HYDROGEOLOGICAL SURVEY REPORT

FOR

FATIMA CHILDREN HOME

P.O. BOX 215-60500,

MARSABIT.

SITING OF ONE BOREHOLE ON A 10 ACRES PLOT LOCATED WITHIN DIRIB GOMBO VILLAGE, GADAMOJI SUB LOCATION, MARSABIT COUNTY

REPORT COMPILED

MR. BERNARD C. MUHANG'U
(Reg/LICENSE No. WD/WP/194)
Consulting Hydrogeologist

AUGUST 2017.

SUMMARY

Marsabit County is situated in the former Eastern Province, while the Marsabit Town is almost surrounded by the Marsabit National Park and Marsabit National Reserve. The town is located 170 km east of the center of the East African Rift, at 37°58' E, 2°19' N (37.97°E, 2.32 N). Marsabit is approximately 550 kilometers or 7 - 8 Hour drive from Nairobi via the towns of Isiolo and Archers Post. It serves as the capital of Marsabit County, and lies southeast of the Chalbi Desert in a forested area known for its volcanoes and crater lakes and others.

The St. Paul Parish under the Diocese of Marsabit is located 12 kilometres to the south-east of the Marsabit Town. The parish is within Dirib Gombo market and has 6 sisters, 4 priests, a secondary school, a dispensary with 40 patients attended daily, **Fatima Children Home** with 30 children boarding and 10 acres of land.

Fatima Children Home targets abandoned and vulnerable rural children, predominantly pastoral, communities in the arid and semi-arid areas in Marsabit. The home takes care, health, wellbeing and educate the abandoned children in the society. The Institution depends on support from well-wishers and donors to run and sustain the operations of the home through **Sister Mary** and her colleagues.

This report summarizes and describes the results of groundwater resources assessment study carried out within the children home and nearby areas of Dirib Gombo. The purpose of the study was to identify 1Nos borehole that would meet the water demand challenges faced by the institutions and the community within Dirib Gombo area.

The report outlines the hydrogeological study carried out in the project area to arrive at the conclusions and recommendations given at the end of this report and is based on the findings and analysis of data from the desk study, field reconnaissance, geophysical survey, and analysis of existing hydrogeological and previously drilled borehole data.

The general subsurface geology of the project area is composed of superficial deposits of red loamy soils, Basalts lava flows and the Basement System in that stratigraphic succession. The project area can be described as being of variable groundwater resources potential.

The report recommends: -

- That any aquifer struck between 0 metres and **10 metres** below ground level should be sealed off completely with clay/bentonite or neat cement grout to ensure the borehole water is protected from surface seepage.
- That a borehole should be authorized for drilling at the selected site to a **maximum depth of 250 metres** to tap the deeper unexploited aquifer(s).
- The site is pegged on the ground for ease of identification.
- The quality and the quantity of groundwater at the proposed site are expected to be good.

The report is accompanied by maps, geophysical data and curves.

The VES survey sites are marked on the topo map/satellite imagery extract and are also marked on the ground for ease of identification.

The recommended and pegged site is known to the **Sister In-charge (Sr. Mary 0723101567).**

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ABBREVIATIONS AND GLOSSARY OF TERMS

ABBREVIATIONS (S.I. Units throughout, unless indicated otherwise)

agl	above ground level
amsl	above mean sea
level bgl	below ground level
DWR	Department of Water Resources
E	East
EC(µS/cm)	Electrical conductivity
GSK	Groundwater Survey (K)
Ltd	
hr	hour
l	litre
m	metre
N	North
PWL	pumped water level
Q	discharge (m^3/hr)
s	drawdown
(m) S	South
SWL	static water level
T	transmissivity (m^2/day)
VES	Vertical Electrical Sounding
W	West
WAB	Water Apportionment Board
WSL	water struck level
µS/cm	micro-Siemens per centimeter: Unit for electrical conductivity
°C	degrees Celsius: Unit for temperature
"	Inch

GLOSSARY OF TERMS

Aquifer A geological formation or structure, which stores and transmits water and which is able to supply water to wells, boreholes or springs.

Conductivity Transmissivity per unit length (m/day)

Confined aquifer A formation in which the groundwater is isolated from the atmosphere by impermeable geologic formations. Confined water is generally at greater pressure than atmospheric, and will therefore rise above the struck level in a borehole.

Development In borehole engineering, this is the general term for procedures applied to repair the damage done to the formation during drilling. Often the borehole walls are partially clogged by an impermeable "wall cake", consisting of fine debris crushed during drilling, and clays from the penetrated formations. Well development removes these clayey cakes, and increases the porosity and permeability of the materials around the intake portion of the well. As a result, a higher sustainable yield can be achieved.

Fault A larger fracture surface along which appreciable displacement has taken place.

Gradient The rate of change in total head per unit of distance, which causes flow in the direction of the lowest head.

Hydraulic head Energy contained in a water mass, produced by elevation, pressure or velocity.

Hydro geological Those factors that deal with subsurface waters and related geological aspects of surface waters.

Infiltration Process of water entering the soil through the ground surface.

Joint Fractures along which no significant displacement has taken place.

Percolation Process of water seeping through the unsaturated zone, generally from a surface source to the saturated zone.

Perched aquifer Unconfined groundwater separated from an underlying main aquifer by an unsaturated zone.

Downward percolation hindered by an impermeable layer.

Permeability The capacity of a porous medium for transmitting fluid.

Piezometric level An imaginary water table, representing the total head in a confined aquifer, and is defined by the level to which water would rise in a well.

Porosity The portion of bulk volume in a rock or sediment that is occupied by openings, whether isolated or connected.

Pumping test A test that is conducted to determine aquifer and/or well characteristics.

Recharge General term applied to the passage of water from surface or subsurface sources (e.g. rivers, rainfall, and lateral groundwater flow) to the aquifer zones.

Specific capacity The rate of discharge from a well per unit drawdown.

Static water level The level of water in a well that is not being affected by pumping. (Also known as "rest water level")

Transmissivity A measure for the capacity of an aquifer to conduct water through its saturated thickness (m^2/day).

Unconfined Referring to an aquifer situation whereby the water table is exposed to the atmosphere through openings in the overlying materials (as opposed to confined conditions).

Yield Volume of water discharged from a well.

1. INTRODUCTION

This report has been prepared as part of the Contract for Consultancy Services for **Fatima Children Home** who provide support to abandoned and vulnerable rural children, predominantly pastoral, communities in the arid and semi-arid areas in Marsabit. The home takes care, health, wellbeing and educate the abandoned children in the society.

The Institution depends on support from well-wishers and donors to run and sustain the operations of the home through **Sister Mary** and her colleagues. Consideration of groundwater to augment the current water sources to the institution was done and a hydro-geological survey was deemed necessary in order to come up with possible sites and estimated depths for sinking of a boreholes.

In order to achieve this, the Client commissioned a Consultant, to carry out a hydrogeological survey of the prioritized areas and identify 1 No suitable site for borehole sinking.

2. TERMS OF REFERENCE

The Consultant will undertake for the Client to carry out a hydrogeological survey of selected rural community area of the project area and subsequently identify ONE (1) possible shallow well site and present a hydrogeological report under the following terms:

- Go through a thorough literature review regarding the geology of the area to back up the report and study outcomes. This should include, but not limited to study location, physiographic, regional and local drainage, rainfall and climate, and water demand.
- Technically assess the geology of the proposed site/area in terms of, but not limited to, regional geology, geology of the project area, basalts, and structural geology.
- Conduct Hydrogeology, using up to date tools and equipment to ascertain the hydrogeology of the project area, previous ground water development, aquifer parameters, hydraulic conductivity (K) or the ground flux, ground water discharge, as well as estimating the mean annual recharge.
- Perform Geophysics relating to basic principles, and Vertical Electrical Soundings within the proposed area.
- Check on site conditions including the availability of space for a drilling rig and other allied machineries to access the project area.
- Analyze the data aforementioned to assess the ground water potential in the project area.
- Select the MOST SUITABLE borehole site within the project area subject to the above results and taking into account the water quality expected and the requirements of the Water Act, WHO, and other line ministries.
- Compile and submit to the client a comprehensive report, which shall include all the details of the above investigations and the Consultant's recommendations on the proposed well site. Produce three copies of the geosurvey report, of which one is colored.

3. BACKGROUND INFORMATION

3.1 General Description of the Project area.

The town is situated on an isolated extinct volcano, Mount Marsabit, which rises almost a kilometer above the desert (1450m). The hills here are heavily forested, in contrast to the desert beyond, with their own "insular" eco-system. The town currently has a population of about 5,000.

