Hydrogeological/Geophysical Survey Report

For

ONE PRODUCTION BOREHOLE

Within

Emraash Area, Lesuta Sub-Location, Nakarra Location, Narok West Sub-County, Narok County

****

Client:

OLENKUYA PRIMARY SCHOOL

****

Consultants:

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SUMMARY

Introduction

This brief report describes the results of hydrogeological and geophysical investigations for the client, Olenkuya Primary School in its piece of land located in Emraash Area, Lesuta Sub-Location, Nakarra Location, Narok West Sub-County, Narok County. The site is defined by Latitude **S 01° 42' 4.59" and Longitude E 035° 41' 4.22" (UTM-S 36M, 798698-x, 9811750-y)** at an elevation of 2053m amsl. The borehole is to be used to supply water for domestic use within the school.

Hydrogeology

The investigated site is located in a hydrogeological zone characterized by low to medium groundwater potential. The major water bearing formations in the area are: - Sedimentary intercalations in the faulted lava flows, Old Land Surfaces (OLS) separating lava flows, Fissures within body of the lava flows and welded Tuff formations and weathered/fractured basalts and trachytes. In the investigated area, the aquifers are expected with fractured/weathered gneisses and Migmatites while shallow aquifers within saturated alluvial deposits.

Geophysics and Fieldwork

The Geophysical fieldwork was carried out on the 19th December 2022. Electrical resistivity method was used for geophysical investigations. One Electrical Profiling and Vertical Electrical Sounding (VES) was carried out to determine the prevailing hydro-stratigraphy and their suitability for groundwater storage in the investigated site.

Conclusion

The results from the hydrogeological and geophysical investigations indicate that the investigated area is situated in a hydrogeological zone which is characterized by medium groundwater potential. A well drilled in this area should target both the shallow (80-150m) and deep (200-250mbgl) aquifers. From the current boreholes within the site, the yield is expected to be low but may increase with depth. The two boreholes drilled within a radius of 2km have yields below 5m^3/hour while the existing borehole within the site is yielding about 0.5m^3/hour. The total borehole yield will only be identified after or from drilling.

Recommendations

It is recommended that: -

a) An 8" borehole should be drilled at the location of **VES 3 (Point 13** along the Geo-Electrical **Profile 1)** to a **minimum depth of 200m** and a **maximum depth of 250m bgl.**

b) Before drilling commences, a drilling permit should be applied and obtained from the relevant Regional Water Resource Authority (WRA) within Nakuru Region.

c) Proper supervision and monitoring of drilling by a qualified hydrogeologist should be provided.

d) The borehole should be installed with a water meter and an airline/piezometer to monitor the groundwater abstraction.

e) Enough storage tanks should be provided and installed for continuous water supply to the community and this will also give enough time for the aquifer recharge.

f) Water samples should be taken after test pumping and taken to a recognized laboratory for full physical, chemical and bacteriological analysis and results taken to Water Resources Authority.

The proposed drilling site is benchmarked and known to the Client.

Water Quality

Generally, the water quality is expected to be good. The fluoride concentrations may however, exceed the WHO limit of 1.5 mg/L.

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 levels 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. It determines the water quality and longevity of the borehole.

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LIST OF ABBREVIATIONS

ABBREVIATIONS: (NOTE: SI spellings used throughout).

Agl	above ground level
amsl	above mean sea level
bgl	below ground level
E	East
EC	electrical conductivity (µS/cm)
h	head
hr	hour
K	hydraulic conductivity (m/day)
L	litre
m	metre
N	North
PWL	pumped water level
Q	discharge
Q/s	specific capacity (discharge – drawdown ratio; in m. cu/hr/m)
Cu	cubic
Sq	square
s	drawdown (m)
S	South
Sec	second
SWL	static water level
T	Transmissivity (m.sq/day)
VES	Vertical Electrical Sounding
W	West
WSL	water struck level
µS/cm	micro-Siemens per centimetre: Unit for electrical conductivity
°C	degrees Celsius: Unit for temperature
Ω-m:	Unit for apparent resistivity
ρa	Apparent resistivity
“	Inch

GLOSSARY OF TERMS

Alluvium This is a general term for detrital material deposited by flowing water**.**

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

Colluvium General term for detrital material deposited by hill slope gravitational process, with or without water as an agent usually of mixed texture.

Conductivity Transmissivity per unit length (m/day)

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

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 well. As a result, a higher sustainable yield can be achieved.

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

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

Hydrogeological Those factors that deal with sub-surface waters and related geological aspects of surface waters.

Infiltration Process of water entering the soil through the ground surface

Percolation This is the 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. It can also be described as downward percolation hindered by an impermeable layer.

Peneplain A level surface, which has lost nearly all its relief by passing through a complete cycle of erosion (also used in a wider sense to describe a flat erosional surface in general)

Permeability This is 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, this may be isolated or connected.

Recharge General term applied to the passage of water from surface of sub-surface sources (E.g., Rivers, rainfall, lateral groundwater flow) to the aquifer zones.

Static water level This is 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. sq. /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

1.1. Background Information

The Consultant was commissioned by the client to site a borehole in its piece of land located in Emraash Area, Lesuta Sub-Location, Nakarra Location, Narok West Sub-County, Narok County. The site is defined by Latitude **S 01° 42' 4.59" and Longitude E 035° 41' 4.22" (UTM-S 36M, 798698-x, 9811750-y)** at an elevation of 2053m amsl. The client required detailed information on prospects of drilling a productive borehole in the land to supply enough water for domestic use.

1.2. Objective of the Study

The objectives of the investigations were: -

- To assess the groundwater resources in the area.
- To advice on the viability of drilling a production borehole that can be used to supply water for domestic use.
- To prepare Hydrogeological Survey Report in conformity with the provision of the rules and procedure outlined by the Water Resource Authority which includes the following: -
    - ✓ Site Name, Location, GPS readings
    - ✓ Geology and hydrogeology
    - ✓ Present sources and status of the existing water supply
    - ✓ Existing borehole data information
    - ✓ Geophysical data analysis
    - ✓ Conclusions and recommendations including groundwater potential of the investigated site, name and location of the site recommended for drilling and recommended maximum depth of drilling in metres and the appropriate method of drilling.

The investigations involved hydrogeological, geophysical field investigations and study of available relevant geological and hydrogeological materials. Several data sources such as published master plans, geological and hydrogeological reports and maps, Ministry of Water and Irrigation borehole completion records and technical reports of the area by various organizations were used.

Addresses:

The address of the Client is as follows:

<u>Client's Contacts:</u>
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2. BACKGROUND INFORMATION

2.1. Location

The investigated site is within Emraash Area, Lesuta Sub-Location, Nakarra Location, Narok West Sub-County, Narok County. The site is defined by Latitude S 01° 42' 4.59" and Longitude E 035° 41' 4.22" (UTM-S 36M, 798698-x, 9811750-y) at an elevation of 2053m amsl. The location is shown in Figure 1.

2.2. Climate and Land Use

The district has diversified topography, which ranges from a plateau with altitudes ranging from 1000m-2350 M.A.S.L at the Southern parts to mountainous landscape ranging to about 3098 M A.S.L at the highest peak of Mau escarpment in the North. The district has five agro-climatic zones namely humid, sub-humid, semi-humid to arid and semi-arid. Two-thirds of the district is classified as semi-arid. The agro-ecological zones found in the district include: Tropical Alpine (TA), Upper Highland zones (UH) Lower Highland zones (LH) and upper-midland zones (UM). The district experiences bi-modal pattern of rainfall with long rains (Mid-March – June) and short rains (September-November). The amount of rainfall is influenced by bi-annual passage of Inter-Tropical Convergence Zone (ITCZ). Rainfall distribution is uneven with high potential areas receiving the highest amount of rainfall ranging from 1200mm – 1800mm p.a. while the lower and drier areas classified as semi-arid receiving 500mm or less p.a. The district experiences a wide variation of temperatures throughout the year with mean annual temperatures varying from 10^{o}C in Mau escarpment to about 20^{o}C in the lower drier areas.

2.3. Drainage

Ewaso Nyiro South is the drainage system of rivers emerging from part of Mau Towers and draining into Lake Natron and comprises Rivers: Enkare Narok, Ewaso Nyiro, Siyiabei and its tributary Enkare Ngoshor. Regionally, Lake Victoria South drainage area comprises all the rivers emanating from part of Maasai Mau Towers and draining into Lake Victoria. These include Amala River bordering Bomet District on the upper side and Mara River (downstream) when Amala River is joined by River / Nyangores. Mara River borders Narok District with Transmara District towards Kuria District with the Kenya and Tanzania.

2.4. Physiography

The area is located within the Rift System at an elevation of 1948 m amsl. The conspicuous features are Mau Forest, Mount Longonot and Suswa on the western side and plains within Narok region.

2.5. Water Demand

The projected daily water demand is about 20 m^3/day mainly for domestic use for daily washing and drinking. It is estimated that the demand will be met by the borehole. A borehole with a production of 5 m^3/h pumped for 4 hours will adequately serve the Client.

2.6. Current Water Supply

The current source of water at the site is from the neighbouring river and harvested rain water during rainy season. The expected increase in water supply demand within the homestead and need of a safe drinking water calls for an alternative constant source. It is therefore necessary that there should be an additional standby water supply to supplement the current supply.

