Groundwater resources in Kenya

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Abstract

The hydrogeological zones of Kenya can be regarded as simplified geological areas, which are characterized by:

- Volcanic rocks,
- Pre-Cambrian Metamorphic Basement rocks,
- Sedimentary rocks.

The Volcanic rocks cover about 26% of the country and are more common in the Western and Central Kenya. The lithology is widely variable and includes Phonolites, Trachytes, Tuffs and Basalts. Groundwater in this geological setting is stored in the old weathered surfaces between the Lava flows and the older formations, as well as between successive flows.

The Pre-Cambrian rocks are widely distributed in the Central, Western and North-Western parts of Kenya and covers about 17% of the country. The lithology is dominated by granites, gneisses, schists and sediments. The aquifers in these geological formations are found within fractures and weathered surfaces of the formation.

The Sedimentary rocks cover about 55% of Kenya, predominantly in the Eastern, North-Western parts, L. Victoria regions and the coastal areas. These rocks are mainly composed of sands, clays, sandstones, shales and limestone. Aquifers are mainly found within the coarse grained sediments and solution cavities.

Surface water bodies cover 2% of the land surface.

The groundwater in Kenya is extremely variable in chemical composition, and the variation occurs both spatially and seasonally. Its quality is influenced by the geological formation in which the aquifer occurs. In Central and Western Kenya, the quality is generally soft with moderate alkalinity. In the Coast, Eastern and Northeastern regions the water is saline and of poor quality. The water quality is one of the major limiting factors in groundwater utilization in Kenya

One of the main shared groundwater resource is the Merti aquifer in the North Eastern part of the country and which occurs in semi-consolidated Merti Beds of Pliocene age. The Merti Beds include gravel, grit, sand, silt and clay and are of variable thickness, extent and lithologic character, suggesting rapid deposition of detrital materials derived from the erosion of adjacent areas of older rocks. This aquifer extends from North East of Habaswein through the Kenya/Somalia border at Liboi and beyond into Somalia.

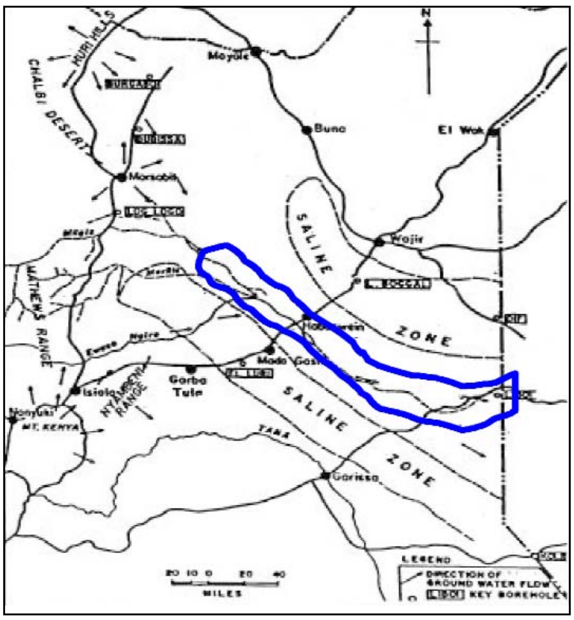

FIGURE 1. Groundwater resource in the eastern and central parts of Kenya (The Merti Aquifer)

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Groundwater flow at Liboi area has been estimated (Swarzenki and Mundorft, 1977) to be about 7,200 m^3/day. This is the amount of groundwater that leaves Kenya daily and enters Somalia.

Overview of groundwater resources

Location and physiography

The Republic of Kenya covers an area of about 592,000 square kilometres and is bound by latitudes 5°20′ N and 4°40′ S and longitudes 33°50′ E and 41°45′ E. The location of Kenya along the equator and the greatly varied surface configuration ranging from sea level to heights of over 5,500 m above sea level combine to create a physical environment varying from almost equatorial characteristics to polarial ones on highlands. The country's topography can be divided into two distinct physical regions, which are the lowland and upland. The entire terrain is dominated by wellpreserved plateaus whose height is used as a rational basis for dividing the country into eight physiographic units. These are the Coastal Belt and plains, the Duruma-Wajir Low Belt, the Low Foreland Plateau, the Kenya Highlands (Western and Eastern), the Kenya Rift Valley, the Nyanza Low Plateau, the Nyanza Lowlands, the Northern Plain land. The present drainage pattern is either radial from the Central Highlands or up from the south foothills of the Ethiopian Highlands.

