeable on images by similar spectral value in shades of blue color. Unit is clearly contoured on RS interpretation.

Sand dunes and beach deposits cover a thin belt along the coastal line. Unit is not recognizable on satellite images and this is a reason why is not singled out on visual interpretation.

The two new Quaternary units on RS interpretation map are: diluvial-proluvial deposits and Tiger Bush. Diluvial-proluvial deposits (dpr) are developed in the lower part of slopes, in places where slope of the hills suddenly reduce angle of dip. Mostly it is presented by large diluvial-proluvial screens (heterogeneous material accumulated during the transition of diffuse to linear flow regime), wide spread out but often thick, built of unconsolidated, unrounded, unsorted material with heterogeneous lithological composition. In general, this unit is diluvial in origin. Material is transported and disposed of periodic flows at the bottom of the slopes where the slope gradient shortly reduced. Deposits are easily recognized on satellite images like large proluvial fans often associated together. They are widely distributed in Nugaal and Dharror basin. Deluvial-proluvijal deposits which are distinguished by analyzing of satellite images partly corresponding to the Qa unit on the geological map in the Nugaal basin, or Pb and Ms Unit in Dharror basin. According to their position in relief as well as their recent morphological features it's obvious that those units shown on the Geological map in scale 1:1,500,000 has deluvial-proluvial origin. It seems very difficult to correlate map unit signed by Qa exclusively to fluvial process. Deposits observed on satellite images as products of pure fluvial process are noticed locally only in the western part of the terrain where they are identified as alluvium and signed by symbol al.

The second new unit is marked by Qt. In the literature it is so-called Tiger Bush. This pattern has the following characteristics:

- Quaternary deposit is predisposed by rupture or fault pattern,
- This phenomenon have unknown genesis, but seems that bush fills abandoned stream; this process can be developed afterwards,

- Is clearly observed more or less water-logging areas, wetlands and elevated humidity (quantity of moisture was tested from moisture index derived from Landsat spectral bands 4 and 5),
- Pattern (Tiger Bush) has arc-sickle shape and characteristic expression in the landscape fill with low vegetation that accompanies this form,
- Tiger Bush shows clearly dependence of fault pattern; in some area possibility that the material contains a certain percentage of clay components is obvious related to water-bearing.

Among other things, one of the important contributions of remote sensing method is the possibility to distinct and separates a certain geological unit in more detail, especially Quaternary deposits.

4.1.3 1:750 000 scale map

Authenticity of determining geological units, faults, strikes, folds, and hydrogeological phenomenas, is achieved by performing independent analysis and interpretation of the same image by different interpreters. All those data are collected, correlated and compiled first on Remote Sensing interpretation map for Somaliland and Puntland 1:750,000 (*Appendix III*) and then are incorporated in interconnecting (or working) geological map in the same scale from which final Regional Hydrogeological map 1:750,000 is produced (*Annex I*). Preview of low resolution Remote Sensing Interpretation map is shown in Figure 4.25.

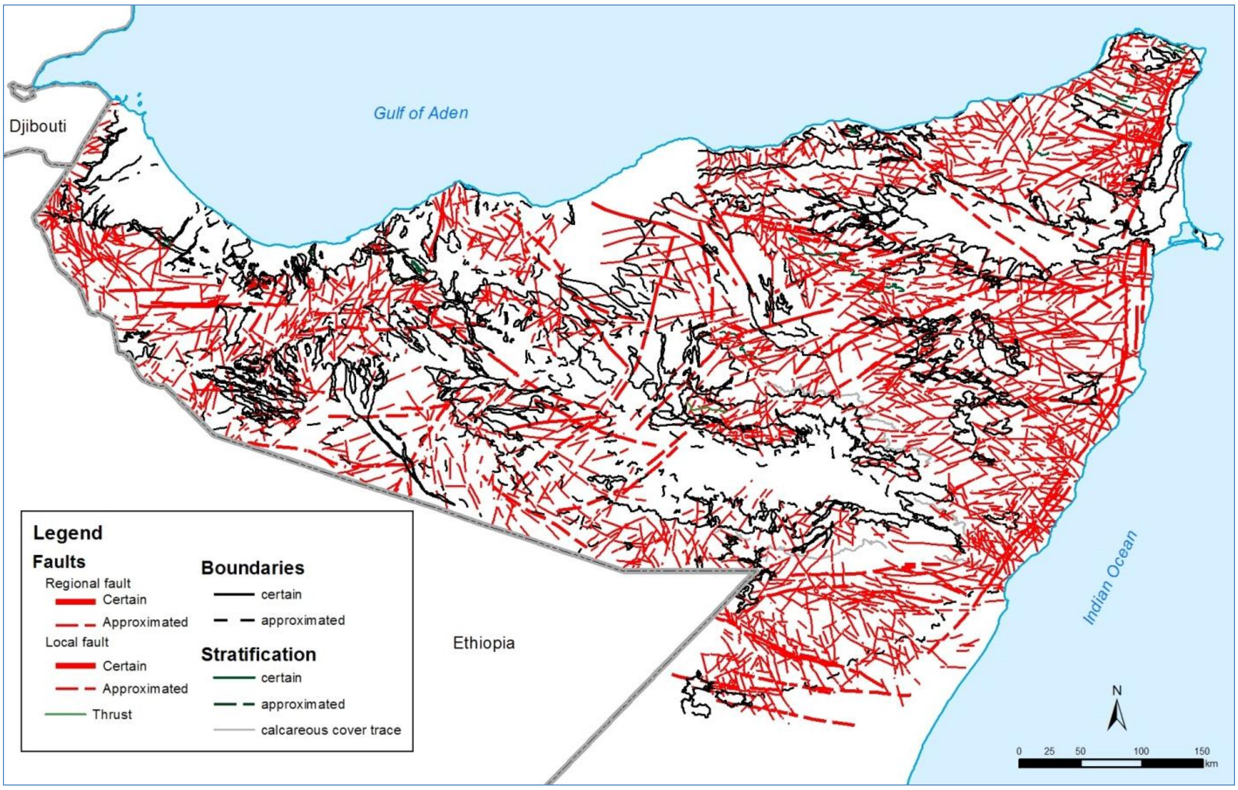


Figure 4.25 Preview of Remote Sensing Interpretation map for Somaliland and Puntland 1:750 000

For 4 selected areas RS interpretation maps in different scale are also produced. The reason of using a different map scale is various surface in square kilometers which selected AOIs covered. If we consider fact that all material will be provide in ArcGIS format and that remote sensing interpretation includes very detailed RS data, changes and production in some other scale for AOIs can be done very fast and easily.

In general, basic criteria for pointing potential RS promising area were comprehensive study of geological composition, spatial location as well as orientation of regional (also local) fault systems and at last results of mineral mapping. Significance of the obtained indexes is tested in HG sense and has some kind of HG valuation. So, only those classes which have highest code number are taking into account. For example, a different number of classes for NDVI index were separated in different AOIs (for detailed information see *Appendix III*).

With specific hatching line pattern and dark blue colour promising area are appointed in different scale in RS maps for all 4 AOIs.

Final results of RS interpretation, in draft version with low resolution, are presented in this report (Figure 4.26) as RS interpretation map in scale of 1:250,000. Full resolution Remote Sensing Interpretation map for Area of Interest 1 (SE of

Hargeysa, Hawd Plateau) is delivered to SWALIM FAO in *.pdf format as well as ArcMap layout format for hardcopy map production in preferred scale. The same procedure was applied for all other AOIs.

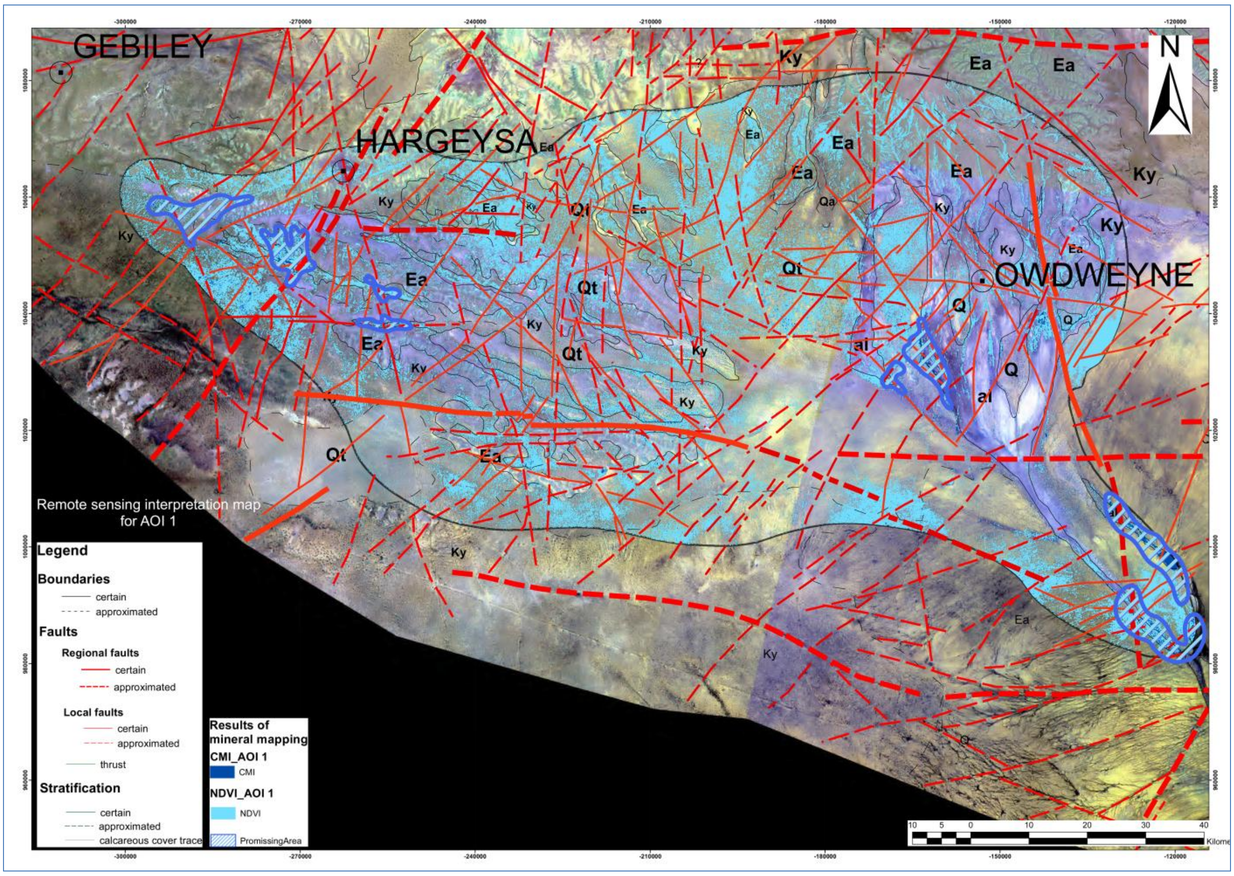


Figure 4.26 Preview of final results from RS interpretation for AOI 1

In Figure 4.27 draft version of final RS map for AOI 2 is presented. RS map is produced in scale of 1:350,000. In final version, full resolution map has title Remote Sensing Interpretation Map for Area of Interest 2 (Laas Caanood-garowe, Nugaal valley) and is presented in *Annex IV*.

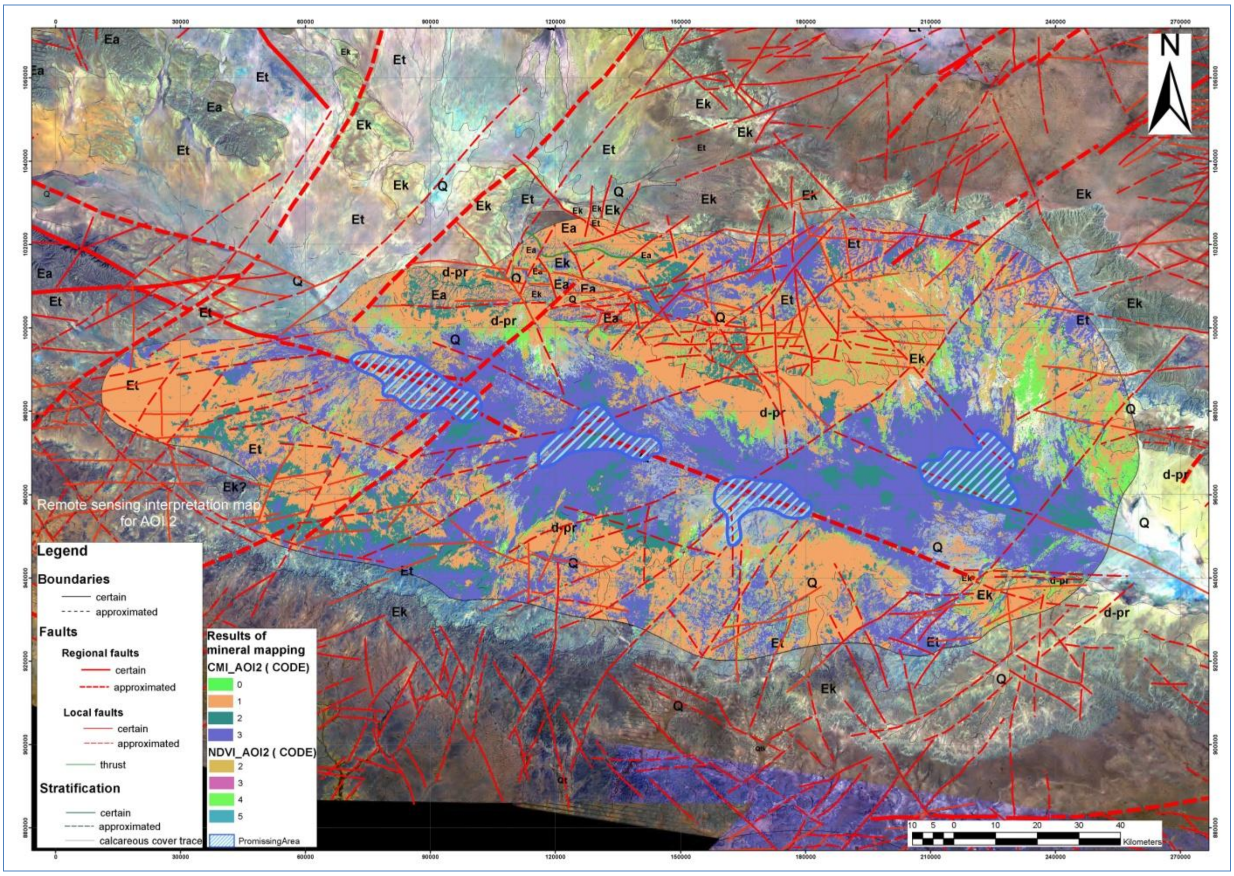


Figure 4.27 Final results from RS interpretation for AOI 2

Using the same criteria, results of RS analysis for area between Burtinle in the north and Galdogov on south, are presented in Figure 4.28. Seven potential areas are appointed in RS interpretation map in scale of 1:300,000. Final presentation of RS data are given in full resolution map Remote Sensing Interpretation Map for Area of Interest 3 (Butinle, Puntland), in *Annex V*.

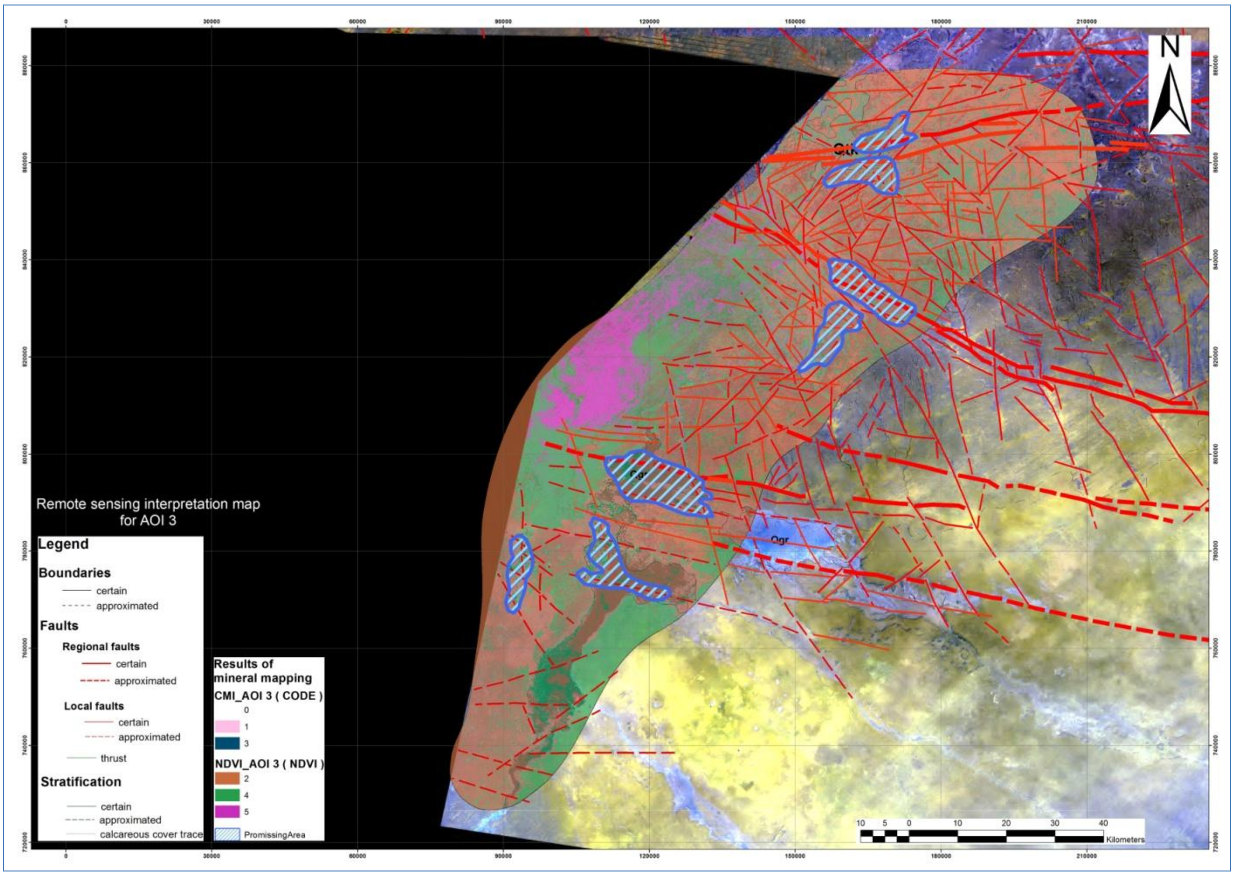


Figure 4.28 Final results from RS interpretation for AOI 3

Results of RS analysis in last selected area of interest are presented in draft version in Figure 4.29 and in full resolution map Remote Sensing Interpretation map for Area of Interest 4 (Qardho, Puntland) in *Annex VI*. Two perspective zone close to the city Qardho are appointed as it can be seen on RS interpretation map shown in Figure 4.29. Map is produced in scale of 1:250,000.

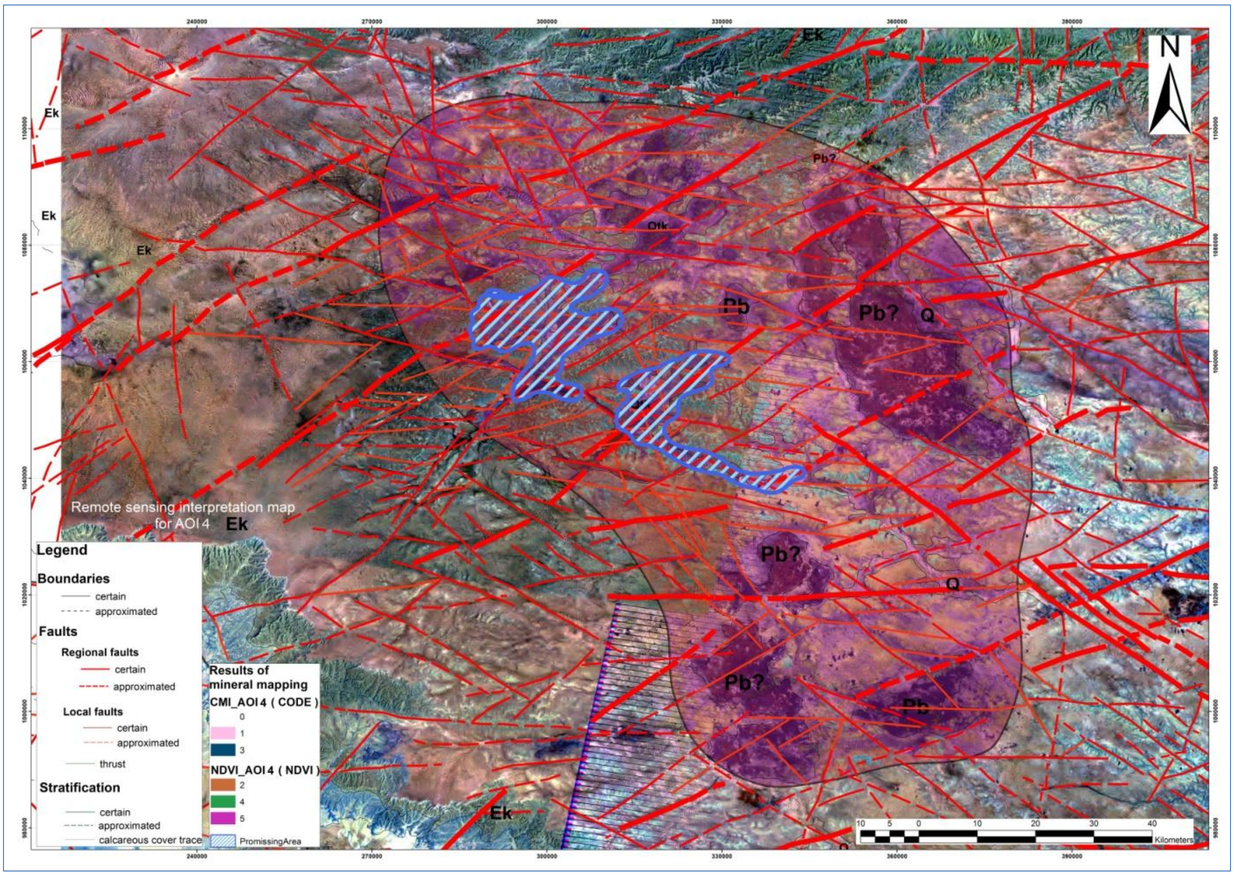


Figure 4.29 Final results from RS interpretation for AOI 4

4.2 Geophysics

The geophysical investigations were carried out in both Somaliland and Puntland where a total of one hundred eighteen (118) Vertical Electrical Soundings (VES) were conducted in Somaliland whereas in Puntland, a total of eighty eight (88) Vertical Electrical Soundings (VES) were carried out. The surveyed sites are situated in the regions such that in Awdal Region, eleven (11) VES points were carried out, in Togdheer region, forty eight (48) VES points were carried out, in Sool region, twenty two (22) VES points were carried out, in Sanaag region, fifty (50) VES points were carried out, in Waqooyi Galbeed region, forty (40) VES points were carried out, in Bari region, two (2) VES points, in Mudug region, five (5) VES points, and in Nugaal region, twenty nine (29) VES points were conducted. The summary of recommended drilling depths together with the site preferences for each region are presented in the next sub sections.

SOOL REGION

A total of 22 sounding stations were surveyed in Sool Region covering seven localities namely, Boocame, Xuddun, Carooley, Go'aalo, and Sarmaanyo. The summary of recommended drilling depth together with the site preferences are given in Table 4.1 below.

Table 4.1 Summary of drilling sites based on geophysical survey in Sool Region

Village	VES Name	Longitude	Latitude	Recommended Depth of Drilling	Order of Preference
Carooley	CAR02	48.16926	8.88196	Up to 100 m	1st choice
	CAR03	48.09852	8.88585	Up to 20 m	2nd choice
God'aalo	GOD01	47.92522	9.08310	Up to 400 m	1st choice
	GOD02	47.90551	9.09227	Up to 50 m	2nd choice
Xuddun	Xud1	47.49311	9.17341	Up to 50 m	1st choice
	Xud3	47.50323	9.15719	Up to 40 m	2nd choice
Saarmayo	SAR02	47.99130	9.50371	Up to 200 m	2nd choice
	SAR03	47.977732	9.49414	Up to 380 m	1st choice

SANAAG REGION – Somaliland Team

The geoelectric surveys in Sanaag Region were carried out by two teams, one from Puntland and the second from Somaliland. The Somaliland team during their survey in this region covered the following areas; Badhan, Cali ciise, Caynabo, Ceelafweyn, Damalo-xagaro, Erigavo, Qoton dabo, and Yufle. The summary of recommended drilling depth together with the site preferences are given in Table 4.2 below.

Table 4.2 Summary of drilling sites based on geophysical survey in Sanaag Region

Village	VES Name	Longitude	Latitude	Recommended Depth of Drilling	Order of Preference
Badhan	Badhan2	48.402210	10.697318	Up to 300 m	1st choice
	Badhan3	48.361160	10.722900	Up to 150 m	3rd choice
	Badhan4	48. 353911	10. 67037	Up to 330 m	2nd choice
Cali ciise	Cali ciise	45.508380	8.548990	Up to 100 m	1st choice
Ceelafweyn	Ceelafweyn01	47.167240	10.112180	Up to 330 m	3rd choice
	Ceelafweyn02	47.171950	10.084400	Up to 330 m	2nd choice
	Ceelafweyn06	47.217030	9.862910	Up to 330 m	1st choice
Damalo-xagaro	Damalo-xagaro2	47.948690	9.787920	Up to 200 m	1st choice
Erigavo Area	Erigavo1	47.352760	10.636000	Up to 50 m	2nd choice
	Erigavo2	47.344140	10.649100	Up to 200 m	1st choice
	Erigavo3	47.356590	10.627900	Up to 50 m	3rd choice
Qoton dabo	Qoton dabo	44.656350	9.184820	Up to 130 m	1st choice
Yufle Area	Yufle1	47.212010	10.391620	Up to 200 m	2nd choice
	Yufle2	47.226720	10.403060	Up to 200 m	1st choice

SANAAG REGION – Puntland Team

The Resistivity survey in Saanag Region covered such areas as Badhan, Gumar, Laako, Cawsane, Damala/Xagare, Wardheer, Qol, Dhahar, Balibusire, HabarShiro and Kaladhac. The summary of recommended drilling depth together with the site preferences are given in Table 4.3 below.

Table 4.3 Summary of drilling sites based on geophysical survey in Mudug Region

Village	VES Name	Longitude	Latitude	Recommended Depth of Drilling	Order of Preference
Badhan	Bar01	48.40302	10.69675	Up to 150 m	2nd choice
	Bar02	48.36005	10.76323	Up to 100 m	1st choice
Laako	Laak01	48.58864	10.71457	Up to 200 m	1st choice
	Laak02	48.55426	10.73328	Up to 400 m	2nd choice
Cawsane	Caw01	48.79421	10.58243	Up to 50 m	3rd choice
	Caw02	48.75901	10.59921	Up to 300 m	1st choice
	Caw03	48.81461	10.56963	Up to 80 m	2nd choice
Kaladhac	Kala01	48.90474	10.05949	Not good	
	Kala02	48.91858	10.05797	Up to 320 m	1st choice
	Kala03	48.90541	10.02731	Up to 380 m	2nd choice
Gumar	Gum01	48.4788	10.69760	Up to 100 m	1st choice
	Gum02	48.46817	10.70594	Up to 100 m	2nd choice
Qol	QOL01	48.49791	9.54327	Up to 200 m	3rd choice
	QOL03	48.51324	9.55268	Up to 350 m	1st choice
	QOL04	48.49066	9.56216	Up to 340 m	2nd choice
Wardheer	War01	48.11680	9.67365	Up to 100 m	3rd choice
	War02	48.13272	9.65849	Up to 320 m	2nd choice
	War03	48.10699	9.67902	Up to 450 m	1st choice
HabarShiro	Hab01	48.50013	10.2504	Up to 100 m	2nd choice
	Hab02	48.51169	10.24966	Up to 300 m	1st choice
Damalxagare	Dam01	47.95059	9.79841	Up to 100 m	2nd choice
	Dam02	47.96772	9.81114	Up to 400 m	1st choice
	Dam03	47.96399	9.83370	Up to 60 m	3rd choice

TOGDHEER REGION

The geoelectric survey in Togdheer Region were carried out by the Somaliland geophysics team and during their survey in this region, the following villages were covered; Awmaageer, Bali Dhiig, Ceeg, Darfacle, Dhoqoshay, Dhubato, Duriqisi, Faraskabood, Heshay, Oog, Qarar, Qayta, Qoryaale, Wacays Oodane, Waridaad, Xaaji Saalax, Xaaxi, Xood, and Yaroowe. The summary of recommended drilling depth together with the site preferences are given in Table 4.4 below.

Table 4.4 Summary of drilling sites based on geophysical survey in Togdheer Region

Village	VES Name	Longitude	Latitude	Recommended Depth of Drilling	Order of Preference
Awmaageer	Awmaageer1	45.603821	9.439690	Up to 350 m	1st choice
	Awmaageer2	45.588920	9.452310	Up to 330 m	2nd choice
Bali dhiig	Balidhiig 3	45.935460	8.425290	Up to 350 m	3rd choice
	Balidhiig 4	45.945541	8.384190	Up to 350 m	2nd choice
	Balidhiig 5	45.962190	8.384140	Up to 350 m	1st choice
Burco	Burco1	45.472860	9.485730	Up to 40 m	3rd choice
	Burco2	45.486260	9.493130	Up to 200 m	1st choice
	Burco3	45.508090	9.504600	Up to 120 m	2nd choice
Caynabo	Caynabo1	46.396230	9.000320	Up to 200 m	2nd choice
	Caynabo2	46.410810	8.991700	Up to 300 m	1st choice
	Caynabo3	46.461730	9.028190	Up to 100 m	3rd choice
Ceeg	Ceeg01	46.461830	9.128190	Up to 100 m	1st choice
Dhoqoshay	Dhoqoshay1	45.714400	8.501420	Up to 330 m	1st choice
	Dhoqoshay4	45.730840	8.503230	Up to 350 m	2nd choice
Dhubato	Dhubato1			Up to 30 m	1st choice
Duruqsi	Duruqsid2	45.488000	8.526730	Up to 200 m	1st choice
Faraskabood	Faraskabood1	45.538412	9.452660	Up to 300 m	2nd choice
	Faraskabood2	45.533290	9.434480	Up to 300 m	1st choice
Heshay	Heshay1	46.418590	8.845460	Up to 50 m	1st choice
	Heshay2	46.395240	8.831660	Up to 30 m	2nd choice
Oog	Oog1	46.597270	8.932510	Up to 70 m	1st choice
	Oog3	46.612930	8.924440	Up to 50 m	2nd choice
Qayta	Qayta1			Up to 100 m	2nd choice
	Qayta2			Up to 200 m	1st choice
Qoryaale	Qoryaale1	45.974040	9.082410	Up to 200 m	1st choice
Wacay Oodane	Wacay oodane1			Up to 130 m	1st choice
Waridaad	Waridad3	46.349600	9.267250	Up to 130 m	1st choice
Xaaji Saalax	Xaaji Saalax2	45.233460	8.603710	Up to 330 m	1st choice
Xaaxi	Saalax1	44.978400	9.357330	Up to 100 m	1st choice
	Saalax2	44.970590	9.341350	Up to 100 m	2nd choice
Xood	Xood1	46.179570	9.350620	Up to 330 m	1st choice
Yaroowe	Yaroowe2	45.653900	9.431010	Up to 50 m	2nd choice
	Yaroowe3	45.650730	9.411560	Up to 50 m	1st choice
	Yaroowe4	45.653880	9.445380	Up to 50 m	3rd choice

WAQOOYI GALBEED REGION

The geoelectric survey in Waqooyi Galbeed Region were carried out by the Somaliland geophysical team and during their survey in this region the areas covered were; Abaarso, Bali cabane, Bali gubadle, Bali matan, Dhimbriyaale, Farawayne, Garabis, Gobdheer, Gumar, Halaya, Labisagaala, Qudhaca Abrin, Salaxley, Taysa, Tincade, Toon, Wadamakaahiil, and Wajaale. The summary of recommended drilling depth together with the site preferences are given in Table 4.5 below.

Table 4.5 Summary of drilling sites based on geophysical survey in Waqooyi Galbeed Region

Village	VES Name	Longitude	Latitude	Recommended Depth of Drilling	Order of Preference
Abaarso	Abaarso1	43.901020	9.583970	Up to 120 m	2nd choice
	Abaarso2	43.891270	9.596980	Up to 120 m	1st choice
Bali Cabane	Bali cabane2	43.865310	9.146740	Up to 100 m	1st choice
Bali Gubadle	Baligubadle1	44.008210	9.046040	Up to 150 m	4th choice
	Baligubadle2	43.977190	9.021100	Up to 250 m	3rd choice
	Baligubadle3	43.961400	9.037520	Up to 300 m	2nd choice
	Baligubadle7	43.929700	9.064570	Up to 400 m	1st choice
Bali Matan	Bali matan1	44.462480	9.105600	Up to 100 m	2nd choice
	Bali matan2	44.479630	9.104620	Up to 200 m	1st choice
Farawayne	Farawayne1	43.592900	9.341530	Up to 300 m	2nd choice
	Farawayne 2	43.646060	9.354840	Up to 300 m	1st choice
	Farawayne 3	43.698960	9.315690	Up to 300 m	3rd choice
Garabis	Garabis2	43.947150	9.436320	Up to 350 m	1st choice
Garadag	Garadag2	46.836800	9.483800	Up to 150 m	1st choice
Goobare	Goobare2	45.287650	10.415520	Up to 200 m	1st choice
	Goobare3	45.342700	10.374480	Up to 120 m	2nd choice
Gumar	Gumar1	43.906440	9.092440	Up to 350 m	1st choice
Halaya	Halaya1			Up to 110 m	1st choice
Labisagaala	Labisagaala1			Up to 300 m	1st choice
Qudhaca Aburin	Qudhaca Aburin2	43.793190	9.498600	Up to 200 m	1st choice
Salaxley	Salaxley1	44.207398	9.025790	Up to 400 m	1st choice
	Salaxley3	44.179660	9.123777	Up to 150 m	2nd choice
	Salaxley4	44.205300	9.039800	Up to 30 m	3rd choice
Taysa	Taysa1			Up to 10 m	1st choice
Tincade	Tincade1	43.600440	9.476930	Up to 70 m	1st choice
Toon	Toon1	44.087320	9.390880	Up to 100 m	2nd choice
	Toon2	44.089230	9.407630	Up to 40 m	3rd choice
	Toon3	44.140770	9.390250	Up to 330 m	1st choice
Wadama-kaahiil	Wadama-kaahiil1	43.612323	9.362538	Up to 90 m	1st choice
Wajaale	Wajaale1			Up to 150 m	3rd choice
	Wajaale2			Up to 230 m	2nd choice
	Wajaale3			Up to 260 m	1st choice

AWDAL REGION

The geoelectric survey in Awdal Region were carried out by the Somaliland geophysical team and during their survey in this region the areas covered were; Boroma, Dila, and Qonujeed. The summary of recommended drilling depth together with the site preferences are given in Table 4.6 below.

Table 4.6 Summary of drilling sites based on geophysical survey in Awdal Region

Village	VES Name	Longitude	Latitude	Recommended Depth of Drilling	Order of Preference
Boroma	Boroma01			Up to 160 m	2nd choice
	Boroma_amuud01	43.268100	9.947510	Up to 70 m	3rd choice
	Boroma_shaba1	43.233510	9.934730	Up to 70 m	4th choice
	Boroma_amuud2	43.244360	9.941760	Up to 200 m	1st choice
Qonujeed	Qonujeed2	43.015340	10.093470	Up to 150 m	1st choice

MUDUG REGION

In the Mudug Region, the geoelectric surveys were conducted in Galdogbo and Buubi. The summary of recommended drilling depth together with the site preferences are given in Table 4.7 below.

Table 4.7 Summary of drilling sites based on geophysical survey in Mudug Region

Village	VES Name	Longitude	Latitude	Recommended Depth of Drilling	Order of Preference
Galdogob/ Xamure	Xam01	47.02372	6.97687	Up to 70 m	1st choice
	Xam02	47.02126	7.00954	Up to 40 m	2nd choice
Buubi	Bubi01	48.37732	7.14681	Up to 300 m	1st choice
	Bibi02	48.38282	7.13447	Up to 110 m	2nd choice

BARI REGION

The geoelectric survey in Bari region covered the following villages; Carmo and Sheerb. The summary of recommended drilling depth together with the site preferences are given in Table 4.8 below.

Table 4.8 Summary of drilling sites based on geophysical survey in Bari Region

Village	VES Name	Longitude	Latitude	Recommended Depth of Drilling	Order of Preference
Carmo	CARM01	49.06715	10.53865	Up to 150 m	2nd choice
	CARM02	49.07942	10.51630	Up to 180 m	1st choice
Sheerbi	SHER01	49.09400	09.84923	Up to 200 m	3rd choice
	SHER02	49.10132	09.86028	Up to 350 m	1st choice
	SHER03	49.07978	09.86942	Up to 200 m	2nd choice

NUGAAL REGION

The survey in Nugaal Region covered the following areas; Warguud, Garowe, Qarixs, Jalam, Reebant, Mayle, Kalabayr, Budunbuto and Shaxda. The summary of recommended drilling depth together with the site preferences are given in Table 4.9 below.

Table 4.9 Summary of drilling sites based on geophysical survey in Nugaal Region

Village	VES Name	Longitude	Latitude	Recommended Depth of Drilling	Order of Preference
Wargaduud	War 01	49.06805	7.73429	Up to 250 m	2nd choice
	War 02	49.06852	7.73335	Up to 120 m	1st choice
	War 03	49.071174	7.71546	Up to 80 m	3rd choice
Garowe	Gar03	48.51658	8.40139	Up to 400 m	2nd choice
	Gar04	48.52507	8.39258	Up to 400 m	1st choice
	Gar07	48.52077	8.41615	Up to 120 m	3rd choice
Reebanti	Reb01	48.52333	7.80832	Up to 60 m	2nd choices
	Reb02	48.53023	7.80330	Up to 300 m	1st choice
	Reb03	48.53050	7.81115	Up to 90 m	3rd choice
Mayle	May01	48.67241	7.75603	Up to 200 m	1st choice
	May02	48.66117	7.75752	Up to 60 m	2nd choice
Budunbuto	Budn01	49.36800	8.53074	Up to 50 m	3rd choice
	Budn02	49.42184	8.51437	Up to 50 m	2nd choice
	Budun03	49.42614	8.50853	Up to 60 m	1st choice
Jalam	Jal01	48.04260	7.88070	Up to 330 m	1st choice
	Jal02	48.05481	7.86527	Up to 60 m	2nd choice
Qarixs	QAR01	49.59703	8.48764	Up to 80 m	2nd choice
	QAR02	49.59298	8.48176	Up to 100 m	1st choice
Kalabayr	KAL01	48.10353	7.96915	Up to 400 m	1st choice
	KAL02	48.09923	7.97300	Up to 400 m	2nd choice
	KAL03	48.09009	7.99009	Up to 100 m	3rd choice
Shaxda	SHAX01	48.91010	9.17367	Up to 100 m	1st choice
	SHAX02	48.89357	9.1802	Up to 100 m	2nd choice

4.3 Hydrogeology

4.3.1 Aquifer systems in Somaliland and Puntland

The hydrogeological classification was one of the initial steps in HASP. To undertake this step and also to make possible the creation of the Regional Hydrogeological Map of the study area on a scale of 1:750.000 (Annex I) along with other GIS-based thematic maps and layers, it was necessary first to explain lithostratigraphy and the permeability of rocks to the trainees before they started field survey. Therefore, initial classification has been made in the beginning of HASP, while some additional information obtained from the field survey (hydrogeology, geophysics, hydrochemistry), remote sensing and available references, and pumping tests results provided an opportunity to revise, upgrade and finally to complete this classification of the HG systems in the region (included also in the Legend of the GIS-based Regional HG map 1:750.000, Annex I).

4.3.1.1 Classification of aquifers systems and basins

In total, six main hydrogeological systems (or groups) are sorted out. They are the following:

1. Intergranular Aquifer Systems – I

1.1 Intergranular aquifer of high permeability and significant GW reserves – I1

1.2 Intergranular aquifer of moderate permeability and local GW reserves – I2

1.3 Intergranular aquifer of low permeability and limited GW reserves – I3

1. Karstic aquifers – K

2.1 Karstic aquifer of high permeability and large GW reserves - K1

2.2 Karstic aquifer of moderate to high permeability and moderate GW reserves – K2

2. Karstic-fissured aquifer – KF

Aquifer of moderate permeability and moderate GW reserves

3. Fissured aquifers – F

Aquifer of moderate to low permeability and moderate to small GW reserves

4. Aquitrad to Aquiclude - A

Rocks of low permeability with periodically or locally present groundwater

5. Impermeable rocks – Aquifuge - N

Impermeable rocks without groundwater acting as a barrier to GW flow

For the purpose of the Regional Hydrogeological map of Somaliland and Puntland, adequate hydrogeological characterization is given to each of the existing lithostratigraphical units (Table 4.10). Some of the units with a small extension at the surface are not presented on this map because of the scale of 1:750.000 chosen to make data interpretation at the regional level. For instance, pre-Jurassic Adigrat sandstones or lacustrine clays in the Awdal area (described in the report of Petrucci, 2008) are excluded from this map, but would be considered in the preparation of GIS larger scales maps, if required.