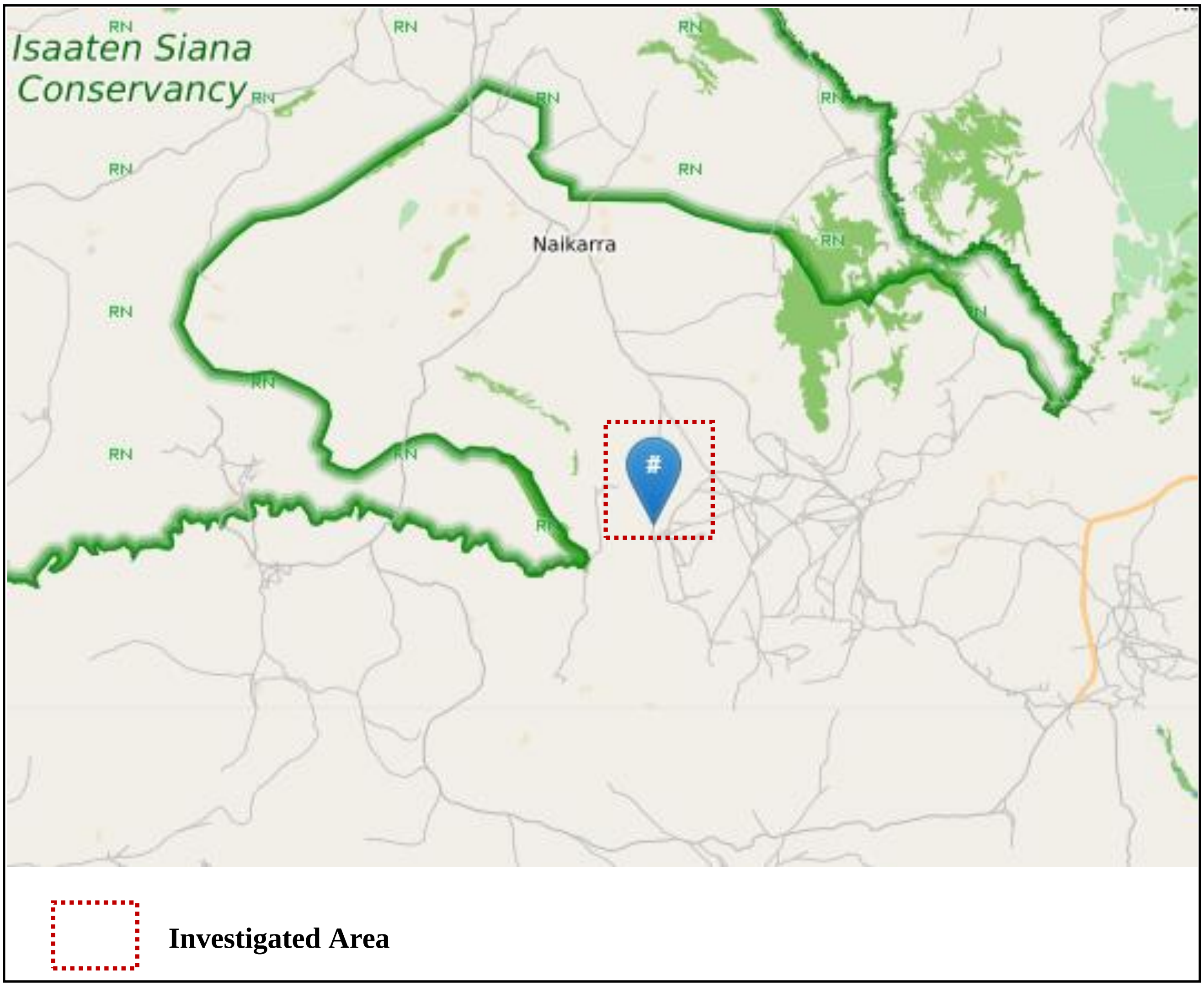


Figure 1: Site Location Map

3. GEOLOGY

3.1. Regional Geology

The oldest rocks exposed are quartzo-felspathic gneisses, quartzites and mica-quartzites of the Kenya Basement System, believed to be of late Precambrian age. The gneisses are exposed in windows within volcanics in the south-eastern part of the area, and quartzites form the Loita Hills and the inselbergs rising from the Loita Plains. The rocks represent an original series of arenaceous shallow-water sediments which have been metamorphosed, recrystallized and folded.

Vulcanicity in the area is thought to have commenced in the Miocene with the eruption of a melanephelinite lava series in the south-east, on the downwarped sub-Miocene peneplain. The lavas are between 600 and 900 ft. thick along the ridge extending south from Legorinyo, which is probably close to the fissure or line of vents from which they were erupted, and they are well developed further south in the Loita Hills area. They skirt the quartzite hill north of Legorinyo, and become less widespread north of it. The lavas north-west of Legorinyo may be the products of another eruptive centre. In the south of the area the basic lavas are intruded by a highly porphyritic nephelinite.

Extrusion of phonolites followed later in the Miocene, the main mass forming the high ground between Ntuka and Inkitintini where two different phonolite types are distinguishable, reaching a maximum combined thickness of about 900 ft. These were probably derived from local eruptive centres, and differ from other phonolites originating from the Mau highlands exposed farther north in the Narok river. I"

The melanephe1inite lavas were subsequently downfaulted eastwards along the Naitiami fault, and the Pliocene(?) Kirikiti basalts of the Magadi area were later erupted on to them, wedging out near the fault scarp. The Naitiami me1anephelinite scarps had suffered considerable erosion and retreated about 1t miles by the early Pleistocene, when deposition of tuffs and ashes filled many i.rregularities in the older lava surfaces. Some of the pyroclastic rocks were laid down in temporary lakes occupying part of the present-day Uaso Ngiro, Seyabei and Olongoirenito valleys. The tuffs and ashes are thickest in the north-east and thin westwards across the Loita Plains; in the south of the area, they are preserved only in valleys.

After deposition of the pyroclastic rocks had commenced the Enkorika fault was initiated and the Naitiami fault moved again. The Enkorika fault threw down about 350 ft. in the south-east, and terminated near Enkorika. The renewed Naitiami fault terminated near Legorinyo, and its maximum throw was about 400 ft. in the south of the area. The deposition of the pyroclastic rocks was punctuated by flows of basalt, alkali basalt, plateau trachyte and orthophyre-type trachyte lava; and by two movements along the Oletugathi fault. The four olivine melanephelinite plugs distributed about the northern part of the area may also belong to this episode. The plateau trachytes are similar to those in the Magadi area described by Baker (1958, p. 18) and extend south and east outside the area, but are exposed northwards only as far as Enkorika. The orthophyre-type trachytes, which form the Angata Naado platform, are the equivalents of the orthophyre-type trachytes in the Magadi area.

3.2. *Structural Geology*

The most striking structural feature is the Gregory Rift Valley, the eastern flank of which, marked by a wide zone of sub-parallel faults, occupies the western third of the area. Fractures and joints are some of the minor structures within the investigated area and where the groundwater occur.

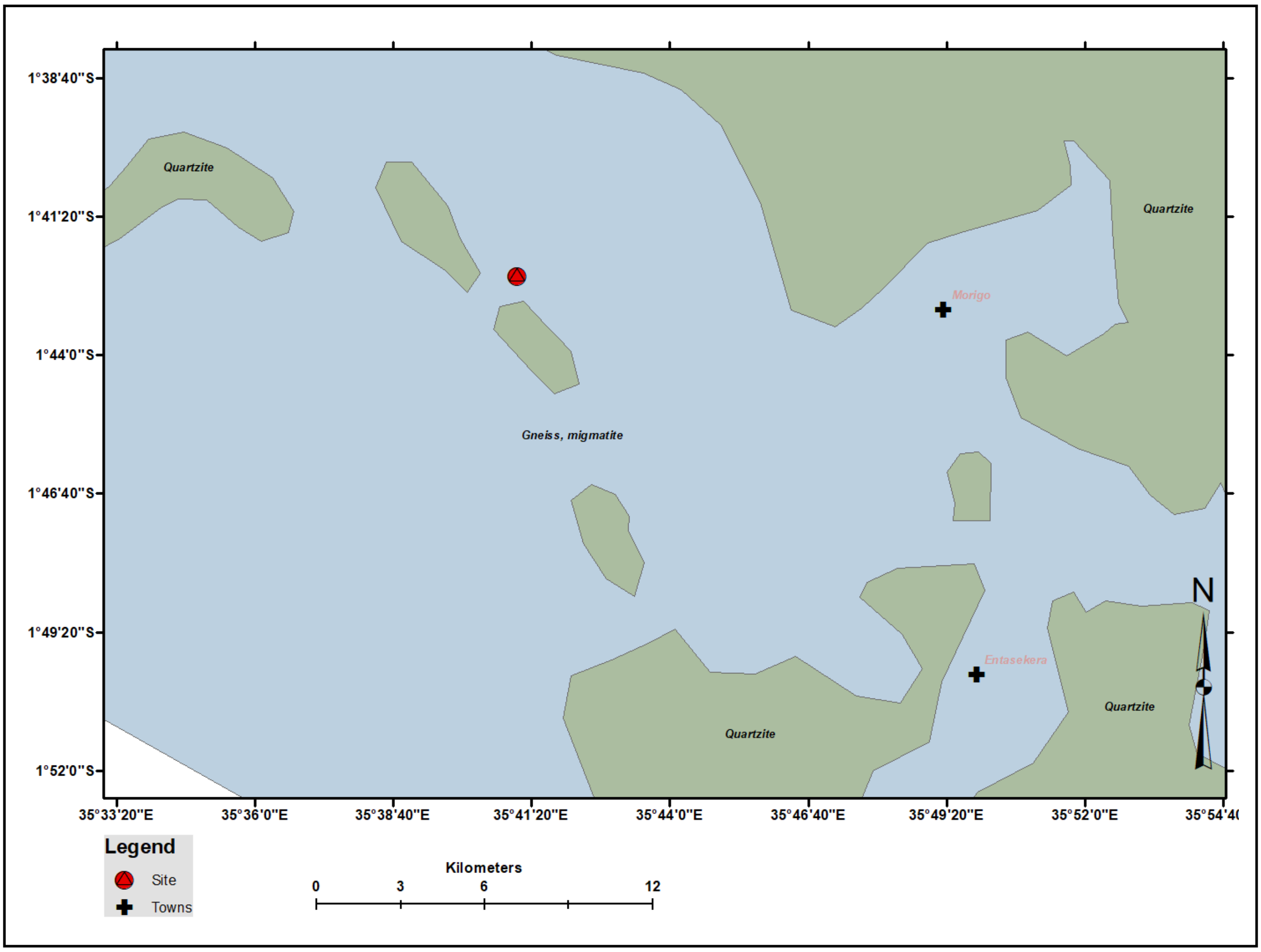


Figure 2: Geological Map of the Area

4. HYDROGEOLOGY

The annual rainfall through direct recharge infiltrates the highly permeable soils derived from the weathering of the Gneisses/Quartzites and other meta-sediments that form the phreatic zone. Percolation into the subsurface sustains the underground water regime.