Geology

The Rift Valley system is represented by volcanics as well as igneous and Pre-Cambrian metamorphic complexes divided into four major systems. The Palaeozoic is well-developed and mostly important in terms of surface coverage and is represented by Quaternary sedimentary and Tertiary volcanic rocks. These igneous, metamorphic and sedimentary rocks occupy 26%, 17% and 55% of the land surface, respectively. Water availability and water quality depend on all the four major geologic areas that are represented in the complex geology of Kenya.

The structural geology is dominated by a gentle domeshaped asymmetrical shield. The earliest fault probably appeared in late Miocene, and another phase of major faulting is known to have occurred in Pliocene and Quarternary times.

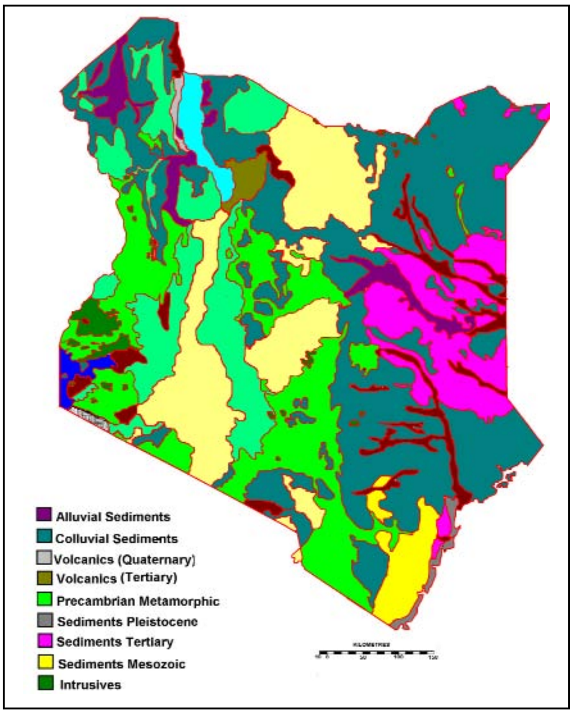

FIGURE 2. Simplified geological map of Kenya

Groundwater resources

Groundwater is extremely variable in chemical composition and this variation occurs both spatially and seasonally. The major uses of boreholes are public water supply, agricultural, domestic, industrial, and livestock. Rock type remarkably affects aquifer characteristics. Groundwater abstraction has seldom been investigated in Kenya. The total present groundwater abstraction rate in Kenya is estimated at 57.21 million m^3/year. Total safe abstraction rate in Kenya is estimated to be 193 million m^3/year.

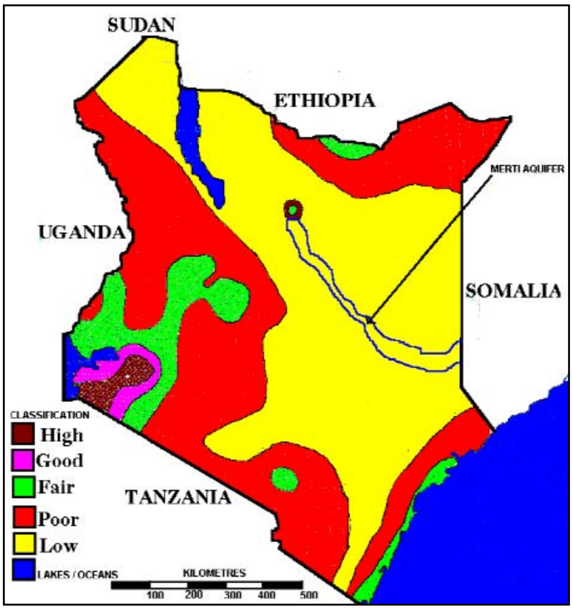

FIGURE 3. Hydrogeological map: groundwater potential in Kenya

Case study of the Merti Aquifer

There are several aquifers shared between Kenya and her neighbours. One of these is the Merti Aquifer that stretches from Yamicha through Habaswein to Liboi at the Kenya/Somali border.

This paper is based on the hypothesis that the Merti Aquifer is limited both spatially and vertically and that the increase in human and livestock development both within the project area and catchment zones accelerates groundwater abstractions and hence over exploitation. The primary aim of this paper is to analyse and qualify the existing information on the aquifer characteristics and propose the way forward. The information on aquifer characteristics, which is either lacking or inadequate at present, is essential for sound planning, water resources development and management.