Table 4.10 Hydrogeological classification of the aquifer systems in Somaliland and Puntland

Age	Symbol	Lithology	Aquifer ID
Quaternary			
Quaternary	Qsd	Sand dunes and beach sediments (along the coastline)	**I1**
	al	Alluvial sediments, deposited along toggas and temporary streams	**I1**
	d-pr	Diluvial-proluvial sediments deposited at the foothills, and basins slopes often create large thick blanket of unsorted heterogeneous material.	**I2**
	Qt	“Tigers” pattern mostly present in water-logging areas, ponds and zones with elevated humidity. A rare vegetation usually accompanies this formation	**I2**
	Qc	Re-deposited sediments, red soil, continental carbonate crust, laterites. Heterogeneous lithology often well cemented and poorly permeable rocks	**I3**
Tertiary			
Late Miocene to Pleistocene	β	Basalt lava flow and volcanic products; rare rhyolites	**F**
Early to Middle Miocene	Md	Dubar Limestones: biogenic limestone	**KF**
	Mdc	Conglomerates and sands in alluvial plains and delta plains	**I1**
	Mi	Iskushuban: marl, sandstone, gypsum, coal, limestone and fine conglomerates	**F**
Miocene (undifferentiated)	M	Biogenic reefal limestones	**KF**
Oligocene to Early Miocene	OMmb	Gypsiferous sands and sandy calys, limestones	**F**

Age	Symbol	Lithology	Aquifer ID
Oligocene	Oh	Marly and biogenic limestones, calcarenites and sandstones	**F**
Middle Eocene to Oligocene	Od	Daban sections: siltstones, sandstones, conglomerates, gypsum, limestone	**F**
Middle to Late Eocene	Ek	Karkar (Karkaar) limestones: nodular nummulitic limestones and marl intercalations with a rich shallow-marine fauna.	**K1**
Early to Middle Eocene	Et	Taleh (Taleex) evaporites: anhydrites, gypsum, dolomites, cherty limestones and shals	**K2**
Maastrichtian to Early Eocene	Ea	Auradu limestones: limestones with corals and intercalations of marls and cherts	**K1**
Mesozoic			
Cretaceous (undiferentiated)	Ky	Yesomma (Nubian) sandstones: Continental facies - variegated quartzose sandstones and siltstones, mainly fluvial. Near Ceerigaabo marine calcareous intercalations.	**F**
Aptian-Campanian	Kt	Tisje Form. Shallow-water limestones with corals, rudists and orbitolinas, marls, localy with amonites, littoral to continental sandstones and conglomerates with rare coal seams	**K2**
Neocomian	Kα	Medium to coarse grained, syenites in Nugaal Valley non-comformably overlain by a few tens of meters of Yesomma sandstones	**A**
Middle to Late Jurassic	Jc	Shallow-water limestones separated by dark, grey marls and shales underlain by fluvial quartzose sandstones	**K1**
Early Jurassic to Kimmeridgian	JA	Ahl Madow Group: limestones, marlstones, dolostones, pebbly sandstones, clays and rare gypsum	**F**
Precambrium			
Late Proterozoic to Cambrian	γ	Granites; massive to foliated granitoides	**A**
Late Proterozoic	XI	Inda Ad Complex; low grade metaclastics, with interbeded pillow marbles	**A**
	XM	Maydh Complex; grained metaclastics, with interbeded pillow metabasalts	**N**
	XA	Abdulkadir Complex; metapellites; with acids and basic metavolcanic	**N**
	Xγ	Gabbros and metagabbros	**A**
	χσ	Syenites	**A**
Basement Complex (Proterozoic)	Mm	Marbles and related rocks	**KF**
	Ma	Biotite and/or amphibole schists	**N**
	Ms	Quartz-feldspar schists and quartzrich gneisses	**N**
	Mμ	Migmatites rich in amphibole and marble intercalations	**A**
	χB	Qabri Baxar Complex; Migmatites rich in leucosomes and granitoid patches; minor paragneisses including local granulite relics	**A**

The most important aquifers for the development of the groundwater reserves are intergranular and karstic aquifers.

Intergranular aquifers (I) characterized the following lithostratigraphical units:

I1 - Sand dunes and beach sediments (Qsd).

I1 - Alluvial sediments, deposits along toggas and temporary streams (al).

I2 – Diluvial-proluvial sediments at the foothills and slopes (d-pr).

I2 – Tiger pattern and terrace deposits (Qt).

I3 – Quaternary laterites and carbonate crust (Qc).

While sand dunes and beach sediments (Qsd) have a relatively small extension limited to the Red Sea and Indian Ocean shorelines, Quaternary alluvial sediments deposited along toggas and temporary streams (al) are widely present and represent the most prosperous aquifer in Somaliland and Puntland. However, there are some exceptions to this rule as described in the report of Petrucci (2008) who investigated groundwater in the Borama area: “Recent and actual alluvials are characterized by medium-high permeability, hence high infiltration rate. Their thickness is variable and along wadi courses often it has been completely eroded and the underlain clay appears to the base of the banks. For this reason there is not in the area a wide shallow aquifer”.

Recent alluviums are often associated with the deeper terrace deposits (old alluvium), which in some cases resulted in very thick aquifer (over 100 m). For instance, the thickness of tapped sediments at the Geed Deeble source (Hargeysa water supply) is over 150 m (Water Supply Survey Team of the PRC, 1983). The most productive wells are often pumped out with discharge rates over 20 l/s. When older alluviums are covered or associated with basaltic rocks this aquifer is confined and the initial artesian pressure could be considerable (e.g. Xunboweyle area).

Figure 4.30 Section of terrace deposits near Xudun, mixture of boulders, pebbles, gravels and clays (photo Puntland team 2)

Karstic aquifers (K) are linked to the following lithostratigraphical units:

K1 – Eocene Karkar Fm. (Ek).
K2 – Eocene Taleh Fm. (Et).
K1 – Eocene Auradu Fm. (Ea)
K2 – Aptian-Campanian Tisje Fm. (K1)
K1 - Middle to Late Jurassic (Jc)
Eocene Karkar limestones (Ek) represent the most prospective fresh groundwater reservoir for further development in the central and eastern parts of the study area (Sool and Hawd plateaus). The quality of water from springs and wells is relatively fresh with an EC value of 1490 to 1800 μS /cm (Faillace & Faillace, 1986). But the practical problem is the variable thickness of the Karkar, the percolation towards underlying Taleh (Taleex) evaporitic rocks and often present groundwater mixture of the two aquifers. Faillace & Faillace (1986) stated that “the Karkar Formation of the central and eastern parts of the Sool Hawd Plateau is generally dry and 300-400m deep wells need to be drilled in order to tap water from the underlying Taleex Formation. In the western part of the plateau the lower section of the Karkar Formation generally contains a few water-bearing limestone layers; boreholes tapping these layers produce a moderate yield.”

The Taleh (Taleex) Series (Et) are formed in typical arid climate conditions. The evaporitic rocks (gypsum, anhydrites, limestones, dolostones) usually yield moderate to highly mineralized groundwater. The Ca or $CaSO_4$ type of water prevails with TDS usually greater than 3800 mg/l. Many boreholes were abandoned because of a high salinity content not fit for human consumption.

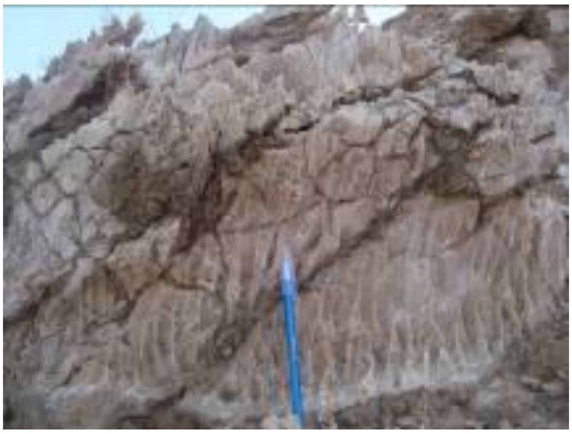


Figure 4.31   Gypsum layers of Taleh (Taleex) Fm.

In order for fresh groundwater to be obtained, the underlying Auradu limestones formation should be reached and the two aquifers should be separated and sealed. For instance, Faillace & Faillace (1986) described several boreholes drilled for the Laas-Canood town water supply which were drilled in the Taleh formation and have been abandoned.

Figure 4.32 Pothole and small pond in evaporitic rocks of Taleh (Taleex) Fm.

The Auradu limestones (Ea) are also very promising aquifer as they may yield water of good quality. If present, the overlying Taleh (Taleex) aquifer must be sealed off in order to secure tapping of fresh water. The chemical analyses of groundwater from wells tapping the Auradu limestones show a bicarbonate type of water with low mineralization, and with an EC value generally below 1,000 μS /cm.

Figure 4.33 Sinkhole used for tapping groundwater

Karstic aquifer of Aptian-Campanian limestones, marls, and sandstones of Tisje Fm. belongs to the K2 group and is locally developed and utilized by moderately productive wells.

In contrast to Aptian-Campanian limestones the Jurassic shallow-water limestones (Jc) is an important aquifer. Only when separated by dark, grey marls and shales does its permeability lower, as in the case of the Borama area (Petrucci, 2008). This aquifer could also be underlain by fluvial quartzose sandstones (Adigrat sandstones). In some areas, the limestones have weathered to a clay rich residuum which reduces the recharge capability of the aquifer. This residuum tends to accumulate in some of the alluvial valleys reducing the ability of a well in the bedrock to make use of the recharge from the overlying togga beds, which would then represent a significant groundwater resource.

The Jurassic limestones have the greatest potential for groundwater development of any rock type. Observations made in the study area indicate that this rock should be a significant aquifer where it is fractured or has undergone extensive karstification development. According to German Agro-Action (2005), "The most extensive karst development is in the study area near Borama where the limestone has probably been exposed continuously since the Jurassic. Karst development decreases toward the north probably because there was no hiatus between the Jurassic and the Cretaceous and because the Nubian sandstone deposited in this area has protected the limestones from karst development."

"Jurassic Limestones represent the best aquifer of the Borama area. They are usually characterized by a high degree of fracturation, by the presence of pure limestones in the upper part of the formation, with marly levels and calcareous sandstones in the terminal section. With this structure, the water circulation can develop mainly in the upper part, along fractures and (probably) karstic cavities. The marly levels if continuous can create difficulties to a deeper infiltration. As a matter of fact, in the new well drilled the groundwater was kept below its piezometric level because of a marly layer dividing two limestone sections and forcing the water into an artesian aquifer."[10]

These limestones are more easily recharged in areas where the bedding is not horizontal. The greater the dip of the sediments, the greater is the recharge capability. The lower section, which usually contains lenses of sandstones and conglomerates up to 90 m thick, may be less favorable.

Karstic fissure aquifers (KF) characterized the lithostratigraphical units which belong to two age extremes: the younger Miocene carbonates and very old Proterozoic rocks. The following members are classified into this group: Miocene Dubar biogenic limestoness (Md), Miocene diogenic reefal limestoness (M) and Proterozoic marbles of Mora Complex (Mm).

This aquifer is complex, represents an aquifer in soluble rocks but with a low degree of karstification and dominant fissure systems which act as privileged groundwater pathways.

Of the few wells drilled in this aquifer, some are located in the Awdal area in the west (Somaliland) and some in Dharoor Valley in the eastern part of the study area (Puntland), but no data on their testing and utilization is available.

Fissure aquifers (F) characterized the following lithostratigraphical units: The youngest member is Late Miocene to Pleistocene basaltic lava flow, volcanic products with rare rhyolites (β); Miocene marl, sandstone, gypsum, coal, limestones and fine conglomerates of Iskushuban Fm. (Mi); Oligocene – Miocene gypsiferous sands, sandy clays, limestones of Mudug Fm. (OMmb); Oligocene marly and biogenic limestones, calcarenites and sandstones (Oh); and Oligocene siltstones, sandstones, conglomerates, gypsum, limestones of Daban Fm. To this aquifer also belongs the widely present Nubian sandstone (Yesomma Fm., Ky) as well as limestones, marlstones, dolostones, pebbly sandstones, clays and rare gypsum of Ahl Madow Group (JA).

Similar to karstic-fissure aquifers (KF), the fissure systems act as privileged groundwater pathways, but due to a very low degree of karstification of carbonate rocks (no cavities) or to the dominant presence of non-carbonates (clastic rocks, sandstones) in the lithological composition, permeability and groundwater reserves are even smaller than in "transition" KF aquifer.

[10] Cited from Petrucci (2008)

Pleistocene basalts occur primarily as elevated plateaus and are generally unsaturated. German Agro-Action (2005) noticed that in a few areas, such as Agabar and Las Dhure, they are found in the lowlands and appear saturated. Wells drilled in these areas have intersected water-bearing zones composed of sand lenses and weathered basalt. “Field observations made in stream channels indicate that there is a paucity of vertical fractures in the basalt flows as might be expected; since these basalts are extremely young and have been subject to less tectonic disturbance than neighboring formations. In certain areas, however, vertical fractures resulting from the cooling of the basalts might be expected. These areas probably represent primary recharge zones.”

A few wells were drilled in fissure aquifer of Oligocene – Miocene sediments, some in Oligocene carbonates in Daban, south of Berbera, and some near Gaalkacyo in Puntland.

Faillace & Faillace (1986) stated that drilling through sediments of the Iskushuban Fm. is rather easy, but the two exploratory boreholes drilled in the evaporitic sediments filling the Dharoor Valley yielded small amounts of highly mineralized water and were abandoned.

Evaluating the hydrogeological properties of Nubian Yesomma sandstones, Faillace & Faillace (1986) cited results of a hydrogeological survey conducted for Hargeysa in the 1950s: “The groundwater investigation of both the shallow aquifers and the Nubian sandstone was carried out by drilling shallow and deep exploration boreholes. The Nubian sandstone aquifer yields little water which is, in most cases, of poor quality (EC 4,000 to 5,500 μS/cm); the contact between the Nubian sandstone and the basement, investigated by the drilling of two deep boreholes, contains little or no water.” The authors provided data on 12 boreholes drilled at that time. Their depths ranked between 77 and 330 m, seven were totally dry, while the best yield obtained from borehole H10 was only 3.7 m^3/h (~ 1 l/s).

The water-bearing section in Nubian Yesomma sandstone is usually at the base of the formation just above the Basement complex or Jurassic rocks. The yield obtained from individual wells drilled in the Wajaale area was less than 2 m^3/hr.

Therefore, drilling attempts in the western and southern Hawd plateau resulted in high failure rates, low yields, and/or poor groundwater quality. Nevertheless, van der Plac (2001) confirmed that Nubian Sandstone supports productive wells at Burco. “The gently rising plain between Burco and Sheikh appears to be one of the few places where this formation forms a reliable, high-yielding aquifer.

Better results were obtained at Geed Ballaadh, Dameera Boob, Allay Bady and Burco, which are all located south of the margin of the basin. At Burco, the sandstone occurs at a depth of approximately 120 metres. Here, it is the main aquifer, with reasonable water quality. Borehole yields are over 20 m^3/hr, in general.

The potential for groundwater development decreases towards the central and eastern parts of the Hawd. The depth of the water table is generally greater than 250-300 m below ground level (bgl), and most boreholes are either dry or low-yielding. In the interior of the plains, aquifer development is affected by poor recharge conditions. Direct recharge and infiltration from toggas is blocked by a thick sequence of impermeable shales and clays that overlie the Auradu limestones. Groundwater drainage within the Nubian Sandstones is slow, due to an unfavorable texture of fine sand, silty sand, and silty clay. Moreover, the recharge area is very far away. The water quality is affected by long residence times, and varies from marginal to brackish."[11]

Aquitards (A) contain very little groundwater in the fissures systems and weathering zones. They include different lithological units: Neocomian medium to coarse grained, syenites in the Nugaal Valley; Cambrian granites; Late Proterozoic migmatites and marble intercalations, migmatites of the Qabri Baxar Complex. The granites in the study area are productive aquifers only where they have been fractured and faulted by tectonic activity. Since the granites do not have a significant amount of porosity or secondary permeability, except where there are well-developed fracture systems, there is no significant groundwater storage within these rocks. Weathered, granitic residuum can act as a significant reservoir for the storage of groundwater, but in contrast the weathering products, consisting primarily of clay and calcite, tend to plug existing fractures and prevent them from transmitting groundwater. In principle, wells drilled in the weathered zones have low yields. The most productive fracture zones are probably related to the recent rifting in the Red Sea and the Gulf of Aden.

Petrucci (2008) affirmed that "abundance of pelites strongly reduces the chances of infiltration along fractures in the basement. Around the town (Borama) there are few boreholes drilled with the hope to find groundwater, but the results are very poor and usually the yields are less than 10-20 m^3/day. Several shallow wells are located downstream of the confluence between Amoud and Damouq, downstream of the study area; they get a small quantity of water from the top weathered section of the basement."

[11] van der Plac, 2001: Burao water supply project...p. 33

Aquifuges (N) or totally impermeable rocks which act as groundwater barriers are predominantly of the Proterozoic age and include: metaclastics of the Maydh Complex interbedded with pillow metabasalts, metapellites; with acids and basic metavolcanic of Abdulkadir Complex, and biotite and amphibole schists, quartz-feldspar schists and quartzrich gneisses. The schist and gneisses tend to have tectonic stress relieved by movement along crystal boundaries and foliation planes and are less likely to produce open water-bearing fracture systems. But, large open fracture systems are not formed except in places where there has been very significant tectonic movement and a tremendous amount of stress.

Figure 4.34 Excavated hole for utilization of small groundwater seepage

The UNDP report (Popov et al., 1973) identifies seven hydrogeological provinces in Somaliland and Puntland, which are in fact based on their morphological characteristics:

1. Gulf of Aden Coast
2. Sloping Plains
3. Mountainous Zone
4. Dharoor Depression
5. Hawd Plateau
6. Taleex Plateau and Nugal Valley
7. Sool-Hawd and Sool Plateaus

"The first two are part of the coastal plain, the third coincides with the second physiographic province and the 4th, 5th, 6th, and 7th are included in the third physiographic province. The limits between some provinces are not always well defined, as is the case between the 1st and 2nd and between the 5th, 6th, and 7th. In fact, the geological formations of the Hawd, Sool-Hawd, and Sool plateaus belong to the Eocene and are widely exposed in these areas. At a regional scale the movement and discharge of groundwater is better defined within the subdivision of the area according to the three major physiographic provinces than within the seven hydrogeological provinces."[12]

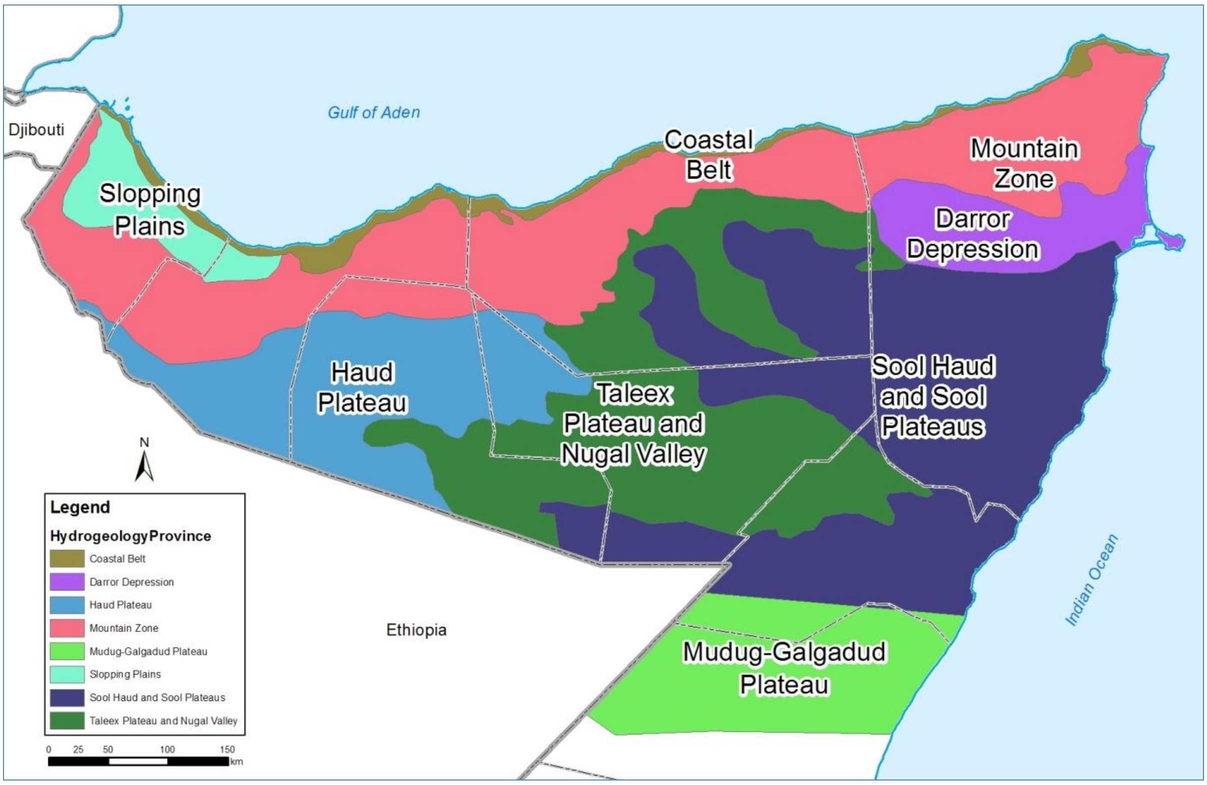


Figure 4.35 Hydrogeological provinces of the study area (by Popov et al.1973, redrawn by Milanovic, 2011)

4.3.1.2 Aquifer permeability

The results of pumping tests conducted in Somaliland and Puntland during the last decade are presented in the chapter 3.2.5.

Intergranular aquifers characterized by different permeability characteristics. Calculated transmissivity parameters for alluvial aquifer are commonly in the range of 10^{-2} - 10^{-3} m^2/s. In the Geed Deeble area (Hargeysa water supply source), out of ten wells tested in 2006, only one resulted with transmissivity smaller than 10^{-3} m^2/s. In others, values of 2.86 - 5.18 x 10^{-3} m^2/s were calculated based on the Jacob recovery method. Calculated equivalent hydraulic conductivities were in the range of 1.4 x 10^{-4} – 7.7 x 10^{-5} m/s. Discharge of tested productive wells ranked between 12-20 l/s with insignificant drawdown, regularly lower than 20 m (data provided by Hargeysa Water Utility).

[12] Cited from Faillace & Faillace (1986)

Diluvial-proluvial sediments are characterized by lower permeability and accordingly by smaller transmissivity and hydraulic conductivity. For example, one of the wells drilled in the Garoowe area (MAM) was pumped with a capacity of 4 l/s and the related calculated transmissivity was 6.4 x 10^{-4} m^2/s.

Figure 4.36 Very little water in well dug in Quaternary cemented carbonate crust (Photo of Somaliland team 2)

Karstic aquifers. Auradu aquifer is tapped out by many wells particularly in the Puntland. An average transmissivity value for this aquifer is in the magnitude of 10^{-3} m^2/s.

Some other well drilled in limestones such one in the Garoowe area (213 m deep) was tested with a small yield of 2 l/s. For a drawdown of 186 m, the transmissivity value of 1 x 10^{-4} m^2/s was obtained.

Jurassic limestone is one of the most permeable aquifers in the study area. As example the transmissivity value obtained from the test of well Bo-12 was 3.1 x 10^{-3} m^2/s.

Fissure aquifers. Data from pumping tests of four wells were available for evaluation in this study. Three of them are located near Gaalkacyo (Beyra) and were drilled in Oligocene Mudug Fm. to the similar depth of 180-220 m. Discharge of the wells was 3-5 l/s for a drawdown in the range of only 3 m to 24 m. Therefore, calculated transmissivity confirmed relatively moderate permeability from 3.1 x 10^{-3} m^2/s to 2.9 x 10^{-4} m^2/s.

The well drilled in Iskushuban Fm. in Timirishe (Bari area) yielded 5 l/s for a drawdown of some 50 m, with resulting transmissivity of 4.5 x 10^{-4} m^2/s.

Van der Plac (2001) estimated the transmissivity of Nubian sandstones: "The coarsest part of the formation (probably coinciding with the main water strike) occurs between 140 and 180 m bgl. With an average specific capacity of 7.5 m^3/hr/m, the aquifer transmissivity is about 220 m^2/day (2.5 x 10^{-3} m^2/s). Most boreholes penetrating this formation can sustain a yield of more than 30 m^3/hr."

4.3.2 Distribution of groundwater resources in Somaliland and Puntland

4.3.2.1 Distribution by region

AWDAL

The Awdal Region is situated in the west-north part of Somaliland. It includes territory from the Gulf of Aden up to the Ethiopian border. The biggest towns as well as district capitals in the Awdal region are Borama, Baki, Lughaye and Zeylac.

Generally, the Awdal Region belongs to four hydrogeological provinces: 1. Coastal Belt i.e. Gulf of Aden Coast (according to Popov et al. 1973), 2. Hawd Plateau, 3. Mountainous Zone and 4. Sloping Plains. The main aquifer for the purpose of water supply in the Awdal region belongs to Jurassic limestone on the Mountainous Area and Hawd Plateau. The Quaternary aquifers in the Sloping Plains area (Qc, al) are another well-exploited aquifer. No permanent rivers flow in the Awdal Region, but toggas which are formed in the Sloping Plains areas can be potential sources for local water supply.

WOQOOYI GELBEED

The Woqooyi Gelbeed Region is situated in the central part of Somaliland. It covers territory from the Gulf of Aden up to the Ethiopian border. The biggest towns as well as district capitals in the Woqooyi Gelbeed region are Hargeysa, Gebyli and Berbera.

Generally, the Woqooyi Gelbeed Region as previously discussed Awdal belongs to four hydrogeological provinces (Coastal Belt, Hawd Plateau, Mountainous Zone and Sloping Plains). The main geological formation together with the hydrogeological characterization is shown in Annex I. As can be seen from that map, the main aquifers for supplying water in the Woqooyi Gelbeed Region belong to the Auradu limestones, Quaternary re-deposited sediments, red soil, continental carbonate crust, laterites and to less productive aquifers such as rocks from the Basement Complex in the Mountain Area. The water supply on the Hawd Plateau is connected mostly to Yesomma (Nubian) sandstones, while in the area of the Coastal Belt the water supply is dominantly depending on aquifer formed in sand dunes and other Quaternary sediments. As in other parts of the investigated area no permanent rivers flow, but some toggas can be potential sources for future water supply.

TOGDHEER

The Togdheer Region is situated in the central part of Somaliland along the Ethiopian border. The biggest towns as well as district capitals in Togdheer region are Burco, Buuhoodle and Sheekh (Sheikh).

Generally, the Togdheer Region shares four hydrogeological provinces (Hawd Plateau, Mountainous Zone, Sool-Hawd and Sool Plateaus, Nugal Valley and Taleex Plateau). The main water bearing layers in the Togdheer region belong to karstified rocks such as Auradu limestones and Karkar and Taleh (Taleex) formations, to Quaternary sediments formed along toggas, and to re-deposited sediments, red soil, continental carbonate crust, and laterites. As in the other parts of the study areas some toggas can be promised water sources.

SANAAG

The Sanaag Region is situated in the central-northern part of Somaliland. The biggest towns as well as district capitals in Sanaag region are Ceerigaabo, Ceelafweyn and Lasqoray.

The Sanaag Region also shares several hydrogeological provinces (Coastal Belt, Hawd Plateau, Mountain Zone, Sool-Hawd and Sool Plateaus and Taleex Plateau and Nugal Valley and Dharoor Valley). The aquifers of the largest potential in the Sanaag region belong to the karstified rocks of Eocene Karkar and Auradu limestones and Taleh (Taleex) evaporites. The Quaternary sediments formed along toggas and sand dunes and beach sediments (along the coastline) is also aquifer of a good potential, but intrusion of salty waters may be very probable as closest to the shoreline and the sea.

SOOL

The Sool Region is situated in the central part of the investigated area between the Togdheer, Sanaag, Bari and Nugaal regions and the Ethiopian border to the south. The biggest towns as well as district capitals in Togdheer region are Caynabo, Xudun, Taleex and Laas Caanood.

Generally, the Sool Region belongs to three hydrogeological provinces (Hawd Plateau, Sool- Hawd and Sool Plateaus, Taleex Plateau and Nugal Valley). The main aquifers in the Sool Region belong to karstified rocks such as Auradu limestones, Karkar and Taleh (Taleex) formations and to Quaternary sediments formed in the middle of the region which consist of re-deposited sediments, red soil, continental carbonate crust, and laterites.

BARI

The Bari Region is situated in the northeastern part of Puntland. The biggest towns as well as district capitals in the Bari region are Qardho, Boosaaso and Iskushuban.

The Bari Region shares several hydrogeological provinces (Coastal Belt, Mountain Zone, Sool Hawd and Sool Plateaus and Taleex Plateau, Nugal Valley and Dharoor Depression). The main geological formations together with its hydrogeological characterization are shown in Annex I. As can be seen from the map, the main aquifers in the Bari Region belong to karstified rocks of Auradu limestones, Karkar and Taleh (Taleex) formations and to Quaternary sediments formed along toggas, mainly in the Dharoor Depression. As in other parts of the investigated areas no permanent rivers flow.

MUDUG

The Mudug Region is situated on the most southern part of the investigated area. Only its northern part is included in SWALIM survey. The biggest towns as well as district capitals in the Mudug region are Gaalkacyo, Galdogob and Jariiban.

The Mudug Region belongs to hydrogeological province of Mudug-Galgadud plateau. The main aquifers in the Mudug region belong to Karkar and to a lesser extent to Oligocene – Miocene gipsiferous sands, sandy clays and limestones (Mudug beds).

4.3.2.2 Distribution by aquifer system

The HASP hydrogeological survey, carried out in 2011 and 2012, confirmed that the main aquifers and richest in groundwater are karstic ones, formed in the limestone lithological beds and sequences (Jurassic limestone, Auradu formation and Karkar formation) and in layers constituted by sand and gravel deposits of variable thickness of Quaternary age. Most promising and rich in groundwater, alluvial aquifer (al) in shallow togga’s deposits is mostly captured with shallow dug wells. Widely distributed red soils and carbonate crust of Quaternary age are greatly reduces the infiltration to the most of the underlying karstic aquifers’ lower parts and with its high salt content contributes to the increase in the water salinity of the underlying karstic aquifers.

Generally, the water point distribution in study area can be discussed for seven major aquifer systems with greater extension, as they have been classified in chapter 4.3.1.1 of this report.

1. Basement Complex

The Basement Complex outcrops just at Berbera near the sea, and in the western part of Somaliland (Awdal region). The Basement Complex is composed of schists, ortogneiss, quartzites and paragneiss intruded by granite, diorite and gabbro, and generally has poor permeability characteristics. Only a few wells were drilled in this unit, usually with a yield of just a few l/s. Only 33 springs with a discharge no higher than 2 l/s are registered in the area which belongs to the Basement Complex. Around 150 dug wells were registered in the Basement Complex area with a depth usually no deeper than 15 m, and with a small yield (Figure 4.37). They are all dug in uppermost weathering zone.

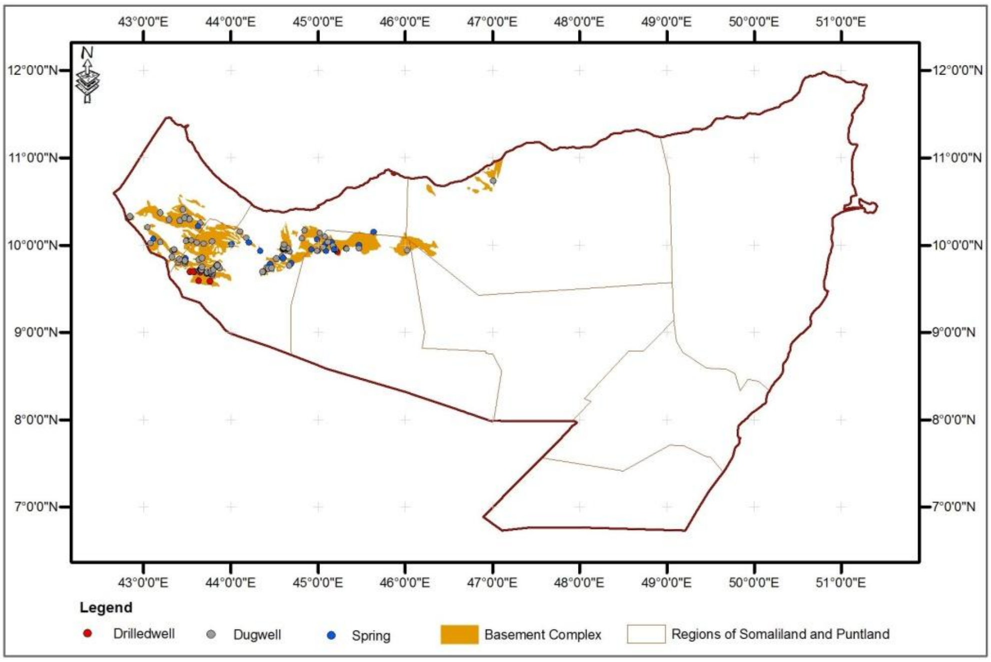


Figure 4.37 Basement Complex with position of surveyed water points

2. Nubian Sandstone

The Nubian Sandstone is deposited under continental or lagoonal conditions and consists of fine- to coarse-grained white to red-brown quartz sandstones. Some conglomerate beds are also present. The sandstone is often cross-bedded, soft and friable. The Nubian sandstone unconformably overlies the Basement Complex along the plateau escarpment and in some areas underlies by the Auradu limestone. The sandstone occupies the southern part of Hargeysa and Gabiley districts (Geed-

Balaadh, Faroweyne, Alleybadey and Salaxlay). There have been numerous investigations carried out in areas of Nubian sandstone along the Ethiopian border (10 wells), especially near Wajaale, Gee-Balaadh, Alleybadey, Salaxlay, and Baligubadle. The depth of wells is from 150 m to 330 m with an average yield of 4 l/s. The thickness ranges from 100 m in the area of Wajaale, while it can reach more than 500 m in the area of Baligubadle.

From a hydrogeological point of view the Nubian sandstone is not productive aquifer but because in some parts of Somaliland there is only aquifer for water supply, it must be considered as one of future local water supply sources.

3. Jurassic limestones

Although it does not occupy a large area, Jurassic limestones is of great importance for the water supply in the western part of Somaliland. Usually, these formations consist of shallow-water limestones separated by dark, grey marls and shales underlain by fluvial quartzose sandstones. They are well-karstified and have favorable hydrogeological characteristics. These formations are especially important for Borama town. Most of the wells are from 50 to 130 m deep with a yield from 5 to 10 l/s. There are 25 drilled wells registered, and around 100 dug wells and 45 springs, some of which have a discharge of more than 10 l/s.

4. Auradu limestones

The Auradu formation consists of hard and massive, grey to white limestone, and limestone with corals and intercalations of marls and cherts, often unbedded. The Auradu limestones outcrops in a large, discontinuous and fault-dissected belt bordering the edge of the plateaus (Figure 4.38). As well, the Auradu limestones outcrops from the elongated hills especially around the Yagoori and Hudun (Lafaweyne) areas. In the Nugaal valley it is overlain by the Taleh (Taleex) formation which itself can be overlain by the Karkar formation.

The Auradu limestones are the most productive aquifers of the investigated area and the most important aquifer for the future groundwater development.

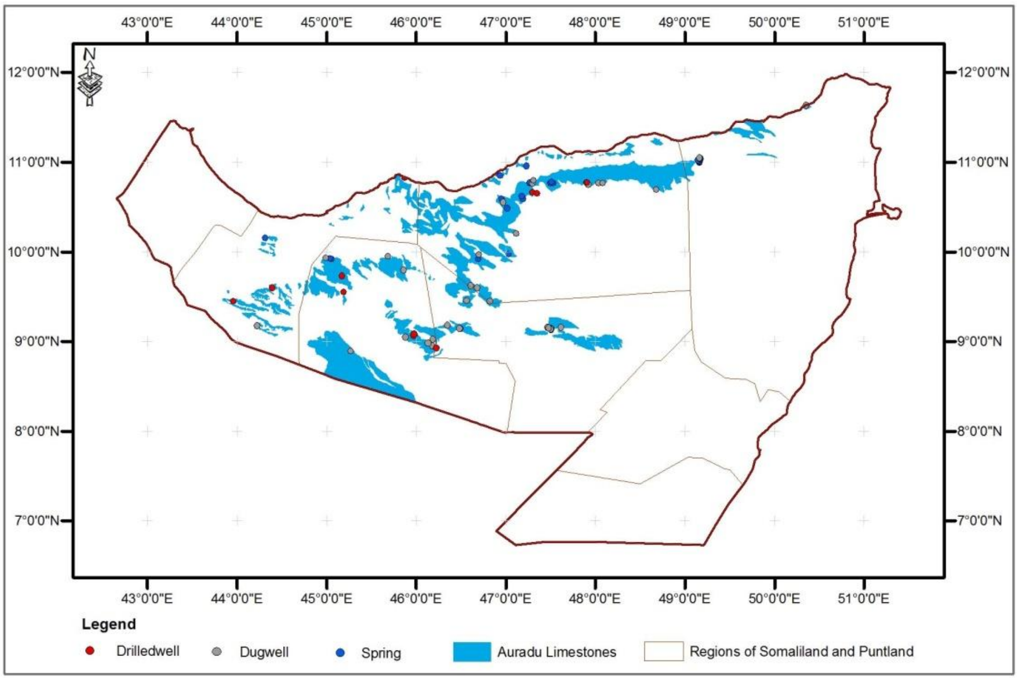


Figure 4.38 Auradu limestones with position of surveyed water points

5. Taleh (Taleex) Formation

The evaporitic Taleh (Taleex) Formation consists of anhydrites beds with intercalations of limestone and gypsum. Changes from anhydrite through gypsiferous limestone to dense limestone occur frequently and can easily be followed in a comparatively short distance. The greatest succession of an anhydrite series occurs in the Nugaal Valley, where it covers a large part of the Sool and Nugaal Regions.

Around 50 boreholes were drilled in the Taleh Series. Water from these wells is highly mineralized and in most cases is of the calcium or sodium sulphate type of water. Most of these boreholes were abandoned because of their high salinity content which makes the water unfit for human consumption (Figure 4.39).

Of most importance about the Taleh formation is the Auradu limestone that in most cases underlies Taleh. As already mentioned Auradu is a very promising aquifer and it may yield water of good quality if the overlying Taleh aquifer is sealed off in order to secure the expected fresh bottom waters.

There are around 50 drilled wells with an average depth of 150 to 350 m located in the area covered by the Taleh formation. Most of these wells in fact reached bottom Auradu limestones. The yields are not greater than 7 l/s.

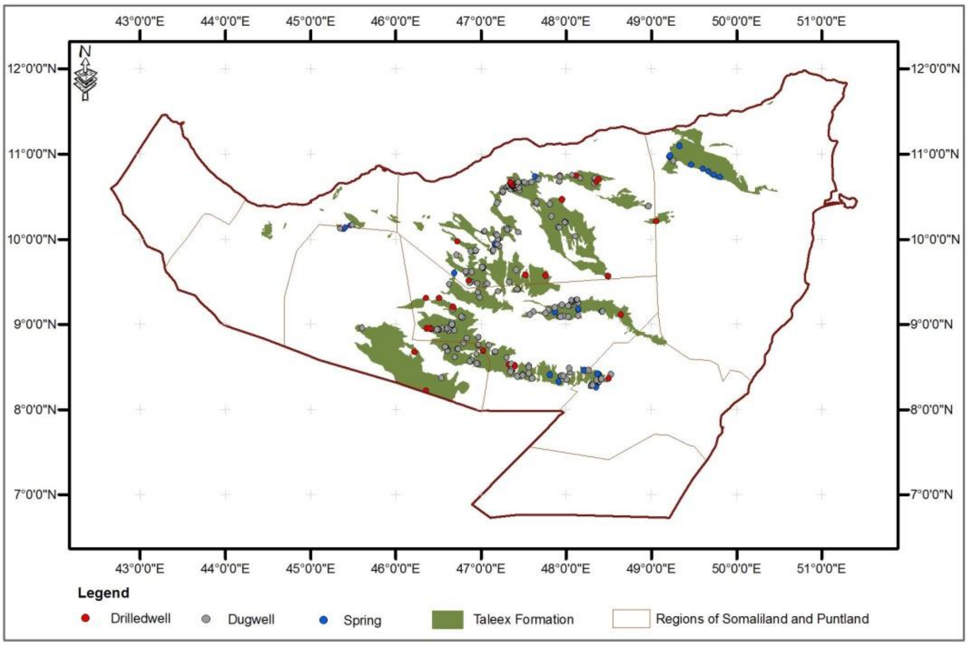


Figure 4.39 Taleh (Taleex) Fm. with position of surveyed water points

Figure 4.40 Pit with groundwater in Taleh (Taleex) Fm.(Sanga Naaxshe, Ceel Afweyne, Somaliland 2)

7. Karkar Formation

The Karkar Formation is constituted by bedded limestone, marly limestone, and white marls. The Karkar formation is generally conformable on the Taleh (Taleex) Formation as well as in some parts on the Auradu Limestone and its thickness varies between 150 to 450 m.

Karkar Fm. is situated mostly in Puntland, and is generally superficially covered by more recent sedimentary deposits in the form of red soils and sand dunes which give the region the character of aridity. Water quality from the Karkar springs and wells is usually good with an EC value of 1,490 to 1,800 μS/cm.

There are about 80 deep borehole-wells located in the Karkar formation (Figure 4.41) with a range of depth from 160 to 440 m, and a yield not exceeding 7 l/s. The static water level is usually very deep, from 110 to max 250 m b.g.l.