Lateral recharge from the nearby highland areas is likely to enrich the ground water occurrence through regional replenishment. The medium rainfall and the high gradient from the catchment towards this site encourage recharge.

Potential aquifers are expected within the weathered horizons and the fractured and faulted rocks; old land surfaces (OLS's) defining the various metasediment bed forming favorable storage horizons. The aquifer system is deduced to be both confined and semi-confined.

Aquifer recharge is expected to be mainly by regional replenishment under hydraulic gradient from higher grounds on the hill ranges. This recharge confined deeper aquifers. Direct infiltration from precipitation also contributes towards recharge of shallower semi-aquifers.
Regionally, groundwater occurs at the following formations: -

- The saturated pyroclastics and tuffs.
- Sedimentary intercalations in the faulted lava flows
- Old land surfaces separating lava flows
- Fissures within body of the lava flows and welded Tuff formations
- Lacustrine sedimentary deposited subsequent to the major faulting.
- Buried faults acting as shuttered or conduits to groundwater flow.
- Weathered/Fractured Basement rocks

4.1. Borehole Data

Drilling record have been studied for one borehole within the area.

The depth of the borehole is 120m bgl and aquifer struck at 80m bgl while water rest level reported as 30m bgl. The boreholes yield ranges 8.0 m^3/hour. The area is classified under medium groundwater potential zone. Table 1 below summarizes the borehole data for boreholes near the investigated site.

Table 1: Boreholes Close to the Investigated Site

Borehole no.	Borehole name	TD (m)	WSL (m)	WRL (m)	Tested Yield (m3/hr)	Drawdown (m)
	Maji Moto Camp	120	80	30	8	-

4.1.1. Specific Capacity

This is a crude indication of the efficiency of a borehole as an engineered structure, and is calculated by dividing the discharge rate (in m3/day) by the total drawdown. High specific capacities generally indicate high transmissivities and low specific capacities indicate low transmissivities.

4.1.2. Transmissivity

This is the rate of flow of water under a unit hydraulic gradient through a cross-section of unit width across the entire saturated section of an aquifer. Strictly speaking, transmissivity should be determined from the analysis of a well test, but in most cases, its determined from past studies using Logan's method. Logan (1964) developed a relationship between specific capacity and transmissivity, 1.22 X Q/s, based on a reworking of Thiem's seminal steady-state groundwater flow equation (T'hiem 1906).

The product of (K) and thickness (D) is defined as the transmissivity (T) of an aquifer system (KD=T). This property can be derived from the commonly applied Jacob's formula (Driscoll 1986):

$$T=1.22Q/\Delta s$$

Where: T= Transmissivity, Q=Tested Yield (m^3/day), Δs = increase in drawdown over 1 log cycle of time.

4.1.3. Hydraulic Conductivity

This is defined as the volume of water that will move through a porous medium in unit hydraulic gradient through a unit area measured at right angles to the direction of flow.
The hydraulic Conductivity (K) is estimated as follows:

$$K=T/\text{Aquifer Thickness}$$

4.1.4. The Storage Coefficient

The storage coefficient S of an aquifer is the volume of water released from or taken up per unit surface area per unit change in head. It is dimensionless. Empirical values of S cannot be determined from test data collected in previous drilling programmes in the area, as no aquifer tests have been conducted. In an aquifer test, a borehole is pumped at a known discharge rate and water levels in one or more neighbouring observation boreholes, and the shape and type of drawdown curve in the observation borehole(s) is used to calculate S (de Ridder et al 1990). Storage coefficient for confined aquifers lies in the range 5 x 10^{-5} to 5 x 10^{-3} (Todd et al 2005). A "rule of thumb" estimate of the storage coefficient (Lohman 1972 cited in Todd et al 2005) can be made from: -

$$S = 3 \times 10^{-6} \times D$$, where D is aquifer thickness.

4.1.5. Ground Water Movement

Ground water in this region is supplied by a number of aquifers either in: -

- Sedimentary intercalations in the faulted lava flows
- Old land surfaces separating lava flows
- Fissures within body of the lava flows and welded Tuff formations
- Lacustrine sedimentary deposited subsequent to the major faulting.

The harder or compact volcanic rocks yield little or no water due to their generally impervious character. In addition, faults fissures and joints also, all may carry water and thus forming a potential aquifer.

4.1.6. Groundwater Quality

Generally, the groundwater quality in the study area is expected to be moderately good for general domestic use and suitable for livestock. However, fluoride concentration may be slightly higher than the maximum permissible WHO limits of 1.5 mg/L for human consumption.

5. GEOPHYSICAL INVESTIGATION METHODS

There exist a variety of geophysical methods available to assist in the assessment of geological subsurface conditions. The methods chosen should be suitable to meet the desired objectives for the investigation being carried out. In this study, PQWT-S500 Electrical Equipment were used to understand the sub-surface geology of the study area and advice on a good point to sink a production borehole. For better understanding, the general principle of how resistivity method works is discussed, followed by the Electrical Potential measurement's principle, which is primarily used in this study. The methods were able to achieve the desired objective.

The electrical potentials of the subsurface measured translated to profile curves and maps. These profile maps indicate the hydrostratigraphic changes within the rock units. The techniques are described below.

5.1. Basic Principles (Resistivity Method)

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 pore water. Saturated rocks have lower resistivities than unsaturated and dry rocks. The higher the porosity of 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 minerals also 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 the earth.

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

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

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

$$R = dV/I \quad \text{(Ohm)} \qquad (2)$$

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

$$Rs = (A/L) * (dV/I) \quad \text{(Ohm.m)} \qquad (3)$$

5.2. Basic Principles, PQWT-S Series

By the use M, N electrode probe (transducer) via a cable earth's magnetic field to electrical signal input to high impedance input stage, after the anti-jamming exchange amplification, frequency selection, the desired is selected as operating frequency, and then by the A / D sampling, central processor (CPU) for data processing. Where in the entire measurement process, high-speed Central Processing Unit (CPU) of the control, instrumentation automatic range conversion and automatic frequency selection. Finally, the result is displayed in form profile curves and profile maps automatically on the LCD of instrument, the data can also be transferred as output measurement data, curve graph and profile map by USB cable to computer for analysis and making geological conclusion.

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 pore water. Saturated rocks have lower resistivities than unsaturated and dry rocks. The higher the porosity of 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 minerals also reduces the resistivity of the rock.

5.2.1. Working Principle of PQWT-S Series Equipment

The equipment uses the natural electric field source as a main principle contrasting with the subsurface resistivity of different rocks, groundwater and minerals. Based on measuring the natural electric field on the surface of the N different frequency electric field component, according to their different variation to study the changes in the sub-surface geology, geological problems are therefore resolved. Abnormal changes in geological bodies produce, reaching solve geological problems one electrical prospecting methods. Because this method measures the electrical component of the electromagnetic field of the earth, so called natural electric field method; and we chose the corresponding frequency as measured meters, that were selected frequency, so called frequency selection method, it is always referred to as natural potential frequency method. The equipment is classified under electrical equipment due to its design and production; measuring natural electric field for geological exploration work.

PQWT-S500 series was used, with a frequency of 56, this usually gives accuracy of 0.001 mV and probes to a depth of 500 m bgl (PQWT-S500 Manual, 2017). In this study, the depth was set to maximum of 300m bgl in all the profile. The interval between the measuring points was kept at 1m for all the profiles investigated. The machine measures and stores the data automatically, curves and drawing the profile maps is thereafter auto-generated. The collected data is for the midpoint between the two electrodes while the point O is the first set of data. The illustration is given in Figure 1. The depths and electrical potential values provide the hydrogeologist with information on the geological layering and thus the occurrence of groundwater.

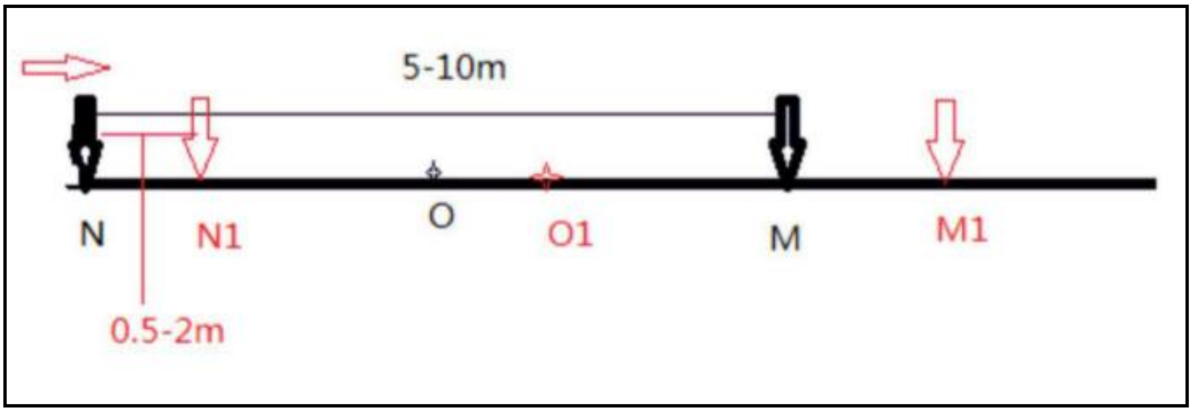


Figure 3: Illustration of Equipment Arrangement (After PQWT-S500 Manual, 2017)

6. FIELDWORK AND RESULTS

6.1. Fieldwork

Fieldwork was carried out on 19th December 2022. Three Electrical Profiling survey and Six Vertical Electrical Soundings (VES) were carried out to map the sub-surface fractured/weak zones and the best point to sink a borehole. In addition, the profiling was to determine the prevailing hydrostratigraphy at the respective site.