Previous studies

There have been a number of studies covering eastern Isiolo, Wajir and Garissa Districts. Ministry of Works (1963), carried out a hydrogeological assessment. The report stated *'… It is believed that, with the exception of areas near Mado Gashi and north-east of Habaswein, groundwater of good quality can be obtained by drilling anywhere.'* Subsequent studies have improved upon this assessment and shown up differences. Swarzenki et al. (1977) described the hydrogeological components of an extensive range of development project that covered the whole of North Eastern Province and Eastern Isiolo District. Part of the project's activities was the drilling of exploratory boreholes across much of the Merti Formation, thus allowing a clearer indication of the presence of portable water within it. In respect of the Modogashe area, the report indicated that saline water would be encountered in the Modogashe-Sericho-Merti area, and to the east of Habaswein: however, the Habaswein area itself was reported to be underlain by a fresh water aquifer. Lester (1985), evaluated the results of borehole drilling undertaken in the area and recommended that a comprehensive geophysics programme to delineate the freshwater Merti Aquifer, that boreholes in the fresh water aquifer drilled not less than 110 metres below ground level Shallow boreholes adjacent to the Ewaso Nyiro to exploit alluvial aquifers and that '*No boreholes, either shallow or deep, should be drilled along the Galana Gof east of Benane. Fresh water supplies can be developed from clay fill subsurface dams in the sandy river bed'*. Ministry of Water Development (1991) defined all the Merti Formation in the southern part of the Isiolo District as *'…very poor…'*, stating that *'the southern part of this area offers no good chances for groundwater development as the groundwater is highly mineralised'*. Lane (1995), in his thesis, attempted a synthesis of all data available on the Merti Aquifer, and broadly confirmed the findings of earlier studies. Geologists from the Water Development Department have also been carrying out hydrogeological surveys and studies at various locations within the Merti Aquifer. These surveys have been conducted on demand basis or as need arises. The resulting data for the entire study area has not been analysed in details.

Description of the study area

Presently, the several Rural Towns which lie within the study area with a human and livestock population of 235,500 and 511,700 respectively have a mean daily demand of 11,675 m^3 and 25,585 m^3 respectively. Groundwater abstraction for domestic and livestock purposes averages 4,800 m^3 per day. During and immediately after the rains, the project area relies on a number of public and privately-owned pans and water holes situated on the banks of the Lagh Dera, the seasonal watercourse traversing the various Centres and markets. Water Supply in the study area is acutely sensitive to drought and a number of water holes are usually dry three months after the end of the rains.

The topography of the project area is generally flat, with elevation differences of the order of few metres and range from 360 metres in Urura area of Isiolo, 300 metres within Habaswein and 90 metres within Liboi on Kenya/Somali border. Mean annual rainfall at Habaswein town, which is typical of the study area is 261.1 mm. However, year-on-year rainfall variability is high. Rainfall distribution is bimodal, with two wet seasons in April and November. The annual evaporation is about 2,330 millimetres per year, thus the study area lies in a very arid zone .

There are no perennial streams in the area. The nearest perennial water body is the Tana River located over 100 km to the south. The ephemeral Ewaso Nyiro rises west of Isiolo and traverses Merti, Sericho and eventually reaches the alignment of the Lagh Dera at the vicinity of Habaswein and towards Liboi. The Galana Gof flows only after heavy rains and disappears underground before reaching the Lagh Dera.

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Geology

The soils of the area are generally sandy, with some clay patches. Sub-soils comprise fine sand, silt and clay, which are the erosion products of the mudstones and shales. These soils are poorly permeable, thus limiting the ease with which rainfall can infiltrate.

There are beds of alluvial sands and sandy clays laid down adjacent to the watercourse during flooding by the Lagh Dera, Ewaso Nyiro and Galana Gof. However, outcrops are presently obscured by latter deposition as well as thicker riverine vegetation.

The recent deposits are underlain by the Merti Formation, which is a marine to peri-marine sedimentary formation of Miocene to Pliocene age. The formation is of unknown thickness in this area, though in the Garissa area it is believed to be at least 270 metres thick (Nyagah, 1995). The Merti Formation is underlain by a succession of Jurassic and Cretaceous rocks, which are in turn underlain by metamorphic rocks of the Mozambique Belt, more commonly known as Basement.

Tertiary/Jurassic marine clays, sands and conglomerates, the so-called Merti Beds cover the whole eastern area, extends also to Somali. Sands and conglomerates form extensive aquifers.

Rivers have incised the Merti Formation to create sand rivers which are filled to varying depths with sands and clays in varying proportion.