The town is mainly inhabited by the Cushitic-speaking Borana, Burji, Gabbra and Rendille. There are also some Nilotic Turkana and Bantu Ameru residents. Additionally, there are a few Somali traders.

The upgrading of sections of the Isiolo – Moyale road to bitumen standard has greatly improved the transportation of goods and services in the county. This has greatly boosted cross-border trade between Kenya and Ethiopia. Marsabit is approximately 550 kilometers or 7 - 8 Hour drive from Nairobi via the towns of Isiolo and Archers Post. Accessing the town was previously a challenge as you had to either hang on top of the trucks or hike lifts in government vehicles. Currently, there are multiple bus services which ply the Isiolo - Marsabit route on a daily basis. It leaves Isiolo for Marsabit at 8pm, arriving between 3 - 5am and leaves Marsabit at 8am arriving in Isiolo between 3 - 7pm. In addition to this, there are other buses which ply the Nairobi - Moyale route, through Marsabit.

The road has been recently paved and connects all the way to the Kenya-Ethiopia Border at Moyale. It is approximately 277 kilometers from Isiolo and takes between 3 and 4 hours. Marsabit has one airstrip servicing charter aircraft close to town about 10 minutes' drive towards Moyale (Marsabit Airstrip) and a mountain peak (Mount Marsabit), with "singing" wells just outside the town. Elephants can also often be seen in the local wildlife refuge that surrounds the town, occasionally breaking down fences and causing damage to local farmers crop beds.

Marsabit town is a trading and commercial center, with three petrol stations, three commercial banks, post office, shops, restaurants, lodges and even a dry cleaner. The town facilitates the supply and movement of goods and services between Moyale (goods from Ethiopia) and Isiolo (goods from Nairobi). Agriculture also plays a role, as many grow millet and maize to be consumed locally and nomadic people supply beef by selling their cows. The main traded goods in urban centres and local markets are livestock, fruits, vegetables, maize, beans, wheat, millet and teff - a cereal mostly cultivated in Ethiopia. Most of the maize and beans comes from other counties whereas some fruits and vegetables come from Ethiopia through Moyale, the border town.

Lake Paradise (which attracts game animals such as elephants and buffalo), and Bongole Crater located in the heart of the forest are both local attractions for tourists. The town and surrounding area are of rich cultural interest to anthropologists and other researchers.

Fatima Children Home with 30 children boarding and 10 acres of land is located in Dirib Gombo about 12 kilometres to the south-east of the Marsabit Town. The institution is accessible through a murrum road.

Location:
37 + 395928
252589
Elevation: 957m above sea level.

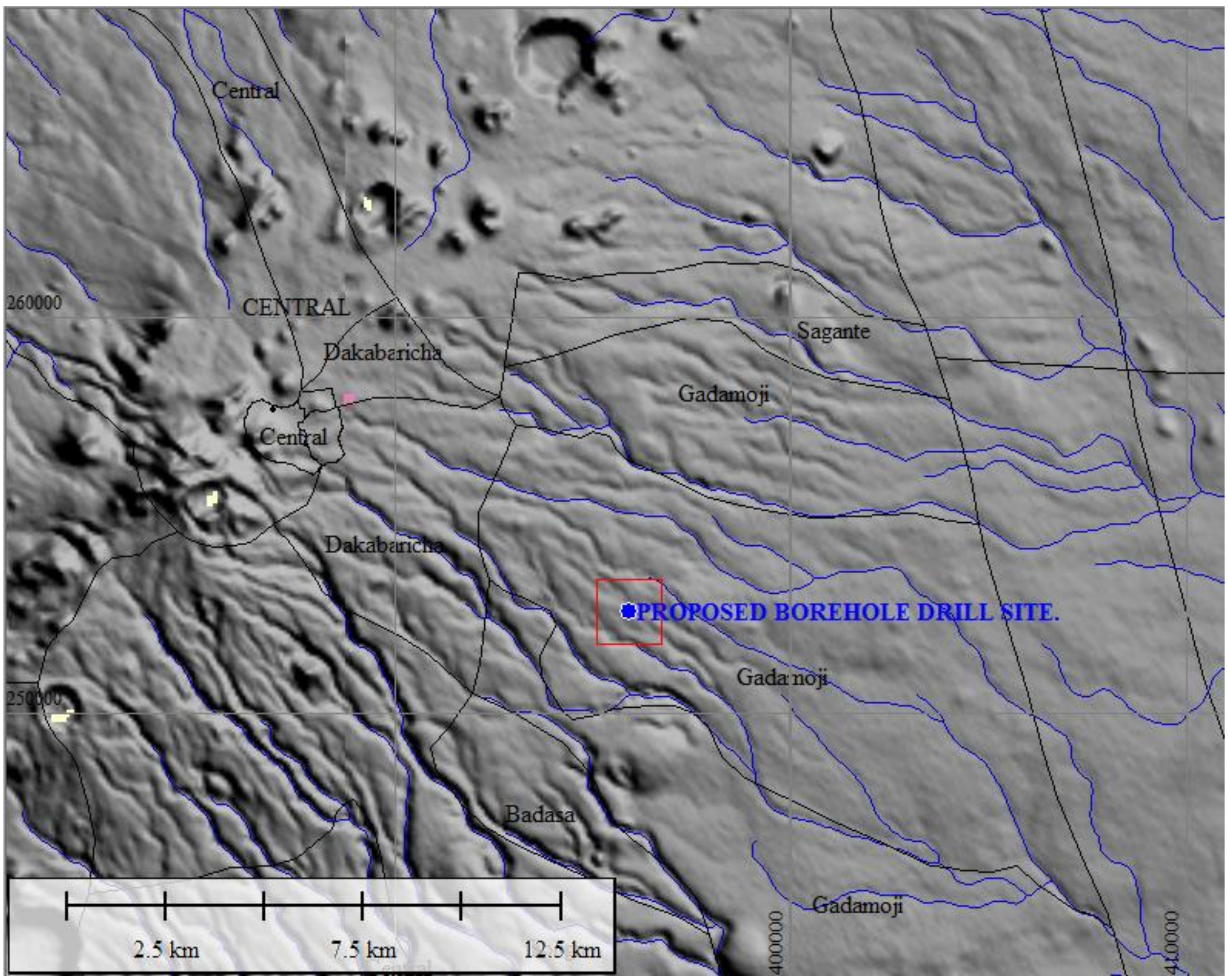
Satellite imagery shoeing the accessibility from Marsabit Town to Dirib Gombo Market.

Zoomed-in Satellite imagery showing the Fatima Children Home location in Dirib Gombo Market.

3.2 Topography

Most of the county constitutes an extensive plain lying between 300 and 900m above sea level, sloping gently towards the south east. The plain is bordered to the west and north by hills and mountain ranges and is broken by volcanic cones and calderas. The most notable topographical features of the county are Ol Donyo Ranges (2,066m above sea level) in the south west, Mt. Marsabit (1,865m above sea level) in the central part of the county, Hurri Hills (1,685m above sea level) in the north eastern part of the county, Mt. Kulal (2,235m above sea level) in the north west and the mountains around Sololo-Moyale escarpment (up to 1,400m above sea level) in the north east. The main physical feature is the Chalbi Desert which forms a large depression covering an area of 948 sq km, lying between 435 and 500m elevation. The depression is within the Great Rift Valley and is separated from Lake Turkana, which is 65 -100m lower in elevation, by a ridge that rises to 700m.

The eastern part of the County that including Dirib Gombo area consists of a gently lying slope at about 1,000 to 500 metres above mean sea level (amsl), associated with the end-Tertiary erosion level. The Pleistocene Basaltic flows originating from the Eastern slopes of Mount Marsabit has covered large areas of this surface. The highest area is formed by the Mt. Marsabit rising to 1,865 m amsl. The larger part of the eastern part of the project area (Dirib Gombo and surrounding areas) is a gently sloping, low-lying, plain resulting from the weathering of the friable tertiary volcanics.



Terrain map of the Marsabit and surrounding areas.

3.4 Rainfall and Climate

The general project area falls into three agro-climatic zones, namely: semi-arid, arid and very arid. Most parts of the county are arid with the exception of high potential areas around Mt. Marsabit, Mt. Kulal, Hurri Hills and the Moyale-Sololo escarpment. The county experiences tropical climatic conditions with extreme temperatures ranging from a minimum of 150 C to a maximum of 26o C, with an annual average of 20.50 C (World Weather and Climate Information, 2015). Rainfall ranges between 200 and 1,000mm per annum and its duration, amount and reliability increases as altitude rises. North Horr (550m) has a mean annual rainfall of 150mm; Mt. Marsabit and Mt. Kulal 800mm while Moyale receives a mean annual rainfall of 700mm.