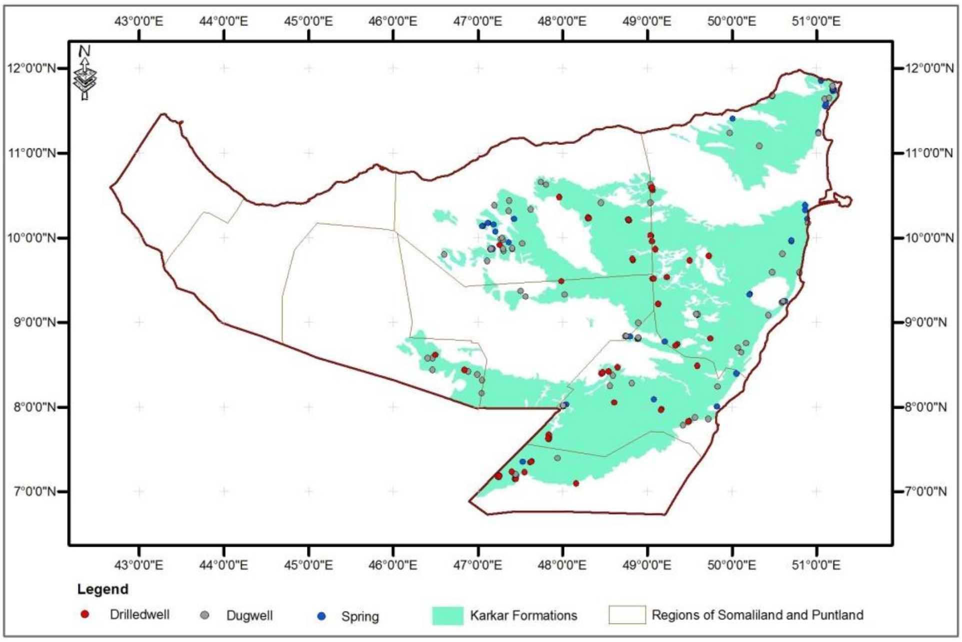


Figure 4.41 Karkar Fm. with position of surveyed water points

8. Quaternary Formations

The Quaternary formation plays a very important role in the water supply of Somaliland and Puntland. It is composed mostly of sand deposited along toggas and temporary streams. There are also re-deposited sediments, red soil, continental carbonate crust, and laterites as well as a heterogeneous lithology often with well-cemented and poorly permeable rocks. Also, diluvial-proluvial sediments are deposited at the foothills and slopes of basins. Considering data from the field survey and from previous SWALIM investigations (surveyed water points are presented in Figure 3.14) it can be concluded that the depth of the drilled wells varies from 50 to 350 m with yields which can reach up to 17 l/s [13]. There are more than 500 shallow wells registered in Somaliland and Puntland which are connected to Quaternary deposits with depths no greater than 30 m, and with a small yield.

[13] Some of previously drilled wells were tested with discharge of even 50 l/s (GTZ), but during this survey no actual larger pumping rate than 17 l/s is noticed.

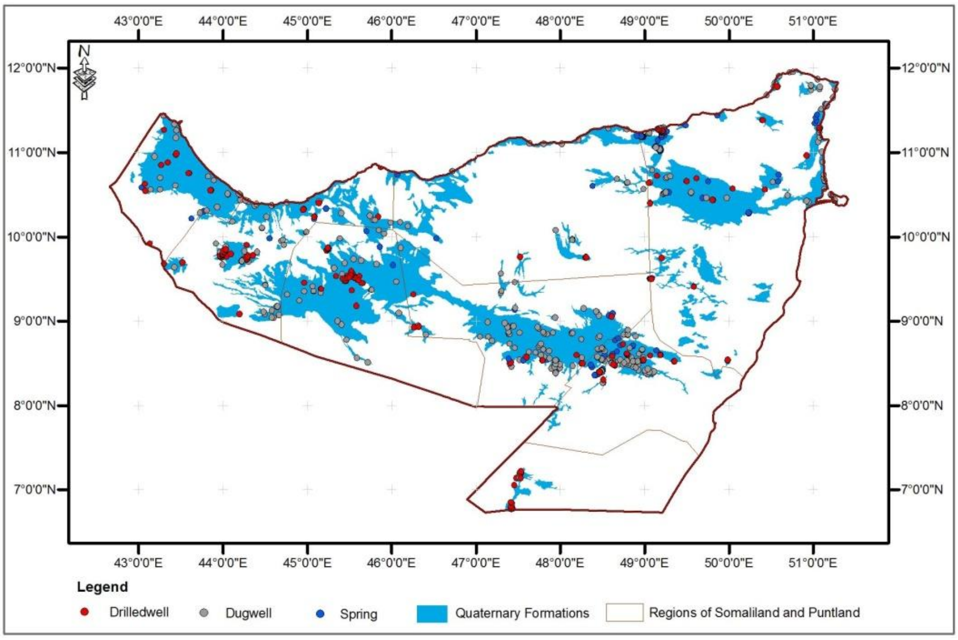


Figure 4.42 Distribution of Quaternary formations with position of examined water points

Figure 4.43 Water tank above the well tapping terrace Quaternary deposits near Jalelo (Hargeysa district, photo Z.Stevanovic)

4.3.3 Groundwater recharge and flow

4.3.3.1 Groundwater recharge

The main recharge of the aquifers of Somaliland and Puntland comes from rainfall as well as infiltrated runoff water after the rainy periods. Rain in the region often comes during thunderstorms, lasting a short time, but providing a relatively good amount of water for aquifer recharge.

The effective infiltration capacity of the **karstic aquifers** is highly variable, depending on lithology, local fissuration degree and actual saturation of the aquifer. The assessment of the infiltration rate relies also on the outcrops of highly fractured and karstified rocks, lack of vegetation and a poorly developed hydrography. During long dry months with little rain evaporation is very high and infiltration is significantly reduced, while during the wet season, especially in April and May, the decreased evaporation rate and intensive rainfall contribute to the recharge of the aquifer.

The presence of a massive rock structure, fissures, joints and cavities are the major factors contributing to aquifer recharge. Topography might be a significant element controlling infiltration rate, but depressions and sinkholes that are considered favorable factors are not widely present at the outcropping surface of the karstic aquifer. However, the above-mentioned package of characteristics and factors should, in principle, guarantee the good recharge potential of the karstic aquifers.

On average, the effective infiltration capacity of the Jurassic limestones (Jc) has been estimated at generally over 30 percent and in some parts even up to 50 percent of total rainfall. Similar infiltration rates also characterize Eocene Auradu aquifer, while the infiltration capacity of the Taleh (Taleex) and Karkar aquifers as well as of the Aptian-Campanian Tisje Fm. could be estimated as regularly less than 30% of the rainfall.

Although no essential differences in karstification rates exist between Jurassic and Eocene karstic aquifers, the extension of the pure limestones outcrops is less for Taleh and Karkar, lowering the absolute value of the aquifer recharge. Thus, the impure sequences of marly and clayed components in the limestone beds directly reduce the absorption capacity of the layers. This also contributes to the secondary filling up of existing fractures.

Of the five hydrogeological systems distinguished in **intergranular aquifer** sand dunes and beach sediments (Qsd) have the highest infiltration rate but more important for groundwater development are alluvial sediments, deposited along toggas and temporary streams (al). Due to the dominant presence of unconsolidated sand and gravel sediments, direct infiltration and percolation of temporary runoff to the alluvial aquifer could be assessed as very high, consuming in certain periods even 60-70% of the rainfall. Unfortunately, the shallow aquifer is also exposed to the higher evaporation from the groundwater table more than other aquifers, such as karstic ones, which reduces its water availability throughout the year.

"The streams flowing towards the Hawd and Sool plateaus and the Nugaal and Dharoor valleys, which generally have a northwest to southeast direction such as the T. Togdheer, carry a large amount of run-off water which is spread out in floodable areas and lost by evaporation and infiltration. In these floodable areas and along the stream beds nomads have dug numerous shallow wells. Many of these wells dry up after prolonged dry seasons but are recharged during the recurrent spate flow events. Shallow groundwater aquifers along the temporary water courses and in the terminal, floodable areas of the internal basin are lens-like and generally have a thickness of a few meters."[14]

The infiltration rate in the Tiger bush pattern and terrace deposits (Qt) can be generally assessed as in the range of 20-40% of the rainfall. Much lower is the infiltration capacity of diluvial-proluvial sediments at the foothills and slopes (d-pr), and especially Quaternary laterites and carbonate crust (Qc). Their role is important in transferring runoff water towards the toggas and in this way contributing to their recharge.

Other aquifers are characterized by even smaller infiltration rates. Somehow the exception is Pleistocene basaltic rocks. Primary recharge zones occur where vertical fractures exist, resulting from the cooling of the basalt flows. Although the basaltic fissure aquifers themselves have no great potential, the water percolates downward and recharges underlying or interfingered older terraces and other Quaternary layers.

There are many small natural or artificial depressions (berkad, war) on the broad plains where rainwater remains for some time and slowly infiltrates and/or evaporates over time. After heavy rains, many small- or medium-sized swamps can be seen dispersed throughout the Sool and Hawd plateaus.

[14] cited from Faillace & Faillace (1986), p.29

Figure 4.44 Regularly very dry carbonate crust and red soil become flood plain after heavy rains. Runoff water is then slowly flowing toward togga beds (Jalelo-Hargeysa, Photo Z.Stevanovic)

As a very rough assessment, not more than 5-10% of the rainfall could be infiltrated into other poor aquifers and aquicludes present in the study area. However limited, this recharge can contribute to the refreshment of some locally utilized sources in remote areas.

Faillace & Faillace (1986) concluded that "recharge occurs under special conditions and only if the rainfall regime is favorable. In areas with scarce and uneven rainfall infiltration may occur only along stream beds and floodable depressions. Short duration thunderstorms covering small areas usually occur in the northern regions and generate spate flows in toggas lasting from a couple of hours to a couple of days. Erosion is very active and flood waters contain large amounts of suspended sediments. In these areas infiltration occurs mainly in the sandy alluvial deposits of the stream beds and in the underlying rocks, if they are permeable. Rains of short duration generally do not generate recharge due to the high temperature and hot dry winds which accentuate the evaporation, estimated between 2,000 and 3,000 mm/year.

Recharge occurs mainly during April and May, when medium to heavy showers account for 40-60% of the annual rainfall. From the mountainous area, which enjoys a relatively high rainfall, run-off water reaches the coastal plain and infiltrates into the large alluvial fans formed by the numerous toggas in the upper part of the sloping plain."[15]

[15] cited from Faillace & Faillace (1986), p.29

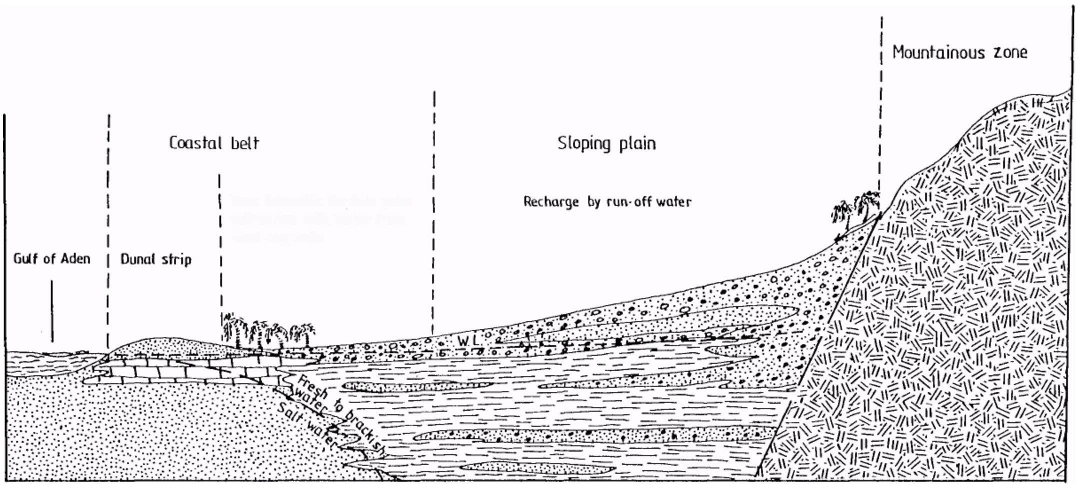


Figure 4.45 Typical cross-section through coastal zone. The runoff water from the hilly area is flowing downward and infiltrates in porous sloping plains and beach dunes and in this way slowing negative impact of sea water intrusion (after Faillace & Faillace, 1986)

4.3.3.2 Groundwater flow directions and drainage

Groundwater flow direction is a result of many regional and local factors: position of erosional base, dipping of the layers, orientation of the fold axis and major faults and fissures, and many others.

Available reports and documentation do not contain information on any kind of tracing tests performed in the area, either in the sinkholes located in fissured-karstic aquifer, or in the wells drilled in the intergranular aquifer. The direction of groundwater flow within the intergranular aquifers could be reconstructed only by defining the groundwater table position (recorded elevation of GWL at the observation boreholes). This data is available for only a few narrow zones, mostly around water sources for larger settlements as in the case of Hargeysa (Geed Deeble) or Borama (Dhamuuq well field).

Groundwater flow-paths are oriented mainly in two directions: from south to north (or west to east) to the coasts of the Gulf of Aden and the Indian Ocean respectively as the main erosional bases, or to the centre of major closed or semi-opened depressions such as the Nugaal or Dharoor valleys.

The groundwater flows often follow the general trend of strata inclination. The position of the anticline limbs or regional and local faults might be a local determinant in controlling flow orientation.

The intergranular aquifers are characterized by seepage flows, which generally follow the hydrographic network and position of the main toggas. Therefore, T. Biji, T. Waheen, T. Togdheer, T. Nugaal and many others represent the bases of erosion and have a key role in controlling groundwater circulation. Locally, groundwater streamlines follow the smaller toggas or wadis orientation.

"The hydrogeological divide coincides to a certain extent with the hydrological divide. Movement of groundwater from the mountain area towards the Hawd and Sool plateaus occurs mainly in the Auradu limestones and in the Taleex Formation. Since these formations are interlaid with clay and marls, water-bearing layers may be under semi-confined conditions. Groundwater movement follows the general dip of the formations which are karstified to different degrees and at different depths.

Perched shallow water from karstified gypsum is generally under phreatic conditions. The alluvial areas along the major toggas, like T. Togdheer, have a permanent underground flow. They are recharged by spate flows. Groundwater movement in these areas, as well as along the togga channels, is related to the occurrence of these spate flows."[16]

In the case of the main karstic and intergranular aquifers, only the main groundwater flow directions are inferred and presented on the Regional hydrogeological map (Annex I).

Three kinds of drainage characterize aquifers in Somaliland and Puntland:

1. drainage through springs;
2. subsurface drainage;
3. artificial drainage by pumping from wells.

The first type is present in all distinguished aquifer systems but to a much lesser extent in intergranular than in karstic or fissure ones.

There are numerous springs spread throughout the entire study area. During the earlier phase of the SWALIM programme (SWIMS) 287 springs were registered in the database, unfortunately without information on their discharges. During the current stage of SWALIM an additional 61 springs have been visited, surveyed and included in the GIS data base. This number of 61 springs represents less than 10% of all surveyed water points which somehow reflects the fact that dug and drilled wells are much more present in the field and that groundwater is usually inaccessible from the surface without artificial intakes. This is of particular concern for flat areas and slightly undulated plains (Hawd and Sool plateaus, Nugaal valley). The majority of springs are located along the contacts of aquifer and impermeable rocks, or along the

[16] cited from Faillace & Faillace (1986), p.31

contact of permeable sequences such as limestoness and less permeable layers such as marl, clay, but within the same aquifer system (Annex I). There are some springs in the Taleh Fm. issuing from the contact between permeable gypsiferous layers and marls.

A large majority of the springs are of the gravity type, so just a very few artesian springs from confined aquifers are recorded. Examples of the latter are hot springs near Berbera (Isha Bug Sugule, Isha Bug Kulule, Biyoguure, Dubar, etc.). Some estimates count about 40 thermal springs in Somaliland and Puntland. Some of these, and fresh water springs as well, are predisposed by regional or local faults and fractures and follow their orientation.

Figure 4.46 Small discharging spring issued from interbedded Karkar limestones (Buuhoodle area, Photo Puntland team 2)

The discharge of the springs depends primarily on the size of their catchment area. However, a discharge larger than 10 l/s is the exception rather than the rule, while just a very few yielding over 50 l/s have been found in the field. The majority of springs are recorded near Baki (Awdal region) issuing from Jurassic limestoness, then between Ceerigabo and Ceel Afweyn and SW from Garoowe (in both cases from Taleh and Karkar Fm.).

Figure 4.47 Hayasee spring from Taleh Fm. in Ceel Afweyne area, predisposed by the fault which also cut a narrow and steep valley (Photo Somaliland team 2)

Faillace & Faillace (1986) reported discharges of several springs issuing from different formations and aquifer systems. The largest spring drain Basement Proterozoic complex (granitic rocks) is Lafamordi (6.8 l/s; note: no precise data from the period of the year when discharge is measured). The Dhamuuq spring as the largest drain of Jurassic limestones was for a long time the single source supplying drinking water to Borama (see Chapter 5.1.1.2. for detailed explanation and cross-section). Nadho and Bixunduule springs also issue from Jurassic limestones and discharge from 5-10 l/s on average.

The largest springs draining Auradu Fm. are spread all around outcrops of this karstic aquifer, from Boosaaso at the coast to the Ethiopian border in the south. Faillace & Faillace (1986) described several of them: Isha Ufeyn 6.8-8.3 l/s; Isha Ufeyn Sare 30 l/s after Popov (1973); Gaha spring 10 l/s; Galgalo spring 8.3 l/s; Karin spring 8-10 l/s, all three located 35-40 km S of Boosaaso; Midhisho spring 20.5 l/s.

The area of Taleex and Xalin is one of the major discharge zones of Taleh gypsiferous formation. The water of Isha C. Ileed, Dayaxa, and Gob (near Ceerigabo) springs were previously used for irrigation.

A well known group of springs is located at the edge of Dharoor Valley near Iskushuban. The first group is in Togga Dhut 3-7 l/s and is used for the town’s water supply. The second group discharges 1-5 l/s in total (Faillace & Faillace, 1986).

In the case of karst following rainfall peaks, drainage through the system of developed channels often results in a highly variable discharge, but decreases at an almost constant rate during recession periods (summer/autumn). The regime of spring discharges from fissured and intergranular types of aquifer is characterized by smaller values, but a more stable flow.

The second drainage way includes subsurface outflow, either through togga beds to the downstream parts or by natural or artificial structures which enable an access point to the groundwater. Such structures thus represent natural or artificial outlets of the aquifer. Groundwater is tapped by pumps, by use of buckets, or freely by evaporation, in this way reducing the already limited amount of water. On the plains, there is a large number of water-tapping structures in unconsolidated and semi-consolidated rocks.

Figure 4.48 FAO SWALIM surveyors after visits of one typical ground holes intake in the field

When permeable rocks of certain aquifers are connected, this kind of drainage beneath the surface of the ground is very common. For instance, drainage of karstic aquifer linked with younger sediments of terraces or alluvium at the same time represents a recharging (alimentation) process for recent connected deposits. Direct seepage into the riverbed also belongs to such drainage.

Pumping both shallow and deep wells is an important output of the drainage system included in the groundwater balance equation. SWALIM earlier and current surveys comprise data on more than two thousand shallow (dug) and drilled wells. They are at the same time strategic water points for supplying water to the population and animals, and representative of one of the main output elements in the groundwater budget.

The yield of pumping wells varies greatly. While for shallow wells not many pumps are installed and the water is accessed only to a small extent, either by hand-pumping or by using buckets, most of the drilled wells are utilized by installed submersible pumps. The yield of the latter also depends on aquifer permeability and recovery. Most of the drilled wells (boreholes) are pumped out by capacities in the range of 1-5 l/s but there are many plus or minus variations. In some cases high discharge causes very fast depletion of groundwater and pumping must stop, but in certain cases aquifer could yield much more water if installed pumps or pipe diameters were allowed to increase the well's capacity.

An illustration of the potential of the aquifers is the most productive well in the region described by Faillace & Faillace (1986). It was drilled in Ceerigabo, to the depth of 159 m and was tested by pumping 50 l/s for an obtained drawdown of only 2.43 m. It is drilled in Auradu karstic aquifer. Good productivity is also characterized by the terrace and alluvial sediments of Geed Deeble where pumping on average 15 l/s per well causes a local drawdown not larger than 5-10 m.

Figure 4.49 Dhabardalool shallow well in Ceel Afweyne area. Concrete construction is regularly includes canal for animals watering (Photo Somaliland team 2)

Finally, evapotranspiration is a natural output contributing significantly to the drainage process, especially in a hot and dry environment such as that of Somaliland and Puntland.

4.3.4 Groundwater chemistry

Access to clean water of good quality is a vital issue for the growth of the Somaliland and Puntland population but a big part of the country still has no access to this basic and life-saving commodity. Because understanding the quality of groundwater is the main factor in determining its suitability for drinking, domestic, agricultural and industrial purposes, assessment of the quality of drinking water supplies has always been paramount in the field of environmental quality management. The quality of the groundwater of Somaliland and Puntland has special significance and needs greater attention as it is the only source for domestic consumption.

4.3.4.1 Variability of groundwater quality in the different geological formations

The chemical quality of groundwater depends on the characteristics of the soil and rock media through which it passes to the zone of saturation as well as on the length of time the water is stored in the aquifer. Various researchers have analyzed the hydrochemical characteristics of groundwater and the quality of groundwater in different lithological formations. The quality of groundwater is the function of its physical and chemical parameters which depend upon the lithology and soluble products of weathering, and even from season to season the quality of groundwater varies.

The best way to present variations in water quality in different aquifers and geological formations was to analyse characteristics through main previously described geological formations. The graphical presentation is given on the Regional Groundwater Quality Map of Somaliland and Puntland (Annex II).

The ***Basement Complex***. On the basis of more than 20 analyses of deep wells, springs and dug wells, it can be concluded that the water quality in the Basement Complex is generally good. More than 70% of the analyzed waters have good characteristics according to the WHO standards for drinking water in arid regions. Water from this aquifer has low to moderate mineralization, which is often between 300 µS/cm and 1,400 µS/cm, while the maximum can reach 3,570 µS/cm, as in some shallow wells near Hargeysa. Temperatures are often in the range of 21 to 28^{o}C, but on average are around 25^{o}C. pH is more constant, and neither value shows pH to be less than 7 or higher than 8. According to the analyses, in the few samples taken from shallow wells nitrates are generally slightly increased. High concentration of sulphate was detected in four samples with a range from 1 370 mg/l to 2 500 mg/l, but generally most of the samples have a normal concentration of sulphate. Water with a slightly higher concentration of sodium was found only in a few shallow wells and toggas, but even in these cases concentrations are not higher than 300 mg/l. Other components such as nitrites, ammonium, iron are generally within the normal range according to the WHO.

The ***Nubian sandstone.*** While water quality in the Nubian sandstone is generally good, some analyses from shallow wells from the Hargeysa area reveal sodium limits surpassing the limit acceptable for drinking water, with maximum concentration measured in a deep borehole in Gebiley. Also, water of good quality is generally supplied by dug wells in the weathered part of the Nubian sandstone. After ten chemical analyses it can be concluded that water from Nubian sandstone is predominantly of the sodium chloride type. Some of the known thermal springs (for example, the spring near Berbera) issuing from the Nubian sandstone yield water of the sulphate type SO_4>Cl>HCO_3/Na+K>Ca>Mg. However, according to some previous data from chemical analyses of the same spring done at different times the main anion was chloride, not sulphate. This change may be connected to factors of groundwater flow pattern during the hydrological cycle. The EC values of the thermal water vary from 320 μS/cm to 3,780 μS/cm. Temperatures are often in the range of 23 to 35^{o}C, but on average are around 27^{o}C. pH is more constant, between 7 and 8. The main cation in six of the ten available analyses is sodium, while calcium is dominant in the others.

The ***Jurassic limestones***. Water from this aquifer has a moderate mineralization where the EC does not exceed 2,000 μS/cm and is commonly in the range of 600 μS/cm to 1,200 μS/cm. The bicarbonate type of water prevails. Other components such as sodium, sulphate and chloride are generally slightly higher in some samples but overall the water is of good quality in terms of water supply needs. Only in two wells in the Borama area sulphates found in higher concentration than is allowed. Water from aquifer formed in Jurassic limestones is probably the best quality water in terms of geological formations. Temperatures are often between 24 and 30^{o}C, but on average are around 26^{o}C. pH is constant (7 – 8). Water in all the analyses is of the sodium bicarbonate type, with HCO_3>SO_4>Cl/Na+K>Mg>Ca.

The ***Auradu limestones***. While only 12 analyses were done on samples taken in the area of the Auradu Fm., only the general water quality can be concluded. The main characteristic of water from Auradu limestones is moderate to high mineralization, and is predominantly of the sulphate bicarbonate type. Sulphate is the dominant element in almost all samples with a range up to 3,220 mg/l. One explanation of the high sulphate concentration in some areas of Auradu limestones can be that the recharge area is covered by the Taleh Formation. Water mixtures of those two aquifers usually have water of the calcium sulphate type (SO_4>HCO_3>Cl/Ca>Mg>Na+K). The EC values of the water from Auradu limestones vary from 1034 μS/cm to 5840 μS/cm, with an average temperature of 26^{o}C. A generally higher concentration of sodium in water tapped in the Auradu limestones is connected to a deep borehole, which indicates the circulation type of the groundwater (deep and slow circulation), while waters from springs have faster circulation as well as less sodium. The higher concentration of sodium in those karstic waters is 561 mg/l. High concentrations of nitrates, around 50-60 mg/l, were found in shallow wells.

Large areas covered by the ***Taleh formation*** are in the Sanaag, Sool, and Nugaal regions. Water derives either from the Taleh outcrops or from connected alluvial deposits containing secondary gypsum. Water of the Taleh Formation is in most cases of the calcium sulphate type. Analyses from drilled and dug wells show that the value of the EC is very high, ranging from 890 to 7,270 μS/cm. Evaporites, such as the Taleh formation, are generated during precipitation from an over-saturated brine solution which are usually highly soluble where concentrations rapidly increase, even if the portion of evaporitic material is relatively small. When recharging fresh water comes into contact with a thin layer of anhydrite or gypsum, the EC will rapidly increase (usually beyond the potable limit). Water is often highly sulphatic, with calcium as the predominant cation. Sulphate is in the range 125 mg/l up to 3,100 mg/l, with an average concentration of 1,300 mg/l. Water with an EC less than 1,500 μS/cm is often of the calcium bicarbonate type which derives from often connected underlying aquifer of Auradu limestones, as is the case in the Ceerigaabo area. Temperatures are often in the range of 21 to 30^{o}C, but on average are around 27^{o}C, while pH is in the range from 6 to 9.

The ***Karkar Formation*** covers the majority of the eastern part of the study area (Puntland). The Karkar Fm. is constituted by cherty limestone and marls. Water from wells drilled in the Karkar carbonate rocks is exclusively of the chloride sulphate type; calcium is the main cation in most of the analyses. Springs from the Karkar Fm. generally yield water of the calcium or sodium bicarbonate type. There have been more than 40 analyses made in the area covered by the Karkar Formation. Water is often highly sulphatic, in the range of 212 mg/l to 2,890 mg/l, with an average concentration of 110 mg/l. Water from this aquifer has a high mineralization where the EC often exceeds 5,000 μS/cm and is commonly in the range of 2,000 μS/cm to 4,000 μS/cm. Temperatures are often in the range of 21 to 37^{o}C, but on average are around 27^{o}C; pH is in the range from 7 to 8.

Water from different types of ***Quaternary formations*** is generally of moderate to good quality for drinking. Although water from dug wells and some springs generally has a mineralization in the range of 2,000 to 4,000 μS/cm, other samples from shallow water in the western part have mineralization of less than 1,500 μS/cm. According to new data from the survey, water from deep drilled wells generally has a much higher mineralization as well as concentration of sulphates. From all analyzed samples it can be concluded that the bigger problem of water from re-deposited sediments, red soil, continental carbonate crust and laterites is sulphates and sodium, while the “Tigers” pattern and delluvial-prolluvial sediments have a lower concentration of sulphates in water. In the eastern part of the study area, almost all analyzed water from alluvial deposits has a high concentration of sulphates. For example, water from the area in the Nugaal Valley is predominantly of the sodium bicarbonate type, followed by a high concentration of sulphate. The percentage of the bicarbonate, chloride, and sulphate water types was obtained from the 122 chemical analyses of alluvial aquifers. The concentration of sodium is generally connected to the deeper part of the quaternary formations. From statistical analyses it can be concluded that most of the samples (80 samples) have less than 200 mg/l of sodium and belong to shallow layers, while water tapped with deep boreholes has a higher concentration of sodium up to 2,526 mg/l (68 samples).

Temperatures are often in the range of 19 to 38^oC, but on average are around 27^oC. pH is more constant, and neither value shows a pH less than 7 or higher than 8. According to analyses, nitrates are generally slightly increased in samples taken from shallow wells, while in only 20 % of samples nitrates were higher than 50 mg/l.

The spatial distribution and variations of the physico-chemical characteristics of the groundwater in the different aquifers are presented in Annex II.

A weight index of six basic parameters (EC, pH, SO_4, Na, Cl, NO_3) that characterizes the greater part of the composition of water and their relationship to geology has been introduced to enhance visualization and generalization of the chemical composition data of groundwater in geological terms.

Indexing for variations in groundwater quality in different aquifers was performed through three steps. The first was that on the basis of the chemical analysis of the elements the groundwater quality was determined. The second step was to divide all elements into five groups by weight and classification: ***very good, good, moderate, bad*** and ***very bad*** (Table 4.11). The third step was the addition of elements of difficulty and to obtain the weight of a common carrier that has been through a number of subsequent procedures adapted that most closely reflect the general water quality. Good quality water is in the maximum range to 11, the moderate ranges from 11 to 17, and everything of separate weights that is greater than the sum of 17 is in the bad/very bad quality range.

Certainly, this division cannot represent a detailed classification of water quality in relation to geological formations, particularly when one bears in mind the parameters used as input and the data from deep boreholes and from shallow wells and springs.

Table 4.11 Indexing for variations of groundwater quality

EC µS/cm	pH	Weight INDEX (case)
< 700 Very good	6.5 - 7.5 Very good	1 (best)
700-1200 Good	6 - 6.5 and 7.5 - 8 Good	2
1200-2000 Moderate	5.5 - 6 and 8 - 8.5 Moderate	3
2000-3000 Bad	4.5 - 5.5 and 8.5 - 9.5 Bad	4
>3000 Very bad	< 4.5 and > 9.5 Very bad	5 (worst)
SO_4 (mg/l)	Na (mg/l)	
< 250 Very good	< 50 Very good	1 (best)
250-300 Good	50-80 Good	2
300-500 Moderate	80-150 Moderate	3
500-1000 Bad	150-300 Bad	4
>1000 Very bad	>300 Very bad	5 (worst)
Cl (mg/l)	NO_3 (mg/l)	
< 250 Very good	< 50 Very good	1 (best)
250-300 Good	50-60 Good	2
300-500 Moderate	60-80 Moderate	3
500-1000 Bad	80-100 Bad	4
>1000 Very bad	>100 Very bad	5 (worst)

The water quality index can help as a tool to communicate information on the overall quality status of water to the concerned user community and policy makers. Thus, it becomes a viable parameter for the assessment of groundwater. The purpose of this exercise is to estimate the groundwater quality in Somaliland and Puntland and visually present spatial groundwater quality distributions by using the Geographic Information System (GIS). The water quality variations and weight indexes of some of major geological units are presented in Figure 4.50 – 4.53.

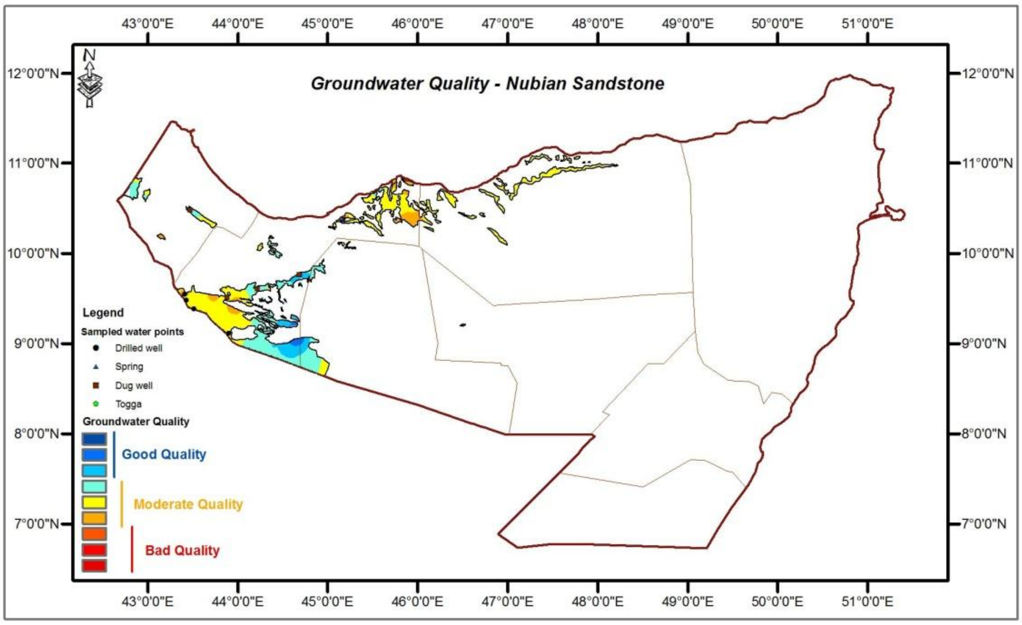


Figure 4.50 Spatial distribution of groundwater quality in aquifer formed in Nubian Sandstone

The ***quality of the groundwater varies by region*** and depends mainly on the underlying rock formations and their thickness. For instance, the EC for the Bari region varies between approximately 1,139 and 4,000 µS/cm with pH ranges of 7.4 – 7.8. In the Sanaag, Nugaal, Sool and Mudug regions, the EC varies between approximately 2,100 and 5,500 µS/cm with a pH in the range of 7.6 – 8.0. In the Awdal, Galbeedand and Togdheer regions, the EC ranges between 417 to approximately 4,000 µS/cm with a pH in the range of 7.0 – 7.6. Therefore, water quality in most parts of the study area is often below requirements for good quality water according the international standard (WHO guideline).

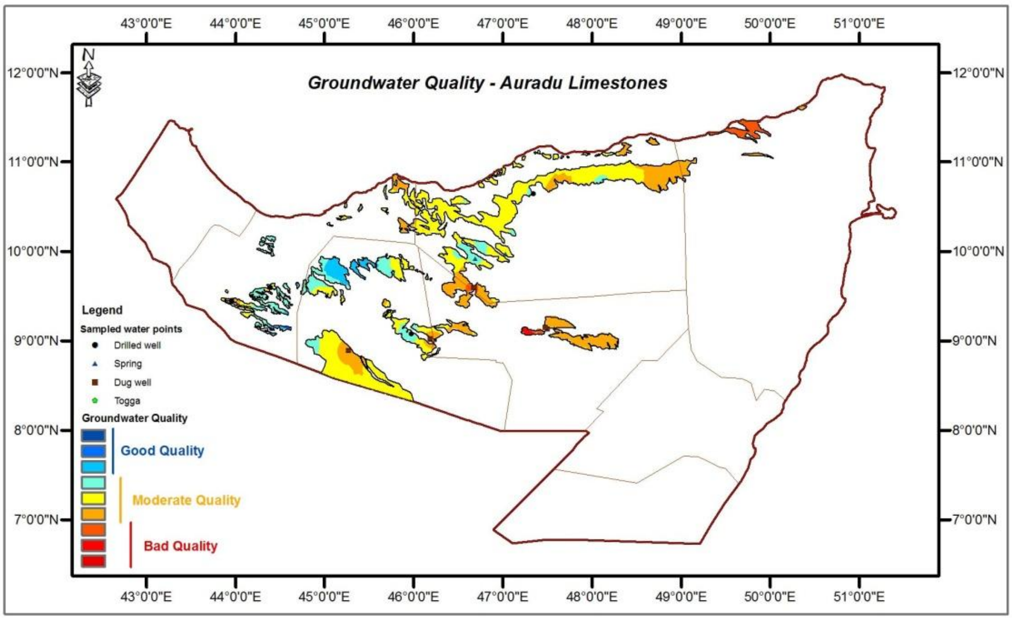


Figure 4.51 Spatial distribution of groundwater quality in aquifer formed in Auradu limestones

Deep aquifer layers are found within the Karkar, Taleh and Auradu formations. In the majority of the boreholes drilled within these formations, the salinity levels often go beyond the potable drinking standards. Nonetheless, in arid lands like Somaliland and Puntland, where water is scarce, it is difficult to establish water quality standards and thus define areas where water can be used for different purposes.

In the study area, characteristics of groundwater originating from the Taleh Formation or Oligocene-Miocene sediments generally are consistently more mineralised than waters from any other aquifers. Waters from deeper boreholes are generally more likely to be excessively mineralised, though not always, and the units that produce the least mineralised groundwater are the Jurassic sediments.

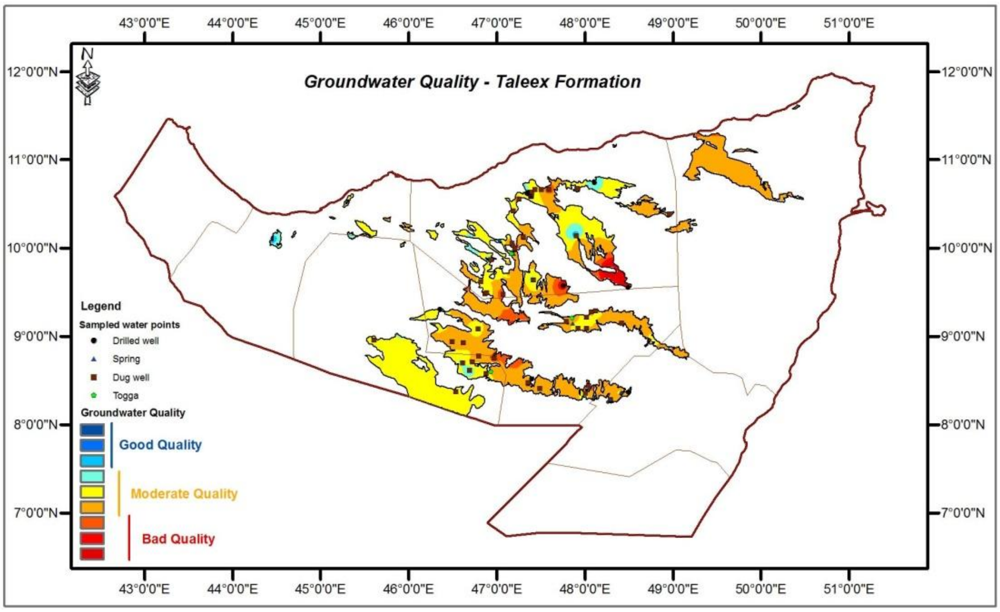


Figure 4.52 Spatial distribution of groundwater quality in aquifer formed in Taleh (Taleex) Formation

Other minor water quality problems include elevated hardness from dissolution of limestone and elevated iron concentrations in waters flowing through crystalline rocks.

In general, the less a water supply is subject to evaporation and the faster it flows from the area of recharge to the area of discharge or withdrawal, the better the quality will be.

Water quality is rather uniform in areas where the Taleh Formation outcrops. Average salinity values range from 2 to 3 gr/l in a well drilled through the Taleh Formation in the Sanaag region (EC values ranging from 2,550 to 3,250 μS/cm). Water with an EC of 2,850 to 5,750 μS/cm is encountered in the Sool, Bari and Nugaal regions.

In the central part of the Sool plateau, water is also of marginal quality but suitable for livestock watering. There are prospects, however, of finding good quality water in the Auradu limestone along the northern edge of the Sool - Hawd plateau where the water is of very good and good quality.

In spite of low rainfall in the Sool, and Sool & Hawd plateaus the deep water table levels, the semi-confined aquifers between thick marls and clay layers have relatively low mineralization. High mineralization is usually associated with the fossil nature of water trapped between marls and other impervious layers.

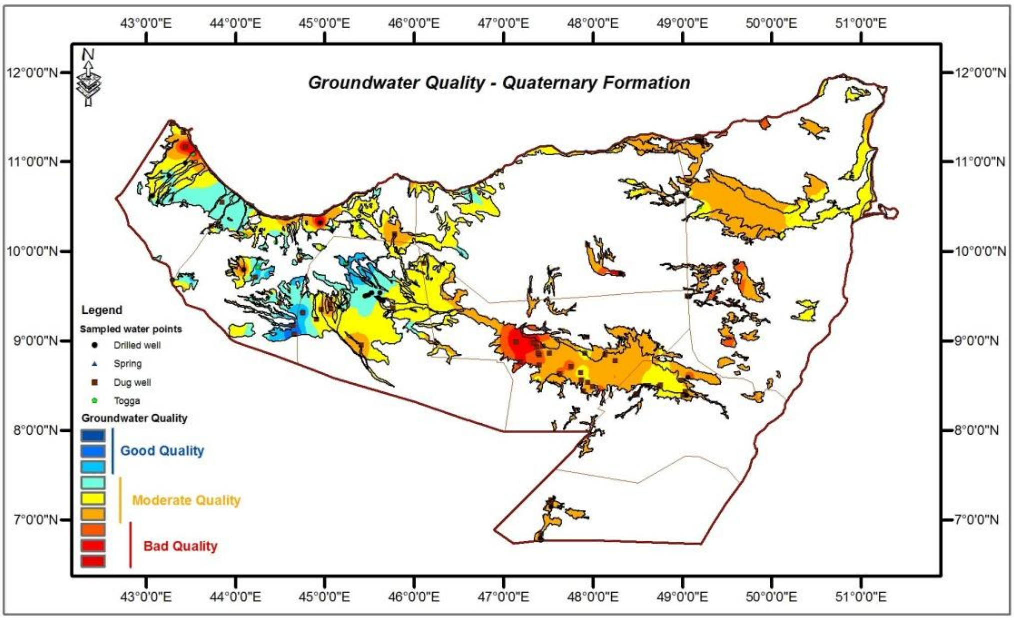


Figure 4.53 Spatial distribution of groundwater quality in aquifer formed in Quaternary formations

4.3.4.2. Groundwater suitability for different purposes

Chemical analyses of groundwater in hydrogeology are commonly used to provide information concerning the quality of water and its suitability for different purposes. The water quality may yield information about the geological formations through which the water has circulated. Following the hydro-geochemical assessment, the main objective is to determine groundwater suitability for different uses based on different chemical indices. The suitability for drinking and domestic consumption was assessed by comparing the chemical parameters of groundwater in the study area with the prescribed specifications of the World Health Organization (WHO). The most important purpose of water quality evaluation, after suitability for human consumption, is its suitability for agricultural purposes. The suitability of groundwater for irrigation is contingent on the effects on the mineral constituents of the water on both the plant and the soil.

