Technical Report

Somalia: Groundwater Assessment

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An accompanying report (of a suite of six reports) with

Economics of Water:
Digging for Data—Towards Understanding Water as a Limiting or Enabling Factor for Socioeconomic Growth in Somalia

Contents

Abbreviations and Acronyms

ASA	Advisory Services and Analytics
CAPEX	Capital Expenditure
ET	Evapotranspiration
FAO	Food and Agriculture Organization
ha	Hectare
km	Kilometer
lcd	Liter Per Capita Per Day
l/s/km^2	Liters Per Second Per Square Kilometer
m^3	Cubic Meter
microS/cm	Micro Siemens Per Centimeter
mm/d	Millimeter Per Day
mm/yr	Millimeter Per Year
OPEX	Operational Expenditure
PET	Potential Evapotranspiration
SWC	Soil and Water Conservation
SRTM	Shuttle Radar Topography Mission
SWALIM	Somalia Water and Land Information Management (FAO)
ToR	Terms of Reference
WaPOR	Water Productivity Open-access portal (FAO)
WB	World Bank
WBG	World Bank Group
WDA	Somali Water Development Agency
WDS	Water Delivery System
WHO	World Health Organization
WSC	Water and Soil Conservation
yr	Year

Executive Summary

Climate and hydrology: Rainfall in Somalia ranges from 700 mm/yr in the south to less than 100 mm/yr in the northeast and is mainly confined to the *gu* season (April and May) and the *deyr* season (October and November). The potential evapotranspiration is 2,000–3,000 mm/yr and the open water in hafirs (dams) and berkads may lose about 1 meter by evaporation in the dry season. As is commonly observed in desert and semi-arid climates, the variability of rainfall is quite large in the Horn of Africa. An important aspect related to the seasonal and interannual variability of rainfall is the absence of any natural surface water storage in Somalia. Water can only be stored in man-made facilities such as berkads, hafirs (dams) and, indirectly, in sand dams.

After reaching the surface, rainwater stays behind in and on the soil. Only a small percentage runs off by overland flow. After the rains, most water in the soil and on the wet surface evaporates or transpires (by vegetation) back into the atmosphere. A minor part passes by the soil zone and recharges the deeper groundwater body. BGS (MacDonald et al. 2012) and BRGM (Seguin and Gutierrez 2016)[1] estimated annual groundwater recharge values varying from 1 mm/yr or 0.03 l/s/km^2 in the outer northeast to 20 mm/yr or 0.63 l/s/km^2 in the south.

Renewable (blue) water resources are groundwater and internally produced surface water from rainfall. We have defined a conservative estimate of the **renewable groundwater** resources using the groundwater recharge values reported in the BGS and BRGM studies mentioned above, converting them from mm/yr to l/s/km^2 and assuming a linear relationship with rainfall. Internally generated specific **renewable surface water** resources have also been determined, assuming an average runoff of 3 percent of annual rainfall. The total internally produced specific renewable water resources in Somalia are summarized in Table 1 and vary from 0.1 to 1.1 l/s/km^2 from the dry northeastern to the more humid southern regions. These values are in line with the Food and Agriculture Organization, or FAO (2014) Aquastat estimates and the FAO-SWALIM (2012) study.

Not all renewable water can be used or withdrawn, in practice. The amount of water which can sustainably be withdrawn (**sustainably available water resources**) depends on local conditions and is also somewhat subjective. In various policy studies,[2] sustainably available water resources are considered to be 20 percent of the renewable water resources. Above this limit, both water supply and demand need to be managed and conflicts between competing uses will need to be resolved (EEA 2005).

Renewable water resources and water demand. Comparing the available renewable water with the estimated 2030 blue water demand in Somalia[3] shows that the 2030 demand does not exceed the 20 percent scarcity limits with the exception of Benadir and Awdal (see the last two columns in Table 1). This conclusion is a bit indicative as all these values are averaged over time and space and only the water demand for people and livestock are taken into account. Water shortages will still occur at places with high concentrated demand like towns and large villages (blue water) or green water shortages during drought periods. This is also confirmed by various water scarcity indicators which rate Somalia as a severe water scarce country (Table 2).

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[1] BGS: British Geological Survey; BRGM: Bureau de Recherches Géologiques et Minières Briaue (France).

[2] van Ham et al. 2018; WWAP/UN-Water 2018; EEA 2005; and UN 1997.

[3] Data sources: Population and Livestock (UNDP 2014), growth rates (4.14 percent for urban and 1.79 percent for rural) from the World Bank database and unit water consumption (20 lcd for rural and 40 lcd for urban) from Somalia WASH Cluster (2020), and livestock water intakes based on Peden et al. (2003).

Table 1. Specific Internally Produced Renewable Water Resources Per Region in Somalia

Region	Rainfall	Specific renewable water			Renewable water			Available (20% of renewable)	Water demand 2030	Availabe minus - Demand
		Ground water	Surface water	total	Ground water	Surface water	total			
	mm/yr	l/s/km2	l/s/km2	l/s/km2	10^6 m3/yr	10^6 m3/yr	10^6 m3/yr	10^6 m3/yr	10^6 m3/yr	10^6 m3/yr
Awdal	215	0.16	0.17	0.33	60	82	143	29	28	1
Bakool	354	0.30	0.31	0.61	211	247	458	92	23	69
Banaadir	376	0.32	0.33	0.65	1	2	3	1	45	-44
Bari	101	0.05	0.05	0.10	93	111	204	41	24	17
Bay	505	0.44	0.47	0.91	382	646	1,028	206	26	180
Galgaduud	233	0.18	0.19	0.37	69	289	358	72	23	49
Gedo	392	0.33	0.35	0.68	373	487	860	172	28	144
Hiiraan	287	0.23	0.24	0.47	139	258	397	79	26	53
Lower Juba	598	0.53	0.56	1.10	322	843	1,165	233	23	210
Lower Shabelle	461	0.40	0.42	0.82	248	340	588	118	29	89
Middle Juba	574	0.51	0.54	1.05	148	318	466	93	14	79
Middle Shabelle	357	0.30	0.31	0.61	159	180	339	68	15	53
Mudug	173	0.12	0.13	0.25	110	232	342	68	29	39
Nugaal	154	0.10	0.11	0.21	82	93	175	35	20	15
Sanaag	178	0.13	0.13	0.26	143	223	366	73	23	50
Sool	139	0.09	0.09	0.18	69	108	176	35	16	20
Togdheer	261	0.21	0.22	0.42	160	233	393	79	32	46
Woqooyi Galbeed	305	0.25	0.26	0.51	171	231	403	81	50	31
Average/total	315	0.26	0.27	0.53	2,941	4,923	7,863	1,573	473	1,100

Groundwater and aquifers. The most widespread source of groundwater are the **deep limestone, sandstone, and basalt aquifers**. They are exposed in the northwest of Somalia and in the Bay region in the south but are buried under hundreds to thousands of meters of sediments in the rest of the country. Not all water in these aquifers is locally recharged. Some of the transboundary aquifers are recharged in Ethiopia. The sediments of the Jurassic to Tertiary age consist of extensive consolidated and more or less horizontally layered rocks. The limestones and sandstones of this series form aquifers with primary intergranular porosity (sandstones) and secondary fracture porosity (limestones). Due to financial and technical restrictions, boreholes generally tap only the upper 100 to 400.

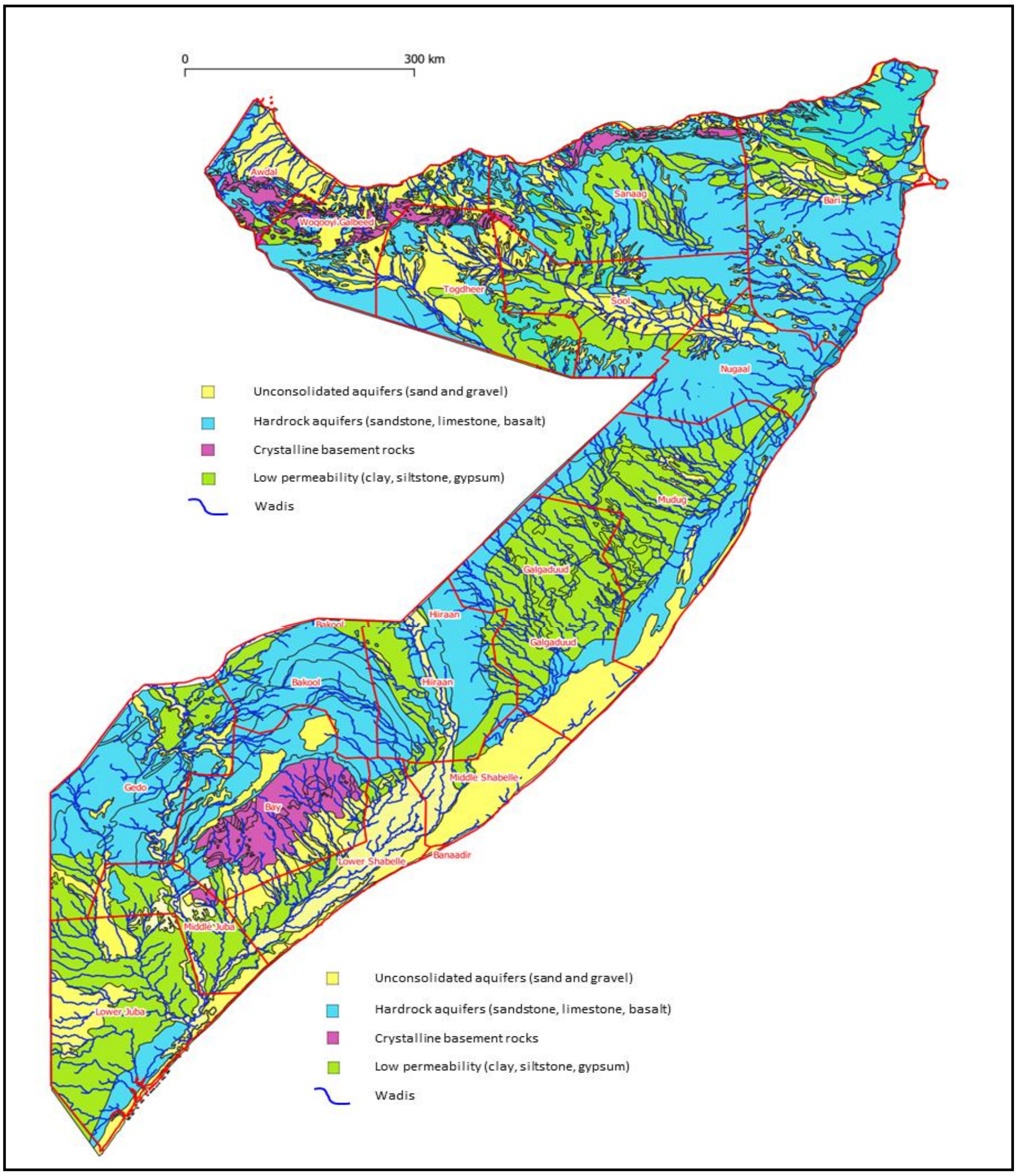
Table 2. Summary of Water Scarcity Indicators

Indicator	Data	Rating
Falkenburg (2007)	Table 1 (total renewable water) and population of 16 million	Index is 490—meaning absolute scarcity
NASA (2019)	Same basis as Falkenburg but based on more spatial data	Absolute scarcity in Middle Somalia, Puntland, and Somaliland
Blue water Footprint (2011)	Relates to fresh (surface and ground) water but also includes the virtual water needs	Absolute scarcity everywhere in the country
FAO (2017)/green water	Based on the occurrence of droughts	Frequency of severe droughts affecting 50% of cropland and grassland

Note: Also see Appendix 1.

The Quaternary **sand and gravels** are of local extent and are found as alluvial fills along wadis and valleys and in some structural basins. Groundwater occurs at a shallow depth (<15 m), indicating perched aquifer systems overlying the deep regional aquifers. Where the Quaternary sands have been mapped, we assume the sands form extensive bodies with saturated thicknesses of more than 10 m allowing groundwater abstraction by means of (hand drilled) boreholes.

Figure 1. Simplified Hydrogeological Map of Somalia



Note: Based on Abbate et al. (1993).

Crystalline basement rocks do not hold much water. Shallow boreholes (30 to 60 m) drilled into the bedrock in these fracture zones may yield 0.25 to 1 l/s, but success rates are low (around 50 percent).

All sediments dominated by **clay, claystone, shale, siltstone, marl, and gypsum** are considered to be unproductive as far as water recovery is concerned.

Aquifers are shown in Figure 1 along with the wadis, which are narrow bands of alluvial deposits with widths of 20 to 100 m, and thicknesses of a few meters to 10 m. The numerous dug wells and scoop holes along these wadis, albeit having low capacities, are of crucial importance to the population.

Groundwater quality. The salinity of groundwater in dug wells, boreholes, and springs is relatively high in Somalia. The SWALIM database indicates that about 70 percent of these water points have salinity levels above the WHO limit of 1,500 microS/cm, while 30 percent are above the Somali Water Development Agency (WDA) limit of 3,500 microS/cm. High salinity is often accompanied by high concentrations of sulfate, calcium, magnesium (which can cause kidney problems) and fluoride (which can cause fluorosis). There are many studies reporting the problem of bacteriological and nitrate contamination of open water points like dug wells, berkads and hafirs. However, badly sealed deep boreholes are also sometimes bacteriologically contaminated. This anthropogenic pollution is exacerbated by poor sanitary conditions around the water points. Pollution of open water points can hardly be avoided. Therefore, our advice is to focus investments on boreholes (manual and machine drilling) and improved closed dug wells or collector wells in conjunction with sand dams.

Climate change and impacts. Petersen's and Gadain's (2012) study and the data from the World Bank Climate Change Knowledge Portal (2021) indicate that temperature, annual rainfall, and evapotranspiration in Somalia will rise during this century. Seasonal rainfall during the *gu* and *deyr* season will increase, with most rains falling during the *gu* season. Frequencies of droughts will not change. (The drought indicator of the World Bank portal does not change much.)

In the future, high intensity rains will become more common, resulting in more frequent flooding and higher runoff in general. Impacts are difficult to ascertain with respect to groundwater and groundwater recharge, but they probably are not very high. We assume groundwater will not benefit much from the increased rainfall as most of this rain is converted into surface runoff and evapotranspiration.

Water Points and Water Delivery Systems (WDS)

Overview of water points. Water for domestic and livestock use is drawn from a variety of water points which depend on the accessibility of the groundwater and the opportunities to capture surface runoff for storage in reservoirs. Important sources of information are the SWALIM reports and the SWALIM Water Points Database (Box 1).

Box 1. SWALIM Water Point Database

Under the SWALIM project, the Somalia Water Sources Information Management System (SWIMS) was developed. The SWIMS stores a wide range of data for different types of water points used in Somalia: boreholes, shallow wells, springs, dams, and berkads. Sand dams and subsurface dams are not included yet.

There are 387 berkads, 555 dams, 2,981 dug wells, 1,997 boreholes, and 439 springs in the database.

The data are not complete for all fields and do not cover all existing water points. Therefore, this set of data cannot be used to estimate the current water production.

Some districts have no water points at all or much less than reported in the specific studies. Other districts have a lot of water points and are apparently visited by the SWALIM survey teams.

This is also illustrated by the many water points in Somaliland and Puntland, probably because this area was safe enough for the teams to visit. The latest update (Livemap) shows 1,500 additional water points entered after Phase 1.

Berkads are open plastered cisterns dug in unconsolidated soil or hewn in bedrock. Storage capacities generally range from 150 to 500 m^3. **Hafirs** are created behind dams on gently sloping terrain, preferably on clayey soils to reduce infiltration losses. Storage capacities range from 500 to 10,000 m^3. Most hafirs are found in the northwest and the south, where rainfall is more abundant.

More recent are **sand dams and subsurface dams** in combination with collector drains and wells. Sand dams are constructed in alluvial beds. The storage capacities of the sand bodies behind these dams vary from 5,000 to 40,000 m^3. This volume is available for use during the dry season (180 days) but is often augmented by recharge of groundwater inflow from the surrounding soils.

There are **hand dug wells** in alluvial unconsolidated sands. Generally, the depth is less than 15 m. Water is recovered by buckets or bags, or by a handpump or motorized pump if larger abstraction is possible. Production capacities of dug wells are about 1–5 m^3/d depending on the type of pump used.

Manually drilled wells with a depth up to 40 meters are a practical alternative for boreholes in alluvial soils and soft rock formations. They are more affordable than machine drilled wells and are also a good alternative for hand dug wells at lower costs. Furthermore, manual drilled boreholes are often deeper than excavated wells and, if properly sealed, provide better protection from contamination.

Deep motorized boreholes (50 to 400 m deep) are drilled into limestone and sandstone aquifers and thick alluvial sand deposits. Generally, borehole depths increase from west to east and production capacities of boreholes vary from 3 to 35 m^3/hr. Drilling requires specialized equipment and is expensive because of the high mobilization cost in remote areas; low success rate because of technical problems during drilling; well failure because they are dry; or if the water has high salinity.

More reliable are the **springs** arising at the foot of mountains, escarpments or along geological boundaries and structures. Springs' discharge typically vary from 1 to 3 m^3/hr. Most of the known springs are already in use as a source for water supply and small-scale irrigation.

Applicability of water points. The reliability of the berkads and hafirs is not very high (SWALIM); they have low capacities, are bacteriologically unsafe, and are constructed at low costs with local expertise. Sand dams, manually-drilled boreholes, and machine-drilled boreholes provide safer and more reliable water. Their applicability is further analyzed below:

- **Sand dams or underground dams** are only feasible in larger wadis with upstream catchments of at least 200 km^2. The minimum distance of 10 km between the dams is recommended accommodating the large throwback of some dams and the limited and temporary runoff in the wadis. The maximum number of sand dams or underground dams in each region has been calculated in this report.

- **Manually-drilled boreholes** can be drilled to 40 m, mainly in unconsolidated material. These areas are identified and the number of boreholes in each region is estimated based on the unit production capacity of 6,570 m^3/yr and reduced with 30 percent for salinities above 3,500 microS/cm.

- **Machine-drilled boreholes** can be as deep as 400 m and are drilled mainly into hard limestone and sandstone aquifers. These zones are mapped, and the maximum number of machine-drilled boreholes is estimated for each region based on the unit production capacity of 86,400 m^3/yr and reduced by30 percent to account for salinity above 3,500 microS/cm, the acceptable WDA limit.

A **Water Delivery System (WDS)** refers to the infrastructure needed to deliver the water from the source to the point of use (pumping, collection, transmission, treatment, storage, and distribution of water).

For rural water schemes, a WDS typically consists of a pump (motorized pump) and a reservoir (10–25 m^3) with taps and animal troughs, costing US$25,000–35,000. For sand dams, there may also be the need for a (maybe 3” or 4”) conveyance pipeline which costs US$20–30/m depending on the terrain conditions (Biyoole project).

WDSs for towns and cities have the same components but are larger in size and scale (conveyance, treatment, storage, and distribution) and require professional operation and maintenance. The estimated cost of a small town or multiple village scheme is in the range of US$60–90 per consumer. For larger towns and cities, the per capita cost for drinking water supply improvement is also dependent on the level of supply (number of house connections and large consumers with specific demands) and will range from around US$100 per capita for supply through standposts to over US$300 for household connections.

Two particular components of a WDS are discussed in more detail: solar pumping and desalination of salt and brackish water. The cost of **solar pump systems** (pumps, inverters, junction boxes, and PV modules) in Somalia is in the range of US$20,000–30,000 but its annual costs are lower than for motorized pumps. Energy-wise, the use of solar pumps is clearly advantageous in Somalia, but the real cost will largely depend on the sustainability and continuity of the operation, especially in remote areas.

Desalination of seawater or brackish groundwater can improve the access to freshwater for cities and towns in Somalia. The cost of desalination of seawater by Salt Water Reverse Osmosis (SWRO, also known as RO) is currently in the range of US$0.5–1.5/$m^3$, depending on electricity costs and production capacity. For Somalia, it is safe to use the higher price ranges. Desalination of **brackish groundwater by RO** is roughly 50–75 percent of the cost for seawater desalination; it is estimated to be in the range ofUS$0.8–1.0/$m^3$ for Somalia. An alternative for village level water supply is brackish groundwater desalination through **Photovoltaic (PV)-powered electrodialysis (ED**). The PV-ED requires less energy than RO for brackish water with a salt concentration less than 4,000 ppm and produces high quality water at a water production cost of US$3.5–5.5/$m^3$ (2017). Developments in PV-ED are progressing and may have reduced the production cost in the last five years.

OPEX and CAPEX of Water Points and WDS

An excel calculation sheet has been prepared to summarize the CAPEX and OPEX of the different water points and their characteristics. Table 3 gives an overview of these characteristics, as well as the minimum, maximum, and median CAPEX, and a summary with the estimated OPEX as a percentage of the CAPEX. The calculation sheet also includes a table with the total annualized cost of the waterpoints for a given lifetime and interest rate, and shows the total annualized cost (CAPEX and OPEX) per consumer and per m^3. Values can be adapted in the calculation sheets when new or updated information becomes available.

The CAPEX of a WDS cannot be generalized because of the varying size of the schemes and the variable cost of specific water infrastructure components. An estimate based on recent investment plans for secondary cities[4] indicates US$50–130/consumer (average US$70/consumer). Similar values are also reported from multiple villages and small-town water supply schemes in Punjab, India (World Bank, Rural Drinking Water Quality Management in Punjab, India 2018).

Table 3. Characteristics and Costs of Water Points

Characteristics and Cost of Water Points

Water Points	Storage (m3)			Depth (m)			Production			CAPEX		
	range	maximum	median	min	max	average	l/sec	m3/day	m^3/yr	min	max	median
Berkad x1	200-400	3,000	300					2	600	5,000	40,000	7,500
Dam with reservoir (Balli, War) x4)	2,500-15,000	450,000	7,500					40	15,000			100,000
Hand dug well + handpump				3	20	8	0.2	4	1,260	2,000	10,000	7,500
Handdug well +motorpump				*5*	*20*	*10*	0.5	18	6,300		15,000	15,000
Manual drilled well + handpump x3)				10	50	30	0.2	4	1,260	2,000	8,000	6,000
Manual drilled well + motorpump				10	50	30	0.5	18	6,300			13,000
Sanddam/sub surface dam +HP x1,x5	6,000-40,000		17,000					93	34,000	20,000	150,000	70,000
Sanddam/sub surface dam +MP	6,000-40,000		17,000					93	34,000			80,000
Drilled deep well + MP min *2)				100	400	225	8	288	100,800	75,000	500,000	200,000

x1): based on dry season use: 180 days | x2) multiplier for succes | x3) excl traning & PS developı | x4): silting not accounted f | x5: storage in sandbed behind the dam

Summary table

Water Points	Storage	Depth	Production	CAPEX	OPEX	
	m3	m	m3/yr	USD	%	USD /yr
Berkad	300		600	7,500	5	375
Dam+ Res, War, Waterpan, pond	7,500		15,000	100,000	5	5,000
Hand dug well + handpump		8	1,260	7,500	5	375
Handdug well +motorpump		10	6,300	15,000	15	2,250
Manual drilled well + handpump		30	1,260	6,000	5	300
Manual drilled well + motorpump		30	6,300	13,000	15	1,950
Sanddam/sub surface dam +HP	15,000		34,000	70,000	5	3,500
Sand dam/sub surface dam +MP	15,000		34,000	80,000	15	12,000
Drilled deep well + MP		200	100,800	200,000	20	40,000

Green Water for Rainfed Agriculture

Increasing production of rainfed agriculture can be better realized with soil and water conservation (SWC) techniques. These techniques—such as stone bunds, terraces, half-moons, retard overland runoff, and erosion—promote infiltration and increase soil moisture content (Liniger and Critchley 2007). As a result, crop yields will increase and, in any case, will be less affected by moderate droughts. Rainfed agriculture is carried out mainly in (a) the northwestern regions of Awdal, Woqooyi Galbeed, and Toghdeer along the Ethiopian border; (b) the Bay region; and (c) the coastal strip in the Lower and Middle Shabelle and Lower and Middle Jubba regions.

[4] Summary of WB-funded investment plans for secondary cities in Puntland and Somaliland (2020).

The WaPOR tool of the FAO (https://wapor.apps.fao.org/home/WAPOR_2/1) has been used to delineate where SWC interventions (per region) are assumed to be most effective. It is no surprise that these prospective areas fall in the zones where the population already practices rainfed agriculture. From various references, the unit prices for known SWC measures in Somalia are estimated to be US$300–1,200/ha (average: US$700/ha) and a 5 percent annual cost for operation and maintenance.

Conclusions and Potential Investment Opportunities

Water is felt as a scarce resource in Somalia, mainly because it is not available at the right place, at the right time or with the right quality. The extensive limestone and sandstone aquifers are too deep in some areas, while shallow and more easily accessible sand aquifers are restricted to the wadis, river valleys, dunes, and certain tectonic basins. It also appears that in some areas the quality of groundwater is unacceptable for human consumption (for instance, due to the presence of salinity and fluoride). Though surface water can be collected in many places in berkads and hafirs, these reservoirs prove to be unreliable during droughts: the little water that is collected evaporates before the end of the dry season. Also, shallow dug wells tend to fall dry during droughts, and water in many reservoirs and dug wells is bacteriologically contaminated.

Despite the water scarcity and the mismatch of supply and demand in time and place, opportunities still exist for developing water resources with the following strategies:

- **Water storage.** Construction such as sand dams and underground dams, already successfully applied under the Biyoole project, must be continued. In addition, recharge ponds surrounded by shallow wells are options for further investigations. van Haren et al. (2017) mention the presence of hafirs on permeable subsurfaces in Somaliland, where infiltrated water is captured by shallow wells.

- **Manual drilling.** To bridge drought periods, policies should be geared towards underground water storage. By nature, groundwater is the largest and most reliable storage medium. So, exploration and drilling of traditional boreholes remains a viable option, particularly relatively cheap manual drilling. However, success rates, well integrity, and therefore well costs, must be improved by capacity building both in the private sector and in governmental organizations.

- **Drilling deep wells.** Deep groundwater remains an important source of water including for urban and industrial water supply. We recommend investing in regional and local hydrogeological studies using geophysical techniques, and to invest in technical capacity development of local private sector parties, such as drilling companies and consultants. The same holds for increasing the capacity of governmental bodies responsible for planning and setting the standards for drilling. If, for instance, the success rate of 100 boreholes (with a depth 250 m) could be stepped up from 50 to 60 percent, this would already result in US$5–6 million savings on drilling. Such an amount certainly warrants an investment in capacity development of the drilling sector in Somalia.

- **Water transport.** Water is not always available in the right place. This is particularly relevant around towns with relatively high water demand. In most cases, such a large amount of water cannot be sustainably produced by some wells close to the town. Well fields need to be spread out over larger areas or hydrogeologically favorable zones must be explored at larger distances. In any case, water must be transported to the demand centers. For smaller settlements, particularly in pastoralist areas, it may be the other way around and people may need to move to the places where water is available.

- **Water quality.** With respect to water quality, investments in surface water reservoirs and dug wells are not warranted if they cannot be protected from contamination. Lined, closed, and deeply excavated dug wells, as the ones constructed for sand dams, may be a viable solution. Salinity and accompanying fluoride must be investigated and mapped in regional studies. Finally, construction of boreholes must adhere to state-of-the-art guidelines to avoid leakage around the well casing.

- **Green water.** For rainfed agriculture, the impact of droughts can be alleviated by applying SWC measures as proposed in the report. It is important to note that green water adds to the soil moisture and *does not compete with the blue water* withdrawals for rural and urban population and livestock.

Introduction

This is the Groundwater Technical Report for Chapter 1 of the 'Economics of Water: Digging for Data—Towards Understanding Water as a Limiting or Enabling Factor for Socioeconomic Growth in Somalia'.[5] It provides information on the total renewable water resources in Somalia and presents an assessment of the main groundwater resources and water harvesting techniques, its spatial distribution, and the potential for use (quality and quantity). Water points and the infrastructure needed to supply the water (water delivery systems [WDS]) are also described, including the estimated cost (CAPEX and OPEX) for waterpoints and water distribution infrastructure. Green water for rainfed agriculture is also covered, including the mapping of appropriate soil and water conservation (SWC) measures and its cost. The report concludes with a number of promising investment options for groundwater WDSs to improve drought resilience and water supply for people and livestock. Bibliography and a repository of geographical information have been added and are available with the authors for future use.

Technical issues to be covered

- What are the volumes of water that can be sustainably withdrawn, realistically, for use (at the local level, and by water source type)?
- What are the risks and vulnerabilities involved? How do these vary at the regional/district levels? What social capital coping mechanisms exist? How are climate, conflict, and legal issues addressed?
- What is the estimated financial cost of water provision?

Methodology for analyzing groundwater resources

- **Step 1:** Develop regional level estimates of total renewable groundwater resources (in m^3/yr) and the volumes of groundwater available for use.
- **Step 2:** Develop national maps highlighting hydrogeological features that influence how groundwater can be extracted, for example, a national map highlighting areas with limestone aquifers.
- **Step 3:** Analyze the types of groundwater extraction models that are suitable for each geological zone in Step 2. These will include both small and large scale models, from handpumps to machine drilled deep boreholes. Map each groundwater extraction model to ideal use scenarios. Handpumps, for instance, are suitable for rural household use but not for large towns.
- **Step 4:** Identify risks for each scenario.

[5] This technical report is one of a suite of six supporting documents along with the 'Economics of Water: Digging for Data—Towards Understanding Water as a Limiting or Enabling Factor for Socioeconomic Growth in Somalia' report. The other five supporting documents comprise: (a) three technical reports (Somalia: An Institutional Analysis Report; Somalia: Surface Water and Riverine Assessment Technical Report; and Water+ in Somalia: A Sectoral Analysis); (b) Somalia: Groundwater Quality Technical Note; and (c) a Summary Report. All the reports can be accessed at: the Ministry of Energy and Water Resources' website (https://moewr.gov.so) [the reports will be available in 2022 as the site is currently under development]; the World Bank's Water Global Practice website (https://www.worldbank.org/en/topic/water); as well as the World Bank's Somalia website (https://www.worldbank.org/en/country/somalia).

This report is focused on the supply side of the water resources available for use. Section 1.3, on sustainable renewable groundwater, also touches on the demand side and, in particular, on the question of water scarcity. A note on this topic is added as Appendix 1: Water Scarcity Viewed from the Supply Side. The last chapter (Chapter 4) presents the strategies and potential investment opportunities to increase the availability of the various water resources for people, livestock, and economic use.

The references and the repository of geographical information collected and used for the analyses in this report are listed in the Bibliography. Appendix 11 has some photos of typical water points. Appendix 12 gives some useful data on population and water points at the district (73 districts) and the regional (19 regions) levels.

1 Water Resources in Somalia

1.1 Climate

According to the Köppen classification, the major part of Somalia has a hot desert climate (BWh). In the southern part and the far northwest of the country, a hot semi-arid climate (BSh) and a tropical savannah climate (Aw/As) exists (Rubel and Kottek 2010). Rainfall ranges from 700 mm/yr in the south to less than 100 mm/yr in the northeast (Figure 2).

Figure 2. (Left) Average Annual Precipitation, 1981–2019,[6] and (right) Reference Evapotranspiration in 2019[7]

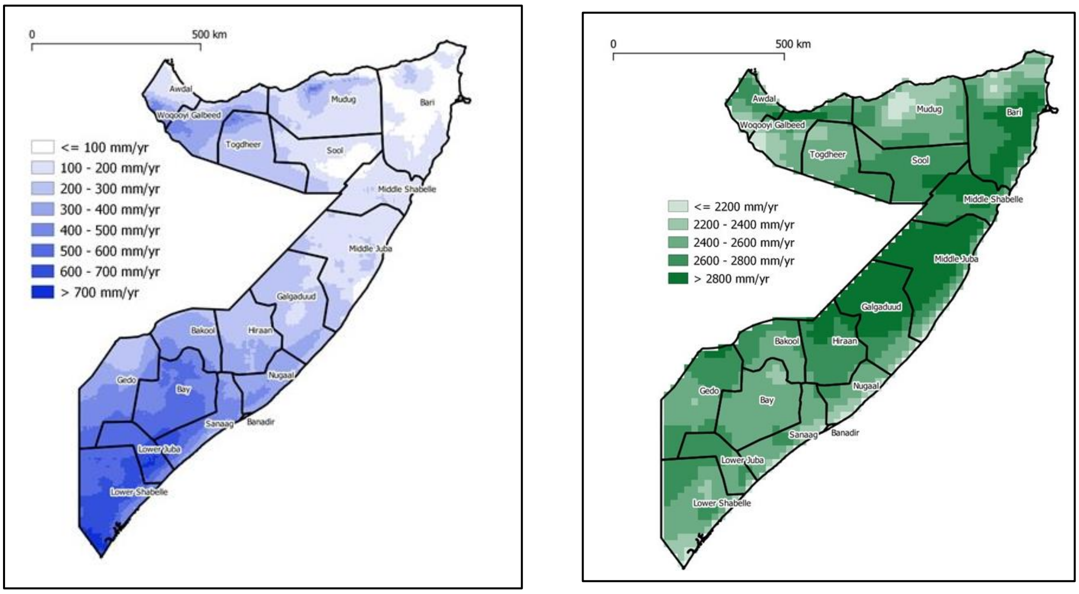
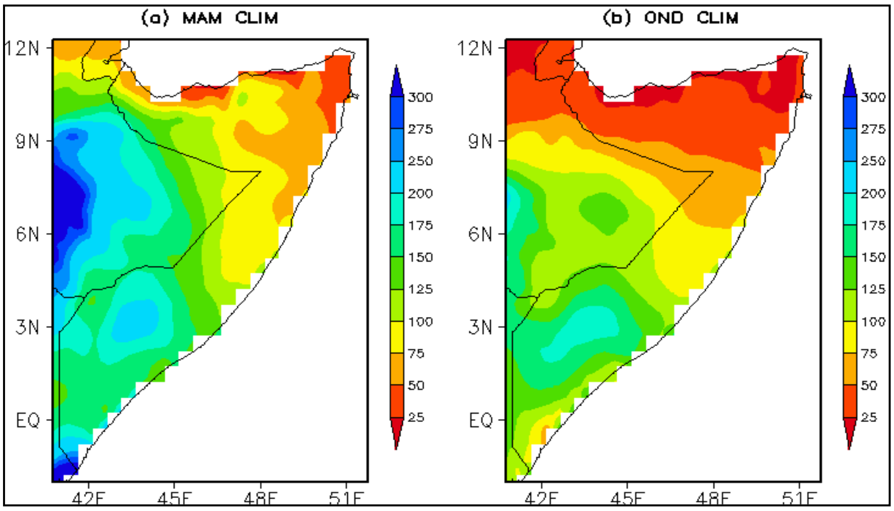


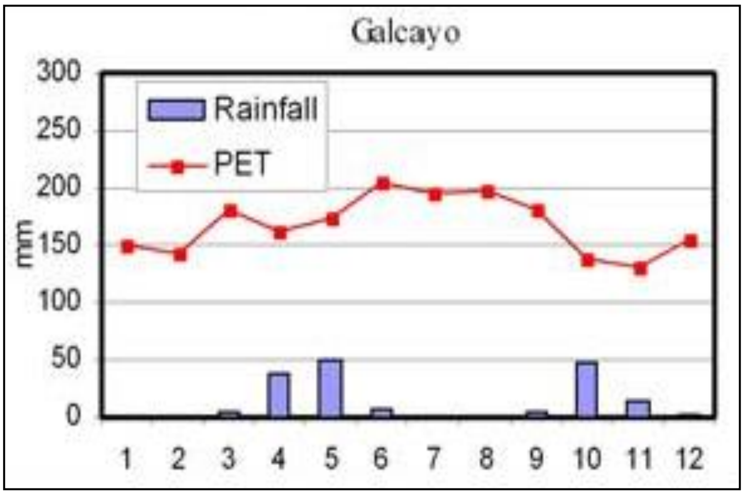
Figure 3. Average Rainfall in the *Gu* and *Deyr* Seasons[8]



[6] CLIMATESERV, CHIRPS data, retrieved from https://climateserv.servirglobal.net/; Funk et al. (2014).
[7] WaPOR: https://wapor.apps.fao.org/home/WAPOR_2/1.
[8] Shilenje and Ongoma (2014).