Hydrogeology and aquifer characteristics

Methodology

The hydrogeological and geohydrological aspects of the Merti aquifer are described in this section. These aspects have been determined by using various methods.

■ **Geological maps and sections**

The Geological Map of the area was used to delineate the hydrogeological zones that outline the fresh water aquifer.

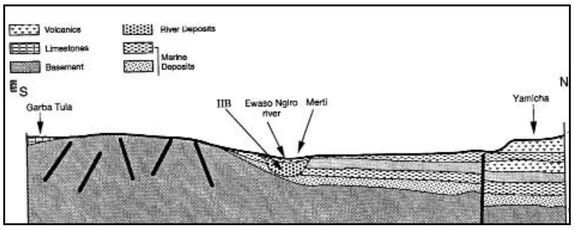

FIGURE 4. Hydrogeological section at the Upper part of Merti Aquifer

■ **Resistivity method**

The purpose of the resistivity surveys was to determine the lateral extent and the geometry of the fresh zone of the Merti Aquifer. The resistivity surveys have been carried out between the Yamicha-Boji-Habaswein area. The soundings were conducted across the Choichuff Lineament. The aim of this survey was to find out whether there exists a buried Paleo-Channel that runs from Yamicha to Habaswein and along the Choichuff Lineament and that recharge the Merti Aquifer.

Other surveys have been carried out around Habaswein, Daadab and at Liboi among other small rural centres within the Merti Aquifer.

The soundings were carried out with a current electrode spacing of between 500 metres and 800 metres using the Schlumberger configuration. The type of apparent resistivity curves obtained during the geophysical site investigations is a function of the resistivities, thickness of the layers and electrode configuration. This anomaly of homogeneity continuity as marked by the resistivity values were used to estimate the dimensions and geometry of the aquifer system with reasonable degree of accuracy.

The plotted resistivity curves indicate low resistivity values on the flanks with moderate values of 20–50 ohms metres within the Paleo-Channel. This is an indication of the Paleo-Channel flanks being inclined at an angle towards the middle section. The width and the thickness of the aquifer is estimated to 6 kilometres and 15 metres, respectively, with the discharge boundary occurring at Liboi on the Kenya-Somali border, a distance of 340 kilometres. Thus the method provides a tentative aquifer dimension.

