HYDROGEOLOGICAL SURVEY REPORT

FOR JAMES SIOLOLO c/o

OSILALEI COMMUNITY

P.O.BOX OSILALEI, NAROK

IN

OSILALEI VILLAGE, MAJI MOTO LOCATION, OSUPUKO DIVISION, NAROK NORTH SUB COUNTY

WITHIN NAROK COUNTY

CO-ORDINATES: UTM 36M 0794973E & 9852589S

ELEVATION : 1928m amsl (BY GPS)

Report Compiled By;
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EXECUTIVE SUMMARY

Introduction

This report describes the results of hydrogeological and geophysical borehole site investigations on a parcel of land Owned by **JAMES SIOLOLO** and donated to Osilalei community village.The property is located in **Osilalei Village, Maji Moto Location, Osupuko Division, Narok North Sub County, Narok County.** The main objective of the survey was to locate a suitable borehole drilling site within the plot to provide water for domestic use by a population of atleast 2500 people with a demand of **30m^3/day** within the facility. To accomplish this, detailed hydrogeological and geophysical investigations were executed on the property.

Climate

The climate in Narok's Maji Moto area is warm and temperate. The precipitation levels in Narok are noteworthy, as there is rainfall even during the most arid month. The climate here is classified as Cfb by the Köppen-Geiger. The mean temperature prevailing in the general area is recorded as 17.8 °C | 64.0 °F, according to statistical data. About 1045 mm | 41.1 inch of precipitation falls annually.

Narok is characterized by a temperate climate, and the summer season presents some challenges in terms of precise categorization.

Geology

Narok area consists the rocks under three main geologic ages. These include the Pleistocene rock unit formations, the Pliocene and the Miocene as the oldest rocks in the area. recent deposits overly the rocks of the Pleistocene and comprise silt, sands, volcanic ash and clay. this is due to the location of the study area within the basin of the Rift Valley. These are sediments washed downslope from the raised area bordering the valley. They vary in composition depending on the parent material from which they got eroded.

Hydrogeology

The study area is of fairly medium to high groundwater potential. The hydrology of Maji Moto area is a function of the structural features within the strata in the region. Aquifers are present in the deformation areas within the volcanic formations in the area; secondary porosity. These comprise fault lines, joints and fracture zones. The water quality in the area is generally good.

Geophysical Fieldwork

Geophysical measurements were used to determine the thickness of the underlying layers, their potential as aquifers, and the expected quality of groundwater in these formations. Four electromagnetic profiling traverses were executed at the site to a depth of 300metres of penetration on the 12th February 2026. This was carried out in an attempt to unveil the hydro-stratigraphy of the study area.

Conclusions

The study concludes that, on the basis of hydrogeological evidence, groundwater prospects in the study area are good. The investigated area is located in an area with medium to high groundwater potential. The major aquifer is the unconformity zone between the rocks of the Pleistocene age. Most of then were deposited and were water underlain at formation. Another significant aquifer in the study area is that formed by fractured, weathered and jointed zones within the formations in the area following the fact that the area is one that underwent intense metamorphism. This resulted into a lot of deformation that led to the development of such structures.

Other significant aquifers in the area of study could be encountered at the weathered and fractured zones of the volcanic and the basement sedimentary rocks within the study area.

The groundwater quality in the investigated area is expected to be good going by the testimony from the locals about the already existing boreholes in the area.

Recommendations for Drilling

In view of the geophysical results and hydrogeological nature of the area, it is recommended that**a borehole be drilled at Point 11 of traverse 1 to a minimum depth of 230 meters bgl and a maximum of 240m bgl.** A summary of all the investigations done and the recommended drilling site are given in the table on the following page: -

Recommended Drilling Location for the Investigated Site

No. Profile traverses done	Recommended traverse	Min Depth (m)	Max Depth (m)	Groundwater Prospects
2	1 Point 11	230	240	Good

The site (point 11 on traverse 1) is benchmarked on site. The site

coordinates were obtained using Global Positioning System (GPS) as UTM 36M 0794973E and 9852589S with altitude 1920m amsl.

Monitoring

Regular monitoring should be instituted and maintained in the borehole in order to keep track of groundwater levels. A monitoring tube should be installed in the borehole to be able to monitor the water level in the well.

Borehole Construction

Recommendations are given for borehole construction and completion methods. The importance of correct and comprehensive techniques in this particular aspect cannot be over-emphasized.

Drilling Permits

A drilling authorization permit must be applied for from the Water Resources Authority (WRA) Regional office under the Ministry of Water and Irrigation and Sanitation (MoWIS). A license from the National Environmental Management Authority (NEMA) is also required for drilling to proceed. In addition, a no objection letter should be sought from the local water resource user's association (WRUA) in the area of study.

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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
E	East
EC	electrical conductivity (S/cm)
Hr.	hour
L	liter
M	meter
N	North
NEMA	National Environment Management Authority
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
WARA	Water Resources Authority
WSL	Water Struck Level
WRUA	Water Resource Users Association
S/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 takenplace.

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 orvelocity.

Hydrogeological Those factors that deal with subsurface waters and related geologicalaspects 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 froma surface source to the saturated zone.

Old Land Surface Old Land Surface (OLS) is the term given to an ancient erosion surfacenow covered by younger surface material. In hydrogeology, OLS's frequently make good aquifers, especially where the erosion debris left behind is coarse in nature. OLS's are a frequent occurrence in the Nairobi Volcanic Suite.

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.

Pyroclastic rocks Group of rocks consisting of volcanic dust, ashes, lapilli and coarse lumps of lava (volcanic bombs), explosively thrown up in molten condition, and deposited by gravity. Hardened masses of dust, ashes and lapilli are known as tuff, while coarse, consolidated pyroclastic debris is referred to as agglomerate.

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, 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. (Alsoknown 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 tothe atmosphere through openings in the overlying materials (as opposedto >confined conditions).

Yield Volume of water discharged from a well.

1. INTRODUCTION

1.1 Background Information

The client, **JAMES SILOLO** commissioned a hydrogeological site investigation on his plot of land. It is a proposed residential property with rental units. It is currently under construction. The proposed site is located within **in Osilalei Village, Maji Moto Location, Osupuko Division, Narok North Sub County, Narok County**. The intention of the investigations was to locate a potent site for sinking one production borehole to provide water for domestic purpose within the hotel premises.

The site selected was informed by the outcome of the geophysical investigations and is defined by co-ordinates **UTM 36M 0794973E and 9852589S.** It's approximate elevation is **1920** metres amsl.

1.2 The Objectives of the Study

The objective of the investigation was to assess the groundwater potential and advice on the viability of drilling a borehole. The investigations involved hydrogeological, geophysical field investigations and a detailed desk study in which the available relevant geological and hydrogeological data were collected, analyzed, collated and evaluated to meet the client's requirements. The three sources of information used to accomplish this project included:

- Geological and Hydrogeological Reports and Maps.
- Ministry of Water and Irrigation and Sanitation (MoWIS) Borehole Completion Records, usually a valuable source of data.
- Various technical reports of the Rural Domestic Water Supply and SanitationProgramme, BKH Consulting Engineers.

1.3 Reporting Requirements

The format of writing the Hydrogeological Investigations Report, as described out in theSecond Schedule of the Water Resources Management Rules, 2007 outlines that such a report must consider the following (verbatim): -

- Name and details of applicant
- Location and description of proposed Activity

- Details of climate
- Details of geology and hydrogeology
- Details of neighbouring boreholes, including location, distance from proposed borehole or boreholes, number and construction details, age, current status and use,current abstraction and use.
- Description and details (including raw and processed data) of prospecting methods adopted, e.g. remote sensing, geophysics, geological and or hydrogeological cross sections. Hydrogeological characteristics and analysis, to include but not necessarilybe limited to, the following:
- Aquifer transmissivity
- Borehole specific capacities
- Storage coefficient and or specific yield
- Hydraulic conductivity
- Groundwater flux
- Estimated mean annual recharge, and sensitivity to external factors
- Assessment of water quality and potential infringement of National standards
- Assessment of availability of groundwater
- Analysis of the reserve
- Impact of proposed activity on aquifer, water quality, other abstractors, including likelihood of coalescing cones of depression and implications for other groundwater users in any potentially impacted areas
- Recommendations for borehole development, to include but not limited to, thefollowing:
- Locations of recommended borehole(s) expressed as a coordinate(s) and indicatedon a sketch map
- Recommendations regarding borehole or well density and minimum spacing in theproject area
- Recommended depth and maximum diameter
- Recommended construction characteristics, e.g. wire-wound screen, grouting depth
- Anticipated yield
- Any other relevant information (e.g. need to monitor neighbouring boreholes duringtests).

This report is written so as to cover each of the above, insofar as data limitations allow. The report also includes maps, diagrams, tables and appendices as appropriate.