Given that rainfall or this amount of water is not available in an arid region, so actual transpiration from the land surface is much lower and depends on a number of factors related to soil and vegetation. However, potential evaporation from open water surfaces, also hafirs and berkads, will be close to the above-mentioned values. During the dry season these reservoirs may lose about 1 m of water by evaporation. This slice of water is a substantial part of their storage volume as the depth of the reservoirs is only a few meters (see Section 2.1).

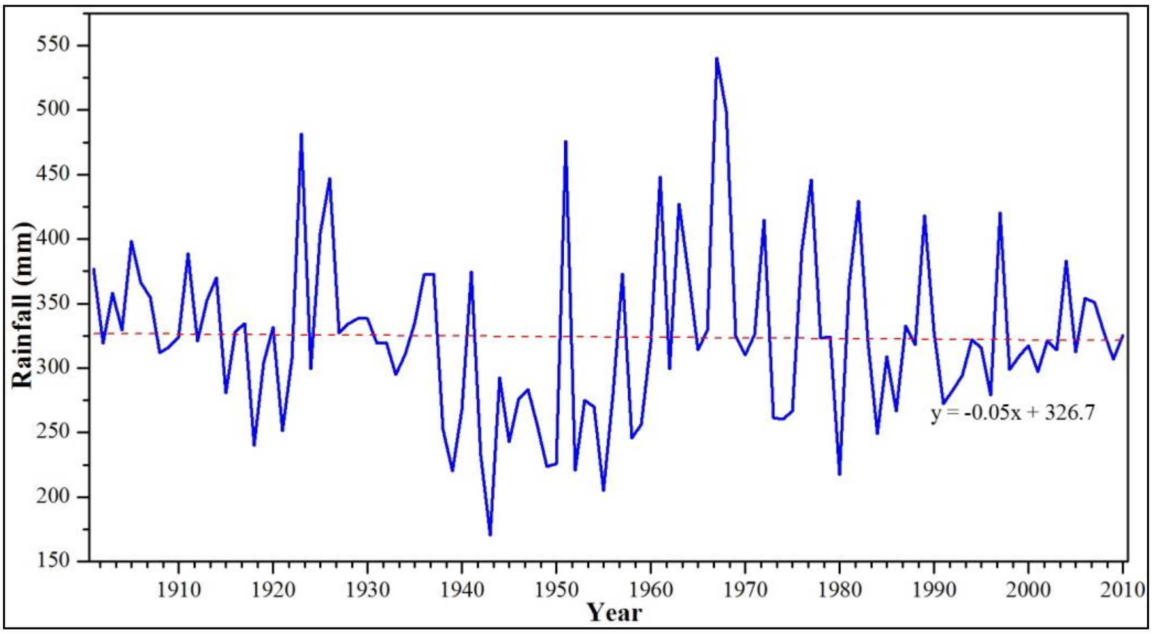
Figure 4. Average Monthly Rainfall and Potential Evapotranspiration, in Galkayo in Mudug Region



Source: SWALIM (2007a).

As is commonly observed in desert and semi-arid climates, the variability of rainfall is quite large in the Horn of Africa. Figure 5 from Shilenje and Ongoma (2014) shows a 110-year record. Various cycles can be discerned around a slightly declining trendline. There is an interdecadal cycle showing dry years during the 1940s and wet years during the 1960s, and smaller interannual cycles.

Figure 5. Interannual Variability of Rainfall in the Horn of Africa[9]



Shilenje and Ongoma (2014) quantified the drought frequency based on the standardized precipitation index (SPI) for the *gu* and *deyr* rainy seasons calculated from a 110-year perspective: mild droughts (SPI: -0.5 to -1) occur every three and two years for the *gu* and *deyr* seasons, respectively; moderate droughts (SPI: -1 to -1.5) every 11 and 12 years; and severe droughts (SPI: -1.5 to -2) every

[9] Shilenje and Ongoma (2014).

28 years, for both seasons; extreme drought (SPI < -2) can be expected once every 37 and 110 years, respectively.

Societal resilience depends on the intensity of droughts and has a bearing on the question: To what degree do water security strategies need to cope with droughts? Climate extremes can also result in floods, which are equally disruptive, but these events fall outside the scope of this study focusing on water availability.

An important aspect related to the seasonal and interannual variability of rainfall is water storage. There is hardly any natural surface water storage in Somalia. Water can only be stored in man-made facilities such as berkads, hafirs (dams) and, indirectly, sand dams. The reliability of the berkads and hafirs, as perceived by the respondents in the SWALIM water points' database, is not very high. These systems will certainly fail to bridge the dry season during moderate droughts (once every 11 years). Also, many shallow traditional dug wells, reaching only the upper shallow groundwater, will run dry during droughts.

Groundwater is still the largest natural storage medium. Boreholes well below the static groundwater, large sand dams, and underground dams are the best options to overcome moderate and severe droughts. Apart from sand dams, other managed aquifer recharge techniques may be applied to increase groundwater storage. The hafirs are preferably constructed in areas with an impermeable substratum, though van Haren et al. (2017) report a few examples of hafirs with wells around the reservoirs capturing the infiltrated water. These kinds of systems are common in West Africa, where wells around leaking reservoirs are used for drinking water supply and small-scale irrigation (Bambara et al. 2020).

1.2 Hydrology

After reaching the surface, rainwater infiltrates into the soil. Most of the water in the soil and on the wet surface evaporates or is transpired (by vegetation) back into the atmosphere. When rains are of high intensity or soils are waterlogged or water repellent (common in Somalia because of calcium- or gypsum-rich duricrusts), overland flow arises. Overland flow takes place above a daily rainfall threshold of 20 mm/d (Basnyat 2007). The overland flow gets concentrated and accumulates in low-lying areas and wadis. Water can be diverted from temporary streams into man-made reservoirs, such as berkads and hafirs, or is passively stored in wadi sediments behind sand dams and underground dams. Runoff in wadis or toggas persists for some hours to several days after rainfall events. The runoff coefficient, defined as the part of rainfall converted into overland flow, varies over time and space and depends on the upstream catchment size, land cover, and slope. In Basnyat (2007), values are mentioned as varying between 1 to 10 percent, with higher values for smaller catchments. Hafirs and berkads are typically fed by manageable runoff from typical upstream catchments of 2 to 3 km^3 (Basnyat 2007).

Only the large Jubba and Shabelle rivers in the south have a perennial flow, but these rivers receive most of their water in their upstream stretches in Ethiopia. Springs are found in many places, but discharges are small and disappear downstream because of water withdrawals, infiltration, and evaporation.

Though most water entering the unsaturated soil zone is transpired back into the atmosphere, a minor part passes by this zone and recharges the deeper groundwater body. In their Africa-wide groundwater mapping studies, BGS (MacDonald et al. 2012) and BRGM (Seguin and Gutierrez 2016) estimated annual groundwater recharge, which is equivalent to renewable groundwater. For Somalia, they estimated recharge values varying from 1 mm/yr or 0.03 l/s/km^2 in the outer northeast to 20 mm/yr or 0.63 l/s/km^2 in the south. Note that these values indicate orders of magnitude. Locally, recharge may vary strongly depending on a variety of factors related to climate, soil, and slope.

1.3 Renewable Water Resources

Renewable (blue) water is the groundwater and surface internally produced water from rainfall. The internally produced renewable water amounts to 6 km^3/yr (FAO 2014). Somalia also receives externally produced water from Ethiopia via transboundary aquifers and rivers and wadis, mainly the Shabelle and Jubba rivers. This externally produced renewable water resources amounts to 8.2 km^3/yr (FAO 2014).

Distributing the internally produced renewable water resources over the country gives a value 0.30l/s/km^2 for the so-called **specific** internally produced renewable water resources

As for groundwater separately, FAO-SWALIM (2012) estimated an amount of 0.5 l/s/km^2 as internally produced specific **renewable groundwater resources** in Somaliland and Puntland. As a more conservative estimate, we have defined renewable groundwater resources using the groundwater recharge values reported in the BGS and BRGM studies (see previous Section 1.2). By converting the recharge values from mm/yr to l/s/km^2 and assuming a linear relationship with rainfall, specific renewable groundwater resources in the regions range from 0.05 l/s/km^2 in the northeast to 0.53 l/s/km^2 in the south (Table 1).

Internally generated specific **renewable surface water** resources have also been determined, assuming an average runoff of 3 percent of annual rainfall. This yields values ranging from 0.05 to 0.56 l/s/km^2 (Table 1).

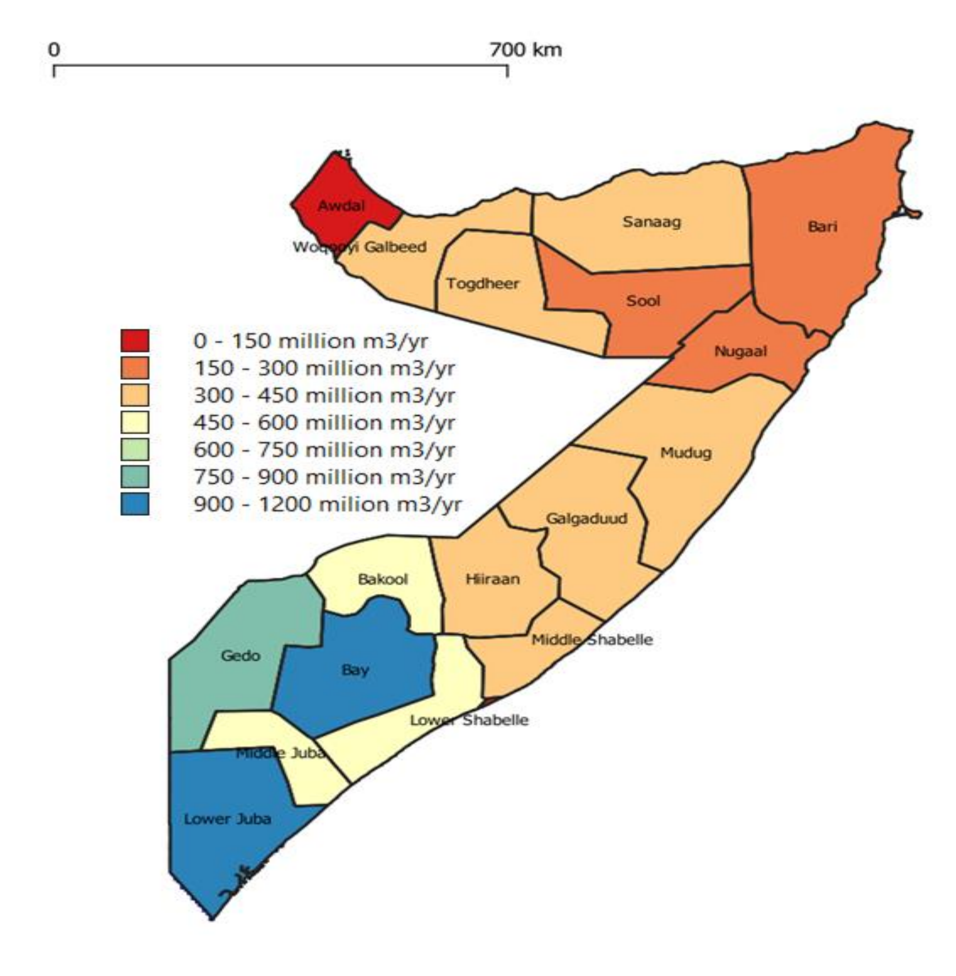
In conclusion: The total internally produced specific renewable water resources in Somalia vary from 0.1 to 1.1 l/s/km^2 from the dry northeastern to the more humid southern regions. These values are in line with FAO (2014) Aquastat estimates and the FAO-SWALIM (2012) study.

Table 1 and the map in Figure 6 display the amount of total internally produced renewable water resources for each region based on the specific renewable resources.

Not all renewable water can be used or withdrawn, in practice. Every withdrawal has an impact in some way. The amount of water which can sustainably be withdrawn, here denoted as **sustainably available** water, depends on various local conditions and cannot be determined in this study because of insufficient data and project resources.

In policy studies, rules of thumb are being applied for sustainably available water resources as percentages of the renewable resources (minus environmental flow requirements) (van Ham et al. 2018; WWAP/UN-Water 2018; EEA 2005, UN 1997). In these studies, the 20 percent ratio is regarded as a critical limit above which both water supply and demand will need to be managed and conflicts between competing uses will need to be resolved (EEA 2005). For this study we have adopted the 20 percent ratio as a tool to define the sustainably available water resources in the regions, the main objective according to the ToR. The result is shown in Table 1 and Figure 7. As a disclaimer, we would like to point out that these figures of renewable water resources per region are of indicative value with respect to orienting policies and investments on a national level. For local and regional fine-tuning, dedicated water resources studies are required using state-of-the-art hydrological methodologies.

Figure 6. Internally Produced Renewable Water Resources in Somalia



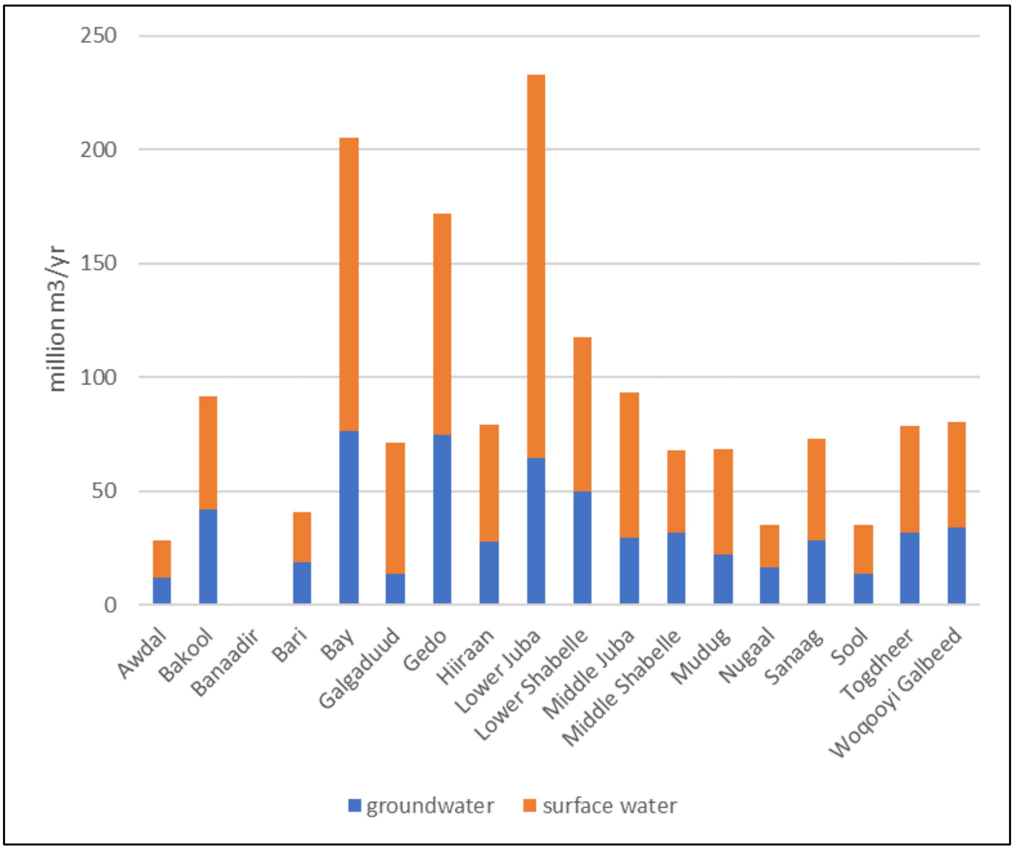
1.3.1 Renewable Water and Water Demand: Supply Side of Water Scarcity

Comparing the available renewable water with the estimated 2030 blue water demand in Somalia[10] (Appendix 1 and Appendix 12) shows that the 2030 demand does not exceed the 20 percent scarcity limits, with the exception of Benadir and Awdal (see the last two columns of Table 1). This conclusion is a bit indicative as all these values are averaged over time and space, and only the water demands for people and livestock are taken into account.

Water shortages will still occur at places with high concentrated demand, like towns and large villages (blue water) or green water shortages or during drought periods. This is also confirmed by various water scarcity indicators (Appendix 1) which rate Somalia as a severe water-scarce country (Table 2).

[10] Population and livestock data from the UNDP 2014, growth rates (4.14 percent for urban and 1.79 percent for rural) from the World Bank database (World Bank, Data Somalia 2020) and unit water consumption (20 lcd for rural and 40 lcd for urban) from Somalia WASH Cluster (2020) and livestock water intakes based on Peden et al. (2003).

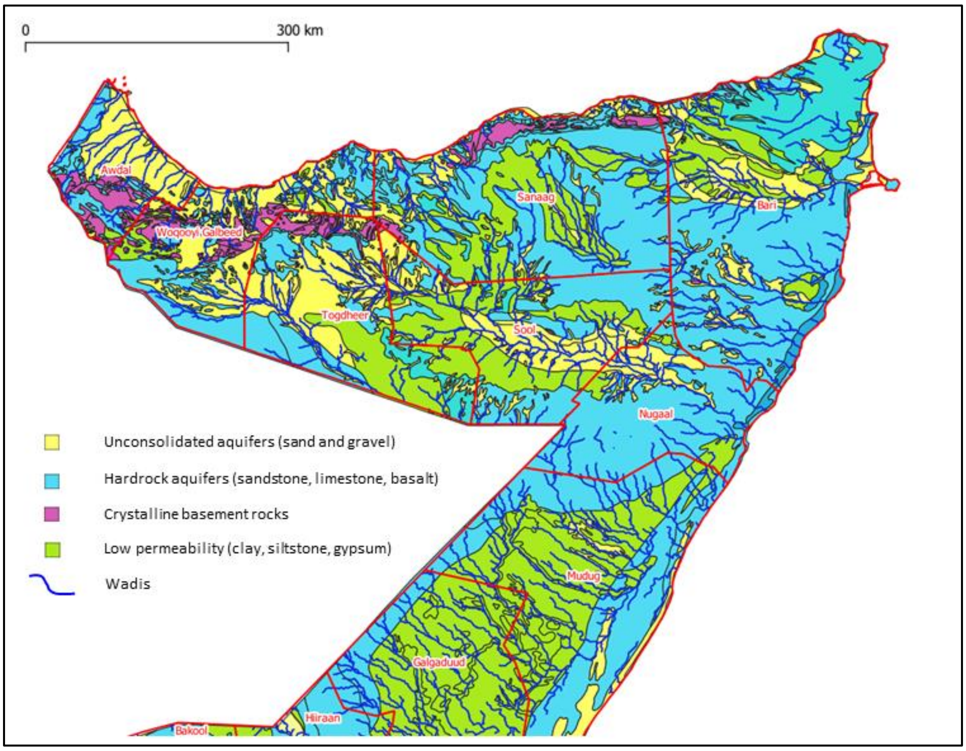
Figure 7. 20% of Internally Produced Renewable Groundwater and Surface Water Resources in Somalia



1.4 Groundwater and Aquifers

This section presents an overview of the main characteristics of the hydrogeology of Somalia where relevant for this analysis. In general, the scarcity, incompleteness, and somewhat anecdotal nature of data and information complicate making a balanced description of the hydrogeology of Somalia. The main sources of information are the reports and articles of Berger Inc. (1985), Bisson and Lehr (2004), FAO-SWALIM (2012), Kebede (2013), Nasreldin et al. (2016), van Haren et al. (2017), the geological maps of Abbate et al. (1993), and the LiveMap database of water points of FAO-SWALIM (2020). Reference is also made to the overview in Appendix 2 from the WASH Cluster Somalia (2020).

Figure 8. Simplified Hydrogeological Map of North Somalia



Source: Based on Abbate et al. (1993).

1.4.1 Limestone and Sandstone Aquifers

The Precambrian crystalline basement consisting of metamorphic and intrusive rocks is the hydrogeological basis of the groundwater flow domain in Somalia. The basement rocks are exposed in the northwest of Somalia and in the Bay region in the south, but are buried under hundreds to thousands of meters of sediments in the rest of the country. The sediments of Jurassic to Tertiary age consist of extensive consolidated and more or less horizontally layered rocks. The limestones and sandstones of this series form aquifers with primary intergranular porosity (sandstones) and secondary fracture porosity. Limestones are often particularly permeable because of carbonate dissolution and widening of fractures (karstic limestones). Aquifers, yielding productive boreholes, are the Jurassic limestones' outcropping in the northwest of Somalia and west of the Bay region (Iscia Baidoa Formation), the Yessoma sandstones (Cretaceous) and Auradu limestones (Tertiary) underlying most of middle and north Somalia and the isolated Karkar limestones (Tertiary) in north Somalia. The Talex formation between the Auradu and Karkar formations comprises limestone strata acting as productive aquifers in some areas. However, the formation is not considered favorable because of the marls and gypsum layers producing mineralized water.

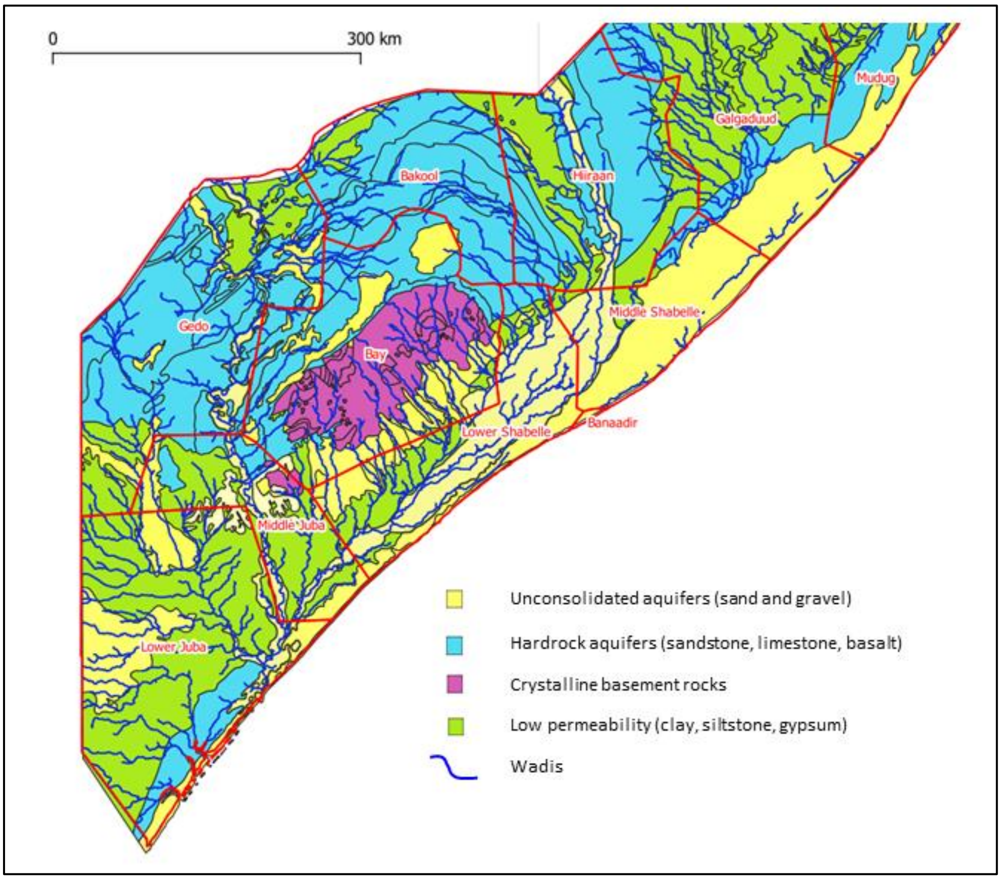
Figures 7 and 8 show simplified geological maps distinguishing the unconsolidated and hard rock aquifers, crystalline basement rocks, and low permeability rock and wadis with alluvial sediments.

Because of financial and technical restrictions, boreholes generally tap only the upper 100 to 400 m of the subsurface depending on the depth of the aquifers and the groundwater levels (Section 2.1). Groundwater levels in the aquifers are often more than 100 m below the surface. Note that in large parts of middle and northern Somalia, where low permeability sediments are found at the surface, deeper aquifers like the Auradu limestones in North Somalia or Quaternary sands are still within drilling reach.

1.4.2 Quaternary Sand Aquifers

The recent Quaternary sand and gravels can be regarded as a separate group of aquifers. They are of local extent and found as alluvial fills in structural basins like the Nugaal valley and the area north of Hargeisa depressions, fan deposits along mountain ranges, alluvium along wadis (sand rivers) and the Shabelle and Jubba rivers and coastal dunes. Groundwater occurs at shallow depths (<15 m) indicating perched aquifer systems overlying the deep regional aquifers. Where the Quaternary sands have been mapped (Figures 7 and 8) we assume the sands form extensive bodies with saturated thicknesses of>10 m allowing groundwater abstraction by means of manual drilled boreholes.

Figure 9. Simplified Hydrogeological Map of South Somalia



Source: Based on Abbate et al. (1993).

The narrow bands of alluvial deposits along wadis with widths of 20 to 100 m and thicknesses of a few meters to 10 m are not mapped on the 1:1.5 million scale map of Abbate et al. (1993). However, the numerous dug wells and scoop holes along these wadis, albeit having low capacities, are of crucial importance to the population. Water storage and production from these wadi sediments can be boosted by means of sand dams or underground dams in the wadi channel as has been successfully demonstrated in the World Bank 'Biyoole' and WALP programs (Hydro Nova 2019; Paz Lopez-Rey 2019). Wadi deposits and upstream catchments need to be sufficiently thick and wide for the construction of sand dams, underground dams or manually drilled wells. Based on the studies above, as well as reports from Earthwater (1998), Bisson and Lehr (2004), and van Haren et al. (2017), and visual observations with Google Earth, we assume development of wadi sediments are feasible where upstream catchments are at least 200 km^2. The wadis fulfilling this condition have been delineated by water accumulation routines applied on Shuttle Radar Topography Mission (SRTM) digital elevation models. These wadis are shown in the maps in Figures 7 and 8.

1.4.3 Crystalline Basement Rocks

Crystalline basement rocks are cropping out in the Bay region in South Somalia and in the far north. Basement rocks do not hold much water. There is no primary porosity and rock fracturing does not result in continuous aquifers. Most water is stored in the weathering layer (regolith) and in specific well fractured zones. Shallow boreholes (30 to 60 m) drilled into the bedrock in these fracture zones may yield 0.25 to 1 l/s, but success rates are low (around 50 percent). Dug wells and manual drilled boreholes with handpumps may tap the saturated part of the regolith.

1.4.4 Clay, Siltstone, and Gypsum Deposits

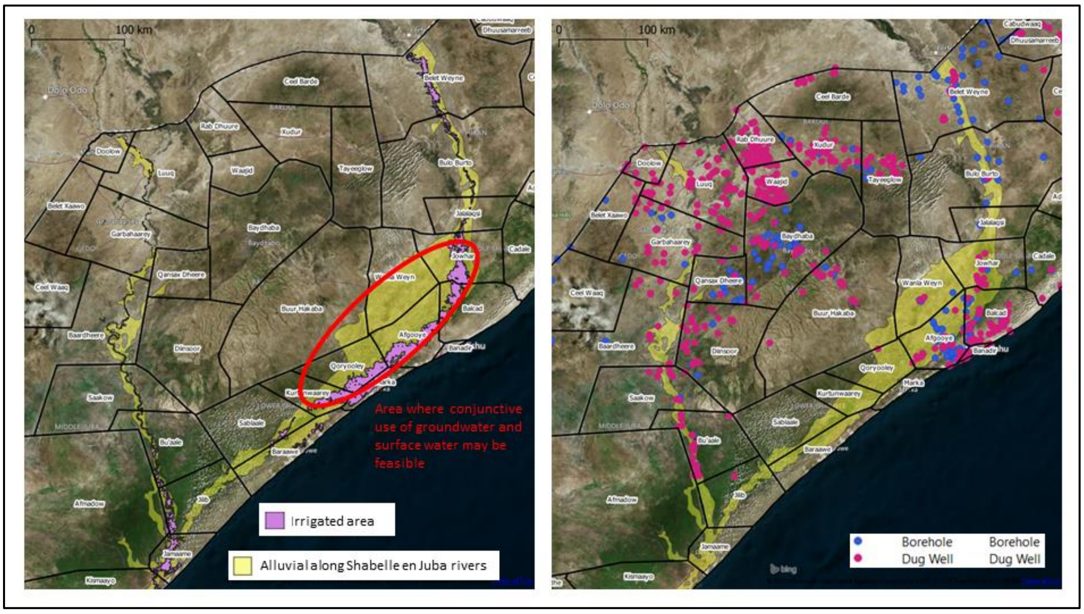
All sediments dominated by clay, claystone, shale, siltstone, marl, and gypsum, as described in the geological map of Abbate (1993), are considered to be unproductive as far as water recovery is concerned. These sediments cover large parts of Somalia, but their thickness is not well known. In some areas, underlying productive aquifers are within drilling reach. This is probably the case in the Sool, Sanaag, and Toghdeer regions in the north where the Taleh formation overlies the Auradu limestone (van Haren et al. 2017) and in the Quaternary floodplains of the Shabelle and Jubba rivers, where sand deposits are probably present below the clay deposits at the surface.

The Taleh formation is categorized here as a nonproductive formation, but the formation contains limestones which, in some areas, yield water. However, because of the gypsum layers the water is often brackish, exceeding the 3,500 microS/cm threshold.

1.4.5 Groundwater in Riverine Areas

The perennial Shabelle and Jubba rivers are also bordered by alluvial plains and terraces, where irrigated agriculture is practiced with gravity supply from the rivers. The alluvial plains are underlain by thick sand and gravel deposits (Figure 10). Communities in these valleys have dug wells and boreholes for domestic water supply, but there are no reports of groundwater-based irrigation. Given the abundant recharge from the perennial rivers, wells could be drilled as complementary sources to surface water supply in dry periods, specifically at the tail ends of the distribution system; the wells, however, need to be in hydraulic contact with the rivers. In general, there is not much scope for development of large commercial stand-alone groundwater irrigation. Irrigation water demands (around 0.5 to 1 l/s/ha) far exceed renewable groundwater resources (0.3 to 0.6 l/s/km^2).

Figure 10. Groundwater in Riverine Areas



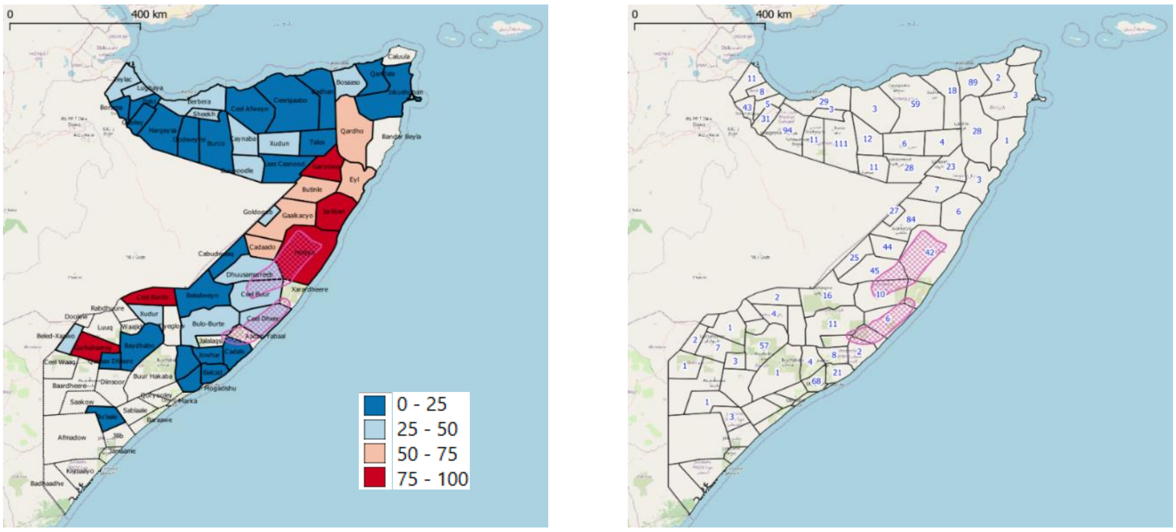
1.5 Groundwater Quality

The salinity of groundwater in dug wells, boreholes, and springs is relatively high in Somalia. It can be inferred from the SWALIM database that about 70 percent of these water points have salinity levels above the WHO limit of 1,500 microS/cm, while 30 percent are above the Somali Water Development Agency (WDA) limit of 3,500 microS/cm. The high degree of mineralization in most wells results from the dissolution of salts from evaporitic rocks. These groundwaters typically have high concentrations of sulfate. The WDA sulfate limit is 600 mg/l (Berger 1985), while the WHO guideline is 250 mg/l. Wells along the coast with high salinities may be affected by seawater intrusion. In these wells, salinity is caused mainly by high chloride contents (WDA limit is 800 mg/l; WHO guideline is 250 mg/l).

High chloride and sulfate levels are not preferred because of taste. However, in a study of Middle Somalia, Berger (1985) states that high salinities in combination with high calcium and magnesium contents may cause kidney problems, which is common in that area. In addition, EarthWater (1998) reports high salinity as the cause of kidney problems in their study for the water supply of Garowe.

Nasreldin et al. (2016) also studied water quality in Middle Somalia (50 samples). They showed that wells with high salinities (56 percent are above 3,500 microS/cm) also had high fluoride contents, exceeding the WHO guideline of 1.5 mg/l. Intake of drinking water with these high fluoride contents poses more serious health risks (fluorosis) than just salinity. Faillace (1998) studies water analysis throughout the country (81 samples) and considered fluoride as one of the major problem in drinking water: 51 percent of the sampled wells had salinities above 3,500 microS/cm. In all wells, fluoride contents exceeded 1 mg/l, while in 65 percent fluoride contents were higher than 1.5 mg/l. Within this batch of samples, Faillace (1998) did not find a correlation between salinity and fluoride.

Figure 11. Groundwater Salinity in Boreholes



Left: Districts with percentage of boreholes with salinities (in electrical conductivity, or EC) higher than 3,500 microS/cm. *Right:* Number of boreholes with EC measurements.