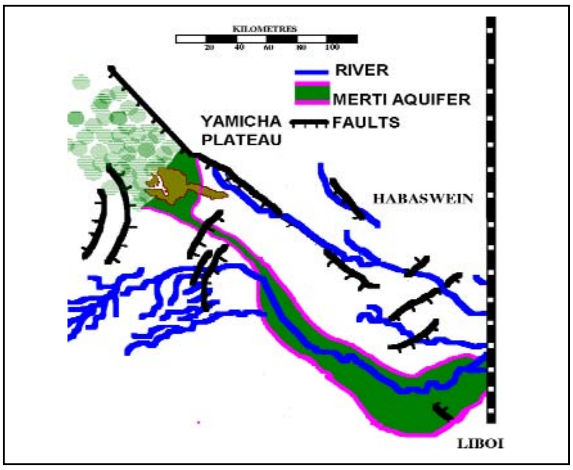

FIGURE 5. Paleo-Channel obtained from resistivity data

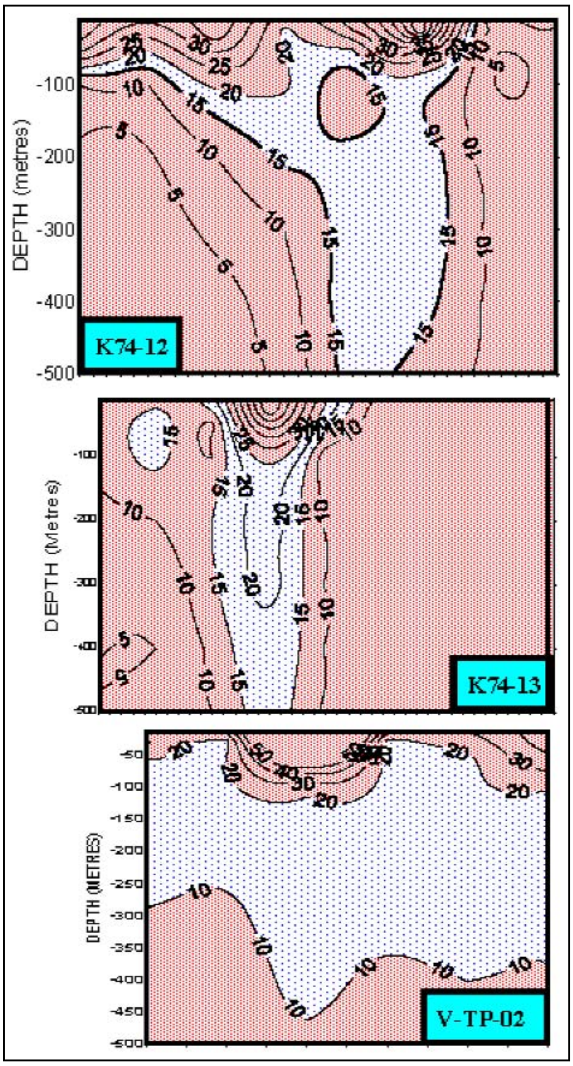

FIGURE 6. Apparent resistivity sections indicating width of fresh water Paleo-channel

■ Borehole data

There are several boreholes that have been drilled within and along the fresh zone of the Merti Aquifer. The Static water levels, water rest levels and borehole lithological logs have been recorded for all boreholes drilled within the Merti aquifer. Some of the boreholes have the Test Pumping data.

These data have been analysed to determine the approximate depth to the Aquifer, thickness a piezometric levels of the Aquifer, and the Aquifer and material. The test-pumping data during the borehole pumping and recovery phases of several boreholes has been analysed in order to deduce information on discharge, transmissivity and storage capacity.

Table 1 shows data of selected representative boreholes evenly distributed over the entire Aquifer length.

The boreholes between the Yamicha to the North of the Habaswein have yields ranging between 4–18 m^3/hr, while those between Habaswein and Daadab have yields averaging 8–15 m^3/hr. Boreholes between Daadab and Liboi, have yields ranging between 10–19 m^3/hr. The water struck levels range between 110–180 metres, while water rest level ranges between 110 and 140 metres below ground level. The hydraulic gradient between Habaswein and Liboi is 1.66 x 10^{-3}.

Borehole Number	*Locality*	*Depth (m)*	*Struck level (m bgl)*	*Rest level (m bgl)*	*Yield (m^3/hr)*	*Quality (MS/cm)*
C-3830	Sericho	129.5	118; 129	107	10.9	2.55
C-3893	Hadado	213	195	190	2.3	5.5
C-10094	Daadab	153.5	104-120	110	4.5	
C-3877	Sebule	131.97	96.9	94.7	8.2	
C-4176	Arba Jahan	109	104 -106	–	12.5	
C-4586	Yamicha	150	116; 130	128	3	
C-4587	Yamicha	164	120	123	2	
C-5795	Habaswei	156	124; 110	123	8.4	1.92
C-4699	Yamicha	170	33; 94	30.34	6	0.62
C-9758	Habaswei	130.5	86; 93.8	91.41	11	
C-9009	Liboi	123	93	88.12	9	
C-9384	Diri	170	112	108	3.5	1.2
C-9758	IFO	130.5	913	914	11.7	1.1
C-3684	Kulan	119.2	108.3	102.8	9.6	
C-9749	Ifo	141	110	108.8	6.9	
C-3684		119.2	108.2	102.7	6.9	

TABLE 1. Selected representative borehole data

Aquifer type

The Merti Aquifer is unconfined in some areas and semi-confined in other areas. The aquitards are comprised of clays and sandy clays, which are lacking in the areas where the Aquifer is unconfined. The Aquifer material comprises of sands and clayey sands.

Recharge

One of the catchment for the Merti Aquifer is the Yamicha-Marsabit area, whose average annual rainfall is 290 mm.

Groundwater movement from recharge area is controlled by on the available recharge, the aquifer characteristics and the mode of discharge. These conditions are not uniform in the project area mainly due to variations in precipitation in different recharge areas of the same system and geological conditions underground. Structural features such as the faults and lineaments contribute to the flow direction.

The groundwater flow is in two directions. In the northern part of the System, groundwater flow is in a south-eastern direction, while in the south it flows eastward.

The other main catchment is the Ewaso Nyiro whose source is the Aberdare Ranges and mount Kenya to the west. Intensive human activities and settlement on these catchments has reduced the flow in recent times.

From the above data, the recharge has been estimated to be 23,633 per hour assuming the flow is concentrated within the Ewaso Nyiro graben that extends through Habaswein.

The faulted basement boundary acts as one of the draining channels of the Ewaso Nyiro river towards the north and north-west but the flow along this fault zone is interrupted by other fracture systems trending in the north-west-south-east direction and moving beyond Sericho. These fracture systems drain the water back to the Ewaso Nyiro rift like graben and thus recharging the Merti Aquifer.