1.4 Climate and Vegetation

The climate in Narok is warm and temperate. The precipitation levels in Narok are noteworthy, as there is rainfall even during the most arid month. The climate here is classified as Cfb by the Köppen-Geiger. The mean temperature prevailing in Narok is recorded as 17.8 °C | 64.0 °F, according to statistical data. About 1045 mm | 41.1 inch of precipitation falls annually.

The region is characterized by a temperate climate, and the summer season presents some challenges in terms of precise categorization. A summary of the climate of the study area is given in the figure bellow:

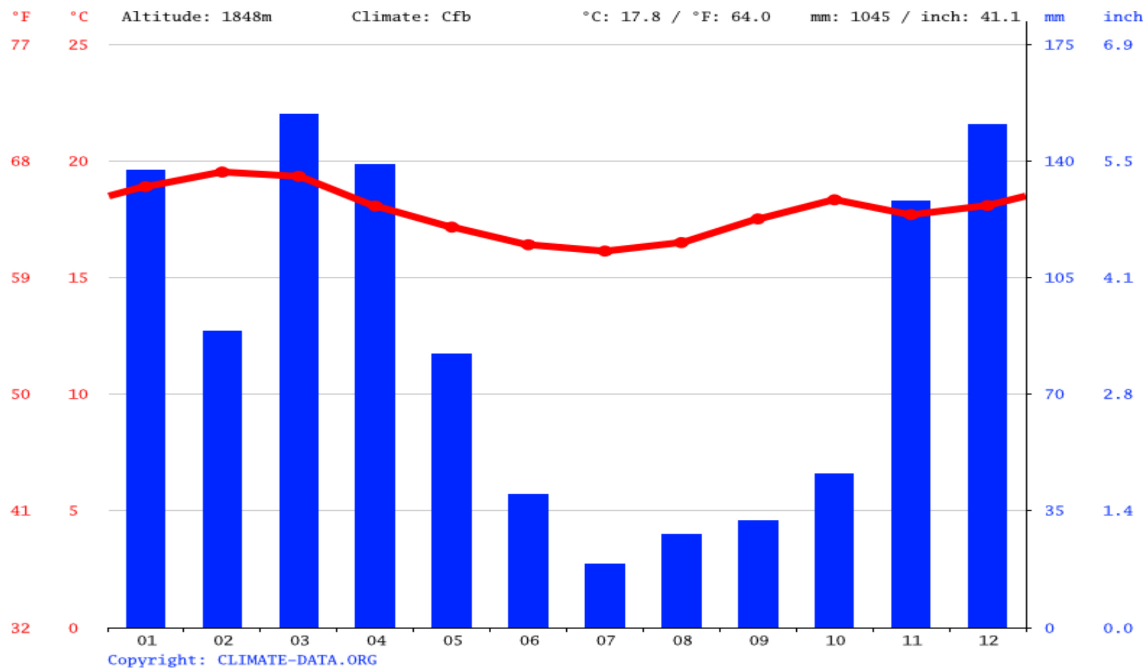


Figure 1.2: Narok County Climate data (Adapted from Climate data.org)

The general Maji Moto area has an arid to semi-arid vegetation consisting of short dry to green grass and thorny leafed desert plants. The plants include euphorbia and acacia and other bushy desert plants. Majority of the vegetation is natural vegetation as the place borders the Maasai Mara National Park and a conservancy.

1.5 Physiography and Drainage

The general area is composed of alternating plains, valleys and small hills with several seasonal streams intersecting them. The site under investigation is fairly flat. The area is drained by the Ewaso Ngiro River that flows in a general South Eastern direction. The site is located about 64.24km North of River Ewaso Ngiro System.

The site has an altitude of **1920m** amsl. The soils here are black cotton soils with clay, light brown sands and silt deposits. The soils are deeper downslope and at the plains than uphill. The soil cover of the study area is shown in the figure below:

1.6 Water Demand and Land Use

There is no gazetted water provider within the area of study. The client depends on water supply from a nearby River which has proven quite insufficient to meet it's water demand apart from being unreliable. The client therefore seeking to get a reliable and sufficient water supply for domestic use.

It is this quest to address perennial water provision unreliability that the client has resorted to sinking the proposed borehole to meet communities water demand. Water from the proposed borehole will be used for domestic purpose. The client's water demand is estimated at **30m³/day** of which **20m³** will be used for domestic purposes by approximately **2500 persons** translating into individual's water demand of **0.2m³/day.** The remaining **10m³** will be used for construction purposes. The water use of the proposed borehole and the former's demand distribution is shown in the table in the following table:

Water use	**Demand (m³/day)**	**Population**	**Individual Demand (m³/day)**
Domestic	20	2500	0.3
Other uses	10	-	-
Total demand	30	-	30

Table 1.1: Water usage by the client and demand distribution

The local community; the Maasai use their parcels of land for pasture. They are a pastoralist community. Other chunks of land in the area are under conservancies. The parcel of land belonging to the client is a residential village but exclusively donated to the community. Livestock herding takes place on the fallow section of the land where the site has been identified.The villages have surrounded the community land.

2. GEOLOGY

2.1 Regional Geology

The Narok region's rocks falls into three geological ages as has been argued by many scholars. These include the following:

1) Pleistocene
2) Pliocene and the
3) Miocene

A short description of the different rock units within these geological ages is given below starting from the youngest rock way up to the oldest.

2.1.1 The Pleistocene

These are the youngest within the strata in the Narok area. they are listed from the youngest to the oldest in this category. The rocks in this age within the area include the ones in the final ash phase, orthophyre type trachytes, plateau trachytes, the second Oletugathi Fault, Alkali Basalts of the Oletugathi Plateau and the Tuffs and Ashes which are in part water lain. The first Oletugathi Fault, the Alkali Basalts of the Enamankoen plateau that follow the second Naititiami Fault. The Enkorika fault deposits and Tuffs and Ashes which in part are water lain.

2.1.2 Pliocene

Consists of rock formations which are second oldest in the stratigraphy of the study area. the youngest in this category include deposits of the erosion of the first Naitiami Fault Scarp that is underlain by the Kirikiti Basalts found in the Magadi and the Loita Hills area. the oldest are those that were deposited during the First Naitiami Fault formation.

2.1.3 Miocene

In this age are Phonolites, Kishalduga melanephenelite lavas and those associated with the arching of the sub-Miocene peneplane.

2.1.4 Structural Geology

Structural features such as faults in the rocks often optimize storage, transmissivity and recharge, particularly when they occur adjacent to, or within, surface drainage systems.

Faulting will have the highest impact on hard and massive rock types; elastic formations such as tuffs and weakly consolidated deposits will bend (fold) rather than break (fault). As a result, they tend to suppress the radius of influence and the magnitude of the damage caused by tectonic events. In relatively plastic rocks, the porosity will not increase in the area affected by the fault. Hard layers such as lavas, on the other hand, will be broken by fractures and joints, thus giving rise to increased (secondary) porosity.

The formations of the rocks in the study area has structures associated to intense metamorphism and metasomatism arising from geological the activities within the Rift Valley. Joints and faults are common too within the study area that indicate tectonism within the area. The effects of these on the aquifer characteristics of the formations in a given area is enhanced ground water holding and transmission ability. These are important in volcanic and basement area in regard to ground water storage and transmissivity.

2.2 Geology of the study area.

The geology of the study area conforms to that already described above. The depths and thicknesses of the formations within the strata vary from one location to the other. This is based on the factors that were prevailing during their deposition and thereafter. These factors are mostly those associated to denudation and weathering.

Silt ad clay are a great factor within the recent deposits because the study area lies within the basin in the great rift valley. Volcanic ash dominates the study area and recent sands as well. These overlay the formations already described in the previous chapter. The geology of the study area is shown in the following diagramme;