In the map at left, only percentages are displayed for districts with more than one measurement. The low number of measurements in the south is probably not because there are less boreholes, but because of the security situation complicating water point surveys. The purple shaded area in middle Somalia is an area with high salinities according to a SWALIM map (concentrations are unknown).

There are many studies reporting the problem of bacteriological contamination of dug wells, berkads and hafirs (Berger 1985; EarthWater 1998; Muthusi et al. 2007; van Haren et al. 2017; WASH cluster Somalia 2017), though there are not many systematic surveys. Though groundwater, especially from deep aquifers, is normally free of pathogenic bacteria, Berger (1985) reports human and animal fecal contamination in old WDA boreholes and high nitrate levels, another indication of man-made influence. The well contamination probably results from leakage along badly sealed boreholes without sanitary provisions and accessible for large numbers of people and livestock. WASH Cluster Somalia (2020) also stresses the need for proper designing of wells to prevent pollution of shallow aquifers.

1.6 Climate Change and Impacts

The study of Petersen and Gadain (2012) and the data from the World Bank Climate Change Knowledge Portal (2021) indicate that temperature, annual rainfall, and evapotranspiration in Somalia will rise during this century. Seasonal rainfall during the *gu* and *deyr* season will increase, with most rains falling during the former season. Frequencies of droughts will not change. (The drought indicator of the World Bank portal does not change much.)

In future, high intensity rains will become more common, resulting in more frequent flooding and higher runoff in general. With respect to groundwater and groundwater recharge, impacts are difficult to ascertain but probably not very high. We assume groundwater will not benefit much from the increased rainfall as most of this rain is converted into surface runoff and evapotranspiration.

2 Blue Water Points and Water Delivery Systems

2.1 Current Water Points

Water for domestic use and watering livestock is drawn from a variety of water points which depend on the accessibility of the groundwater and the opportunities to capture surface runoff for storage in reservoirs. Important sources of information are the SWALIM reports and the SWALIM Water Points Database (see Appendix 3 [the first table], and Appendix 12). Presented here is a short overview of the different water points and their main characteristics (Table 4) based on the information in available reports.

Table 4. Characteristics of Typical Water Points

Water Points	Code	Unit	Range	Median
Reservoirs, Berkat, Ballis	Res	m^3/season	300-5000	
Sanddam + Handpumps (HP)	SD+H	m^3/hr ; m^3/day	1-1.5 ; 5-8	1 ; 5
Sanddam + Motorpump (MP)	SD+P	m^3/hr ; m^3/day; infiltration: mm/ss	3-10 ; 30-100; 2000-10000	5 ; 30 ; 5000
Dugwell + Handpump (HP)	Dw+Hp	m^3/hr	1-1.5 ; 5-8	1 ; 5
Dugwell + Moterpump MP)	Dw+Mp	m^3/hr	3-10	5
Manual drilled shallow well + HP	Sw+Hd+Hp	m^3/hr ; m^3/day	1-1.5 ; 5-8	1 ; 5
Manual drilled shallow well + MP	Sw+Hd+Mp	m^3/hr	3-10	5
Machine drilled shallow wells +HP	Sw+Md+Hp	m^3/hr ; m^3/day	1-1.5 ; 5-8	1 ; 5
Machine drilled shallow well + MP	Sw+Md-Mp	m^3/hr	10-20	15
Machine drilled deep well + MP	Deepw++	m^3/hr	20-50	30

Note: MP: Motorized pump; HP: Handpump.

2.1.1 Berkads and Hafirs

Where groundwater is difficult to find or costly to access, people traditionally rely on water harvesting. Ephemeral surface runoff water is collected in berkads and hafirs (or ballis). Berkads are open plastered cisterns dug in unconsolidated soil or hewn in bedrock. Storage capacities generally range from 150 to 500 m^3. Hafirs are created behind dams on gently sloping terrain, preferably on clayey soils, to reduce infiltration losses. Storage capacities of these water harvesting systems range from 500 to 10,000 m^3. Most hafirs are found in the northwest and the south, where rainfall is more abundant.

Berkads and hafirs get filled after the two rainy seasons. Evaporation is high (potentially 1,500 to 2,500 mm/yr) and leads to large losses from these reservoirs. Depending on rainfall, berkads and hafirs last for about two to five months after the end of the rainy season. Just like hand dug wells, berkads and hafirs are bacteriologically polluted and not safe as sources of drinking water.

2.1.2 Sand Dams and Underground Dams

Among are more recent interventions are sand dams and underground dams (subsurface dams) in combination with collector drains and wells. Sand dams are constructed in alluvial beds. The storage capacities of the sand bodies behind these dams vary from 5,000 to 40,000 m^3. This volume is available for use during the dry season (180 days) but is often augmented by recharge through groundwater inflow from the surrounding soils. There is no information on the total number of sand dams and subsurface dams in Somalia, but useful information is available from dams constructed or designed in the Biyoole project (Hydro Nova 2019). Most of these dams are in Somaliland and Puntland. Water quality (including salinity) of sand dams is generally good. Bacteriological quality depends on the protection of the upstream wadi. Groundwater abstraction is generally with hand dug or manual drilled wells or through infiltration galleries.

2.1.3 Hand Dug Wells

There are hand dug wells in alluvial unconsolidated sands in tectonic depressions or along the toggas. Generally, the depth of these wells is not more than 15 m. Water is recovered by buckets or bags or by means of a handpump or by a motorized pump if larger abstraction is possible. Production capacities of manually operated dug wells are about 1 m^3/hr or 5 m^3/d, depending on the type of pump. As the wells depend on shallow groundwater, the water levels fluctuate strongly both seasonally and interannually. Dug wells often run dry at the end of the dry season. However, water in the majority of open traditional dug wells is compromised by the presence of pathogen microorganisms. Improved (lined and closed) dug wells, with handpumps, provide better quality water.

2.1.4 Manually-Drilled Wells

Manually drilled wells are a practical alternative for boreholes in alluvial soils and soft rock formation with a depth up to 40 meters. They are more affordable than machine-drilled wells and are also a good alternative for hand dug wells at lower cost. Furthermore, manually-drilled boreholes are often deeper than excavated wells, and thus tap deeper aquifers and, if properly sealed, they provide better protection from surface contamination (Martínez-Santos a.o. 2020).

There are a number of methods available—hand augering, percussion, simple sludging, rota sludging, jetting, baptist and rotary types (see Appendix 4). Drilling equipment can be locally manufactured and maintained, which will reduce the cost of manual drilling substantially if combined with training and private sector development (providing local employment).There is a wide network of organizations (including Practica, RWSN, and UNICEF) which promote manual drilling and have produced a range of manuals and training material.

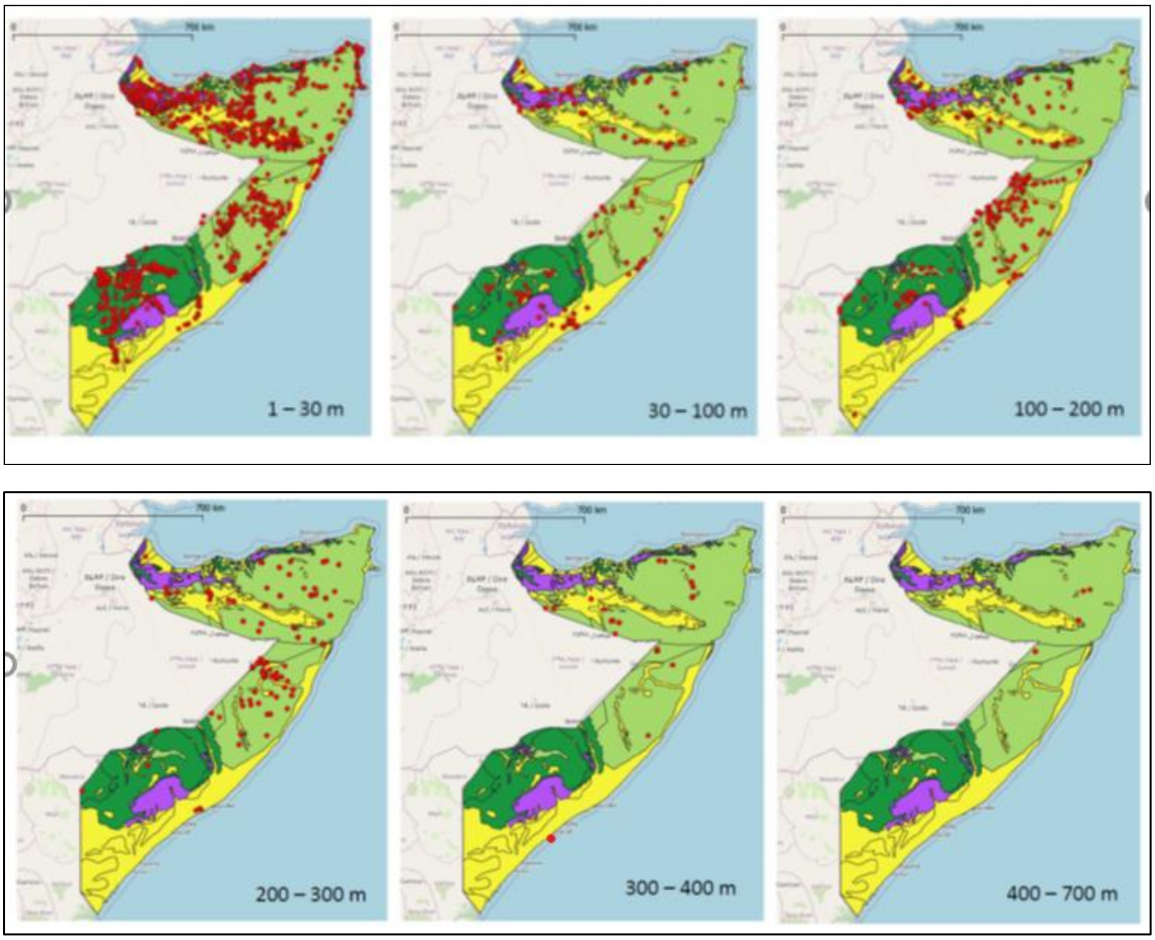
Manual drilling has been introduced in many countries (Martinez-Santos 2020) but in Somalia it is still in an early stage. A quick web search shows that Relief International is working on professionalizing manual drilling in Somalia. Given its potential (both in terms of the provision of safe water points and stimulating job creation), it will be a promising investment to introduce manual drilling on a wider scale through capacity building and private sector development.

2.1.5 Motorized Boreholes

During the last century, modern systems, such as deep motorized boreholes, have been introduced. Deep boreholes (50 to 400 m) have been drilled into limestone and sandstone aquifers and thick alluvial sand deposits. Generally, borehole depths increase from west to east (Figure 13). Production capacities of boreholes vary from 3 to 35 m^3/hr. Drilling requires specialized equipment and is expensive because of its high mobilization cost in remote areas and low success rate (because of technical problems during drilling, well failure because they are dry or the water has a high salinity). Proper siting and adequate drilling supervision are often lacking but could contribute to improving the success rate, which is currently estimated to be below 50 percent. A particular point of concern is the salinity and high fluoride content of groundwater from drilled boreholes. About 70 percent of the drilled boreholes produce water with salinity higher than that recommended by WHO and UNICEF, and 30 percent is above the salinity limit of the WDA limit of 3,500 microS/cm (SWALIM database in Appendix 3).

Drilling requires specialized equipment. Drilling companies in Somalia operate rigs of several makes from different countries (China, Japan, Europe, India, South Africa, and the United States of America) which makes it difficult for local suppliers to stock spare parts to meet the requirements of different brands. Drilling costs are also expensive because of the high mobilization cost in remote areas and low success rate, as discussed above.

Figure 13. Depths of Boreholes



2.1.6 Springs

More reliable are the springs arising at the foot of mountains, escarpments or along geological boundaries and structures. Spring discharge typically varies from 1 to 35 m^3/hr. Most of the known springs are already in use as a source for water supply and small-scale irrigation.

2.2 Applicability of Water Points

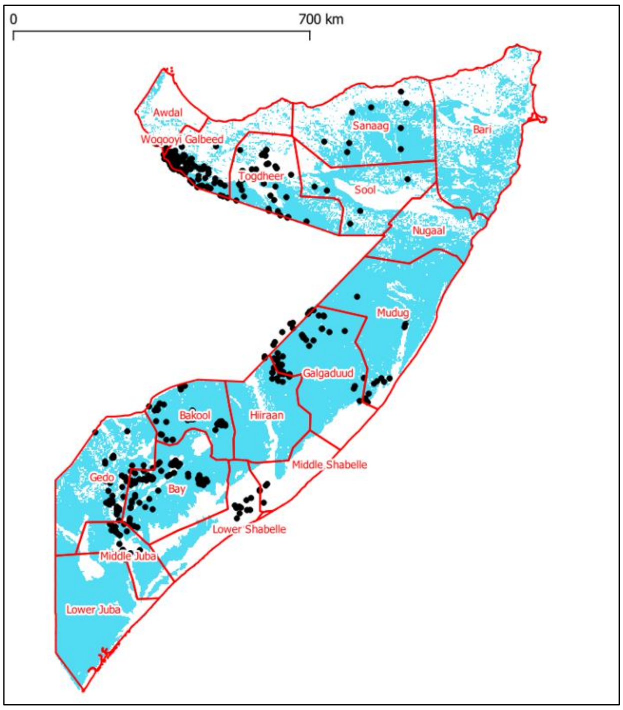
In this section, we analyze the applicability of four blue water delivery systems (WDS): hafirs, sand dams, manually-drilled boreholes, and machine-drilled boreholes. The first two draw water from surface water resources, the latter two from groundwater resources. Dug wells and berkads have been left out from this analysis as these water points have low capacities, are bacteriologically unsafe, and do not need foreign investments because they are constructed at low costs with local expertise.

In some high yielding sand and gravel aquifers, modern dug wells may be constructed with concrete lining and submersible pumps as is done in combination with sand dams.

2.2.1 Hafirs

Hafirs have been included in this analysis, but mainly for the purpose of livestock watering. The low water quality makes them unsuitable for human consumption unless chlorination is applied. Hafirs are reservoirs bounded by dams and are preferably constructed on an impermeable substratum with slopes of less than 4 percent. Figure 14 shows the zones (in blue) where these conditions are met. The map has been prepared by combining in GIS terrain slope made from SRTM elevation data and the geological map. Upstream catchments of 3 km^2 are required for filling hafirs (Basnyat 2007). Because of various terrain inhibitions, we estimate that hafirs, including their upstream catchments, can be realized on 25 percent of the mapped zones.

Figure 14. Suitable Zones for Hafirs or Dams (in Blue)



Note: Black dots represent hafirs from the SWALIM Live Map database.

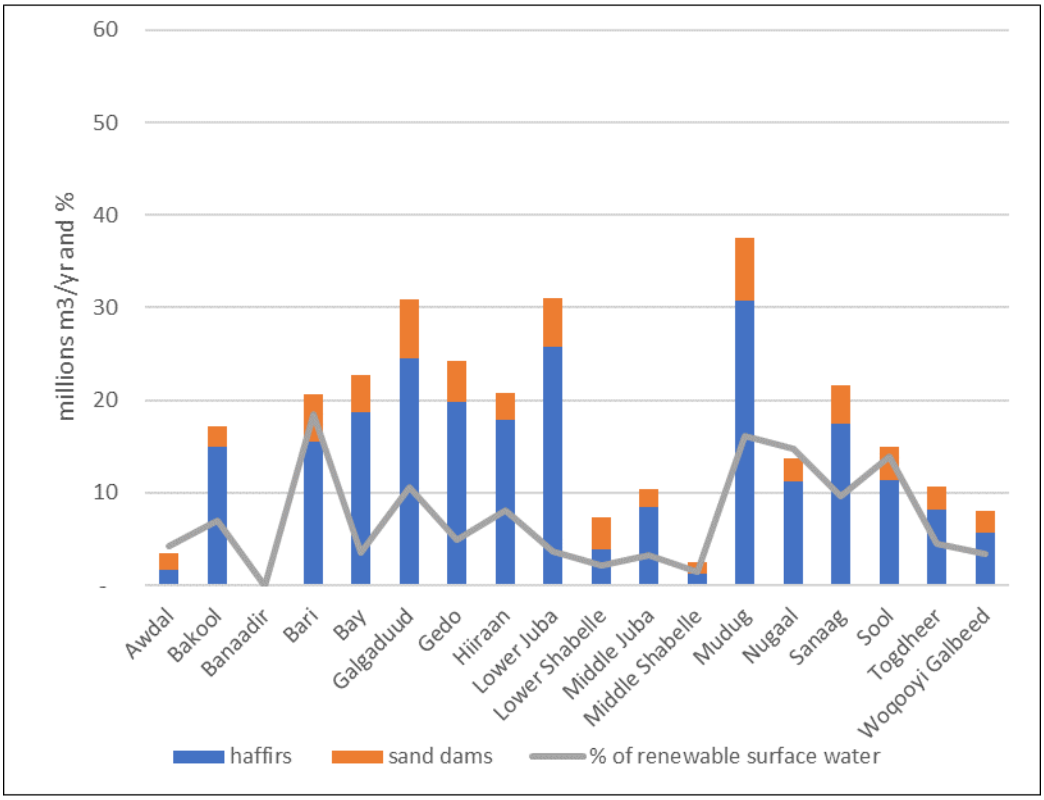
Based on the conditions given above, the maximum number of hafirs in each region has been calculated with their total water production (Figure 15). In the Bari region, because the combined water production by hafirs and sand dams exceeded the 20 percent scarcity criterion of the renewable surface water resources, the number of hafirs has been reduced by 20 percent. This corrected number is given in Table 3 and Figure 14.

2.2.2 Sand Dams or Underground Dams

As described above, we assume that sand dams or underground dams having the envisaged storage capacities of 15,000 m^3 are only feasible in larger wadis with upstream catchments of at least 200 km^2. These wadis are shown in the maps in Figure 8 and Figure 9. Because of the large throwback of some dams (1 to 2 km) and the limited and temporary runoff in the wadis, we maintain a minimum distance of 10 km between the dams.

Based on the total length of wadis the maximum number of sand dams or underground dams in each region has been calculated with their total production (Figure 15). Because the combined water production of hafirs and sand dams exceeded the 20 percent scarcity criterion of the renewable surface water resources, the number of sand dams has been reduced by 20 percent (see Table 3).

Figure 15. Feasible Water Production from Hafirs and Sand Dams in Regions of Somalia

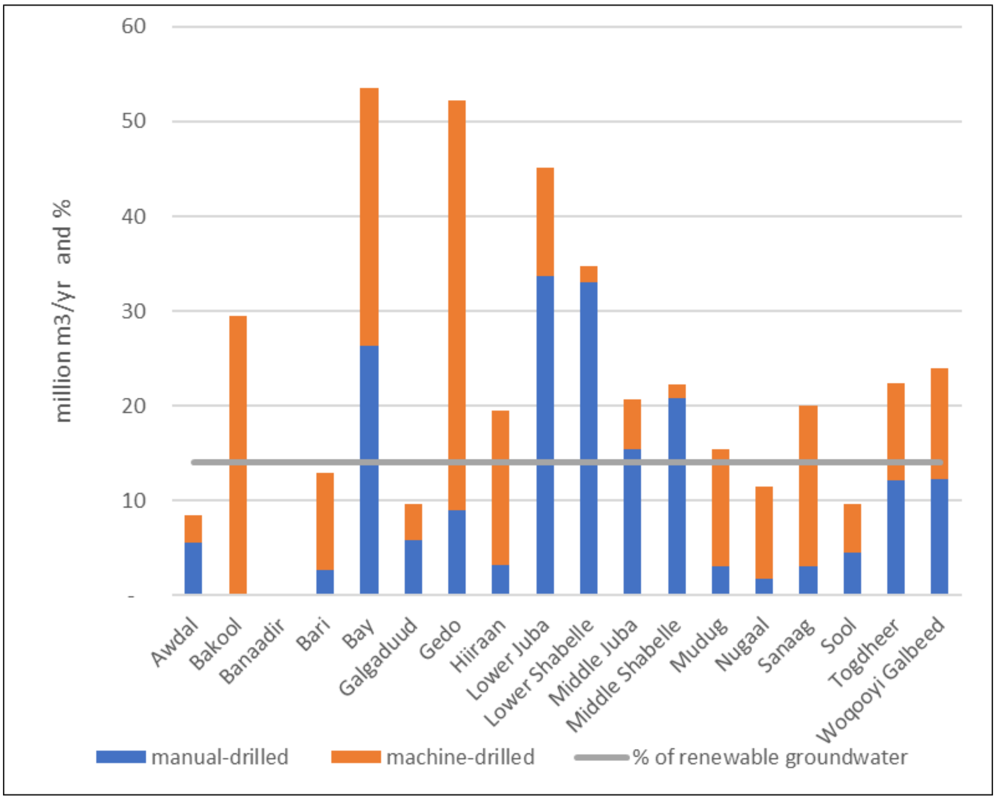


2.2.3 Manually-Drilled Boreholes

Shallow boreholes can be drilled manually up to 40 m in unconsolidated material like the Quaternary sands and possibly also in the weathering zone of the crystalline basement. These areas are displayed in Figure 8 and Figure 9 (in yellow). To increase their resilience, the wells must be drilled to at least 10 m below the static water level. Wadi sediments may not have the required thickness everywhere.

As a basis for the maximum number of manually drilled boreholes, we assume 20 percent of renewable groundwater can be withdrawn in the area covered by Quaternary sands. This defines the number of boreholes based on the unit production capacity of 6,570 m^3/yr. This number has been reduced by 30 percent, as an analysis of the SWALIM database revealed that 30 percent of the boreholes had salinities above 3,500 microS/cm, the acceptable WDA limit. The maximum number of boreholes for each region and their total water production are given in Table 3 and Figure 16. (For cost calculations, 30 percent more wells need to be accounted for because of the estimated 25 percent failure rate in drilling.)

Figure 16. Feasible Water Production and Percentage of Renewable Groundwater



Note: (a) This is from manually-drilled boreholes (Quaternary sands) and machine-drilled boreholes (hard limestones and sandstones) in regions of Somalia; and (b) The scarcity limit is 20 percent of renewable water resources.

2.2.4 Machine-Drilled Boreholes

Machine-drilled boreholes can be as deep as 400 m and are drilled into hard limestone and sandstone aquifers (and also unconsolidated aquifers). The zones with these hard rock aquifers are displayed in Figure 8 and Figure 9 (in blue). In some areas where low permeability rocks and sediments are found at the surface, like the Taleh formation in North and Middle Somalia and the Quaternary clays in the Lower Jubba region, the underlying aquifers may be within reach of deep boreholes. Therefore, the suitability zones for deep drilling may be larger than the zones where the aquifers are exposed at the surface.

As a basis for the maximum number of machine-drilled boreholes, we assume 20 percent of the renewable groundwater can be withdrawn in the area covered by Quaternary sands. This defines the number of boreholes based on the unit production capacity of 86,400 m^3/yr. This number has been reduced by 30 percent, as an analysis of the SWALIM database revealed that 30 percent of the boreholes had salinities above 3,500 microS/cm, the acceptable WDA limit. The maximum number of boreholes for each region and their total water production is given in Table 3 and Figure 16. (For cost calculations, twice as much wells need to be accounted for because of the 50 percent failure rate in drilling.)

In Table 5, the maximum number of sustainable water delivery systems are given for each region, together with total water production of these systems and the available (20 percent) renewable water resources.

Table 5. Potential Numbers of Water Points Per Region Limited by Available Land and Water

regiom	haffirs		sand dams		manual drilled boreholes		machine drilled boreholes	
	nr	production million m3/yr	nr	production million m3/yr	nr	production million m3/yr	nr	production million m3/yr
Awdal	226	2	127	2	846	6	33	3
Bakool	2071	15	153	2	18	0	341	29
Banaadir	0	-	-	0	31	0	0	-
Bari	2151	15	342	5	418	3	119	10
Bay	2599	19	265	4	4009	26	314	27
Galgaduud	3414	25	418	6	892	6	43	4
Gedo	2753	20	294	4	1373	9	500	43
Hiiraan	2477	18	199	3	495	3	188	16
Lower Juba	3573	26	358	5	5131	34	131	11
Lower Shabelle	533	4	236	4	5020	33	20	2
Middle Juba	1174	8	134	2	2355	15	61	5
Middle Shabelle	182	1	83	1	3174	21	16	1
Mudug	4281	31	448	7	464	3	143	12
Nugaal	1560	11	164	2	263	2	113	10
Sanaag	2419	17	280	4	472	3	196	17
Sool	1587	11	239	4	698	5	58	5
Togdheer	1140	8	165	2	1849	12	118	10
Woqooyi Galbee	796	6	153	2	1876	12	135	12

Note: 20 percent scarcity limit of renewable water resources.

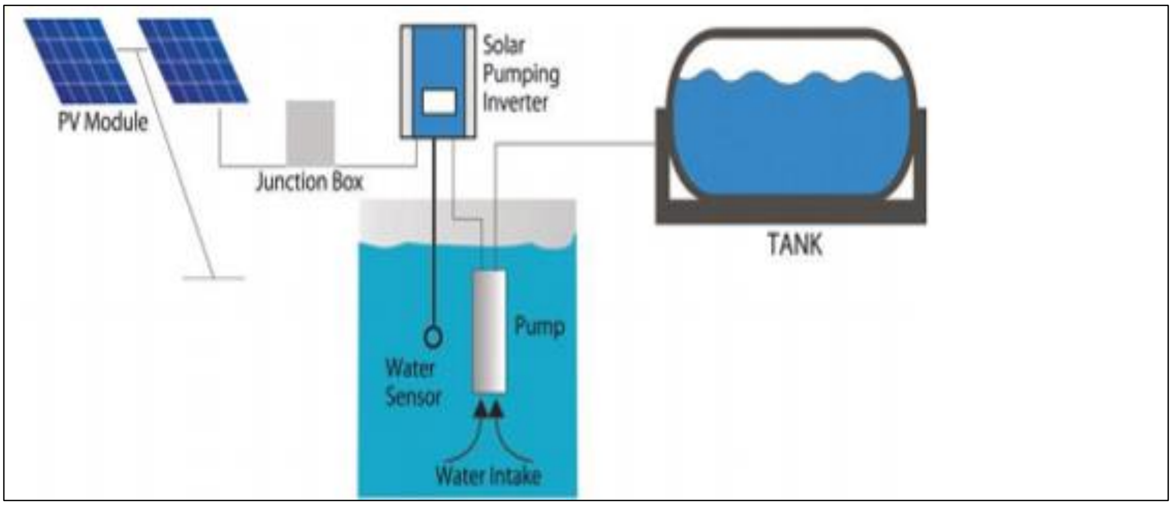
2.3 Water Points and Water Delivery Systems

Water points are the infrastructural means to provide access to water but, in many cases, these points are not at the point of use. A water delivery system (WDS) includes also the infrastructure needed to deliver the water at the point of use (pumping, collection, transmission, treatment, storage, and distribution of water).

Hafirs and berkads generally have no additional infrastructure except for a handpump and troughs for livestock. The same holds true for hand dug wells serving a few families.

The water conveyance infrastructure for rural water schemes (hand dug wells, manually-drilled wells, small sand dams with a well) typically exist with the following components: a pump (handpump or motorized pump or solar-driven pump) to pump the water into a reservoir (10–25 m^3) with one (or more) standpost(s) with taps and with animal troughs. Figure 17 shows an example of a solar pump system. In the case of sand dams, there may also be the need for a (3″ or 4″) pipeline to convey the water nearer to the village.

Figure 171. Basic Elements of Solar Pumping



Source: World Bank (2018).

For small town water supply served by sand dams and/or deep wells, it is likely that the water comes from different sources; conveyance pipelines are needed to pump the water to a central reservoir (underground or elevated) near the town from which a distribution system feeds standposts, water kiosks, yard connection or house connections. Chlorination is needed to assure safe water at the taps. Other treatment requirements depend on the quality of the water

For larger towns and cities, the same components are needed but at a larger scale (more sources, larger distances and pipe diameters, multiple reservoirs, full scale treatment facilities, more house connections including large consumers, among others). More professional operation and maintenance will be needed to assure the continuity of supply and the quality of the water.

The characteristics of the different WDSs make them more suitable for specific water user groups (Table 6). For example, the water from expensive deep drilled wells will be more suitable for urban and industrial water supply, while cheaper systems from shallow wells or sand dams are preferred for rural and small town water supply and livestock water. Also, water quality is a driver to prefer groundwater for human consumption above surface or polluted water in shallow dug wells. Table 6 gives a proposed classification of the preferred user groups for the different WDSs based on the water point and pump type.

Table 6. WDS and Preferred User Groups

User Group / WDS	Subs Farming	Live stock	SS Irr	Hamlet <200	Village 200-10000	Town >10000	Ind LSIrr.
Reservoirs, Berkat, Ballis		X					
Sanddam + Handpump		X		X			
Sanddam + Motorpump	X	X			X		
Other water harvesting systems	X	X		X			
Dugwell + Handpump				X			
Dugwell + Motorpump		X	X				
Manual drilled well + Handpump				X			
Manual drilled well + Motorpump		X	X		X		
Machine drilled well + handpump				X			
Machine drilled well + motorpump		X	X		X	X	X
Deep Well +Motorpump					X	X	X

2.4 Cost of Water Points and WDSs

Presented below is a short overview of the costs for water points and additional water infrastructure. An overview of some typical unit prices for different WDS components from various sources (Water Cluster Somalia 2017, WALP Endline report, design reports of sand dams) is given in Appendix 6. Two WDS components—solar pumping and desalination—are discussed separately.

2.4.1 Hand Dug Wells

The costs of hand dug wells are fairly well known from various sources (including UNICEF, WASH Cluster Somalia, SWALIM) and range from US$1,000–2,000 for an unlined well of 5–10 depth (SWALIM), to US$8,000 for a lined dug well of 1.5–2.5 m diameter and equipped with a handpump (Somalia WASH Cluster), to US$15,000 for a concrete-lined 3-m diameter well with a motorized pump or solar pump (Figure 17).

A dug well with a motorized or solar pump can be extended to a WDS with a 10 m^3 reservoir, water kiosk (six taps), and animal water troughs for an additional total cost of US$20,000–30,000.

Figure 18. Design of a Concrete-Lined Dug Well

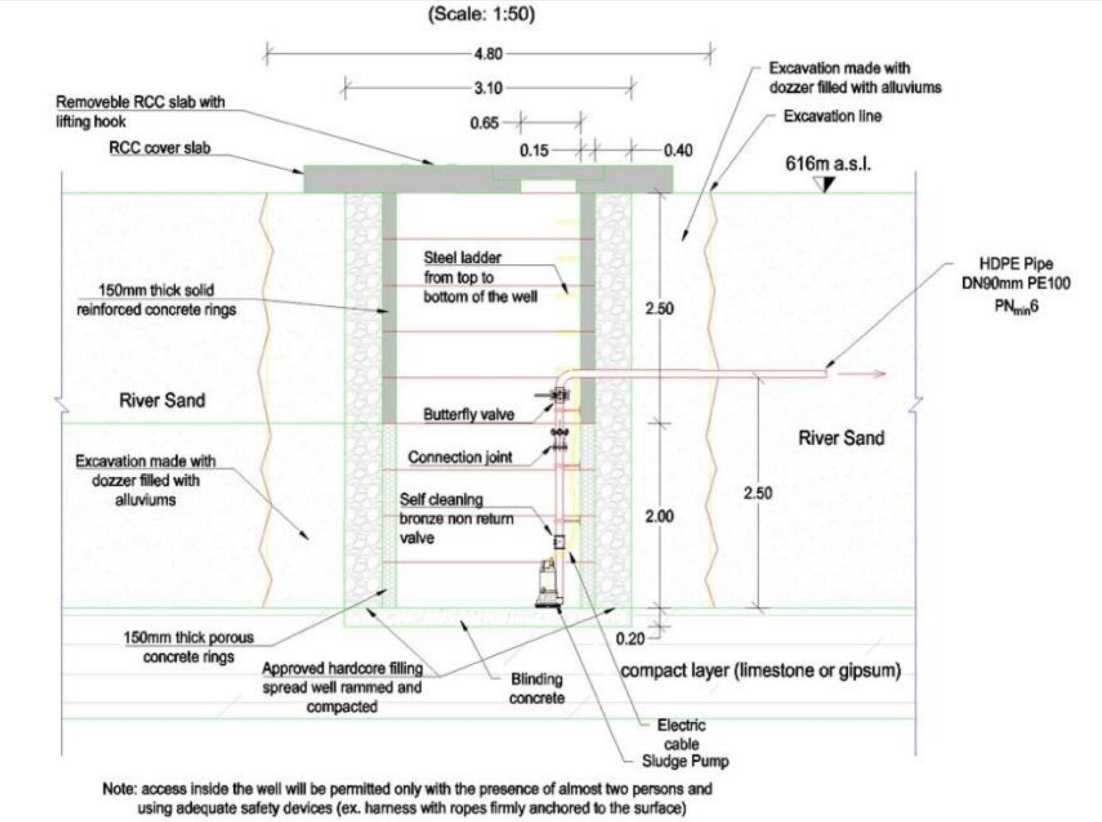


Figure 21: Preliminary design of the well

Source: From the Biyoole project.

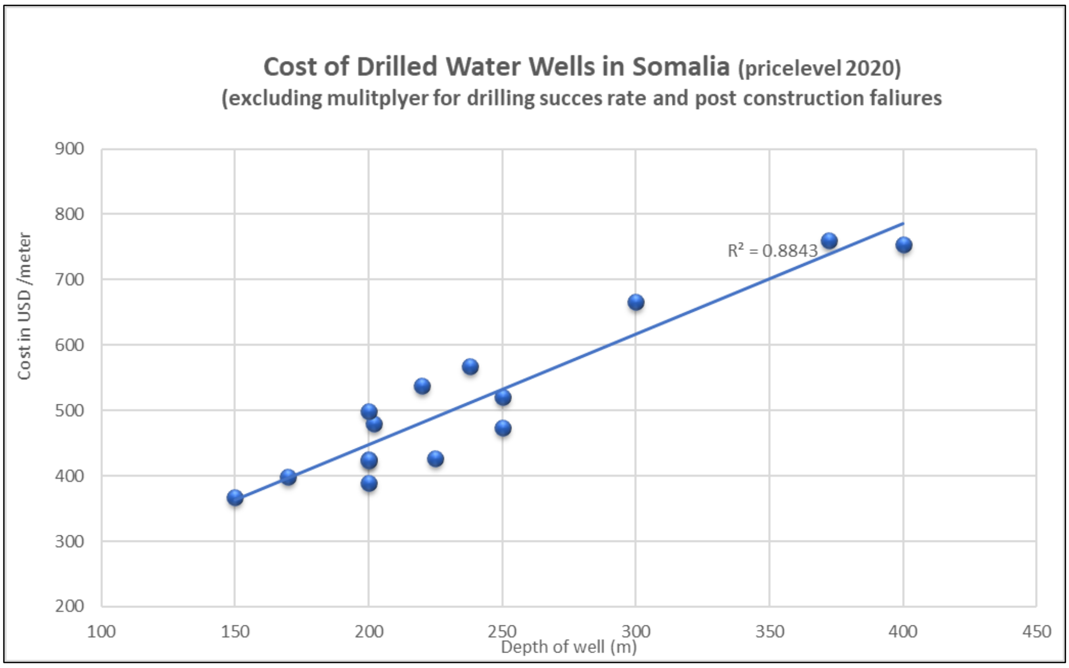
2.4.2 Manually-drilled wells

The required investment in capacity building and private sector development will initially increase the cost of manual drilling. Once this in place these wells are cheaper than excavated wells. For the purpose of this study, the cost of a WDS based on manually-drilled wells is approximately the same as for a hand dug well.