The four main targets for groundwater are:

1. Public water use (water supply systems)
2. Domestic water use
3. Irrigation water use
4. Stock farming water use

Generally, public water use and domestic water use can be put under the same umbrella of groundwater consumption of potable water. A main characteristic of water analyses through mining of human use is that pH values of the groundwater of an investigated area vary mostly between 7 and 8, indicating a slightly alkaline to an alkaline nature of the groundwater. According to the WHO, the range of desirable pH values of water prescribed for drinking purposes is 6.5 – 9.2 (WHO, 2004). There are only a few water samples with pH values outside of the desirable ranges.

Electrical conductivity is an indication of the concentration of total dissolved solids and major ions in a given body of water. Electrical conductivity in groundwater as shown in the text above varies from 300 to over 10,000 μS/cm; the permissible limit for domestic use is <1,500 μS/cm. The EC values in the majority of samples are higher than the permissible limit. Conductivity values are divided into the three groups. The division based on conductivity values suggests that only 30% of the samples are below the safe limit of 1,500 μS/cm while 29 % of the samples are in the range of 1,500-3,000 μS/cm and 41 % of the samples are above 3,000 μS/cm range.

Calcium is naturally present in water and is a determinant of water hardness. Calcium content in the groundwater varies from 21 to 1,080 mg/l. Most of the samples (61%) were within the maximum permissible limit (200 mg/l).

Magnesium has many different purposes and may end up in water in many different ways. Generally in Somaliland and Puntland the values of magnesium range from 5 to 554 mg/l, where 41% of the samples are above the maximum permissible limit.

Chloride originates from sodium chloride which gets dissolved in water from rocks and soil. It is a good indicator of groundwater quality. The chloride content in the study area has shown a variation from 5 to 2,180 mg/l. 43 % of the samples go beyond the maximum permissible limit.

Sodium is probably the most problematic element in the areas investigated in the central, south and east. The sodium content in the study area has shown a variation from 1.9 to 2,530 mg/l. 43% of samples exceeded the maximum permissible limit of 200 mg/l. For this reason special attention must be given to the problem of sodium in waters for drinking and irrigation.

An essential element for humans, plants and animals is potassium. It arrives in the food chain mainly from vegetation and soil. The main sources of potassium in groundwater include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. According to data from analyses, 42 % of the samples exceed the maximum permissible limit while 58% of the samples from the study area fall within the guideline level of 12 mg/l. This is due to the fact that potassium minerals offer resistance to weathering and dissolution. In the present investigation the groundwater samples from different parts of the study area revealed that there is a marked variation in groundwater quality.

Groundwater is also the main source of irrigation in the entire study area. A solution to the problem of adequate water for irrigation is essential for the proper growth of plants but the quality of water used for irrigation purposes should also be well within the permissible limits otherwise it could adversely affect plant growth. The main problem in almost the entire investigated area is that continuous use of poor quality water may lead to saline soil, particularly in shallow aquifer in central and southern parts of the area.

In conclusion, the analytical results show a higher concentration of different elements in the groundwater which indicates signs of low to moderate quality. On the other hand, around 40 - 50% of the groundwater sample is suitable for drinking and irrigation purposes and they must be a guideline for further groundwater investigations for different purposes.

Figure 4.54 One of the shallow wells dug under humanitarian programmes in Somalliland to be used for humans but also for animals watering

4.4 Groundwater monitoring network

Initial data download and interpretation from 6 sites

Diver readings on temperature and pressure taken for a period of two months at six locations were downloaded and analysed. The six locations are Hargeysa, Borama, Berbera, Garoowe, Boosaaso and Galkacyo.However, due to the short period of observations it was not possible at this stage to comment on the character of groundwater regime. The exercise was used to confirm that established network is operational, and is expected to be expanded and operate beyond this project phase.

From the downloaded data, all divers gave good results apart from Borama where the readings appeared to be erroneous due to suspected cable cut, which has since been replaced. Graphs from the downloaded data from the six stations are presented below as examples of how the system operates.

Hargeysa (Geed Deeble)

The data download at Geed Deeble took place on 27th June 2012. The downloaded data (Figure 4.55) show a gradual increase in the water level from time of installation (44.6 m) by about 2 m at the end of May. The level then started decreasing gradually. The level during time of download was 46.45 meters. The rise in water level up to end of May can be attributed to recharge from the Gu rains, which subsidized beginning of June. Temperature increased by 0.1°C during the measurement period.

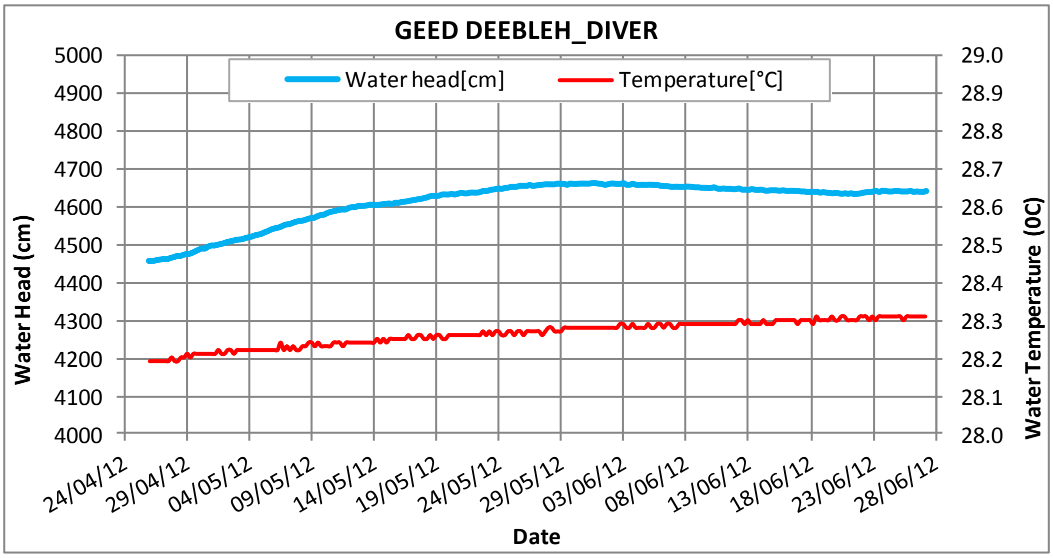


Figure 4.55 Data download at Geed Deeble (water level, temperature)

Borama

In Borama the data download was done on 28th June 2012. The graph on Figure 4.56 shows the downloaded data, after atmospheric pressure compensation. As it can be seen from the graph, the water level above the diver dropped from 10.6 m to zero between 23rd to 24th April. The level then remained at zero until the end of May, when it started oscillating between zero and -3 m. From the results it is clear that the diver is reading atmospheric pressure, hence not submerged in water, when the diver mistakenly dropped to the bottom of the borehole. After recovering, the staff re-installed the diver and lost only probably more than 7 m of the cable.

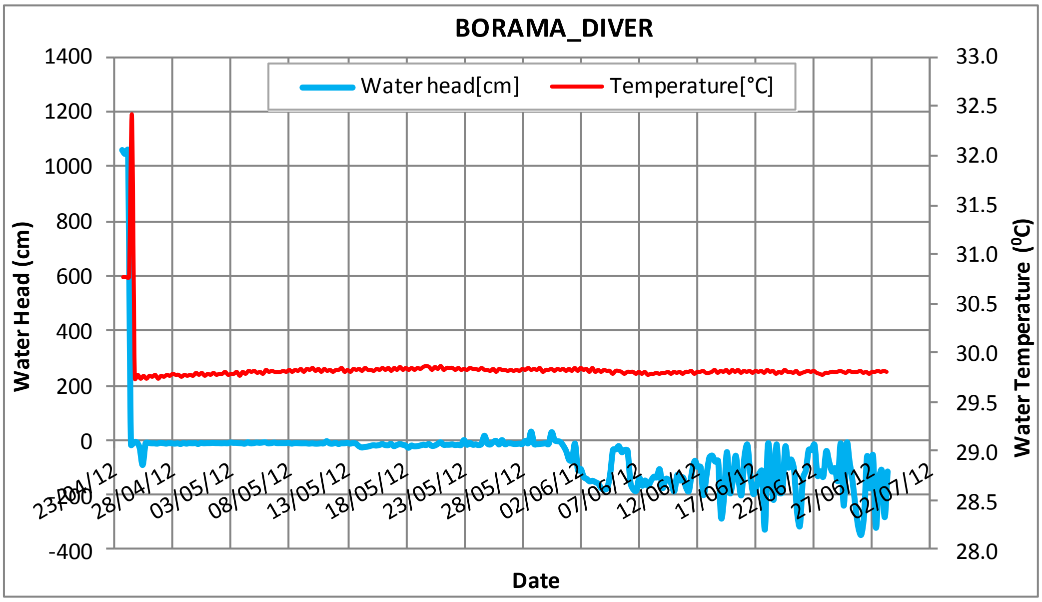


Figure 4.56 Data download at Borama well (water level, temperature)

Berbera

Data download for Berbera was done on 30thJune. The downloaded data was later compensated with data from the baro diver, and the resulting graph presented in Figure 4.57. The water level changed gradually over the first one and half months after installation, with a drop of 75 cm over 45 days. The drop rate however started increasing from mid June, and by 29th June the water level had dropped by additional 1.2 m within 15 days. Between 29 th and 30th there was a big oscillation of the water level, which could not be explained since the operator informed that the operation of the boreholes remained the same as before. The diver would be additionally checked out.

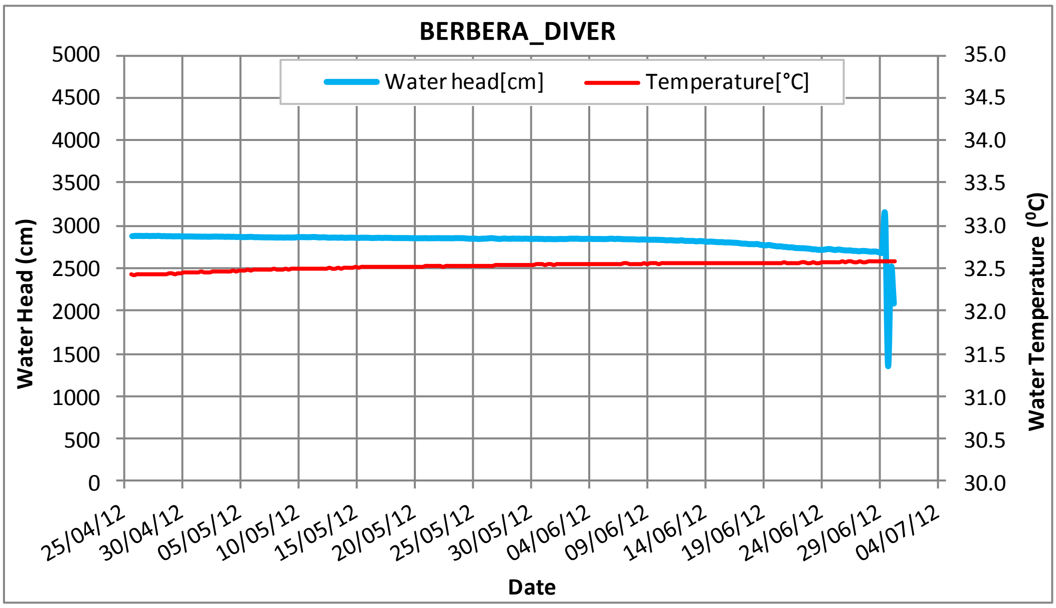


Figure 4.57 Data download at Berbera well (water level, temperature)

Garoowe

Diver data in Garoowe was downloaded on 4thJuly 2012. Unlike the Somaliland graphs which were relatively smooth, there are daily oscillations of water level in this borehole; an indication that it is slightly affected directly by water pumping in the nearest well located about 300 m away. There is a gradual decline in water level in the borehole to a magnitude of 1.2 m in the 38 days of data recording. Temperature in the borehole steadily increased from 32.12°C to 32.95°C (0.83°C increment) over the same period. Data from the Garoowe diver is presented in Figure 4.58.

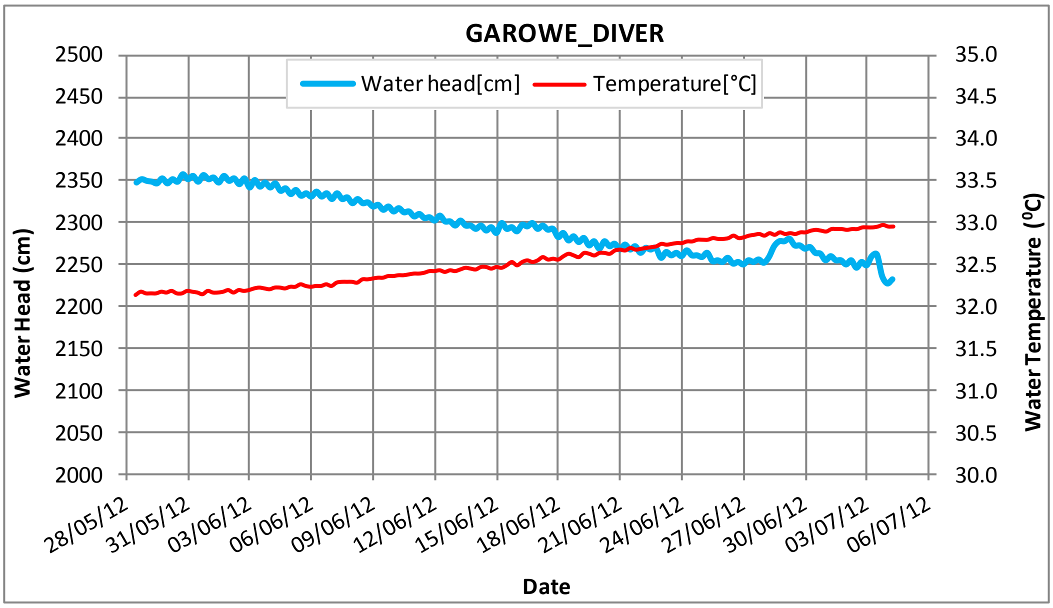


Figure 4.58 Data download at Garoowe well (water level, temperature)

Boosaaso

In Boosaaso the diver data download took place on 7th July 2012. The borehole where the diver is installed is 50 m away from a pumping well, and is affected by the pumping as seen in the daily fluctuations in water level. The water level has gradually increased for the period of data recording, with an overall increase of about 40 cm. Temperature in the borehole has also slightly increased, by 0.11°C over the 36 day period as shown in Figure 4.59.

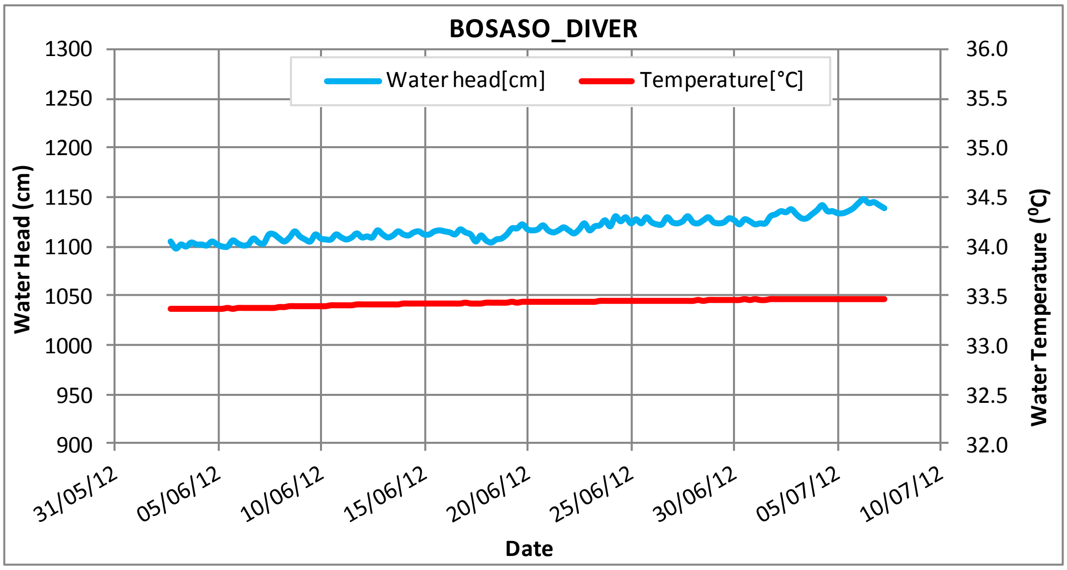


Figure 4.59 Data download at Boosaaso well (water level, temperature)

Galkacyo

Galkacyo data was downloaded on 9th July 2012. Generally the water level remained fairly stable from the date of installation until 24th June. The rate of drop is high, with a total of 4.8 m lost in 16 days. The water agency is reported to have explained this sudden drop to increased daily pumping time. Temperature variation is minimal, 0.1°C increase in over 45 days.

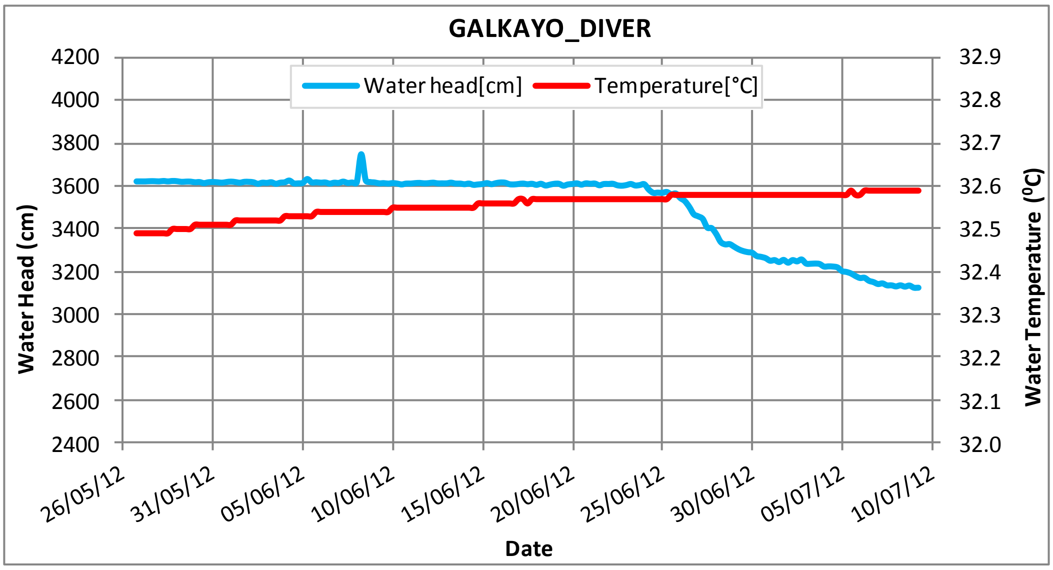


Figure 4.60 Data download at Galkacyo well (water level, temperature)

Baro divers in Hargeysa and Garoowe

A baro diver is used to compensate the atmospheric pressure for the regular divers. Two baro divers were installed in Hargeysa and Garoowe to compensate for the regular divers in Somaliland and Puntland respectively. Data downloaded from the two baro divers is presented in Figures 4.61 and 4.62.

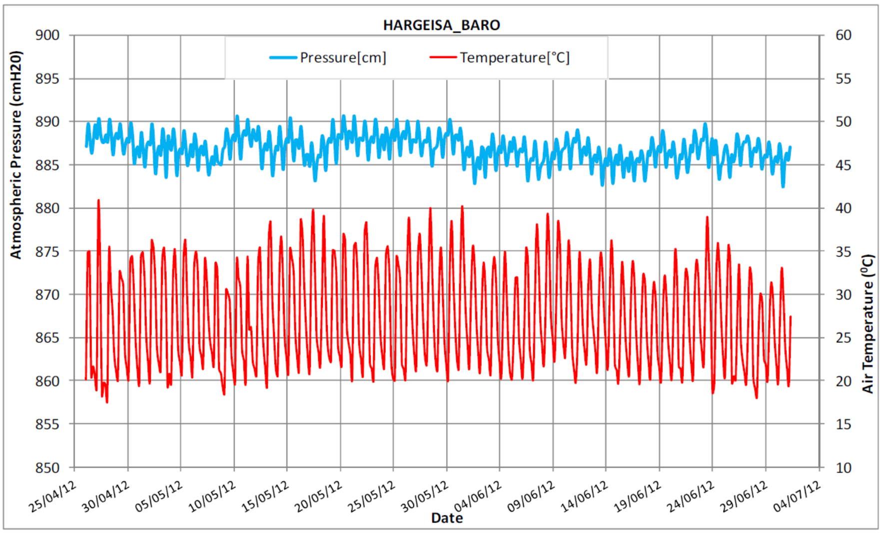


Figure 4.61 Data download from baro diver in Hargeysa

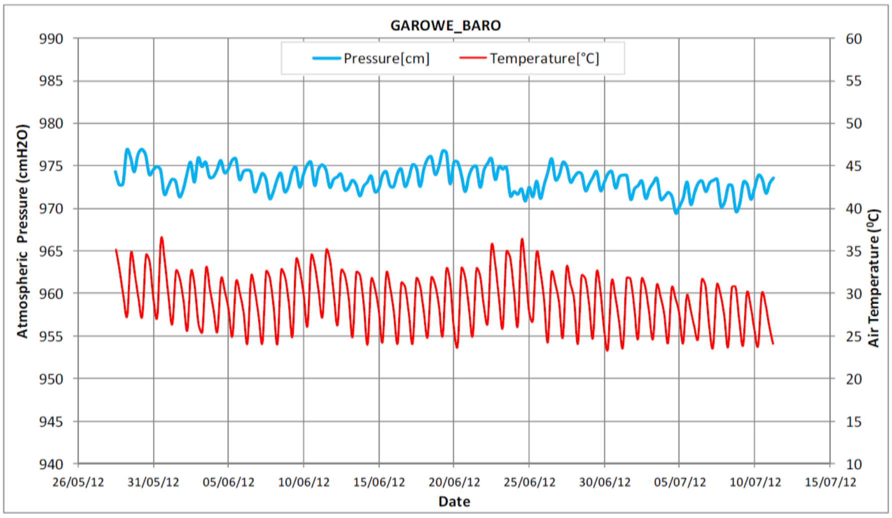


Figure 4.62 Data download from baro diver in Garoowe

The main conclusions on work of newly established Groundwater Monitoring Network (GWMN) in Somaliland and Puntland are:

- Five of the six regular divers and two baro divers were found to functioning properly. The diver located in Borama was found to have erroneous data, which was believed to be as a result of the diver not being submerged in water due to previous cutting of cable. The cable needs to be replaced with a longer one.
- Two divers, one in Geed Deeble and one in Boosaaso had changed their color on one side (Figure 4.63 a,b). The diver in Geed Deeble become redish, while that of Boosaaso is blackish. The cause for these changes is under evaluation and further inspection. All other divers are in a good condition as when they were installed.

Figure 4.63 a,b Geed Deeble and Boosaaso defaced Divers

Recommendation for Future Groundwater Monitoring of Somaliland and Puntland

To enable proper operation and sustainable water utilization of the utilities in Somaliland and in Puntland, managers need to know if groundwater level is falling, steady or rising, and even more important, what is the quality of tapped water. This information is only possible by measuring depth to groundwater level and water quality over time. Collection of data from monitoring network is the only way to get reliable information.

The future completed Groundwater Monitoring Network of Somaliland and Puntland must provide the information necessary to assess groundwater quantitative status, chemical status and significant, long-term trends in natural conditions and trends in groundwater resulting from human activity.

For a whole territory of Somaliland and Puntland according to current assessment and collected and evaluated data on hydrogeology and hydrochemistry it would be is necessary to establish about 100-130 monitoring water points in Somaliland and similar number in Puntland. The total projected number of about 250 monitoring points, is still providing lesser average density than 1 object per each 1,000 km^2):

- About 30-40% of monitoring points should be monitored by divers while for the other objects simple mechanical water level meter can be used (man monitoring).
- In case of sparsely populated area for every 500-1,000 km^2, at least one monitoring water point should be included in GW Quality Monitoring Network. In case of urban settlements or presence of more vulnerable aquifers and potential pollutants, more observation points would be required.
- Recommended monitoring interval for ground water level recording should be the daily basis, while for water quality tests at least a monthly basis.

Chapter 5: Groundwater Management

5.1 Groundwater development and sustainable use

5.1.1 Groundwater utilization and demands

This chapter gives an outline of the current status of the groundwater utilization and the prospect for their further development on a regional scale. The analyses also includes examination of the local groundwater conditions at the visited sites and settlements based on information (often incomplete) obtained from the surveyors during exercises in 2011/12 and analysis, evaluation and interpretation of the available data from the previous SWIMS data base. An important part of this work is the inquiry into the major water utilities located in Somaliland and Puntland conducted by the SWALIM staff in April/May 2012.

The analyses includes two levels described in the two following sub-chapters: 1. Groundwater utilization in the regions (including pure rural and sparsely populated areas) (chapter 5.1.1.1); and 2. Groundwater utilization and demands of major settlements as principle water consumers (5.1.1.2).

5.1.1.1 Groundwater utilization and demands in the regions

Primary data collected in the field and secondary data acquired from different sources were integrated. All information about geological, hydrogeological and geophysical inventory gathered both in the field as well as from different sources has been used to evaluate water situation in the study area. Main input to this evaluation is information regarding the conditions of the existing water supply sources, such as drilled wells, dug wells, springs and toggas.

Drilled wells are the permanent source of water for almost all the populated places in Somaliland and Puntland. These are usually machine-drilled and lined with steel casings. They are located mainly in major trading centers and towns. The depth of boreholes varies from 20 up to 400 m (Figure 5.1), their yield is in the range of 0.5 - 17 l/s (Figure 5.2) while static water level (SWL) is in range from 2-270 m (Figure 5.3).

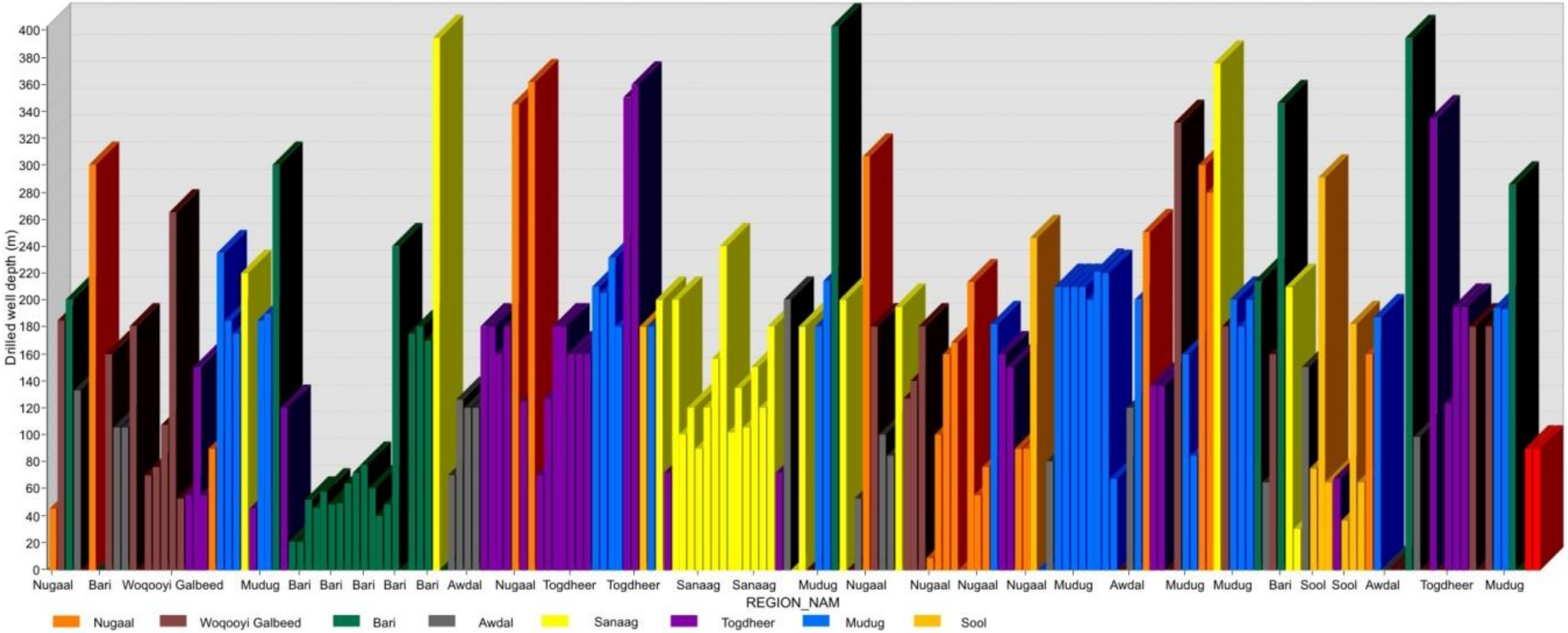


Figure 5.1 Graph of drilled well's depth in different regions of Somaliland and Puntland

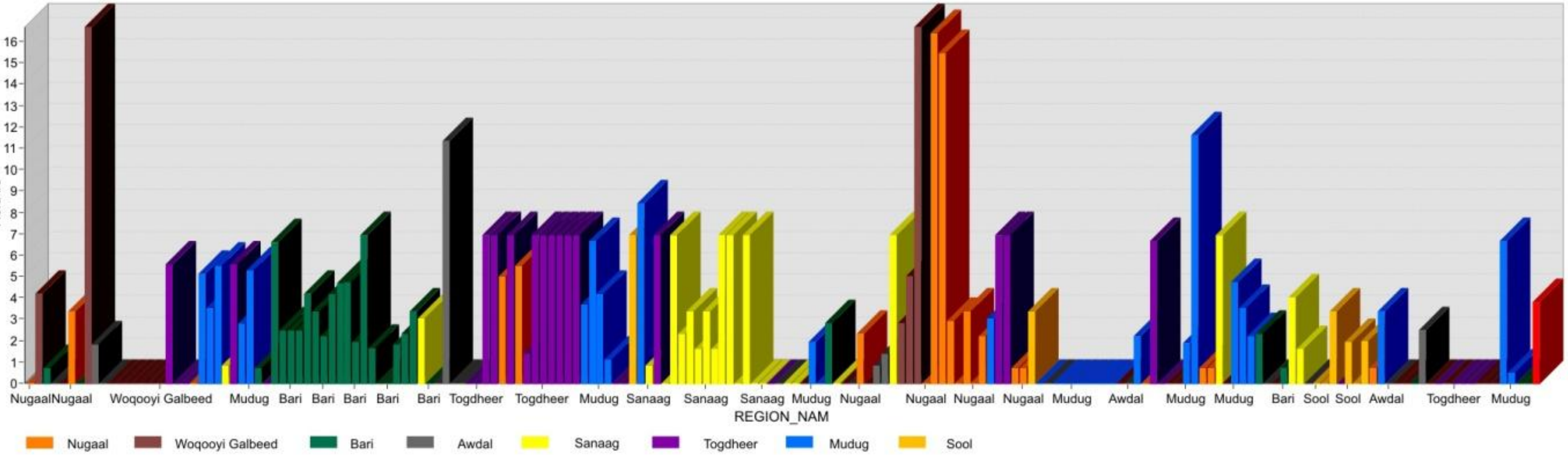


Figure 5.2 Graph of yields obtained from drilled wells in different regions of Somaliland and Puntland

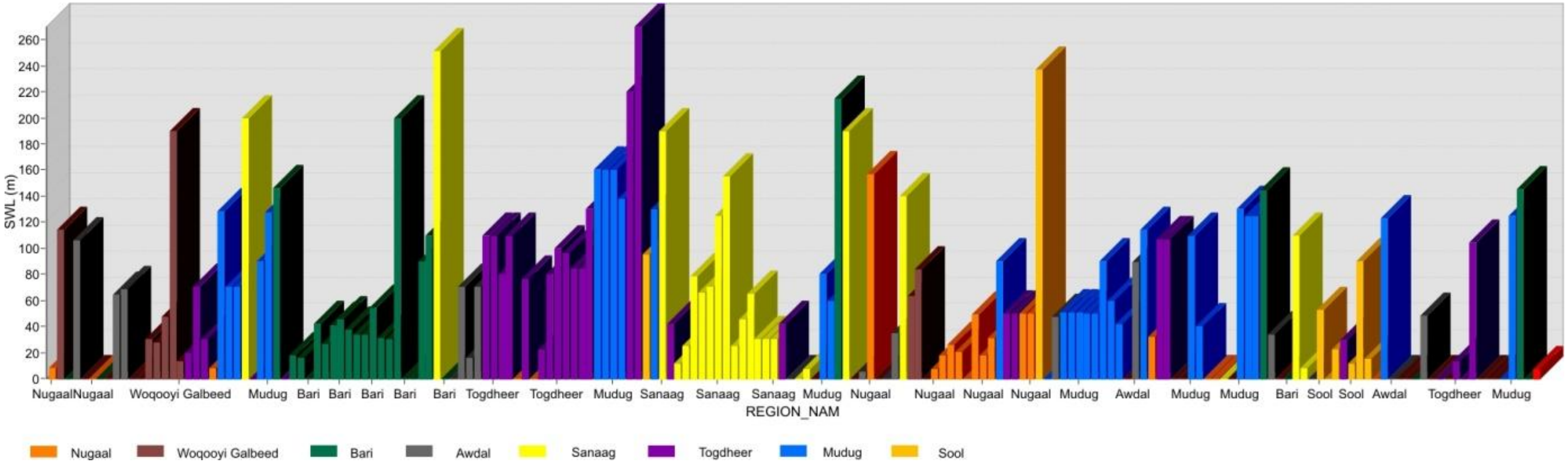


Figure 5.3 Graph of static water table (SWL) in drilled wells in different regions of Somaliland and Puntland

AWDAL

Springs

In total, there are 52 registered springs in the Awdal Region. Most of the springs belong to karstic aquifer (Jurassic) with an average discharge of 3 l/s. The springs with high discharge have over 10 l/s and there are several such springs in the area, such as BAS003 (Figure 5.4), BAS005, and ZES002 (data from the SWALIM Geo database). Due to insufficient data from the previously created SWIMS database, for more than 30 springs there is no discharge data available.

Figure 5.4 Spring BAS003, discharge 12.5 l/s

Drilled wells

There are more than 35 drilled wells in the Awdal Region. Most of the wells belong to Jurassic karstic aquifer. Some of the wells with higher discharge have over 10 l/s and they capture water from Jurassic limestone aquifers for the water supply of Borama. The average discharge of the wells is around 5 l/s, while the static water level can be more than 100 m deep. The depth of the wells is in range from 53 to 200 m.

Figure 5.5 Examination of drilled well used for Borama water supply

Borehole Bo12 (Try n. 4)
Stratigraphic Log

Latitude	1099566
Longitude	307999
Elevation	1423.2

Depth	Thickness	Lithology	aquifer	color
7.6	7.6	brown sand and gravel		
49.0	41.4	limestone		
53.6	4.6	marls and calcarenite		
56.0	2.4	fine sand		
58.2	2.2	clay		
67.4	9.2	limestone (aquifer)		
74.0	6.6	limestone with marly levels		
82.9	8.9	medium fine sand with little gravel		
90.0	7.1	sand and gravel		
99.6	9.6	gravel and sand		
104.2	4.6	coarse gravel and sand		
113.0	8.8	sand		
114.0	1.0	basement		

Static Level	48.66 m (artesian)
Electrical Conductivity	1600 uS/cm
Drilling Diameter	12"
Casing	8"

Figure 5.6 Stratigraphic log of Bo12 drilled in Jurassic limestones (after Petruci B., Africa '70)

Dug wells

There are more than 160 dug wells in the Awdal Region. The depth of the dug wells is generally around 6 to 9 m, while some of them reach even 15 m. Depending on the well depth and local hydrogeological conditions, SWL are usually from 3 to 6 m deep. Almost all the dug wells are in the Mountain region, especially in the region with a thin layer of recent deposits lying on the non-permeable rocks. The estimated yield is usually low rarely exceeds around 0.4 l/s.


Figure 5.7 a,b Dug well BAW036 (left) and BAW039, with hand pumps

WOQOOYI GELBEED

Springs

There are more than 30 registered springs in the Woqooyi Gelbeed Region. Most of the springs are predisposed by tectonics or are located on the contact of good and poor aquifers formed in the late Proterozoic and Basement Complex. As those aquifers are not with well hydrogeological characteristics concerning permeability the discharge is usually in the range of 0.1 - 3 l/s. Most prospective for utilization are the springs issuing from karstic aquifer (Auradu limestones). The spring with highest discharge is Dubur Spring which, with more than 13 l/s (Figure 5.8a,b) is tapped for the Berbera water supply. Due to insufficient data from the SWIMS database more than 30 springs are without discharge data.


Figure 5.8 a,b Photos of Dubur spring (BES013) near Berbera town (Photo S. Milanovic)

Drilled wells

There are more than 60 surveyed drilled wells in the Woqooyi Gelbeed Region. Most of the wells are in aquifers formed in the late Proterozoic and Basement Complex, some with a depth of more than 300 m. The average depth according to data from the field as well as from the data of the SWIMS data base is around 150 m. The static water level according to data from the database is on average depth between 50 and 100 m. The discharge of the wells is in the range of 3 - 15 l/s, average is around 7 l/s, while the static water level can be more than 190 m deep.

Figure 5.9 a,b Drilled well - GEB025 and use of pumped water

Dug wells

There are more than 380 dug wells in the Woqooyi Gelbeed Region. The depth of the dug wells is generally around 6 to 10 m, while some of them can reach even 18 m. Depending on well depth and local hydrogeology, SWL are usually from 3 to 10 m deep. Almost 70% of the dug wells are in the Mountainous region. Their estimated average yield is around 0.3 l/s.

Figure 5.10 a,b Dug wells in Woqooyi Gelbeed region (HAW006, HAW044)

TOGDHEER

Springs

All of the springs in the Togdheer Region are in the Mountainous Zone. There are more than 30 registered springs in the Togdheer region, most of which are predisponed by contact with Auradu limestones and the formation of the Basement Complex. Usually discharge ranges from 0.1 - 5 l/s. Due to insufficient data obtained from field investigation as well as limited previous data no conclusion is possible concerning these springs and their potential for further supply.

Drilled wells

There are more than 80 drilled wells in the Togdheer Region. As in Burco and Sheikh, most of the wells are around big towns. Their average depth according to data from the field as well as from the data of the SWIMS database is from 45 to 360 m while the static water level according to data from the database is on average between 50 and 130 m deep. The discharge is in the range of 3 - 15 l/s, while average is around 7 l/s. The static water level can often be more than 190 m deep.

Figure 5.11 a,b Drilled wells for water supplying of Burco town: BUB008, BUB009

Dug wells

There are more than 140 surveyed dug wells in the region. The depth of the dug wells is usually around 6 to 15 m, the deepest one is 27 m. Depending on hydrogeological formation, SWL is usually from 3 to 10 m deep. The estimated yield of the dug wells is around 0.5 l/s.

Figure 5.12 a,b Dug wells for local water supplying: OWW 001, 002

SANAAG

Springs

Almost all of the springs in the Sanaag Region are formed in karstified rocks of Auradu, Taleh or Karkar formations, usually at the contacts of these three formations. There are around 130 registered springs in the region but for most there is insufficient data concerning discharge. Most of the springs are predisposed by the contact of two different lithological series. The elevation of the springs is in wide range of 4 to 1,600 m a.s.l. One of the biggest springs investigated during the HASP survey is Buran spring (Figure 5.13 a,b).

Figure 5.13 a,b Photo of Buran spring (LAS001) - Sanaag Region

Drilled wells

There are around 70 investigated drilled wells in the Sanaag Region. The majority of them are drilled in and capture water from karstified rocks of Auradu limestones. A good number is also tapping groundwater from Karkar or Taleh formations. The average depth according to data from the field as well as from the data of the SWIMS database is from 120 to 220 m, while the static water level according to data from the database is on average depth between 30 and 190 m. The discharge is in the range of 1 - 5 l/s, with an average value of around 3 l/s.

Figure 5.14 a,b Some of drilled wells for Ceerigaabo water suppy sistem. Photos of wells CEEB016 to 17

Dug wells

There are more than 130 surveyed dug wells in the Sanaag Region. Their depths are between 2 to 21 m. SWLs are usually from 5 to 20 m deep. The estimated yield of dug wells is around 0.3 l/s, but for many of them no pumping rates information is available. Photos of characteristic dug wells are shown in the figures below.

Figure 5.15 a,b Dug wells in the Sanaag region: CEEW 028,032

SOOL

Springs

There are 15 surveyed springs in the Sool Region, all of which are in the rim of the valley along the contact of karstified rocks and Quaternary deposits. Their discharge is in the range from 0.1 - 3 l/s. Due to insufficient data from field investigation as well as to limited previous data no conclusion concerning these springs and their potential for further supply is possible.

Drilled wells

There are around 20 examined drilled wells in the Sool Region. All of the wells are drilled on the west and southwest bank of the Nugaal Valley. Their average depth according to data from the field as well as to the data of the SWIMS database is from 60 to 200 m, while the static water level according to data from the database is on average between 50 and 100 m. The discharge of wells is in the range of 1.5 - 7 l/s.

Dug wells

There are more than 104 surveyed dug wells in the Sool Region. Generally, the depth of the dug wells is around 6 to 16 m. Depending on the well depth and hydrogeological formation, SWL are usually from 0.1 m to 12 m deep. Photos of characteristic dug wells are shown in the figures below.

Figure 5.16 a,b Drilled wells in the area of Laas Caanood

BARI

Springs

Most of the springs in the Bari Region are formed on the border of the Mountainous Zone and the Dharoor Depression, mostly on the contact between karstified rocks and non-karstic sediments. There are around 130 registered springs in the Bari Region but for most there is insufficient data concerning discharge. Most of the springs are predisposed by the contact of the karstified rocks and the Quaternary formations. Also, around 30 springs are connected to a discharge zone along the coast of the Indian Ocean. According to data from the field, discharge is from 0.1 to 3.5 l/s.