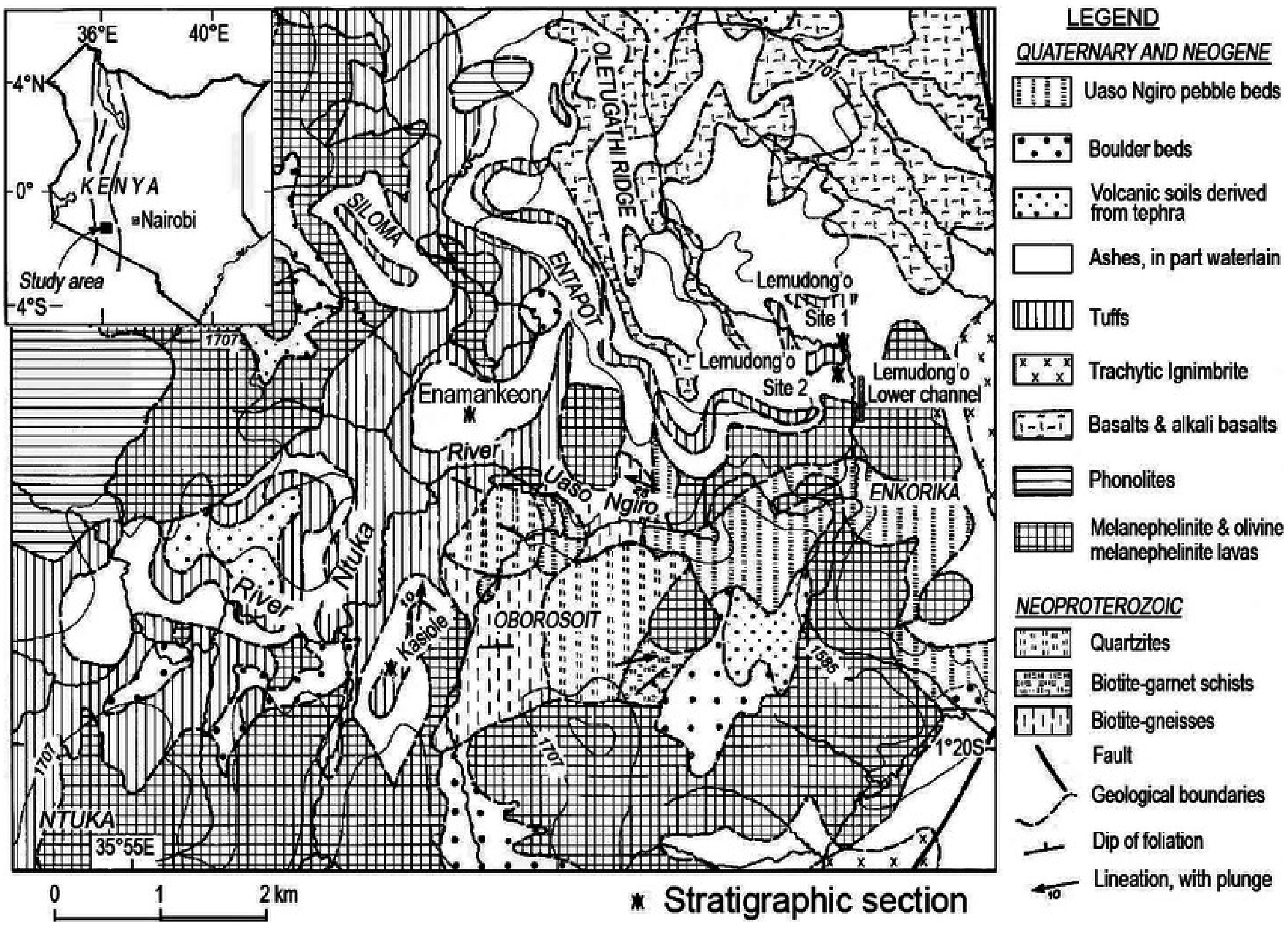


Figure2.1: Geology of the study area within the general geological map of Narok County

3. HYDROGEOLOGY

The hydrogeology of any given area is a function of it's geology, structures and the precipitation within the area. The study area is composed predominantly of volcanics with recent deposition as the sedimentary formations in the area. The volcanics overly metamorphic rocks that are relatively deep seated.

The areas groundwater availability to the proposed borehole will be guaranteed in as much as location of fractures, weathered zones and ancient depositional basins are successfully identified through an effective geophysical means. These zones hold water storage zones in cases where sedimentary formations are absent or few. Their storage sites are referred to as secondary porosity while the pore spaces within rock units are referred to as primary porosity. The latter is the case in the sedimentary formations.

The fractured zones within the various formations in the Narok's Sekenani area are the significant aquifers holding and transmitting groundwater. The upper Pleistocene sediments are good aquifers that can sustain a borehole in the study area coupled with the sediments of the recent deposits in the area. Volcanic ash and recent sands and silt washed into the basin from higher regions around the Rift Valley also constitute the sediments in the area.

Highly weathered formations within the area in the formations of across all the formations within the study area can also form significant aquifers within the area of study. They can get water to hold from the regional recharge zones at the slopes of the mountainous areas surrounding the Rift Valley as well as the escarpments bordering it. The Mau escarpment is key in the area's ground water supply and replenishment.

In highly deformed volcanoclastic sedimentary zones like the one at hand, geological structures are the major targets for groundwater investigations. They form sufficient storage zones whose water can be available for supplying springs, wells and boreholes.

It is therefore worth saying that no any formation can be ignored following that in the event they encounter deformed resulting into them being highly fractured and weathered, they definitely can store groundwater. This is through infiltration and percolation. The only variance can be the rocks ability to transmit the stored water to exploitation points.

The aquifers within the rocks in the study area are generally of good potential and quality. In the case of a relatively high fluoride content in the groundwater then the mineralization could be caused by the volcanic in the area. The water has though not been confessed quite saline by the locals. As a highly deformed area, almost all the formations within the stratigraphy are capable of forming reliable aquifers.

3.1 Existing boreholes

A number of boreholes have been drilled in the project area in the past. Available incomplete records for 2 boreholes within a radius of approximately 8km from the present site were studied for correlation to the proposed borehole.

The data for these boreholes in the vicinity of the project area is given in Table 3.1 on the following page. This was extracted from the consultant's database and from the records at the Ministry of Water and Irrigation and Sanitation.

Table 3.1: Boreholes in the Vicinity of the Site

BH No. C-	Owner	Distance from proposed site	Depth (m bgl)	WSL (m bgl)	WRL (m bgl)	Q (m^3/hr)	PWL (m)
-	X	17SW	250	150, 175, 245	140	2	235
-	Y	30SW	220	155, 167, 190 & 215	160	14	195
Range			220 – 250	150 – 215	140 – 160	2 – 14	195 – 235

3.1.1 Borehole Data Analyses and Aquifer Outline of the Area.

It is evident that the two boreholes abstract water from aquifers that are between **220** and **250m bgl.** They exhibit yields that range between **2.0** and **12m^3/hr**. The yield of the present borehole is expected to be within the

range of the other boreholes in the area.

3.1.2 Impacts to Abstraction Trends and Analyses of Boreholes within 8km-m from the Proposed Site

From the records, only ONE borehole is located within 8km radius. In regard to this borehole and considering that the upper aquifers are a quite vulnerable to depletion, all aquifers encountered from ground level down to a penetration depth of about 30m should be sealed off with plain casings and bentonite cement to avoid any possible further depletion of these shallow groundwater resources and in turn avoid any impact to any surrounding borehole abstracting water from this vulnerable level.

This borehole therefore will only abstract water from the deepest aquifers. The boreholes have good yields which is an indication of underlying productive aquifers.

3.2 Recharge

The recharge mechanisms (and the rate of replenishment) of the local aquifers has not been fully established. This is because there is no sufficient data on the same. The two major processes are probably direct recharge at surface (not necessarily local) and indirect recharge via faults, joints, fractures 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. Aquifers may also be recharged laterally if the rock is permeable over a wide area.

In the present study area, the principal recharge zones are the highlands within the neighbourhood specifically the Mau Hills and the other highlands within the escarpments bordering the Rift Valley. These areas probably receive higher rainfall than the investigated site.

3.2.1 Mean Annual Recharge

Rainfall within the study area is relatively high, (1045 mm), both local and regional recharge is of great essence in this area. Much of regional recharge occurs within the mountains in the region namely Mau Hills and the escarpments bordering the Rift Valley. However, this recharge mechanism is mainly important for the replenishment of (regional) volcanic aquifers and is what has been used to estimate the Mean Annul Recharge.

At the present location, water also percolates directly into the faults, fractures, local rivers and streams (via fractures) thus deeper and adjacent units are recharged over time.

Mean Annual Recharge has therefore been estimated as follows:

The Recharge is estimated as 5% of the Mean Annual Rainfall of the recharge area

1045mm x 5%

Mean Annual Recharge = 52.25mm

However, this recharge amount is probably an estimation due to the possibility of influent local recharge through local rivers and rainwater percolation through faults into the weathered/fractured rock units and formations within the Rift Valley area where the area of study is situated.

3.3 Discharge

Discharge from aquifers is either through natural processes as base-flow to streams and springs, or artificial discharge through human activities. However, considering the fewnumber of boreholes in the area this form of discharge is not much pronounced.

The total effective discharge from the aquifers via either of the above means is not known, and should in fact be studied. The main form of discharge is through flow along formationsand faults/interconnected fractures.

3.4 Aquifer Properties

3.4.1 Calculation of Aquifer Properties and Associated Problems

To calculate the area Aquifer Properties, test pumping data of ***X*** borehole was adopted.

The borehole has a total drilled depth of **250m**, yield of **$2m^3$/hr,** Water Struck level of **150, 175, 245** , Water Rest level of **140m** and Pumping Water Level of **230m**. The borehole has fairly penetrated the productive upper aquifers and thus will be fair enough to deduce the aquifer properties of the project Area. It had a drawdown of **40**.