2.4.3 Machine-drilled wells

The costs per meter of drilled water wells increases with depth (Figure 19). This graph is based on actual prices and quotations by contractors from various sources (Appendix 5). The cost of drilling increases with depth from US$350/m for a 150-meter deep well, to US$700/m for a 300-meter deep well. Part of this increase in cost/m is related to the high mobilization cost in remote locations of the deeper wells (see Section 2.1). The real costs are factor 2 higher to account for the low drilling success rate and postconstruction failures (see Section 2.1).

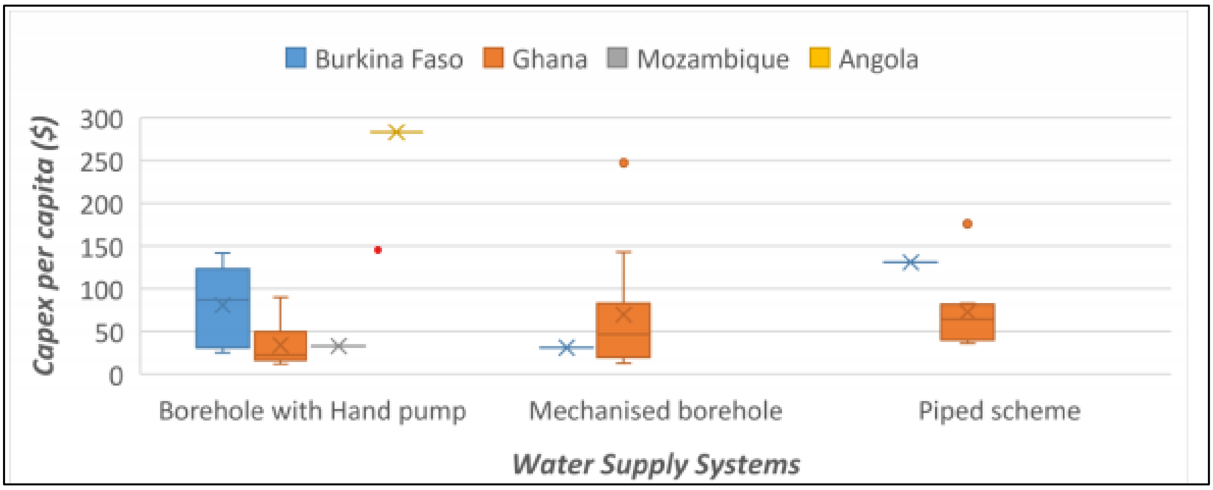
Figure 19. Cost of Drilling in Somalia



The infrastructure needs for a WDS fed by a motorized well can vary from a single well providing water to a nearby village to multiple wells (a wellfield) serving a town at a distance of 10–20 km. The cost for the additional infrastructure can vary as well, depending on total capacity (number of wells) the conveyance distance, the treatment needed, and the number of people/households to be served.

The estimated cost of a multiple-village scheme from a 300-meter deep well in Punjab (India) serving 7,000 people is in the order of US$90/consumer (World Bank 2018). This is in the same order of magnitude as the per capita CAPEX(US$50–150) for a piped scheme in Figure 20 (Torbaghan a.o. 2019).

Figure 20. Range of CAPEX Per Capita



Source: Torbaghan (2019).

For larger towns and cities, the per capita cost for water supply improvement are also dependent on the level of supply (number of house connections and large consumers with specific demands) and will range from around US$100 per capita for standposts to over US$300 for household connections (see Appendix 9).[11]

2.4.4 Sand Dams

Sand dams (and subsurface dams) are relatively new in Somalia. Their costs have been derived from a number of ongoing and recently completed projects funded by the World Bank.

Table 7. Cost of Sand Dams and Subsurface Dams (Biyoole Project)

Name	Type	Volume	Cost	
		m^3	US$	US$/$m^3$
Aw-barkhadle	SD	13,700	130,000	9.5
Dinqal	SD	4,200	113,000	26.9
Debis	SD	13,500	150,000	11.1
Lasa Dawaco	SD	23,800	60,000	2.5
Meeladen	SSD	43,400	120,000	2.8
Xamxama1	SSD	6,500	50,000	7.7
Boocame	SSD	14,000	20,000	1.4
Barokhle	SSD	12,000	40,000	3.3
Ceeldahir	SD	14,400	40,000	2.8
Rabable	SSD/SD	14,000	40,000	2.8
Sinujiif	SSD	35,000	53,000	1.5

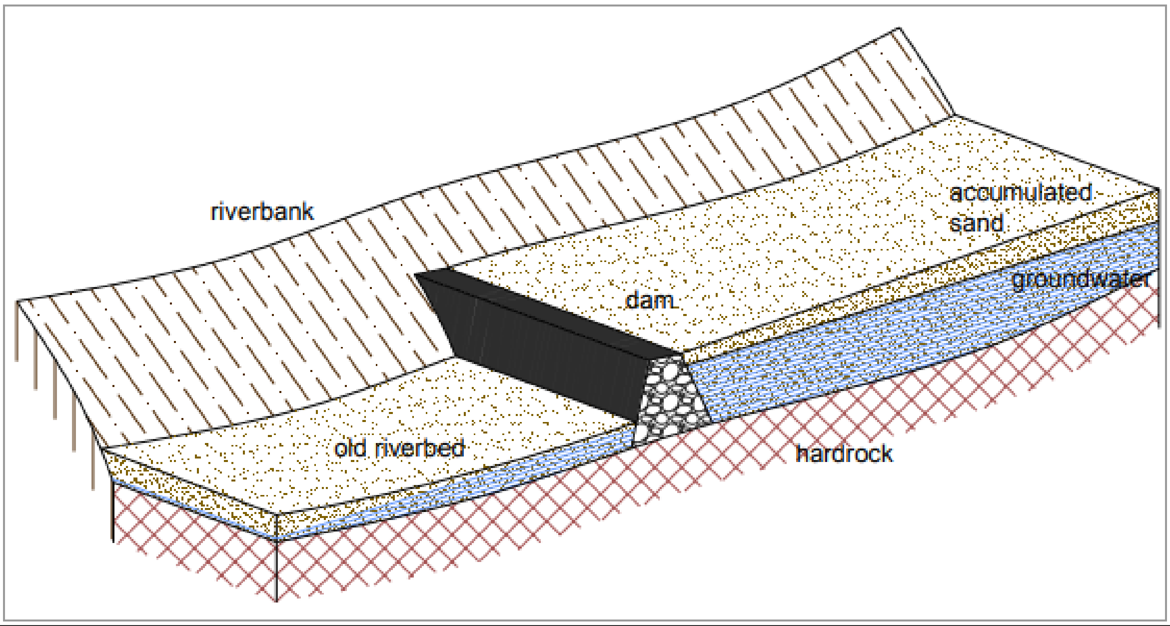
Source: From the Biyoole Project.

The cost per m^3 varies widely depending on the field conditions. Subsurface dams have lower construction costs and are in the range of US$1.5–3 US$/m^3. Sand dams are more expensive but have often a larger storage volume.

The storage volume in Table 7 is the volume of the water which is stored in the accumulated sand upstream of a sand dam (see Figure 21). The real storage capacity during the dry season may be higher if groundwater is also drained from the adjacent aquifers. If these sediments are permeable (sand, sandstone), this inflow may represent a substantial volume; if the surrounding sediments are impermeable (for example, hard rock) it would be much lower or negligible. Only the storage behind the dam is counted for, for the financial analyses in this report. This volume is available to overcome the dry period of six months. The annual capacity is taken as twice this storage to account for the water supplied during the other six months.

[11] Source: World Bank–funded investment plans for secondary cities in Puntland and Somaliland (2020)/Data WHO (2005).

Figure 21. Schematic Cross-Section of a Sand Dam



The average cost of a sand dam is US$40,000–70,000. A WDS consisting of a sand dam, a dug well with a pump (motorized or solar), a 25-m^3 ground reservoir, a water kiosk, and animal troughs will cost US$70,000–100,000. An additional 90-mm conveyance pipeline will cost US$20–30/m depending on the terrain conditions (Biyoole project).

2.4.5 Cost of Solar Pumps

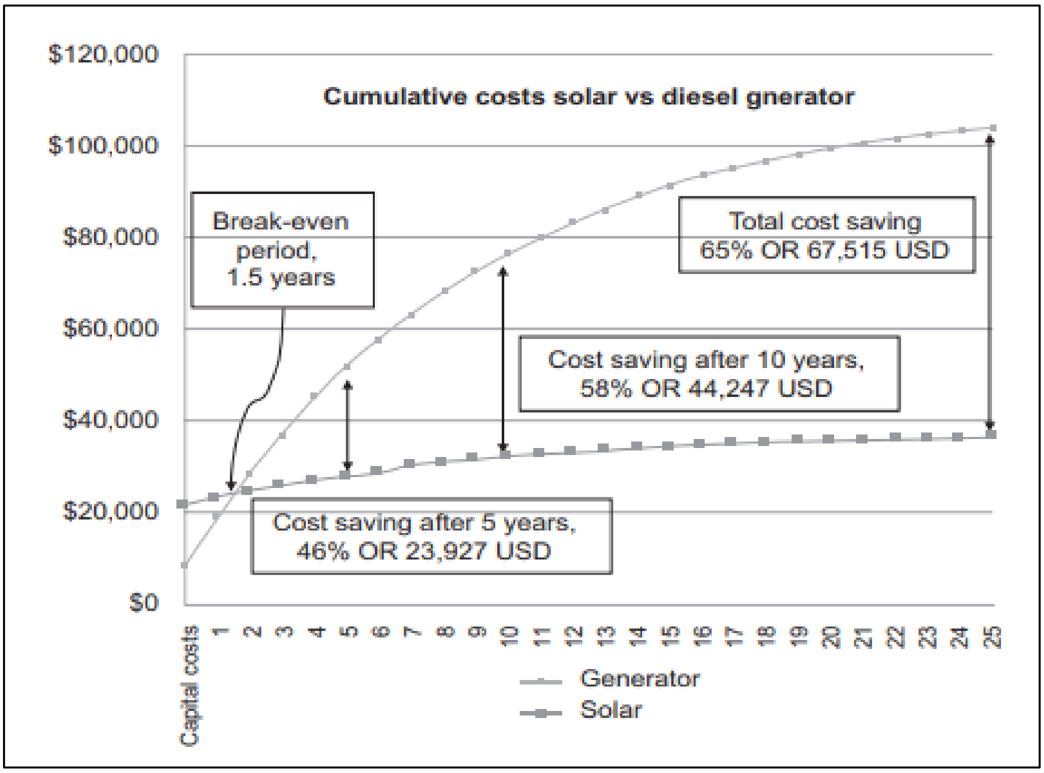
The cost of solar pump systems (pump, inverter, junction box, and photovoltaic [PV] module) in Somalia is in the range of US$20,000–30,000, but its annual costs are lower than for motorized pumps, as illustrated in Figure 22 and Appendix 7. Energy-wise, the use of solar pumps is clearly advantageous in Somalia, but the real cost will largely depend on the sustainability and continuity of the operation, especially in remote areas.

2.4.6 Cost of Desalination

The desalination of seawater or brackish groundwater[12] is one of the technical options to improve the access to fresh water for cities and towns in Somalia. This may apply for the desalination of seawater or brackish groundwater with salinity above the WDA standard. The most important technology today is the membrane desalination technology through Salt Water Reverse Osmosis (SWRO, also known as RO). An alternative for village level water supply is brackish groundwater desalination through PV-powered electrodialysis (ED).

[12] See Appendix 8.

Figure 22. Cost of Solar vs. Diesel



Source: Kiprono (2020).

The desalination of **seawater** is an option for coastal cities in Somalia (see Table 8).[13] Currently, the average price range of desalinated water is between US$0.5–1.5/m3, depending on electricity costs and production capacity.[14] For Somalia, it is safe to use the higher price ranges.

Table 8. Some Major Coastal Cities in Somalia

Name	Population	Name	Population
Mogadishu	2,587,183	**Jamaame**	185,270
Hargeisa	477,876	**Baidoa**	129,839
Berbera	242,344	**Burao**	99,270
Kismayo	234,852	**Bosaso**	74,287
Marka	230,100		

The desalination of **brackish groundwater by RO** is roughly 50–75 percent of the cost for seawater desalination. Data from a study done in Texas are used to calculate the annualized cost of brackish water desalination for a town of 20,000 people and show that the cost to supply 20 liters per capita is indeed in the range of US$1 (at 2021 price levels). This estimate is in the same order of magnitude as the unit prices presented by Karagiannis and Soldatos (2008) which show production cost of €0.63 per m^3 for a plant capacity of 1,000 m^3/day which equals €0.8–0.9 per m^3 for 2020.

[13] Source: https://worldpopulationreview.com/countries/cities.somalia.
[14] Source: Smart Water Magazine. "The evolution of rates in desalination." https://smartwatermagazine.com/blogs.

Photovoltaic-powered electrodialysis is an energy- and cost-effective means of desalinating groundwater in rural areas for village-level water supply systems. PV-ED requires less energy than RO for brackish water with a salt concentration less than 4,000 ppm. Kim a.o. (2017) report that an ED system using a PV cell as power, under small-scale conditions, could produce high quality water at a water production cost of US\$3.6–5.4/m^3. Developments in PV-ED are still ongoing and may have reduced the production cost in the last five years.

2.5 Summary of CAPEX and OPEX for Water Points

A number of interlinked excel sheets have been prepared to summarize the CAPEX and OPEX of the different water points and their characteristics (Appendix 6). Table 9 gives an overview of the characteristics of the main water points as well as the minimum, maximum, and median CAPEX. In the summary table, the median CAPEX are given with the estimated OPEX and a percentage of the CAPEX.

Table 10 gives the annualized capital cost and total annual cost for a given lifetime and interest rate. Values can be adapted when/if new information becomes available.

The calculation sheet also includes a table with the total annualized cost of the waterpoint for a given lifetime and interest rate and shows the total annualized cost (CAPEX and OPEX) per consumer and per m^3. Values can be adapted in the calculation sheets when new or updated information becomes available.

Table 9. Cost of Water Points

Characteristics and Cost of Water Points

Water Points	Storage (m3)			Depth (m)			Production			CAPEX		
	range	maximum	median	min	max	average	l/sec	m3/day	m^3/yr	min	max	median
Berkad [x1]	200-400	3,000	300					2	600	5,000	40,000	7,500
Dam with reservoir (Balli, War) [x4)]	2,500-15,000	450,000	7,500					40	15,000			100,000
Hand dug well + handpump				3	20	8	0.2	4	1,260	2,000	10,000	7,500
Handdug well +motorpump				*5*	*20*	*10*	0.5	18	6,300		15,000	15,000
Manual drilled well + handpump [x3)]				10	50	30	0.2	4	1,260	2,000	8,000	6,000
Manual drilled well + motorpump				10	50	30	0.5	18	6,300			13,000
Sanddam/sub surface dam +HP [x1,x5]	6,000-40,000		17,000					93	34,000	20,000	150,000	70,000
Sanddam/sub surface dam +MP	6,000-40,000		17,000					93	34,000			80,000
Drilled deep well + MP min [*2)]				100	400	225	8	288	100,800	75,000	500,000	200,000

x1): based on dry season use: 180 days | x2) multiplier for succes | x3) excl traning & PS developı | x4): silting not accounted f | x5: storage in sandbed behind the dam

Summary table

Water Points	Storage	Depth	Production	CAPEX	OPEX	
	m3	m	m3/yr	USD	%	USD /yr
Berkad	300		600	7,500	5	375
Dam+ Res, War, Waterpan, pond	7,500		15,000	100,000	5	5,000
Hand dug well + handpump		8	1,260	7,500	5	375
Handdug well +motorpump		10	6,300	15,000	15	2,250
Manual drilled well + handpump		30	1,260	6,000	5	300
Manual drilled well + motorpump		30	6,300	13,000	15	1,950
Sanddam/sub surface dam +HP	15,000		34,000	70,000	5	3,500
Sand dam/sub surface dam +MP	15,000		34,000	80,000	15	12,000
Drilled deep well + MP		200	100,800	200,000	20	40,000

Table 10. Annualized Capital Cost and Total Annualized Cost

Investment: Annualized Capital Recovery (ACR)								
Scheme	capital cost USD	years	interest %	interest factor	(1+i)^n	Factor *1)	Factor *2)	ACR
Berkad, Balli	7,500	25	5	0.05	3.39	0.07	0.07	532
Dam with reservoir	100,000	25	5	0.05	3.39	0.07	0.07	7,095
Hand dug well + handpump	7,500	25	5	0.05	3.39	0.07	0.07	532
Handdug well +motorpump	15,000	25	5	0.05	3.39	0.07	0.07	1,064
Manual drilled well + handpum	6,000	25	5	0.05	3.39	0.07	0.07	426
Manual drilled well + motorpu	13,000	25	5	0.05	3.39	0.07	0.07	922
Sanddam/sub surface dam +HP	70,000	25	5	0.05	3.39	0.07	0.07	4,967
Sanddam/sub surface dam +MF	80,000	25	5	0.05	3.39	0.07	0.07	5,676
Drilled deep well + MP min	200,000	25	5	0.05	3.39	0.07	0.07	14,190

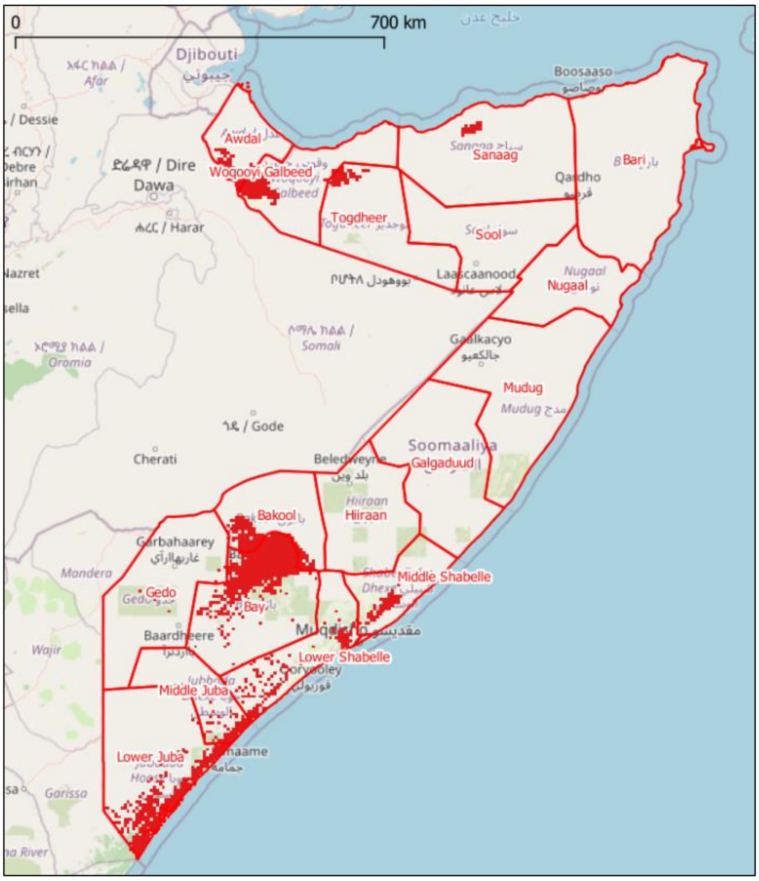
Total Annual Cost												
Scheme type	Life time	Number consumers	Annual productio	Days of use	Water demand/	Capital cost		O&M		Total annualized cost		
	years		m^3	days	lcd	USD	USD $/yr	%	USD/yr	USD/yr	USD/m^3	USD/cons
Berkad, Balli	25	167	600	180	20	7,500	532	5	375	907	1.51	5.4
Dam with reservoir	25	4,167	15,000	180	20	100,000	7,095	5	5,000	12,095	0.81	2.9
Hand dug well + handpump	25	173	1,260	365	20	7,500	532	5	375	907	0.72	5.3
Handdug well +motorpump	25	863	6,300	365	20	15,000	1,064	15	2,250	3,314	0.53	3.8
Manual drilled well + handpump	25	173	1,260	365	20	6,000	426	5	300	726	0.58	4.2
Manual drilled well + motorpump	25	863	6,300	365	20	13,000	922	15	1,950	2,872	0.46	3.3
Sanddam/sub surface dam +HP	25	9,444	34,000	180	20	70,000	4,967	5	3,500	8,467	0.25	0.9
Sanddam/sub surface dam +MP	25	9,444	34,000	180	20	80,000	5,676	15	12,000	17,676	0.52	1.9
Drilled deep well + MP min	25	13,808	100,800	365	20	200,000	14,190	20	40,000	54,190	0.54	3.9

3 Green Water for Rainfed Agriculture

3.1 Suitable Areas for Soil and Water Conservation Measures

The soil itself is an important intermediate storage system for water, which cannot be recovered by man as '"blue" water but is available for vegetation and crops as "green" water. Among other climatic and pedological factors, rainfed agriculture depends largely on the soil moisture storage potential. For the socioeconomy of Somalia, it is essential to safeguard and increase the production of staple foods such as millet and maize, and of livestock fodder. Irrigation is generally preserved for growing cash crops because of water scarcity and other inputs (labor). Increasing production of rainfed agriculture can be better realized with soil and water conservation techniques. These techniques—such as stone bunds, terraces, half-moons, retard overland runoff, and erosion—promote infiltration and increase soil moisture content (Liniger and Critchley 2007). As a result, crop yields will increase and, in any case, will be less affected by moderate droughts. Rainfed agriculture is carried out mainly in (a) the northwestern regions of Awdal, Woqooyi Galbeed and Toghdeer along the Ethiopian border; (b) the Bay region; and (c) the coastal strip in the Lower and Middle Shabelle, and Lower and Middle Jubba, regions.

Figure 23. Areas (Red Pixels) with High Effectivity of Soil and Water Conservation Measures for Rainfed Agriculture



Source: Calculated with FAO-WaPOR (2020) model.

The WaPOR tool of FAO (FAO-WaPOR 2020) has been used to determine where soil and water conservation (SWC) measures are most efficient. With WaPOR, the water productivity and biomass production can be mapped at pixel scale based on remote sensing data. (Water productivity is the ratio of biomass production to the amount of water used by evaporation and transpiration.) After setting certain minimum levels for water productivity and biomass production, areas have been delineated where SWC interventions are assumed to be most effective. It is no surprise these prospective areas fall in the zones where the population already carries out rainfed agriculture. Observations of the land use pattern by Google Earth lead to the assumption that 10 percent of the area indicated in Figure 23 can be treated with SWC measures.

Table 11 lists the areas (in hectares) where SWC measures can be applied in each region and also gives the costs for various combinations of these measures (also see Appendix 10).

Table 11. Suitable Areas for Soil and Water Conservation Measures and Costs for Various Combinations of SWC Measures

Region	suitable area for SWC in ha
Awdal	17,000
Bakool	32,500
Banaadir	-
Bari	-
Bay	104,500
Galgaduud	-
Gedo	2250
Hiiraan	
Lower Juba	15750
Lower Shabelle	71250
Middle Juba	
Middle Shabelle	
Mudug	5000
Nugaal	12750
Sanaag	31250
Sool	
Togdheer	10000
Woqooyi Galbeed	22750

3.2 Types and Costs of SWC Measures

The WOCAT report, *Where the land is greener: Case studies and analysis of soil and water conservation initiatives worldwide* (Liniger and Critchley 2007), describes a wide range of SWC measures, their specific purpose and application conditions, and the approximate cost per hectare (Appendix 4). Measures applied in Somalia include stone bunds, soil bunding, terracing, halfmoons, and water storage in dams and other reservoirs (SWALIM). Other measures may also be applicable in Somalia, but a complete overview is not available.

From the WOCAT report and other references, the unit prices for known SWC measures in Somalia are estimated to be US$300–1,200/ha (average: US$700/ha), and 5 percent annual cost for operation and maintenance.

4 Concluding Remarks

4.1 Water Availability and Water Demand

Water demand by population and livestock projected has been compared to the renewable water resources for all regions. Because of lack of time and data, we did not do this district-wise. In this phase, we projected the demand for the year 2030 given the growth percentages for rural and urban populations. As for the water availability, we did not use the numbers of existing water points in the SWALIM database and their unit production rates as in Phase 1. The reason is that the database appeared to be incomplete. Moreover, the water points do reflect the potential availability of water.

The amount of internally generated renewable groundwater and surface water resources have been determined for all regions based on literature about surface water runoff, groundwater recharge, and groundwater flow (Table 1). Subsequently, sustainably available water resources have been defined as 20 percent of these renewable water resources. The 20 percent rule of thumb is arbitrary, but widely used a critical ratio above which demand and supply need to be managed to avoid conflicts (van Ham et al. 2018; WWAP/UN-Water 2018; EEA 2005; UN 1997).

Comparing water demands or needs in 2030 for rural and urban populations and livestock with sustainably available water resources, we learn that water needs are below these critical values, except for the Benadir region. This conclusion is a bit indicative as all these values are averaged over time and space. Water shortages may still occur at places with high concentrated demand, such as towns, or during drought periods. The spatial problem is illustrated in Table 1 by the Benadir region around Mogadishu, where the high urban water demand in combination with a small and little water-producing region makes the scarcity ratio jump above the absolute water scarcity ratio of 100 percent. If this analysis would have been carried out at the district level, we expect several districts to exceed the scarcity limits. If we would further zoom in to the scale of settlements and their direct surroundings, we foresee water scarcity for about 30 to 40 towns. For these high demand centers, dedicated feasibility studies need to be carried out, including options like managed aquifer recharge, long range transport, and desalination of seawater and brackish groundwater. The same applies to centers where large-scale irrigation and industrial developments are projected.

The fact is that the demand and availability figures in Table 1 are also averaged in time. This obscures the fact that during frequent droughts in Somalia's rivers, reservoirs, and shallow dug wells dry out, and severe water scarcity arises. In addition, the soil moisture (green water) gets depleted during droughts, resulting in failed harvests of staple food and fodder.

Water is felt as a scarce resource in Somalia, mainly because it is not available at the right place, at the right time or in the right quality. The extensive limestone and sandstone aquifers are too deep in some areas, while shallow and more easily accessible sand aquifers are restricted to the wadis, river valleys, dunes, and certain tectonic basins. It also appears that the quality of groundwater is unacceptable for human consumption (due to salinity and fluoride) in some areas. Though surface water can be collected in many places in berkads and hafirs, these reservoirs prove to be unreliable during droughts: little water is collected, and that too evaporates before the end of the dry season. Also, shallow dug wells tend to fall dry during droughts. Finally, we found out that water in many reservoirs and dug wells is bacteriologically contaminated. This may be avoided by better siting and construction of dug wells and boreholes but is more difficult to manage in surface water reservoirs.

Despite the water scarcity and the mismatch of supply and demand in time and place, we still see opportunities for developing water resources with the following strategies.

4.1.1 Water Storage

In order to bridge drought periods, policies should be geared towards underground water storage. By nature, groundwater is the largest and most reliable storage medium. So, exploration and drilling of traditional boreholes remains a viable option, particularly relatively cheap manual drilling. However, success rates, well integrity, and therefore well costs, must be improved by capacity building both in the private sector and in governmental organizations.

We further advocate dedicated water storage in shallow sand aquifers to increase well capacities, or to at least make them more climate robust. Construction such as sand dams and underground dams, already successfully applied under the Biyoole project, must be continued. Recharge ponds surrounded by shallow wells are also options for further investigations. Apparently, they already exist, as van Haren et al. (2017) mention the presence of hafirs on permeable subsurfaces in Somaliland, where infiltrated water is captured by shallow wells.

4.1.2 Water Transport

As mentioned above, water is not always available at the right place. This is particularly relevant around towns with relatively high water demand. In most cases, such a large amount of water cannot be sustainably produced by some wells close to the town. Wells' fields need to be spread out over larger areas, or hydrogeologically favorable zones must be explored at larger distances. In any case, water must be transported to the demand centers. For smaller settlements, particularly in pastoralist areas, it may be the other way around—people may need to move to the places where water is available.

4.1.3 Water Quality

With respect to water quality, investments in surface water reservoirs and dug wells are not warranted if they cannot be protected from contamination. Lined, closed, and deeply excavated dug wells, as well as the ones constructed for sand dams, may be a viable solution. As mentioned earlier, salinity and accompanying fluoride must be investigated and mapped in regional studies. Finally, construction of boreholes must adhere to state-of-the-art guidelines to avoid leakage around the well casing.

4.1.4 Green Water

The large water footprint in Somalia, and consequently the frequent severe water scarcity, according to Mekonnen and Hoekstra (2016) and MacNally et al. (2019), is caused by incorporating water needed for the growth of local crops and fodder and production in other countries (for instance, imported rice). As far as crops and fodder are concerned, this is restricted to (a) irrigated agriculture in the Shabelle and Jubba valleys; and (b) rainfed agriculture in the Bay region in the south and the Awdal and Woqooyi Galbeed regions in the northwest (Figure 23), and finally natural grass in the rangelands). Water for irrigation is coming mainly from Ethiopia and is dealt with in the chapter on riverine areas. Regarding rainfed agriculture, the impact of droughts can be alleviated by applying soil and water conservation measures as proposed in Chapter 3. It is important to note the green water added to the soil moisture by these measures does not compete with the water withdrawals for rural and urban population and livestock. Studies in West Africa suggest soil and conservation (SWC) measures lead to more groundwater recharge and rising water tables. SWC measures may result in lower runoff into downstream reservoirs; on the other hand, however, the siltation rates of reservoirs decrease.

4.2 Suggestions for Potential Investment Opportunities

Topic	Investment Components
Improve drought resilience through capacity development and private sector support to improve quality and lifetime of water points[15]	• Large scale introduction of manual well drilling (training, local equipment production, private sector development) • Support to public/private sector to improve drilling deep motorized wells (siting, design, drilling, supervision, completion) • Upscaling sand dams' construction (siting, design, construction)
Improve data collection on groundwater occurrence and status of water points	• Build on existing data sets databases (SWALIM) • Database access for federal and regional level • Target data collection/monitoring system

Urban water supply (>10,000 population)
Larger cities: Usually, extension and upgrading of existing schemes: investment cost not standard
	• Development of deep groundwater or as alternatives:
	  ○ large MAR systems (bank infiltration Jubba and Shabelle);
	  ○ large infiltrations basins in Quaternary sand and gravel); and
	  ○ seawater/brackish water desalination (coastal cities)
	• Includes: chlorination or other treatment, conveyance, storage and distribution, house connections
	• Requires: regional hydro(geo)logical study, professional consultants and contractors, capacity development for water supply company

Small town water supply (new or expansion of existing scheme); population: 1,500–10,000	• Development of deep groundwater and/or sand dams and/or manually-drilled wells in Quaternary sands • Includes: chlorination, conveyance, storage, distribution, standpipes/house connections • Requires: hydrogeological study, professional consultants and contractors, capacity development for water supply company
Rural water supply and drought preparedness for pastoralist and agropastoralists	• Sand dams and manually-drilled wells in Quaternary sands • Includes: conveyance, storage, kiosks/troughs • Promote sustainable operation of solar pumps • Requires: Cap. Dev. for O&M to NGOs or water committees
Network of emergency wells with water trucking service during droughts (Petersen and Gadain 2012)	• Network of emergency wells in vulnerable regions in combination with a fleet of tankers for water supply to overcome droughts in remote rural areas, in particular for livestock in rangelands and along livestock trade routes
Expanding soil and water conservation in selected areas	• SWC measures to improve rainfed agricultural production in favorable agro-climatological and pedological zones • Areas with highest returns (water productivity) are identified
Groundwater for irrigation to supplement surface water	• In alluvial plains of Shabelle and Jubba rivers (conjunctive use of groundwater and surface water)

[15] These investment opportunities are worked out in more detail in Section 4.3.

Topic	Investment Components
	• Need and feasibility to be assessed

4.3 Investment Opportunities to Improve (Manual and Machine) Drilled Wells

The first investment opportunity in Section 4.2 deals with support to improve quality and lifetime of water points which tap groundwater from various aquifers which form a large natural reservoir, which can sustain water supply during frequent droughts, when traditional reservoirs and dug wells fail. Groundwater needs to be tapped by properly designed infrastructure, such as drilled boreholes, modern dug or collection wells, sand dams, and underground dams. The measures needed to improve the quality and lifetime of drilled wells are presented below. For sand dams, we refer to the successful application of dam construction under the Biyoole project, which can be continued and expanded to other regions.

4.3.1 Capacity Development of Deep Machine-Drilled Wells

Drilled wells, in combination with handpumps or water distribution networks, are the most versatile systems delivering safe water free of pathogen bacteria (if well designed) in contrast to traditional water points. They are also cost effective, provided that the boreholes are properly sited, designed, and supervised.

Traditional machine-drilled wells are quite expensive. An average 250 m deep well costs about US$125,000 or US$250,000, given the low success rates in the fractured hard rock aquifers (Section 2.4). The low success of 50 percent is a combination of “dry” holes (particularly in limestones), technical failures (loss of circulation, sand inflow), and encountering brackish water above the WDA limit of 3,500 microS/cm. Water salinity in 30 percent of the existing wells in the SWALIM live database exceeds 3,500 microS/cm (Section 2.2).

Though expensive, drilling wells in the hard rock aquifers may be the only option, particularly for some urban centers. We recommend investments in regional and local hydrogeological studies using geophysical techniques, and to invest in technical capacity development of local private sector parties, such as drilling companies and consultants. The same holds for increasing the capacity of governmental bodies responsible for planning and setting the standards for drilling.

We think the proposed professionalization of drilling would raise the drilling success considerably. Hence, drilling costs would be reduced. Given future water demand, this study foresees drilling of hundreds of deep boreholes (Section 2.2). If, for instance the success rate of 100 of these boreholes (with a depth of 250 m) could be stepped up from 50–60 percent, this would already result in savings of US$5 million on drilling. Such an amount certainly warrants an investment in capacity development of the drilling sector in Somalia.

4.3.2 Introduction of Manual Drilling

In many places in Somalia, groundwater could be recovered from sand and gravel aquifers by deploying shallow manually drilled wells. However, manual drilling is not being practiced in Somalia unlike in many other African countries. Manual drilling up to depths of 30–40 m is very cheap, while quality and even production capacity of these wells can be just as good as machine drilled wells of the same depth or of those of deep machine drilled wells. Similar standards for well installation, well development, and pump testing can be followed.

Manual well drilling has some other advantages: it requires only low cost technology and no expensive imports; construction and maintenance can be carried out at local workshops, which makes the local companies more sustainable. Furthermore, the equipment is lightweight and portable, making it a suitable technology to drill boreholes in remote rural areas away from road access, even in rainy season conditions.