Tabulated below (Table 2) is miscellaneous flow measurements taken at various station in 1991, by MENR.

The open channel evaporation is insignificant compared to infiltration and seepage, which accounts for 99.8% of the flow. The latter amount percolates as groundwater and into the Merti Aquifer.

The Lagh Choichuff Lineament forming an almost a straight line, indicates partial but permanent recharge from a large catchment of Yamicha and Mt Marsabit to the north.

Station	*Evaporation m^3/day*	*Discharge cumecs*	*Discharge cumecs*
Archers Post		5.558	+2.421
Malka Daka	622.88	7.979	-3.203
Mertil	1551	4.776	-3.656
Sericho		1.12	

Table 2. Selected representative River gauging data

Assuming that only 4% of the total annual rainfall infiltrates into the ground and the recharge area is approximately 340 x 100 km^2. For each square kilometre of land therefore, 228.67 x 10^6 m^3 of water is recharged into the ground aquifer annually.

The assumed recharge may be underestimated considering information gap between Habaswein and Liboi and that the actual aquifer dimension is irregular both laterally and vertically. The figure serves as an ideal estimate for planning on abstraction and formulation of an abstraction future policy and as water demand increases.

Available groundwater

Based on an average thickness of 15 metres, a length of 340 kilometres and a width of 5 to 50 kilometres and that the aquifer material is not well sorted but is mainly composed of fine sands with a mean specific yield of 0.33 then the volume of water stored estimated is:

= 15 x 340,000 x 50,000 x 0.33 m^3 of aquifer volume
= 8.4 x 1,010 m^3 of the aquifer volume.

Underground flow

The underflow beneath the Liboi area can be computed from Darcy's Equation:

Q = T.W.I,

where

Q = Quantity; T= Transmisivity: W=Width:
I= Hydraulic Gradient. I = 1.66 x 10^{-3};
W = 50 Kilometres; T = 80 m^2/day.

Thus the underflow at Liboi is
= 80 x 50,000 x 1.66 x 10^{-3}
=6,640 m^2/day.

Swarzenski and Mundroft (1977) established the flow to be 7,200 cubic metres per day.

Water quality

There are very few monitoring boreholes that are observed along the length of the aquifer. The actively monitored boreholes are at refugee camps in Ifo, Hargadera, Dagahaley and Liboi near Kenya/Somali border.

Although the monitoring boreholes are few, they are ideal since they are located towards the end of the aquifer as it enters Somali.

The data obtained from these boreholes reportedly indicate no adverse fluctuations in terms of quality and quantity. This implies that the aquifer has not undergone any kind of strains.

More monitoring boreholes have been proposed to be drilled at 20 kilometres intervals between Yamicha all the way to Liboi.

For a typical Habaswein groundwater, electrical conductivity ranges from 1,000 to 1,900 µS/cm and Urura groundwater 1,400 µS/cm. The waters from both C-3830 and C-3893 are clearly not potable. The electrical conductivity decreases with increasing proximity to the Lagh Dera.

Most of the groundwater in the marine sedimentary rocks is fossil and saline, but part of it has been replaced by fresh water infiltrating into the aquifer.

Conclusion/Recommendations

The primary aim of analysing information was achieved in this study. An integrated approach was useful in delineating the fresh/saline water zones and hence estimates on the aquifer dimension and potential. Consequently, it was possible to confirm the hypothesis that the fresh water zone within the Merti Aquifer is limited both laterally and vertically.

It is further observed that a future development needs an integrated approach and use of mutually agreed guidelines for water quantity quality and seasonal variations.

This paper concludes that whereas Yamicha-Habaswein area has been fairly established in terms of information on Aquifer characteristics the rest of the Aquifer from Habaswein to Liboi on the Kenya-Somali border has not been well established. Where applied, the integrated groundwater survey method has been found to be more reliable in accurately mapping the Aquifer geometry and potential areas for development.

- Monitoring systems should be put in place to facilitate data collection;
- Further integrated surveys on Merti Aquifer from Habaswein towards Liboi on Kenya-Somali border should be carried out;
- Increase co-ordination between water development authorities between Kenya and Somali;
- Facilitate co-ordination between the water Department and other stakeholders in development;
- Facilitate co-ordination among various stakeholders to ensure that catchment area management is treated as part of the water project management;
- Train and empower communities to start income generating projects using the water resources available.

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