3.4.2 Estimation Aquifer Transmissivity

Aquifer Transmissivity (T) is estimated as follows:

T=1.22Q/ΔS Where: Q = Yield per day

ΔS = Draw

downT=(1.22x2)/ (230-40) = 2.44/44

T=0.05545m2/day

3.4.3 Hydraulic Conductivity

The Hydraulic Conductivity (K) is estimated as follows:

K = T/Aquifer Thickness

Based on the geological logs of the boreholes in the area, the cumulative aquiferthickness for the purpose of this calculation has been estimated at 15m for the Rift Valley Aquifer. Thus,

K = **0.05545m2/day./15**

K = 0.0036m/day

3.4.4 Specific Capacity

The higher the specific capacity the higher the transmissivity of a borehole. It is normally calculated by dividing the discharge rate per day by the draw down. The aquifer Specific Capacity (S) = Q/s.

Where: Q = Discharge (m^3/day) =2.0m^3/day

D = Drawdown (m) = 40.m

S= 0.05m^2/day

3.5 Water Quality

The quality of groundwater throughout Maji Moto area and environs is generally good with fluoride content fairly within the W.H.O. acceptable limit of 1.5 ppm. High fluoride intake, especially by growing infants, may cause dental or skeletal fluorosis. Should the fluoride concentration of the proposed borehole exceed 1.5 ppm, it is advisable to provide an alternative source of drinking water for infants (bottled water would be the best option). Over a short time-span, the consumption of water with excess fluoride is not harmful to adults.

The quality of groundwater in the aquifers within the aquifers in the area is good. Water sample of the borehole is though recommended to be tested for ionic concentration and a decision taken on the outcome before being put into human consumption.

3.6 Impacts of the Proposed Activity to Water Quality, Wetlands

The Proposed drilling site and related works are expected to pose no impact on water quality, either Surface or groundwater resources. There is no any surface water body near the proposed site that can be contaminated by waste waters generated during drilling.

The entire drilling, borehole construction, pump tests, and completion works will be done to professional standards. Entry of any foreign material until completion will be avoided to avoid any entry of foreign material into the borehole. Only inert materials will be used in construction. The borehole will be properlydeveloped to open up the aquifers and clean the borehole water. Monitoring of ec during drilling will be done to detect and seal any aquifer with elevated mineralization.

The site is not located within a wetland and has no negative impacts on biodiversity. It is thus not going to destabilize the ecosystem. It is thus environmentally conservative.

4. GEOPHYSICAL INVESTIGATION METHODS

A great variety of geophysical methods are available to assist in the assessment of geological subsurface conditions. In the present survey electromagnetic method has been used has been used. The use of vertical electrical sounding (resistivity) has also been discussed for more understanding of different physical properties of sub surface materials and their relation to groundwater, aquifer detection, thickness and location.

4.1 Electromagnetic Method

4.2 Basic Principles of EM and Methodology

The EM method makes use of the PQWT equipment. The operation of the equipment is based on the principle of the electrical difference of the natural earth magnetic field that is the use of several different frequencies of electromagnetic field changes as the law to study the underground field or material changes in the subsurface to do groundwater exploration.

4.3 EM Methodology

When carrying out hydrogeological survey using the EM method, the PQWT equipment is connected to two electrode probes 10 apart connected to each other and to the equipment. The site area is identified and the two electrode probes are pegged into the ground 10m distance interval. The current is sent from the equipment into the ground till the set depth which was 300 in our case. As it moves into the subsurface, magnetic fields induced on the different layers from that of the earth are developed and they depict electrical conductivities and resistance of different materials.

The subsurface deviations are then recorded as profiles are curves for all the point sites profiled or tested within the CPU of the equipment. This then can be used by an expert in the interpretation and analysis of the subsurface materials encountered during the profiling. This is owed to the fact that different materials will behave differently to the electromagnetic signals sent through them. This forms the primary argument on which aquifer location, depth, thickness and identification as well as the subsurface structures is pegged in as far as siting a borehole is concerned by use of the PQWT.

At least 15-line testing points are enough to provide sufficient subsurface data for a given area of study that when interpreted accurately will lead to successfully siting a borehole and determining it's minimum and optimum drilling depths. A minimum of 20-line testing points on a traverse is though recommended. With this equipment, the actual point being tested is halfway the 10m interval plus one. This is illustrated in figure 3 below.

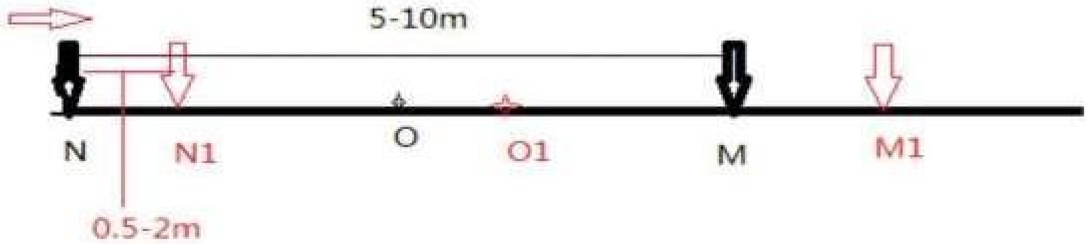


Figure 4.1: Site location formula by PQWT

4.4 Resistivity Method

Vertical electrical soundings (VES) were carried out to probe the condition of the sub-surface and to confirm the existence of deep groundwater. The VES investigates the resistivity layering below the site of measurement. This technique is described below.

4.5 Basic Principles

The electrical properties of rocks in the upper part of the earth's crust are dependent upon the lithology, porosity, and the degree of pore space saturation and the salinity of the porewater. Saturated rocks have lower resistivities than unsaturated and dry rocks. The higherthe porosity of the saturated rock the lower its resistivity, and the higher the salinity of the saturating fluids, the lower the resistivity. The presence of clays and conductive mineralsalso reduces the resistivity of the rock.

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 theearth.

The resistance R of a certain material is directly proportional to its length L and cross-sectional area A, expressed as:

$$R = Rs * L/A \qquad \text{(Ohm)} \ (1)$$

Where: Rs is known as the specific resistivity, characteristic of the material and independent of its shape or size. With Ohm's Law,

R = dV/I (Ohm) (2)

Where: dV is the potential difference across the resistor and I is the electric current throughthe resistor, the specific resistivity may be determined by:

Rs = (A/L) * (dV/I) (Ohm.m) (3)

4.6 Vertical Electrical Soundings (VES)

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

While carrying out the resistivity sounding the separation between the electrodes is step- wise increased (in what is known as a Schlumberger Array), thus causing the flow of current to penetrate greater depths. When plotting the observed resistivity values againstdepth on double logarithmic paper, a resistivity graph is formed, which depicts the variation of resistivity with depth.

This graph can be interpreted with the aid of a computer, and the actual resistivity layering of the subsoil is obtained. The depths and resistivity values provide the hydro-geologist with information on the geological layering and thus the occurrence of groundwater.

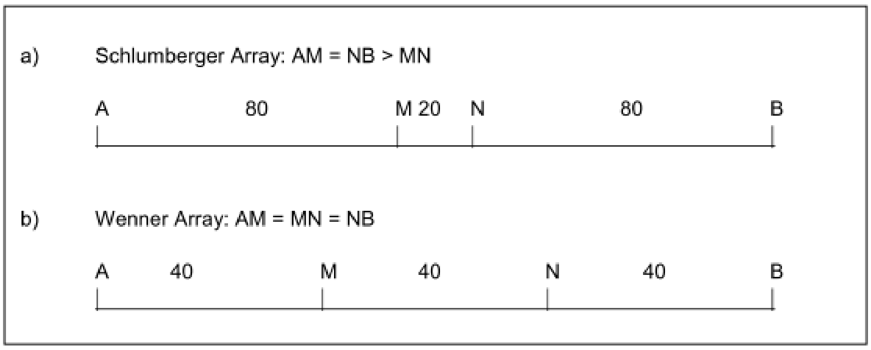


Figure 4.2: Examples of Schlumberger and Wenner Configurations for Resistivity Measurements, where: AB = current electrodes; MN = potential electrodes.

A series of measurements made with an expanding array of current electrodes (Schlumberger Array) allows the flow of current to penetrate progressively greater depths.The apparent resistivity as a function of the electrode separation AB provides information on the vertical variation in resistivity. The depth of penetration varies according to the electrode array, but is also affected by the nature of the material beneaththe array. The point at which a change in earth layering is observed depends on the resistivity contrast, but is generally of the order of a quarter of the current electrode spacingAB (Milsom 1989). By contrast, in a homogeneous medium the depth penetration is ofthe order 0.12 AB (Roy & Apparao 1971).

The calculated apparent resistivity is plotted against current electrode half separation on a bi-logarithmic graph paper to constitute the so-called sounding curve. The curve depicts a layered earth model composed of individual layers of specific thickness and resistivity. Interpretation of field data can be done with hand-fitted curves, but this method is time consuming, and practically limited to 3-layer solutions. Modern interpretation is computer-aided, using a curve fitting procedure based on a mathematical convolution method developed by Ghosh (1971).