Figure 5.17 a-c One of the biggest springs in Bari Region - coded BANS013

Drilled wells

50 drilled wells were examined in the Bari Region. Most of the wells are at the west rim of the the Bari region in the area of Boosaaso and Qardho. The average depth according to data from the field as well as to the data of the SWIMS database is from 125 to 300 m, while the static water level according to data from the database is on average depth between 10 and 180 m. The discharge is in the range of 1 - 6 l/s.

Figure 5.18 a,b Drilled wells: QAB001 (left) and QAB006 (right) in Bari Region

Dug wells

There are more than 120 registered dug wells in the Bari Region. Their depths are between 4 to 19 m. Depending on the well depth and the hydrogeological formation, SWL is usually from 5 to 16 m deep. The estimated average yield of the dug wells is around 0.5 l/s. Most of the dug wells are made in Quaternary deposits in toggas and sediments along the coast.

NUGAAL

Springs

There are around 50 surveyed springs in the Nugaal Region, most of which are in the rim of the valley along the contact of karstified rocks and Quaternary deposits. The discharge of the springs is from 1 to 38 l/s. One of the most yielded spring in the region is GAS002 with a discharge of 20 l/s; another is EYS004 with a discharge of even 38 l/s.

Drilled wells

Around 20 drilled wells were examined in the Nugaal Region. Their average depth according to data from the field as well as from the data of the SWIMS database is from 60 to 200 m, while the static water level is very deep, ranking between 100 and 250 m. Discharge of the wells is in the range of 0.5 - 15 l/s, average is around 4 l/s.

Table 5.1 Lithologic log of MAM/Garoowe/05/08 drilled in Taleh evaporitic rocks

Depth		**Description of Formation**
From (m)	To (m)	
0.0	12.0	Top soil (red sands, limestone boulders with gypsum crystals)
12.0	57.0	Grey limestone inter-bedded with blue clay, anhydrite and marls
57.0	72.0	Anhydrite with grey limestone and gypsum crystals
72.0	99.0	Anhydrite with grey limestone, occasionally with gypsum crystals
99.0	108.0	Clay with grey limestone and marls
108.0	117.0	Anhydrite inter-bedded with marls, occasionally with gypsum crystals
117.0	168.0	Massive anhydrite with fresh gypsum crystals

Figure 5.19 a,b Drilled wells in Nugaal region

Dug wells

There are more than around visited 100 dug wells in the Nugaal Region which are the main water source in remote areas. The depth of the dug wells is between 3 to 15 m. Depending on well depth and hydrogeological settings, SWLs are usually from 0.1 to 13 m deep.

Figure 5.20 a,b Dug wells in Nugaal region - different types and intake structures

MUDUG

Springs
Only two springs are registered to date in the investigated area.

Drilled wells

There are around 20 surveyed drilled wells in the Mudug Region. The average depth according to data from the field is from 60 to 200 m, while the static water level according to data from the database is between 39 and 156 m deep. Discharge of the wells is in the range of 0.5 - 12 l/s.

Dug wells

There are 21 visited dug wells in the Mudug Region. Their depths are from 4 to 11 m. SWL are from 3 to 11 m deep.

5.1.1.2 Groundwater utilization and demands in the main settlements / towns

Given the lack of perennial streams and the arid type of climate in Somaliland and Puntland, groundwater represents the sole resource in most of the study area. However, due to limited reserves, a very deep groundwater table and/or increased water salinity there is a shortage of water and very limited access to it in most of the surveyed sites. This is also a reason why the population of Somaliland and Puntland very often suffers from water shortage and is forced to migrate to areas where access to water and to food produced by irrigated water is available. Since one of the major tasks of HASP was to propose some technical solutions to improve the water situation and provide advice for sustainable GW development, the surveyors were asked not only to identify, visit and measure water quantity/quality at the water points but also to make suggestions how to improve the water situation particularly in the study area close to sites or villages which were visited.

Water supply major consumers – current status

Upon completion of the work of surveying teams and the preliminary evaluation of collected data an extended survey in the area was conducted by visiting major water utilities in Somaliland and in Puntland. This was important both to get proper information on the most critical issue – supplying drinking water to heavily populated settlements – and to identify potential sites to be included in a new GW monitoring network. The results of this successfully conducted inquiry are presented in the Interim reports of the consultants and they are now also a part of newly created SWALIM Geo database.

For this kind of general hydrogeological study it is also important to compare the previous and the current water situation. For this purpose information from previous studies, mainly from the Faillace & Faillace report (1986), has been used and cited.

According to Faillace & Faillace "groundwater investigation programs for Hargeysa started in the late 1940s and continued in the late 1950s. However, it was only in 1974 that, with the financial and technical aid from the People's Republic of China, the town had its water supply. Due to the financial constraints of the Somali Government, the other major towns were left without adequate water supplies until 1976 when a groundwater investigation program began in Burco, Ceerigabo, Garoowe, and Qardho with the financial and technical support of the German Government."

1. Hargeysa – past & present (Woqooyi Galbeed region)

Hargeysa is the capital of Somaliland. It is located at the edge of the Hawd Plateau. Its population has increased considerably, particularly during the last half century: from a very small village before WW II, Hargeysa today is home to over half million inhabitants, while some other sources speak of nearly one million or around one quarter of the total population of Somaliland.

The Faillace & Faillace report states that in 1980 the water supply requirements of the resident population (200,000-250,000 people), suburban residents, commercial enterprises, government establishments, industries, etc. were estimated by the Hargeysa Water Supply Agency at 12 x 10^3 m^3/day or 138 l/s.

Year	Inhabitants
1930	2,000
1952	19,000
1957	54,410
1970	83,000
1982	280,000
1986	300,000
2012	900,000

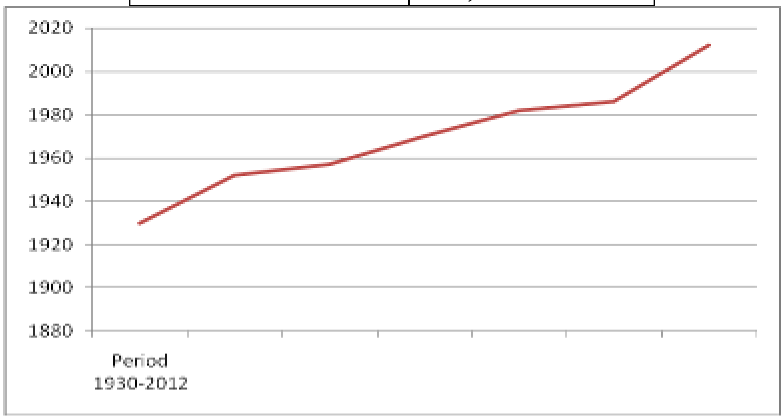


Figure 5.21 Population growth in Hargeysa

In the same report the climate and water situation in the Hargeysa area was described as follows: "The city extends along the banks of Togga Maroodijeex, which flows from west to east. The togga is dry most of the year but water found in its sandy bed is tapped by numerous hand-dug wells. The area surrounding Hargeysa is hilly; flat-topped sandstone mesas are located on the outskirts of the town. Vegetation is scarce and is constituted mainly by thorny bushes and acacias. Soil erosion is severe in the surroundings of the town. Hargeysa, at an elevation of 1,300-1,400 m a.s.l., has a pleasant climate, with cool nights and warm days. The temperature variation between day and night is between 15 and 21 degrees. The highest monthly temperature ranges from 26 to 35 degrees, with a maximum temperature recorded at 39.5 degrees. The lowest average monthly temperature ranges from 6.5 to 21 degrees, with a minimum of 3 degrees occurring from November to January. Full records of rainfall data over a 48-year period (1922-1950, 1959-1981) show that the average yearly rainfall is 429.4 mm. The lowest mean yearly rainfall occurred in 1965, with 156.7 mm; the highest rainfall record, 834 mm, occurred in 1980. Rain often comes under the form of thunderstorms, with downpours lasting a short time and covering small areas. Ninety percent of the annual rainfall occurs from April to September. Evaporation, up to 3500 mm/year, is very high."[17]

In 1947 Macfadyen (1951) investigated 137 wells with depths ranging from 4 to 8 m. He also gave a rather detailed account of the various efforts made to solve the water supply problems of Hargeysa. Before the 1950s, hand-dug wells located on the banks and in the bed of T. Maroodijeex constituted the traditional water source for Hargeysa. Thirteen wells were drilled between 1933 and 1939. Of these wells, four were less than 30 m deep, four others had depths between 30 and 60 m, four exceeded 60 m, and one was 135 m deep. Along with other information, Macfadyen reported that the most productive of these wells had a yield of 2.5 l/s.

In order to improve the water situation of the city, Macfadyen recommended the underground flow of Togga Maroodijeex be tapped by constructing a 500 m-long underground dam across the tug bed along with "a buried infiltration tunnel or perforated pipe of large diameter or a suitable alternative constructed to lie on the impermeable Malas clay at the bottom of the tug bed, at a depth of about 20 feet below the surface". Macfadyen's idea of a subsurface dam was later rejected because the stored water would be insufficient for the needs of the town. The conclusions were that the Maroodijeex Valley had the best conditions but could only have been exploited for about 450 m^3/day or 5 l/s, an amount well below the town's needs even in the 1950s.

Excluding the river bed deposits and the deep aquifer as potential water sources, H. Humphreys recommended the development of four water sources capable of meeting the needs of the growing town until 1980. The recommended sources were two surface water reservoirs created by damming the Dikrile and Agambo toggas, Dibraweyn spring, Durdur water. These later recommendations were also not implemented. The Somali Government, with the help of the Chinese Government, developed another water source: the Geed Deeble alluvial sedimentary basin, which had never been considered in the previous studies, and which is still used to supply the city with potable water.

[17] Faillace & Faillace: Hydrogeology and Water Quality of Northern Somalia (1986)

"The Chinese hydrogeological survey, with the subsequent drilling of exploration and production wells, was carried out from April 1969 through September 1970. During this period 12 wells were drilled in the Geed Deeble area, about 25 km north-northwest of Hargeysa; six of them were completed as production wells, with a total yield of 4,000 m^3/day. The new water supply system began operating with these six wells in 1974. At present, with the exception of a small sector of town which already had its own water distribution network, most of the town's water supply system has been built with the technical and financial aid of the People's Republic of China. Six new wells drilled between January and July 1982 as part of the programmed water supply extension are not yet in operation. The six old wells discharge their water into a reservoir (elevation 1,098 m a.s.l.) from where water is pumped to a relay pumping station located 1228 m a.s.l; from here the water is pumped to the two interconnected high spots."[18]

The main aquifer system is terrace deposits and recent alluvium of nearby togga Geed Deeble. It is a very thick (up to 150 m) and highly permeable aquifer system (belongs to I1 group of imposed HG classification to this report). The lithological descriptions of the boreholes drilled in Geed Deeble have revealed the presence of several layers of permeable sediments such as medium to coarse sand and coarse sand with gravel. The underlying rocks belong to basement Proterozoic complex.

Figure 5.22 Well no 5 of Geed Deeble source for Hargeysa (photo ZS)

[18] Faillace & Faillace: Hydrogeology and Water Quality of Northern Somalia (1986)

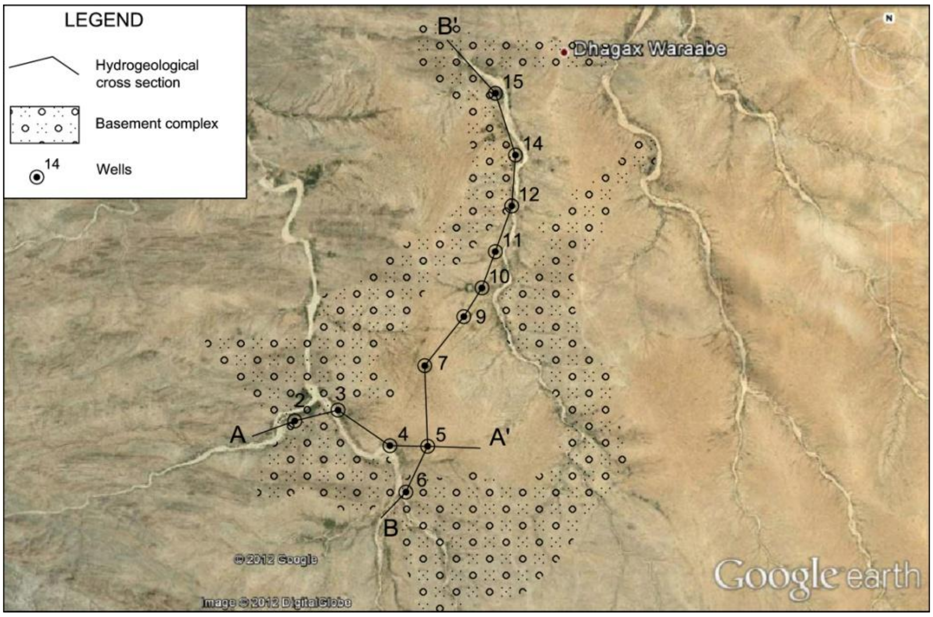


Figure 5.23 Location map of Geed Deeble source (after Petrucci, 2005)

Faillace & Faillace (1986) stated that "Geed Deeble is a closed structural basin in the basement complex filled up by terrigenous sediments consisting of clay, sand, gravel, and intercalations of basalt. In the Geed Deeble Valley several toggas have contributed to the deposition of the thick sequence of sediments. The total thickness of the detritical sediments has most probably been reached in borehole no. 7, where 200 m of sediments were penetrated before reaching the bedrock. Sand and gravel fill the lower part of the basin, while clay with intercalations of sand and thin layers of gravel is predominant in the top 70-80 m of sediments. Basalt intercalations have been found from 39 to 42 m in well K11, and from 29 to 32 m in well K16".

The same authors also stated that "water level observation in some boreholes shows that a certain amount of recharge occurs during the rainy season. Fluctuations of 3.12 and 3.6 m were observed in boreholes Kl and K12, respectively. Recharge in boreholes Kl and K2 is very fast, as was observed in March 1982, when water levels rose 1.8 and 0.70 m, respectively, after 82 mm of rain had fallen on the Geed Deeble Valley. The water level, however, fell rapidly once the flood subsided."

According to SOGREAH (1983) the outlet of this structural basin has not been properly identified since "the basin as a whole has no other outlet than the gorges of the two large toggas Biji and Waaheen, where there is very little flow, subsurface flow in the coarse-grained alluvial fill material in the old valley must be slight. The important point is that the reservoir is not very large and there is a risk of its being over-exploited."

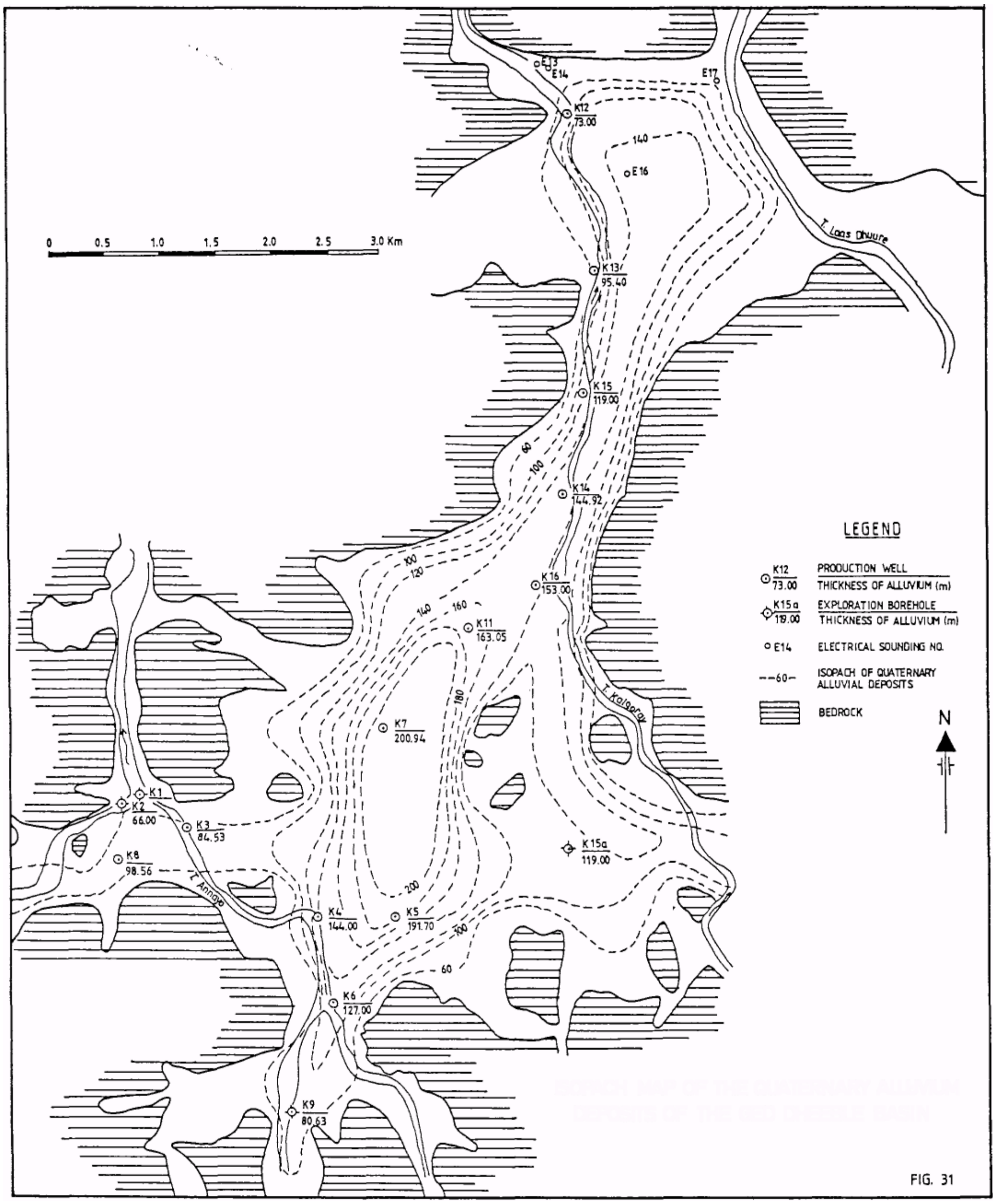


Figure 5.24 Isopach map of Geed Deeble alluvium (Water supply survey team of PR China)

The large variation in aquifer thickness from one borehole to another is reflected in the results of the well yield. In fact, production well yields range from 11 to 25 l/s and specific capacity ranges from 0.50 to 4.56 1/s/m’.

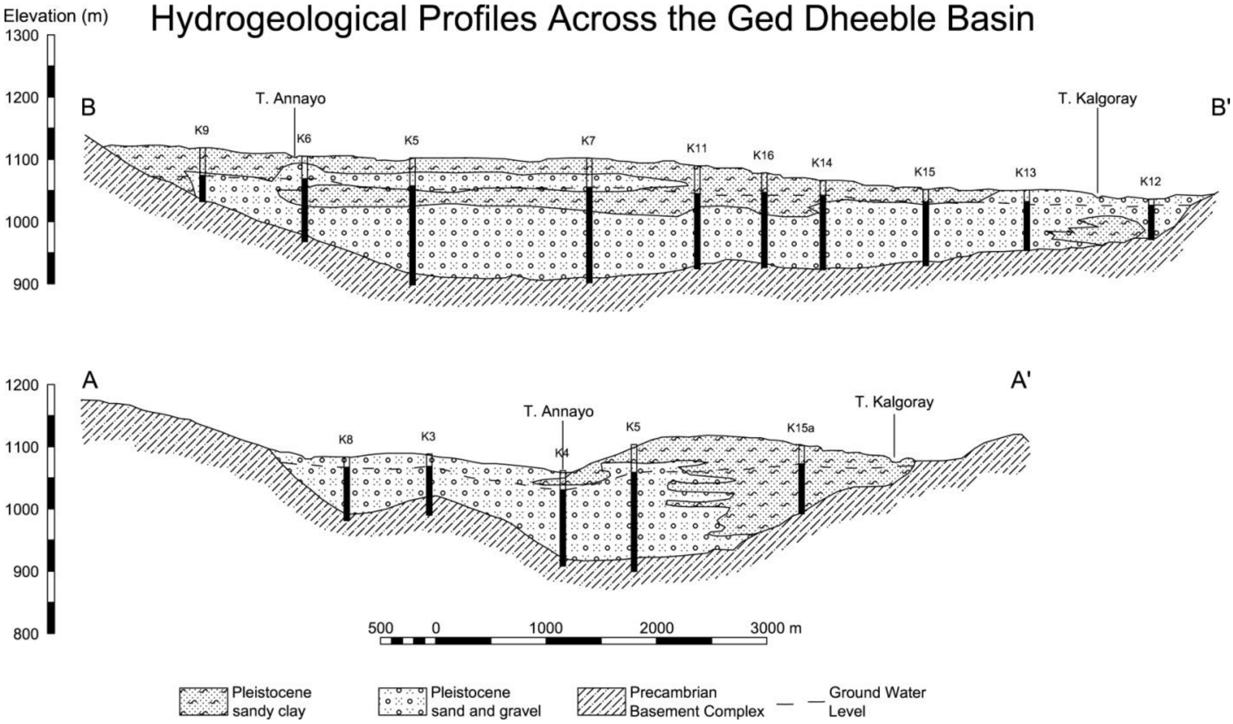


Figure 5.25 Hydrogeological cross section through Geed Deeble source (Chinese report, 1986)

Groundwater balance, calculated on the basis of the yearly water level fluctuation and on the amount of abstraction, has put into evidence that the hydrological balance in 1976 and 1977 was positive due to limited abstraction whereas after 1976-1977 it was always negative. According to the Chinese report (1986), about 1,200 m^3/day are exploited in excess of the daily recharge of the basin and the annual drop of the water level in the valley was 1.25 m. "Water reserve consumed in the dry years could not be recharged, so the second aquifer has been drained. The draining off is now extending down to the third aquifer. As the yield will amount to 8,000 m^3/day, twice as much as before after the completion of the extension, it will certainly speed the fall of water level and the draining of the aquifer."[19]

Faillace & Faillace stated that groundwater quality of the shallow alluvial deposits filling the togga bed incising the Geed Deeble Valley is excellent, with EC values regularly below 1,000 μS /cm. Wells dug far from the banks of toggas may yield water with a higher salinity. Water from the deep, semi-confined aquifer tapped by the Chinese wells has also a low salt content, with TDS values ranging from 297 mg/1 to 633 mg/1; water is generally of the sodium bicarbonate type.

[19] Chinese report on Geed Deeble source (1986)

Figure 5.26 Togga Geed Deeble and dense vegetation near the village of same name (photo ZS)

Geed Deeble is one of very few sources in study area where sporadic monitoring of groundwater regime took place. Figure 5.27 illustrates a comparison between water levels (the elevations of the water table) measured by the Chinese in the 1970-80's, data of 2002-03-04 and 2005-06.

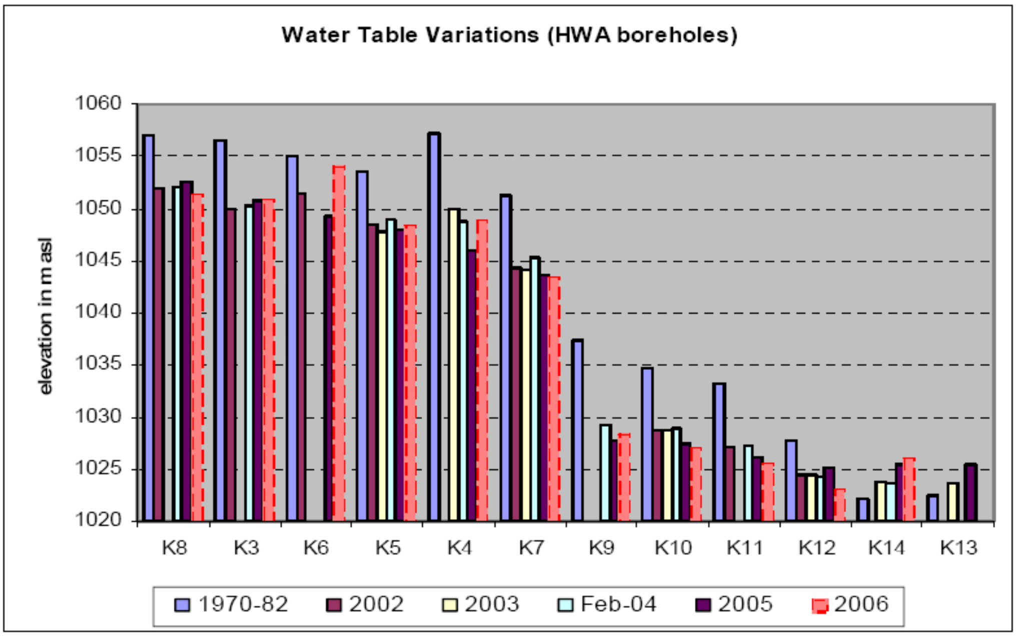


Figure 5.27 Groundwater table fluctuations in the period 1970-2006 (after Petrucci, 2005)

Petrucci (2007) pointed out that " A relevant drop between the data of the period 1970-1980 and all the rest is visible in the graph; in some cases it reaches variations over 8 m. The only wells on which a raising of the water table was registered are K13 and 14. These wells are unexploited since long (more than 5 years) and are located at the lower end of the Kalqoray togga basin; furthermore some of the few measures (the wells not being in production are strictly sealed) have been taken in the rainy season.

In the period between 2002 and 2006 there are not heavy differences, but in the average, in the wells of the upper part of the basin (K8, K3, K5, K4), the water table did not suffered significant drop, while in those located in the intermediate-low section (K7, K9, K10, K11, K12) there is a slightly descending trend.

Only K6 and K8 (apart K13 and K14) have, in some way, a different behavior:

• the water level of K6 is higher (as in the described trend) but it is very close to the height of the water table measured in 1974. Very likely this happened because the well has been out of production for more than one year and the only measure of level (in 2006) was taken before its restart.

•K8, which mean annual level is slightly descending, even being in the upper part of the basin, has been overexploited (more than 1,300 m^3/day) because of its higher potential, to cover the missing yield of K6. Anyway K8 has quickly recovered in the second semester of 2006.”[20]

Source Geed Deeble was also chosen to conduct practical training with surveyors in September, 2011. During that exercise new information on the operation of this utility was collected. In addition, during the survey of waterworks in the region the inquiry form of this source was also filled out.

Currently, 13 wells are working in Geed Deeble. They regularly work 22 hours/day, with a break from 11-13h every day. About 138,000 Hargeysa residents and a majority of small enterprises, which represents around 15% of the city’s total population, are connected to the system. The average daily pumping rate to the two underground reservoirs and further to the city is 10 x 10^3 m^3. The length of the main pipeline is 20 km, while more than 50 km of the pipes of the secondary network lie inside the city. A 12,000 m^3/day water transmission system, from the well field to the town, was installed.

The average pumping rate of the well is 10 l/s. The water table is far below the surface, at a depth of around 50 m, but drawdown during pumping is more or less stable and usually is not more than 10 m below static. Water is fresh, TDS is around 300 mg/l. Chlorination takes place regularly; no heavy pollution is reported.

[20] cited from Petrucci report – Geed Deeble / Well field monitoring (2007)

An extension of the water supply system is planned from the Xunboweyle area where several other highly productive artesian wells were recently drilled. This site was also visited and surveyed during the training held in Hargeysa in September, 2011. The average depth of these wells is 150 m. The lithological section is similar to that of Geed Deeble, with alluvial gravels and sands (I1 HG unit) interfingered with some basaltic products (F) in deeper parts, while bedrock is represented by Proterozoic impermeable rocks (N). The most productive well has freely discharged around 4 l/s with a water temperature of 31^0C.

Figure 5.28 Recently drilled artesian well near Xunboweyle planned for Hargeysa new water source (photo Z.Stevanovic)

2. Gebiley (Woqooyi Galbeed region)

Gebiley is located on the edge of a small valley incised by Togga Gebiley, 50 km from Hargeysa on the road to Borama. The first hydrogeological survey of the area, which aimed to select a site for an additional water well for the town, was carried out by C. Faillace in 1983. Because the five shallow large-diameter hand-dug wells (20 m deep) which had previously been constructed in the area near the town provided only a very small amount of water, another water solution was sought; it was found by drilling a deeper well aside alluvium in quartzite rocks of the basement complex (A HG unit) which, along with the Nubian sandstone (F), represent the main lithostratigraphic unit in the Gebiley area.

Faillace (1983) reported that the new well site was selected about 1 km downstream of Gebiley. In the selected locality there is a series of small seepages originating from a highly fractured and jointed quartzitic rock. Argillaceous shists at the contact with the quartzite act as a vertical barrier to the underground flow occurring in the fractured quartzite and generate an outflow of water through seepages and small springs in the stream bed. The well in the newly selected site was drilled in June 1983 to a depth of 60 m and yielded "abundant water", according to the driller.

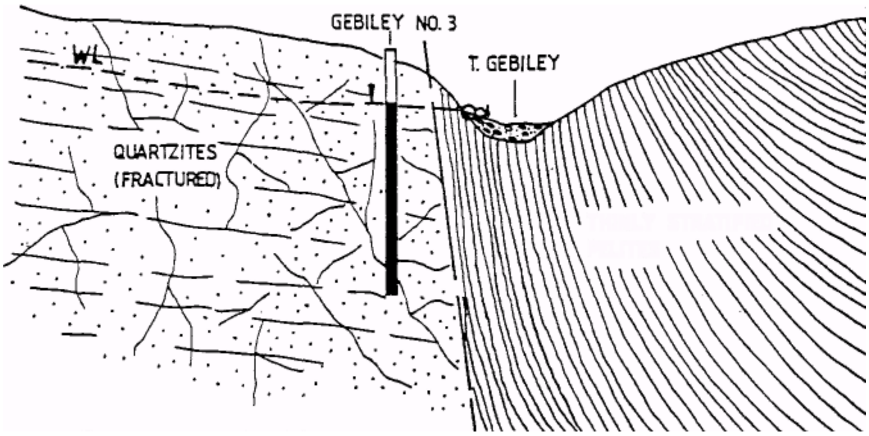


Figure 5.29 Cross section of the well drilled at the Togga Gebiley bank (Faillace, 1983)

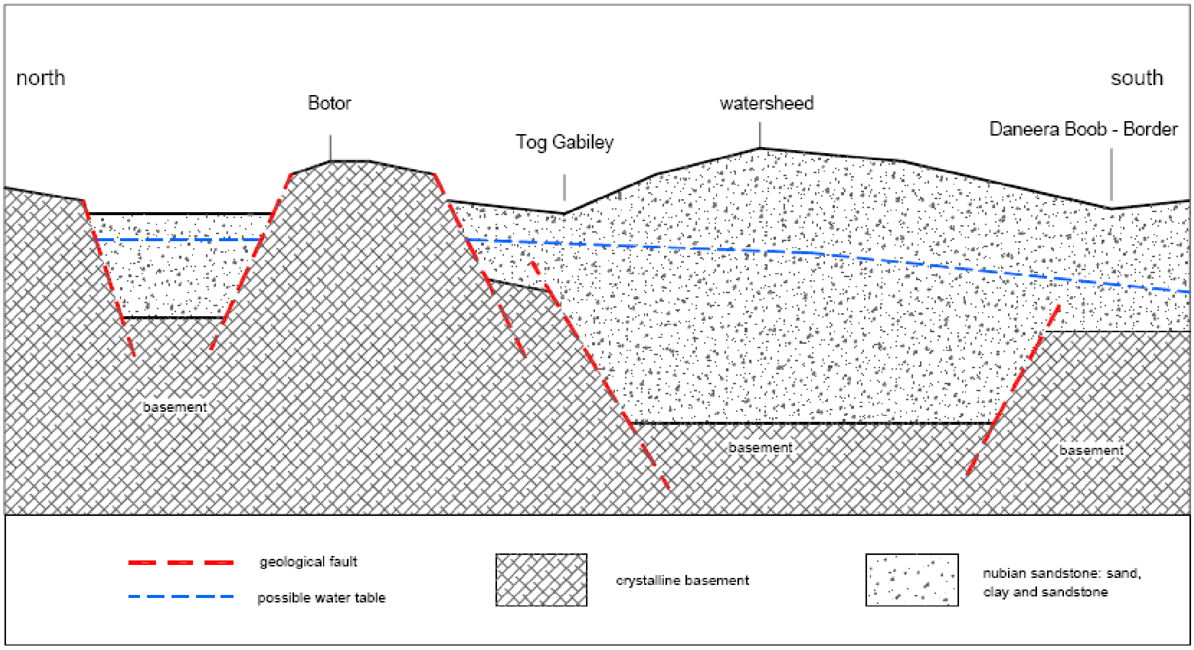


Figure 5.30 Schematic cross section of the Togga Gebiley based on geophysical (geoelectrical) survey of Petrucci (2006)

Water from the hand-dug and the drilled wells in the alluvial deposits is of good quality, with EC values ranging from 700 to 1,600 µS/cm, according to seasonal changes. Water is of the sodium bicarbonate type, with $HC0_3$>$S0_4$>Cl/Na+K>Mg>Ca.

Today, Gebiley is populated by 56,000 inhabitants. For their water supply 3 deep boreholes are operating, producing 13 l/s in total. This amount of water is at least three times less than required as per minimal standard and thus indicates a great water shortage and the need to find an alternative water solution.

3. **Borama (Boorama,** Awdal region)

The town of Borama is located in a hilly area in the western part of Somaliland, only about 20 km from the border with Ethiopia. The population of Borama increased considerably in the 1980s due to the arrival of refugees and the establishment of the refugee camps along the Togga Camuud.

It is a hilly area at an elevation 1,350 to 1,400 m a.s.l. with a mild and pleasant climate for most of the year. Annual average precipitation is around 500 mm.

Three geological formations outcrop in the area of Borama: the basement complex of Pre-Cambrian age, constituted by highly fractured metamorphic pelitic and semi-pelitic rocks (A HG unit); small remains of karstified Jurassic limestone (K2) located in structural depressions of the basement; and widespread alluvial deposits (I1) west of Borama and along the riparian belts of the major toggas.

Macfadyen (1951) reports the lithology of three boreholes drilled in 1933-1934 for the water supply. All three boreholes, drilled to depths of 21, 43.5 and 48 m, were dry.

Faillace & Faillace reported (1986) that “Borama obtains its water from the Dhamuuq spring, located about 5.5 km east of town. The spring is only partially tapped and the remaining water flows along the T. Dhamuuq, reaching its confluence with the T. Camuud. Vegetable gardens are cultivated along the banks of both toggas. Water used for irrigation is pumped from shallow wells and pits dug in the stream beds...

The Dhamuuq spring has been used since time immemorial; however, only since 1938 has it been piped to town. In the 1980s the spring was pumped out for about 11.5 l/s and water was also trucked to the nearby refugee camp. “The spring intake is constituted by a rectangular masonry box buried under the coarse alluvial sediments of the tug bed. Water is pumped from a pump house located on the tug bank. A much greater water quantity could be available through proper works aimed at tapping the whole spring flow, which, to a large extent, is now feeding the stream flow of the Togga Camuud."[21]

"The spring is an outflow of the perched aquifer of the limestone block and it is not connected with northern mountain aquifers; if any connection exists its contribution in feeding the spring is minimum" (Aquater, 1982). This information, however, contrasts with that given by BCI Geonetics (1985): "The recharge of the area is quite high considering the limited extent of the drainage basin area, and the flow of water is remarkably constant...the recharge area extends outside the immediate drainage basin area."

The spring is located close to the fault between the Jurassic limestone and the metamorphic pelitic rock. Breccia and quartzitic conglomerate at the base of the limestone mark the fault zone. The fault dip is of 60-70 degrees.

The limestone is deeply karstified and has a spongy texture near the spring. The joints of stratification are widely opened by solution enlargement. Water surfaces because the impervious pelitic formation acts as a dam along the fault line. Faillace & Faillace (1986) stated that "persons responsible for the pump house of the Dhamuuq spring reported that during the British Administration a well drilled at the spring site resulted artesian. Since too much water was flowing out of the well it was plugged with cement."

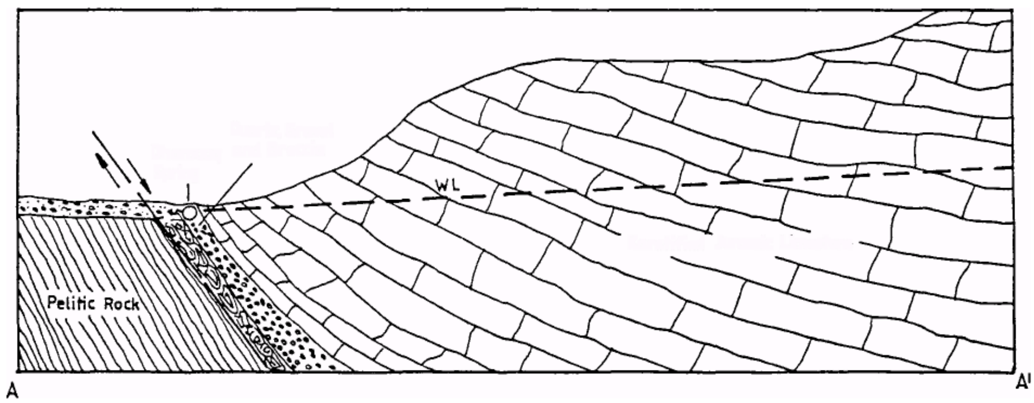


Figure 5.31 Cross section of Dhamuuq (Damuq) spring (Faillace & Faillace, 1986)

In 1982 another borehole was drilled next to the pump house. The well was 125 m deep, penetrating 60 m of limestone and 65 m of pelitic rocks. The borehole, cased by 4-inch galvanized pipes, had an artesian flow of about 2 l/s without affecting the spring yield.

[21] Faillace & Faillace: Hydrogeology and Water Quality of Northern Somalia (1986)

The EC of water from the Dhamuuq spring ranges from 1,050 to 1,300 µS/cm. Water is of the sodium bicarbonate type, with $HC0_3$>$S0_4$>Cl/Na+K>Mg>Ca.

According to Petrucci (2008) "above the limestones (Jurassic – Jc), below the shallow and thin alluvial deposits, a widespread and thick lacustrine unit has been found in all the investigated areas. This unit (usually defined as Quaternary, but of uncertain age, Qc?) highly reduces the infiltration in most of the basins lower parts and contributes with its high salt content to increase the water salinity of the calcareous aquifers.

Hydrogeological and geoelectrical investigations conducted by Petrucci (2008) were focused on five blocks separated in accordance with limestone outcrops in vicinity of Borama and border with Ethiopia. The pumping test carried out on the well of Afraaga found a very productive aquifer layer (prudentially estimated by Petrucci on 1,000 m^3/day) but the insulation of the limestones from the outcrops scattered around (verified in the course of drilling operation) may constitute a serious limit to the recharge mechanisms, unless the aquifer extends more toward Ethiopia.

Geometry of Dhamuuq block (B1 on Figure 5.32) is already known by the numerous boreholes drilled on the hill and on the plain north of the hill. The maximum depth is reached by the limestones near the Togga Camuud (Amoud), in well n. 9 (drilled for a private farm) about 125 m deep. The second block of the lower part of the basin is divided in 3 sections (B2, B3 and B4) by basement outcrops and by lacustrine clay. The possible connection, under the clayey coverage, between the Dhamuuq and Camuud blocks is still uncertain, while the separation among the lower blocks (B3-B4) and the higher southern one (Sheilaha block B5) has been ascertained by the presence of a wide basement strip, raised by a geological fault, between them.

Based on result of the drilling, Petrucci (2008) assumed variable yield from the Camuud block (B2-B3-B4) between 1,000 and 2,000 m^3/day; one of drilled boreholes gave a drawdown of 3.0 m with a yield of 11.7 l/s. Much less is expected from the (B5), which aquifer is regulated by the Byio-Caddo springs. The evaluation of this block potential is very difficult but could be fixed at a maximum value between 200 and 500 m^3/day.