6.2. Results

The section shows the results of the electrical profile maps, curves and 2D profile maps from the electrical measurements taken and VES results.

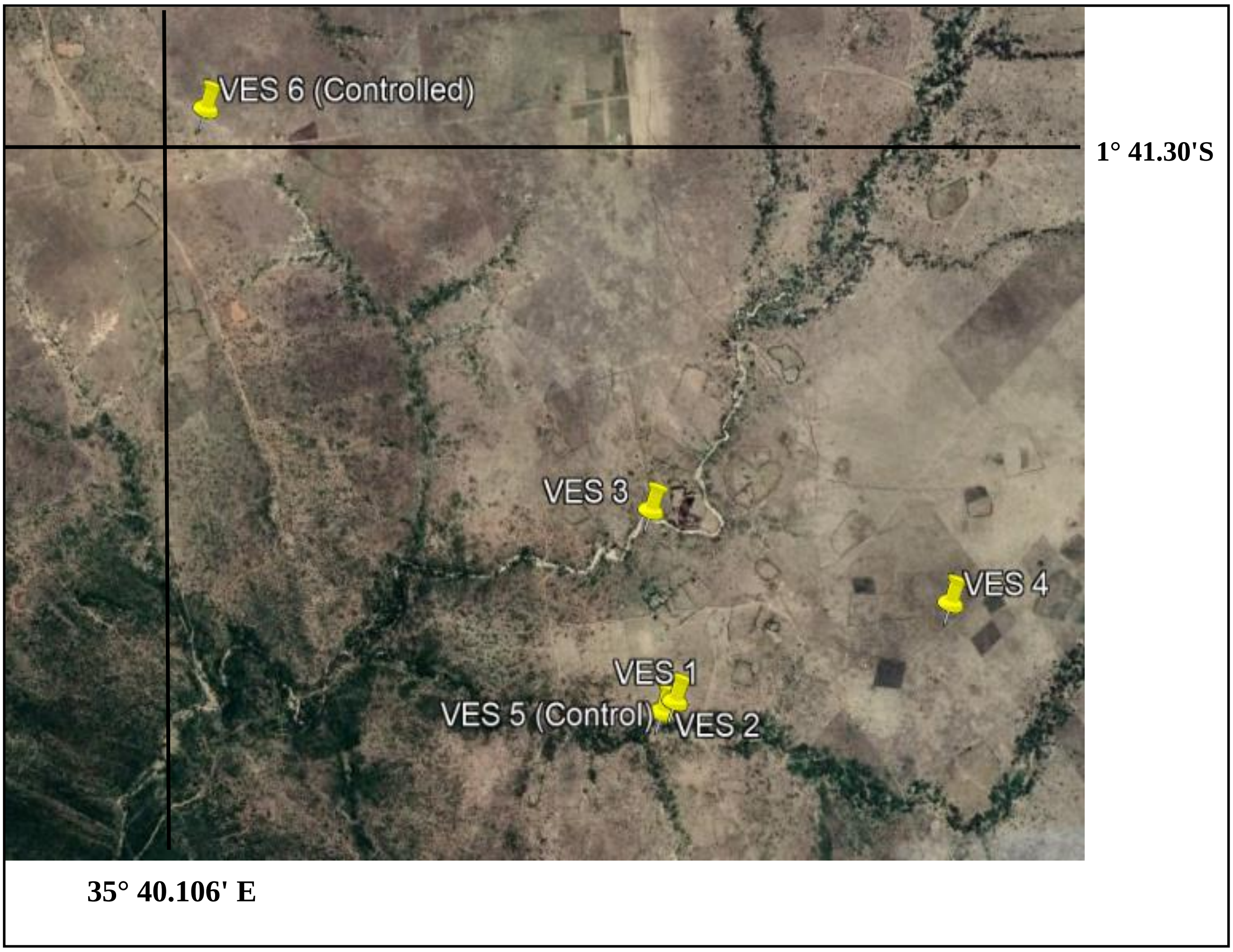


Figure 4: Profile Location Map

6.2.1. Electrical Potential Curve/Map

Profile 1 Results

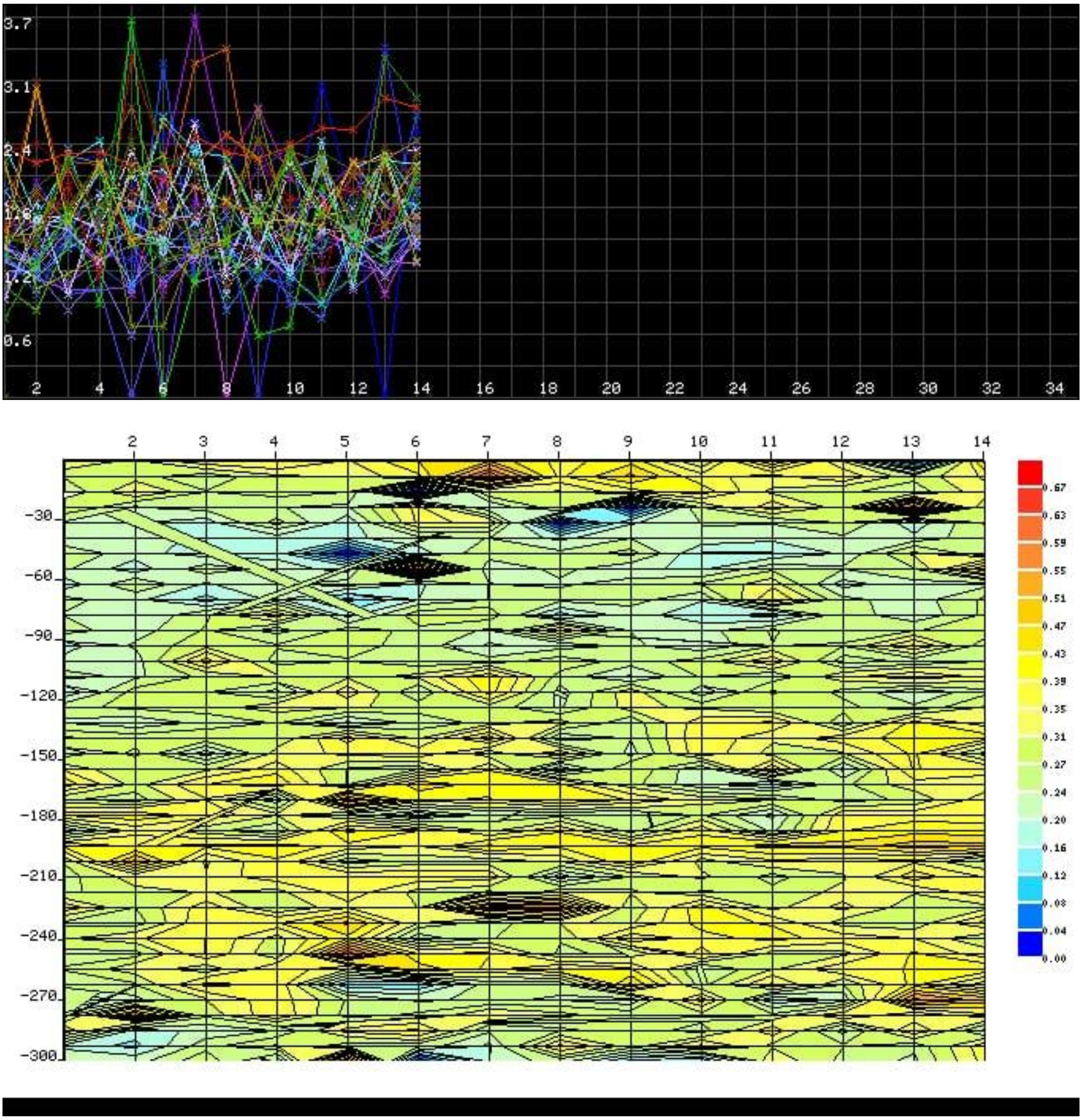


Figure 5: 2D Processed Profile 1 Map

VES 1 was done at Point 11 while VES 2 at point 9 along profile 1 above to further verify the sub-surface geology.