While the resistivity method is a useful tool in groundwater investigations and borehole site surveys, its applicability and reliability should not be overestimated. Themodelling of field data is often attended by problems of equivalence and suppression. Eachcurve has an infinite number of possible solutions with different layer resistivity's and depths (this is known as equivalence).

Mathematical convolution can easily lead to a well-fitting solution, which nonetheless does not correspond to reality. In general, the number of possible solutions is reduced bymutual correlation of several sounding curves, knowledge of the local geology and drillingdata. When deposits with similar resistivities border each other, it is usually not possible to make a differentiation. Intermediate layers, occurring between deposits of contrasting conductivity, may go undetected, as they tend to be obscured within the rising or fallinglimb of the sounding graph (suppression). Additional data, in the form of borehole records,air photography and geological field observations, are therefore required to produce a realistic interpretation.

It should be noted that the layered earth model is very much a simplification of the manydifferent layers, which may be present. The various equivalent solutions, which can be generated by a computer programme, should therefore be carefully analyzed; resistivity soundings should never be interpreted in isolation as this may lead to erroneous results.

5. FIELDWORK AND RESULTS

Field work was carried out on **12th February, 2026.** Two electromagnetic profiling traverses was conducted on the site by use of the PQWT. The aim of the profiling was to determine the prevailing hydro-stratigraphy at the site.

The traverse profiles on the client's land were done up to 300m. out of the three profiled traverses, only one with the most prolific point was selected. The data of the traverse are the ones considered in this report.

5.1 Results

The results of the electromagnetic profiling for the traverse are shown in the figure below:

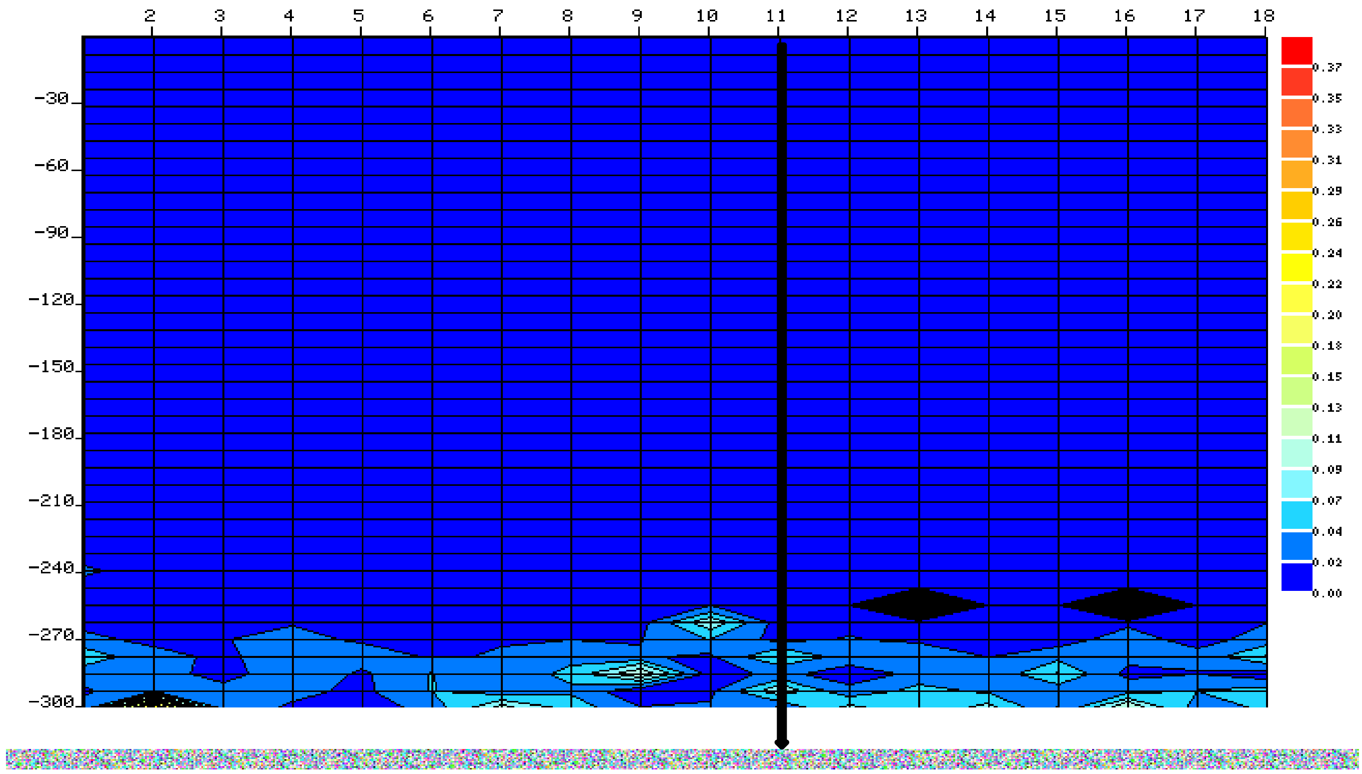


Figure 5.1.1: Original Electromagnetic Profile.

Note the selected drilling point (site) shown by the black arrow at point **11.** A total of **18** points were tested on this traverse giving the profile above.