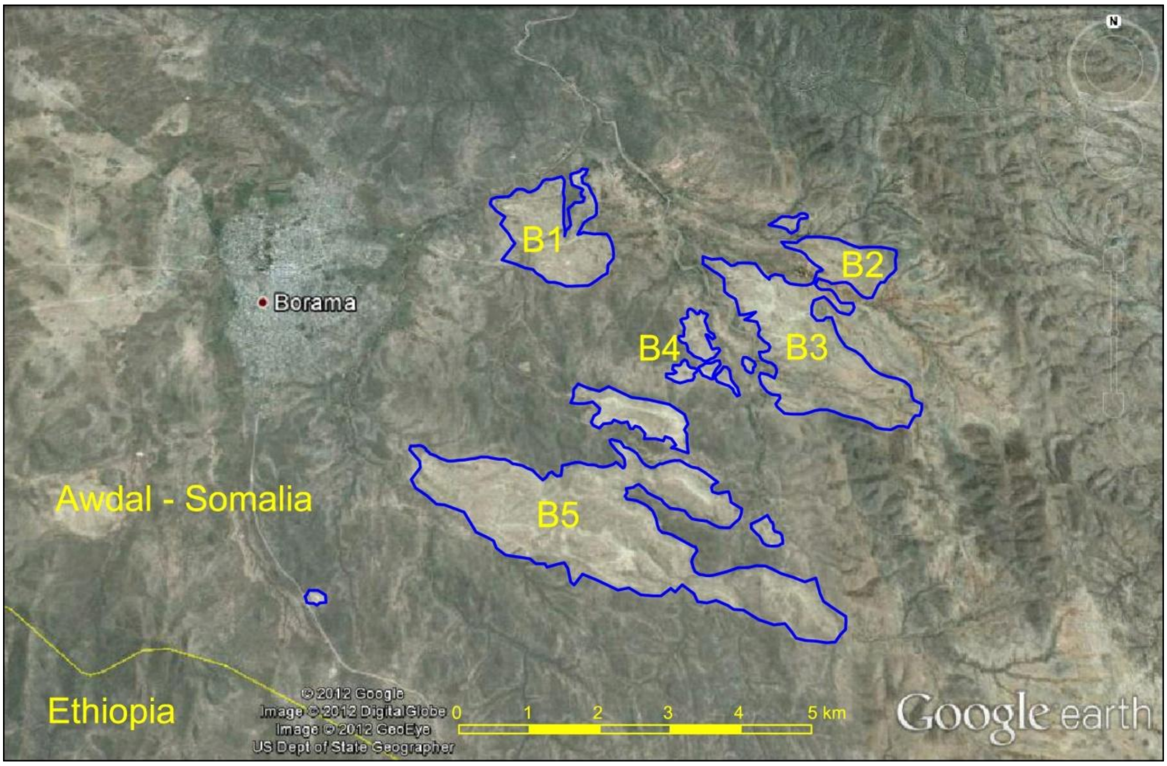


Figure 5.32 Blocks with Jurassic limestones outcrops in vicinity of Borama (Petrucci, 2008)

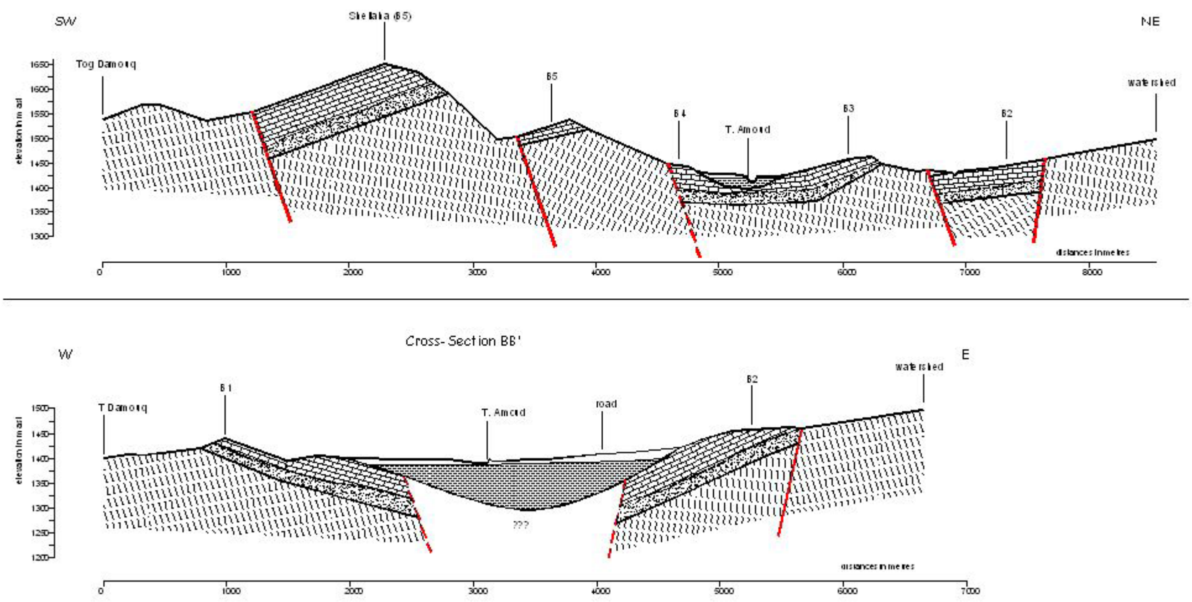


Figure 5.33 Geological cross-section and limestone blocks relationship (Petrucci, 2008)

German Agro-Action (2006) estimated total potable water demands of Borama on 6,000 m^3/day. The fact that groundwater level has dropped by 8.08 m (1986) to 23.91

m (Jan 2005) they explained by over-abstraction, i.e. much larger pumping rates than effective aquifers recharge.

Petrucci (2008) also described groundwater depletion due to increased pumping rate: “The water level dropped between 1986 and 2004 of about 12-13 m (from 7-9 m to 19-22 m). In 2002 the boreholes were tested during the water supply system improvement (funded by UNICEF) and each of the 4 boreholes chosen seemed to give a yield around or above 1,000 m^3/day. In January 2004 started the Shaba Water Utility management according to the principles of the PPP and the production increased from values of about 1,000 m^3/day to the present average of about 1,500 m^3/day (the exploitation time has been increased from 16-20 h/day to 23-24 h/day). The water level started dropping with a much higher rate of about 4 m/years. In the month of July 2008 the water rest levels arrived around 40 m of depths in the 3 wells exploited by Shaba (the forth one, well n. 3 is out of production since 2006, because then the water table reached a level close to the well bottom). The remaining thickness of aquifer in the wells is presently around 30 m and the time estimated for its reduction at only 10 m is between 3 and 6 years. To stop the depletion, a previous study, carried out by Africa ’70 in 2005, evaluated about 700 m^3/day the maximum yield which can be extracted from Dhamuuq aquifer. With the present study the model was fine tuned and the maximum yield which the aquifer can admit was found about 1,000 m^3/day with an annual rain of 500 mm.”

Figure 5.34 Dhamuuq wells field piezometric map (Petrucci, 2008)

Petrucci (2008) also made reconstruction of the changes and the trends of the piezometric surface, which can be summarized as it follows:

• The piezometric surface is dropping since the beginning of the exploitation. Unfortunately the daily yields of the production before Shaba management (2004) are unknown,

• The drawdown pattern, on the wells of Dhamuuq field, presents 3 sections (see Figure 5.35),

• from 1986 to 1998 the drawdown was in the average 0.2-0.3 m/year,

• from 1998 to 2004 it increased to about 2 m/year,

• from 2004 up to date the drawdown has been between 3 and 4 m/year.

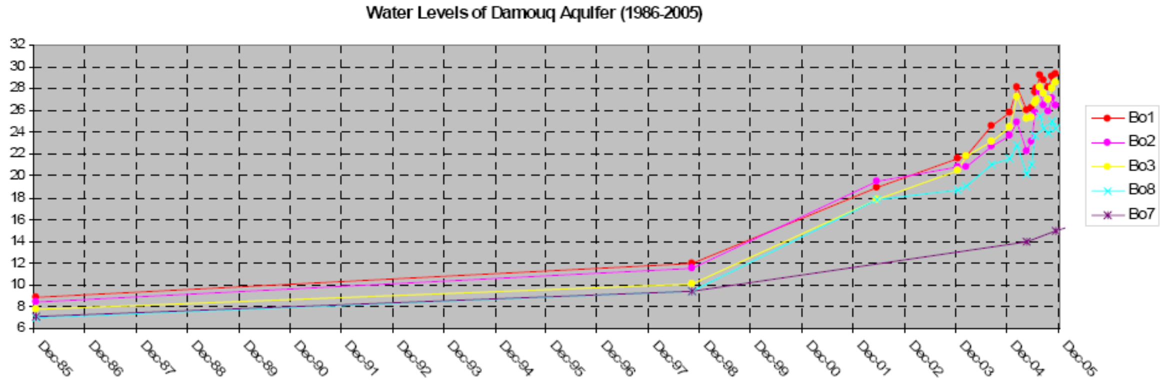


Figure 5.35 Groundwater level fluctuations in Borama wells

Table 5.2 Pumping rate (in m^3) of the Dhamuuq well field (Shaba Water Utility, Borama)

	2004	2005	2006	2007	2008
jan	35,786	34,226	33,857	40,546	44,400
feb	31,980	33,620	35,297	42,057	42,425
mar	34,880	36,264	34,315	46,753	47,437
apr	23,946	30,884	30,136	42,855	46,235
may	37,856	27,900	40,350	44,753	44,880
jun	38,102	38,377	47,574	47,862	41,068
jul	36,080	43,838	43,804	45,640	
aug	36,547	38,907	38,510	43,290	
sept	30,998	34,030	35,576	39,136	
oct	30,619	38,179	42,872	47,456	
nov	31,400	34,273	39,883	42,321	
dec	32,687	32,282	35,066	44,159	
Totals	400,881	422,780	457,240	526,828	532,890

Concerning the importance of groundwater monitoring for sustainable aquifers utilization but a very few available data which may supporting this analysis, above cited Petrucci findings (2008) could be considered as a somehow typical and relevant for any further studies.

Today Borama has around 136,000 residents, of which only ¼ are connected to the waterworks' pipeline. The main source remains in Dhamuuq (Damuq) village, and several boreholes have been drilled there during the last decade: 4 in 2004, an additional 1 in 2008 and another 1 in 2010. Their depths vary between 64 and 120 m. Their total discharge is 27 l/s which, together with 6 l/s of tapped spring water, make a total of 33 l/s available for drinking water supply. Water is distributed to the city by a pipeline 26 km long.

The Borama source is the only one where responsible personnel clearly identified indications of over-exploitation and reported them during our inquiry in May 2012. They said that the water table depleted by some 13 m during the last 5 years (2.6 m/year). The water quality is also controlled by the Borama Water Utility (Shaba), but no treatment is applied (not even chlorination is taking place).

Figure 5.36 One of the wells and water tank in Borama area (Photo of Somaliland Team 2, Awdal)

4. Berbera (Woqooyi Galbeed region)

Berbera is the most important town of the northern coast of Somaliland due to its port facilities. The town is located on a partially eroded marine terrace covered by sand, gravel, and boulders with sandy argillaceous fillings deposited by the togga draining the mountainous area south of the town.

The climate is hot and arid during the summer months. The average annual rainfall is about 50 mm, while the potential evaporation is about 10 mm/day (Faillace & Faillace, 1986).

With the construction of the port, the improved shipping facilities, and the construction of a cement factory, Berbera experienced a considerable growth in population. During the 1980s in addition to the Dubar hot spring as a traditional water source, two new water sources, the Biyoguure springs and the Togga Kalajab, were developed to satisfy the growing water supply needs of Berbera (Faillace & Faillace, 1986).

The Dubar hot spring as a historical water source is located 11 km southwest of the town. Macfadyen (1951) reports that "the line was laid and the entire system designed and built by the Egyptians about 1879". The spring and its pipeline are protected by a fort built around the spring site. During the British Administration the spring intake was improved, and the pipeline was repaired and replaced more than once. Due to high mineralization and water temperature the incrustation process is rather fast, forming concentric yellowish and dark-brown rings of varying thickness.

“The Dubar spring originates from a deep fault at the base of a Nubian sandstone cliff (Cretaceous). Coral limestone and shales of the Dubar Series (Miocene) are found in the area of the spring. To increase the spring yield several 3 m-deep rectangular stone-lined drainage cisterns were constructed. Water is piped to a collector tank from where the pipeline brings water to Berbera by gravity. The regime of the spring is not well-known since no continuous observation has been carried out. Macfadyen estimated a yield of 7.6 l/sec. Popov reports that "according to local inhabitants its total capacity is 30,500 U.S. gallons/hr" (38.6 l/sec). The temperatures of thermal water range from 43 to 46 ^{0}C, with EC values ranging from 2,000 to 2,500 µS/cm. Water is of the sodium chloride type, with a high sulphate and chloride content: $Cl>S0_4>HC0_3/Na+K>Ca>Mg$.

Faillace & Faillace (1986) reported that due to the reduced diameter of the pipeline and leakages, only 2-3 l/s of water have reached Berbera and this amount of water was much below the water needs of the town. The water deficit was later partially balanced by the Biyoguure springs or by water trucked from other places.

The Biyoguure springs are located about 25 km west-southwest of Berbera. Popov et al. (1973) report that "along the zone of sandstone of Cretaceous age there are many hot springs stretching over an area of 300-400 m. Water temperature ranges from 48 to 58^{0}C. Discharge in the zone is up to 37.5 l/s." Aquater (1982) surveyed three main spring points and described the Biyoguure springs as located in a narrow valley consisting of the Nubian sandstones and the overlying Auradu limestone, crossed by numerous faults and fractures. Water of the T. Biyoguure is a mixture of thermal spring water and shallow water of the togga bed. EC values range from 2,600 to 4,025 µS/cm; in one of the springs, an EC of 7,425 µS/cm is also reported. Water is of the sodium sulphate type, with $S0_4>C1>HC0_3/Na+K>Ca>Mg$. Despite the marginal quality and bitter taste of water from T. Biyoguure, the Russians constructed an infiltration gallery as an intake structure and a pipeline delivering water to a desalinization plant. This plant was never operated because the Russians left the country before its completion. From the intake, water is delivered by gravity by a 0.30 m diameter pipeline to the purification/desalinization plant consisting of a 180 m^3 reservoir, three groups for electrolysis, and five rapid filters.

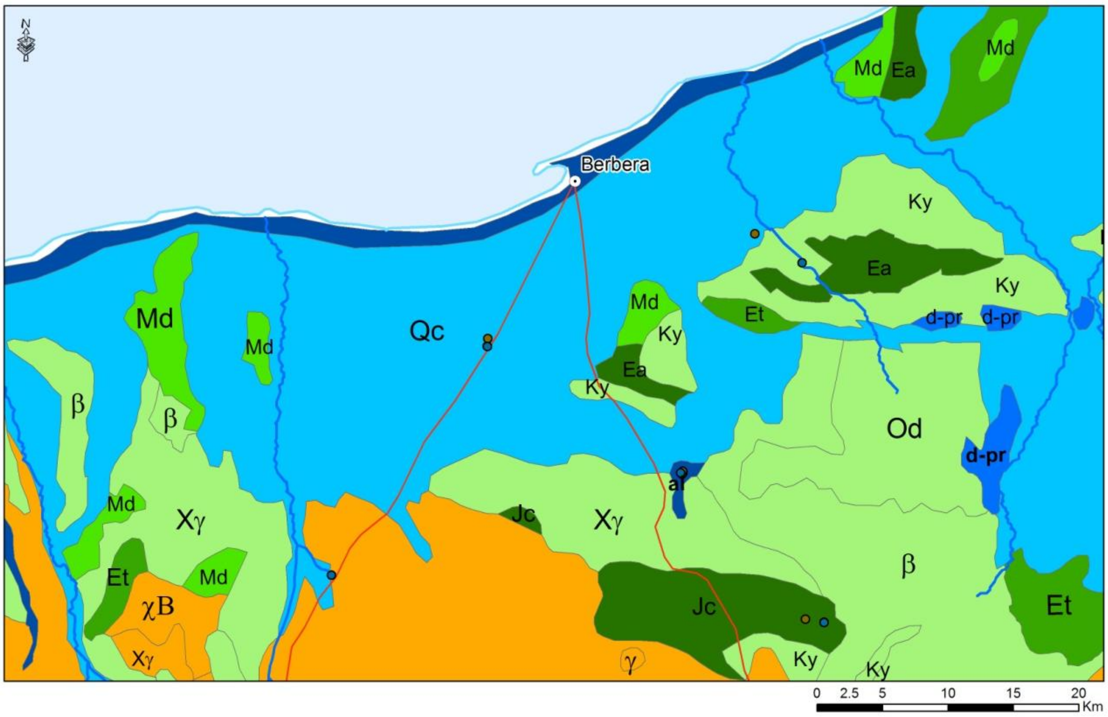


Figure 5.37 Details of the Regional Hydrogeological Map of Somaliland and Puntland – Aquifer systems in Berbera area

The Dubar spring was tapped in 1974 for the water supply of the cement factory constructed at the foot of the Farshahelo ridge, 11 km southwest of Berbera. The daily demands of the cement factory had been estimated at 2,245 m^3. Water from the small Dubar spring (about 1 l/s) issues from boulders and pebbles but disappears in alluvial deposits 200-300 m downstream so it was difficult to estimate the underflow. To assess the water availability, an 80 m-long drainage ditch was dug to intersect the underground flow of the small valley. The ditch, 1.5-2.0 m deep, was dug through gravel and boulders and penetrated 20-30 cm into the underlying sandstone and limestone. The ditch was used to supplement the water supply of Berbera with 60 m^3/day trucked to town.

The groundwater exploration of the Togga Kalajab Valley involved the drilling of 11 piezometers, each 15 m deep, and 4 large diameter production wells. The Kalajab wadi consists of alluvium, conglomerate and limestone overlying fracture biotite gneiss. A subsurface dam was constructed across the valley with the wall formed by pillars of clay. Four production wells 500 mm in diameter and 50 m deep were drilled between 320 and 560 m upstream from the dam. The combined critical yield of 70 l/s (6,000 m^3/day) is claimed to be a "safe yield". Assessment of groundwater storage (based on the apparently very high porosity of 40%) is 2.08 million m^3. According to the pump test results it was assumed that 250 m^3/hr could have been safely pumped from the four production wells but any further extraction would draw water from storage and deplete the aquifer, with a consequent reduction in well yield.

Water from the Kalajab well field is considered excellent; the EC ranges from 610 to 850 µS/cm and can be used for all purposes. Water is of the calcium or sodium bicarbonate type, with $HC0_3$>$S0_4$>C1.

Berbera today has some 30,000 inhabitants. This largest port of Somaliland has an important trading role as an export center of animals mostly to Arab countries. Around 70% of the population is connected to the water pipeline. As compared to previous times, today the majority of tap water comes from the above-mentioned boreholes drilled in Miocene limestones (KF HG unit) with an average depth of 55 m. Their total discharge is 56 l/s, while only 7 l/s of water are tapped from the spring. Neither water sanitary control nor water treatment takes place in Berbera.

5. Sheekh (Sheikh, Togdheer region**)**

This is a city in Togdheer Region on the Hawd plateau.

SHAAC report considered water situation in the year 2006/07 as follows: "Currently Sheekh is supplied water from a borehole drilled at the bank of a stream located at about 10 km south of the town. According to the Sheekh water supply authority head, the well is drilled to 160 m belo ground level (bgl), and pump position is 150 m bgl. The yield of the well is estimated of about 5 l/sec (18 m^3/hr). Water is pumped from the well to a pumping station located at midway between the borehole and the town.

For Sheekh town, the borehole is not capable of supplying water to the entire town; therefore, some of the residents obtain their drinking water from hand-excavated wells in the stream. There are about five hand-dug wells in a stream located in north of the town. The maximum depth of these wells is about 6 m. Water output from these wells was estimated about 20 m^3/day. The sanitary conditions of these wells are very poor."

It is home to around 15,000 inhabitants. Two deep boreholes were drilled (150 m deep) in Dubur village, 12 km to the east, but the small yield they produce, less than 1 l/s, cannot satisfy even basic needs in drinking water. Therefore, only 4% of the population uses water from these boreholes (80 houses and one elementary school).

Figure 5.38 a,b Drilled well OWB002 for water supplying of Sheekh town

6. Burco (Burao, Togdheer region**)**

One the largest towns in Somaliland, it is a livestock trading center. It is situated on the banks of Togga Togdheer at an elevation of 1,060 m a.s.l. and belongs to Togdheer Region. Its population is today assumed to be 450,000, of which around 40% have a connection to tap water. Fresh groundwater is present in alluviums (al) and Auradu (Ea) karstic aquifer (K1).

According to the GKW report (1977) the average annual rainfall is 201 mm; in 34 years with full records the maximum mean yearly rainfall was 333 mm in 1973 while the minimum was 74 mm in 1922. The rainy seasons are from April to June and from September to October. Potential evapotranspiration is highest from June to September, exceeding 200 mm/month.

Macfadyen (1951) carried out a detailed groundwater investigation of the shallow aquifer recharged by the periodical run-off water of T. Togdheer. He inventoried 147 hand-dug wells. The wells are dug in old, red alluvial sand and in river sand. The wells are quite scattered, forming two major groups: the Ceel Gooni wells, with depths ranging from 18 to 24 m; and the Burco Weyn wells, about 1.5 km downstream. Wells located close to the river bank yield the most water while those further away yield less water with a higher EC.

From 1950 to 1975, numerous wells were drilled in Burco, but information is limited to GKW reports which list 11 old wells, three of which were out of operation when the inventory was carried out in 1976. Further wells drilled under the GTZ program helped solve, to a considerable extent, the water supply demands of the growing town. Additional water, used mainly for livestock watering, is obtained from the wells drilled in 1984 by the Chinese project. Faillace & Faillace (1986) concluded that despite these efforts, Burco in the 1980s was still having serious water supply shortages and large sectors of the town were not connected to the town's water supply network.

These GTZ and Chinese boreholes were drilled to greater depths (135 to 218 m), and commonly produced between 20 and 30 m^3/hr. Most of the drilling took place on the northeastern bank of T.Togdheer, in the so-called “Governmental Area”. Water quality was generally acceptable, despite the relatively great depth.

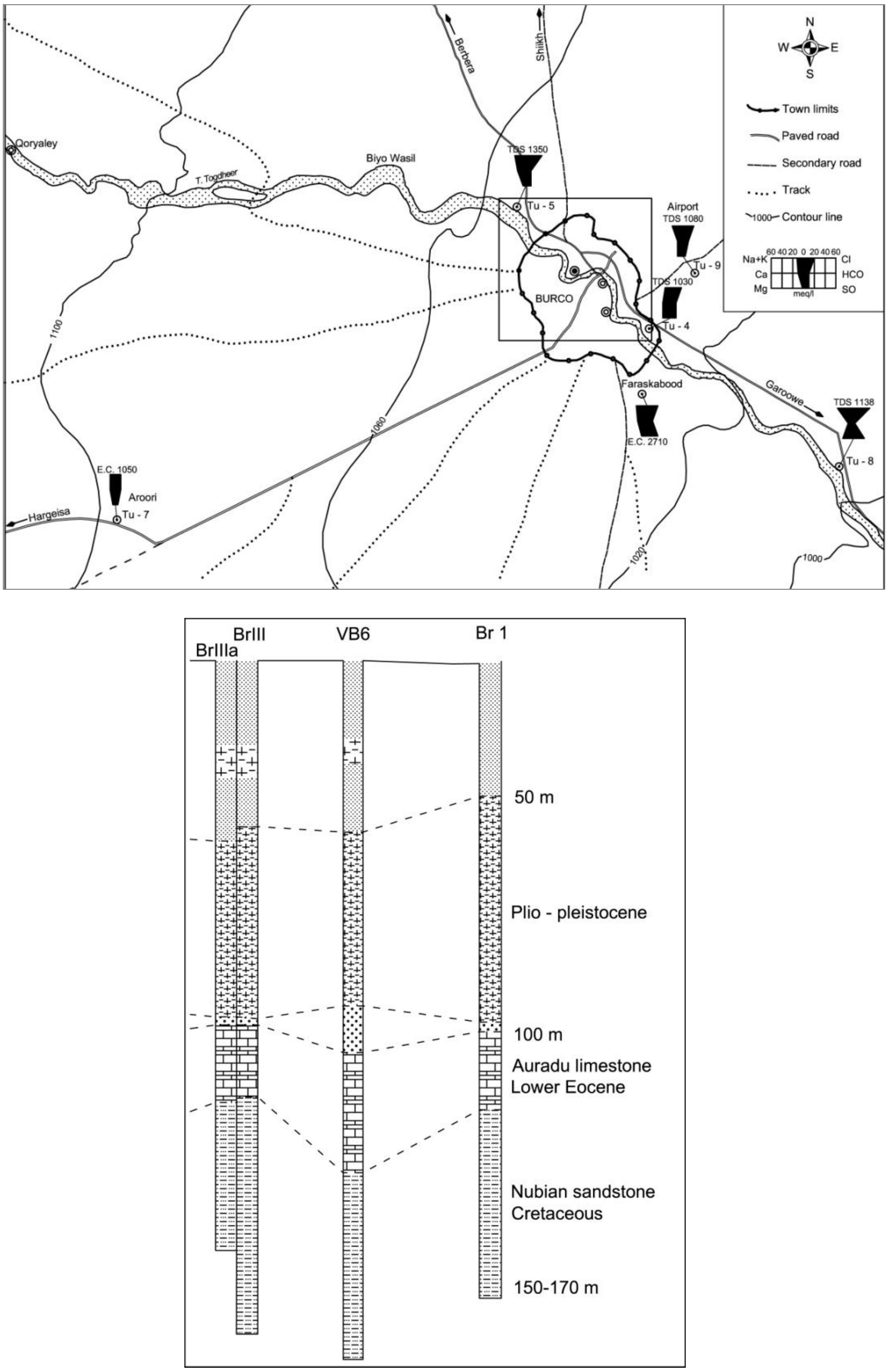


Figure 5.39a,b Map location and logs of Burco wells drilled by GTZ (Faillace & Faillace, 1986)

Faillace & Faillace (1986) stated that deep boreholes drilled through Plio-Pleistocene sediments 90-100 m thick, consisting of reddish-brown sand with silt, gravel and conglomerate, cover 10-20 m of residual Auradu limestones overlying the Nubian sandstone.

The Auradu limestones severely eroded during the uplifting of the mountain area and subsequently covered the thick sequence of the Plio-Pleistocene deposit by Togga Togdheer. The lithological sequence of one of the deepest wells drilled by the support of GTZ is shown on Figure 5.39 b.

"There are three aquifers in the Burco area: the shallow alluvial aquifer, the intermediate Auradu limestone aquifer, and the deeper Nubian sandstone aquifer.

The shallow alluvial aquifer is tapped by numerous shallow wells, 12-25 m deep, dug mainly in the togga banks. The 40 m of alluvial sediments are constituted mostly by red-brown silt and fine sand, including some thin layers of coarse sand. From 40 to 80 m, sediments are mainly silty and clayey, interlaid with coarse pebbles in a clayey matrix. Below 80 m there is a 10 m-thick layer of medium to coarse pebbles.

The shallow drilled wells and most of the hand-dug wells tap water from a perched alluvial aquifer. Below 30 m there is a great reduction in permeability of the alluvial deposits.

The intermediate Auradu limestone aquifer is generally located below the 90-100 m of Pleistocene continental sediments described above. The thickness of this aquifer is around 10-20 m, increasing south of Burco as indicated by the lithological data of a well drilled by the Chinese (9 km southeast of Burco). This well penetrated 66 m of Pleistocene continental sediments, followed by a sequence of limestone and argillaceous limestone from 66 to 173 m, with yellow shales at the bottom.

The water level of this aquifer is below 100 m.

The Nubian sandstone aquifer was penetrated in all deep wells. The fact that most deep wells tap water from both the Auradu limestone and the Nubian sandstone makes it difficult to determine whether these two aquifers behave distinctly or whether they are interdependent; they are most likely interrelated and recharged from the same area.

The hand-dug wells represent the traditional water source of Burco. They tap the shallow groundwater stored in the thick sediments deposited by Togga Togdheer. During the dry season thousands of animals are watered daily from the hand-dug wells in Burco. Hygienic conditions of the wells are very poor and, in most cases, water is polluted both by the skin buckets used to withdraw the water, and the spilled water which brings pollutants into the aquifer.

Figure 5.40 Pumping one of the Burco wells

The somewhat mixed water tapped by deep wells is supplied by the basal conglomerate of the Pleistocene sediments, the Auradu limestone, and the Nubian sandstone. GTZ well Illb taps mainly the Nubian sandstone; its screen section is from 144 to 185 m with three blank casing intervals. This is the most productive well, with a specific capacity of 16 m^3/hr/m (4.5 l/s/m'). The Chinese well Tu5 also taps the Nubian sandstone, having the screen section between 157 and 215 m, but in this case the specific capacity is only 0.98 m^3/hr/m. The yield of the other deep wells ranges between the two values given above."[22]

Shallow wells located on the banks of T. Togdheer yield water of good quality, with EC values ranging from 400 to 800 µS/cm. Deep wells in Burco located on the eastern side of the T. Togdheer have an EC generally below 2,000 µS/cm, while drilled wells located on the western side of the togga have an EC ranging from 1,460 µS/cm to 6,200 µS/cm (Faillace & Faillace (1986). Water from drilled wells is generally of the sodium sulphate type, with $Na+K>Ca>Mg/S0_4>HC0_3>Cl$; in some analyses the second anion is Cl instead of $HC0_3$. Calcium or sodium chloride water type was found in a few wells. However, a deep well drilled in Aroori, near Burco (Chinese programme, 1986), yields excellent water of the sodium bicarbonate type ($HC0_3>Cl>S0_4/Na+K>Ca>Mg$), with an EC of 1,120 µS/cm.

van der Plac stated that in the year 2001 Burco Town is served by two of the old GTZ boreholes (No. 1 and 2, formerly known as GTZ-1 and -3). At 15 hours of pumping, the combined capacity was about 680 m^3/day, excluding additional supplies from shallow wells, private sources and livestock boreholes. Water was

[22] Cited from Faillace & Faillace (1986)

pumped directly into the partially functioning mains, and is further distributed by tankers to areas not yet served by the system.

Apart from the remaining GTZ wells, two of the Chinese boreholes (Tu-4 and Tu-9) on the southeastern outskirts of the town were still in operation in 2001. when van der Plac conducted survey. Water is mainly supplied to displaced and nomadic communities, livestock and tankers. Due to their remote location, connection to the distribution pipes was found not to be economically viable.

The SWALIM survey in 2011/12 found that 6 wells are operating north of the city, while 2 more are tapping groundwater in the southern suburban zone. Their average depth is 170 m and their total discharge amounts to 57.9 l/s. An average yield ranks between 4-6 l/s; the most recent drilled with the support of UAE (Dubai) is yielding 4.4 l/s. An average drawdown is just 3 m according to Burco Water Agency. No chlorination and no permanent sanitary control are established. The total length of pipelines is 30 km, and there is just 1 reservoir constructed; it can store 40 m^3 of water.

7. Ceerigaabo (**Erigavo**, Sanaag region)

Ceerigabo is located in the northern part of Somaliland about 70 km from the coast. It is the capital of the Sanaag Region and its population is continually growing. According to Macfadyen, Ceerigabo had only 2,000 inhabitants in 1948; 30 years later its population was estimated by GKW at 13,000 inhabitants. Livestock rising is the major activity, and limited irrigated agriculture exists along the narrow belt of the two small toggas (T. Gudma and T. Midisho) located in the area of Ceerigabo. Small springs located on the escarpment are also used for the irrigation of agricultural lands and small gardens.

The hydrogeological conditions of Ceerigabo were first investigated by Macfadyen who, in 1948, made an inventory of all water sources including hand-dug wells and springs. In the 1960s three wells were drilled by the government for the township water supply. GKW surveyed the area in 1975-1976 and drilled two production wells. In 1981 GTZ drilled a third well for the future Ceerigabo water supply system under the "Water Supply II" program. A groundwater reconnaissance survey was also carried out by C. Faillace (1983).

"Two major geomorphological features characterize the Ceerigabo area: an east-west mountain range reaching up to 2,400 m in elevation constitutes the impressive escarpment facing the Gulf of Aden; and a plateau, 1,200 to 1,900 m a.s.l, which extends behind the mountain range. Rainfall varies considerably from year to year.

Over a period of 26 years records show that Ceerigabo has a rainfall average of 314 mm/year, with a minimum of 160 mm/year and a maximum of 520 mm/year."[23]

The top of the escarpment located 15 km north of Ceerigabo and ending towards the sea is constituted by Tertiary sediments followed by Mesozoic rocks overlying the basement complex. All three Eocene stratigraphic units are also exposed in the Ceerigabo area: the Auradu limestones (Ea – K1 HG unit), the Taleh (Taleex) evaporitic series (Et - K2), and the Karkar limestones (Ek – K1). Eocene sediments are mostly covered by alluvial or terrace/red soil deposits.

The Auradu limestones (Ea), deeply incised by numerous streams, outcrop along the edge of the escarpment and are composed mainly of cherty limestone and massive dolomite. At the escarpment near Ceerigabo its thickness has been estimated at 380 m. The Auradu is dissected by many faults and fractures enabling fast infiltration and aquifer recharge. Several permanent springs along the escarpment drain the Auradu Formation. These springs are small and generally discharge their water at the contact with interbedded marls.

Figure 5.41 Meer Meer pothole in Auradu limestones(Ceerigabo)

The Taleh (Taleex) Formation (Et) is composed mainly of anhydrite with gypsum in the upper part, followed by clay and marls interlaid with limestone. The series is intensively karstified with sinkholes and dolines. Runoff water rapidly disappears into these collapsed structures. In the past sinkholes represented the traditional water source of the town. At present water from this source is used for watering livestock and for the irrigation of small gardens. Discharge through karst springs occurs in Ceel Afweyn, east of Ceerigabo.

[23] Cited from Faillace & Faillace (1986)

The Karkar Formation (Ek) is constituted by white limestone topping the Taleh sediments and covers small areas north of Ceerigabo.

Alluvial deposits consisting of clay, sand, and gravel are found in depressions of the Taleh Fm. and cover the bottom of dolines. The alluvial aquifer filling a depression north of Ceerigabo supplies water of good quality. The aquifer is recharged by direct rainfall and by the runoff water from the area covered by the Auradu limestones. The eastern alluvial deposits covering the Taleh Fm. yield water of poor quality. The water table is generally at depths between 4 and 5 m.

Water samples collected from numerous hand-dug wells and karstic holes in the Ceerigabo area show that the EC ranges between 3,000 and 4,000 µS/cm. Water is generally of the calcium sulphate type.

Until 1950. Ceerigabo obtained its water from hand-dug wells and karst holes. Several underground reservoirs were built to provide water of better quality for the increasing population. Between 1964 and 1975 three wells were drilled in the northern part of town. Water under phreatic conditions was also struck in the karstified limestone met in GTZ wells I and II, each 66 m deep. GTZ well III also encountered water under similar conditions between 17 and 22 m. Water under confined conditions was struck at 71 m and rose to 17.7 m below ground. Four more wells, as mentioned earlier, were drilled under the GTZ "Water Supply II" program from 1979 to 1981.

The most productive wells yielding fresh water are those drilled in Auradu limestones. Faillace & Faillace (1986) noticed that GTZ borehole Illb was completed at a depth of 163 m; screens of 8 inch steel pipes were installed from 163 to 195 m. The very large discharge of 50 l/s made this well the most productive one in all of Somaliland. In fact, it was found that water from this well alone was sufficient to meet the water supply needs of the town, but people have since filled it with stones.

Nowadays, out of eight drilled, only five wells are operating for the water supply of Ceerigaabo. They produce 45 l/s, in total. The drawdown in some of them can reach 50 m. Water quality is not controlled regularly; during the SWALIM survey it was reported “there is often a change in taste and some people have kidney problems”.

Figure 5.42 The Affaaf spring Ceerigabo (Auradu Fm.)

8. Boosaaso (Bossaso, Bari region**)**

It is the second largest port in Gulf of Aden and the major city in the NE region of Bari. Its importance and size have been growing during recent decades. Currently it has around 350,000 inhabitants, approximately 45% of whom have access to tap water The main water source is located east of the town in Togga Biyo Kulule. There, 10 wells were drilled in alluvial sediments with an average depth of 60 m. The average pumping rate is around 10 l/s which enable a total groundwater extraction of ca. 100 l/s. Given that this port is also one of the largest collecting centers of large ruminants prior to their exportation by ship, part of this water is also used to water them.

9. Laas Canood (Sool region)

This city is located on the high plateau of Sool, which was populated by 10,000 inhabitants in the 1980s. Also an important centre for nomads, its population fluctuates considerably. The city is surrounded by Taleh gypsferous and anhydrite formation (Et – K2 HG unit), while underlying the Auradu limestones (Ea – K1) are very good reservoirs of fresh water. The depth to the Auradu Fm. is 140 m, as recorded in one of the deep boreholes drilled for water supply to a depth of 280 m (Faillace & Faillace, 1986).

In the 1950s, to supply drinking water and to water animals, several shallow wells were dug out, tapping the groundwater from the delluvial and weathering zones as well as alluvial sediments along the Togga Laas Canood. Three wells were drilled in the 1970s. The one at 2,800 m was the deepest, while the other two stayed in Taleh Fm. and in overlying alluvium. Of these two, one is 60 m, and the other 48 m deep.

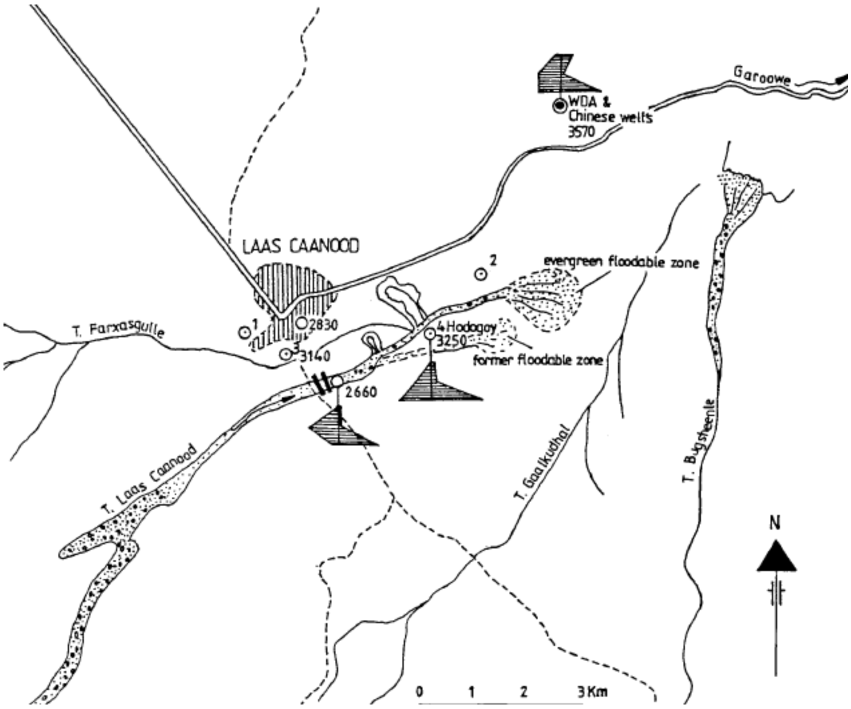
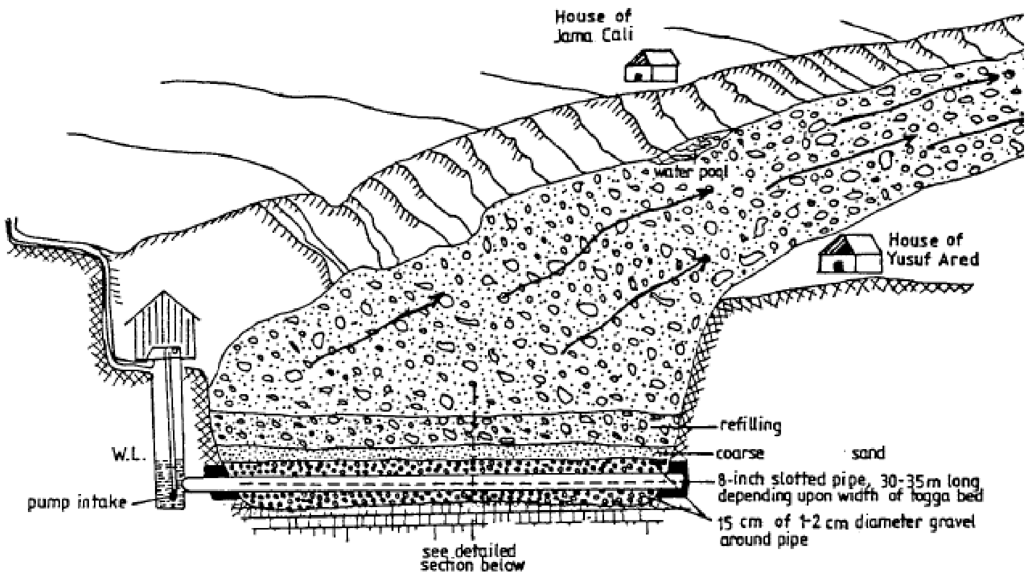


Figure 5.43 Sketch map of Laas Canood area (Faillace & Faillace, 1986)

To improve the water supply of the city, Faillace (1983) proposed the construction of an infiltration gallery (see section in Figure 5.44). According to our knowledge this project was cancelled.



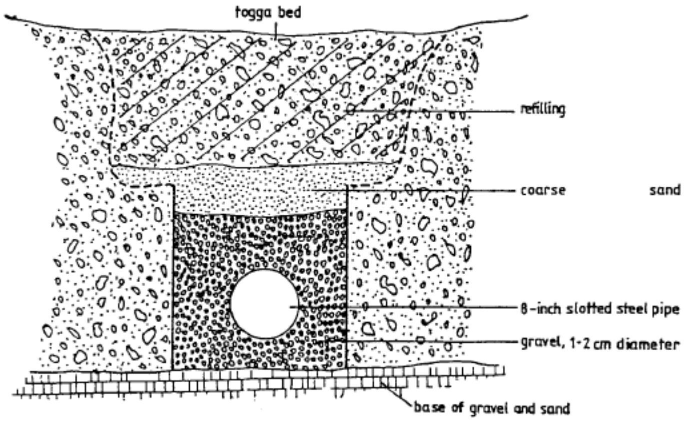


Figure 5.44 a,b Proposed design of an infiltration gallery near Laas Canood (Faillace, 1983)

10. Qardho (Bari region)

Qardho is the second largest town in the Bari region. It is located on a high plateau with a typical arid climate and very low rainfall rate. The average annual rainfall is less than 100 mm, with a maximum of 194 mm in 1963 and a minimum of only 8 mm in 1966.

Faillace & Faillace (1986) described the geological setting as follows: "The hills surrounding Qardho are constituted by stratified limestone of the Karkar Formation. They were incised by a drainage system, occasionally active during flood events. The bottom of the Qardho Valley is covered by alluvial deposits. A gypsum-anhydrite crust, probably of rather recent lacustrine origin, also covers the bottom of the valley. Intense karstification, with sinkholes and karst pipes, affects these deposits and the underlying evaporitic series. Aeolian sands are also present in several areas of the Qardho Valley."

There are two aquifers in Qardho. In the 1980s a shallow aquifer in alluvial deposits was tapped by about 15 hand-dug wells. The aquifer is recharged by the drainage of the Karkar Plateau during the few scattered rains. The water level in these wells varied between 6 and 9 m. Water is of relatively good quality. EC values are less than 2500 µSs/cm.