Climate data for Marsabit [hide]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average high °C (°F)	25.0 (77)	25.7 (78.3)	25.7 (78.3)	24.9 (76.8)	24.8 (76.6)	24.4 (75.9)	23.8 (74.8)	24.1 (75.4)	25.1 (77.2)	25.2 (77.4)	23.8 (74.8)	24.2 (75.6)	24.7 (76.5)
Average low °C (°F)	15.7 (60.3)	15.9 (60.6)	16.2 (61.2)	16.7 (62.1)	16.1 (61)	14.6 (58.3)	13.8 (56.8)	13.5 (56.3)	14.0 (57.2)	15.4 (59.7)	16.0 (60.8)	15.9 (60.6)	15.3 (59.5)
Average precipitation mm (inches)	92 (3.62)	60 (2.36)	91 (3.58)	149 (5.87)	54 (2.13)	14 (0.55)	17 (0.67)	8 (0.31)	9 (0.35)	62 (2.44)	91 (3.58)	46 (1.81)	693 (27.28)
Average precipitation days	6	3	7	9	5	4	3	4	2	6	9	6	64

Source: World Meteorological Organization[3]

3.3 Regional Drainage

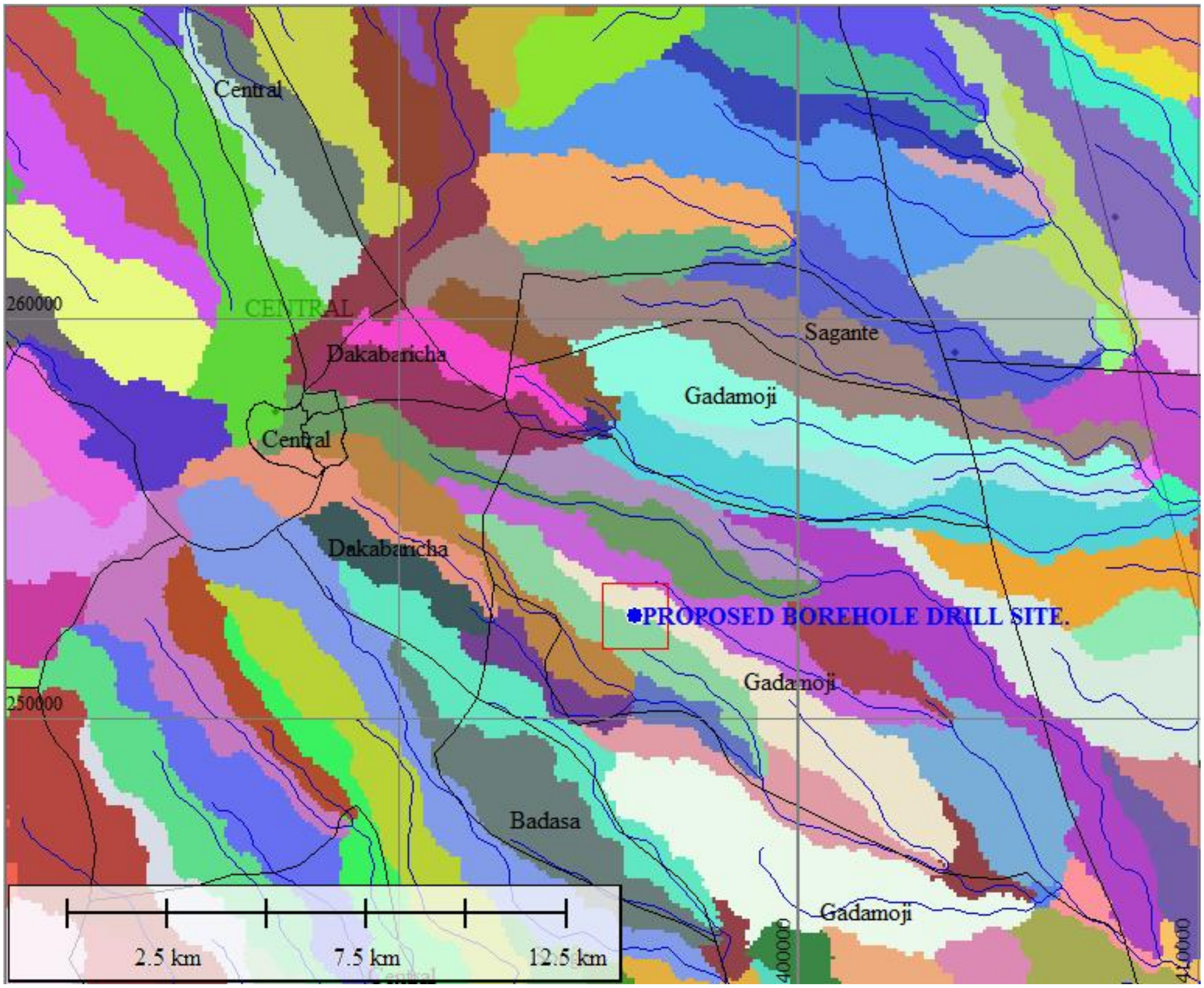
There are no permanent rivers in the county, but four drainage systems exist, covering an area of 948 sq km. Chalbi Desert is the largest of these systems. The depression receives run-off from the surrounding lava and basement surfaces of Mt. Marsabit, Hurri Hills, Mt. Kulal and the Ethiopian plateau. The seasonal rivers of Milgis and Merille to the extreme south flow eastward and drain into the Sori Adio Swamp. There are no permanent rivers in the county, but four drainage systems exist, covering an area of 948 sq km. Chalbi Desert is the largest of these systems. The depression receives run-off from the surrounding lava and basement surfaces of Mt. Marsabit, Hurri Hills, Mt. Kulal and the Ethiopian plateau. The seasonal rivers of Milgis and Merille to the extreme south flow eastward and drain into the Sori Adio Swamp. Other drainage systems include the Dida Galgallu plains which receive run-off from the eastern slopes of Hurri Hills, and Lake Turkana into which drain seasonal rivers from Kulal and Nyiru mountains.

3.4 Local Drainage

Drainage patterns represented in the project are radial, dendritic, sub-parallel and rectangular. These patterns are related to the underlying geology and structure. The radial drainage pattern is dominant on the Cenozoic volcanics in the south of the area, well displayed on the northern and north-western slopes of Mount Marsabit and to a small extent in the south-east, including the area west and south-west of Dirib Gombo. This pattern is thus associated with the regional radial system of the Mount Marsabit massif.

Mt. Marsabit is an important water tower in north eastern Kenya. It functions as a recharge point for water sources in the area which emanates from mist condensate on species of saprophytic moss plants living on indigenous forest trees. The forest has two crater lakes, namely, Paradise and Elephant Pool.

The rivers, streams and gullies have down-cut deep into the lava to produce, particularly in their upper reaches, steep-sided, deep and narrow 'V'-shaped valleys: lower down the valleys broaden, the gradients of the valleys are gentler and the valley floors form flood plains. The rivers forming part of the radial pattern in the area eventually join major tributaries that later form parts of the modified, broadly dendritic system of the Ewaso Ng'iro Basin.



4. GEOLOGY

5.1 Regional Geology

The geology of the project area has been described in the "the Key, R. M., et al (1987) Geology of the Marsabit area – Report 108, Mines and Geology Department, Ministry of Environment and Natural Resources." In general, the geology is characterised by two major geological and lithological systems, the Pre-Cambrian Basement System and the younger Tertiary basaltic lavas.

The Basement System rocks are the oldest in the area being of Precambrian age, and underlie the entire project area. They comprise migmatites, several groups of paragneisses and a variety of intrusives. The paragneisses have been interpreted as meta-sediments ranging from arkoses and sandstones through muddy sandstones to carbonaceous mudstones and limestones. These rocks were affected by a complex sequence of six tectonothermal episodes, which have been dated as late Proterozoic to Cambrian on the basis of radiometric ages from intrusives, which range in composition from granite and trondhjemite through syenitic orthogneiss to amphibolite and ultramafics.