X Axis *– Horizontal surface movement of 1metre interval from successive points*

Y Axis *– Depth in metres below the ground level*

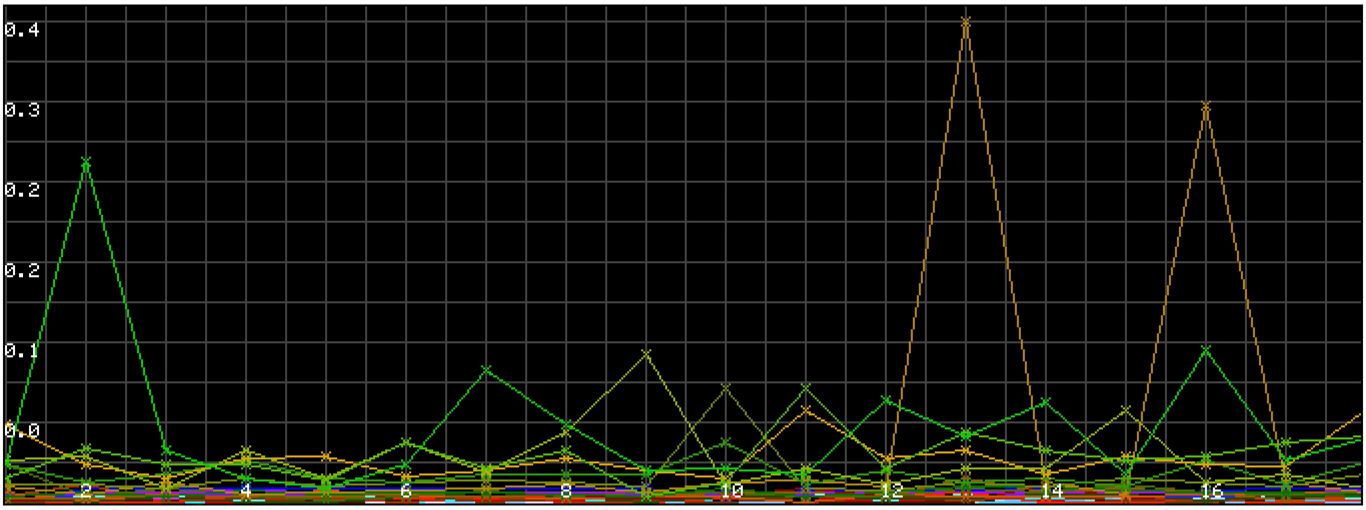


Figure 5.1.2: Original Electromagnetic Curve

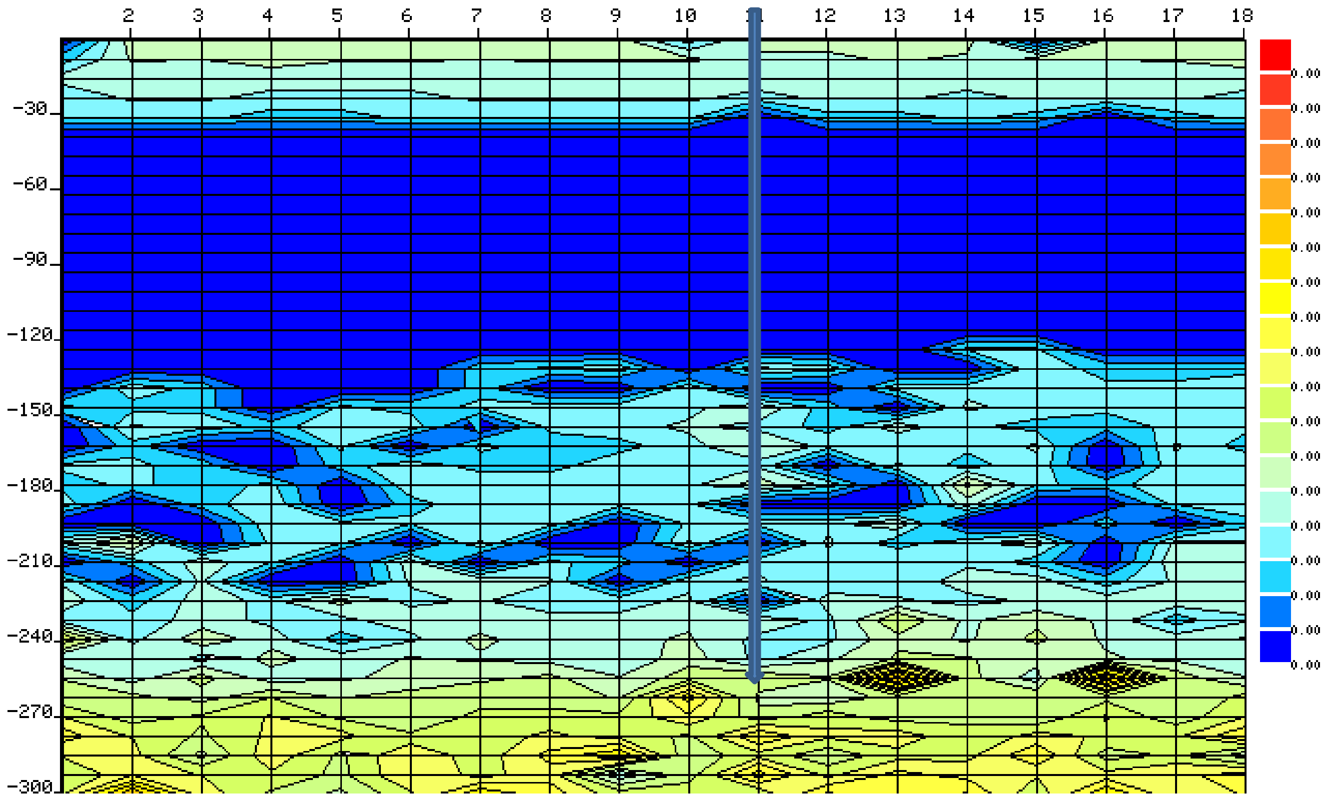


Figure 5.1.3: Processed Electromagnetic Profile showing different sub-surface formations at points and depths.

The selected point and depth of drilling is shown by the blue arrow at point11 on the traverse. It shows highly weathered, fractured and jointed formations accounting for it's light yellow tints.

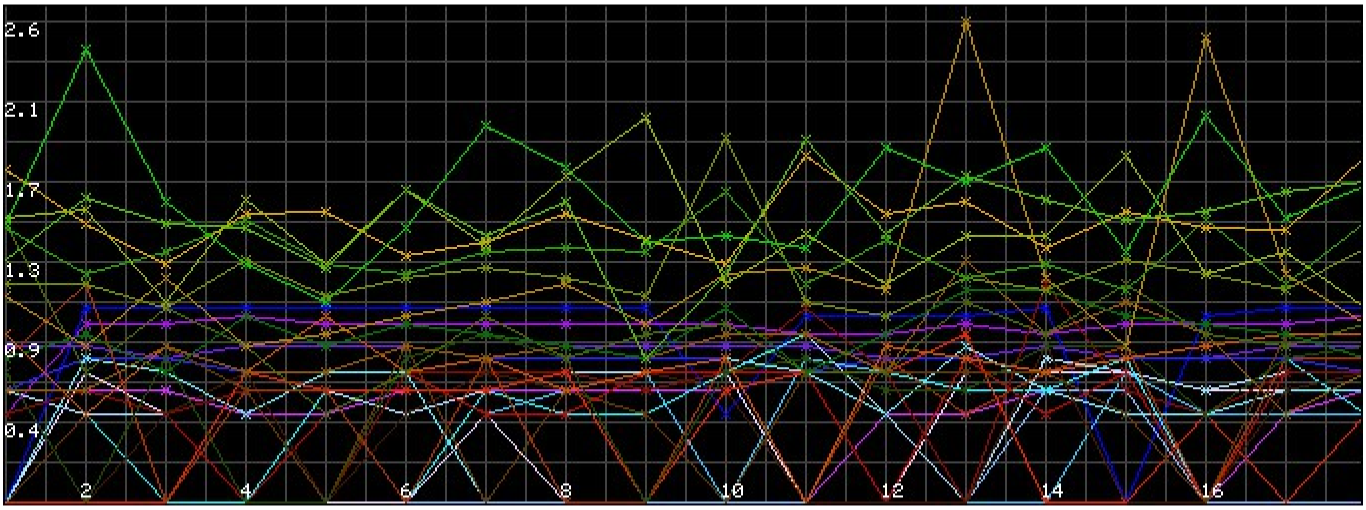


Figure 5.1.4: Processed Electromagnetic Curve.

Point **11** is the best selected from the traverse to site the borehole. It shows low resistivity values with aquifers at relatively shallower depths compared to other points within the traverse line. Drilling should be done at this point to a **minimum** and **maximum** of **230** and **240m** bgl respectively. Note the low values at point **11** on the original curve signaling presence of aquifer.

L	N	freq01	freq02	freq03	freq04	freq05	freq06	freq07	freq08	freq09	freq10	freq11	freq12	freq13	freq14
101	1	0	0.003	0.007	0.004	0.004	0	0	0	0	0	0	0	0	0
101	2	0.011	0.009	0.007	0.006	0.004	0	0	0	0	0	0	0	0	0
101	3	0.011	0.009	0.006	0.006	0.004	0	0	0	0	0	0	0	0	0
101	4	0.011	0.01	0.007	0.005	0.003	0	0	0	0	0	0	0	0	0
101	5	0.011	0.009	0.007	0.005	0.003	0	0	0	0	0	0	0	0	0
101	6	0.011	0.009	0.007	0.005	0.004	0	0	0	0	0	0	0	0	0
101	7	0.011	0.009	0.006	0.006	0.004	0	0	0	0	0	0	0	0	0
101	8	0.011	0.009	0.007	0.006	0.004	0	0	0	0	0	0	0	0	0
101	9	0.011	0.009	0.007	0.006	0.004	0	0	0	0	0	0	0	0	0
101	10	0.003	0.009	0.007	0.006	0.004	0	0	0	0	0	0	0	0	0
101	11	0.01	0.008	0.007	0.005	0	0	0	0	0	0	0	0	0	0
101	12	0.01	0.008	0.006	0.006	0.003	0	0	0	0	0	0	0	0	0
101	13	0.01	0.009	0.006	0.006	0.003	0	0	0	0	0	0	0	0	0
101	14	0.011	0.008	0.007	0.005	0.004	0	0	0	0	0	0	0	0	0
101	15	0	0.009	0.006	0.006	0.003	0	0	0	0	0	0	0	0	0
101	16	0.01	0.009	0.006	0.006	0	0	0	0	0	0	0	0	0	0
101	17	0.011	0.009	0.007	0.006	0.003	0	0	0	0	0	0	0	0	0
101	18	0.011	0.01	0.007	0.005	0.004	0	0	0	0	0	0	0	0	0

Table 5.1. Table of resivity values of the processed data for the proposed site.

Note low values for Line 11 *compared to the others.* ***11*** *is the selected site for proposed borehole.*

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The study concludes that on the basis of geological and hydrogeological evidence, the prospects for sufficient groundwater for domestic purposes are good. The most productive aquifer has been identified to be the recent deposits zone and the Pleistocene sediments and rock formations that underly the recent deposits stratum. Highly weathered, jointed and fractured zones within any of the formations in the study area also form significant aquifers that can supply and replenish boreholes within the area with groundwater.

The water quality is expected to be suitable for domestic use. The area being one within a high groundwater potential zone, the yield of the proposed borehole is expected to be good too.

6.2 Recommendations

It is thus recommended that:

- ✓ The borehole should be drilled at the location of **Point 11 of traverse 1** with an 8-inch diameter hammer to a **minimum depth** of **230m** and a **maximum depth** of **240m bgl. This is bound by co-ordinates UTM 36M 0794973E and 9852589S with an elevation of 1920m amsl.**
- ✓ From the records, only ONE borehole is located within 8km radius. In regard to this borehole and considering that the upper aquifers are a quite vulnerable to depletion,all aquifers encountered from ground level down to a penetration depth of about 30m should be sealed off with plain casings and bentonite cement to avoid any possible further depletion of these shallow groundwater resources and in turn avoid any impact to any surrounding borehole abstracting water from this borehole. This borehole will only abstract water from the deepest aquifers.
- ✓ To install the borehole with mild steel casings and gas-slotted screens.
- ✓ The borehole hydraulic properties and aquifer characteristics should be determined during a 24-hour constant discharge test.
- ✓ Samples taken during test pumping must be submitted to a recognized laboratory for full physical, chemical and bacteriological analyses.
- ✓ A monitoring tube and master meter should be installed in the borehole

to be able to monitor the water level and water consumption respectively.