Profile 2 Results

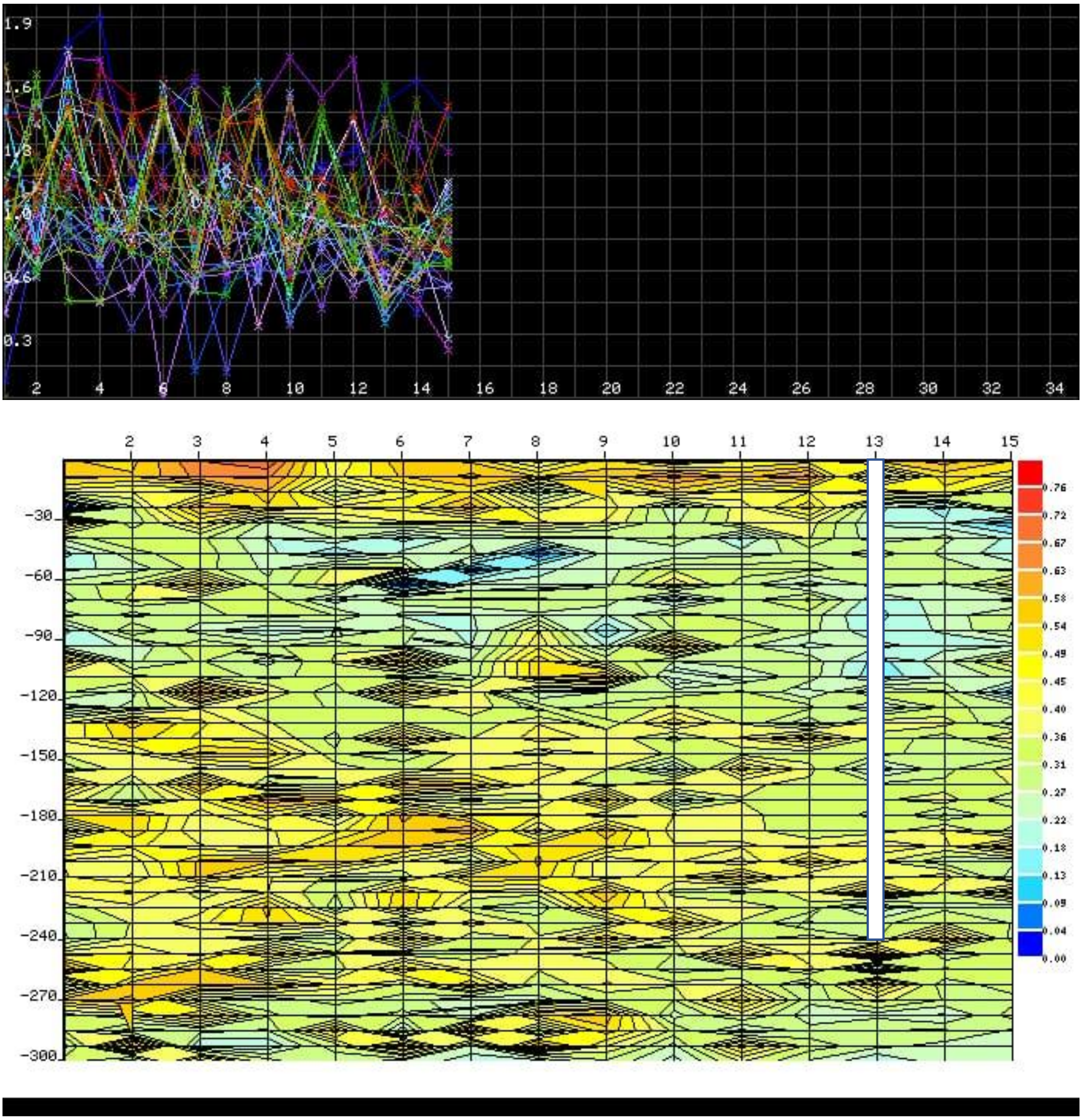


Figure 6: 2D Processed Profile 2 Map

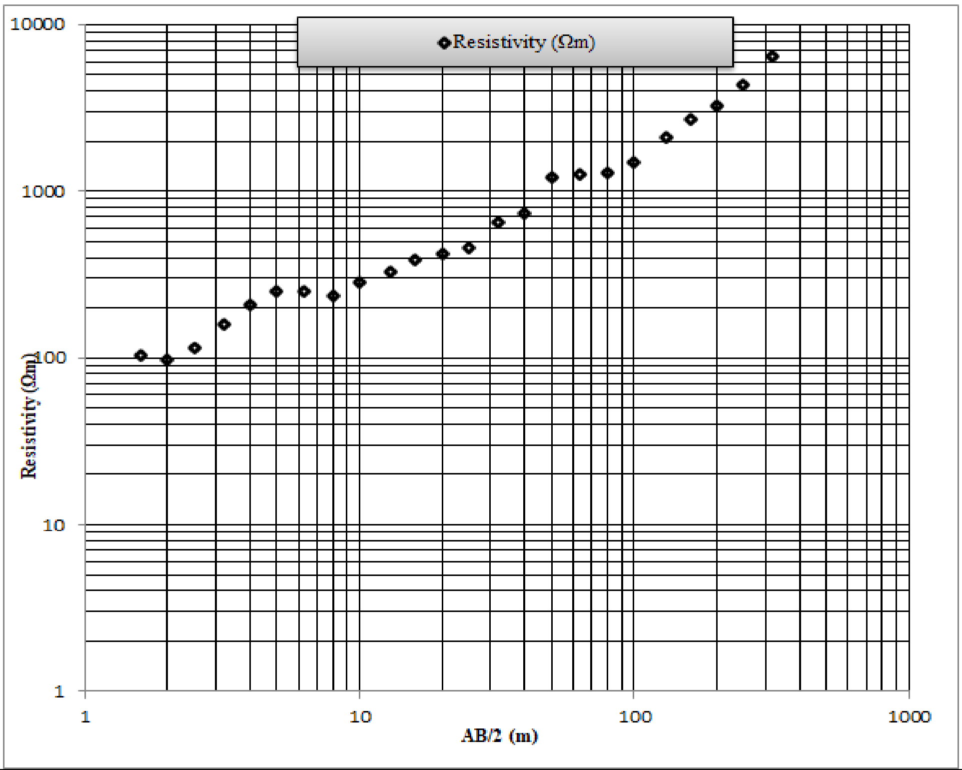
VES 1 was done at Point 13 at point 13 along profile 2 above to further verify the sub-surface geology. VES 5 was done at the location of the existing borehole within the site which was drilled to a depth of 250m bgl and yields little amount of water while VES 6 was done another location far from the site within an existing borehole. The borehole data wasn't available at the moment and the time of the survey but data the data shows that the aquifers occur at depths less than 100m bgl.

6.2.2. Vertical Electrical Sounding (VES) Results

Vertical Electrical Sounding _Data Sheet (Schlumberger)

WGS 84	**County**	Narok	**VES**	1
	Client	Olenkuya Primary School	**Elevation (m)**	2050
	Latitude (S)	1° 42' 28.85"	**Longitude (E)**	035° 41' 3.8"

AB/2 (m)	**Resistivity (Ωm)**
1.6	104
2	97
2.5	114
3.2	160
4	209
5	252
6.3	251
8	237
10	286
13	329
16	388
20	425
25	461
32	653
40	735
50	1210
63	1254
80	1296
100	1484
130	2125
160	2727
200	3242
250	4400
320	6456



Resistivity (Ωm)	**Depth (m)**	**Geological Interpretation**	**Hydrogeological Interpretation**
8.14	0.5	Top Superficial Deposits	Dry
330.07	3	Compact Gneisses	Dry
879	63	Partially Weathered Gneisses	Moist
12200	63	Compact Gneisses	Dry

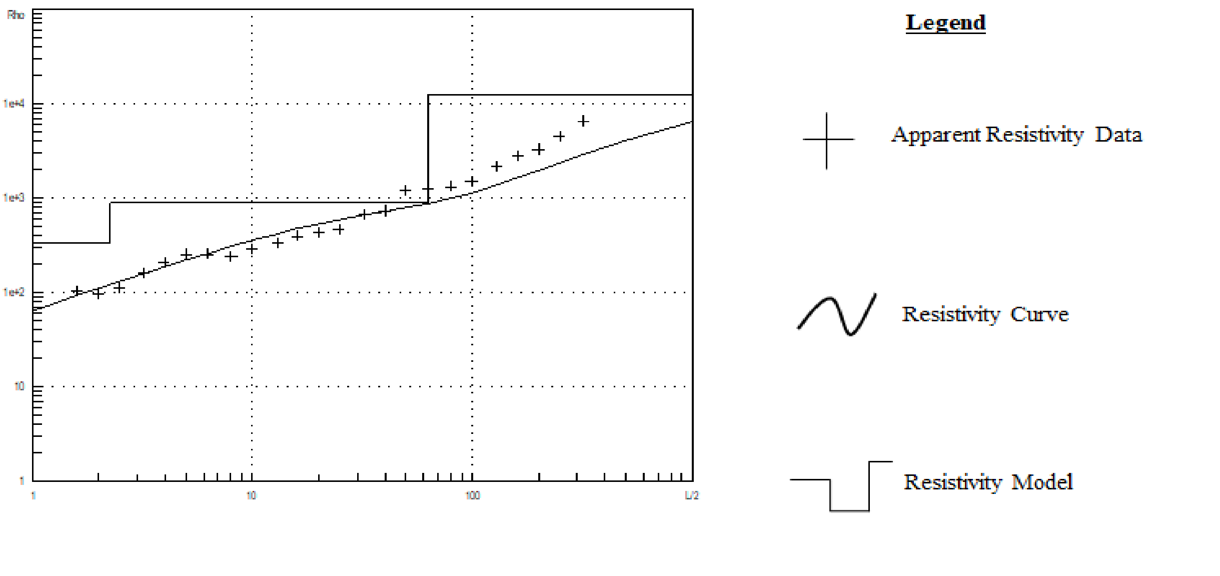
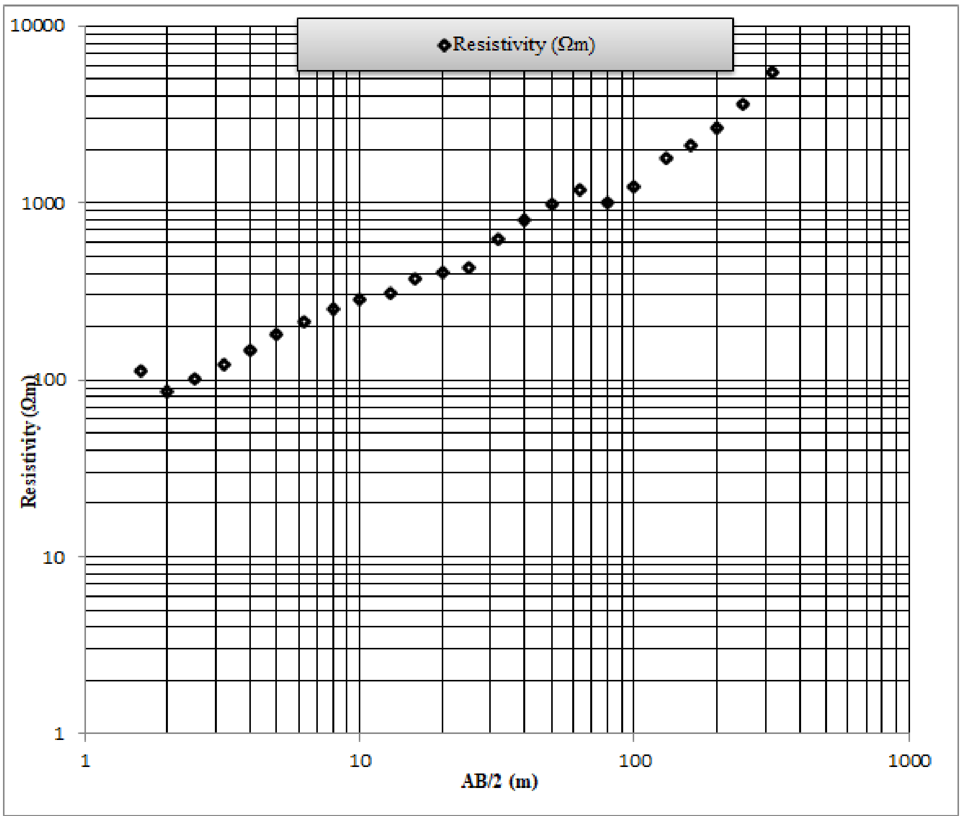