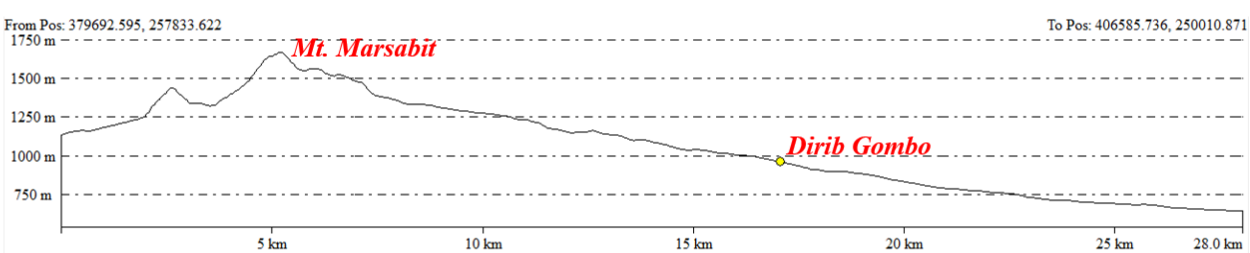
The younger volcanic rocks found in the Dirib Gombo area, are all associated with Mt. Marsabit volcanic activity. The oldest of these rocks are the Miocene phonolites. The volcanics especially those in the south are dominated by the contemporary suites of lava and pyroclastics making up the Mt. Marsabit. In the project area the Basalts form alternating major unit at least 200 m thick with local centres of a more trachytic composition, overlying the Basement rocks.

The rest of the eastern portion of the project area is part of the Anza Basin and as such is dominated by the sedimentary rocks which are sporadically overlain by volcanic rocks as a result of either isolated fissures or lava flow from the Marsabit area.

Most of the colluviums and calcrete in the project area is believed to have been deposited during a time of rapid climatic fluctuation when there was intense weathering followed by erosion and deposition of the weathered material.

5.2 Structural Geology

From the geological map, faults affecting the sedimentary and basement rocks have been indicated. These faults have a general south-west to north-east trend.



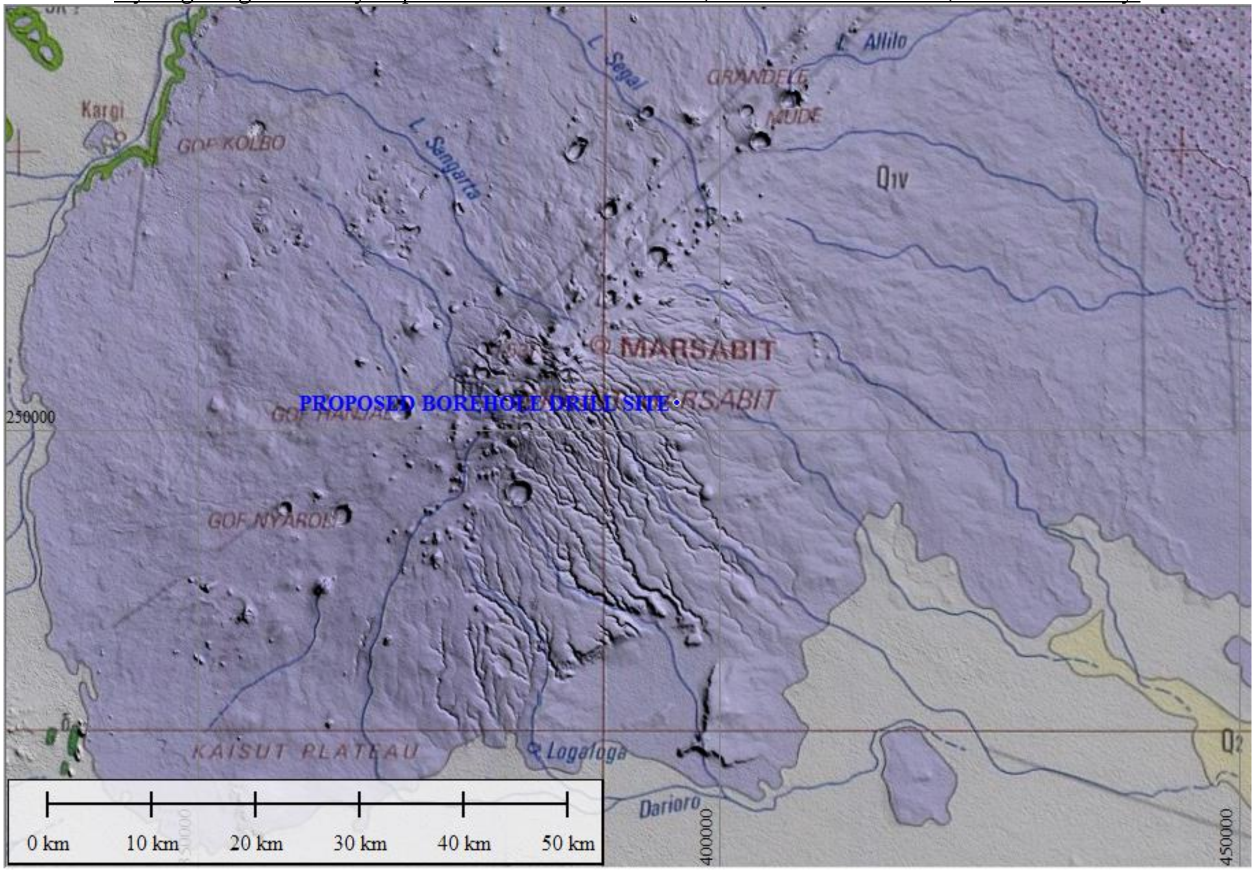
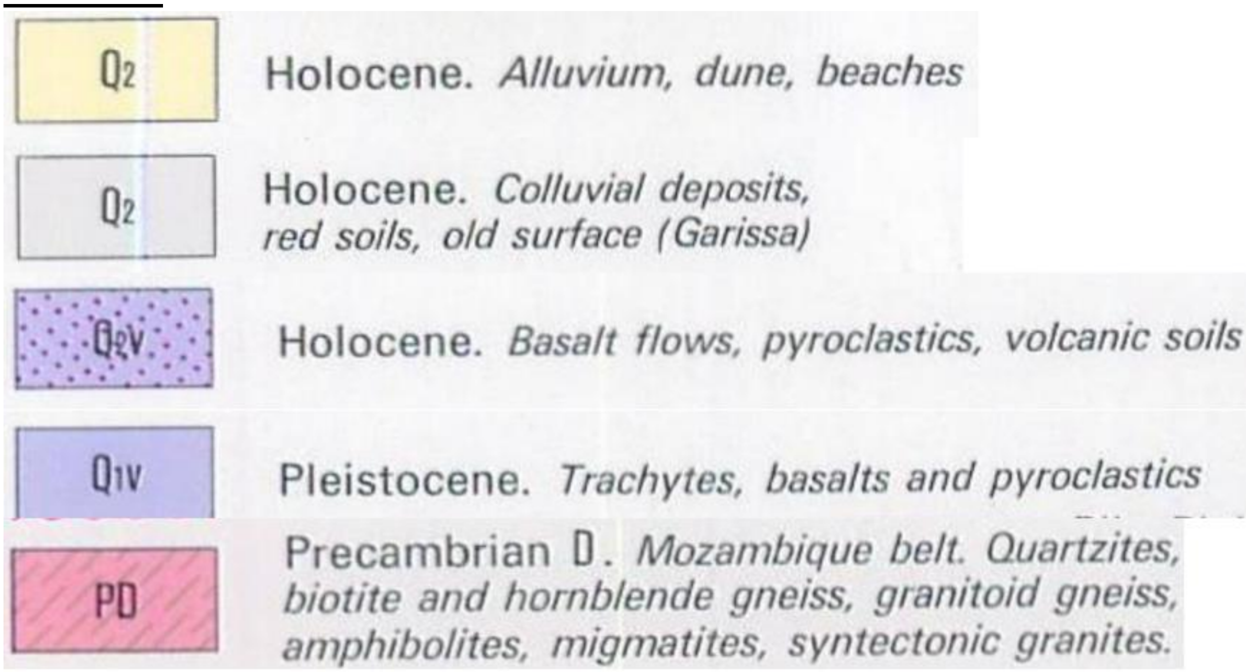
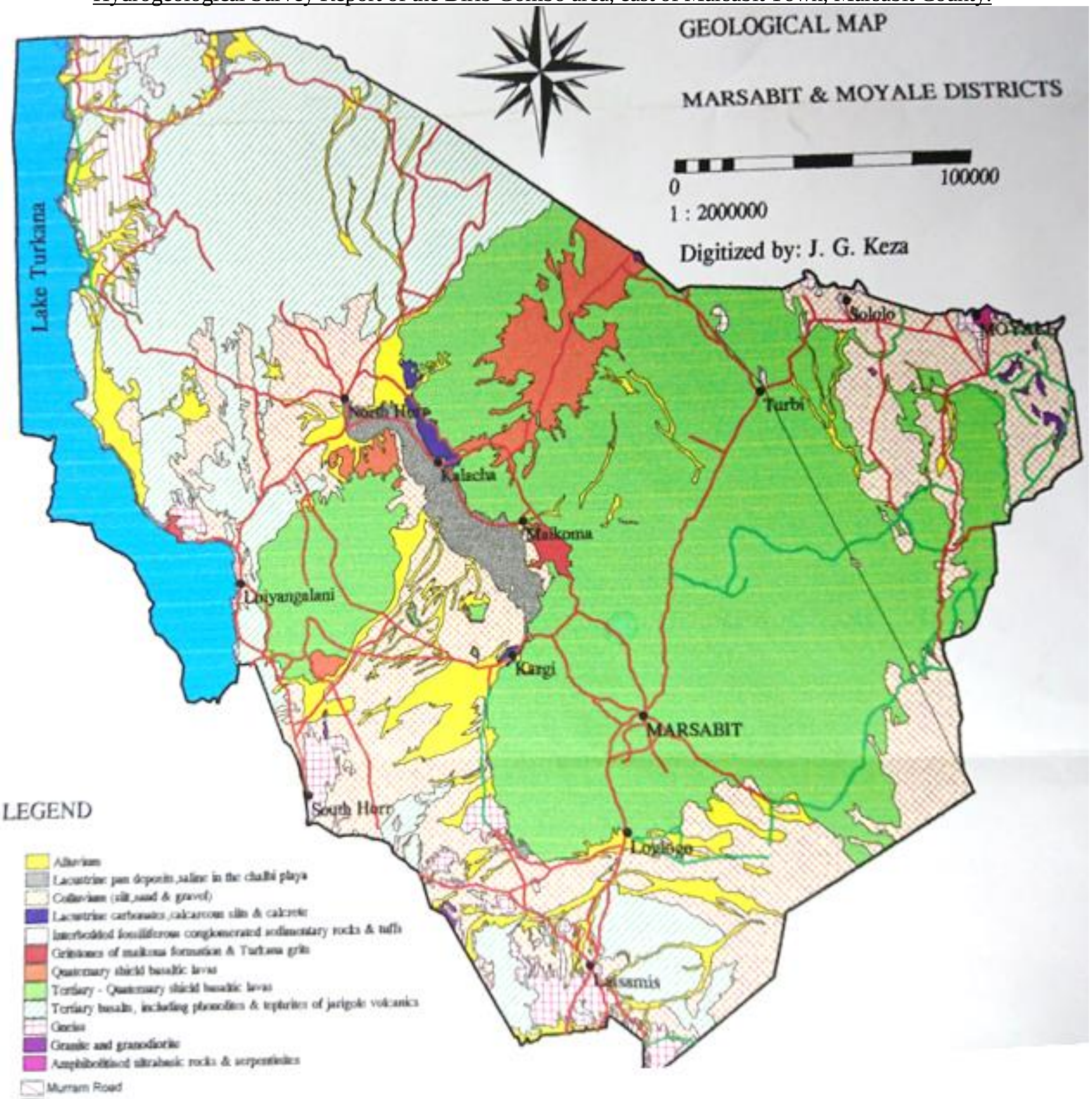