With careful implementation of the project by adhering to the study's findings and recommendations and by following the Water Resource Authority's Guidelines (found in the Authorization letter to Drill the Borehole), the project will safely meet the client's objectives successfully without any impact to groundwater abstraction trends in the area and surrounding boreholes.

7. REFERENCES

Climate Data. ORG

Pinah, P., Cocheriea, A., Thieblemont, D., & Jezequel, P. (January 2000). The Kisii Group of western Kenya: An end-Archaean (2.53 Ga) late orogenic volcano sedimentary sequence. Journal of African Earth Sciences 30(1):79-97. DOI:10.1016/S0899-5362(00)00009-9

WATER ACT 2002. WRMA Rules 2007, Legislative Supplement No. 52.

www.kisii.go.ke/index.php/county-profile/position-and-size/item/1562-physiographic-and-natural-conditionsTams (1980). National Master Water Plan Stage I, Ministry of Water Development.

APPENDICES

Appendix 1: Drilling and Construction of Boreholes

Drilling

Drilling should be carried out with an appropriate rotary drilling method preferably Airdrilling which is considered suitable for the area. Geological rock samples should be collected at 2 metre intervals. Struck and water rest levels and if possible, estimates of the yield of individual aquifers encountered, should also be noted.

Well Design

The design of the well should ensure that screens are placed against the optimum aquiferzones.

Casing and Screens

The well should be cased and screened with good quality screens; considering the depth of the borehole it is recommended to use steel casings and screens of 6" diameter.Slots should be maximum 2 mm in size.

Gravel Pack

The use of a gravel pack is recommended within the aquifer zone, because the aquifercould 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 shouldbe sufficient. Should the slot size chosen be too large, the well will pump sand, thus damaging the pumping plant, and leading to gradual `siltation' of the well. The grain size of the gravel pack should be an average 2 - 4 mm.

Well Construction

Once the design has been agreed, construction can proceed. In installing screen and casing, centralizers at 6m-intervals should be used to ensure centrality within the borehole. This is particularly important to insert the artificial gravel pack all around the screen. If installed, gravel packed sections should be sealed off top and bottom with clay (2 m).

The remaining annular space should be backfilled with an inert material, and the top five metres grouted with cement to ensure that no surface water at the well head can enter the well bore and thus prevent contamination.

Well Development

Once screen, pack, seals and backfill have been installed, the well should be developed. Development aims at repairing the damage done to the aquifer during the course of drilling by removing clays and other additives from the borehole walls. Secondly, it alters the physical characteristics of the aquifer around the screen and removes fine particles.

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

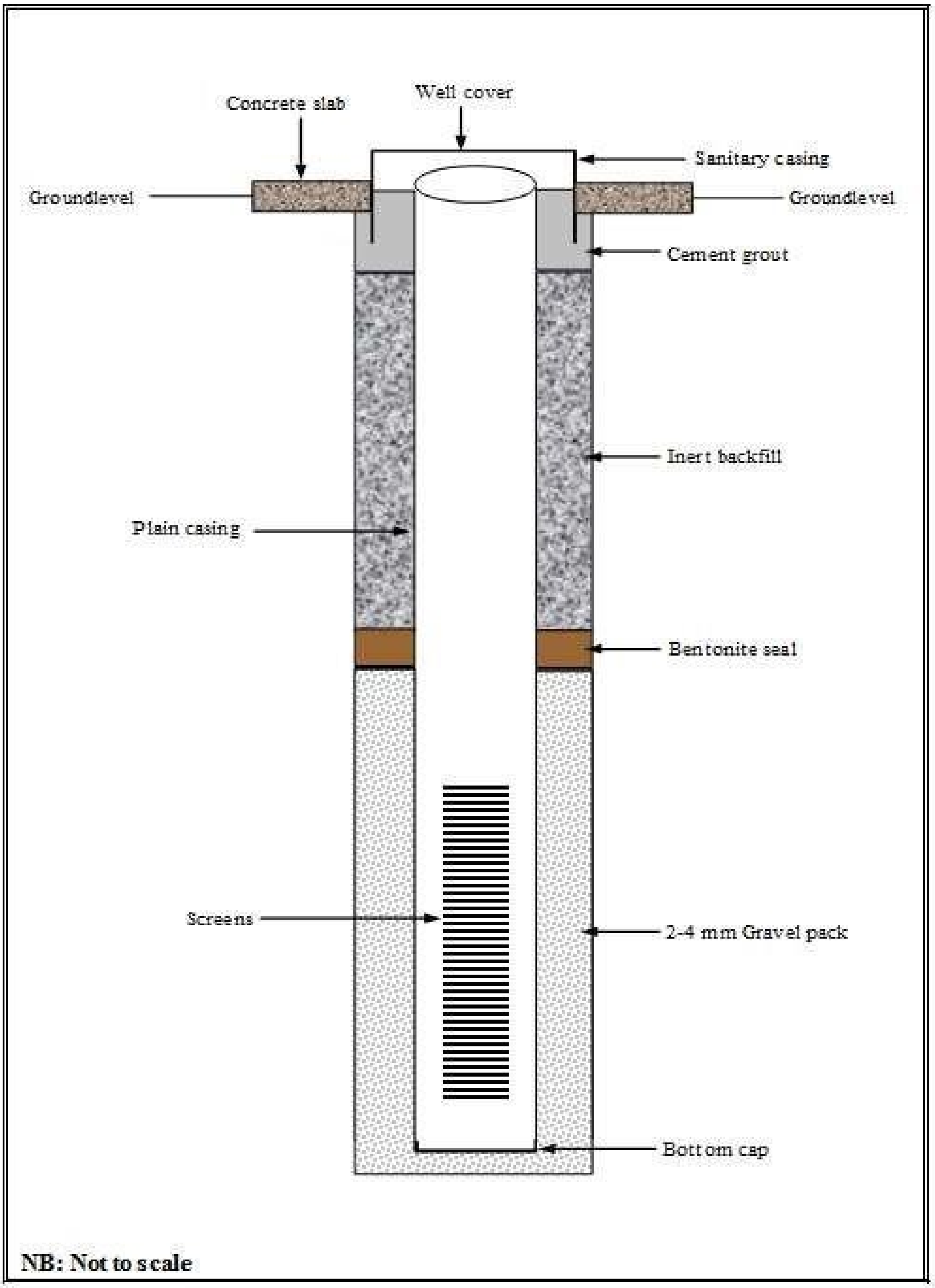
Well development is an expensive element in the completion of a well, but is usually justified in longer well-life, greater efficiencies, lower operational and maintenance costs and a more constant yield. Within this frame the pump should be installed at least2 m above the screen, certainly not at the same depth as the screen.

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 from giving an indication of the quality of drilling, design and development, it also yields information on aquifer parameters which are vital to the hydro-geologist.

A well test consists of pumping a well from a measured start level (Water Rest Level
- (WRL) at a known or measured yield, and simultaneously recording the discharge rate and the resulting drawdown as a function of time. Once a dynamic water level (DWL) is reached, the rate of inflow to the well equals the rate of pumping. Usually the rate of pumping is increased stepwise during the test each time equilibrium has been reached (Step Draw-Down Test). Towards the end of the test a water sample of 2 liters should be collected for chemical analysis.

The duration of the test should be 24 hours, followed by a recovery test for a further 24 hours, or alternatively until the initial WRL has been reached (during which the rate of recovery to WRL is recorded). The results of the test will enable a hydro-geologist to calculate the optimum pumping rate, the installation depth, and the drawdown for agiven discharge rate.