The deeper aquifer is in the limestone of Karkar Fm. (Ek – K1 HG unit). This aquifer has been tapped by several wells drilled in Qardho and surroundings. The first deep well, drilled in 1954, was 200 m deep. It was later abandoned for some unknown reason. Another well was drilled by the Chinese in 1985. Water was usually found under semi-artesian conditions, e.g. GTZ I struck a major inflow of groundwater at the depth of 186.5 m; the water level rose to 128.3 m. The water inflow occurred in soft fissured rock, probably anhydrite and gypsum (probably underlying Taleh Fm.).

Optimal discharge of GTZ I well was calculated on 4.5 l/s. This is one of the very few properly developed and tested wells in the entire region. Transmissivity varied between 4.69×10^{-4} m^2/s and 5.26×10^{-4} m^2/s.

Today Qardho has a population of 42,000, of which ¼ have tap water. For the water supply four wells are currently used, three of them drilled after the year 2,000. The average yield is between 3 and 4 l/s, yielding in total 13.3 l/s. Hodman Water Agency performs a sanitary control once per month while chlorination is regularly applied.

11. Garoowe (Nugaal region)

It is the capital of Puntland and Nugaal Region. The town is situated on the banks of Togga Garoowe and is surrounded by limestone hills. Garoowe is an important trading center. The population of Garoowe was around 15,000 inhabitants in the mid-1980s, while today it is five times larger, with around 75,000. This number, however, fluctuates considerably over the year due to the presence of nomads.

Climatic conditions in Garoowe are similar to those in Qardho. The average annual rainfall was 110 mm over a period of 22 years (1954-1975), with a minimum of 8 mm (1966) and a maximum of 246 mm (1954).

The geology of the area surrounding Garoowe is described by Faillace & Faillace (1986): "The area is covered by stratified limestone of the Karkar Formation, deeply incised by Togga Garoowe. The gypsiferous Taleh Formation outcrops southwest of the town. Alluvial deposits, not over 10-12 m thick, cover the bottom of T. Garoowe. The uplifting of the Nugal Valley, along which Eocene and other older sediments outcrop, caused faulting and folding which affected the Garoowe Valley. An anticline, east of Garoowe, is the most important tectonic structure of the area. The southern side of the anticline is eroded while the northern part, constituted by the Karkar Formation, is preserved. The Garoowe Valley follows a northeast-southwest direction."

Similar to Qardho, there are two main aquifers in Garoowe: a shallow perched aquifer (I1 HG unit) and a deep confined aquifer in Karkar limestones (Ek – K1) or in Taleh Fm. (Et – K2).

Faillace & Faillace (1986) noticed that perched aquifer is located in the alluvial deposits of T. Garoowe and in the upper part of the Taleh Formation which outcrops along the togga. The water level varies between 6 and 10 m below the surface. This shallow aquifer recharges during the flow of the togga; the clay sediments penetrated in GTZ II between 12 and 26 m constitute the impermeable base of the shallow aquifer. Over 30 hand-dug wells tapped the shallow aquifer; they were the main water source of Garoowe in the 1980s. T. Garoowe has a permanent underground flow which is also tapped by shallow wells to serve numerous animals daily.

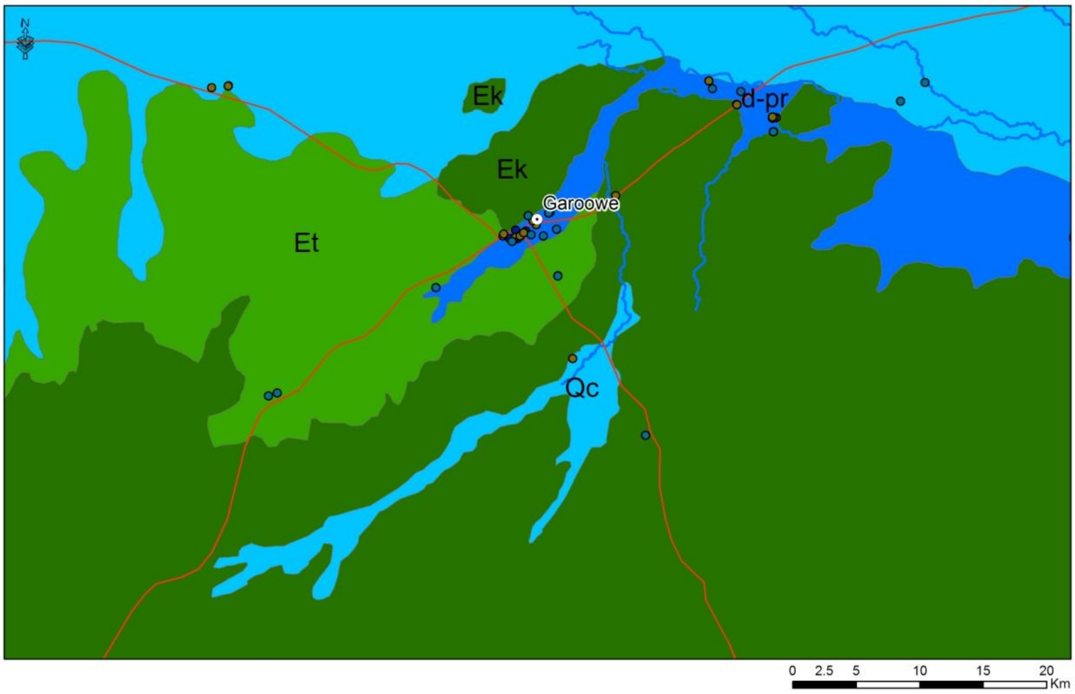


Figure 5.45 Detail of the Regional Hydrogeological Map of Somaliland and Puntland – Garoowe area

Of three drilled wells, the WDA well was drilled in 1976 and is reported to be 160 m deep with a water level at 40 m. The other two wells were drilled under the GTZ program for the township water supply in 1979 and 1981 (details of these two wells are given below, after Faillace & Faillace, 1986).

Well	**Depth**	**W.L.**	**Yield**	**Drawdow**	**EC**
No.	(m)	(m)	m^3/hr	(m)	µS/cm
GTZ I	36	9.04	24	20.5	3348
GTZ II	145	9.70	110	22.4	4170

"GTZ I was pumped for one hour at 24 m^3/hr (6.6 l/s) with a drawdown of 20.5 m, corresponding to a specific capacity of 1.17 m^3/hr/m'. The recommended rate of exploitation was 15 m^3/hr. The transmissivity, as calculated from the recovery test, was 1.36 x 10^{-2} m^2/s.

GTZ II has a much higher production. It taps both the shallow and the deep aquifers with screens located at various intervals between 23.5 and 135.5 m. The specific capacity of this well is 4.93 m^3/hr/m' and the transmissivity was calculated at 4.6 x

10^{-2} m^2/s. According to observations made during the recovery test, the piezometric level of the semi-confined aquifer is about 26 m below the surface. The inflow from the shallow aquifer raises the level to 10 m below the surface."[24]

The water from the GTZ I shallow well had an EC varying between 2,934 and 3,880 µS/cm, while the water from WDA and GTZ II deep wells had EC values between 3,200 and 4,200 µS/cm.

Water in both the shallow and deep wells is of the sulphate type, with $S0_4$>Cl>$HC0_3$/Ca>Mg>Na+K. Sulphate content is very high, ranging from 1,854 to 2,550 mg/l in drilled wells and from 1,911 to 3,240 mg/1 in hand-dug wells. Fluoride content is 1.2 mg/1 in GTZ I and 2.3 mg/1 in GTZ II, while in the WDA well it is 3 mg/1, with 1.5 mg/1 of iron.

Today, just one of the wells drilled in the 1980s is still in use. It discharges 9.7 l/s. Four other wells (100 - 280 m deep) were drilled within the period 2007-2012. Their total production is around 33 l/s, but not all of them are connected to the system. Around 21,000 residents are connected to the pipeline whose length is 48 km. There is one large reservoir; its volume is 725 m^3. Water is sanitary controlled sporadically.

12. Gaalkacyo (Mudug region)

This is another fast-growing centre and the capital of the Mudug region (southermost part of the study area in the Puntland). The city has a population of 450,000, almost 80% of whom have access to tap water. There are 7 boreholes drilled; their average depth is 210 m. They tap the groundwater from younger Quaternary and Miocene deposits to a total amount of around 90 l/s. The two most productive wells drilled recently (2011/12) yield 16-17 l/s but drawdown is significant: it can reach 70 m during pumping.

Water is not sanitary controlled, the pipeline network is over 90 km, and there is one reservoir constructed with a storage capacity of 750 m^3.

13. Bacaad weyn (Mudug region)

This is a town in Mudug region with around 30,000 residents. Two deep boreholes were drilled, one 180 m and one 230 m deep. Their discharge is in the range of 2.2 – 5.6 l/s. The groundwater is tapped out from Karkar limestones (Ek – K1 HG unit).

14. Eyl (Nugaal region)

This is a port in the Indian Ocean. Due to security reasons no SWALIM survey took place in 2012. According to old data, the city is supplied from Togga Nugaal, the

[24] Cited from Faillace & Faillace (1986)

springs, and the shallow aquifer along the coast (Faillace & Faillace, 1986). Especially important is groundwater flow along the togga bed which has been indicated by simultaneous hydrometry. Faillace & Faillace (1986) reported the flow in one section which increased from 73.5 l/s to 490 l/s. In another section the flow increased from 700 to 1,450 l/s.

The major spring is Dabei. Water probably flows out from the contact between white marls and the overlying calcarenite and sandstone (Hafun Series) at the base of the Eyl cliff. According to Pozzi et al. (1983) its flow varies between 9 l/sec and 20-25 l/s.

* * *

Fourteen surveyed water utilities serve major towns and settlements in Somaliland and Puntland which have in total around 2,544,000 inhabitants. This number is roughly almost half of the total population. However, not more than 25% of the population is connected to water distribution systems and pipelines. The minimal percentage of coverage with tap water is in Sheikh, only 4%, but most problematic is Hargeysa where over 750,000 of residents, mostly in suburban areas, have no proper access to tap water (!).

If the amount of around 80 l/capita/day is considered an adequate standard for water requirement in urban areas of Somalia[25], the total water demands for 2.5 million residents located in surveyed settlements are 200 x 10^3 m^3, which is equivalent to 2.31 m^3/s. Considering the fact that the current extraction rate for these settlements is 0.74 m^3/s (according to information provided by the utilities during our recent survey), there is a shortage of around 1.5 m^3/s, or, in other words, almost 70% of actual water needs for 12 cities are not being met.

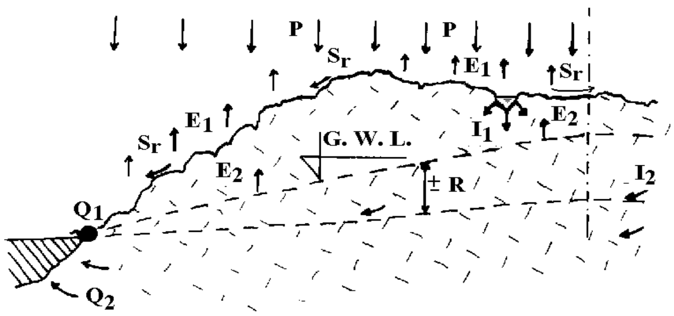
[25] Water demands depending on standard of living and actual sanitary conditions and also including the demands of the industrial sector, but no water for irrigation or animals supply

Figure 5.46 Shallow well dug in God Caanood by some NGO for humanitarian purpose

5.1.2 Groundwater budget and reserves for selected aquifers

The groundwater balance calculation, together with resource assessment, is one of the most important tasks of most hydrogeological projects because it ensures proper planning of groundwater exploitation, determination of safe yield and measures to be applied for control and regulation of aquifers.

Several standard methods can be applied to balance groundwater. The different methods are developed in hydrogeological practice regarding the two main types of aquifer, karstic and intergranular, present in Somaliland and Puntland.



$$P + I_1 + I_2 = S_r + E_1 + Q_1 + Q_2 + E_2 \pm R \pm E$$

p - precipitations
I_1 - surface-water inflow
I_2 - groundwater inflow
S_r - surface runoff
E_1 - evapotranspiration
Q_1 - spingflow
Q_2 - subsurface outflow
E_2 - evaporation from groundwater level
R - groundwater reserves
E - errors

Figure 5.47 An example of basic water budget equation applied in karst terrains (Stevanovic, 1998, 2011)

The selection of the appropriate procedure depends on many factors. Generally, application of a procedure depends on available data. In the case of regional research conducted under HASP and the very limited fund of data on the groundwater regime, a very rough assessment and only some provisional calculations are possible. For example, the simplest balance (budget) equation can be presented as:

Inflow = Outflow +/- Reserves

and if modified to meet hydrogeological (aquifer) basic functions, it can be written as:

P = Q + Losses +/- Reserves

where,

P - total effective precipitation (infiltration from rainfall or surface water)

Q - total aquifer drainage / springflow / subsurface outflow / pumping (artificial)

Losses - total losses on evapotranspiration, surface runoff

Reserves – changes in volume of stored groundwater during period of calculation

This formula can be used as a preliminary step towards the assessment of the annual water cycle by approximating water transit through the selected area during an average hydrologic year (i.e. water transfer in and out of the aquifer system). Conversely, inadequate knowledge of each element of the balance equation, including physical and hydrogeological parameters of the aquifer, is a limiting factor for an accurate and reliable exercise. Some elements, such as evapotranspiration or subsurface drainage, are very difficult to assess. Potential evaporation can be measured by different pan devices, but for the budget element as a whole, which includes transpiration, different empirical formulae can be used, and their careful selection, comparison and evaluation of the results are the preferred way to obtain a preliminary picture of its magnitude.

Different kinds of stochastic and deterministic analysis can be taken into consideration and adequately applied for modeling and forecasting (Bonacci, 1993; Goldscheider & Drew, 2007). In hydrogeological practice the 'black box' system and stochastic analysis are widely applied to fissured non-homogenous mediums. Analysis of the spring hydrograph (and base-flow separation) is also one of the widely applied methods for fissured systems (Padilla et al. 1994). This method provides an assessment of the dynamic and static volume of resources stored or in transit within the aquifer throughout the hydrologic year, and during the recession period in particular (Stevanovic et al. 2010). Analysis of fluctuations of the groundwater table in an intergranular aquifer is an important indicator for natural discharge (including subsurface drainage), artificial extraction (pumping) rate and intensity of evapotranspiration.

Mathematical modeling of groundwater flow through the aquifers is successfully applied mostly within a homogenous and isotropic environment i.e. where the intergranular type of pores dominate. Usually, the first step in this approach is the development of a conceptual model representing a simplified description of the groundwater system to be studied. Geometry of the reservoir area and its boundaries, hydrography, water balance, aquifer properties (porosity, hydraulic conductivity, storativity, isotropy and horizontal and vertical variation), potentiometric surfaces and other features are described in a level of detail commensurate with the ability of the data to represent the system.

However, no other method is possible except provisional simplified assessment of budget elements based on available references, experiences from other similar arid areas (Lerner et al. 1990, Stevanovic & Iurkiewicz, 2004) and, however limited, recently collected data by SWALIM.

Basically, water balance (budget) as a plot of the inflows and outflows through the model body is the key to a conceptual model. Examples of inflows into the study area include: recharge from precipitation, leakage from surface water subsurface flow from up-gradient of the study area. Examples of outflows from the study area include spring discharge, subsurface flow, evapotranspiration, temporary runoff and extraction wells.

Groundwater reserves also may be roughly estimated directly through the balance calculation. Dynamic reserves (renewable annually) can be considered as total outlet (spring) discharge or extracted amount of water without drawdown (in this case the difference between the water table at the beginning and the end of the budgeting period). Static (geological) reserves are usually calculated based on the aquifer's geometry and permeability (effective porosity).

Figure 5.48 Extracting groundwater from shallow and deep wells is one of the main budget output elements (drainage). The well is dug out in delluvial material in the Karkar Fm. foothill (Buuhoodle, Photo Puntland team 2)

Taking into account the conditions described above, only the four most prosperous and, in terms of groundwater, richest aquifer systems are evaluated for the general assessment of the budget elements and renewable groundwater resources. They are:

1. Major Togga'a alluviums (al- I1),
2. Jurassic limestones (Jc-K1),
3. Auradu limestones (Ea-K1),
4. Karkar limestones (Ek-K1).

The surface area of their outcrops in the study area covering Somaliland and Puntland has been taken from a GIS map, while rainfall rates as average values are obtained from the SWALIM database but also from some earlier sources (such as an isochyete map). The balance calculation is done for an average hydrological year.

Major Togga'a alluviums are extended on the surface at 3,663 km^2. This figure should be taken with caution simply because it includes only alluviums presented on the Regional hydrogeological map (Annex I) but not the "smaller" toggas. Considering that the scale of the map is 1:750,000, some toggas with riverbeds 100 m wide or even more may not be included in this number.

Considering that alluviums are highly permeable and that most of the runoff water infiltrates into this aquifer very fast after the rains, an estimated average of 60-70% of rain falling on the alluvium surface could represent its infiltration capacity. Some of these waters evaporate from the free water table making it reasonable to expect that no more than 50% of the rainfall is infiltrated into the aquifer. If 250 mm is taken as a rough approximation of the average annual sum of precipitation (in the "average" area of Somaliland and Puntland), the annual recharge would be theoretically equal to 458 x 10^6 m^3 (or 15.2 m^3/s as an average groundwater flow or renewable resources stored in or flowing through major alluviums). Of course, not all this water could be tapped, which is an issue to be discussed in the following chapters.

Figure 5.49 The dug well in empty togga near Sheekh (Togdheer, Photo Somaliland team 2)

Important support to recharge the alluviums comes from neighboring Quaternary aquifers which are connected to toggas. These are diluvial-proluvial deposits (d-pr) and terrace sediments (Qt), and almost always represent so-called "alogenic" catchments to the alluviums, except in cases where a stream cuts into some gorge or canyon. Their extension at the surface is much larger even than the alluvium ones. The runoff waters at the edges of basins, foothills and slopes are partly infiltrated into diluvial and terrace material, but a certain amount also flows to downward alluviums. On average, how much of these waters reach alluvium? This question is of course difficult to answer, and although a generalization drawn even from concrete local observations would be nothing but speculation, we have made one nonetheless:

- The **Qt** surface area is 5,982 km^2. The average annual rainfall is 250 mm, of which only 30% can reach alluviums. In total, this is about 448.65 x 10^6 m^3 or the equivalent of an average flow of 14.2 m^3/s.
- The **d-pr** is outcropping in the study area at the surface of 10,840 km^2. As in the cases above, the average annual rainfall is equal, but due to longer distances and different permeability only 20% of it can reach alluviums, In total, this corresponds to 542 x 10^6 m^3 which is equivalent to an average flow of 17.2 m^3/s.

In total, a rough assessment indicates that theoretically 46.6 m^3/s of water could be stored in Quaternary reservoirs of study area in an average hydrological year.

Van der Plac (2001) discussed the issue of the alluvium replenishment from the runoff waters. “The major toggas of the arid Hawd Plateau flow about 3 or 4 times during each rainy season, for a duration of 1 to 3 days. This means that surface water is only available for an average of about 14 days per year (less than 5% of the time). Recharge of the alluvial aquifer exclusively takes place during these short periods. After the initial peakflow, the toggas rapidly dry up.

The magnitude of infiltration from the toggas will vary very much at the local level, depending on the nature of the river bed, and the distance to the stream. Where the floodplain deposits are sandy, this process will be highly efficient. The same is true if the stream channel is formed by fractured hard-rock formations, as observed in the upper reaches of the Togdheer.”[26]

Jurassic limestone (Jc) is one of the best aquifer systems containing fresh waters. Unfortunately, its extension is mostly limited to the Borama area (Awdal) where it represents the major water source for the local population and animals.

The anticipated surface area of Jc is 2,660 km^2. One could expect that the annual sum of precipitation in the Awdal region is much larger than in all other regions of Somaliland and could be approximated as 450 mm/an. With a reasonably estimated infiltration rate of 50% of the rainfalls, due to a higher degree of karstification

[26] cited from van der Plac (2001)

(present cavities, joints, micro fissuration), the annually replenished water resources would be ca. 598.5 x 10^6 m^3 or equivalent to an average flow of 18.9 m^3/s.

Petrucci (2008) analyzed the water balance elements in the southwest part of the study area near Borama town in the Awdal region. He stated that the "percentage of rainfall useful for infiltration is 70% of the rainfall (percentage of rains over 10 mm). Since the potential evapotranspiration in the rainy months is well over 100 mm/month, the remaining amount of the rainfall (30%) has been considered part of the evapotranspiration.

The main problem in this type of calculation is to define the percentages that characterize each lithological type, considering the lithological variability, density of fractures, the slopes, etc. Another problem is constituted by the quantity of water that passes from runoff to infiltration when the water flows in permeable sections of the courses (limestones, sandstones, sands). On the other hand, some limestone hills, completely outstanding on the basement, present the inverse problem: the water that infiltrates on the top probably outflows at the contact. In this case as for most of the water infiltrating in recent alluviums, part of the infiltration transforms in runoff."[27]

Karstic aquifer in Auradu limestone (Ea) is less karstified than the Jurassic one, but due to its large extension it is one of the most promising sources of the study area. Its surface area is anticipated to be 24,989 km^2, a size almost equal to that of some European countries. Apart from a large extension of Auradu rocks, the annual rainfalls are scarce and do not exceed 200-250 mm/an, which limits aquifer potential. Although well-karstified, this aquifer probably cannot absorb more than 40% of the rainfall. Thus its average annual replenishment could be equal to 2,000 x 10^6 m^3 or equivalent to an average groundwater flow of 63.4 m^3/s.

Faillace & Faillace (1986) evaluated the recharge of the Auradu limestones and the Nubian sandstones in an area between Burco and Sheikh towns in the Togdheer region. "Recharge occurs through the boulder beds, the fissured Auradu limestone rocks, and the Nubian sandstone outcropping in the Sheikh area. Considering that the catchment area of T. Togdheer is over 1500 km^2, a certain amount of groundwater from the alluvial aquifer may reach the lower aquifer where lithological conditions are favorable".

According to the GKW report the amount recharging the deep aquifer is estimated roughly at 26.5 million m^3/year, about 40-50 times more than the amount of water required for the Burco township water supply. Recharge of the shallow alluvial aquifer is subject to the erratic recurrence of spate flows in T. Togdheer; GKW

[27] cited from Petrucci (2008)

estimated the volume of water recharged by infiltration of runoff water at 300,000 m^3/year.

Karkar limestone aquifer (Ek) is also considered very promising. The majority of infiltrated water percolates downward to the often attached underlying Taleh Fm. evaporitic rocks (also permeable, but inadequate considering the original water quality). The infiltrated fresh water is thus often loose, feeding bottom layers which are producing saline (Na, SO_4) or mixed waters. It can be assumed that in roughly 35-40% of the surface area of Karkar Fm., the Taleh does not disturb the water quality[28]. Taking into consideration a surface of about 4,000 km^2 (out of a total 10,058 km^2), a rainfall sum of 200 mm/an, and an infiltration capacity of 40%, the total renewable resources could be estimated at 320 x 10^6 m^3 or 10.15 m^3/s.

Figure 5.50 Natural pothole with groundwater on its bottom in Taleh (Taleex) evaporitic rocks. The artificially made stairs facilitate access to single available water source in the area (Photo Somaliland team 2)

The total annually rechargeable groundwater (but not available for pumping) in major aquifer systems is therefore theoretically equal to some 4.3 x10^9 m^3 of water.

[28] For instance, when the degree of karstification of Karkar limestones is less, water does not percolate very deep, or when interstratified clays creating an impermeable barrier which again prevents downward circulation are present, or simply when there is an absence of Taleex rocks.

Table 5.3 Potential replenishment of major aquifer systems in Somaliland and Puntland in average hydrological year

Aquifer systems	Symbol	Estimated volume of infiltrated water per annum (10^6 m^3)	Equivalent to flow (m^3/s)
Alluviums (Intergranular I1)	al (+ Qt + d-pr)	458 (+ 448.65 + 542)	15.2 (+ 14.2 + 17.2)
Jurassic limestones (Karstic K1)	Jc	598.5	18.9
Auradu limestones (Karstic K1)	Ea	2,000	63.4
Karkar limestones (Karstic K1)	Ek	320	10.15
TOTAL		4,367.15	139

Although the amount of water which is equivalent to a flow of 139 m^3/s looks very promising, consideration of the size of the two countries and the study area which is larger than 289.000 km^2 just confirms the conclusion about water scarcity: The specific groundwater yield is less even than 0.5 $l/s/km^2$, which classifies Somaliland and Puntland as extremely poor in groundwater reserves (no surface water even exists).

The calculation would not significantly change even if all other aquifer systems present in the regions were included. For instance, van der Plac (2001) assumed that effective recharge of most of the other aquifers (e.g. Nubian sandstones, Basement Complex) is in the magnitude of 3-5% of the rainfall. Therefore, the general water shortage plus an unequal distribution of aquifers and available water sources would continue to present a major obstacle to normal urban and rural development of both, Somaliland and Puntland.

Some preliminary budgeting of groundwater resources has also been made for four selected areas (AoI) where detailed remote sensing was carried out. The results of this assessment are presented in Chapter 5.1.4.

5.1.3 Over-exploitation evidence

In many arid countries in Africa and the Middle East problems with much greater extraction of groundwater than its replenishment has caused the total depletion or significant reduction of the reserves of many aquifers. It is therefore very important in all areas with limited groundwater to determine safe yield and to establish monitoring systems for permanent observation of groundwater quantity and quality and thereby make it possible to issue warnings to reduce pumping rates or to search for other solutions in (ground)water management once over-exploitation is evident.

How can Safe Yield be determined?

“According to Meinzer (1920), an aquifer's safe yield may be defined as the water that can be permanently abstracted from an aquifer without producing undesirable results. This concept has been widely used by the American geological school. Todd (1976) introduced the concept of ‘perennial yield’, as the flow of water that can be abstracted from a given aquifer without producing results that lead to an adverse situation.

Different terms such as over abstraction, over development, over pumping, overdraft, and groundwater mining are used in practice to explain aquifer over-exploitation. The term groundwater mining is used when conscious and planned abstraction rate greatly exceeds aquifer recharge.

In fact, it may be assumed that all the above-mentioned ideas belong to a restrictive conception of the 'conservative' water management school. For its proponents, safe yield is always less than potential average annual recharge. The difference results from the possible influence of different factors such as climatic conditions, uneconomic pumping depths, possible subsurface drainage out of the catchment, and deterioration of water quality. Sometimes, the environmentalists do not allow for exploitation of more than 30% of assumed annual aquifers’ replenishment value (renewable groundwater resource).

In contrast, the liberal conception of safe yield allows for groundwater extraction at values higher than the yearly recharge, but requires careful monitoring and application of groundwater control and regulation measures (artificial recharge). Thus, tapping water from the static or non-renewable part of groundwater reserves is possible for a limited time and limited amount. According to Custodio (1992) “to evaluate a situation that could be termed as ‘overexploitation’, not only hydrogeological aspects have to be taken into account, but also economic, social and political ones, as well as the point of view of the persons concerned (groundwater exploiters, water administrators, water managers, land-use planners, economists, local people, environmentalists)”.

To evaluate possible aquifer (hydrogeological viewpoint) and groundwater (managerial viewpoint) over-exploitation, the detrimental (negative) effects must be considered:

Falling groundwater level, continuously or with fluctuations due to changes in recharge and/or exploitation;

- Diminution of spring and river flow or/and wetland surface reduction;
- Degradation of groundwater quality: either increase in salinity or increase in certain undesirable constituents in the water;
- Land surface changes in the form of generalised or local land subsidence, or ground collapse.

However, in many cases the beneficial aspects may dominate over detrimental ones and this should be taken into account (Custodio, 1992).

From the liberal perspective, benefits exist even if exploitation leads to some kind of over-exploitation. The followers of this approach consider that the term ‘over-exploitation’ is often used as a political weapon to achieve other unrelated goals, or as a means to justify other types of water projects.

Burke and Moench (2000) stated that “the planned mining of an aquifer is a strategic water resource management option where the full physical, social and economic implications are understood and accounted for over time. A declining water table does not necessarily indicate over-abstraction of the groundwater resources.

In conclusion, over-exploitation should be evaluated in terms of inter-annual balance of recharge and groundwater extraction. Attention that is given only to the annual disproportion between balance elements and a temporary fall in groundwater level, resulting from a short drought cycle, can lead to wrong conclusions being made and the unnecessary limitation of groundwater use at critical times.”[29]

Therefore, sustainable groundwater development is crucial to ensure water supply to future generations and prevent aquifer depletion, but in the case of emergency situations and when no other solutions are possible, the groundwater should be utilized to a certain extent.

The issue of safe yield is not commonly discussed in the previous reports on hydrogeology of Somalia. Some findings were presented in the report of van der Plac (2001) who evaluated the water situation in the Burco area. He stated that “with a projected annual abstraction between 2.8 and 6.7% of the recharge and less than 0.1% of the estimated total storage, the effects will be negligible on a regional scale. However, a lowering of the water table may occur within the surroundings of the wellfield, because the abstraction is centred in a small area. This reduction of storage would be strictly local and temporary: the water level will recover to its original level once pumping has stopped.

[29] cited from the Stevanovic & Iurkiewicz study on “Hydrogeology of Northern Iraq, Vol 2”.

Changes in quality may occur if water from intercalated gypsum or salt layers is attracted to the borehole. In the vertical section, this risk can be minimised during construction: aquifers of poor water quality can be effectively isolated and sealed off with clay plugs. Lateral movement of brackish water is difficult to control. However, so far no change in water quality has been observed at any of the existing Burao (Burco) boreholes.

Therefore, it can be concluded that the effects will be negligible on a regional scale."[30]

If we compare actual water demands of the Somaliland and Puntland we should conclude that despite water scarcity and shortage in most of the territories there are still sufficient amounts to cover elementary water requirements.

In Chapter 5.1.1.2 we concluded that almost 70% of water demands in urban areas are not covered. When considering the rural environment it must be noted that the Somali population is not very familiar with land cultivation and irrigation. This might be a result of the lack water, but in any event pastoral nomadic movements and animal husbandry remain the main sources of income in remote areas such as Sool or Hawd plateaus. This situation, however, reduces pressure on water resources, making the supply of drinking water and water for animals the main objectives of any future water management.

The situation in the Dur Dur watershed (Awdal) can be considered typical of most of Somaliland and Puntland, although this particular area is characterized by more available fresh water resources than the eastern regions. "Most people in the watershed are traditionally livestock herders and many still practice livestock keeping, including those families that are now farming so the dominant livelihood practiced today is agro-pastoralism. However, if a choice is to be made by most people between livestock and crop production, most perceive livestock as their ultimate livelihood, while activities in agriculture are more opportunistic. Very few regard themselves as farmers. This will change with time but only if agriculture provides a sustainable livelihood. Important aspects here are marketing of produce which has disappointed farmers on occasion and declining land fertility."[31]

[30] cited from van der Plac (2001)
[31] cited from German Agro-Action IWRMP for Awdal region (2006)

Figure 5.51 One of not commonly seen pictures in the study area: intensively irrigated piece of lands (Photo Puntland team 2)

The total population of Somaliland and Puntland can be roughly estimated at 4,000,000 inhabitants (3.85 millions in census 2009). An average specific consumption for drinking and for elementary sanitary purposes in an environment such as Somalia can be averaged to 80 l/day/capita. Therefore, just for a humanitarian drinking water supply it is necessary to ensure 116 x 10^6 m^3 of water annually. This is equal to a constant flow of 3.7 m^3/s. An approximated number of large (mostly camels, donkeys) and small ruminants (sheep, goats) is probably 4-5 times greater than the number of inhabitants. However their water demands are less and could be averaged roughly at about 15 l/day/ruminant. This is equal to water demands by the animals of around 109.5 x 10^6 m^3/an, or an additional needed flow of ca. 3.5 m^3/s. This basic need of 7.2 m^3/s, even if doubled for the expected agricultural prospect, development, and population growth, could sufficiently be covered by tapped groundwater from main aquifer systems. The demands correspond to around 10% of the groundwater resources of major aquifers estimated above. However, the problem of unequal distribution of water resources remains, and will for a long time be a major obstacle to sustainable water management in the region.

Figure 5.52 The camels watering (Sool plateau)

Chapter 5.1.1.2 has already presented just a very few of the collected data on the over-exploitation of tapped aquifers. Despite some previous estimates done by Chinese experts (1986) drawdown in the "Hargeysa case" has been relatively stable throughout the last two decades and has even enabled larger pumping rates (at least temporarily). Combining this existing source and regulating accordingly the pumping rates in Geed Deeble with the newly explored Xunboweyle site, its prosperous well-field would enable a stable water supply to major consumers in the region for a certain period of time.

It was previously mentioned that the Borama source is the only one where responsible personnel clearly identified indications of over-exploitation and reported them during the SWALIM inquiry in May 2012. The depletion of the groundwater table by 13 m during the last 5 years (2.6 m/year) is an important sign that control of aquifer pumping supported by some new solutions and intakes is a necessary precautionary measure for sustainable aquifer development.

To talk about safe yield and sustainable water development in an environment such as Somaliland and Puntland is not always logical, because most of the water is used purely for humanitarian purposes. For instance, it is not feasible to ask for guaranteed and ecological flows when there is no flow in the streams for most of the year. But an established monitoring network will provide more reliable information about the status of groundwater, the trend of its possible depletion, and measures that could be applied in the water practice to amortize any negative effects of water extraction.

5.1.4 Promising areas for groundwater tapping

Considering the regional character of the hydrogeological research conducted, the scale of the prepared map and other documents, and the still limited knowledge of the surveyors as evident in their reports with their sometimes incomplete information from the field, to expect to get a proper and detailed assessment of hydrogeology in certain areas and a definition of their prospect for further development is not realistic. Such an attempt without additional detailed hydrogeological survey could even lead to an improper definition of drilling sites or drilling technology. However, in some zones where more investigation was performed and where well-fields and single productive wells are placed and are currently functioning, a more reliable base for advising the local water managers about further works and development of tapped water resources is possible. Such a general approach is also defined at the beginning of the survey in the *Concept note of the HASP*: Although aware that it is a complicated and uncertain task, the international consultants agreed to try remote (desk study) analyses of a few selected areas in the two countries. Therefore, based primarily on remote sensing findings (explained in Chapter 1.3.4, and presented in Appendix III), and hydrogeological information obtained from the existing references and field survey, an evaluation of hydrogeological settings and selection of some more promising (potential) areas for groundwater development took place.

Finally four areas of interest (AOI) were selected, two of them in Somaliland, and two in Puntland. The total surface area of AOIs is 46.365 km^2, which represents 16% of the entire study area.

The four selected AOIs (Fig. 180) are located near some of the larger populated places such as Hargeysa, Laas Caanood, Qardho, Burtinle and the hydrogeological interpretation is considered to be a base for the identification of some additional potential areas for their further water supply, or for supply of other smaller permanent or temporary settlements in their vicinity.

The remote sensing maps (Appendix III) include information on the tectonic pattern, soil and vegetation (by Normalized Difference Vegetation Index, NDVI, Moisture Vegetation Index, Clay Mineral Index). As a result of their combination certain zones which may be promising for further GW survey and development are delineated. They have been rechecked and mostly accepted by the hydrogeologists, with upgraded information on local hydrogeology. Therefore, four AOI hydrogeological maps on the same scales (generally adapted to be used in 1:200,000-1:300,000) have been prepared using the same GIS technology as for the regional map.

After getting results from spectral procedures and comparing these newly created maps with the Regional hydrogeological map on the scale of 1:750,000 it was concluded that geological boundaries are fitting and overlapping very well.

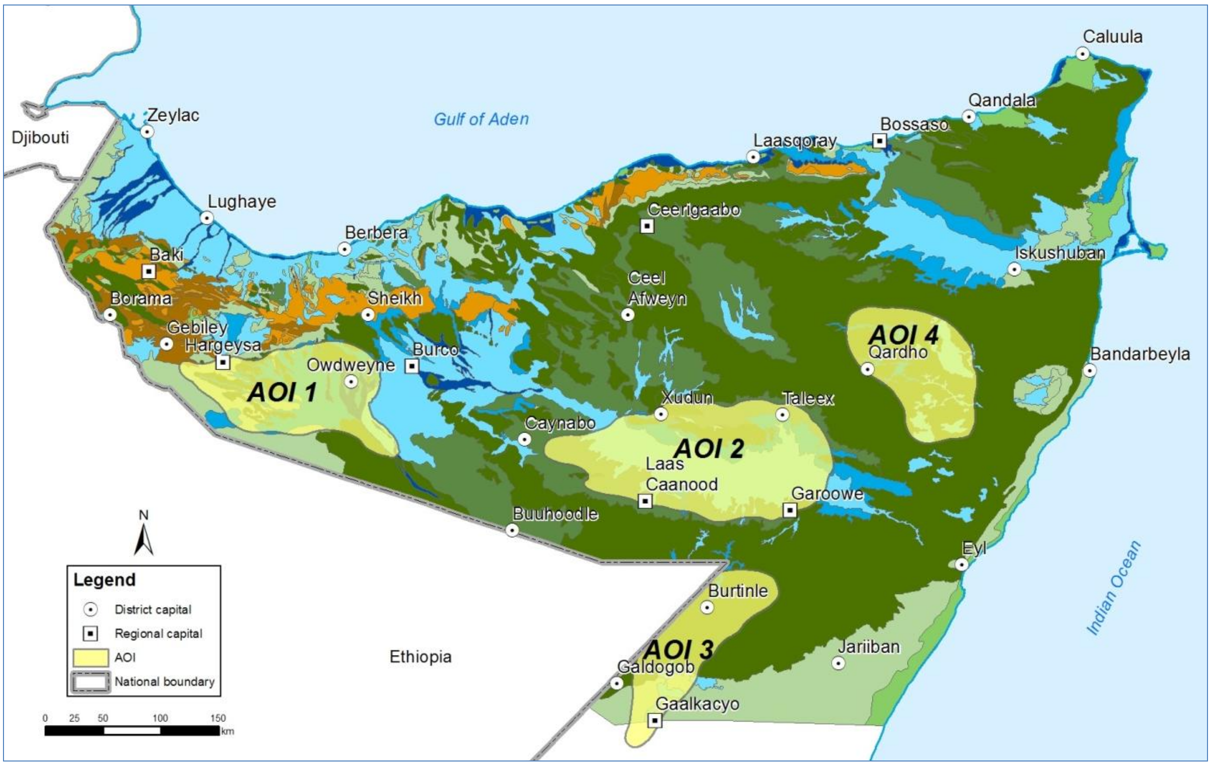


Figure 5.53 Four Areas of interest in Somaliland and Puntland

The first Area of Interest (**AOI 1**) is located in the southwestern part of Somaliland. Southeast of Hargeysa and west of Owdweyne it comprises a surface of 10,735 km^2. In total, 8 promising areas are identified. Most of them are in the central part of this area near its main periodic streams (toggas) in alluvial sediments slightly sloping to ESE. Four potential areas are allocated south of Hargeysa in a zone of intersection of regional faults systems oriented from NE to SW and local faults striking from NW to SE. The other localities are SW and SE of Owdweyne. The surface area of those 8 promising areas ranges from 11 km^2 to 87.5 km^2. Final results of the RS interpretation correlated with hydrogeological settings are presented in a Hydrogeological map (Annex III). It is advisable that this map as well as the other three maps be printed on the scale of ca. 1:500,000, but for observation and examination of detailed sites the scale could be enlarged by GIS or any other software for data visualization. Surfaces of selected promising areas of AOI 1 are shown in Table 5.4.

Table 5.4 Surface of promising sub-areas of Area of Interest 1.

ID Promising Area	Surface areas in km^2
AOI-1-2	59.6
AOI-1-3	49.9
AOI-1-5	8.75
AOI-1-6	13.4
AOI-1-8	47.1
AOI-1-9	11.6
AOI-1-10	72.4
AOI-1-11	86.8

Promising areas of AOI-1 numerated as 2,3,5 and 6 are linked to Auradu limestones. The fissuration and karstification of these rocks look relatively intensive and the groundwater table is probably not very deep. In areas 3, 5 and 6 younger terrace sediments cover Auradu Fm. and they could represent a common complex aquifer. The rainfall water percolates through porous terrace sediments to the underlying Auradu Fm.

The surface area of the three zones of AOI-1 signed as 3,5, and 6 is large, covering almost 120 km^2. The estimated recharge could be some 20% of the rainfall, or around 90 mm/an. This provides an annual theoretical water potential of ca. 10.8 x 10^6 m^3. This is more than three times smaller than the calculated theoretical volume of this zone groundwater stored in Auradu Fm. itself: 36 x 10^6 m^3 which is a result of the Auradu Fm. surface of 60 km^2, average effective porosity of 0.01, and karstification depth of 60 m. Therefore, and in all other estimations done in this chapter, the estimated rechargeable potential (from the rainfall and infiltrated runoff) should be done carefully (taking “safe case”), but not with a hypothetical pumping rate. Otherwise, an extraction rate higher than replenishment definitely leads to over-exploitation of aquifer.

In the case of AOI-1-2, the area is extended to a part consisting of Yesomma sandstones. Although this part is not considered as promising for further survey, it is included due to the possible alogenic recharge of Auradu Fm. on which detailed geophysical and hydrogeological survey should be concentrated. However, it is also important to confirm the altitude, position and morphology of these two aquifers.

In AOI-1-2 the surface area of Auradu Fm. alone is about 6 km^2. Taking into account an average effective porosity of 0.01 of the limestones and depth to the karstification base of around 100 m, the stored volume of groundwater could be assessed at 6 x 10^6 m^3. In the case that the regular recharge of this aquifer is ensured by the precipitation (which is probably the case due to larger rates in this part of Somaliland), it is theoretically possible to pump out up to 190 l/s throughout the year from this zone. The battery of the well should be located closer to the margin of the zone contouring

Auradu Fm. at the south-easternmost part or even outside the delineated AOI-1-2 zone towards the Quaternary terrace sediments. All this should be carefully rechecked in the field.