Figure 4: *Geological map of the general project area.*

LEGEND



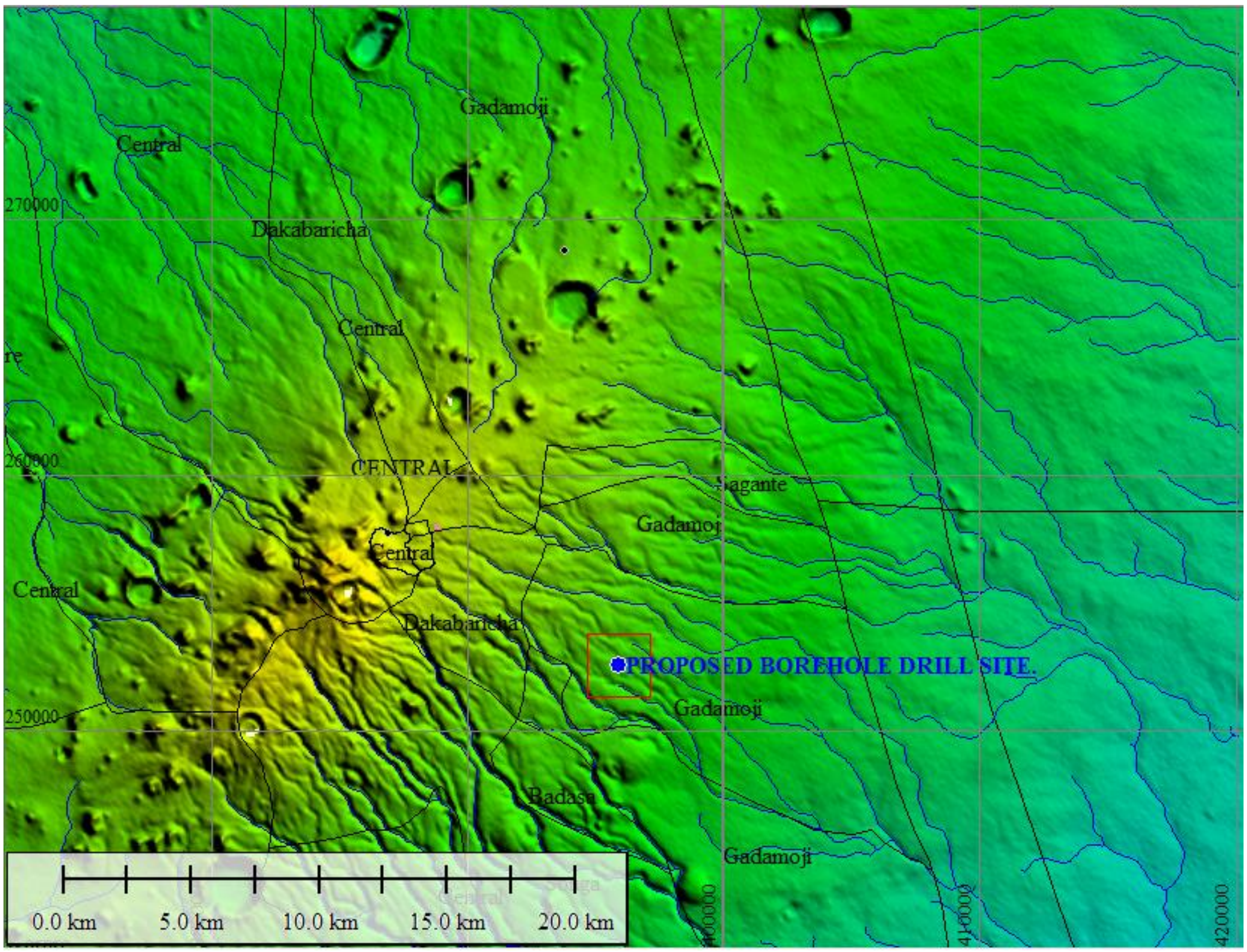

GEOLOGICAL MAP
MARSABIT & MOYALE DISTRICTS
0
100000
1 : 2000000
Digitized by: J. G. Keza
Lake Turkana
Sololo
MOYALE
Turbi
North Horr
Kalacha
Maikona
Loiyangalani
Kargi
MARSABIT
South Horr
Logologo
Laisamis
LEGEND
Alluvium
Lacustrine pan deposits,saline in the chalbi playa
Colluvium (silt,sand & gravel)
Lacustrine carbonates,calcareous silts & calcrete
Interbedded fossiliferous conglomerated sedimentary rocks & tuffs
Gritstones of maikona formation & Turkana grits
Quaternary shield basaltic lavas
Tertiary - Quaternary shield basaltic lavas
Tertiary basalts, including phonolites & tephrites of jarigole volcanics
Gneiss
Granite and granodiorite
Amphibolitised ultrabasic rocks & serpentinites
Murram Road

5. WATER RESOURCES

5.1 Surface Water Resources

The surface water drainage channels are dry river beds (lagas) which only carry water during and after the rains. The surface water drainage system is influenced by the geology and topography of the areas.

A number of water harvesting have been put in place but are dry as the surface water are quite unreliable due to the poor rainfall as well high evaporation. At the time of the survey a few water pans had water which lasts for few days and then are run dry.



Watershed areas and drainage systems within the general area.

5.2 Groundwater Resources

5.2.1 Shallow groundwater potential

The shallow groundwater occurs around Marsabit town and are tapped by means of hand-dug wells that are almost usually unconfined and well digging is usually stopped only after few metres after striking water. To take into accounts the seasonal fluctuations in water levels, wells are deepened during dry seasons.