Schematic Design for Borehole Completion

Appendix 2: Acceptable Ionic Concentrations - Various Authorities

		World Health Organization: Guidelines;	Standards;		European Community :1983 of water intended for human consumption: EC Directive 1980 relating to the quality	
Substance or Characteristic		Value (GV	(HL ,	Upper limit	Guide Level (tentative)	Max. Admissible (GL) Concentration (MAC)
Inorganic Constituents of health significance;						
Antimony	Sb				0.01	
Arsenic	As	0.05	0.05		0.05	
Cadmium	Cd	0.005	0.01		0.005	
Chromium	Cr	0.05	0.05			
Cyanide	CN	0.10	0.05		0.05	
Fluoride	F	1.5	1.7		1.5	
Lead	Pb	0.05	0.10		0.05	
Mercury	Hg	0.001	0.001		0.001	
Nickel	Ni				0.05	
Nitrates		10 (as N)	45 (as NO_3)	25 (as NO_3)	50 (as NO_3)	
Selenium	Se		0.01		0.01	
Other Substances		GV: Desirable Level:	Highest Permissible Level:	Maximum	GV:	MAC:
Aluminum	Al	0.20			0.05	0.20
Ammonium	NH_4				0.05	0.50
Barium	Ba				0.10	
Boron	B				1.0	
Calcium	Ca		75	50	100	
Chloride	Cl	250	200	600	25	
Copper	Cu		0.05		0.10	
Hydrogen Sulphide	H_2S	ND				ND
Iron	Fe	0.30	0.10	1.0	0.05	0.20
Magnesium	Mg	0.10	30	150	30	50
Manganese	Mn	0.10	0.05	0.50	0.02	0.05
Nitrite	NO_2					0.10
Potassium	K				10	12
Silver	Ag					0.01
Sodium	Na	200			20	175
Sulphate	SO_4	400	200	400	25	250
Zinc	Zn		5.0	15	0.10	
Total Dissolved Solids	1000	500	1500		1500	
Total Hardness as $CaCO_3$		500	100	500		
Colour	°Hazen	15	5	50	1	20
Odour		Inoffensive	Unobjectionable			2 or 3
TON						
Taste		Inoffensive	Unobjectionable			2 or 3
TON						
Turbidity	(JTU)	5	5	25	0.4	4
pH		6.5 - 8.5	7.0 - 8.5	6.5 - 9.2	6.5 - 8.5	9.5
(max)						
Temperature	°C				12	25
EC	uS/cm				400	
Notes	ND - Not Detectable		IO - Inoffensive			
	GL - Guide Level	UO - Unobjectionable				

(Based on Table 6.1, in Twort, Law & Crowley, 1985)

Appendix 3: Fluoride in Groundwater

(Source: Endemic Fluorosis in Developing Countries, 1991, J.E. Frenken, editor, TNO Institute for Preventive Health Care, The Netherlands)

Introduction

Fluoride is an essential constituent of the human body where it concentrates mainly inbones and teeth. A deficiency as well as an excess of fluorine may have negative effectson someone's health. Excessive intake of fluorine may lead to Fluorosis, a disease associated with dental and skeletal deterioration.

Especially for drinking water purposes these high concentrations form a limitation. In this appendix the aspects of fluoride in groundwater for instance, the source of fluoride, the health hazard of high fluoride concentrations and fluoride removal methods, will bediscussed briefly.

Sources of Fluoride

Fluoride (F^-) is an ion of the chemical element fluorine (F). The elemental form does not occur in nature due to the electro-negativity and high chemical reactivity.

The geochemical behavior of fluoride is similar to that of the hydroxyl ion (OH^-).

Fluorine bearing minerals are found in igneous, sedimentary and metamorphic rock. Especially in contact metamorphic rocks high concentrations are found. The main fluorine bearing minerals are listed in the Table below.

Fluorine Bearing Minerals

Group	Examples
Silicates	Amphiboles, Micas
Halides	Fluorite, Villiaumite
Phosphates	Apatite
Others	Aragonite

The most important mineral containing fluorine is fluorite (CaF_2). Furthermore, volcanic gases may contain fluorine; examples are HF, SiF_4

and H_2SiF_6.

Other sources of fluorine are related to pollution caused by agricultural and industrial activity (use of phosphatic fertilizers, processing of phosphatic raw materials).

Furthermore, fluoride concentrations in water are determined by weathering processes (CO_2 pressure, hydrothermal activity), evaporation and calcium concentration. At low calcium concentrations (in environments with high alkalinity and when calcite limits calcium concentrations) fluoride cannot be equilibrated by fluorite solubility and can reach very high concentrations.

In volcanic areas without hydrothermal activity the fluoride concentrations are mainlydetermined by the weathering of amphiboles or volcanic glass. Both are important constituents of phonolites. Volcanic tuffs on an average have a higher content of solublevolcanic glass than phonolites.

Health Hazard of Fluoride

The prevalence and severity of dental and skeletal fluorosis is depending on many factors but the most important risk indicator will be fluoridated drinking water. Results of several investigations show that especially children are susceptible to fluorosis if they depend on (drinking) water with high fluoride concentrations. The results indicatethat mild dental fluorosis can occur when concentrations of 0.4 ppm are considered. More serious problems occur at fluoride concentrations of 2.1 ppm (100 % prevalenceof dental fluorosis in age group 10 - 15 years) and 3.6 ppm (skeletal changes in 11 - 15years old). Above 10 ppm skeletal deformities may occur in children.

The World Health Organization uses the guideline limit of 1.5 ppm fluoride. This limitis based on the assumption that people consume only 2 liters of water per day. This assumption seems to be rather low since people, especially in countries with hot climates, consume more than 2 liters per day. The recommended WHO concentration limits together with the possible effects are listed in the Table below.

Fluoride contents in drinking water and possible effects

(WHO) Concentration Fluoride (ppm)	**Possible effects**
0.5 - 1.5	Fluoride in water has no adverse effects, incidence

	of cariesdecreases
> 1.5	Mottling of teeth may occur to an objectionable degree e.g. dental fluorosis incidence of caries decreases
3.0 - 6.0	Association with skeletal fluorosis
> 10.0	crippling skeletal fluorosis

Results of investigations in tropical areas suggest a maximum recommended level of
0.6 ppm more appropriate for tropical regions. Above this value mottling of teeth may occur. Some countries however use higher permissible or maximum recommended levels, simply because of the absence of water with lower concentrations. The maximum permissible level in Tanzania is 8 ppm, while the Kenyan maximum permissible level is set at 1.5 ppm.

Removal of Fluoride from Groundwater

Especially during the last decade several methods have been developed to remove or reduce the fluoride concentration in drinking water. However, most of the methods arerather complicated and expensive and are still in the laboratory or experimental stage. The methods are mainly based on:

-- Precipitation (use of lime, alum, sulphate, gypsum, etc)

-- Adsorption / ion exchange (use of bones, charcoal, clays, etc)

-- Osmosis

-- Electrochemically stimulated coagulation

-- Electrodialysis

Although the methods are still in the laboratory phase, the application potential for thebone char, gypsum / fluorite and clay method are rather good. These methods are simple and the raw materials are often available at the site. The methods can be appliedat household and community level.

The *gypsum / fluorite* method can reduce the fluoride concentrations to 4 ppm only. More advanced steps are necessary to reduce the concentrations below 1.5 ppm. The basic principle of the method is the dissolution of gypsum in drinking water with high fluoride concentrations. Fluoride concentrations will be reduced due to the precipitationof fluorite according the following reaction:

$$CaSO_4 2H_2O + 2F^- \text{--->} CaF2 + SO42^- + 2H2O$$

Fluorite will precipitate as soon as the water is saturated with fluorite. The equilibriumconstant for fluorite:

$$CaF_2 \text{<---->} Ca2^+ + 2F^- \qquad K = 10^{-10.7}$$

The water is saturated as soon as:

$$SI = \log ([CA] * [F]^2 / K)\ ^3\ 1$$

Bone media has been used successfully to remove fluoride. Reductions of the fluoride concentration to less than 1.0 mg/lit are reported. The principle of the method is based on the fact that the bone media is reacting with fluoride in a similar way as bones and teeth of the human body. The fluoride is immobilized in the filter medium through the process of ion exchange.

The equipment used in laboratory and field tests is rather simple. The defluoridator unit consists of a container and a filter. The filter has a bottom layer of 300 gr crushed charcoal for adsorption of color and odor. The middle layer consists of 1000 gr bone media. At the top 200 gr of pebbles are used to prevent the middle layer of floating. The bone media can be either granulated bone media or bone char. In both cases the material has to be pretreated carefully to optimize the results. For the granulated bone media, the bones selected have to be clean, non-porous and crushed into chippings of 1to 2 mm. For the bone char the bones have to be activated by heating to a temperature of 600°C. For both methods it is advised to treat the bone media with sodium hydroxidebefore it is used.

The time over which the filtering material remains active depends on the amount of water that has been treated and the initial fluoride content. In experiments in Argentine (contact time necessary to allow fluoride to chemically combine with granulated bone media amounted to 0.5 hours) the filter had to be replaced every 3 months at a production of 20 l/day and an initial concentration of 10 ppm.

Different *types of clay* have been used in laboratories to reduce the fluoride contents. Kaolinite, serpentinite, china clay and clay pot are used as natural adsorbents. Reductions from 10 ppm to 1.5 ppm and lower are reported. For this methods pH, temperature and/or salt content should be maintained at a level predetermined throughlaboratory experiments.

Conclusions and Recommendations

High fluoride concentrations in drinking water may cause dental and / or skeletal fluorosis. The maximum recommended levels differ per country; the recommended WHO limit is 1.5 ppm. In fact, the maximum advisable level depends on factors such asdiet, climate and age.

Nevertheless, it can be concluded that especially children are susceptible to fluorosis. Therefore, it is recommended not to use borehole water with fluoride concentrations exceeding 0.5 ppm as drinking water for children. The recommended maximum level for adults is 1.0 ppm. These levels only have to be considered when the borehole water is used as a permanent source for drinking water.

The equipment for the removal of fluoride from drinking water is not yet available fordomestic purposes but future prospects are good.