Zones 8, 9, and 10 of the AOI-1-belong to Quaternary alluvial and terrace sediments, while AOI-1-11 is a promising area contacting Auradu Fm. and alluvium. The surface area of the former three zones is about 130 km^2. The value of the effective porosity is larger than the karstified rocks of Auradu, and their saturated thickness is probably larger than 30 m, in which case these areas could be large reservoirs of groundwater. Although the pumping rate of groundwater could exceed 1 m^3/s on an annual level, it seems that the rechargeable potential of the aquifer is significantly less. Roughly not more than 20% of the rainfall (300 mm/an in average) is infiltrated on the aquifer surface, which provides a recharge 6 times lesser than the mentioned pumping potential.

Finally, for the area AOI-1-11 an investigation programme along the contact of Auradu Fm. and alluvium is recommended. The contact is more than 15 km long and hydrogeological reconnaissance should identify prioritized zones for geophysical survey and possible drilling. Wherever the Auradu aquifer is covered by permeable alluviums or terrace deposits there could be very promising reservoirs of fresh waters which exist under possibly semi-confined (sub-artesian) conditions.

* * *

A similar conception and even similar results in remote sensing are obtained in **AOI 2** which extends between Caas Caanood and Garoowe in the south and Xudun Taleex in the north. This terrain belongs mostly to the Nugaal Valley, dipping slightly to the east. The thick Quaternary deposits prevail in a geological composition. Marginal parts of the basin are composed of Auradu limestones and Taleh (Taleex) evaporites. The two systems of regional faults detected are oriented mainly from E to W and from NE to SW. In general, they are accompanied by local faults, but in the central part of the terrain N-S trending faults are observed. All recognized promising areas are located in the central part of the area along the Nugaal Valley. Intersections of regional fault systems as well as clay mineral and vegetation indexes are the main arguments for the allocation of the four major promising areas. In addition, the northern edge of the valley along the contact between Auradu limestones (Ea) and diluvial-proluvial sediments can also be considered a promising area where more detailed hydrogeological survey is recommended.

Surface areas of promising areas of AOI 2 are shown in Table 5.5.

Table 5.5 Surface of four promising sub-areas of Area of Interest 2.

ID Promising Area	Surface areas in km^2
AOI-2-16	249.7
AOI-2-17	203.6
AOI-2-18	181
AOI-2-19	259.9

The total surface of the four areas AOI-2-16, 17, 18 and 19 is very large, nearly 900 km^2. The saturated thickness of the Quaternary sediments (Qc) in this central part of the Nugaal valley probably exceeds 50 m, but the permeability is much smaller than in the case of alluvial (al) or terrace (Qt) sediments. In general, and very roughly, considering that probably not more than 20 mm of rainfall is an annual recharge of these aquifers (20% of 100 mm as average rainfall in the Nugaal basin), not more than 500 l/s can be obtained from all these four zones. Therefore, to prevent over-extraction no more than 0.5 l/s for every square kilometer of the basin should be pumped out.

* * *

Using the same criteria as above, results of remote sensing analysis correlated with hydrogeology data for **AOI 3**, an area between Burtinle in the north and Gaalkacyo in the south, are presented in Annex V. Seven potential areas are delineated. Their surfaces are shown in Table 5.6.

Table 5.6. Surface of promising sub-areas of Area of Interest 3.

ID Promising Area	Surface areas in km^2
AOI-3-20	55.8
AOI-3-21	101.5
AOI-3-24	174.6
AOI-3-25	51
AOI-3-26	77.3
AOI-3-27	106.7
AOI-3-28	72.3

The surfaces of those promising areas are smaller than in the previous case because AOI 3 is smaller than the others and areas with hydrogeological prospect are limited in these parts of the Nugaal and Mudug regions. For instance, AOI-3-20 has very little prospect for groundwater tapping but is nonetheless indicated on the map because it is the only one somehow promising in the Mudug beds (Oligocene-Miocene) where groundwater is generally scarce.

Areas AOI-3-21 and -24 belong to Quaternary red soils and carbonate crust but underlying layers are probably built from terrace deposits where likely more groundwater is to be expected. For the surface of 275 km^2 of these two units comprising a shallow aquifer about 30 m thick and with an estimated effective porosity of 0.005, the stored volume of groundwater could be equal to 41.2 x 10^6 m^3. However, given that the rechargeable potential is three times less, pumping more than 200-250 l/s from these wide areas altogether should not be advisable.

A better situation is the northern part of AOI3. The areas AOI-3-26-27 are delineated in pure Karkar (Ek) limestones while AOI-3-25 and -28 belong to Karkar aquifer covered by terrace deposits (Qc). The surface areas of the latter extend to some 123 km^2 and it is assumed that the accumulated static groundwater reserves could reach ca. 86 x 10^6 m^3 (for an anticipated thickness of the saturated zone of some 70 m and effective porosity of 1%). However, their replenishment is not very promising. Due to low precipitation, probably no more than 50 mm could recharge this aquifer annually, enabling a maximum 200 l/s as an average yield from the entire area to be pumped. If this approximation is accurate, an average segmental yield per square kilometer should be equal to 1.6 l/s. Additionally, the sites of the boreholes and especially their depths should be carefully selected to avoid the impact of the saline groundwater of underlying Taleh (Taleex).

* * *

The results of the remote analyses (remote sensing correlated with hydrogeological data) of AOI 4 are presented in Annex VI. The **AOI 4** covers a wider area north, east and west of the Qardho. The Quaternary deposits and Karkar limestones are dominant lithostratigraphic units. Regional faults systems oriented from NE-SW dominate in this terrain, but so do faults striking from E to W and NW-SE. Two prospective zones close to the city of Qardho are appointed, as can be seen on the map shown in Annex VI. The surfaces of the promising areas of AOI 4 are shown in Table 5.7.

Table 5.7 Surface of promising sub-areas of Area of Interest 4.

ID Promising Area	Surface areas in km^2
AOI-4-14	226.4
AOI-4-15	292.7

The two selected areas at the Sool plateau between Dharoor and Nugaal basins are very large, comprising more than 500 km^2. Their hydrogeological settings are similar: Karkar limestones are covered by Quaternary terrace deposits. Stored groundwater reserves could be large primarily because of the large surface area, and not because of the permeability of the Karkar Fm. itself. However, a small replenishment as in the case of AOI 3 probably would not allow more than 500-600 l/s to be pumped from both areas. This is the equivalent of 1-1.2 l/s/km^2. The impact of the underlying Taleh (Taleex) Fm. on the groundwater quality should also be avoided by careful selection of drilling sites, depth and drilling technology.

* * *

Some provisional calculations of the groundwater budget and reserves for the indicated areas show that the main factor for groundwater development is the recharge potential. Without adequate compensation of stored water reserves in the ground, the over-exploitation could very quickly weaken all efforts of the experts to improve the water situation in the region. Additional verification of estimated water reserves combined with field prospection, adequate drilling, pumping and monitoring are essential for groundwater management, particularly for the aquifers with a very low specific yield.

Although a very problematic and uncertain way to estimate available water reserves in some specific smaller areas and provide proper advice concerning where and how to drill and tap groundwater, the consultants tried to test what is the maximal possible output and useful information that can be obtained from the newly created SWALIM GIS Geo database. Such a supportive mechanism could orient further projects and surveys in designated areas, but should be used only by true professionals and still with great caution. Therefore, the three examples below are used to demonstrate the possible application of the SWALIM Geo database created, the many limitations resulting from the regional scale survey aside.

Example 1. The promising area AOI-1-3 is located 12 km SW of Hargeysa (Figure 5.54). The extension of Auradu limestones (Ea) is 29.7 km^2 in the southern section (F1) and 68.6 km^2 in the northern section (F2). The Quaternary old terrace sediments (Qt) cover an area of 32.6 km^2 (F3). The topography is relatively flat but the elevation is high (1,320 to 1,440 m a.s.l.). There is an absence of permanent streams. Riverbeds are dry most of the time, except for a few days a year after very heavy rainfall. The area includes 5 villages with a population of about 850 inhabitants. There is one permanent spring at the contact of Auradu limestones and terrace sediments.

The zones proposed for detailed hydrogeological survey (and possibly geophysical survey and exploratory drilling) are along the contact of these two formations. Their lengths are about 5 km. It would be important to estimate the depth of Quaternary cover and to examine the Auradu lithology (to avoid impure non-carbonate components) and tectonic fabrics (especially layer dips and faults, joints).

Concerning the relatively good recharge of the Auradu aquifer due to its permeability and the rainfall rate in this part of Somaliland as well, it would be theoretically possible to get some 100 l/s from each side of the valley (along the contacts) by extending the battery of wells (7-10 of them).

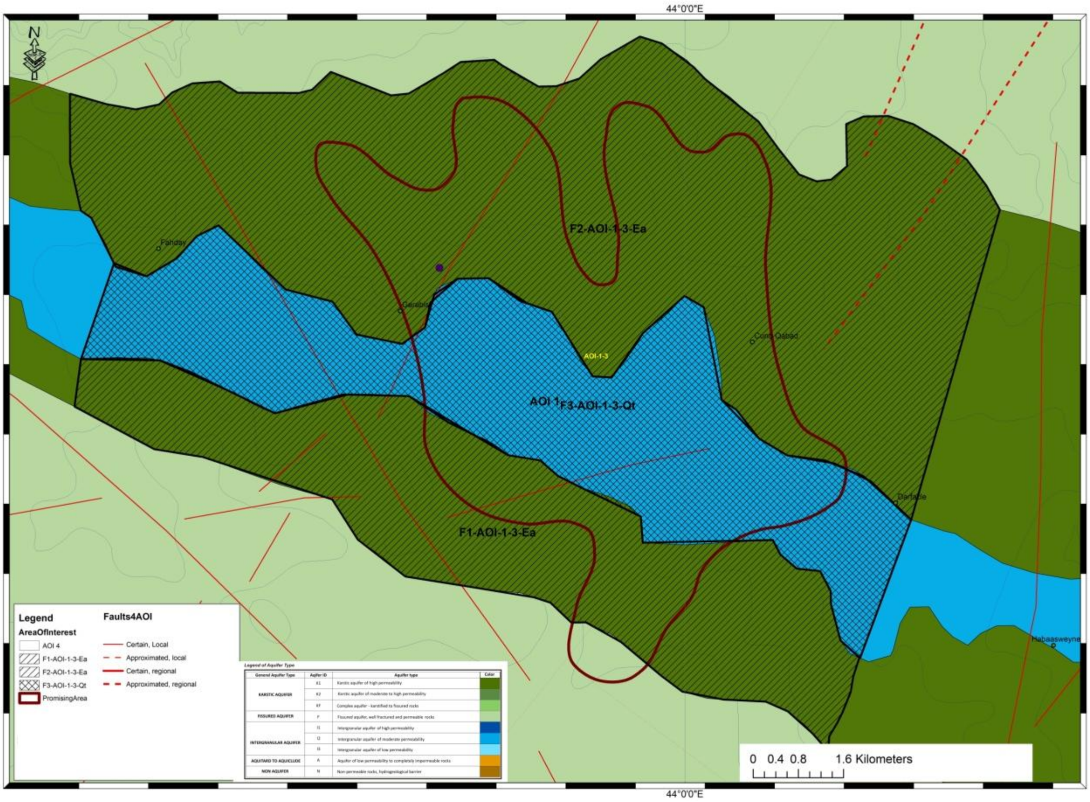


Figure 5.54 Hydrogeological sketch map of promising area AOI-1-3 (SW of Hargeysa)

Example 2. The promising area AOI-4-15 is located in the northern rim of the Qardho town at the Sool plateau. There are four blocks separated in Karkar Fm. Block F1-AOI-4-15-Ek covers an area of 27.6 km^2, block F2-AOI-4-15-Ek has an extension of 102.9 km^2, the surface of block F3-AOI-4-15-Ek is 30.6 km^2, and finally block F4-AOI-4-15-Ek covers an area of 264.2 km^2. The Quaternary sediments overlying Karkar rocks F5-AOI-4-15-Qt cover an area of 192.2 km^2 (Figure 5.55). The topography is relatively flat (720 to 850 m a.s.l.).

The proposal for detailed survey is similar to the previous case. The most promising zones are along the contact of Karkar limestones and Quaternary sediments. The possible drilling sites should follow major faulting structures in Karkar which are perpendicular to the togga’s bed and probably extend to its bedrock.

Considering the significantly lower recharge of the aquifer in this part of Puntland probably not more than 4-5 l/s should be pumped from the wells. It would also be important to keep the well inside Karkar Fm. exclusively and not to reach the bottom layers of Taleh (Taleex) Fm. due to their unfavorable waters.

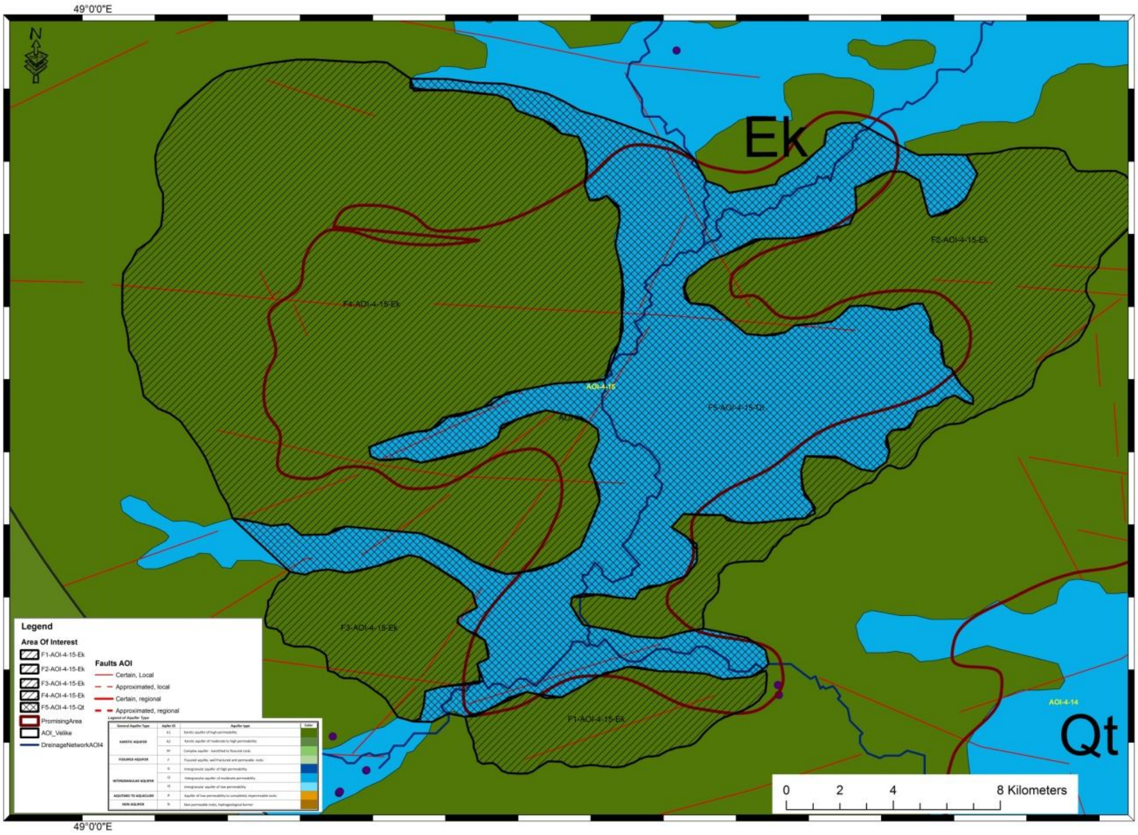


Figure 5.55 Hydrogeological sketch map of promising area AOI-4-15 (Qardho, Sool plateau)

Example 3. The third watershed Dubur near Sheekh (Sheikh) town, which was remotely assessed, is one which does not belong to the group of delineated promising areas. It is clear there are many other locations throughout Somaliland and Puntland where successful results in groundwater search and tapping can also be achieved. But, as repeated many times in this report, detailed field survey is a necessary precondition for any drilling and even for geophysics.

The watershed F1-Dubur-Ea (Auradu Fm.) south of Sheekh covers an area of 28.3 km^2, F2-Dubur-Ea (also Auradu Fm.) covers an area of 66.5 km^2, while an area which is covered by Quaternary sediments with code F3- Dubur-dpr comprises an area of 84 km^2 (Figure 5.56). The topography is relatively hilly (1,360 to 1,600 m a.s.l.).

The regional and local position of recently drilled wells and wells from the database of the Sheekh study area (extract from the Regional Hydrogeological Map, SWALIM Geo database) are shown in Figures 5.56, 5.57.

The question is where to locate a new well(s) in this area. It is definitely quite difficult and problematic to suggest precise locations and technical conditions for drilling by evaluating data from the Geo database and the Regional Hydrogeological map, due to its small scale. Moreover, the area was not covered by remote sensing analyses, while the field survey was not considered an actual request for drilling.

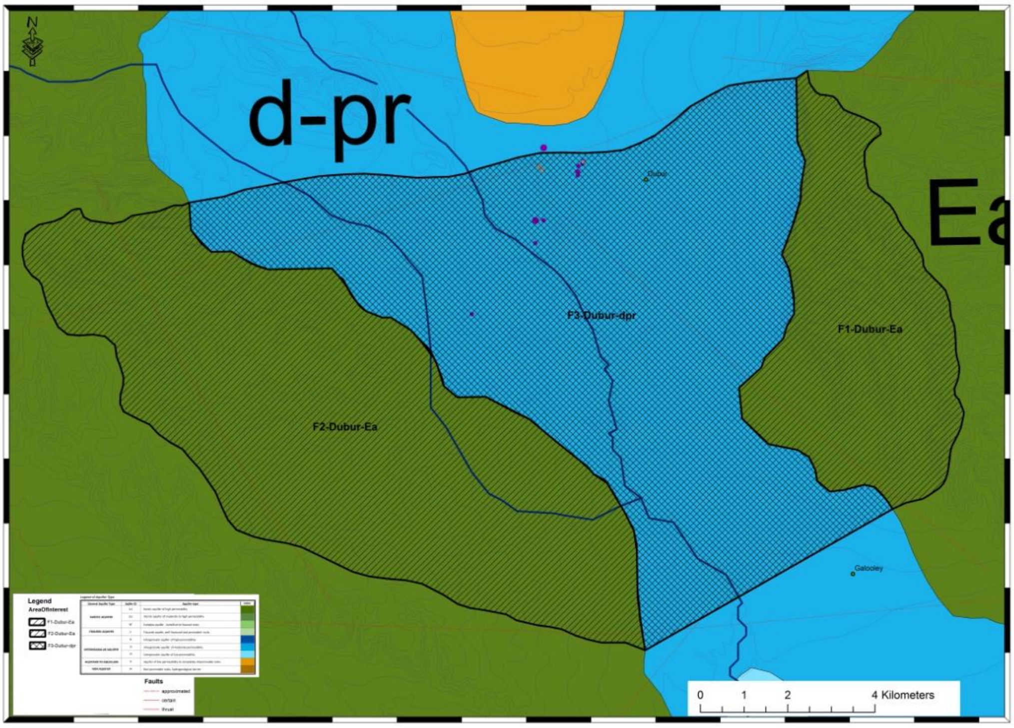


Figure 5.56 Hydrogeological sketch map of Dubur promising area AOI-4-15 (Sheekh, Togdheer)

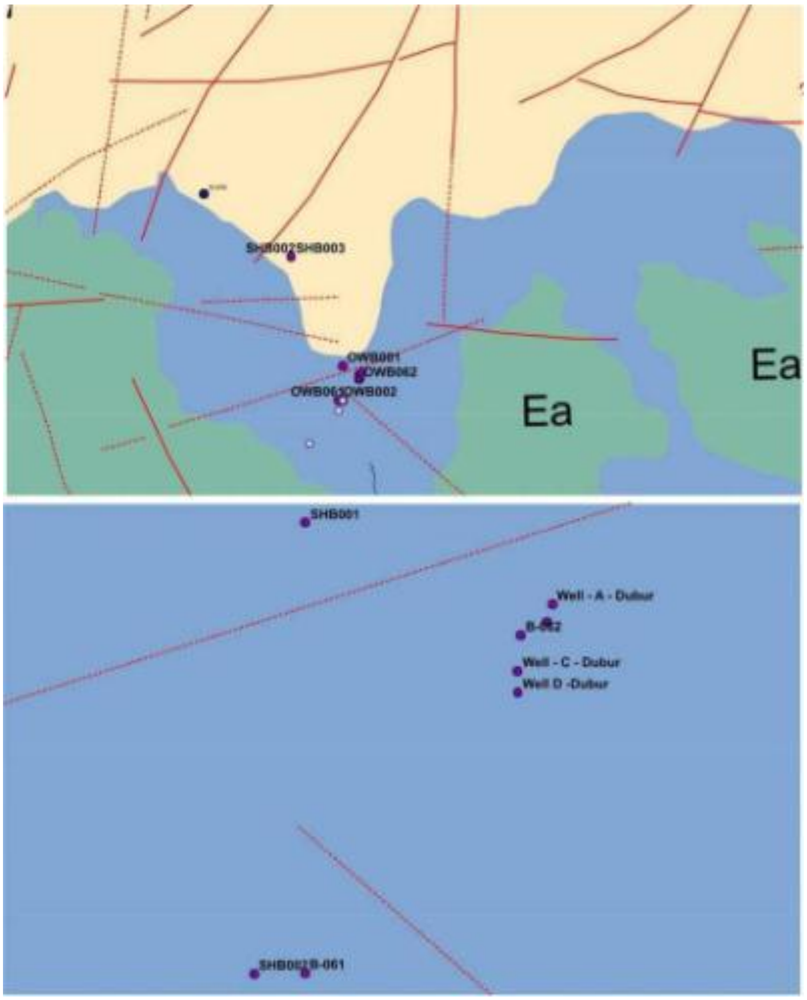


Figure 5.57 The recently drilled wells are positioned according to data provided by the Director of National Water Resources of Ministry of Mining, Energy & Water Resources (MMEWR) Somaliland Government, Hargeysa, Somaliland

Due to the reported small capacity of the existing wells, regarding suitable drilling sites it is strongly advisable to change the location of the new boreholes towards the SE and outcrops of Eocene Auradu Fm. (limestones) but still stay inside or near Togga's bed covered by d-pr deposits. These potential areas are as follows:

- NEW 1 and NEW 2, in which micro locations could be searched for,
- Basically, new boreholes should have depths of at least 150 m, or up to a reached productive aquifer layer consisting either of conglomerates (if any) or Auradu limestones of the bedrock.

Alternatively, in the case that drilling in proposed areas is not feasible because of a long distance from existing wells, the proposed point for boreholes could be in the area of Well B-062, Well -C or Well – D, and should be at a minimal depth of 150 m (deeper than existing ones).

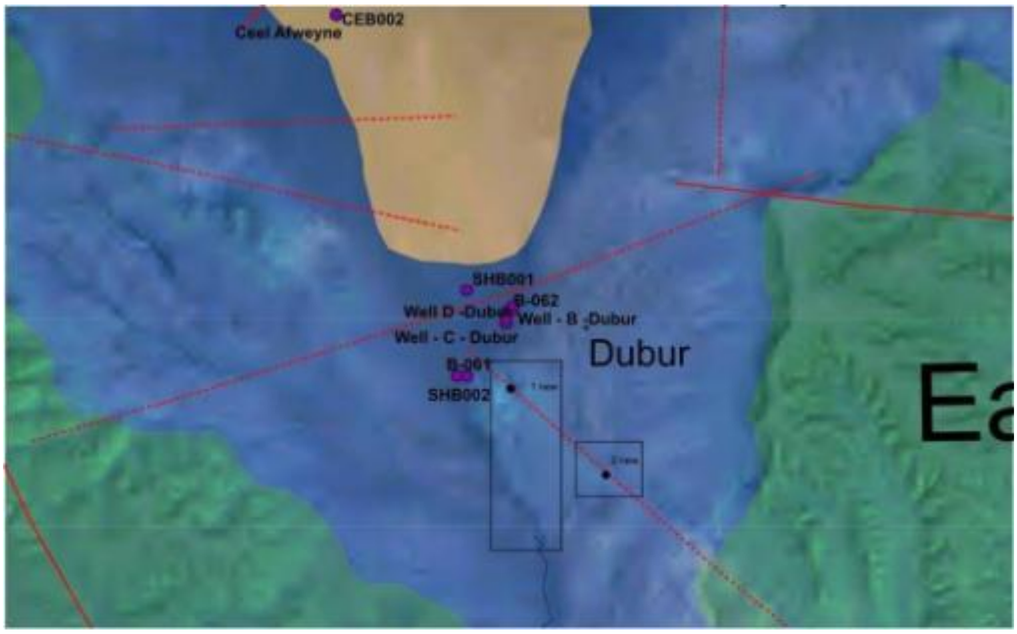


Figure 5.58 Possible locations of new wells in Dubur area south of Sheikh

5.2 Aquifer control and regulation measures

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

At this stage of the SWALIM programme, discussions about aquifer control and regulation measures are more theoretical aiming primarily to promote these approaches to the local water management specialists and decision-makers.

In arid and geological environments such as those in Somaliland and Puntland the two preferred major artificial measures are subsurface dams and direct artificial recharge. They should be followed by monitoring in an established groundwater monitoring network (including existing water utilities) and control of drilling and groundwater extraction.

The construction of **subsurface dams** often takes place in countries having arid and semi-arid climatic conditions, and this kind of structure (sand dam) is well known in Somalia.

The purpose of this dam is to collect water in the alluvium of the togga and to ensure more water available for upstream / downstream consumers throughout the year. The togga's short periods of flow, unstable regime, and the fast propagation through its deposits are the main reasons why such systems should be applied.

Subsurface dams belong to groundwater storage structures (Stevanovic, 2001). Most commonly the objective is to raise an impermeable barrier across the riverbed from the surface down to the bedrock. Wherever the bedrock or riverbanks are fully impermeable the benefit of the subsurface (sand) dam is a new reservoir in the upstream zone, which is filled during flooding. In the case of permeable rocks at the bottom/bank having contact with alluvium, this type of structure may be applied and have a multifunctional character:

1. Groundwater storage in upstream alluvial and riverbed deposits;

2. Extended period of recharge of the underlying aquifer.

In order to tap the stored groundwater, a line of large diameter dug wells or small pits can be located upstream of the dam site. "In arid climatic conditions, the justification for a subsurface dam, instead of 'classical' dam is very simple. In an open reservoir, evaporation losses from the water body are very high, exceeding even 15 mm/day during the summer, so the best way of storing water is to infiltrate them into the ground"[32].

The two main types of subsurface dams are:

1. Clay-plug dam (with compacted clay at the core); and

2. Masonry dam (with stone and mortar or concrete).

To ensure stability the second type is preferred at sites where the runoff could be very intensive. Many such dams, some of them visited during field visits of Somaliland sites, can be destroyed after the floods. The outcropping area of the bedrock in the riverbed always represents the most suitable location for placing the barrier across. This type of setting requires a smaller size of dam and prevents seepage from the reservoir.

[32] Stevanovic, 2001: Subsurface dams – efficient groundwater regulation scheme, p.1,2

Figure 5.59 One of the subsurface (sand) dams near Hargeysa (photo Z.Stevanovic)

The barrier could be extended a few meters above the surface. Sedimentation of sand and suspended solids will continue and perhaps intensify, although it will only serve as a new water storage space in this case. The infiltration rate may significantly reduce if the clogging of the lake bottom initiates the clogging of the underlying sediments. In this event, a temporary cleaning is required.

The typical work procedure is as follows (Stevanovic, 2001):

- Geodetic measurements, longitudinal and transversal sections;
- Excavation in alluvium for the body of the subsurface dam; the dimension of the excavations should accommodate the casting of the body and back-filling. Then, filling the body of the foundation by compacting clays or blocks and mortar or concrete.
- Completion of the weir body and wing walls at the surface (if necessary).
- Possible installation of piezometric pipes upstream and downstream of the dam site for monitoring purposes.
- Implementation of tapping water schemes (large dug holes, shallow wells, in some cases bottom out-flowing perforated pipes).

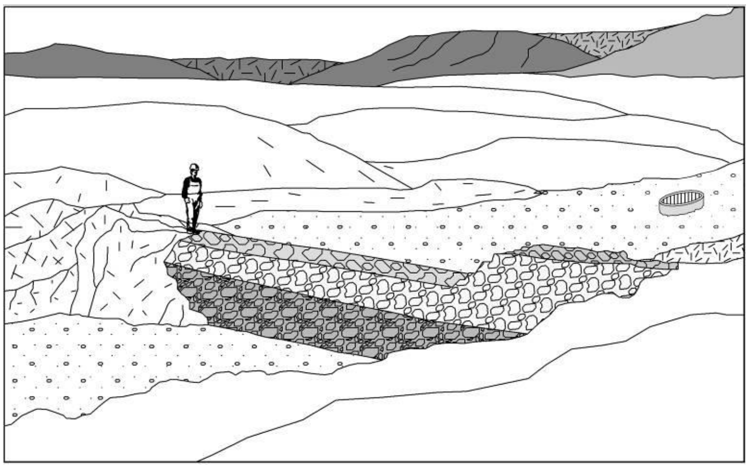


Figure 5.60 Scheme of the subsurface dam across the riverbed (Stevanovic, 2010)

Figure 5.61 Gabions used as a barrier for sand dam (Woqooyi Galbeed, Somaliland, photo Z.Stevanovic)

Proposals to build more subsurface dams are also provided in the report of German Agro-Action, (2006) focused on the Durdur catchment (Awdal region).

"The groundwater survey has clearly concluded that water conservation through sand dams, sub-surface dams and large surface reservoirs has limited impact on the groundwater sources. It may have some very localised effect, such as a sub-surface dam in a togga will provide a better water table for shallow wells in its immediate vicinity.

On limestone, surface stored water can percolate, but due to its highly fractured character, it is impossible to target aquifers as the water may move in any direction through the fissures in the limestone. On basement rock, water will not percolate as is the case with clay sub-strata (Baki Valley).

Figure 5.62 A small gabion barrier placed across togga in Durdur area (photo from German Agro-Action report, 2006)

Subsurface dams in toggas are a solution where groundwater is insufficient in the upper and lower catchments. Any other structure obstructing the powerful water flow during flash floods will fail. They will have to be individually sited based on need and suitability of the site. The latter depends on:

- Width of the togga. The wider the togga, the longer the dam has to be. In a wide togga, a narrow site for the dam is to be selected;
- The dam has to be constructed on bedrock (not limestone) or clay and needs to be well toed into the togga bottom.
- The riverbed behind the dam should be as large as possible to store water and the gradient of the riverbed should not be steep.
- The sides of the dam have to be well toed into the river banks at a higher elevation in order to prevent water to circumvent the structure. "[33]

Direct infiltration of captured surface waters during episodes of peak floods can be considered another efficient way to recharge aquifer systems. Such a system can be applied primarily in karstic or fissured aquifers consisting of hard rocks. The natural swallow holes, potholes or even fracturated depressions in relief are the

[33] cited from German Agro-Action, 2006

places where diverted runoff water could be stored and infiltrated. More efficient in terms of infiltration capacity will be a system of drilled inflow wells or wells which can be use for dual purposes – injecting and pumping, depending on season and water situation. This kind of well is also known as SAR – Storage and Recovery wells. And it may primarily improve the situation of water supply for larger consumers.

Figure 5.63 Sand dam near Awbarkhadle (Photo Somalinad team 1)

Figure 5.64 One of the potential places for subsurface dam – togga near Berbera (Photo Somaliland team 2)

Storing surface waters in the ground for their further utilization in critical dry periods is a much better solution than allowing these waters to flow downstream and to evaporate. Of course, assessment of environmental conditions and demands of downstream consumers (if any) is of crucial importance and should be implemented together with a hydrogeological survey and feasibility study (location, conditions, solutions, cost-benefit analysis). In any case, the construction of such a system requires professional and experienced staff.

Based on the results of the survey, a combined system including small ponds for storing runoff water, a booster pump station and pipe/canals for diverting the water to the wells could be considered an optimal preliminary option. Clogging of the water paths is the main problem that could appear during the operation. The clogged topsoil may be crumbled by encouraging the farmer to use the ponds for agricultural purposes during the dry season (in summer). In order to avoid clogging of the well-screen, stabilisation and initial water treatment are required before infiltration. The dual utilisation of the well can be an optimal solution, implying infiltration in high water periods, and pumping during the summer/autumn season.

Figure 5.65 A small pond could be used for storing flood waters to be pumped out to the wells or nearby aquifers (along the togga's banks)

Controlling and licensing the drilling and pumping of the well is an important task which supports aquifer control. Many groundwater degradation problems worldwide are the direct result of policies that encourage unlimited extraction. In Somaliland and Puntland most of the wells are on private lands and used by individuals or small communities. Controlling the number of deep wells, locations, pumping rates and working hours is an important task of the national institutions responsible for water management. Despite this, management of such issues with hundreds or thousands of smallholders is unlikely to be practical. However, it was noted during HASP that there are generally both a good relationship and links between local institutions and the rural population which is a prerequisite for establishing control mechanisms.

Figure 5.66 Drilling rig in operation in Toghdeer region (Photo Somaliland team 2)

5.3 Groundwater protection from pollution

The water quality situation in most of the surveyed villages in remote areas was found to be very poor. An earlier report of SHAAC Co. (2006) which investigated promising sites for drilling in Somaliland and Puntland found that “almost all respondents of the studied sites believe that the existing water currently in use has serious health problems and the community has realized they are highly susceptible to most easily preventable diseases. It was found that around 60% of the health problems affecting adults are either endemic diseases or water related and similarly, 75% of the diseases which often attack children are either water borne or related to water. Water-borne diseases are among the major health threats in all study sites. According to elders and local health professionals in the area, the very common clinical cases are water-borne diseases such as amoeba, Jardia, Pathogenic Ecolie, dysentery etc. and significant water-washed diseases such as trachoma, conjunctivitis, scabies etc. Malaria is also the most dangerous life threat in most of the study sites.”

The SHAAC report (2006) pointed out that distances to water supply sources could be very long. “It is obvious that community members travel long distances to collect water from the available sources, whatever the quantity or quality of the water may be. The average fetching distance was found to be 10 to 20 km. Where berkads exist, in the rainy seasons, almost all people have the opportunity of using water from individually owned berkads or natural ponds which are located in the proximity of their villages. However, in the dry season (when berkads & ponds completely dry up), people travel long distances under harsh weather in search of water.“[34]

The survey for this Phase IV of SWALIM conducted in 2011/2012 confirmed an unequal distribution of water resources, and a shortage of water even for the basic needs of the population and livestock in certain areas, but also some sites where groundwater could satisfy most needs of the local population. For example, the survey of Puntland team 1 which covered the central part of the Sool plateau and region shows the following coverage in water demands of some surveyed group of villages (Table 5.8).

Table 5.8 Group of villages and their water situation according to Puntland team 1

District /Villages	**Estimated water resources (m^3/day)**	**Total water demands (m^3/day)**	**Percentage of coverage Available/Demand**
Laas Caanood (Yagoori, Yeyle, etc.)	23180	84773	27%
Buuhoodle (Tukaraq, Higlo, Ceegaag, etc. near Ethiopian border)	15132	19115	79%
Taleex (Labas, Goodalo, etc.)	5051	9161	82 %
Laasqoray – Sanaag (Buurawadal, Dhahor, etc.)	4561	5257	86%
Xudun (Gorofley, etc.)	27954	88483	31%
Buraan- Laasqoray- Sanaag (Carmo, Lasdawaco, etc.)	4614	4743	97%

The most vulnerable aquifer systems are phreatic, those such as the alluviums of togga with a shallow and free water table. The Auradu or Karkar limestones have better preconditions for preventive protection of groundwater, but in the case of large cavities or direct access to the groundwater table (as indicated in many places during the field survey) their situation is even worse.

Sanitary protection zones exist only in water utilities of large settlements and they mainly concern the first zone around water sources or around the main pumping/water treatment station (as in the case of Geed Deeble). Typically, the pump houses are not fenced and they are not even locked everywhere. Therefore, improvement of the sanitary situation should involve several essential steps:

[34] cited from SHAAC report (2006)

- delineate sanitary protection zones;
- fence the wells and pump houses used for drinking water supply (kiosks or utilities);
- separate canals for animals watering from taps;
- clean any landfill in the vicinity of water sources.

Van der Plac (2001) indicated several theoretical pollutants and potential contaminant activities:

- agrochemicals (fertilisers, pesticides and herbicides),
- pathogenic micro-organisms (unsewered sanitation systems),
- oil spills (careless handling, repair works, traffic accidents and leaking of oil tanks),
- degreasing agents and other industrial chemicals (from light industry/small workshops),
- domestic waste (uncontrolled and /or unauthorised waste disposal), and
- quarrying operations.

"Pathogenic micro-organisms and domestic waste are the main potential contaminants of the upper catchment. The warm climate allows the relatively rapid propagation of bacteria. While this may be a problem for surface water and shallow groundwater resources, the organisms cannot survive without oxygen. In deep groundwater bodies, all micro-organisms will be eradicated within a few days.

The minimum distance from a well or borehole to a possible source of pollution should be great enough to provide reasonable assurance that sub-surface flow or seepage of contaminated water will not reach the well."[35]

Groundwater in the study area can also be contaminated by various chemical pollutants. The consequence of the civil war is presence of explosives and different dangerous materials in certain areas. The Puntaland team 2 indicated such case by surveying near Madow Mt in Huddun district (Sool Region). They found large amount of DDT deposited in one of the local caves. Presence of such poisons in highly permeable karstic aquifer is extremely dangerous and if reach groundwater flow can eventually result with direct loss of human lives.

[35] cited from van der Plac report (2001)

Figure 5.67 Drilling of a new well in Xumba Weyne for Hargeysa water supply. The adequate groundwater protection measures must be taken in consideration along with building of a new infrastructure (pump rooms, pipes, chlorinators, etc.)

Based on international practice, the recommendations of Driscoll (1986) and Van der Plac (2001), we advise the following distances of water sources from potential pollutants:

12 m from:

- a buried sewer (tested and watertight) constructed of cast iron pipe or plastic pipe,
- a pit, cave or unused open space below ground surface,
- a watertight sewage tank.

30 m from:

- a buried sewer,
- a subsurface disposal field (waste pit),
- a grave, or graveyard
- an animal yard or building,

- a place where manure is stored or used,
- a house or any other building apart from the pump house.
- surface water (seasonal)

50 m from:

- cesspools, unsecured septic tanks or leaching pits (including pit latrines),
- dry or open, unprotected wells and unsealed abandoned wells
- surface water (permanent)

100 m from:

- any area where oils, commercial fertilisers, spray materials or chemicals are either prepared, stored or used.

"The above mentioned safety distances are based on soil material with a filtering capacity comparable to sand. Increasing the distance between boreholes and possible sources of contamination will further decrease the pollution risk. Hence, a larger spacing should be applied where possible."[36]

"Water is a source of life": In some cases free access to water should be limited. This is not currently the situation with Meer Meer source in Auradu limestones in Figure 5.68.

Figure 5.68 Meer Meer source in Auradu limestones (*Ceerigaboo area, Photo of Somaliland team 2)*

[36] cited from van der Plac report (2001)

Some of the recommendations regarding the groundwater protection in arid environment can be taken from DWAF & NORAD “Guidelines on protecting groundwater from contamination” (2004) (http://www.dwaf.gov.za/dir_ws/tkc/vdFileLoad/file.asp?ID=213)

“Generally, the risk of water from a spring, well or borehole being contaminated is increased when:

- There is little or generaly no vegetation cover in the catchment Animal faeces such as manure are disposed near or in the water table, or near or in a water source. This reduces the time that unsaturated soils can remove potential contaminants before they reach the water table or the water source.

- There is heavy rainfall produces water runoff. Runoff carries with it contaminants from the wastes it encounters. High part of water runoff enters to shallow aquifer.

- There is a shallow water table. Where the water table is close to the ground surface, there is little depth of unsaturated soil available that can effectively remove / reduce contaminants before they reach the groundwater.

- There are highly permeable soils and rocks as limestones or alluvial deposits...

Protection zone 1 is the radius of influence of the water supply well. The radius of influence can be defined as the radial distance to points where the water level in the aquifer is noticeably affected by the pumping well. No contaminant source or contaminating activity should be practiced in this zone (with the exception of pump engines).

Protection zone 2 is the distance outwards from the well, beyond the radius of influence, for which the travel time of groundwater is less than 25 days.

Protection zone 3 is the distance, outwards from the well beyond protection zone 2, for which the travel time of groundwater is between 25 days and 50 days.

Protection zone 4 is the distance, outwards from the well beyond protection zone 3, for which the travel time of ground water is more than 50 days.”[37]

[37] DWAF & NORAD(2004) (http://www.dwaf.gov.za/dir_ws/tkc/vdFileLoad/file.asp?ID=213)

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Annexes

Annex – I: Regional Hydrogeological Map of Somaliland and Puntland

Annex – II: Regionl Water Quality Map of Somaliland and Puntland

Annex – III: Hydrogeological Map of Area of Interest 1 (AOI-1)

Annex – IV: Hydrogeological Map of Area of Interest 2 (AOI-2)

Annex – V: Hydrogeological Map of Area of Interest 3 (AOI-3)

Annex – VI: Hydrogeological Map of Area of Interest 4 (AOI-4)

FAO-SWALIM serves water and land information needs of Somali administrations, UN Organizations, Development Agencies and NGOs. To reach this goal, we are re-establishing data collection networks in collaboration with Somali institutions and partner agencies and at the same time recovering lost information from all over the world. The information-building process involves collecting primary and secondary data needed for water and land resources management, generating user-friendly information from the data, storing the information in easily accessible databases and disseminating it through conventional and electronic media.

Our products are available for free to all organizations and individuals working in related fields in Somalia. They include 35 technical reports on water and land resources of Somalia and related datasets, our website which provides access to 2 searchable online data catalogues and links to other products and a reference library and data access terminal at each of our 3 information resource centres.

These products can be accessed at our Nairobi office, online by visiting our website (*www.faoswalim.org*), through email request (swalim@fao.org) or by visiting our field information resources centres at Hargeisa and Garowe.

To facilitate the eventual transfer of SWALIM's function to Somali authorities, SWALIM is working with Somali Ministries and institutions to build their information management capacity.

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