Shallow groundwater may be developed in the following zones:

i) Unconsolidated alluvial sediments of lagas
ii) Consolidated but porous sediments along buried streams.
iii) In buried valleys originating from outwash fans
iv) Fractured tertiary basalts
v) Areas where laggas cross vesicular lavas and pyroclastics as the eastern slope
vi) Dry River beds (Laggas) in fractured metamorphic complexes of the Mathews Ranges.

The potential of most of the shallow groundwater occurs in and at the banks of seasonal streams known as laggas. They draw their recharge from percolating seasonal streams run-off which enters groundwater zones as bank storage and perched aquifers below the streams bed. There is no potential for shallow well development within Dirib Gombo due to presence of hard fresh volcanics found few metres below the soil.

5.2.2 Deep groundwater potential

Deep groundwater potential occurs at greater depths and have fair water quantity and quality. These aquifers are classified under the Ewaso Ngiro North Catchments aquifers.

Groundwater occurrence within the project area is expected to occur at multi-aquifer systems in volcanic areas. The water bearing materials includes fractured lava, pyroclastics and intervolcanic sediments (old erosional surfaces).

The boreholes sunk in the region have discharge ranging from 3 m^3 per hour to 7m^3 per hour. The water quality in this zone is generally fresh with low electrical conductivity values of less than 1000microsiemens per cm.

The aquifers found in the Dirib Gombo basin are largely consists of groundwater occurring in weathered and fractured zones of basement gneisses with depth to water being less than 300 metres.

6. HYDROGEOLOGY

6.1 Introduction

The hydrogeology of an area is determined by the nature of the parent rock, structural features, weathering processes and precipitation patterns. Within volcanic rocks, groundwater primarily occurs within fissure zones, fractures, sedimentary beds, lithological contacts and Old Land Surfaces (OLS) which characterize periods of erosion between volcanic eruptions and subsequent lava flows. These OLS's comprise soils, weathered rocks and water-lain erosional material of volcanic origin. Lava flows rarely possess significant pores pace; instead, their porosity is largely determined by secondary features, such as cracks. However, pyroclastic deposits and especially sediments do have a primary porosity: the cavities between the mineral grains or clasts are usually open and interconnected. Consequently, they can contain and transmit water and are therefore potential aquifers

6.2 Groundwater Recharge

The recharge mechanisms (and the rate of replenishment) of the local aquifers has not been fully established. The two major processes are probably direct recharge at surface (not necessarily local) and indirect recharge via faults and/or other aquifers.

Direct recharge is obtained through downward percolation of rainfall or river water into aquifer. If the infiltration rate is low due to the presence of an aquiclude (such as clay), the recharge to the aquifer is low. Percolation will depend on the soil structure, vegetation cover and the state of erosion of the parent rock. Rocks weathering to clayey soils naturally inhibit infiltration and downward percolation.

In the case of regional aquifer systems, it is possible to have the recharge occurring on one side of the aquifer and the groundwater traveling through the aquifer to its distant sections where it is either stored or discharged naturally as springs or swamps.

Areas of high altitude and therefore with higher rainfall and good vegetation cover are usually the commonest groundwater recharge zones in the project area.

In most cases the direction of groundwater flow tends to follow the surface water flow. Therefore the surface water flow direction can be employed to make a general assessment of the groundwater flow direction. The groundwater flow directions within the project area tend to take a south easterly direction.

Below is a tabulation of existing boreholes close to the proposed borehole drill site.

	BH No.	TD	Water Struck Level	Water Rest	Yield	PWL
		(m)	(m)	(m)	(m3/hr)	(m)
1	ST. PAUL SEC. SCH.	73	-	-	1.00	-
2	C-4582	250	86.5; 155; 177; 234	82; 114.37	Water disappeared	
3	C-4583	130	76; 80-94; 96; 110	72.5	7.56	72.5
4	Mosque Borehole	-	NO DATA	-	NO	DATA

6.3 Determination of Aquifer Parameters

6.3.1 Aquifer Characteristics

The ground water is constantly moving very slowly over extensive distances from areas of recharge to areas of discharge. In this connection, an aquifer performs two functions – a storage function and a conduit function. Consequently, it detains varying quantities of water in transient storage. Two properties of an aquifer related to its storage function are its porosity and its specific yield.

Given the information from the existing borehole data, an attempt will be made to determine potential yields by looking at the following parameters of selected/available borehole test pumping data in the identified sites:

6.3.2 Borehole Specific Capacity

Specific Capacity of a borehole is its yield per unit of drawdown, usually expressed in cubic meters per hour per meter of drawdown. The objective is to obtain information on the performance and efficiency of the borehole being pumped. The data taken under controlled conditions give a measure of the productive capacity of the completed borehole and provide data upon which the selection of the pumping equipment can be based.

It can be calculated based on the formula S=Q/s (Driscoll, 1986), where Q is the yield during the pump test and s is the drawdown (the difference between the water rest level and the pumping water level).

$$S = \text{Discharge in } m^3/hr \,/\, \text{Drawdown in } m$$

6.3.3 Aquifer Transmissivity

From hydrogeological point of view, it has been established that formations made entirely of coarse, unconsolidated materials like gravel give relatively high yields to boreholes constructed in them. Because of the large particle sizes in such formation, the pores or voids are large. The large pores offer less resistance to water flow than the smaller pores in finer sands, so more water will flow through each square meter of the coarser material under any given pressure difference.

This is to say that the permeability of the coarser material is greater than the permeability of the fine material.

Aquifer Transmissivity is calculated using the formula T= 0.183Q/s. However, this formula is applicable where pump testing data is available in log scale.

The alternative is to use Logan's formula (Logan, 1964), that is T=1.22Q/s which gives a fair indication of the value of aquifer transmissivity.

6.3.4 Specific Yield

The quantity of water that a unit volume of the material will give up when drained by gravity is called Specific Yield. Due to lack of specific aquifer tests, specific yields are difficult to determine. However, studies have been carried out on specific yields of various geological materials which give indications of specific yield ranges for selected Earth Materials (Driscoll 1986) as indicated below:

Item of Earth Materials Specific Yield %:

Sediment	Specific Yield, %
Clay	1 – 10%
Sand	10 – 30%
Gravel	15 – 30%
Sand and Gravel	15 – 25%
Sandstone	5 – 15%
Shale	0.5 – 5%
Limestone	0.5 – 5%

The table below gives a summary of the aquifer parameters within the study area.

Bore Hole Serial No.	SPECIFIC CAPACITY Sc=	TRANSMISSIVITY T=1.385xSc	HYDRAULIC CONDUCTIVITY k=T/D
C-4583	0.104	0.142	0.00473

6.4 Groundwater Quality

In Marsabit County, high fluoride values are found in the volcanic areas. The water is of the Na+K – CO^3 type. It is classified as generally good for domestic, livestock and irrigation use. Water from the Basement areas is also generally good and is of the Ca – Mg – HCO^3 type.

In the Marsabit - Merti Aquifer, groundwater quality is good along the Ewaso Ng'iro River channel's axis. Away from this axis, the water quality deteriorates as the salinity increases with increasing distance from the river channel. The outer margin of the aquifer is not clearly defined.

BH No.	pH=	Ec=	Fe=	TA=	Cl=	F=	SO4=
C4583	8.6	660	0.1	306	49.4	0.18	3.0

The water quality is slightly alkaline, portable and therefore suitable for domestic use.

7. GEOPHYSICS & FIELDWORK

7.1 Introduction

The Electrical Resistivity method was used to carry out the geophysical survey of the proposed borehole and shallow well sites. This Section therefore briefly presents the basic theoretical elements of the resistivity method.

The main emphasis of the geophysical survey undertaken by the Consultant was to determine the nature of the underlying strata, the presence of faults and to trace water-bearing zones.

This information is obtained in the field using resistivity method: mainly Horizontal electric profiling [HEP] and the Vertical Electrical Sounding (VES): The resistivity profiling method is used to trace lateral variation in resistivity and to locate fractured and fault zones, while the VES probes the resistivity layering below the site of measurement.

7.2 Basic Principles

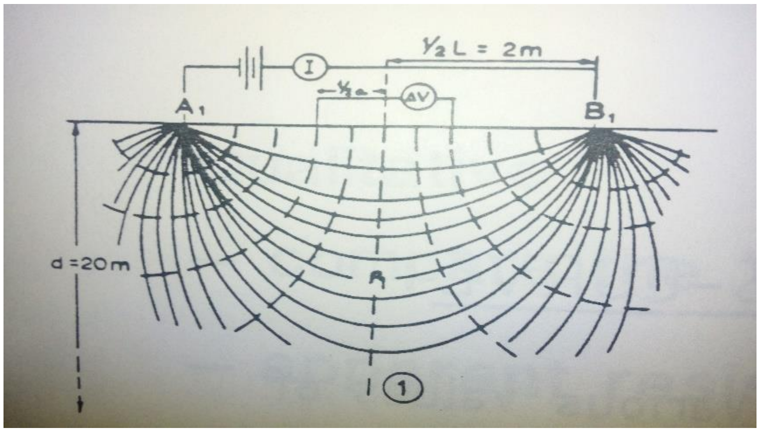
The electrical properties of rocks in the upper part of the earth's crust are dependent upon the lithology, porosity, the degree of pore space saturation and the salinity of the pore water. Saturated rocks have lower resistivities that unsaturated and dry rocks. The higher the porosity of the saturated rock, the lower its resistivity.