Figure 7: Interpretation of VES 1 Data

Vertical Electrical Sounding _Data Sheet (Schlumberger)				
WGS 84	**County**	Narok	**VES**	2
	Client	Olenkuya Primary School	**Elevation (m)**	2029
	Latitude (S)	1° 42' 28.96"	**Longitude (E)**	035° 41' 3.89"

AB/2 (m)	**Resistivity (Ωm)**
1.6	112
2	85
2.5	101
3.2	123
4	148
5	179
6.3	215
8	252
10	282
13	307
16	370
20	405
25	428
32	622
40	802
50	991
63	1194
80	1005
100	1231
130	1777
160	2125
200	2652
250	3600
320	5439



Resistivity (Ωm)	**Depth (m)**	**Geological Interpretation**	**Hydrogeological Interpretation**
6.52	0.1	Top Superficial Deposits	Dry
311.4	5	Compact Gneisses	Dry
1219.58	43	Partially Weathered Gneisses	Moist
12200	>43	Compact Gneisses	Dry

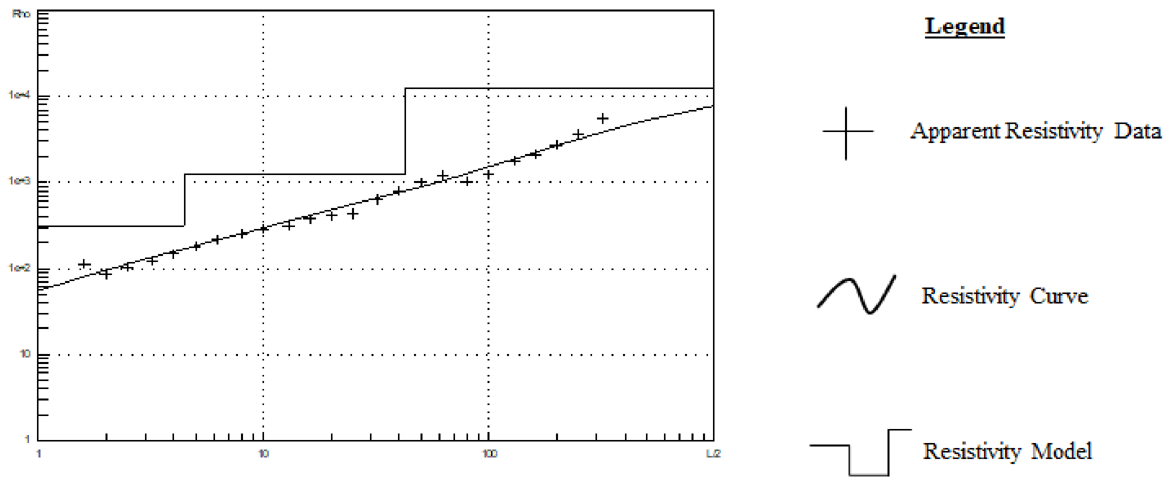
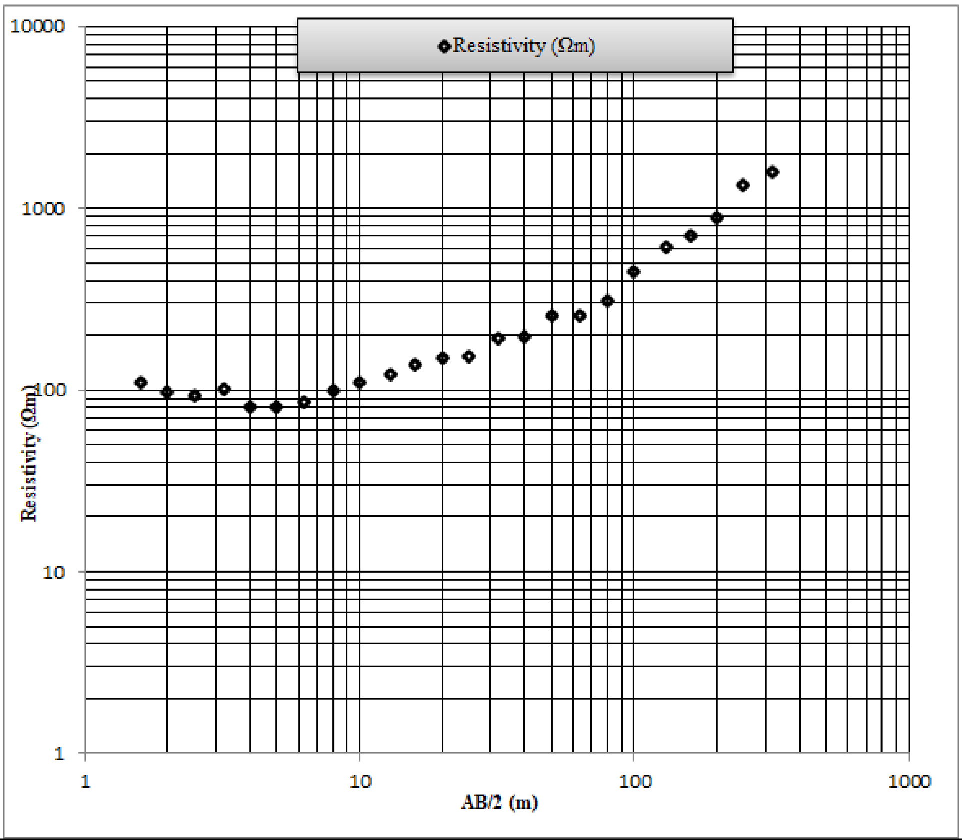


Figure 8: Interpretation of VES 2 Data

Vertical Electrical Sounding _Data Sheet (Schlumberger)				
WGS 84	**County**	Narok	**VES**	3
	Client	Olenkuya Primary School	**Elevation (m)**	2053
	Latitude (S)	1° 42' 4.59"	**Longitude (E)**	035° 41' 4.22"

AB/2 (m)	**Resistivity (Ωm)**
1.6	109
2	96.3
2.5	93.4
3.2	100.5
4	80.1
5	81.3
6.3	85.4
8	98.8
10	111.1
13	123
16	138
20	151
25	154.2
32	192.8
40	194.5
50	258.3
63	255.7
80	309
100	447
130	615
160	705
200	891
250	1347
320	1584

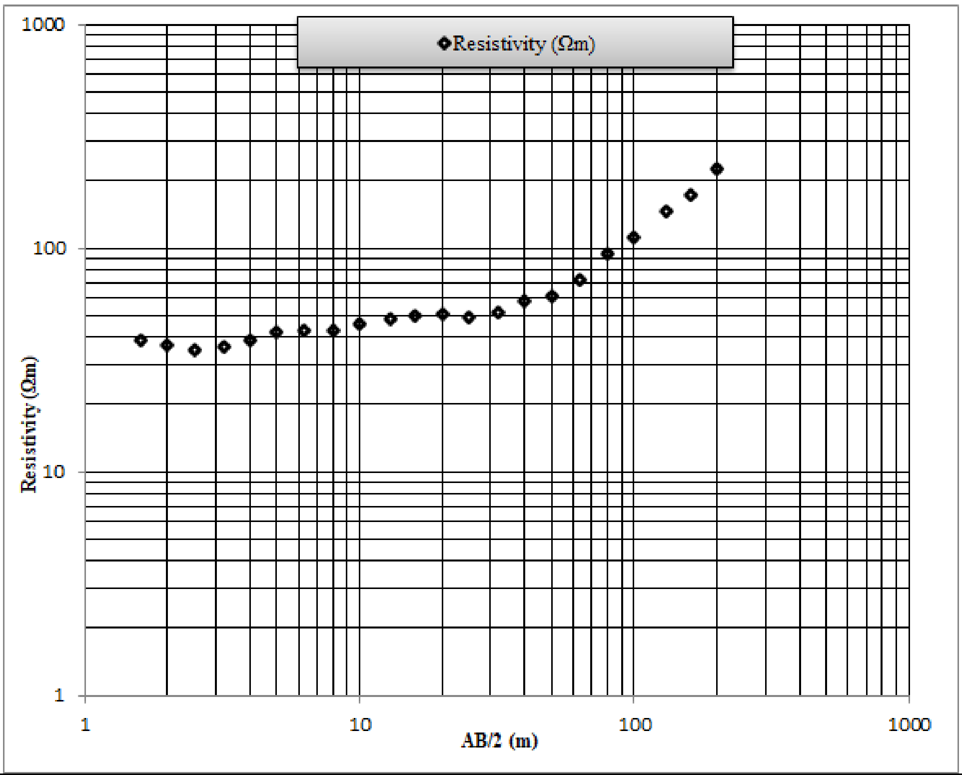


Resistivity (Ωm)	**Depth (m)**	**Geological Interpretation**	**Hydrogeological Interpretation**
105.21	2	Top Superficial Deposits	Dry
61.93	10	Compact Gneisses	Dry
987.68	55	Partially Weathered Gneisses	Moist
4634	>55	Fractured/Partially Weathered Gneisses	Slghtly Aquiferous

Figure 9: Interpretation of VES 3 Data

Vertical Electrical Sounding _Data Sheet (Schlumberger)				
WGS 84	**County**	Narok	**VES**	4
	Client	Olenkuya Primary School	**Elevation (m)**	2053
	Latitude (S)	1° 42' 18.4"	**Longitude (E)**	035° 41' 4.43"