Manual drilling has been introduced successfully in several African countries (for instance, in Chad, Niger, Mauritania, Zambia, Guinea, Mali, Madagascar, Liberia, Togo, Ivory Coast, and Congo), while groundwater mapping for manual drilling has been carried out in Sierra Leone, Ghana, Senegal, and Guinea Bissau (Danert 2015; Deal and Sabatini 2020; Fussi et al. 2017a, 2017b; Harvey and Naugle 2011; Kane and Danert 2020; Martínez-Santos et al. 2020; Martínez-Santos et al. 2017; PRACTICA 2009a, 2009b, 2010a, 2010b, 2011; Thomas et al. 2012; UNICEF 2010; van Herwijnen 2005).

Manual drilling has received significant attention since 2005 through promotion and financial support from UNICEF to scale manual drilling in a number of countries in Africa as a complementary option in water supply. PRACTICA Foundation and EnterpriseWorks/VITA (Relief International) have been involved as technical agencies to support capacity-building programs and have developed the necessary training materials for countries to embark on manual drilling. This has sparked several organizations to use and promote manual drilling in their projects throughout Africa.

Unconsolidated Quaternary sand and gravel deposits cover about 25 percent of the land surface, according to the national geological map. The deposits are found mainly along the coasts (dunes), along the major rivers, and in tectonic basins in the north. However, sands and gravel are also present as narrow unmapped zones along the many wadis. Unconsolidated material is also present as regolith formed on basement rocks. We are convinced that manually drilled wells, in combination with handpumps or motorized, and connected to distribution systems, would be useful and applicable for many settlements. Another indication of the applicability of manual drilling is the fact that dug wells, which can only be constructed in unconsolidated material, are the most common water points and occur throughout the country. Drilled wells of the same or deeper depth have the potential to provide higher quality of water due to the use of sanitary seals.

Given the water demand extrapolated to 2030, thousands of manually-drilled wells would be needed, as shown in this study (Section 2.2). Manually-drilled wells cannot replace machine-drilled wells in all situations. Deep machine-drilled wells are, in some cases, the only option in the absence of sand aquifers. However, the savings are considerable in many locations. Let us assume that in 500 locations manually-drilled wells, having a depth of 30 m and costing US$5,000,[16] could replace machine-drilled wells of similar depth and costing US$12,500.[17] We further assume drilling success rate is 80 percent in these sediments. Under these assumptions, the savings of these 500 manually drilled wells would amount to US$2.8 million.

We advise launching a three-year nationwide program introducing the technology of manual drilling, conducting training sessions, and supporting the private sector. Three or four pilots in different zones and settings could be carried out under such a program. The deliverables of such a program are building the capacity to continue drilling thousands of boreholes in the years thereafter, and the 300 boreholes created under the three-year program. The costs of such a program are approximately US$1–1.3 million,[18] which is less than the costs savings of the 300 manually drilled wells.

[16] Personal communication, Robert Vuik, PRACTICA, March 2021.

[17] This study and personal communication, Albert Tuinhof, March 2021.

[18] PRACTICA personal communication.

The assumptions above need to be verified in a feasibility study including:

- A sector survey assessing (a) local practices and insights in suitability conditions, skills and availability of local entrepreneurs, service providers, and workshops; (b) WASH programs of NGOs for partnership developments and lessons learned; and (c) policies and regulating framework.

- Mapping of water demand and the acceptability of manually drilled wells at the local level.

- National mapping of the hydrogeological suitability of manually drilled wells.

- Test drilling to verify mapping and optimize general well designs.

We expect that the costs of this feasibility study would be approximately US$200,000.

Appendix 1. Water Scarcity: Viewed from the Supply Side

The Global Water Forum (2012)[19] defines water scarcity as **the lack of access to adequate quantities of water for human and environmental uses**. The same article states that, despite its frequent use, there is no consensus on how water scarcity should be defined or measured. The supply side may consider blue water or also green water and virtual water. The demand side depends on the quantification of the specific water needs of the different water users' groups (quantity and quality) and is also related to the cost for access to water.

To compare water scarcity between countries or regions, there are a range of water scarcity indicators which define water scarcity on the basis of available data and information. Most of these indicators include available renewable water and blue water use (or water demand).

Available Renewable Water Resources in Somalia

The available water resources in Somalia are estimated in this report.[20] A calculation is presented of the specific internally produced renewable water resources (groundwater and surface water) in Somalia. The total is 7.864 10^6 m^3/yr of which 2.941 0^6 m^3/yr is groundwater and 4.923 10^6 m^3/yr is surface water (Table A1.1 and Figure A1.1). The specific renewable groundwater may be larger if externally produced groundwater from transboundary aquifers is accounted for.

Blue Water Demand

The 2030 blue water demand in Somalia is calculated by using population and livestock data from UNDP 2014, growth rates (4.14 percent for urban and 1.79 percent for rural) from the World Bank database (World Bank, Data Somalia 2020), unit water consumption (20 lcd for rural and 40 lcd for urban) from Somalia WASH Cluster (2020), and livestock water intakes based on Peden et al. (2003). Figure A1.2 shows the projected water demand for the 17 regions.

Water Scarcity Indicators

World Water Development Report (WWAP/UN-Water, 2018): TableA1.1 shows the calculated internally produced renewable water resources in Somalia. The total renewable water resource is a hydrological notion and does not represent the amount of water available for water supply because not all renewable water can be used or withdrawn. The WWAP (2018) states that water scarcity problems may arise in regions where more than 20 percent of the **renewable water** is used as blue water, while severe water scarcity arises when 40 percent is used.

Other sources (van Ham et al. 2018; EEA 2005; UN 1997) also apply the 20 percent scarcity criterion—it is applied as a limit for the available water resources in Somalia.

[19] GWF. 2012. Understanding water scarcity: Definitions and measurements.

[20] This technical report is one of a suite of six supporting documents along with the 'Economics of Water: Digging for Data—Towards Understanding Water as a Limiting or Enabling Factor for Socioeconomic Growth in Somalia' report.

Figure A1.1: Specific Internally Produced Renewable Water Resources Per Region in Somalia

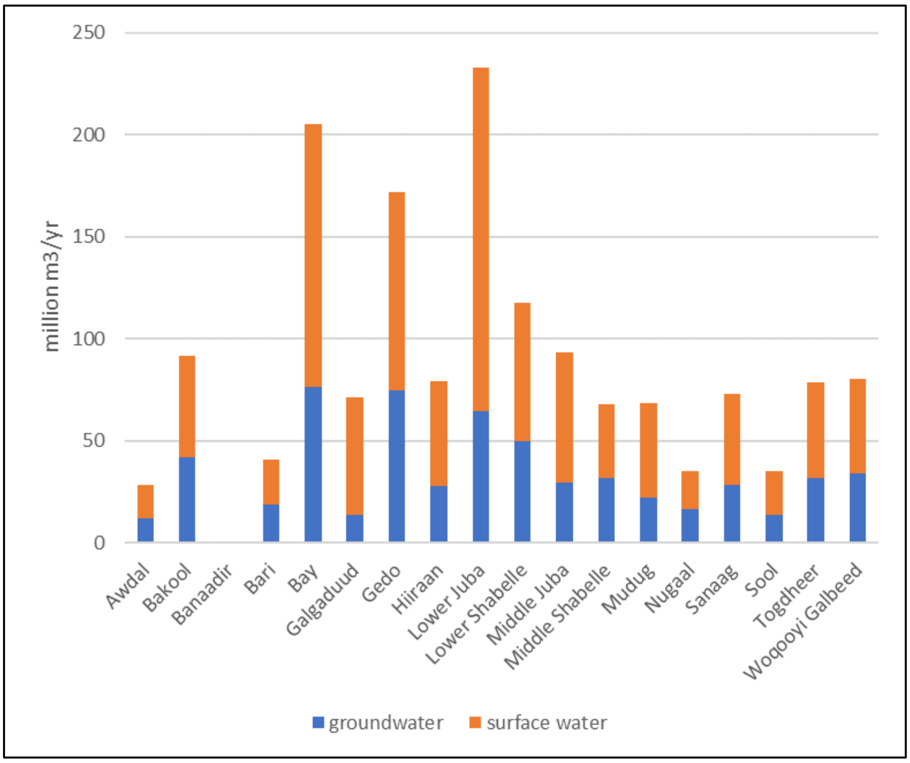
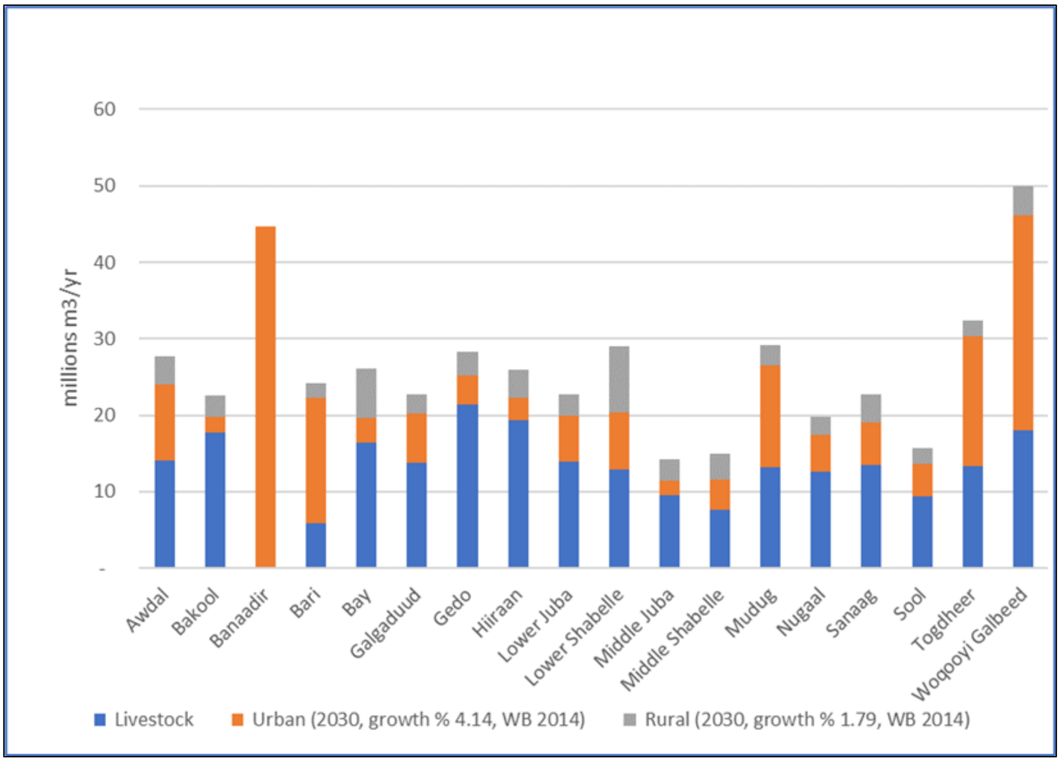


Figure A1.2. Projected Water Demand in 2030



The 20 percent ratio and 2030 water demand per region are shown in Table A1.1. The last column gives the difference between the two and shows that the 2030 blue water demands in the regions do not exceed the 20 percent scarcity limits, with the exception of Benadir and Awdal. This conclusion is a bit indicative as all these values are averaged over time and space, and only the water demand for people and livestock are taken into account. Water shortages may still occur at places with high concentrated demand, such as towns and large villages, or during periods of drought.

Table A1.1. Specific Internally Produced Renewable Water Resources Per Region in Somalia

Region	Rainfall	Specific renewable water			Renewable water			Available (20% of renewable)	Water demand 2030	Availabe minus - Demand
		Ground water	Surface water	total	Ground water	Surface water	total			
	mm/yr	l/s/km2	l/s/km2	l/s/km2	10^6 m3/yr	10^6 m3/yr	10^6 m3/yr	10^6 m3/yr	10^6 m3/yr	10^6 m3/yr
Awdal	215	0.16	0.17	0.33	60	82	143	29	28	1
Bakool	354	0.30	0.31	0.61	211	247	458	92	23	69
Banaadir	376	0.32	0.33	0.65	1	2	3	1	45	-44
Bari	101	0.05	0.05	0.10	93	111	204	41	24	17
Bay	505	0.44	0.47	0.91	382	646	1,028	206	26	180
Galgaduud	233	0.18	0.19	0.37	69	289	358	72	23	49
Gedo	392	0.33	0.35	0.68	373	487	860	172	28	144
Hiiraan	287	0.23	0.24	0.47	139	258	397	79	26	53
Lower Juba	598	0.53	0.56	1.10	322	843	1,165	233	23	210
Lower Shabelle	461	0.40	0.42	0.82	248	340	588	118	29	89
Middle Juba	574	0.51	0.54	1.05	148	318	466	93	14	79
Middle Shabelle	357	0.30	0.31	0.61	159	180	339	68	15	53
Mudug	173	0.12	0.13	0.25	110	232	342	68	29	39
Nugaal	154	0.10	0.11	0.21	82	93	175	35	20	15
Sanaag	178	0.13	0.13	0.26	143	223	366	73	23	50
Sool	139	0.09	0.09	0.18	69	108	176	35	16	20
Togdheer	261	0.21	0.22	0.42	160	233	393	79	32	46
Woqooyi Galbeed	305	0.25	0.26	0.51	171	231	403	81	50	31
Average/total	315	0.26	0.27	0.53	2,941	4,923	7,863	1,573	473	1,100

The **Falkenburg indicator**[21] introduced an indicator for water stress that expresses the level of water scarcity in a certain region as the amount of **renewable freshwater** that is available for each person each year. It is one of the most used indicators to measure and describe water availability for human use based on three thresholds: if the amount of renewable water in a country is below 1,700 m^3 per person per year, that country is said to be experiencing water stress; below 1,000 m^3 it is said to be experiencing water scarcity; and below 500 m^3, absolute water scarcity.

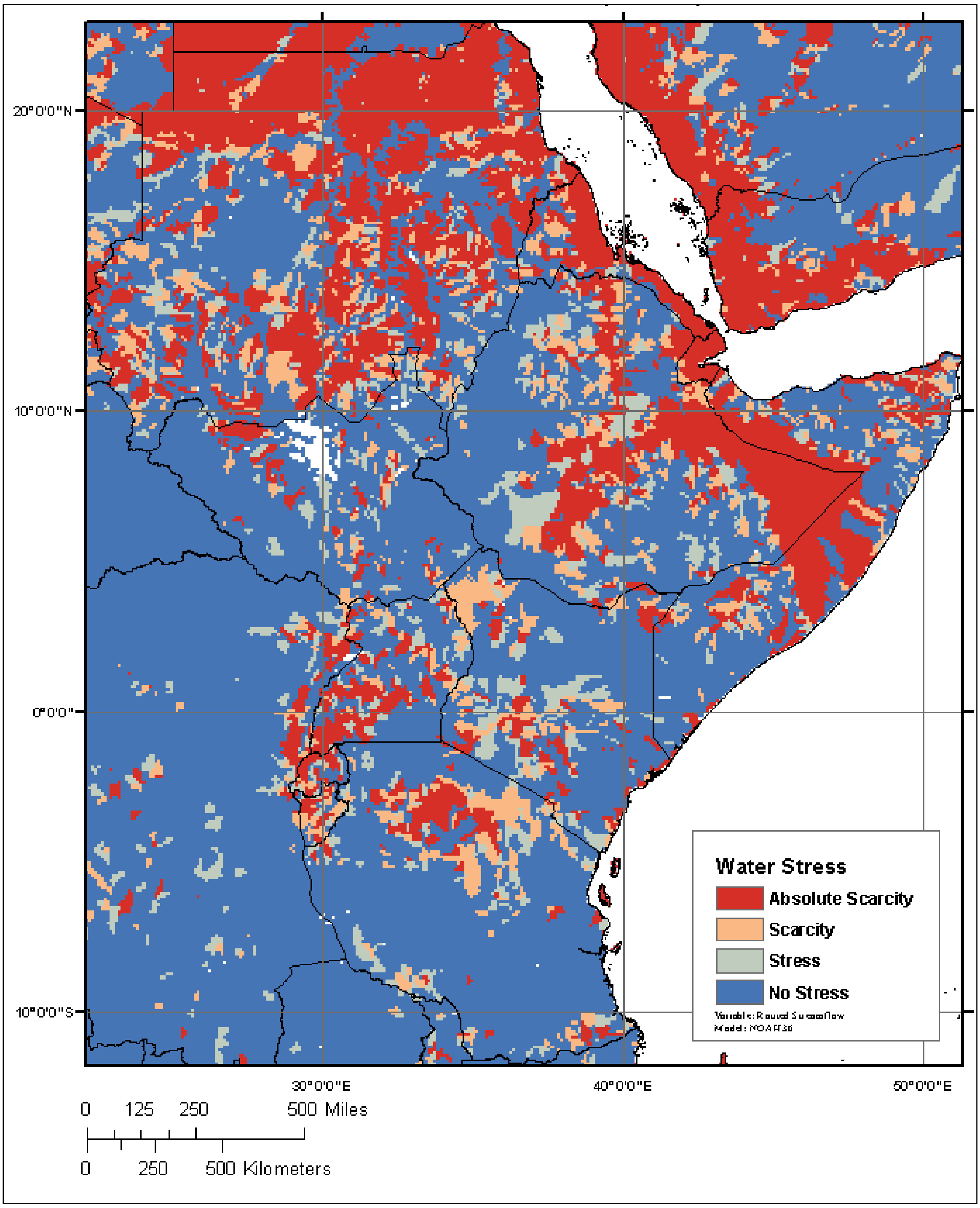
Applying this to Somalia (total renewable water: 7.863 106 m^3/yr and a population of 16 million) the index is 490, ***meaning absolute scarcity***.

The **National Aeronautics and Space Administration (NASA) water stress indicator** is in line with the water footprint concept. NASA, under the FEWSNET project of its Land Information System, developed another water stress indicator and carried out global water scarcity mapping (https://lis.gsfc.nasa.gov/projects/fewsnet; McNally et al. 2019). The FEWSNET water stress definition is equal to the Falkenburg Indicator: areas with "absolute water scarcity" (less than 500 m^3/yr/cap), "water scarcity" (500 to 1,000 m^3/yr/cap), and "water stress" (1,000 to 1,700 m^3/yr/cap), and "no stress"

[21] Falkenmark, M., J. Lundqvist, and C. Widstrand. November 1, 1989. "Macro-scale water scarcity requires micro-scale approaches." *Natural Resources Forum* 13(4): 258–267.

(more than 1,700 m^3/yr/cap). Figure A1.3 shows a map of Somalia with the average situation for 2020. *Absolute water stress is found in Middle Somalia, Puntland, and Somaliland along the Ethiopian border.* Note that there are large differences: parts of the country have no water stress according to this method.

Figure A1.3. Water Stress According to FEWSNET

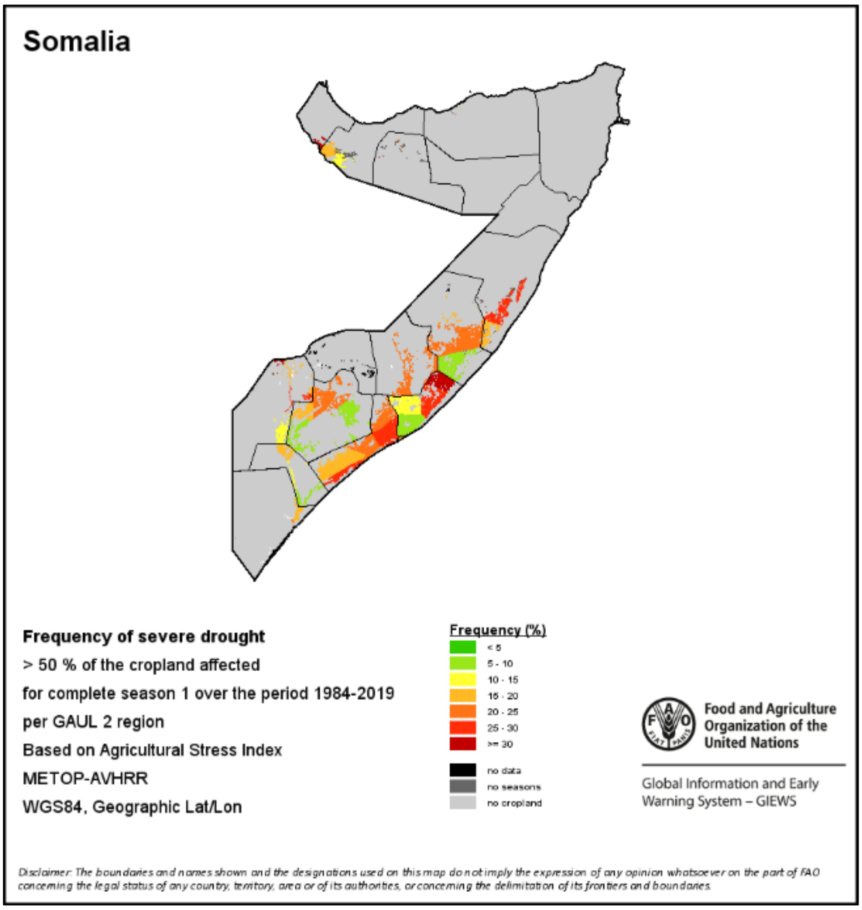


Source: From https://lis.gsfc.nasa.gov/projects/fewsnet.

The **Blue water footprint** concept of Hoekstra et al. (2011) relates to "the freshwater (surface and groundwater)" needed to produce the goods and services by the individual or community. It includes "evaporated water, water incorporated within products, water not returned to the same catchment area, and water not returned during the same period". The water footprint is higher than the amount of water used for domestic water supply. It includes the so-called virtual water in all kind of products, which may originate from far-away areas. According to this concept, Somalia suffers everywhere from ***severe water scarcity*** as indicated on the map of Mekonnen and Hoekstra (2016).

The **FAO agricultural stress index (ASI)**[22] is another interesting scarcity indicator. The ASI is used to investigate the occurrence of droughts in Somalia and the impacts on cropland and grassland (rangeland). The frequency of severe droughts as defined by the ASI for the *deyr* season for cropland (in Figure A1.4a) and for grassland (in Figure A1.4b) are shown here. Note that rainfed crops are primarily grown in the Bay region and the Awdal and Woqooyi Galbeed in the north. Cropland in the Lower and Middle Shabelle region is probably mainly irrigated. The figures show that 50 percent of the cropland and grassland is affected by severe drought in one out of five, and in one out of 10 years. This "one out of 10 years" droughts correspond to the one out of 11 droughts based on the SPI rainfall analysis of Shilenje and Ongoma (2014).

Figure A1.4a. Frequency of Severe Droughts Affecting More Than 50% of Cropland



[22] http://www.fao.org/giews/earthobservation/country/index.jsp?lang=en&code=SOM; van Hoolst et al. (2016).

Figure A1.4b. Frequency of Severe Droughts Affecting More Than 50% of Grassland

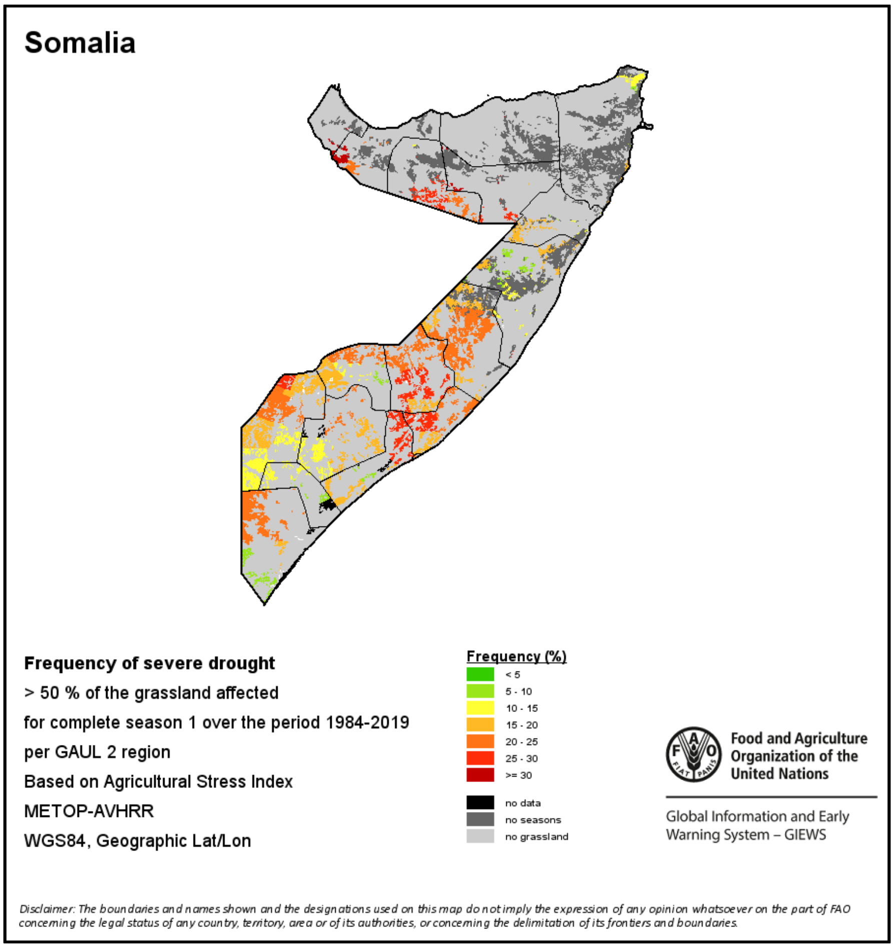
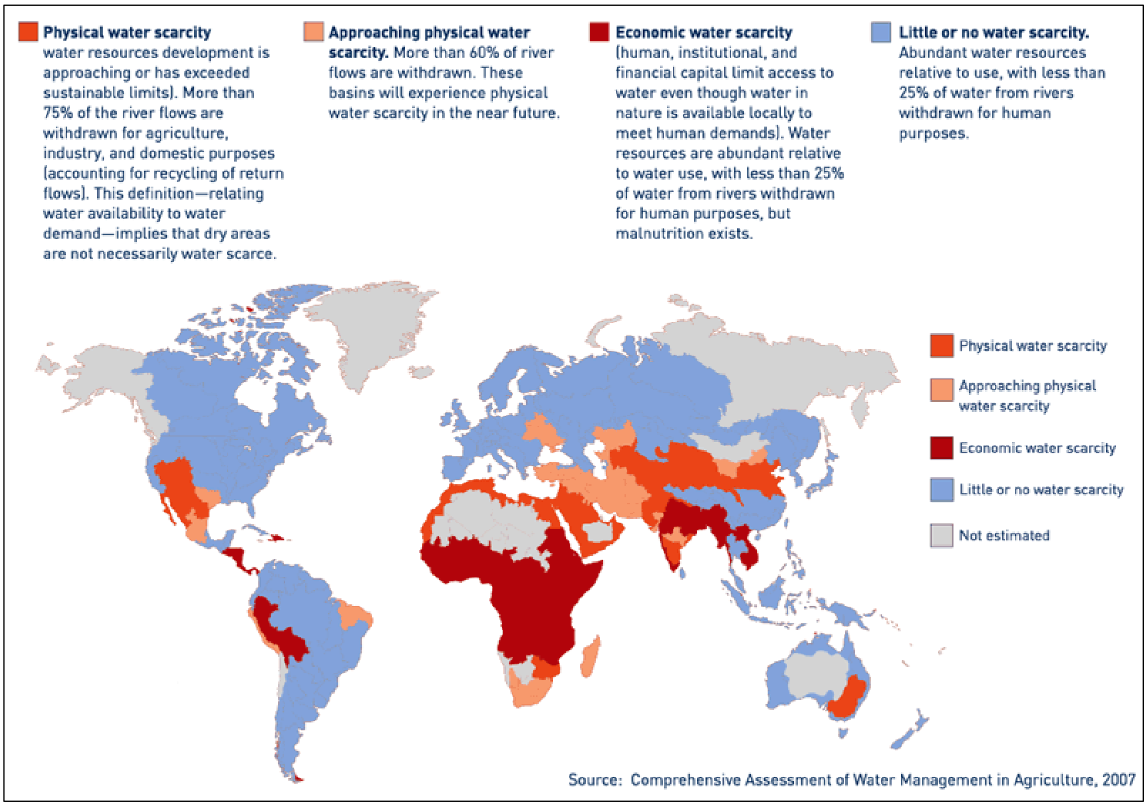


Table A1.2. Summary of Water Scarcity Indicators

Indicator	Data	Rating
WWAP	Table A1.1 and Figure A1.3	No water scarcity except in two regions
Falkenburg (2007)	Table A1.1 (total renewable water) and population of 16 million	Index is 490, meaning absolute scarcity
NASA (2019)	Same basis as Falkenburg but based on more spatial data	Absolute scarcity in Middle Somalia, Puntland, and Somaliland
Blue Water Footprint (2011)	Relates to fresh (surface and ground) water but includes also the virtual water needs	Absolute scarcity everywhere in the country
FAO (2017)	Based on the occurrence of droughts	Frequency of severe droughts affecting 50 percent of cropland and grassland

Figure A1.5. Areas of Physical and Economic Water Scarcity



Conclusion

Comparing water demands or needs in 2030 for rural and urban population and livestock with the sustainable available water resources (based on the 20 percent from WWAP/UN-Water [2018]), we learn that water needs are below these critical values (except for the Benadir region), suggesting that there is not a **water shortage** in Somalia. This conclusion is a bit indicative, as all these values are averaged over time and space. At a local scale, large demand centers such as towns still face scarcity. It also obscures the fact that during the frequent droughts in Somalia, rivers, reservoirs, and shallow dug wells dry up and severe **water scarcity arises**. This scarcity may be less severe if the government or private sector could invest more in better well siting and drilling, water storage (MAR), water transport, and governance of the water infrastructure. In that sense, water scarcity in Somalia, as in the rest of Sub-Saharan Africa, is often considered as an economic scarcity.

Also, soil moisture (green water) gets depleted during droughts, resulting in failed harvests of staple food and fodder. The other water scarcity indicators indeed rate Somalia as a water scarce country. Water is felt as a scarce resource in Somalia, mainly because it is not available at the right place, at the right time or of the right quality.

As a result, relying on a single indicator may give a misleading impression about water scarcity issues. It is, therefore, important when discussing 'water scarcity', to be clear how the term is defined and which aspects of water scarcity it measures, and to recognize that one measure by itself is not enough to give the whole picture.

Appendix 2. Formation Types and Named Aquifers in Somalia[23]

Unconsolidated Aquifers[24]	General Description	Water Quality Issues	Recharge
Alluvial terrace deposits: Pleistocene to Holocene/Recent	Terrace deposits in major wadis (called toggas) often overlie and are in hydraulic continuity with older Pleistocene deposits, which can result in very thick aquifers of over 100 m. Typically high productivity aquifers, with medium to high permeability and high infiltration capacity. Estimated transmissivity values (kD) are in the range 10-2 to 10-3 m^2/sec. In the Geed Deeble area (Hargeisa water supply), only one in ten tested boreholes showed a kD of less than 10-3 m^2/sec; the others ranged from 2.86 to 5.18 x 10-3 m^2/sec. Calculated hydraulic conductivities were in the range 1.4 x 10-4 m/sec to 7.7 x 10-5 m/sec. Test yields of the production boreholes ranged from 12 to 20 l/s, with drawdowns less than 20 m. Generally unconfined, but where covered with Quaternary volcanic basalts, they can be confined, sometimes with considerable artesian pressure (for example, in the Xunboweyle area). In unconfined aquifers the water table is typically 2 to 3 m deep throughout the year, related to seasonal flows along riverbeds. In deeper confined, artesian aquifers in older deposits, the piezometric head does not fluctuate much during the year. Thickness varies from a few meters to over 100 m. At Geed Deeble (Hargeisa), the tapped aquifer depth is over 150 m. Boreholes are 10-10-50 m deep. In Somaliland the dynamic (sustainable) groundwater reserves in the major alluvial aquifers are estimated at an average flow of ~30 m^3/sec.	Generally low levels of mineralization, with TDS below 1,000 mg/l, and of moderate to good drinking water quality. Water from shallow dug wells and some springs often has a conductivity in the range 2,000 to 4,000 microS/cm, but other samples of shallow groundwater in the western part of northern Somalia have conductivity values of less than 1,500 microS/cm.	High infiltration capacity.
Alluvial sediments filling major valleys and plateaus: Holocene/Recent	Low to high productivity, depending on local lithology, thickness, and lateral extent.		Direct rainfall recharge, and indirect recharge from infiltration of river water.

[23] Source: WASH Cluster Somalia. 2020. Technical Guidelines for the Construction, Rehabilitation of Drilled Water Wells.

[24] Key references: Faillace and Faillace (1986), FAO/SWALIM (2012), Water Supply Survey Team of the PRC (1983), Petrucci (2008), and German Agro-Action (2005).

Volcanic Aquifers[25]	General Description	Water Quality Issues	Recharge
Pleistocene basaltic lava flows	These are a potential aquifer in some areas. They contain groundwater only where fractured and/or weathered, or in lenses of pyroclastic material between lava flows. They typically have low to moderate permeability, but are locally highly fractured, increasing permeability. However, they occur primarily as elevated plateaus, and are often unsaturated. In some areas, such as Agabar and Las Dhure, they are found in the lowlands and may be saturated, and in this case are likely to be unconfined. Boreholes drilled in these areas have intersected water-bearing zones composed of sand/pyroclastic lenses and weathered basalt.		In some areas, vertical fractures resulting from cooling of the basalts may occur, and are likely to form primary recharge route.
Sedimentary Aquifers[26] ***Intergranular***	**General Description**	**Water Quality Issues**	**Recharge**
Cretaceous Yessoma Formation (Nubian sandstone)	The Yessoma Formation is of Nubian sandstone type and can form a high productivity aquifer. The coarsest grained part of the formation occurs between 140 m and 180 m depth. Calculated aquifer transmissivity is around 2 x 10-3 m^2/sec (220 m^2/day), with an average specific capacity of 7.5 m^3/hour/m. Most boreholes penetrating the formation can sustain a yield of more than 30 m^3/hour.	Groundwater of good quality is generally supplied by dug wells in the weathered part of the aquifer.	Recharge is estimated to be approximately in the range of 3 to 5% of annual rainfall (van der Plac 2001).
Jurassic sandstones	Jurassic sedimentary rocks in the South of Somalia are likely to be dominated by sandstone. Their groundwater potential is not well known. Groundwater storage and flow may be by both intergranular and fracture flow. Low to moderate yields may be possible.		

[25] Key references: Faillace and Faillace (1986), FAO/SWALIM (2012), and German Agro-Action (2005).
[26] Key references: Faillace and Faillace (1986), FAO/SWALIM (2012), Petrucci (2008), German Agro-Action (2005), GKW (1977), and van der Plac (2001).