The presence of clays and conductive minerals also reduce the resistivity of the rocks. The resistivity of earth materials can be studied by measuring the electrical potential distribution produced at the earth's surface by an electric current that is passed through the earth.

This generates a potential difference between the two inner electrodes M and N. this potential difference (V) and the strength of the current applied (I) is measured. The formation resistivity value is then calculated using the formula:

$$\rho_a = \pi.\left(\frac{L_2 - a_2}{4a}\right).\left(\frac{V}{I}\right)$$

In which ***a*** and ***L*** are the spacing between ***M*** and ***N***, respectively ***A*** and ***B***.



If the measurement is executed over a homogeneous and isotropic earth, the value of ρ computed from the present formula will be the true resistivity of the material of which the earth consists. However, the earth is always inhomogeneous and the calculated value is called apparent resistivity ρ_a. A sounding consists of a series of observations of current strengths and potential differences with varying electrode distances.

The calculated resistivity values are plotted against the value of **L/2** pertaining to it. The distance between the current electrodes (***L***) is at first usually 3 metres. The potential electrodes are then placed at a distance (***a***) one metres from each other. The distance between the current electrodes is subsequently increased in steps. Expanding the arrangement a larger percentage of the current penetrates deeper into the affected into the earth. As a consequence the deeper situated layers increasingly affect the measured values while the influences of the shallow saturated layers diminish. The distance between the potential electrodes remains an unchanged, unless ***V*** becomes too small to be accurate read. Then the spacing between the potential electrodes is increased, after which the expanding of the AB - spacing is continued.

7.3 Vertical Electrical Soundings

When carrying out a resistivity sounding, current is let into the ground by means of two electrodes. With two other electrodes, situated near the center of the array, the potential field generated by the current is measured. From the observations of the current strength and the potential difference, and taking into account the electrodes separations, the ground resistivity can be determined.

While carrying out a resistivity sounding, the separation between the electrodes is stepwise increased (in what is known as a Schlumberger Array), thus causing the flow of current to penetrate greater depths. By plotting the observed of resistivity values against depth on double logarithmic paper, a graph of resistivity Versus depth is obtained.

This graph can be interpreted in the field by an experienced geophysicist. Final interpretation is done with the aid of a computer. The actual resistivity layering of the subsoil is obtained. The depths by resistivity values provide the hydrogeologist with information on the geological layering and thus the occurrence of groundwater. The method is otherwise called *Electric drilling*.

7.4 Fieldwork

The fieldwork was carried out on the 29th of June, 2017. An initial meeting with the Sister In-Charge was held to finalize on the strategy of the fieldwork. Discussions came up with priority areas that the consultant would carry out surveys.

The surveys comprised visual observation at the proposed site with a view of checking its accessibility by a drilling rig.

The drainage and recharge of the area, and where known, the distances to the neighbouring boreholes were also observed. One Vertical Electrical Soundings (VES) was conducted at the site.

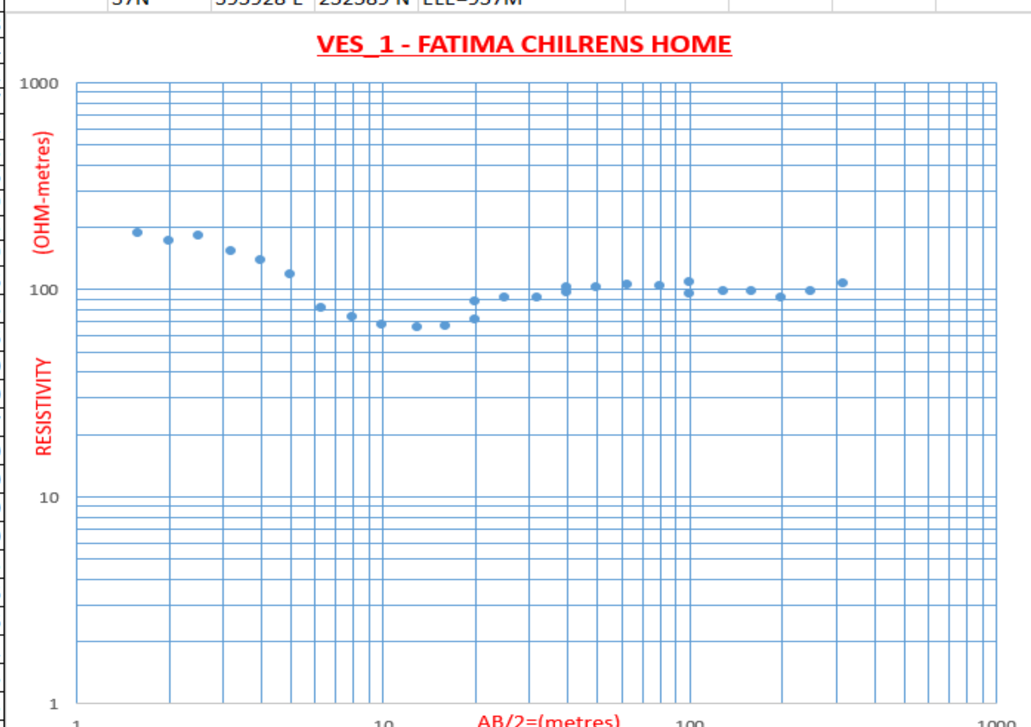
7.5 Fieldwork Results

One Vertical Electric Sounding (VES) was carried out within the school garden area to determine the nature of the underlying rock formation capable of groundwater storage.

A satellite imagery of Fatima Children Home area showing the proposed drill site.

37N 395928 E 252589 N ELE=957M

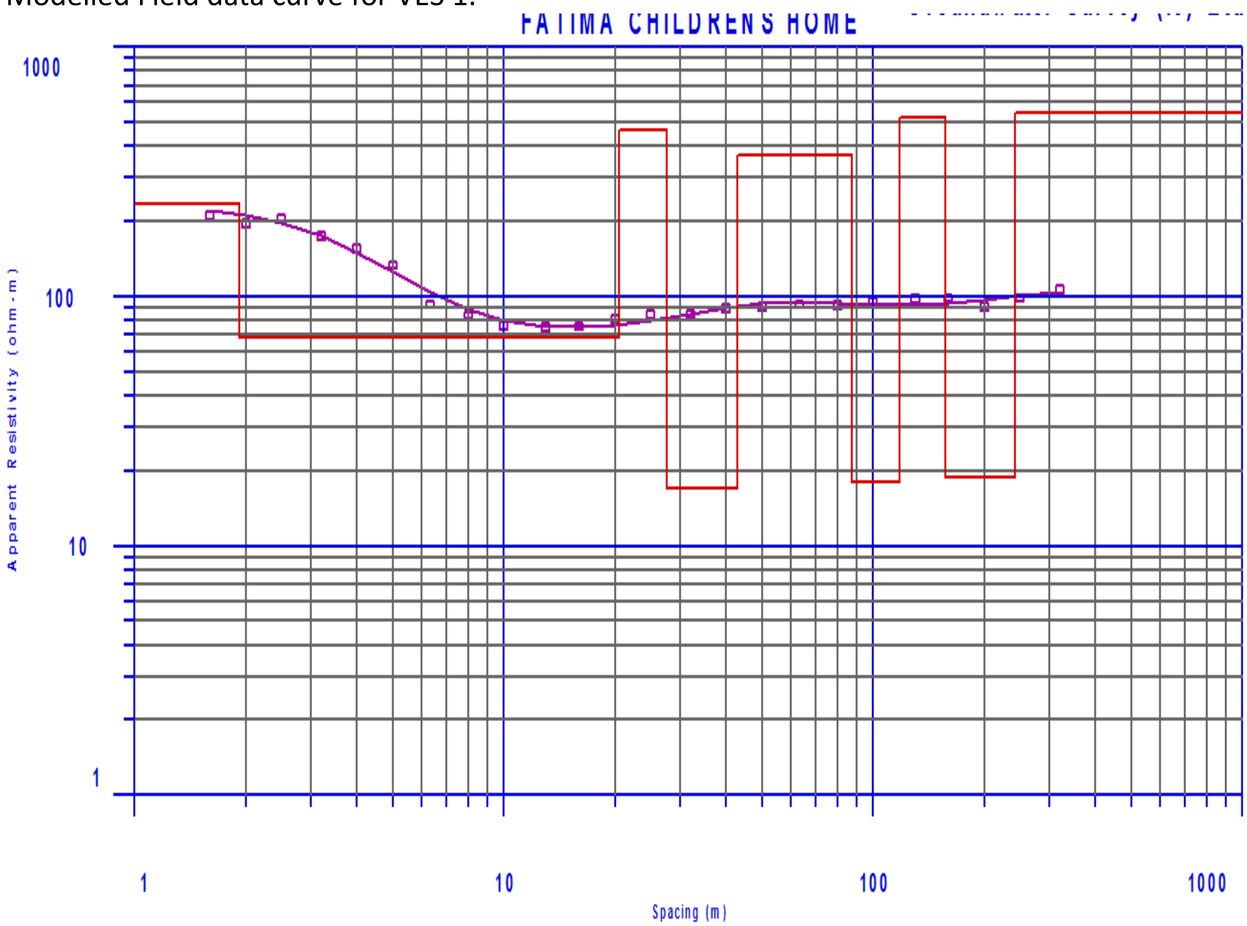
AB/2	VES_1
1.6	185.8
2	172.04
2.5	181.1
3.2	152.7
4	137.1
5	117.3
6.3	81.6
8	73.9
10	67.3
13	65.9
16	66.6
20	71.5
20	87.6
25	90.70
32	91.70
40	97
40	101.80
50	102.60
63	105.00
80	104.00
100	108.3
100	95.6
130	97.6
160	98.1
200	90.5
250	98.3
320	106