AB/2 (m)	**Resistivity (Ωm)**
1.6	39
2	37
2.5	35
3.2	36
4	39
5	42
6.3	43
8	43
10	46
13	48
16	50
20	51
25	49
32	52
40	58
50	61
63	72
80	95
100	111
130	146
160	174
200	228



Resistivity (Ωm)	**Depth (m)**	**Geological Interpretation**	**Hydrogeological Interpretation**
36.25	2	Top Superficial Deposits	Dry
44.64	10	Compact Gneisses	Dry
63.46	55	Partially Weathered Gneisses	Moist
2000	>55	Fractured/Partially Weathered Gneisses	Slghtly Aquiferous

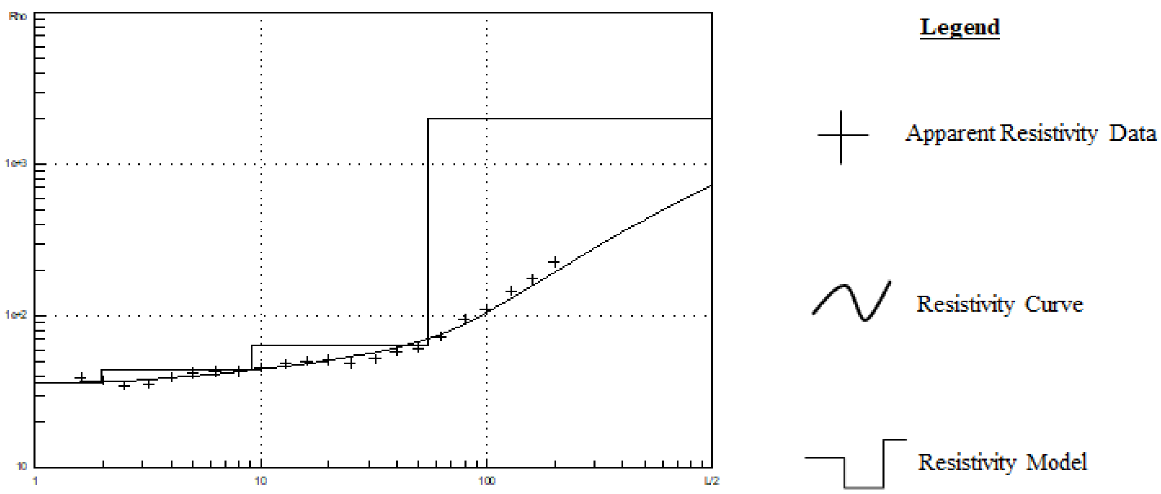
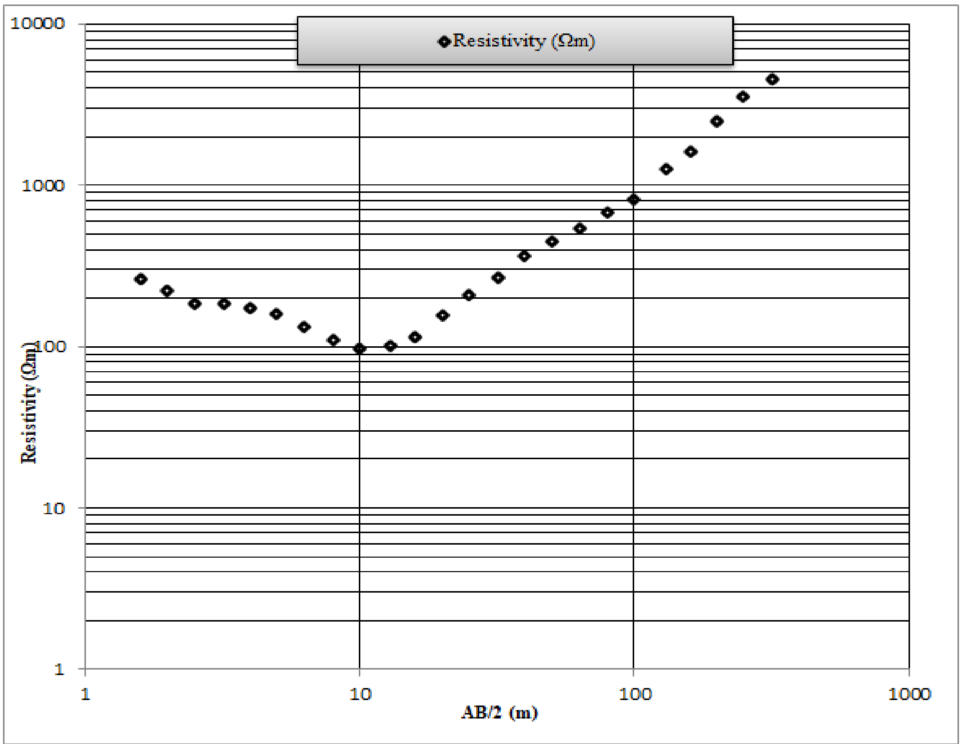


Figure 10: Interpretation of VES 4 Data

Vertical Electrical Sounding _Data Sheet (Schlumberger)

WGS 84	County	Narok	VES	Controlled VES
	Client	Olenkuya Primary School	Elevation (m)	2031
	Latitude (S)	1° 42' 27.78"	Longitude (E)	035° 41' 5.63"

AB/2 (m)	Resistivity (Ωm)
1.6	261
2	224
2.5	186
3.2	183
4	175
5	160
6.3	133
8	111
10	98
13	101
16	115
20	155
25	210
32	270
40	368
50	448
63	544
80	676
100	810
130	1250
160	1624
200	2489
250	3538
320	4562



Resistivity (Ωm)	Depth (m)	Geological Interpretation	Hydrogeological Interpretation
270.03	2	Top Superficial Deposits	Dry
73.87	9	Compact Gneisses	Dry
5606.65	40	Partially Weathered Gneisses	Moist
8900	>40	Compact Gneisses	Dry

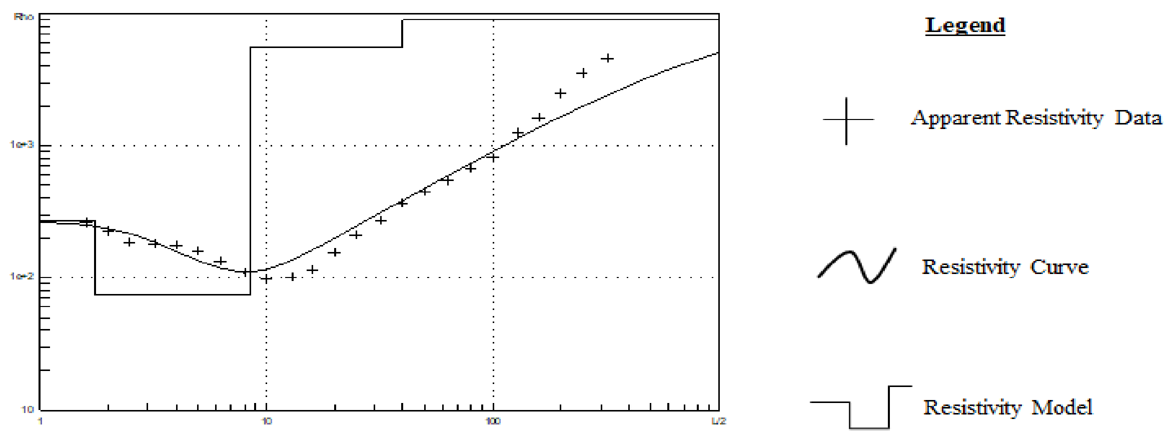
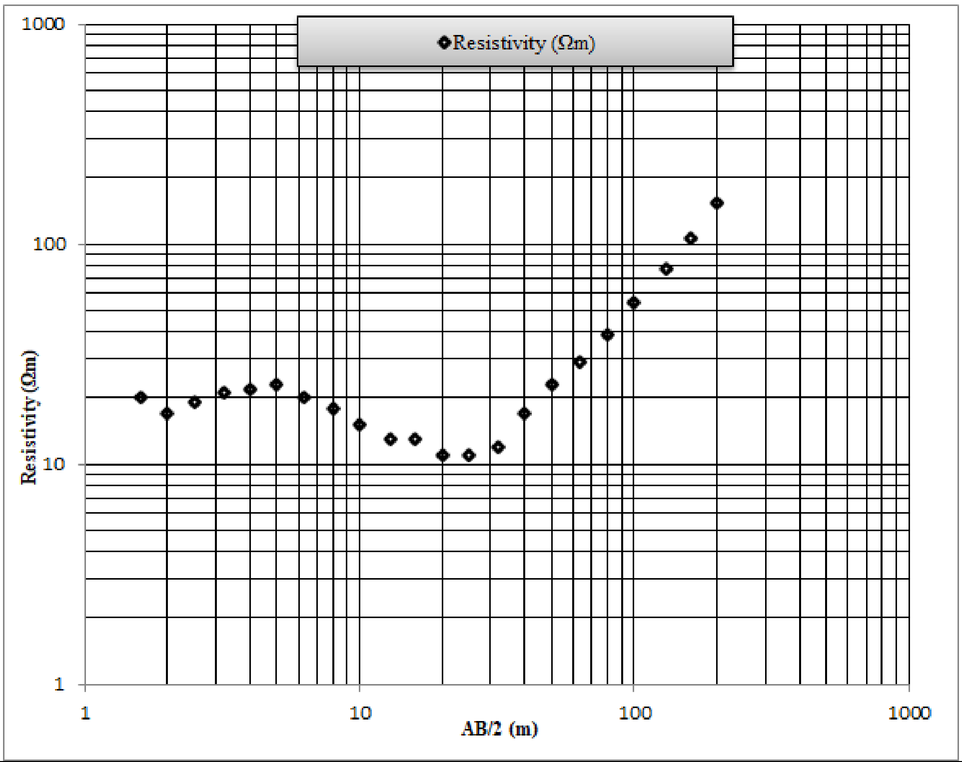


Figure 11: Interpretation of VES 5 (Controlled on Existing BH) Data

Vertical Electrical Sounding _Data Sheet (Schlumberger)