Sedimentary Aquifers[27] *Fracture flow*	General Description	Water Quality Issues	Recharge
Tertiary: Iskushuban Formation (Miocene); Mudug Formation (Oligocene/Miocene); Daban Formation (Oligocene)	These form moderate productivity aquifers. Fractures act as pathways for rapid groundwater flow, but permeability and groundwater storage are small. A borehole drilled into the Miocene Iskushuban Formation in Timirishe in the Bari area yielded 5 l/s for a drawdown of some 50 m, with a calculated transmissivity of 4.5 x 10-4 m²/sec. Boreholes in the Oligocene/Miocene Mudug Formation are drilled to 180 to 220 m deep, and provide yields of 3 to 5 l/s for drawdowns in the range 3 to 24 m. Transmissivity values of 3.1 x 10-3 to 2.9 x 10-4 m²/sec were calculated.		Recharge is estimated to be approximately in the range of 3 to 5% of annual rainfall (van der Plac 2001).
Cretaceous undifferentiated:	Sandstones, conglomerates, limestones and evaporitic rocks Little is known about the aquifer properties of these rocks.		
Sedimentary Aquifers[28] ***Karstic***	**General Description**	**Water Quality Issues**	**Recharge**
Eocene Karkar, Taalex, and Auradu limestones	The Eocene limestone (Karkar and Auradu) and limestone/evaporite (Taalex) formations are often karstic, and are among the most significant aquifers in the north of Somalia, in the Somaliland and Puntland regions. The Karkar limestone represents the most promising fresh groundwater resource for further development in the Sool and Hawd plateaus in the north of Somalia. It typically forms a moderately productive aquifer. The Auradu limestones can form a high productivity aquifer, with good quality groundwater, although more investigation is needed. If groundwater is present, the overlying Taalex aquifer should be sealed off to prevent inflow of lower quality water. Many boreholes abstract from the aquifer, particularly in the Puntland region, with an average transmissivity of 10-3 m²/sec (860 m²/day). Other boreholes over 200 m deep are drilled in limestones in the Garowe area. Where these limestones are overlain by the Karkar formation, they are often semiconfined, with low subartesian	Groundwater in the Karkar karst aquifer is slightly mineralized, with an EC (conductivity) between 1,500 and 1,800 micromhos/cm. The Taalex aquifer yields moderately to highly mineralized groundwater, derived from geogenic evaporitic minerals. Ca or $CaSO_4$ type groundwater is dominant, with TDS usually >3800 mg/l. EC levels are generally very high, from 890-7270 microS/cm. Sulphate concentrations are in the range 125-3100 mg/l (average	

[27] Key references: Faillace and Faillace (1986), FAO/SWALIM (2012), Petrucci (2008), German Agro-Action (2005), GKW (1977), and van der Plac (2001).

[28] Key references for these aquifers are: Faillace and Faillace (1986), FAO/SWALIM (2012), Petrucci (2008), German Agro-Action (2005), GKW (1977), and van der Plac (2001).

	pressure. The depth to water table in unconfined parts of these aquifers is usually between 5 and 15 m throughout the year. Fresh groundwater reserves in the Auradu aquifer in the Somaliland and Puntland regions are estimated as equivalent to an average flow of 63.4 m³/sec. The estimated fresh groundwater reserve in the Karkar aquifer is lower at approximately 10 m³/sec.	1300 mg/l. Many boreholes are abandoned because of high salinity. Groundwater from the Auradu limestones is typically of sulfate-bicarbonate type with moderate to high mineralization, and an EC <1000 micromhos/cm. Sulphate is the dominant element in almost all samples ranging from 3 to 220 mg/l.	
Jurassic limestones	The Jurassic limestones in the north have the greatest potential for groundwater development in the country. There is usually pure limestone in the upper part of the formation, with marly levels and calcareous sandstones in the lower part. The upper parts in particular are usually characterized by a high degree of fracturing and probably karstic cavities, and groundwater circulation probably develops mainly in this zone. The limestones can be highly permeable, with a transmissivity value from one test borehole at Borama of 270 m²/day. The depth to water table in unconfined parts is 5-15 m throughout the year	Groundwater in the Jurassic aquifer is generally of bicarbonate type with low levels of mineralization, with SEC (conductivity) commonly in the range 600 microS/cm to 1,200 microS/cm.	Estimates of recharge are 35% of annual rainfall for the Karkar aquifer to 50% of rainfall for the Jurassic limestone aquifer.
Basement	**General Description**	**Water Quality Issues**	**Recharge**
	Forms a low productivity aquifer or an aquitard, depending on the development of permeability by weathering/fracturing.	Low to moderate mineralization, with conductivity often between 300 and 1400 mS/cm, up to a maximum of 3,570 mS/cm in some shallow wells. More than 70% of analyzed waters have good characteristics according to WHO standards.	

Appendix 3. Summary of SWALIM Water Points Database (With Some Observations and Comments)

Áttribute	Unit	Waterpoints				
		Dugwells	Boreholes	Berkads	Dams	Springs
Permanent	%	**82**	**86**	**51**	**40**	**92**
data nr		1818	1513	239	509	302
Functioning	%	**58**	**77**	**65**	**81**	
data nr		2727	1885	251	531	
Storage capacity dam/berkad	m3					
data nr				180	151	
min				48	200	
quartile_low				199	4925	
median				**273**	**11400**	
quartile_high				360	30000	
max				3000	918400	
Depth borehole/dugwell	m - surface					
data nr		2506	1724			
min		0.45	7			
quartile_low		5	100			
median		**8**	**150**			
quartile_high		13	200			
max		198	480			
Static water level	m - surface					
data nr		2291	1381			
min		0.1	1			
quartile_low		2.9	30			
median		**5**	**60**			
quartile_high		9	100			
max		120	360			
Capacity dugwell/borehole	l/s					
data nr		442	1165			
min		0.5	1			
quartile_low		2	8			
median		**4**	**13**			
quartile_high		10	20			
max		78	90			
Depth of pump	m - surface					
data nr			953			
min			2			
quartile_low			66			
median			**110**			
quartile_high			159			
max			420			

Áttribute	Unit	Waterpoints				
		Dugwells	Boreholes	Berkads	Dams	Springs
% > electr. cond. in microS/cm	%					
data nr		1915	1155	139	289	333
% > 1500 (WHO)		68.25065	70	9	6	63
% > 3500 (WDA,Somalia)		26.16188	30	4	1	18
% > 11000 (FAO)		1.044386	2	0	1	0
Operating hours	nr hours					
data nr		218	947			
min		0.2	1			
quartile_low		6	6			
median		**10**	**10**			
quartile_high		12	18			
max		24	24			
Nr users/wpoint	nr users					
data nr		508	323	148	57	
min		1	1	5	25	
quartile_low		150	170	30	50	
median		**500**	**385**	**51**	**150**	
quartile_high		1215	1116	200	300	
max		**100000**	**172800**	**5700**	**1800**	
Nr animals/wpoint	nr animals					
data nr		577	585	137	91	
min		20	10	100	3	
quartile_low		610	1400	465	520	
median		**1500**	**3200**	**965**	**1300**	
quartile_high		3500	8800	1600	3415	
max		52800	8001500	33000	35000	
Household connections	nr conn.					
data nr		105	280	44	10	
min		1	1	60	1	
quartile_low		80	224	200	275	
median		**250**	**1088**	**540**	**850**	
quartile_high		700	3000	1400	1875	
max		10000	50000	5000	3000	
Water delivery/person (median)	l/c/d	**108**	**385**			
Water delivery/animal (median)	l/c/d	**56.0708**	**107**			

Observations and Comments

Berkads and Dams (Hafirs, Ballis)

- The attribute ‘Permanent’ indicates that 50 percent or more of the berkads and dams provide water till the end of the dry season.

- The storage capacity (median) of the berkads is 272 m^3 and much lower than the capacity of the dams (5,700 m^3). The maximum dam capacities are even much higher (up to 400,000 m^3). The effective storage capacity of the dams is taken as 50 percent to account for evaporation and silting.

- The salinity of berkads and dams is good. Only 9 percent and 6 percent, respectively, are higher than the WHO limit (1,500 microS/cm) and 4 percent/1 percent higher than the WPA (Water Development Agency of Somalia) limit (3,500 microS/cm).

- The bacteriological quality is not included in the database but is reported to be bad according to various reports. The water from berkads and dams is, hence, unfit for human consumption unless it is chlorinated.

- In some cases, the dams are combined with a bank infiltration system (MAR) such as that described in Kamkwalala and Wijnen (2017).

- The number of people and animals using these waterpoints is low: 51/965, respectively, for berkads and 150/1,300 for the dams. The latter is questionable because the dams are predominantly constructed for livestock water supply.

Hand-Dug Wells

- Almost half of the dug wells are not functioning well. These do probably include the wells without lining.

- The ‘Permanent’ score of the dug wells (82 percent) is higher than berkads and dams (51 percent/40 percent.). This is questionable because there are many reports that dug wells dry up at the end of the dry season. The wells are generally shallow (median: 8 m) while groundwater level is in the range of 5 m below the ground’s surface which means that the dry season storage is 3 meters.

- The capacity of dug wells is 4 l/sec which seems too high unless there is a motorized pump. A human being can pump 0.3 l/s (1 m^3/hr) with a handpump and even less with a leather bag or bucket. This has to be checked with SWALIM.

- The water quality of dug wells is bad, with 68 percent and 26 percent above the respective WHO and WPA limits.

- Operating hours are 10, which seems to be on the high side if water is collected with a handpump.

- The number of users per dug well is 500 people and 1,500 cattle.

Manually-Drilled Wells

- Manually-drilled wells are still new in Somalia and not included in the SWALIM database.

- These wells are cheaper than dug wells, have a much shorter construction time, and provide a safer water source if properly drilled and finished. A prerequisite is that the appropriate drilling technology is introduced through training and private sector development. This is not yet the case in Somalia.

Machine-Drilled Wells/Boreholes

- The average number of house connections is 250. This applies for urban areas only and would represent a consumption of 108 lcd (based on average capacity and operating hours).

- The average depth of boreholes is 150 m, with the groundwater level at 60 m below the ground's surface. The average depth of the submersible pump is 110 m, which means an average drawdown of 40–50 m.

- Salinity is a serious water quality issue with 70 percent of the wells above the WHO limit and 30 percent above the WPA limit. The bacteriological quality is good.

- 'Functioning' and 'Permanent' scores are 86 and 77 percent, respectively. This figure may be distorted because more functioning wells are generally visited during surveys.

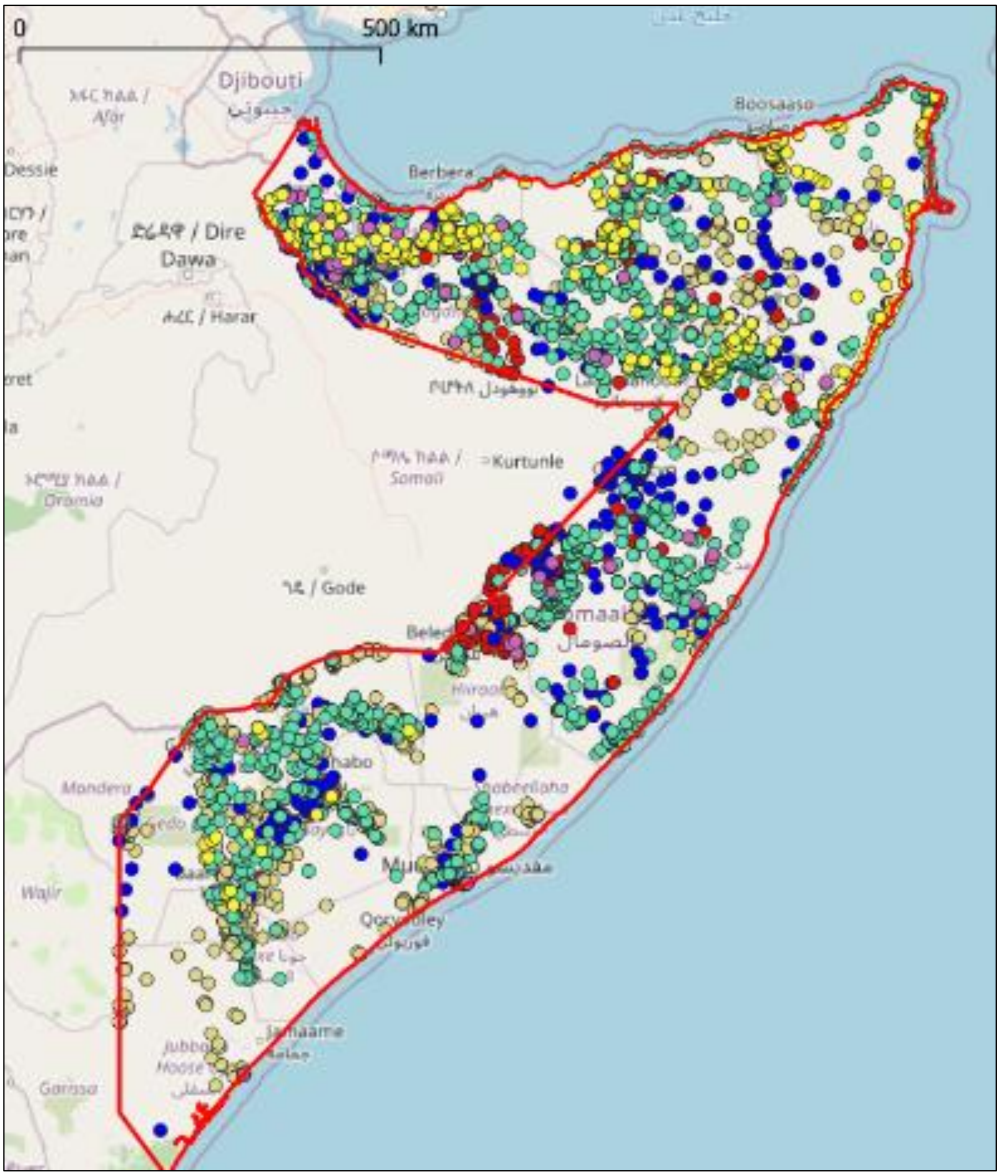
- Average capacity of the pumps is 13 l/s with a power of 12 kVA. With a pumping head of 100 m, the actual yield will be 9 l/s.

- Average number of users is 385 people and 3,200 animals. The number of people is low, and the large number of animals indicates that the expensive boreholes are widely used for livestock water supply. This needs to be verified along with the water use figures for people and animals (385 and 107 lcd, respectively).

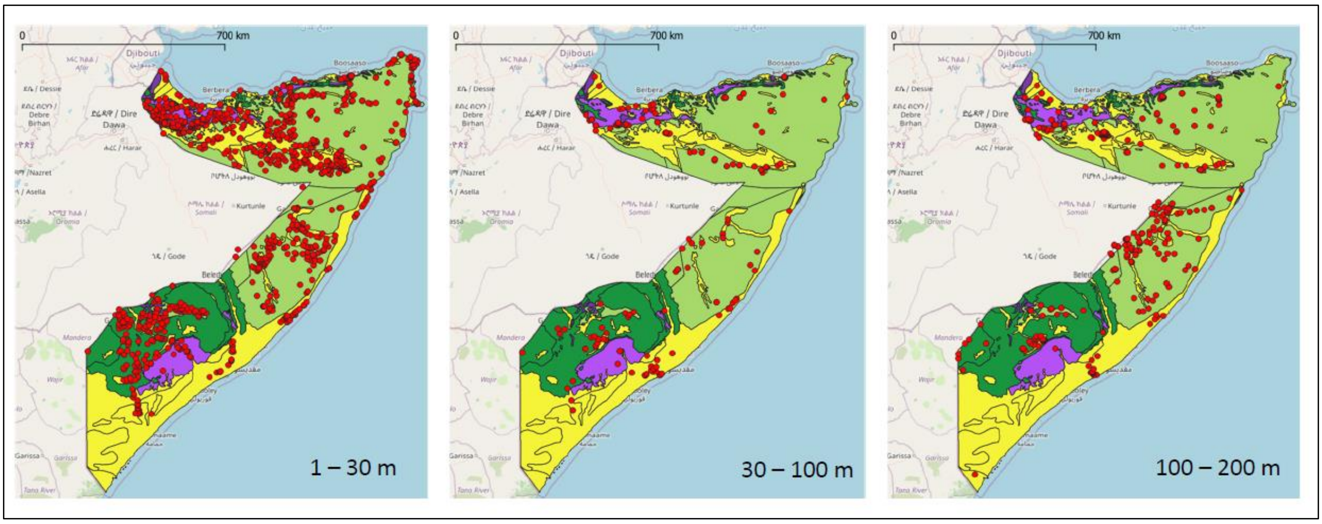
Sand Dams

- The SWALIM database does not contain sand dams and subsurface dams.

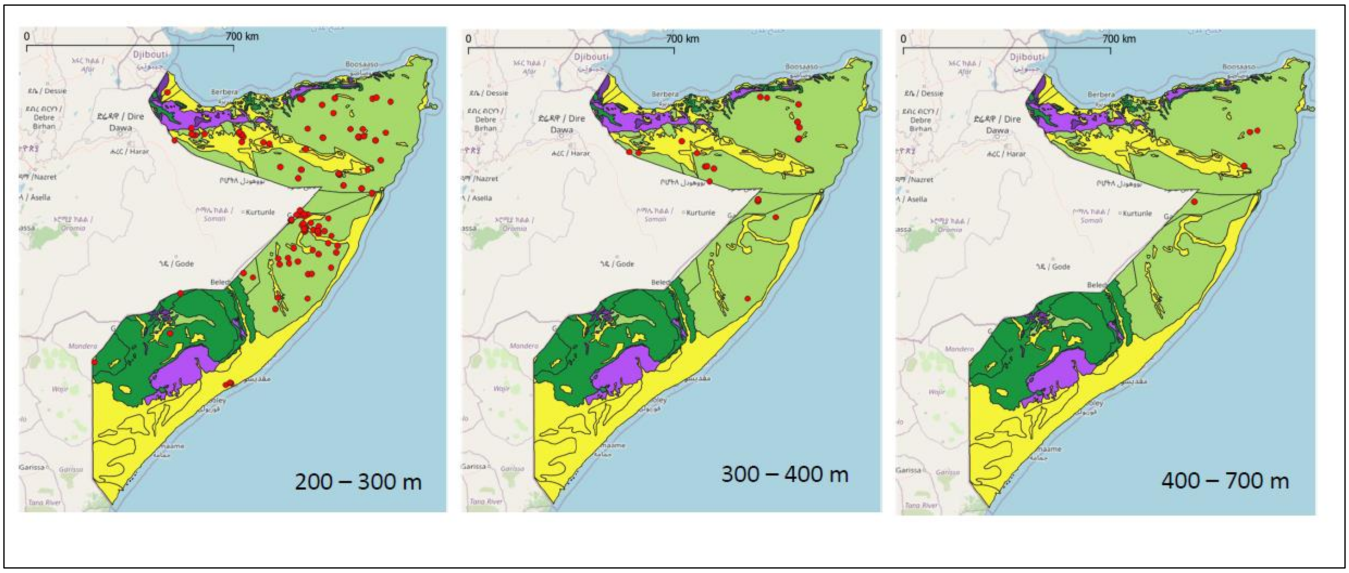
Location of Wells



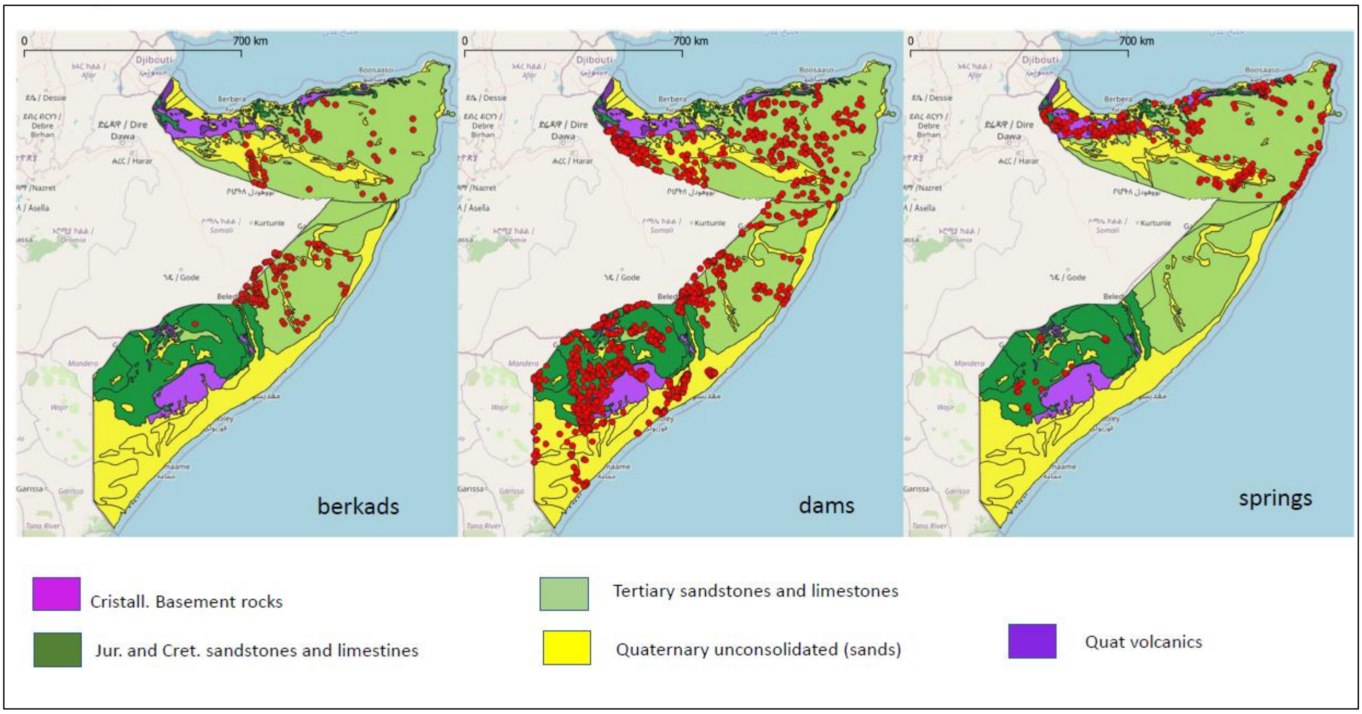
Depth of Dug Wells and Boreholes



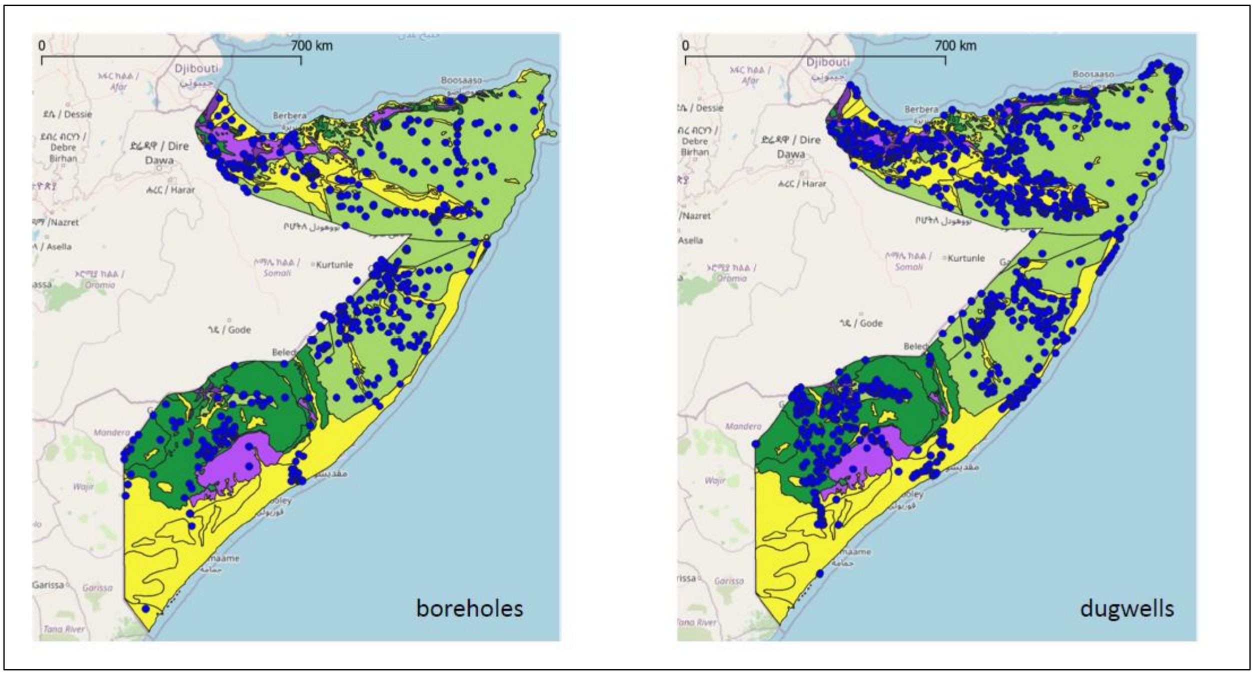
Depth of Dug Wells and Boreholes



Superficial Water Sources



Boreholes and Dug Wells



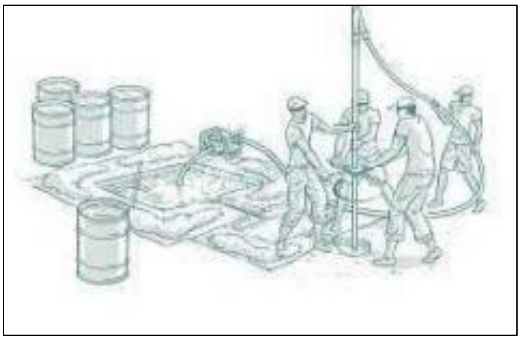
Appendix 4. Manually-Drilled Wells

Drilling Techniques

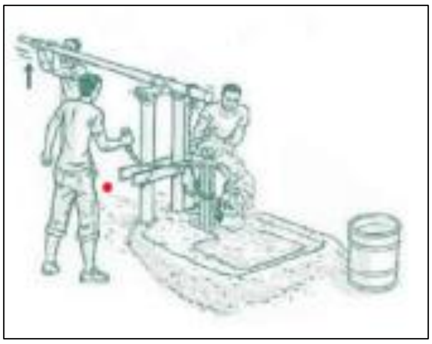
Essentially, a drilling machine consists of a mast from which the drilling string components (tools plus drill pipes or cables) are suspended and, in most cases, driven. Modern systems are powered, rotary-driven, but it is probably worth a short digression to describe some methods of manual drilling for water. Simple, low-cost methods include:

Hand-auger drilling, or auger drills, which are rotated by hand, cut into the soil with blades and pass the cut material up a continuous screw or into a 'bucket' (bucket auger). Excavated material must be removed and the augering continued until the required depth has been reached. Auger drilling by hand is slow and limited to a depth of about 10 meters (maximum 20 meters) in unconsolidated deposits (not coarser than sand), but it is a cheap and simple process.

Jetting, a method whereby water is pumped down a string of rods—from which it emerges as a jet that cuts into the formation. Drilling may be aided by rotating the jet or by moving it up and down in the hole. Cuttings are washed out of the borehole by the circulating water. Again, jetting is useful only in unconsolidated formations and only down to relatively shallow depths and would have to be halted if a boulder is encountered.



Sludging, a method which may be described as reverse jetting, that involves a pipe (bamboo has been successfully employed) being lowered into the hole and moved up and down, perhaps by a lever arm. A one-way valve (such as someone's hand at the top of the pipe) provides pumping action as water is fed into the hole and returns (with debris) up the drill pipe. There may be simple metal teeth at the cutting end of the pipe, and a small reservoir is required at the top of the hole for recirculation. The limitations of sludging are similar to those of the previous two methods.



Source: UNCEF WASH Cluster (2020).

Table A4.1: Additional Information for Manual Drilled Wells

Drilling Technique*	Equipment cost (€)	Average drilling speed for 15m in different geological formations (days)**				
		Weak cohesive sand, silt gravel	Soft clay <u>Stiff clay</u> formations	Soft consolidated formations	Soft weathered rock	Un-weathered Crystalline basement rock, e.g. granite
Hand auger	200 - 600	1	1-2 <u>2-4</u>	Not suitable	Not suitable	Not suitable
Percussion	300 -1200	2-3	2-3 <u>3-4</u>	> 3	> 8	Not suitable
Rotary Jetting	800 - 1400	1	1-2 <u>Less effective</u>	Not suitable	Not suitable	Not suitable
Rota Sludging	600 - 1000	1-2	1-2 <u>2-3</u>	> 3	Less effective	Not suitable

Drilling Technique*	Advantages	Disadvantages	Average drilling depth (m)
Hand auger	Easy to use above groundwater table. Cheap equipment	Use of the temporary casing if clay layers are penetrated is very limited If a collapsing sand layer is encountered below a clay layer (through which the temporary casing could not penetrate), the borehole does not stay open	15 - 25
Percussion	Drills hard formations	Slow and high equipment costs	25
Rotary Jetting	Quick	Lots of working water is needed at once	35 - 45
Rota Sludging	Easy to use Applicable in most soft formations	Highly permeable layers (coarse gravel) causes loss of working water and cannot be drilled	35

* Note: Drilling teams are keen on using a variety of drilling techniques to penetrate different geological formations.

Table A4.2: Manual Drilling in Selected Countries

Country	Estimated Number	Location	Techniques	Date	Costs
Bangladesh	Millions	Most sedimentary basins	Sludging	1900s to date	$1 per meter
Bolivia	30,000		EMAS, Baptist	1983 to date	$300
Chad	Thousands	Central Chad		1960s to date	
Democratic Republic of Congo	>1000	West, south and some in the east	Jetting, village drill	2007 to date	
Kenya	10,000	Various regions	Augering, sludging, percussion, Baptist	1979 to date	$4000 (augered to 40 m)
India	Millions	Various regions	Sludging, jetting, augering	Indigenous technology	
Madagascar	12,000	East and west coast (driven wells), throughout the country (jetting, rota-sludge)	Driven wells, jetting, rota-sludge	1960s to date (driven); early 2000s to date (jetting, rota-sludge)	$35 to $50 (driven wells); $1000 to $3000 (<30 m depth)
Nepal	>100,000	Terai (lowland)	Sludging	1950s to date	$20–$450
Niger	16,000	Maradi and Zinder regions	Augering, jetting, rota-sludge, percussion	1900s (irrigation; 2005 to date	
Nigeria	30,000	At least 27 of the 36 states	Jetting, augering, percussion, Baptist	Early 1980s to date	$2500 or less
Senegal	>4000	Various regions	Augering, jetting, percussion, rota-jetting	1991 to date	$1600 to $2000
Uganda	<1000	Lake Victoria, west, north and south	Rotary-sludge, rotary jetting, Baptist	Late 1980s to early 1990s; pilot projects from 1998 to 2013.	
Vietnam	>100,000		Sludging	1980s	

Source: Pedro Martínez-Santos, a.o. 2020. "Manual Borehole Drilling as a Cost-Effective Solution for Drinking Water Access in Low-Income Contexts." *Water* 2020, 12(7): 981, https://doi.org/10.3390/w12071981.

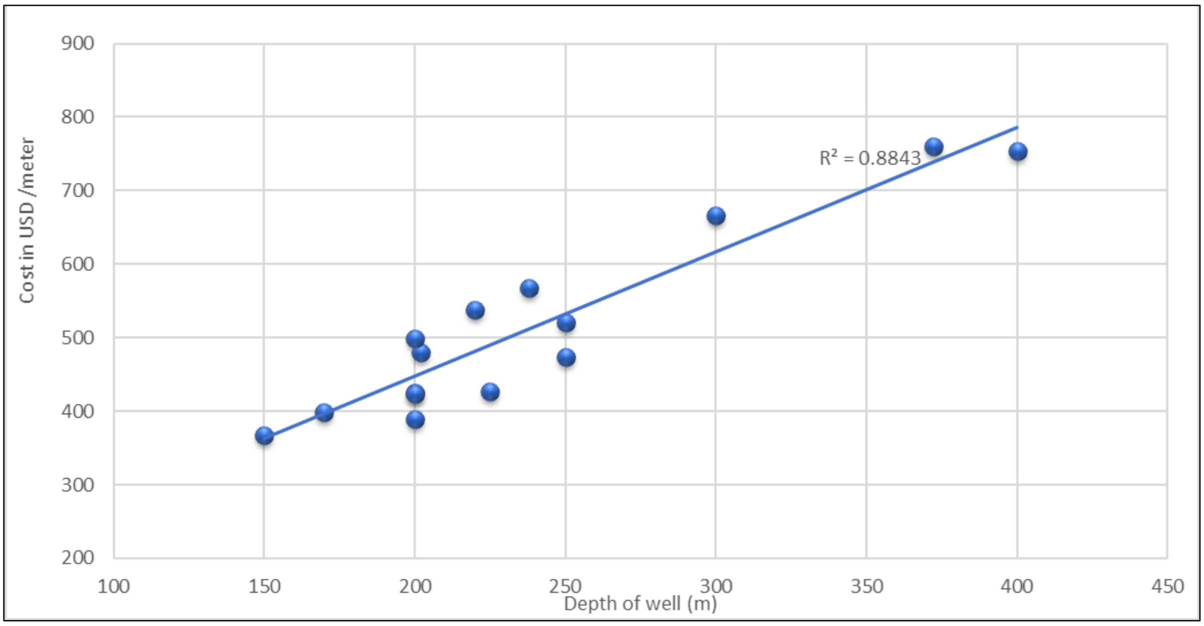
Appendix 5. Cost of Well Drilling

The costs are for the mobilization, drilling, completion, and testing of the well as quoted by drilling companies or reported by clients who finance well drilling. The costs are calculated for the 2020 price level using a 2.5 percent inflation rate.

Table A5.1: Costs of Motorized Well Drilling of Boreholes in Somalia

Borehole	Cost				Source	
Depth	**Cost**	**Year**	**Cost 2020**	**Cost/m**	**Country**	**Source**
(m)	**(US$)**		Footnote (US$)	**(US$)**		
250	110,000	2017	118,458	474	Somalia	Som Floods
300	200,000	2020	200,000	667	Somalia	UNICEF*)
200	76,000	2019	77,900	390	Jubbaland	UNICEF guidelines
220	110,000	2017	118,458	538	Somalia	WASH cluster
200	85,000	2020	85,000	425	Hargeisa	EarthWater: 4 wells
170	60,000	2015	67,884	399	Hargeisa	EW4wells
225	85,000	2015	96,170	427	North Somalia	EarthWater
200	75,000	2015	84,856	424	Somalia	EarthWater
238	103,000	2009	135,145	568	Somalia	EarthWater
202	72,000	2008	96,832	479	Puntland	EarthWater
200	70,500	2006	99,615	498	Puntland	EarthWater
372	200,000	2006	282,595	760	Puntland	EarthWater
250	130,000	2020	130,000	520	Jubba/SWS	UNICEF
150	40,000	2007	55,140	368	Somalia	SWALIM WR
400	280,000	2017	301,529	754	Somalia	WB Wijnen
Note: Inflation (%):	**2.5**		1.025		*1)	**incl. 10% VAT**

Figure A5.1: Cost of Drilled Water Wells in Somalia



Note:

(a) Price level: 2020.

(b) Excluding multiplier for drilling success rate and postconstruction failures.