7.6 Interpreted Field Data of VES 1.

No	Depth Interval (m)	Resistivity (Ohm-m)	Expected Formation.	Aquifer Potential
1	0-1.9	235.2	Dry loose brown loamy soils	Poor
2	1.9-20.5	68.4	Dry compact gravelly soils.	Poor
3	20.5-27.6	464.9	Fresh Basaltic flow.	Poor
4	27.6-42.8	17.1	Weathered Basaltic flow.	High
5	42.8-87.8	366.8	Fresh Basaltic flow.	Poor
6	87.8-118.2	17.9	Weathered Basaltic flow.	High
7	118.2-156.8	523.1	Fresh Basaltic flow.	Poor
8	156.8-241.7	18.8	Pyroclastic and gravelly sediments.	High
9	>241.7	546.3	Fresh Basement Rock.	Poor

Modelled Field data curve for VES 1.



7.6.1 *Conclusions*

On the basis of the geological survey, hydrogeological assessment and geophysical data analysis, it is recommended:-

- The surveyed site has good groundwater potential,
- The site is underlain by alternating basaltic lava flows, sediments and Basement rock.

8. CONCLUSIONS & RECOMMENDATIONS

8.1 Conclusions

By rigorously integrating resistivity data (VES), processing workflows, careful Earth model interpretation, existing borehole logs data, a clearer picture of the aquifer structures emerged.

In addition, the work has helped to increase confidence in earlier theories as to the nature and extent of several deep aquifer potentials, as well as better explain the overall tectonic development in the area. This new understanding of the local aquifers is of essential importance to rank the exploration potentials of the area under investigation.

8.2 Recommendations

From a Hydrogeological point of view and based on the foregoing study, the recommendations are as below:-

- That any aquifer struck between 0 metres and **10 metres** below ground level should be sealed off completely with clay/bentonite or neat cement grout to ensure the borehole water is protected from surface seepage.
- That a borehole should be authorized for drilling at the selected site to a **maximum depth of 250 metres** to tap the deeper unexploited aquifer(s).
- The site is known to the client and is also pegged on the ground for ease of identification.
- The quality and the quantity of groundwater at the proposed site are expected to be good.

NB. Before drilling commences, 'Authorization to Drill Permits' should be obtained from the Water Resources Authority (WRA), Ewaso Nyiro Catchment, in Nanyuki Town through the Sub-regional Office in Marsabit.

9. REFERENCES

Key, R. M., et al (1987)
Geology of the Marsabit area – Report 108, Mines and Geology Department, Ministry of Environment and Natural Resources.

Driscoll F G, (1986)
Groundwater and Wells (2nd ed.).*Johnson Division.*

Holmes A, (1978)
Principles of Physical Geology *(3rd ed.), Van Nostrand Reinhold (UK) Ltd.*

Sombroek W.G; Braun H.M.H; and van der Pouw B.J.A, (1982)
Exploratory Soil Map and Agroclimatic Zone map of Kenya, 1980, *Kenya Soil Survey.*

Tippetts-Abbett-McCarthy-Stratton (TAMS, 1980)
National Master Water Plan, Stage 1, *Ministry of Water Development.*

Whitten D G A & Brooks J R V, (1972)
The Penguin Dictionary of Geology, *Penguin Book*

ADDENDUM I

DRILLING, CONSTRUCTION AND DEVELOPMENT PROCEDURES

1. Drilling

Drilling should be carried out with an appropriate tool - either percussion or rotary machines will be suitable, though the latter are considerably faster and have a low noise level. Geological rock samples should be collected at 2 metre intervals. Struck and rest water levels and if possible, estimates of the yield of individual aquifers encountered, should also be noted.

2. Well Design

The design of the well should ensure that screens are placed opposite the optimum aquifer zones. The final design should be left in the hands of an experienced driller or hydrogeologist.

3. Casing and Screens

The well should be cased and screened with appropriate steel casings and screens as per the design given above. In comparatively shallow wells, uPVC casing and screens of 5" or 6" diameter may be adequate. Slots should be 1 mm in size.

4. Gravel Pack

The use of gravel pack is recommended within the aquifer zone, because the aquifer could contain sands or silts which are finer than the screen slot size. An 8" diameter borehole screened at 6" will leave an annular space of approximately 1", which should be sufficient. Should the slot size chosen be too large, the well will `pump sand', thus damaging pumping plant, and leading to gradual `siltation' of the well. The grain size of the gravel pack should be an average 2 - 4 mm.

5. Well Construction

Once the design has been agreed upon, construction can proceed. In installing screen and casing, centralizers at 6 metre intervals should be used to ensure centrality within the borehole.

This is particularly important if an artificial gravel pack is to be installed as it ensures an approximately even annular space. If installed, gravel packed sections should be sealed off top and bottom with clay. It is normal practice nowadays to gravel pack nearly the total length of the borehole but seal off the weathered/topsoil zone at the top. The remaining annular space should be backfilled with an inert material, and the top five metres grouted with cement to ensure that no surface water at the well head can enter the well bore.

6. Well Development

Once the screen, gravel pack, seals and backfill have been installed, the well should be developed. Development has two broad aims:

a) It repairs the damage done to the aquifer during the course of drilling by removing clays and other additives from the borehole walls, and
b) It alters the physical characteristics of the aquifer around the screen and removes fine particles.

We would not advocate the use of overpumping as a means of development since it only increases permeability in zones which are already permeable. Instead, we would recommend the use of air or water jetting, which physically agitates the gravel pack and adjacent aquifer material. This is an extremely efficient method of developing and cleaning wells.

Well development is an expensive element in the completion of a well but it is usually justified in longer well life, greater efficiencies, lower operational and maintenance costs and a more constant yield.

7. Well Testing

After development and preliminary tests, a long-duration well test should be carried out. Well tests have to be carried out on all newly completed wells, because not only does this give an indication of the success of the drilling, design and development, but it also yields information on aquifer parameters which are vital to hydrogeologists.

A well test consists of pumping a well from a measured start level (SWL) at a known or measured yield, and recording the rate and pattern by which the water level within the well changes. Once a dynamic water level is reached, the rate of inflow to the well equals to the rate of pumping. Towards the end of the test a water sample of at least two litres should be collected for chemical analysis.

The duration of the test should be 24 hours, with a further 24 hours for a recovery test (during which the rate of recovery to SWL is recorded). The results of the test will enable a hydrogeologist to calculate the best pumping rate, the pump installation depth, and the drawdown for a given discharge rate.

8. Well Maintenance

Once the well has been commissioned and a pump installed at the correct depth, the maintenance schedule should be established. Checks on discharge (m^3/day), pumping water level (metres below a leveled and immovable bench mark), and static water level (if for any reason the well is not used for a 24-hour period) should be taken as part of a regular, routing process. This will enable the evaluation of all known conditions should reduction in the yield or other problems occur in the future, and recommend the most appropriate action.