WGS 84	**County**	Narok	**VES**	Controlled BH
	Client	Olenkuya Primary School	**Elevation (m)**	2069
	Latitude (S)	1° 41' 12.43"	**Longitude (E)**	035° 40' 11.14"

AB/2 (m)	**Resistivity (Ωm)**
1.6	20
2	17
2.5	19
3.2	21
4	22
5	23
6.3	20
8	18
10	15
13	13
16	13
20	11
25	11
32	12
40	17
50	23
63	29
80	39
100	54
130	77
160	106
200	154



Resistivity (Ωm)	**Depth (m)**	**Geological Interpretation**	**Hydrogeological Interpretation**
21.93	3	Top Superficial Deposits	Dry
11.86	19	Compact Gneisses	Dry
43	55	Weathered Gneisses	Slightly Aquiferous
400	>55	Compact Gneisses	Dry

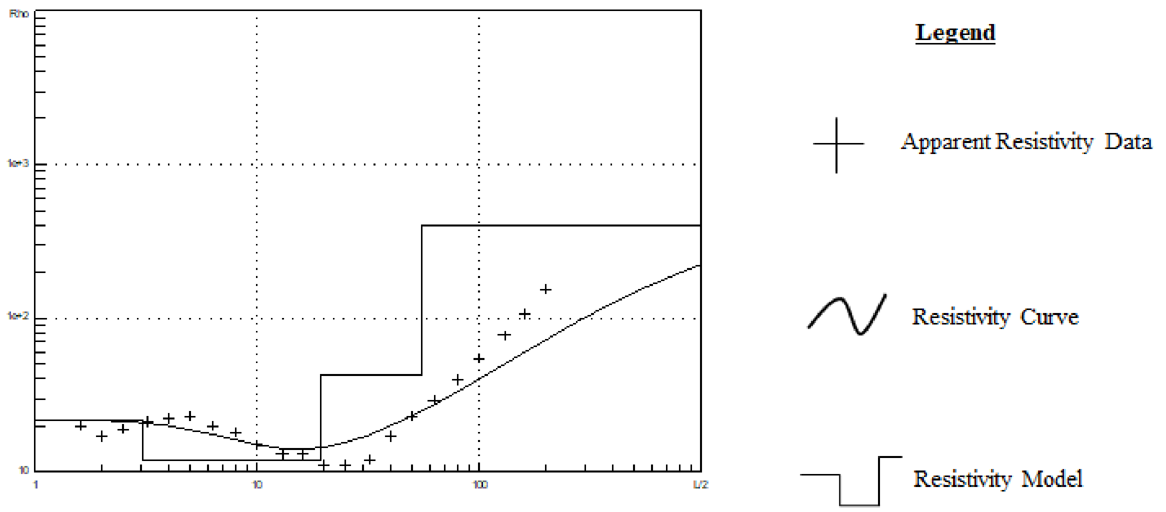


Figure 12: Interpretation of VES 6 (Controlled on Yielding BH) Data

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

The results from the hydrogeological and geophysical investigations indicate that the investigated area is situated in a hydrogeological zone which is characterized by medium groundwater potential. A well drilled in this area should target both the shallow (80-150m) and deep (200-250mbgl) aquifers. From the current boreholes within the site, the yield is expected to be low but may increase with depth. The two boreholes drilled within a radius of 2km have yields below 5m^3/hour while the existing borehole within the site is yielding about 0.5m^3/hour. The total borehole yield will only be identified after or from drilling.

7.2. Recommendations

It is recommended that: -

a) An 8" borehole should be drilled at the location of **VES 3** (**Point 13** along the Geo-electrical **Profile 2) to a minimum depth of 200m and a maximum depth of 250 m bgl.**
b) Before drilling commences, a drilling permit should be applied and obtained from the relevant Regional Water Resource Authority (WRA) within Nakuru Region.
c) Proper supervision and monitoring of drilling by a qualified hydrogeologist should be provided.
d) The borehole should be installed with a water meter and an airline/piezometer to monitor the groundwater abstraction.
e) Enough storage tanks should be provided and installed for continuous water supply to the community and this will also give enough time for the aquifer recharge.
f) Water samples should be taken after test pumping and taken to a recognized laboratory for full physical, chemical and bacteriological analysis and results taken to Water Resources Authority.

The proposed drilling site is benchmarked and known to the Client.

Note: -Additional recommendations for drilling, construction and completion of a borehole are provided in Appendix 1

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 levels 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. It determines the water quality and longevity of the borehole.

8. REFERENCES

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APPENDICES

Appendix 1: Drilling and Construction of Boreholes

Drilling

Drilling should be carried out using a DTH (Down to Hole Hammer) employing the Rotary technique 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 aquifer zones. The final design should be made by an experienced hydrogeologist.

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 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 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 only increases 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.

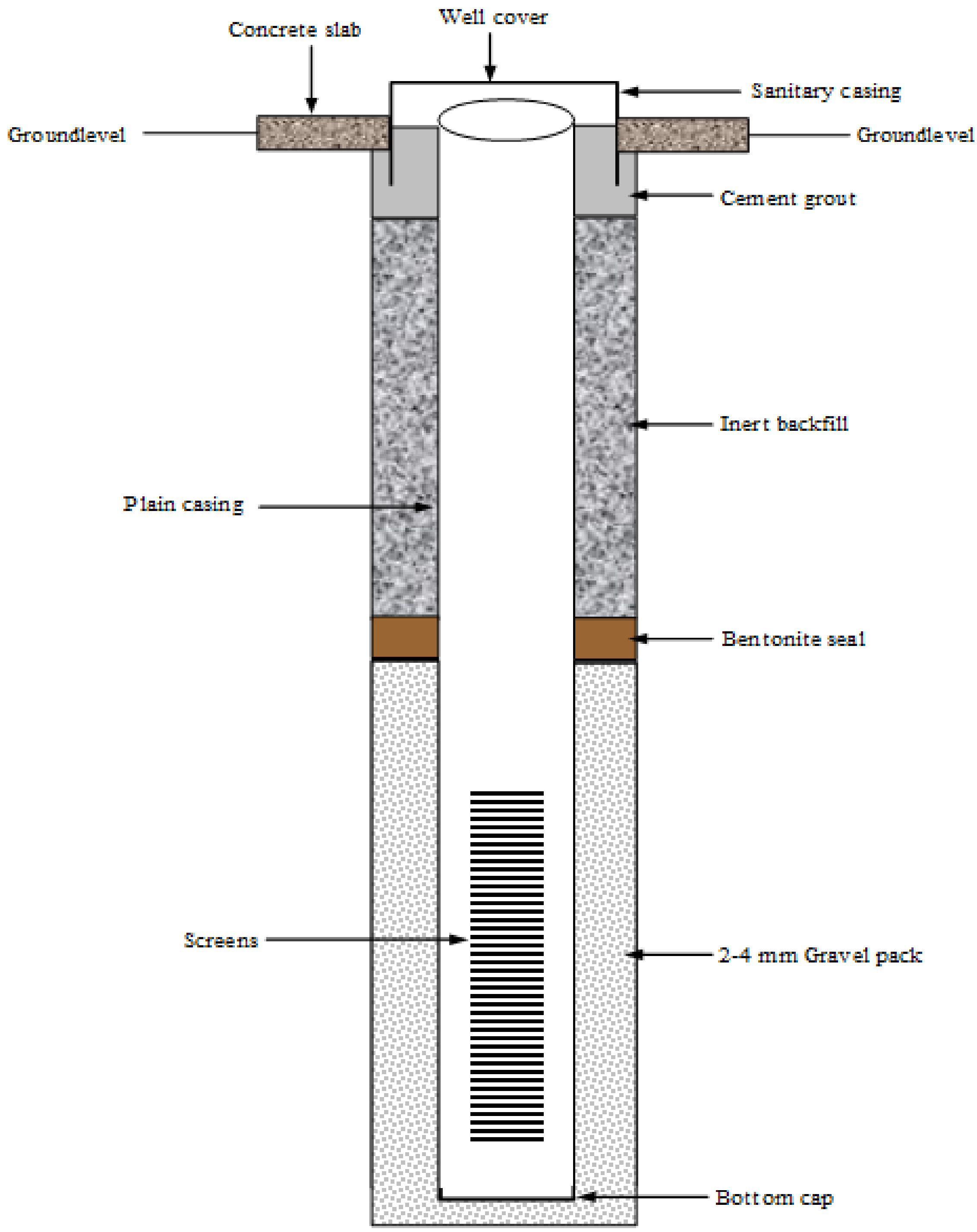
Well development is an expensive element in the completion of a well, but is usually justified in longer well-life, greater efficiencies, lower operational and maintenance costs and a more constant yield. Within this frame the pump should be installed at least 2 m above the screen, certainly not at the 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 hydrogeologist.

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 12 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 hydrogeologist to calculate the optimum pumping rate, the installation depth, and the drawdown for a given discharge rate.



NB: Not to scale

Schematic Design for Borehole Completion

Appendix 2: Acceptable Ionic Concentrations - Various Authorities

		World Health Organization:			European Community:	
		1983	1971 Int.	EC Directive 1980 relating to the quality		
	Guidelines;	Standards;	of water intended for human consumption:			
Substance or		Guideline	Upper limit	Guide Level	Max. Admissible	
Characteristic		Value (GV	(HL),	(tentative)	(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 $N0_3$)	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 in bones and teeth. A deficiency as well as an excess of fluorine may have negative effects on 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 be discussed 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 mainly determined by the weathering of amphiboles or volcanic glass. Both are important constituents of phonolites. Volcanic tuffs on an average have a higher content of soluble volcanic 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 indicate that 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 % prevalence of dental fluorosis in age group 10 - 15 years) and 3.6 ppm (skeletal changes in 11 - 15 years old). Above 10 ppm skeletal deformities may occur in children.

The World Health Organization uses the guideline limit of 1.5 ppm fluoride. This limit is 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 caries decreases
> 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 are rather 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 the bone 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 applied at 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 precipitation of 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 equilibrium constant 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 1 to 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 hydroxide before 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 through laboratory 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 as diet, 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 for domestic purposes but future prospect is good.