Appendix 6. Cost of Water Delivery Systems' Infrastructure

Component	Unit	Quantity	Cost (US$)		Source
Elevated tank	m^3	20	13,000		UNICEF
		25	15,000		UNICEF
		50	30,000		UNICEF
		60	35,000		UNICEF
		75	35,000		UNICEF
Ground tank		20	5,340		UNICEF
		25	6,200		UNICEF
		25	13000		Biyoole
Elevated steel tank	m^3	100	26,400		UNICEF
		150	36,500		UNICEF
Single generator room			7,000		UNICEF
Twin gen room			9,500		UNICEF
Caretaker room			2,900		UNICEF
Water kiosk			4,000		UNICEF
Water kiosk			1,000		Biyoole
Animal trough			5000		Biyoole
Solar panel stand			2,800		UNICEF
Handwashing tank	m^3	4.25	1,700		UNICEF
RO 20 m^3/hr	m^3/hr	20			Wijnen, 2017
Device			60,000		
Civil works			20,000		
Installation			20,000		
Pipeline rural (dia 90 mm)	m	1000	16,000	XharkaDheere	Biyoole, 2020
Pipeline crossing wadi	m	3780	40,000	Barookhle	
Solar pump (incl panel)	US$/person	10-90	10-90		

Protected well, solar pump unit, elevated reservoir	US$		50,000	Construction	Lopez-Rey 2020
	$/person		1		
	US$		100,000	O&M 30 yrs	
	$/person		3		
Community well with manual lifting	US$		16,500	Construction	
	$/person		.4		
	US$		3,600	O&M 30 yrs	
	$/person		.1		

Appendix 7. Comparative Costs for Solar Pumps and Motorized Pumps

Table A7.1: Comparative Installation Costs for Solar Powered and Motorized* Water Pumping Systems

Country	Average number of beneficiaries	Solar Powered Systems		Motorised Water Supply Systems*		Overall Price Difference
		Average cost per system (USD)	Average cost per person (USD)	Average cost per system (USD)	Average cost per person (USD)	
Myanmar	686	$27,261	$40	$16,753	$24	Solar is 42% more expensive
Nigeria	2,500	$20,583	$8	$18,298	$7	Solar is 14% more expensive
Uganda	2,500	$71,709	$29	$64,634	$26	Solar is 12% more expensive
Mauritania	300	$21,000	$70	$27,000	$90	Solar is 29% cheaper

* Mechanized includes those systems using a generator-based power source.

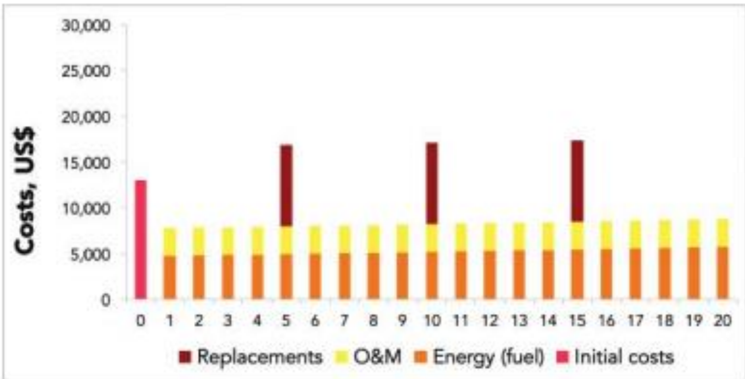
Source: UNICEF.2017. Scaling up solar powered water supply systems: Review of experiences.

Table A7.2: Additional Information

Type of system	Unit	Value	Component
Protected well, solar pump unit, elevated reservoir	**(US$)**	**50,000**	**Construction**
	$/person	1	
	US$	100,000	O&M 30yrs
	$/person	3	
Community well with manual lifting	US$	16,500	Construction
	$/person	.4	
	US$	3,600	O&M 30yrs

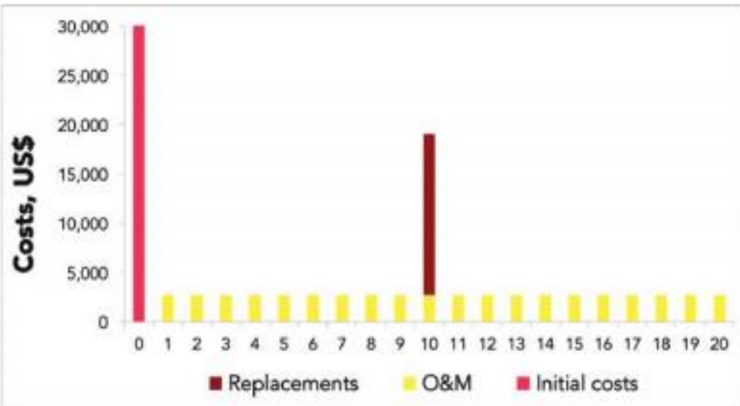
Source: Comparing solar and manual pumping (Paz Lopez-Rey S. 2019).

Figure A7.1: Yearly Cost of a Diesel-Based Pumping System



The initial system costs are around US$13,000. Thereafter, the system incurs substantial annual costs for diesel fuel (the average yearly expenditure in fuel is over US$5,000, or 40 percent of initial costs), as well as periodic replacement costs.

Figure A7.2: Yearly Cost of a Hypothetical Solar Pumping System



By comparison, Figure A7.2 represents the yearly costs of the average solar pumping system. Although initial costs are higher (around US$30,000) and there would be significant expenditure in year 10 to replace the pump, these costs are more than compensated for by the vast reduction in energy costs.

Source: Solar pumping: The basics (World Bank 2018).

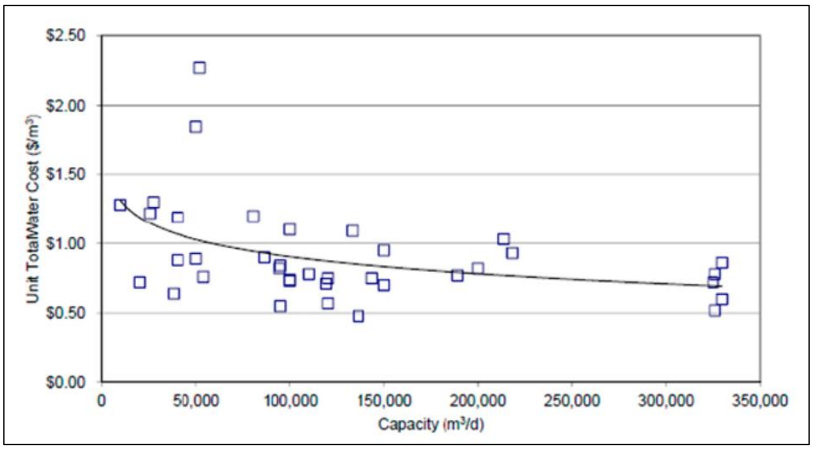
Appendix 8. Cost of Desalination of Seawater and Brackish Groundwater

Cost of Seawater Desalination by SWRO (Reverse Osmosis)

According to the 2017 IDA Desalination Yearbook, the water sector produced 9,758 billion m^3/day of desalinated water throughout the planet, produced by more than 20,000 facilities of different sizes, varying from small production focused on residential or private industrial areas (between 50 and 600 m^3/day) to large plants that supply municipal utilities and industries.

Increasingly, desalination plants are contracted under the BOOT (Build, Own, Operate, and Transfer) model because it provides a balance in the distribution of the risks, which makes very competitive rates possible. Currently, the average price range of desalinated water is between US$0.5–1.5/$m^3$, depending on the electricity cost (ranging from cheap fossil fuel in the Middle East to renewable energy in Australia).

Figure A8.1: Comparing Costs and Capacities



Desalination technologies used were generally Multiple Effect Distillation (MED) and Multistage Flash Distillation (MSF). However, in the last 10 years these have been largely replaced by membrane desalination technology (Salt Water Reverse Osmosis), which has lower investment and operating costs (see Table A8.1).

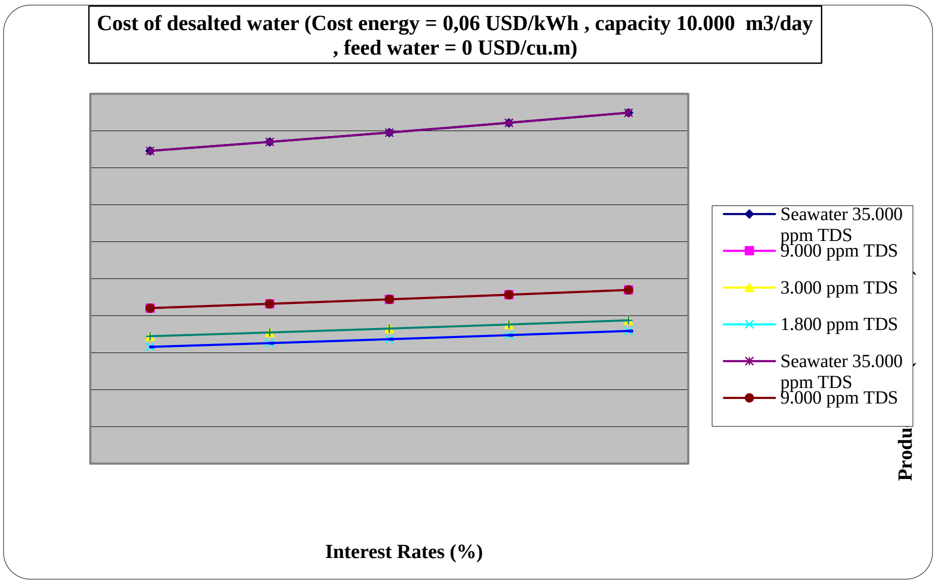
Table A8.1: Desalination Investments and Operating Costs

DESALINATION REFERENCES							
Name	Geography	Year	Capacity m3/d	Technology	CAPEX	Tariff	Contract
Skikda	Algeria	2009	100.000	RO	$110.8 million	$0.7398 /m3	DBO
Beni Saf	Algeria	2010	200.000	RO	$153.4 million	$0.6994 /m3	DBO
Ténès	Algeria	2015	200.000	RO	$231 million	$0.59 /m3	DBO
Perth	Australia	2006	143.000	RO	AUS$387 million	$1.17/kl	DBO
Qingdao	China	2013	100.000	RO	€135 million	$0.71 /m3	EPC + O&M
Larnaca	Cyprus	2001	52.000	RO	€47 million	$ 0.74 /m3	EPC
Limassol	Cyprus	2012	40.000	RO	€55 million	€ 0.8725 /m3	BOT
Chennai	India	2010	100.000	RO	$91 million	$1.03 /m³	BOT
Ashkelon	Israel	2005	396.000	RO	$212 million	$0.52/m3	BOT
Shuqaiq 3	Saudi Arabia	2021	450.000	RO	$ 600 million	$0.52 m3	BOT
Rabigh	Saudi Arabia	2022	600.000	RO	$650 million	$0.55 m3	DBO
SingSpring	Singapore	2005	136.380	RO	$117 million	S$0.49/m3	BOO
Tuaspring	Singapore	2013	318.500	RO	$635 million	$0.36 /m3	BOOT
Tuas III	Singapore	2018	136.000	RO	S$217 million	$0.54 /m3	DBOO
Taweelah	UAE	2022	909.000	RO	$550 million to $1.2 billion	$0.49 m3	BOT

Cost of Brackish Groundwater Desalination by Reverse Osmosis

A study by Philipp Tod in 2000[29] compared desalination cost of seawater and brackish groundwater for a range of salinities and cost variables. One of the conclusions from that study is that the cost of brackish water desalination is about 50 percent of the coast of seawater desalination (see Figure A8.1). Although the study is 20 years old, one may expect that this ratio is still in the same order of magnitude.

Figure A8.2: Costs of Brackish vs. Seawater Desalination



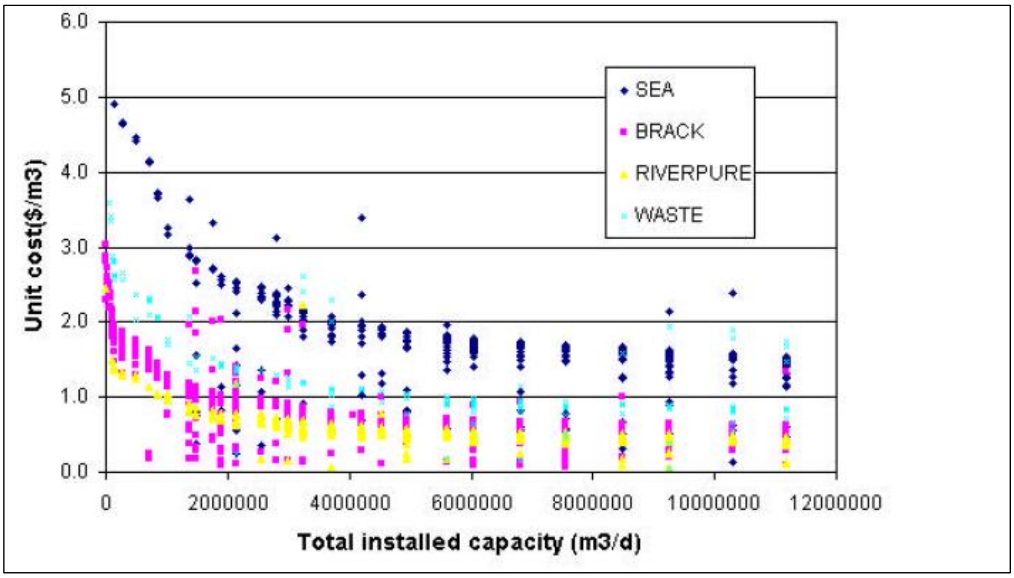
This is confirmed by a more recent study[30] which shows the same ratio for a range of capacities.

Given the present cost range for seawater desalination of US$0.5–1.5/m^3, the cost of brackish water desalination is expected to be approximately US$1/m^3 for large capacities, and US$1.5/m^3 for small capacities.

[29] Tod (2000).

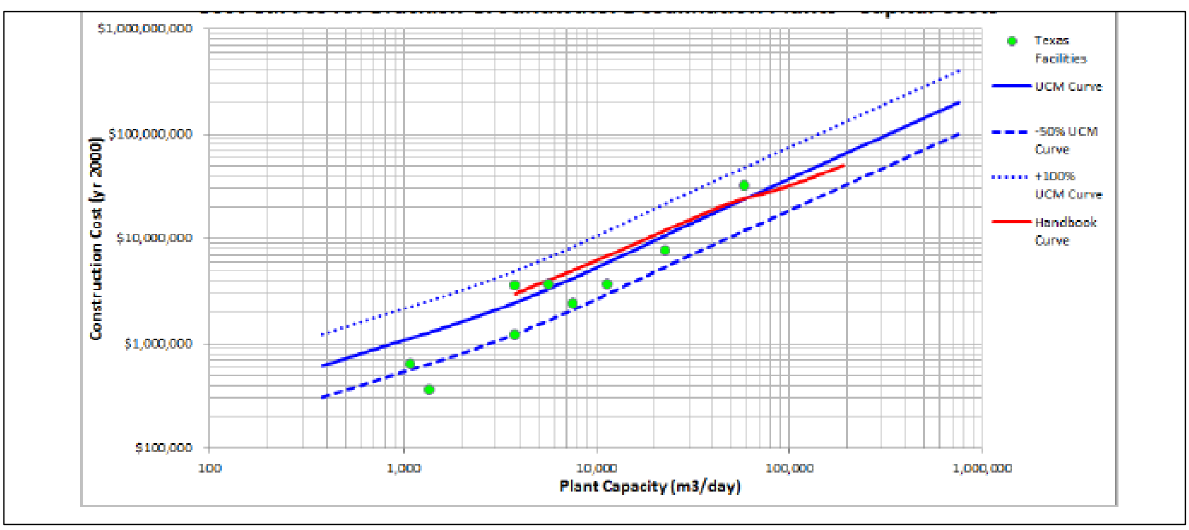
[30] Zhou a.o. (2004).

Figure A8.3: Unit Costs vs. Total Installed Capacity by the RO Process



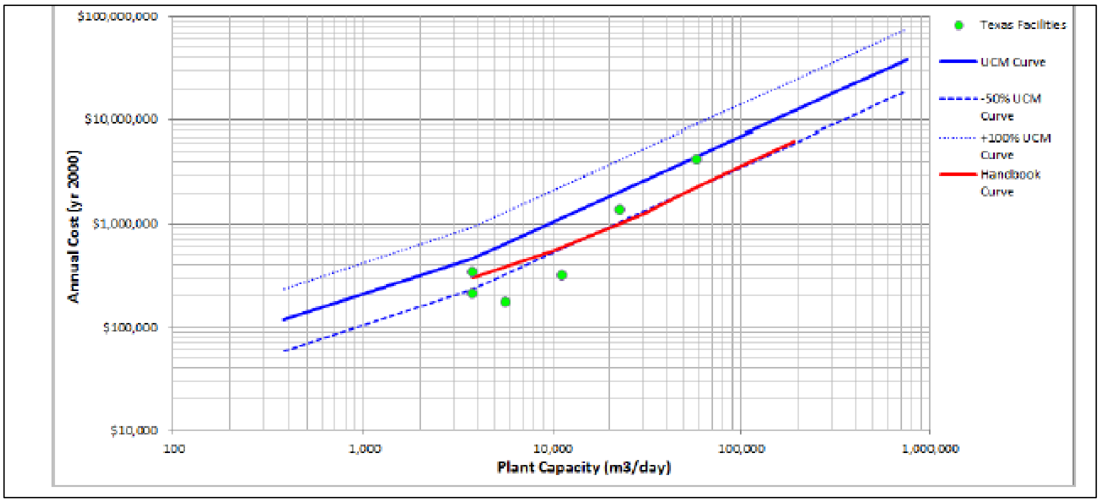
The Texas Water Development Board[31] implemented a study to develop a planning-level cost estimate (including capital and operation and maintenance costs) for brackish groundwater desalination facilities based on data from operational desalination plants. The summary tables below show that a plant with a capacity of 1,000 m^3/day will cost approximately US$1,000,000 (CAPEX). The annual costs (OPEX) would be approximately 10–20 percent of the CAPEX.

Figure A8.4: Cost Curves for Brackish Groundwater Desalination Plants—Capital Costs



[31] US Department of the Interior, Bureau of Reclamation. 2014. Estmating the Cost of Brackish Groundwater Desalination in Texas. Report submitted to theTexas Water Development Board.

Figure A8.5: Cost Curves for Brackish Groundwater Desalination Plants—O&M Costs



Annualizing these costs for a 15-year lifetime and 5 percent interest rate shows that a plant of 1,000 m^3/day capacity can serve 20,000 persons with 40 liters per day for a water production cost price of around US$1 per person (price level: 2020).

This estimate is in the same order of magnitude as the figures presented in Table A8.2 (Karagiannis and Soldatos 2008), which shows production costs of €0.63 per m^3 for a plant capacity of 1,000 m^3/day (€0.75 per m^3 for 2020).

Table A8.2: Cost of Water Produced According to the Type of Water Desalted

Type of feed water	Plant capacity (m^3/day)	Cost (€/m^3)
Brackish	<1,000	0.63–1.06
	5,000–60,000	0.21–0.43
Seawater	<1,000	1.78 – 9.00
	1,000–5,000	0.56–3.15
	12,000–60,000	0.35–1.30
	> 60,000	0.40–0.80

Table 7. Cost of water produced according to the type of energy supply system (Karagiannis & Soldatos, 2008).

Type of feed water	Type of energy used	Cost (€/m^3)
Brackish	Conventional	0.21–1.06
	Photovoltaic	4.50–10.32
	Geothermal	2.00
Seawater	Conventional	0.35–2.70
	Wind	1.00–5.00
	Photovoltaic	3.14–9.00
	Solar collectors	3.50–8.00

Cost of Brackish Groundwater Desalination by Photovoltaic-Powered Electrodialysis

Wright, Amos, and Winter (2014)[32] conclude that photovoltaic (PV)-powered electrodialysis (ED) is an energy- and cost-effective means of desalinating groundwater in rural areas for village-level water supply systems. Technical and ethnographic factors to develop an argument for PV-ED for rural locations include system capacity, biological and chemical contaminant removal; water aesthetics; recovery ratio; energy source; economics of water provision; maintenance; and the energy and cost considerations of available technologies. For brackish water, the ED system requires less specific energy than the RO (75 percent less at 1,000 mg/L and 30 percent less at 3,000 mg/L). At 2,000 mg/L, this energy scaling translates to a 50 percent lower PV power system cost for ED versus RO.

Figure A8.6: Electrodialysis Process

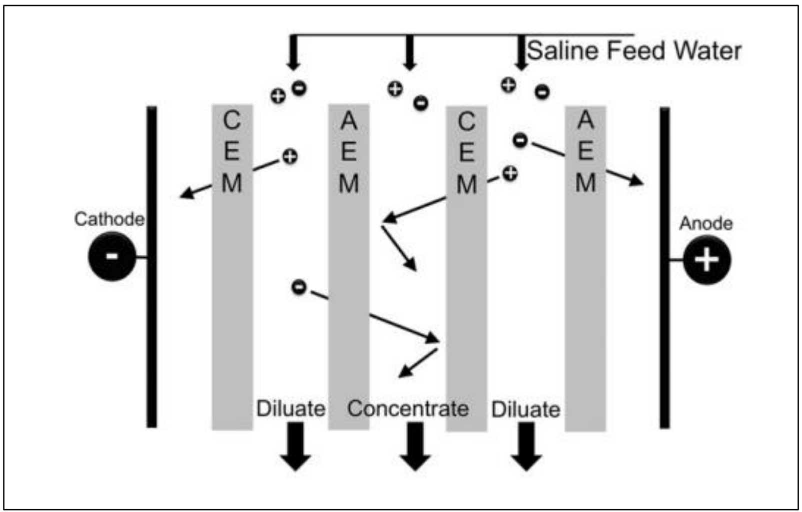
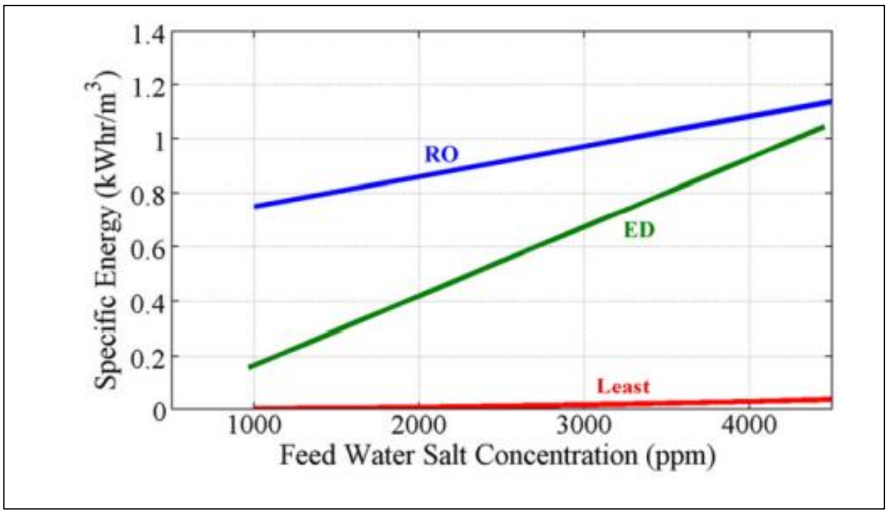


Figure A8.7: Dependence of Specific Energy on Feed Water Salinity



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[32] Wright, N.C., G. Amos, and V. Winter. November 3, 2014. "Justification for community-scale photovoltaic-powered electrodialysis desalination systems for inland rural villages in India." *Desalination* Volume 352: 82–91.

Note: The salinity range presented represents that commonly found in Indian groundwater. The energy required for RO and ED is compared to the thermodynamic least energy needed to separate the given salt concentration from water.

Kim a.o. (2017) described that ED has been employed for brackish water desalination. ED can remove salt ions and charged organic matter using an ion exchange membrane. The major advantage of ED is that it does not use pressure and thus can reduce energy consumption. Also, ED has low instances of membrane fouling and scaling, and it is easy to clean the membrane through chemical cleaning and a change of polarity. Even though there are notable advantages of ED, the cost of electrodes and membranes remains high as ED membranes have a short lifespan when employed in a desalination plant. Notably, an FO-ED system using a PV cell as power, under small-scale conditions, could produce high quality water at a water production cost of US$3.6–5.4/m^3.

Appendix 9. Data on Urban Water Supply Schemes

Table A9.1: Somalia Secondary Cities Investment Plans

City	Population and Growth		Production	Supply	HC[b]	Water Quality	Investment Needed	
	2020	Growth	m³/day	LCD	%		Million US$	US$/ consumer
Garowe	150,000	3.4 %	1800	12	<30	Poor	14	93
Bosaso	425,000	3.2 %	7100 [a]	8	<30	Good	10.8	25
Galkayo	300,000	3,2 %	4500 [a]	8.5	<30	Poor	10.9	36
Berbera	67,000	4.1%	1800	40	<50	Good	6.24	93
Borama	120,000	3.2%	4000	21.5	<60	Medium	16.64	139
Burco	400,000	2.8 %	4500	12	<50	Medium	9.56	24
Ceerigaabo	20,000	1.1%	1000	35-50	<50	Medium	1.15	58

Note:

[a] 50 percent private.

[b] House connection.

Source: Summary of World Bank-funded investment plans for secondary cities in Puntland and Somaliland (2020).

Current Water Supply Sources

- **Garowe:** Provided for by 10 municipal wells, seven of which are connected to the water supply system. Two wells are connected to a 650-m³ storage tank.

- **Bosaso:** GUMCO manages 14 boreholes excavated in two nearby aquifer zones—a 500-m³ elevated tank and a 1,000-m³ semi-buried storage tank which is currently nonoperational. Private companies manage and truck water from 18 additional wells located in the vicinity of the city.

- **Galkayo:** Five existing boreholes are connected to the water distribution system. Eleven more—privately owned—boreholes exist in the area, augmenting the total water supplied to the city to the minimum survival standards of 15 l/p/d.

- **Berbera:** At the present time, the Fara Dero well field is the most important source of water for Berbera town with about 1,800 m³/day of water capacity. Six boreholes (two of which have recently gone dry) are used to feed two reservoirs (one of 150 m³ located near the city and a main 4,000 m³ reservoir served by the adduction network near the city). An old 300-m³ steel tank served by gravity is currently not functioning and is in need of repair/replacement.

- **Borama:** The water supply is provided by three aquifers. These aquifers are overexploited (safe yield should be maintained below 2,000 m³/d). The water table is dropping steadily, and these aquifers will soon run out of water.

- **Burco:** Provided for by nine municipal wells, many of which are not correctly gravel-packed and have not yet been fully developed. About 80 percent of the town is supplied by the Burco Water Agency by means of piped water supply and trucking service; the daily production is about 3,700 m³.

- **Ceerigaabo:** The present water demand is between 700 to 1,000 m^3 and will reach ±1,370 m^3/day by the year 2040. Water is currently provided by four main wells able to yield up to 2,350 m^3/day.

Per Capita Cost of Water Improvement (WHO 2005)

The typical costs (CAPEX and OPEX) for water and sanitation improvement are shown in Table A9.2. Although the figures are from 2005, it shows that investment for urban water supply is strongly dependent on the level of supply. House connections are three times more expensive than standposts. If these figure are adjusted to the 2020 price level (using an inflation rate of 5 percent), the cost for household connections will be US$350/capita and US$100/per capita for supply through standposts.

The average cost of 30 percent house connections and 70 percent standposts will be around US$175/capita.

Table A9.2: Typical CAPEX and OPEX for Water and Sanitation Improvement (Excluding Program Costs)

	Per capita costs (US$ year 2005[a])					
	Initial investment cost			Annual recurrent cost		
Improvement type	Africa	Asia	LAC	Africa	Asia	LAC
Water improvement						
Household connection (treated)	164	148	232	13.4	9.6	14.6
Standpost	50	103	66	0.5	1.0	0.7
Borehole	37	27	89	0.2	0.2	0.6
Dug well	34	35	77	0.2	0.2	0.5
Rainwater	79	55	58	0.5	0.4	0.4
Average of non-household connection options	50	55	72	0.4	0.5	0.5
Sanitation improvement						
Household connection (partial treatment)	193	248	258	8.2	9.1	11.0
Septic tank	185	167	258	6.2	6.1	6.8
Pour-flush	147	81	97	6.1	5.5	5.7
VIP	92	81	84	3.8	3.8	3.8
Simple pit latrine	63	42	97	3.6	3.5	3.9
Average of non-household connection options	122	93	134	4.9	4.7	5.0

Note:
LAC: Latin America and the Caribbean.
[a] Data from 2000 adjusted to 2005 prices using an average annual gross domestic product deflator of 10 percent.

Source: Hutton and Betram (WHO 2005).

Appendix 10. Land Water Conservation Measures and Cost

Table A10.1: Profile of Some Conservation Farming Practices

Type	Technical description	Development domain	Advantages	Limitation	Costs
Planting Pits (a) Zai holes	-Holes measuring 10–30 cm wide,5–15cm deep and spaced 75–90 cm (inter-row) -Ideal for cereal crops (millet, sorghum, maize, etc.)	-Successful in areas receiving 200–750 mm annual rainfall -Does best in silt clay soil on gentle slopes Composed/manure fertilizer very necessary	-Traps moisture and increase soil water Reduces soil erosion	Labour intensive Animal draft not applicable	8 man days/acre 2 man days/ 0.25acre @ USD 2 + USD 4
(b) Tumbukiza	Holes measuring 2x2x2 ft to 3x3x2. Holes spacing based on specific crop. Ideal for Napier maize (multiple seeding), pawpaw, mangoes and other fruit trees	Ideal for all slopes/rainfall regimes in dry areas. Topsoil must be mixed with manure, fertilizers	Act as micro-catchments Can harvest water from external catchments	Labor intensive Animal draft not applicable	10 holes/ person/day 75 holes/0.25acre 8md x USD 2 = USD 16
Semi-circular bands	Earth bands in the shape of a semi-circle (eye brows) Holes (planting) dug to specific crop recommendation Bands vary from structure with radius 2–30 m. Ideal for fruit trees and fodder crops Staggered in arrangement to get spill over	Suitable on gentle slopes with 200–250 mm rainfall Soil should not be too shallow or saline	Easy to construct Suitable for uneven terrain Increase soil moisture Control soil erosion	Animal draft not applicable Requires regular maintenance	32md/acre 8md/1/4 acre 8xUSD 2 USD 16
Retention ditch	Laid along contour Measures 0.3x0.6 m deep, 0.5–1 m wide Ends are closed May be a trench or a hole Capture runoff from ext. catchments	Suitable on flat gentle/steep slopes On permeable, deep and stable soils	Reduces soil erosion. Holds runoff for use by crops and ground recharge Guards other structure down stream	Labour demanding Requires regular maintenance Risk some erosion/processes Prone to overflow	USD 0.75 /meter of excavation 20 m= USD 15
Cover crop	Usually creeping legumes e.g. *Mucuna, Dolichos lablab*, etc. Used to cover the ground below widely spaced tall crop	Used for deep-rooted crop to avoid competition for nutrients	Improve soil fertility Suppress weeds Regulates soil temperatures	Competes for water with shallow rooted crops	Cost of establishing = . USD 4.2 = per 0.25acre
Conservation tillage Agriculture	Entails minimal soil disturbance Permanent soil cover Crop rotations/associations	Herbicides selection based on type of weed and crop	Reduces labour, lost energy needed to increase SWC water. infiltration	Selective use of herbicides	USD 4.2 = per 1/4 acre
Ripping (in CA)	Ripper works by ripping the soil and therefore cracking it It breaks any paw (hard)that may have developed Magoye ripper - used in place of mould board on ox-driven ploughs	On gentle flat terrain On field free of rocks and tree roots	Breaks hard pan Moisture stored in root zone. Soil nutrients are accessible by the plant. Productivity increase by 78% compared to conventional farming practices	Only applicable where animal draft power is used	- USD 3 per 0.25 acre

Source: Wilfred Miriithi (2007).

Table A10.2: Case Studies/Technologies by Group

Group Case study/ technology	Country	Climatic zone: arid	semi-arid	subhumid	humid	Land use type: annual crops	perennial crops	grazing land	forest	mixed	other[1]	Degradation type: water erosion	wind erosion	chemical deterioration	physical deterioration	vegetation degrad.	water degradation	Conservation measure: agronomic	vegetative	structural	management	Intervention type: prevention	mitigation	rehabilitation
1 Conservation agriculture																								
No-till technology	Morocco		■	■		■						■	□	□	■			■			■		■	
Conservation agriculture	UK			■		■						■		□				■					■	
Small-scale conservation tillage	Kenya		■			■						■			□		■	■	□				■	
No-till with controlled traffic	Australia	■	■			■						■	□		■			■					■	
Green cane trash blanket	Australia				■		■					■		■				■					■	
2 Manuring/ composting																								
Vermiculture	Nicaragua			■	■	■	■							■				■					■	
Composting/ planting pits	Burkina Faso		■							■		■		■	□		■	■					■	
Improved trash lines	Uganda			■		■						■		■			■	■					■	
3 Vegetative strips/ cover																								
Natural vegetative strips	Philippines				■	■						■		□				■	■				■	
Green cover in vineyards	Switzerland			■			■					■		□				■	■				■	
Vetiver grass lines	South Africa			■			■					■	□					□	■	□			■	
4 Agroforestry																								
Shelterbelts	P.R. China		■			■				□			■				■		■				■	
Grevillea agroforestry system	Kenya			■		■	■			□		■		□			■		■			■		
Poplar trees for bio-drainage	Kyrgyzstan		■			■				□	■			■	■			■	■					■
Multi-storey cropping	Philippines				■	■				□		■		■				■	■			■		
Intensive agroforestry system	Colombia			■						□	■	■	□	■				■	■	■			■	
Shade-grown coffee	Costa Rica				■					■		■		■				■	■	□		■		
Conversion of grazing land	Tajikistan			■				■		□		■			■	□		■	■	■	■			■
Orchard-based agroforestry	Tajikistan			■			■			□		■	□	□				■	■	■			■	
5 Water harvesting																								
Sunken streambed structure	India		■			■		■				■					■				■		■	
Planting pits and stone lines	Niger		■			□				■	■	■	■	□	□			□			■			■
Furrow-enhanced runoff harvesting	Syria		■				□	■		□		■	□	□			■	■			■			■
6 Gully rehabilitation																								
Check dams from stem cuttings	Nicaragua		■			■		■				■							■	■				■
Gully control and catchment protection	Bolivia		■	■		■		■				■				□			■	■				■
Landslip and stream bank stabilisation	Nepal			■						□	■	■		□					■	■				■
7 Terraces																								
Stone wall bench terraces	Syria		■				■					■					■			■		■		
Rehabilitation of ancient terraces	Peru		■			■		■				■		■			□	□	□	■				■
Traditional stone wall terraces	South Africa			■		■	■					■		■				□		■		■		
Fanya juu terraces	Kenya		■	■		■						■					■		□	■			■	
Small level bench terraces	Thailand				■	□	□		■			■		■			□		□	■			■	
Orchard terraces with bahia grass cover	PR China				■		□				■	■		□				■	■	■			■	
Zhuanglang loess terraces	PR China		■			■	■					■		■			□	□		■				■
Rainfed paddy rice terraces	Philippines				■	■						■		■					□	■		■		
Traditional irrigated rice terraces	Nepal				■	■						■						■	■	■		■		
8 Grazing land management																								
Ecograze	Australia		■					■				■			■	□			■		■		■	
Restoration of degraded rangeland	South Africa			■				■				□		■	□	■		■	■	■				■
Improved grazing land management	Ethiopia				■			■		□		■		■		□		■	■		■		■	
Area closure for rehabilitation	Ethiopia		■	■		■		■		□		■		■		■		■	■	□	■			■
9 Other technologies																								
Pepsee micro-irrigation system	India		■			■											■			■	■		■	
Sand dune stabilisation	Niger		■					■					■	□		□			■	■	■			■
Forest catchment treatment	India			■					■			■					■		■	■	■		■	
Strip mine rehabilitation	South Africa	■						□			■	■	□		■				■	■				■

[1] other land use types: eg wasteland, degraded land

	■	□
Land use type	before SWC technology was implemented	after SWC technology was implemented
Degradation type	main degradation type addressed	minor degradation type addressed
Conservation measure	main conservation measure	supportive / optional SWC measure

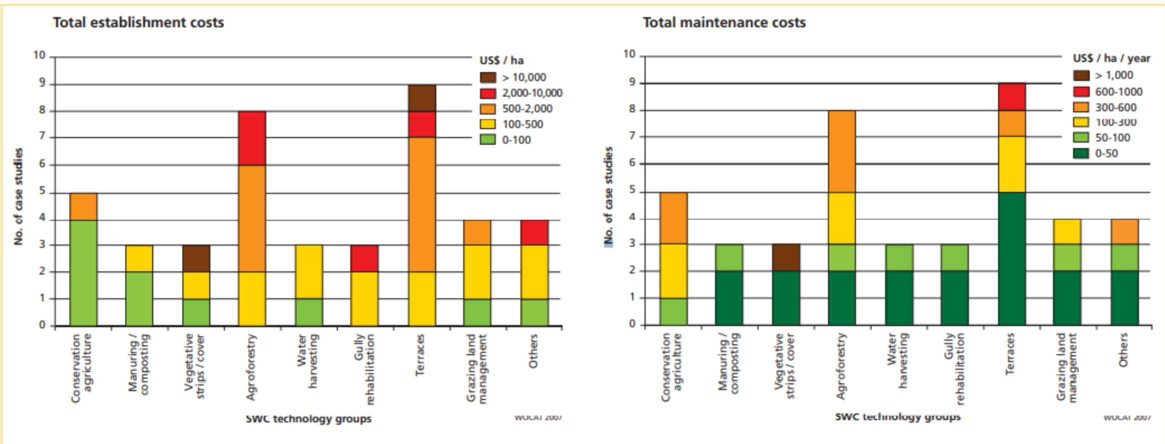


Table A10.3: A Comparison of Inputs Involved in Terrace Establishment and Maintenance

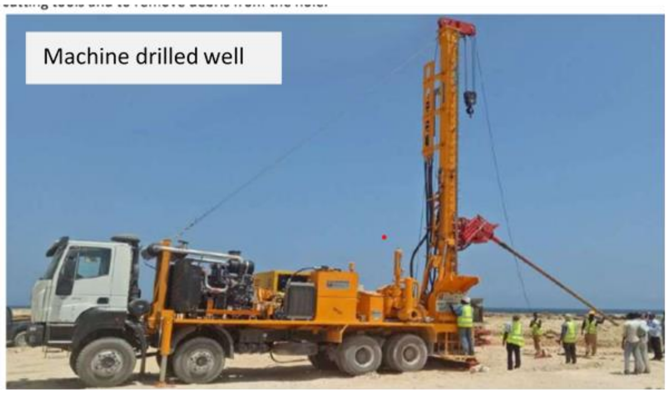
Technology	Country	Slope	Rainfed/ irrigated	Establishment			Maintenance		
				Person-days/ha	Total costs/ha US $	% met by land users	Person-days/ ha/year	Total costs/ha/ year US $	% met by land users
Orchard terraces with bahia grass cover	China	16–30%	Rainfed	350	1,840	70	60	376	100
Loess plateau terraces	China	16–30%	Rainfed	600	1,200	95	12	25	95
Fanya juu terraces	Kenya	5–8%	Rainfed	90	320	100	10	38	100
Rainfed paddy rice terraces	Philipp.	30–60%	Rainfed	800	2,700	100	10	40	100
Traditional stone wall terraces	Syria	16–30%	Rainfed	375	1,270	100	50	160	100
Small level bench terraces	Thailand	8–16%	Rainfed	125	275	100	20	45	100
Stone wall bench terraces	S. Africa	16–30%	Rainfed	420	1,460	100	5	20	100
Traditional irrigated rice terraces[1]	Nepal	30–60%	Irrigated	unknown	unknown	100	125	840	100
Rehabilitation of ancient terraces[2]	Peru	30–60%	Irrigated	130	1,400	35	6	126	100

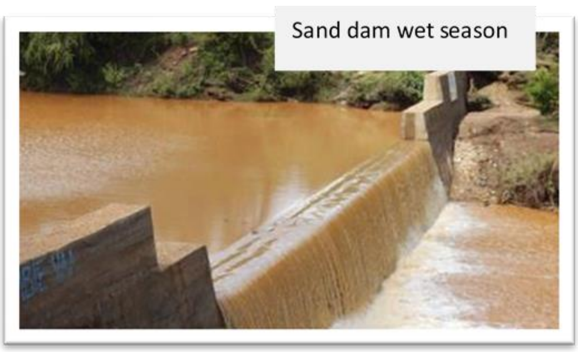
[1] no information on labour input in contraction of these ancient terraces

[2] refers to rehabilitation of ancient systems, not original establishment

Source: Figures and table from: Liniger and Critchley (2007).

Appendix 11. Some Photographs





Appendix 12. Population (UNDP 2014) and Water Points (SWALIM 2020) per District and Region

Table A12.1: Population and Water Points in Districts of Somalia

Regions	Districts	Population 2020 (based on UNDP, 2014)				Waterpoints (SWALIM, Dec 2020)						
		IDP	Urban	Rural	Total	Berkad	Boreh.	Haffirs	Dugw.	Others	Springs	Total
Awdal	Baki	-	5,412	103,048	108,460		6	1	99	3	20	129
Awdal	Borama	67	345,738	141,826	487,630	30	83	22	83	10	23	251
Awdal	Lughaye	8,743	8,173	96,274	113,189		16		17	2	1	36
Awdal	Zeylac	78	7,815	78,701	86,595		17		43	6	16	82
Bakool	Ceel Barde	3,337	5,901	57,288	66,526		4	3	19			26
Bakool	Rab Dhuure	-	-	-	-			24	14			38
Bakool	Tayeeglow	8,009	22,830	54,033	84,872		4	15	31			50
Bakool	Waajid	10,011	24,763	108,015	142,789		2	56	60			118
Bakool	Xudur	5,339	25,501	93,557	124,398	3	18	23	44			88
Banadir	Banadir	410,768	1,633,932	-	2,044,700		5		140			145
Bari	Bandarbeyla	-	5,561	12,370	17,932		1		17	1	30	49
Bari	Bossaso	54,504	503,636	28,626	586,765	1	120		85	1	55	262
Bari	Caluula	-	11,747	44,245	55,992		1		29		11	41
Bari	Iskushuban	-	4,612	60,954	65,567	2	7		35		17	61
Bari	Qandala	-	8,664	50,409	59,073		2		5		3	10
Bari	Qardho	11,842	67,575	24,433	103,850	4	54		11	1	2	72
Bay	Baydhaba	22,992	46,655	287,461	357,108		87	31	43		7	168
Bay	Buur Hakaba	13,092	32,134	178,234	223,460		3	23	25			51
Bay	Diinsoor	3,704	30,221	164,524	198,449		3	18	25		1	47
Bay	Qansax Dheere	4,505	9,676	103,153	117,335		19	19	6		1	45
Galgaduud	Cabudwaaq	13,535	59,095	48,345	120,974	58	33	24	33			148
Galgaduud	Cadaado	30,033	63,905	58,385	152,322	11	49	6	56			122
Galgaduud	Ceel Buur	30,355	16,108	48,600	95,063	10	18	4	7			39
Galgaduud	Ceel Dheer	19,922	48,981	59,577	128,480	4	12		82			98
Galgaduud	Dhuusamarreeb	39,376	46,047	81,097	166,520	11	59	9	68			147
Gedo	Baardheere	20,022	38,738	143,506	202,266	5	4	23	10		5	47
Gedo	Belet Xaawo	13,971	34,338	48,537	96,847		2	1	4			7
Gedo	Ceel Waaq	14,471	12,891	41,078	68,440		4		2			6
Gedo	Doolow	8,652	9,642	28,818	47,112		2		12			14
Gedo	Garbahaarey	10,011	23,499	55,093	88,603		8	15	26			49
Gedo	Luuq	18,220	20,109	41,729	80,058		1	4	93		2	100
Hiraan	Belet Weyne	36,050	40,658	190,129	266,837	33	40	14	33			120
Hiraan	Bulo Burto	10,701	33,100	114,251	158,051		16		5			21
Hiraan	Jalalaqsi	10,156	30,047	127,364	167,567		2					2
Middle Juba	Bu'aale	13,348	22,291	88,442	124,080		3	4	20			27
Middle Juba	Jilib	8,899	26,482	162,465	197,845				1			1
Middle Juba	Saakow	7,786	22,968	60,188	90,942		1	11	9		3	24
Lower Juba	Afmadow	14,460	44,368	138,709	197,537			2	1			3
Lower Juba	Badhaadhe	667	14,647	49,048	64,363							0
Lower Juba	Jamaame	7,786	12,953	89,827	110,566							0
Lower Juba	Kismaayo	11,123	148,528	40,370	200,021				2			2
Mudug	Gaalkacyo	51,525	345,235	80,333	477,093	6	134	1	49			190
Mudug	Galdogob	22	53,260	42,069	95,352		42		14			56
Mudug	Hobyo	12,992	17,785	99,663	130,440	8	68	5	112			193
Mudug	Jariiban	100	31,925	63,149	95,174		14		18		1	33

Regions	Districts	Population (UNDP, 2014)				Waterpoints (SWALIM, Dec 2020)						
		IDP	Urban	Rural	Total	Berkad	Boreh.	Haffirs	Dugw.	Others	Springs	Total
Mudug	Xarardheere	14,204	38,416	10,093	62,714		1	9	12			22
Nugaal	Burtinle	-	39,789	37,563	77,352	1	22					23
Nugaal	Eyl	-	10,402	81,063	91,465	3	9		33	1	23	69
Nugaal	Garoowe	10,562	127,023	153,084	290,669	1	68		139	1	35	244
Sanaag	Ceel Afweyn	-	33,220	82,208	115,428	12	12	3	120	3	39	189
Sanaag	Ceerigaabo	901	108,576	132,799	242,276	14	108	4	180	1	23	330
Sanaag	Laasqoray	111	61,935	211,564	273,610	3	26	2	22	1	5	59
Middle Shabelle	Adan Yabaal	-	9,162	34,035	43,197	0	0	0	0	0	0	0
Middle Shabelle	Balcad	24,716	32,266	183,251	240,232		29	2	46			77
Middle Shabelle	Cadale	3,749	23,955	72,018	99,722		3		4			7
Middle Shabelle	Jowhar	29,332	80,476	99,705	209,513		9	1	18			28
Lower Shabelle	Afgooye	27,597	78,580	169,341	275,518		137	12	49			198
Lower Shabelle	Baraawe	15,172	15,684	53,543	84,399							0
Lower Shabelle	Kurtunwaarey	1,657	10,987	280,543	293,187							0
Lower Shabelle	Marka	41,267	53,647	132,527	227,440							0
Lower Shabelle	Qoryooley	12,113	54,082	265,963	332,158				2			2
Lower Shabelle	Sablaale	834	8,493	17,841	27,168							0
Lower Shabelle	Wanla Weyn	15,895	53,735	62,979	132,608		7		2			9
Sool	Caynabo	1,557	24,966	42,388	68,911	1	21	2	55			79
Sool	Laas Caanood	3,804	97,579	85,115	186,498		54	2	109		15	180
Sool	Taleex	-	17,321	66,684	84,005		6	1	71	2	9	89
Sool	Xudun	-	14,470	30,073	44,543			10		101	1	112
Togdheer	Burco	28,653	479,628	65,164	573,446	87	176	23	67	2	2	357
Togdheer	Buuhoodle	-	63,752	37,561	101,313	28	21	1	29	3		82
Togdheer	Owdweyne	-	29,081	87,384	116,465	14	29	15	74	4		136
Togdheer	Sheikh	-	44,565	45,569	90,133		3		39		30	72
Woqooyi Galbeed	Berbera	656	94,355	112,842	207,853		42		47	6	25	120
Woqooyi Galbeed	Gebiley	-	47,090	77,859	124,950	9	60	59	76	6	10	220
Woqooyi Galbeed	Hargeysa	48,942	882,508	248,303	1,179,753	28	172	61	189	9	22	481
Total		1,242,896	6,653,891	6,666,984	14,563,770	387	1979	565	2871	164	437	6403

Note: Population figures are based on the UNDP survey of 2014 and projected to 2020 using an annual urban growth rate of 4.14 percent, and rural and IDP growth rates of 1.79 percent (World Bank Database Somalia 2020).

Table A12.2: Population, Livestock, and Water Points in Regions of Somalia

Region	Population 2020 (based on UNDP, 2014)				Livestock (UNDP '14)	Waterpoints (Swalim, Dec 2020)						
	IDP	Urban	Rural	Total		Berkad	Boreh.	Haffirs	Dugw.	Others	Springs	Total
Awdal	8,887	367,138	419,848	795,874	4,320,257	30	122	23	242	21	60	498
Bakool	26,696	78,995	312,894	418,585	3,176,063	3	28	121	168	0	0	320
Banaadir	410,768	1,633,932	-	2,044,700	-	0	5	0	140	0	0	145
Bari	66,346	601,795	221,037	889,178	2,590,231	7	185	0	182	3	118	495
Bay	44,293	118,687	733,372	896,352	2,726,313	0	112	91	99	0	9	311
Galgaduud	133,221	234,135	296,003	663,359	3,756,787	94	171	43	246	0	0	554
Gedo	85,346	139,217	358,762	583,325	4,097,323	5	21	43	147	0	7	223
Hiiraan	56,906	103,805	431,745	592,456	4,073,899	33	58	14	38	0	0	143
Lower Juba	34,037	220,497	317,953	572,487	2,411,062	0	0	2	3	0	0	5
Lower Shabelle	114,536	275,208	982,736	1,372,479	2,522,117	0	144	12	53	0	0	209
Middle Juba	30,033	71,741	311,094	412,868	1,731,982	0	4	15	30	0	3	52
Middle Shabelle	57,796	145,859	389,009	592,665	2,183,727	0	41	3	68	0	0	112
Mudug	78,844	486,622	295,307	860,773	3,770,373	14	259	15	205	0	1	494
Nugaal	10,562	177,214	271,710	459,486	3,954,602	5	99	0	172	2	58	336
Sanaag	1,012	203,731	426,571	631,314	5,696,955	29	146	9	322	5	67	578
Sool	5,361	154,335	224,260	383,957	3,387,808	1	81	15	235	103	25	460
Togdheer	28,653	617,025	235,678	881,357	3,378,614	129	229	39	209	9	32	647
Woqooyi Galbeed	49,598	1,023,954	439,004	1,512,556	5,056,522	37	274	120	312	21	57	821
Total	1,242,896	6,653,891	6,666,984	14,563,770	58,834,633	387	1979	565	2871	164	437	6403

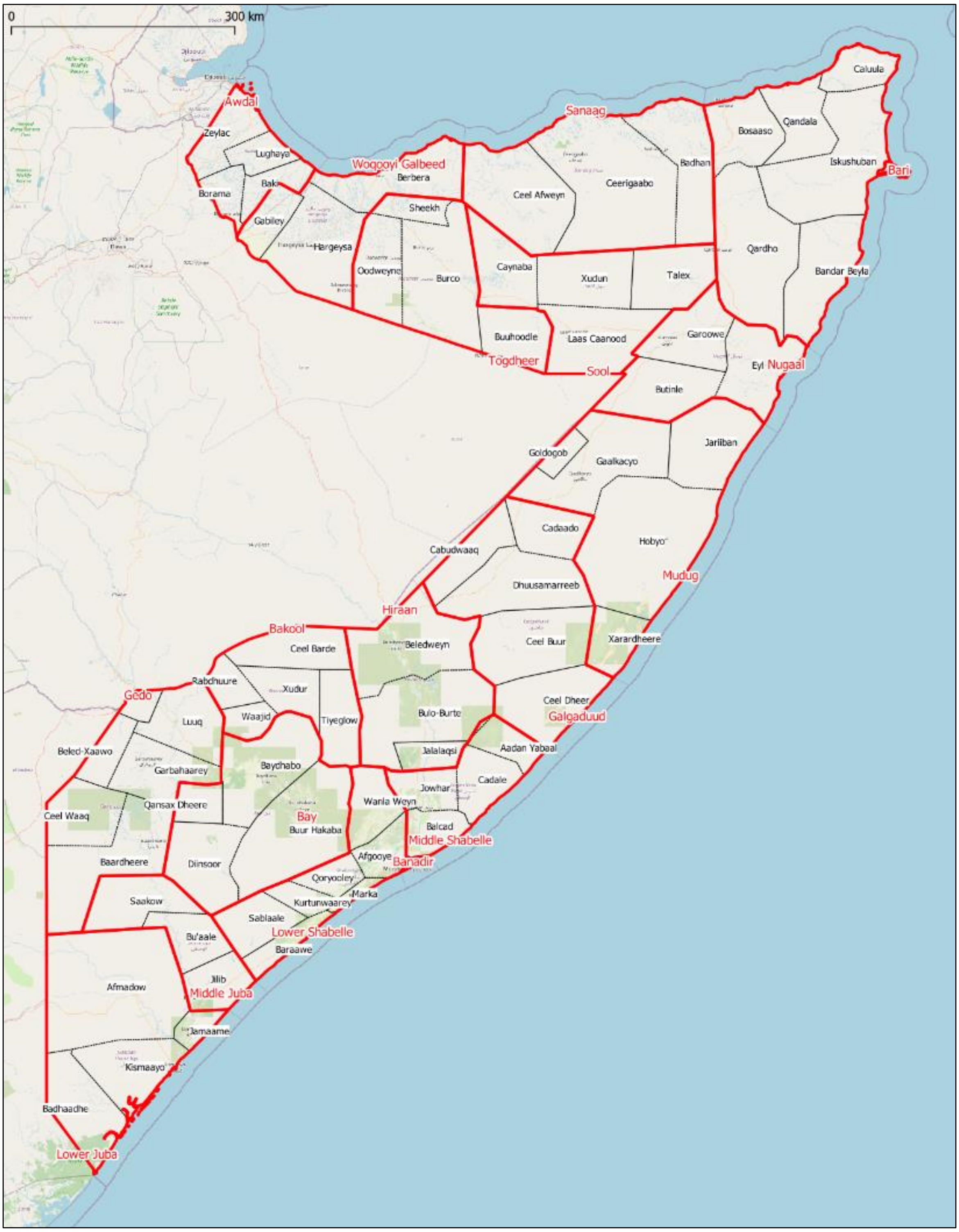
Note: Population figures are based on the UNDP survey of 2014 and projected to 2020 using an annual urban growth rate of 4.14 percent, and rural, IDP, and livestock growth rates of 1.79 percent (World Bank Database Somalia 2020).

Table A12.3: Livestock in Regions of Somalia

Region	Livestock (UNDP, 2014)				
	Goats	Sheep	Camel	Cattle	Total
Awdal	2,594,454	1,088,945	396,890	65,696	3,883,997
Bakool	1,622,887	454,751	687,310	411,115	3,176,063
Banaadir	-	-	-	-	-
Bari	1,664,460	829,390	96,382	-	2,590,231
Bay	1,303,060	130,150	402,174	890,930	2,726,313
Galgaduud	2,259,127	946,534	513,331	37,794	3,756,787
Gedo	2,030,933	834,466	857,483	374,440	4,097,323
Hiiraan	2,219,772	757,399	710,702	386,025	4,073,899
Lower Juba	814,469	548,011	358,215	690,367	2,411,062
Lower Shabe	1,091,213	516,332	318,981	595,590	2,522,117
Middle Juba	531,965	437,509	183,906	578,602	1,731,982
Middle Shabe	1,223,308	580,364	173,676	206,380	2,183,727
Mudug	2,288,983	980,019	486,832	14,538	3,770,373
Nugaal	2,179,699	1,354,587	420,315	-	3,954,602
Sanaag	3,162,146	2,274,589	260,219	-	5,696,955
Sool	1,714,820	1,410,191	262,797	-	3,387,808
Togdheer	2,172,274	648,138	552,618	5,582	3,378,614
Woqooyi Gal	3,053,842	1,267,184	628,083	107,414	5,056,522
Total	31,927,412	15,180,874	7,354,492	4,371,853	58,834,633

Note: Figures are based on the UNDP survey of 2014 and projected to 2020 using an annual growth rate of 1.79 percent (World Bank Database Somalia 2020).

Figure A12.1: Map with Regions and Districts



Bibliography and Geographic Data/Information

Abbate, E., M. Sagri, and F.P. Sassi. 1993. Geology and Mineral Resources of Somalia and Surrounding Regions (with geological map of Somalia 1:1,500,000), A – Regional Geology. Instituto AgronomicoperL' Oltromare, Firenze.

Bambara, A., P. Orban, I. Ouedraogo, E. Hallot, F. Guyon, A. Zangré, and S. Brouyère. 2020. "Quantifying Focused Groundwater Recharge Induced by Irrigation Surface Water Reservoirs in Crystalline Basement Areas for Complementary Irrigation." *Water* 12(10): 2880.

Basnyat, D.B. 2007. Water Resources of Somalia. Technical Report No W-11, FAO-SWALIM, Nairobi, Kenya.

BGS, Earthwise. Africa Groundwater Atlas. Retrieved December 2, 2020, from http://earthwise.bgs.ac.uk/index.php/Africa_Groundwater_Atlas_Home

Bisson, R.A., and J.H. Lehr. 2004. Modern groundwater exploration: Discovering new water resources in consolidated rocks using innovative hydrogeologic concepts, exploration, drilling, aquifer testing and management methods. John Wiley & Sons.

CLIMATESERV. CHIRPS data. Retrieved December 8, 2020, from https://climateserv.servirglobal.net/

EarthWater. 1998. Pre-feasibility Geophysical investigations. Garowe Town Water Supply. Puntland State, Somalia.

Faillace, C. 1998. Brief Note on the occurrence of High Fluoride Content in Groundwater of Somalia. *Geologica Romana* 34: 51–57.

Faillace, C., and E.R. Faillace. 1986. Water quality data book of Somalia. Hydrogeology and water quality of northern Somalia. Vol. 1, Text. GTZ & WDA, Rosdorf.

FAO, AQUASTAT. 2014. Country profile Somalia. Retrieved January 8, 2021, from http://www.fao.org/aquastat/en/countries-and-basins/country-profiles/country/SOM

FAO-SWALIM. 2012. Hydrogeological Survey and Assessment of Selected Areas in Somalila.

———. 2020. Livemap Mapped Water Sources. Retrieved November 23, 2020, from https://swims.faoswalim.org/dashboard/view

FAO-WaPOR. Retrieved December 4, 2020, from https://wapor.apps.fao.org/home/WAPOR_2/1

Funk, C.C., P.J. Peterson, M.F. Landsfeld, D.H. Pedreros, J.P. Verdin, J.D. Rowland, ... and A.P. Verdin. 2014. A quasi-global precipitation time series for drought monitoring. US Geological Survey data series, 832(4), 1–12.

Hydro Nova 2019. Turning Sand into Water, Endline report. Water for Agropastoralist Livelihoods Pilot Project in Somaliland and Puntland (WALP). World Bank Group.

IGAD. 2020. “Report for Groundwater Knowledge management in Somalia.” Prepared by Abdi Mohamed Sheikh for IGAD under the Horn of Africa Groundwater Initiative.

Kebede, S. 2013. Groundwater in Ethiopia: Features, numbers and opportunities. Springer Science & Business Media.

Kim, a.o. 2017. “FO-Electrodialysis Hybrid Process.” *Desalination Sustainability*.

Kiprono, A.W., and A.I. Llario. 2020. *Solar Pumping for Water Supply: Harnessing solar power in humanitarian and development contexts*. Practical Action Publishing.

Liniger, H., and W. Critchley. 2007. *Where the land is greener: Case-studies and analysis of soil and water conservation initiatives worldwide*. CTA/CDE/FAO/UNEP/WOCAT.

Louis Berger Inc. 1985. Comprehensive groundwater development, project 104. Final report Volume II, Hydrology. Somali Democratic Republic, Ministry of Minerals and Water Resources, Water Development Agency.

MacDonald, A.M., H.C. Bonsor, B.É.Ó. Dochartaigh, and R.G. Taylor. 2012. Quantitative maps of groundwater resources in Africa. *Environmental Research Letters* 7(2): 024009.

Martínez-Santos, P., M. Martín-Loeches, S. Díaz-Alcaide, and K. Danert. 2020. “Manual Borehole Drilling as a Cost-Effective Solution for Drinking Water Access in Low-Income Contexts.” *Water* 12(7): 1981. https://doi.org/10.3390/w12071981

Nasreldin, H.A., A.H. Ahmednor, and A.B. Mohamed. 2016. Hydrogeochemical assessment of groundwater in central region of Somalia. *ResearchGate*. https://www.researchgate.net/publication/313860927

Paz Lopez-Rey, S. 2019. An appraisal of the effectiveness and sustainability of sand dams to improve water security and resilience in rural Somaliland. MSc Thesis, Loughborough University, UK.

Peden, D., G. Tadesse, and M. Mammo. 2003. Improving the water productivity of livestock: An opportunity for poverty reduction. *Integrated water and land management research and capacity building priorities for Ethiopia*, 2–4.

Petersen, G., and H.M. Gadain. 2012. Climate change impacts on water resources of Somaliland and Puntland. FAO SWALIM Technical Report No W-21. Nairobi, Kenya: FAO.

Puntland. Technical Report No. W-20, FAO-SWALIM (GCP/SOM/049/EC) Project, Nairobi, Kenya.

Rubel, F., and M. Kottek. 2010. “Observed and projected climate shifts 1901–2100 depicted by world maps of the Köppen-Geiger climate classification.” *Meteorologische Zeitschrift* 19(2): 135–141.

Seguin, J.J., and A. Gutierrez. 2016. A. Les ressources en eau du continent africain : rareté et abondance. *Structure* 3, 5.

Shilenje, Z.W., and V. Ongoma. 2014. “Observed surface ozone trend in the year 2012 over Nairobi, Kenya.” *Atmósfera* 27(4): 377–384.

SmartWater Magazine. The evolution of rates in desalination. https://smartwatermagazine.com/blogs

Tod, P. 2000. Desalination of Off-Shore Underground Brackish Water**.** Technical-economic opportunity study. IWACO, Rotterdam.

Torbaghan, M.E., and M. Burrow. 2019. Small town water supply infrastructure costs; University of Birmingham April 2019.

UNICEF. 2016. Scaling up solar powered water supply systems: A review of experiences.

———. 2018. Terms of Reference for drilling of two deep boreholes in Somaliland.

———. 2021. Somalia, Water, Sanitation and Hygiene. Retrieved January 22, 2021, from ,https://www.unicef.org/somalia/water-sanitation-and-hygiene#_ftnref1

UNICEF, EW, Practica. 2009. Technical note 3 Manual drilling 2009.

US Department of the Interior, Bureau of Reclamation. 2014. Estimating the Cost of Brackish Groundwater Desalination in Texas. Report submitted to the Texas Water Development Board.

van Haren, I., L. Bastidas, N. Limones, and M. Wijnen. 2017. Assessment of Water Resources for Priority.

WASH Cluster Somalia. 2017. Minimum WASH Technical Guidelines.

———. 2020. Technical Guidelines for the Construction, Rehabilitation of Drilled Water Wells. UNICEF, Ministry of Energy and Water Resources.

World Bank. 2018. Solar Pumping, The Basics.

———. 2019. Somalia Floods (Lower Shabelle and Hiraan Region).

World Bank, Climate Change Knowledge Portal. 2021. Retrieved January 23, 2021, from https://climateknowledgeportal.worldbank.org/country/somalia/impacts-water

World Bank, Data Somalia. 2021. Retrieved January 17, 2021, from https://data.worldbank.org/country/somalia

World Bank Group. Areas in Somaliland. Final Report. Somalia Drought Emergency Response. Water Partnership Program, World Bank Group.

Wright, N.C., G. Amos, and V. Winter. 2014. “Justification for community-scale photovoltaic-powered electrodialysis desalination systems for inland rural villages in India.” *Desalination* Vol 352: 82–91, November 3, 2014.

WWAP/UN-Water. 2018. The United Nations World Water Development Report 2018: Nature-Based Solutions for Water. Paris, UNESCO.

Zhou, Y., and R. Tol. 2004. Evaluating the cost of desalination and water transport; Working Paper FNU-41. Revised.

Literature on Manual Drilling

Danert, K. 2015. Manual Drilling Compendium. *Rural Water Supply Network Publication 2*.

Deal, P.T., and D.A. Sabatini. 2020. Utilizing indicator kriging to identify suitable zones for manual drilling in weathered crystalline basement aquifers. *Groundwater for Sustainable Development 11*: 100402.

Fussi, F.F., L. Fumagalli, F. Fava, B. Di Mauro, C.H. Kane, M. Niang, ... and T. Bonomi. 2017a. Classifying zones of suitability for manual drilling using textural and hydraulic parameters of shallow aquifers: A case study in northwestern Senegal. *Hydrogeology Journal 25*(8): 2263–2279.

Fussi, F., F. Asplund, M. Caruba, L. Fumagalli, M. Rottier, and T. Bonomi. 2017b. Promotion of manual drilling in Guinea Bissau: Mapping suitable zones and estimating the potential. Briefing Paper 2760. 35th WEDC International Conference, 'The future of water, sanitation and hygiene: Innovation, adaptation and engagement in a changing world', Loughborough, UK, 2011.

Harvey, P., and J. Naugle. 2011. Professionalizing manual drilling in Africa: A complimentary strategy to achieve the MDG water target. Briefing Paper 1070. 35th WEDC International Conference, 'The future of water, sanitation and hygiene: Innovation, adaptation and engagement in a changing world', Loughborough, UK, 2011.

Kane, C.H., and K. Danert. 2020. A Turning Point for Manual Drilling in the Democratic Republic of Congo. Rural Water Supply Network (RWSN) Publication 2020-2.

Martínez-Santos, P., M. Martín-Loeches, S. Díaz-Alcaide, and K. Danert. 2020. Manual Borehole Drilling as a Cost-Effective Solution for Drinking Water Access in Low-Income Contexts. *Water 12*(7): 1981.

Martínez-Santos, P., M. Martín-Loeches, D. Solera, B. Cano, and S. Díaz-Alcaide. 2017. Mapping the viability, time, and cost of manual borehole drilling in developing regions. *Water 9*(4): 262.

PRACTICA. 2009. The Case for Manual Drilling in Africa. Technical Note No 1. PRACTICA, EnterpriseWorks/VITA, UNICEF.

———. 2009a. Etude de faisabilite des forages manuels identification des zones potentiellement favorables, Cote d'Ivoire. PRACTICA, EnterpriseWorks/VITA, UNICEF. Republique de la Cote d'Ivoire.

———. 2009b. The impact of manual drilling for the construction of sustainable water-points in Chad. PRACTICA, EnterpriseWorks/VITA, UNICEF.

———. 2010a. Understanding groundwater & wells in manual drilling. PRACTICA, EnterpriseWorks/VITA, UNICEF, USAID, ETC.

———. 2010b. Jetting. Manual drilling series. PRACTICA, EnterpriseWorks/VITA, UNICEF, USAID, ETC.

———. 2011. Feasibility study for manual drilling mapping of favourable zones. Republic of Sierra Leone. Ministry of Energy and Water Resources. PRACTICA, EnterpriseWorks/VITA, UNICEF.

Thomas, S.A., K.C. McGwire, A. Lutz, C. Kratt, E.J. Trammell, J.M. Thomas, and W.A. McKay. 2012. Geospatial and regression tree analysis to map groundwater depth for manual well drilling suitability in the Zinder region of Niger. *Journal of Hydrology 446*, 35–47.

UNICEF. 2010. Professionalizing the Manual Drilling Sector in Africa: A Guide to Building Capacity to Increase Access to Safe Water in Rural Areas. PRACTICA, EnterpriseWorks/VITA, UNICEF.

van Herwijnen, A. 2005. Rota Sludge & Stone Hammer drilling Part one Drilling Manual. PRACTICA, ETC Energy.

Repository of Geographical Information

During the project, various geographical data sets have been collected. These data files are available in ESRI shape or geotiff formats. The files can be processed and combined by GIS software to produce various maps and to carry out statistical analyses. The list of numerical geographical information that we have in the project repository is given below.

Administration

- Regions: Names locations, population, and livestock (UNDP 2014).
- Districts: Names, locations, population (UNDP 2016).
- Settlements: Names, locations, (without population) (UNSOS 2016).

Socioeconomic

- Livelihood zones (FSNAU 2015) (FEWS NET 2015).
- Livestock routes (IGAD).
- Livestock markets (IGAD).
- Irrigation canals (SWALIM 2018).
- Food Security classification and outlooks (FEWS NET 2019, 2020, 2021).
- Schools (UNCEF 2004).
- Clan distribution (SWALIM based on Abikar 1999).
- Primary roads (UNCHA).
- Secondary roads (ADC 2010).
- Land use system (SWALIM 2007).

Soil, Land Cover, Landscape, and Agriculture

- Harmonized soil map (FAO 2008).
- Digital soil map of the world (FAO 2005).
- Land cover/land use (ESA 2009; FAO 2014).
- Landforms (SWALIM 2008).
- Biomass water productivity from WAPOR (FAO 2019).
- NDVI (SWALIM; SENTINEL).
- Land use suitability (SWALIM).
- Suitability sorghum (SWALIM).
- Slope (derived from SRTM-DEM 1 arc-second).
- Elevation (SRTM-DEM 1 arc-second).
- Agricultural production (time series) (FSNAU).

Climate

- Drought-prone areas (risk levels) (IGAD 2017).
- Climate zones (SWALIM 2019).
- Precipitation (CHIRPS 2019).
- Potential and actual evapotranspiration (FAO, WAPOR 2019).
- Drought indexes time series (SWALIM).

Hydro(geo)logy

- Watersheds (this project from SRTM_DEM 1 arc-second; also from SWALIM).
- Steams (this project from SRTM_DEM 1 arc-second; also from SWALIM and IGAD).
- Geology (Abbate et al. 1993).
- Hydrogeological map (SWALIM; BGS 2019).
- Groundwater storage (BGS 2019).
- Groundwater productivity (BGS 2019).
- Groundwater depth (BGS 2019).

- Water points (berkads, hafirs, dug wells, boreholes, springs) (FAO Live Database December 2020).

Besides the GIS data above, the repository also contains other maps in PDF or image formats and data in excel format, which can be georeferenced and processed in GIS analyses.