HYDROGEOLOGICAL ASSESSMENT REPORT

FOR

CLIENT;

OLOMANIRA PRIMARY SCHOOL, C/O AMREF KENYA

P.O.BOX 30125 – 00100 NAIROBI

LOCATION;

OLOMANIRA AREA – NAROK WEST DISTRICT, NAROK COUNTY

REPORT NO. SMW/093/2022

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SUMMARY

This Report discusses the results of a geophysical site survey for one borehole within Olomanira Village, Olkinyei Sub-location, Narasha Location, Maara Division of Narok West Sub-County, Narok County at Olomanira Primary School's parcel of land. The plot is situated approximately 9.8 kilometers off the tarmac road, within Olomanira area.

The boreholes with recorded yield in this area have yields ranging between 2.0 – 10.0m^3/hour. The yield of a borehole drilled at the recommended location is expected to be within the above range, but careful construction and development will lead to maximum borehole productivity, efficiency and long life.

Groundwater occurs within the OLS and highly weathered/ fractured basement rocks.

Recharge of the aquifers is by direct and indirect replenishment.

A suitable site has been located by means of geophysical field measurements to tap water from the main water bearing aquifers within the OLS and highly weathered/ fractured basement rocks.

The proposed borehole should be drilled to a depth of 220 metres below ground level.

The quality and the quantity of groundwater at the proposed site are expected to be good.

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

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ABBREVIATIONS (All S.I Units unless indicated otherwise)

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

GLOSSARY OF TERMS

Alluvium *General term for detrital material deposited by flowing water.*

Aquifer *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 processes, with or without water as an agent. Usually of mixed texture.*

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

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

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

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

Grit *Coarse sandstone of angular grain*

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

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

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

Joint *Fractures along which no significant displacement has taken place.*

Lava sheet *Lava flow, in parts very thick, covering a large area.*

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

Permeability *The capacity of a porous medium for transmitting fluid.*

Phenocrysts *Large, conspicuous crystals in porphyritic rocks (i.e. rocks with visible mineral crystals in a generally fine groundmass).*

Phonolite *Compact and fine textured volcanic rock, belonging to the trachyte-group (together with trachyte ss. and latite). Defined by a high portion of feldspar (40-90%) and feldspatoidic minerals (10-60%: analcite, nepheline, leucite, etc.), and very low to negligible quartz content (0-2%). Incorporated dark coloured minerals (0-40%) most commonly include hornblende, olivine, melanite and acmite. The structure is porphyritic with common phenocrysts of sanidine (orthoclase, or Potassium-feldspar) and nepheline.*

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

Pyroclastic rocks *Group of rocks consisting of volcanic dust, ashes, lapilli and coarse lumps of lava, 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.*

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

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

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

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

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

Tuff *Here: hardened volcanic ash.*

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. NAME AND DETAILS OF APPLICANT

***Olomanira Primary School C/O AMREF Kenya** herein referred to as the client and the proprietor of the plot commissioned the present consultants to carry out a hydrogeological and geophysical survey within their parcel of land in Narok West Sub-County.*

The hydrogeological survey was envisaged to determine the best location for drilling the proposed borehole to supply water for domestic use.

The Client's contact details are as follows:

Olomanira Primary School,
C/O Amref Kenya
P.O. Box 30125 - 00100
Nairobi

The objective of the survey was to establish the optimum location of a borehole planned to provide water to our Client for domestic purposes.

The project area is not connected to any public water supply system and the client relies on water pans and also water vendors which are expensive and unreliable. Chronic water shortages have driven the client to think of drilling a borehole to act as the main water supply for this plot.

It is against this background that a detailed hydrogeological survey was envisaged to determine groundwater potential within the plot and the possibility of sinking the proposed borehole.

The hydrogeological assessment report gives the details of drilling depth, water quality and estimated yields. It also assists in registration of the borehole with the Water Resources Management Authority of the Ministry of Water and irrigation.

Based on the recommendations of the report, the contractor can project cost estimates for the drilling and construction works.

2. BACKGROUND INFORMATION

2.1 Location

The site is situated within Olomanira Village, Olkinyei Sub-location, Narasha Location, Maara Division of Narok West Sub-County, Narok County. It lies within the 1:50,000 Survey of Kenya topographic sheet for Maji Moto (No. 146/3). Its defining coordinates in UTM are 0784309E and 98526622N (Fig.2.1).

Figure 2-1 – Google Earth Image showing the site locations

2.2 Physiography

The plot lies at an altitude of about 1875m. The general area is formed by a flat terrain, within the Loita Plains.

Figure 2-2 – Photograph showing the topography of the site

2.3 Climate

Precipitation: *The area in which the farm is situated is characterized by a semi-arid, warm temperate climate (Sombroek et al, 1982). The mean annual precipitation amounts to 800 mm. There is no a well defined rainy season but the heaviest rainfall is recorded in December-January and again in March-April with the maximum in April.*

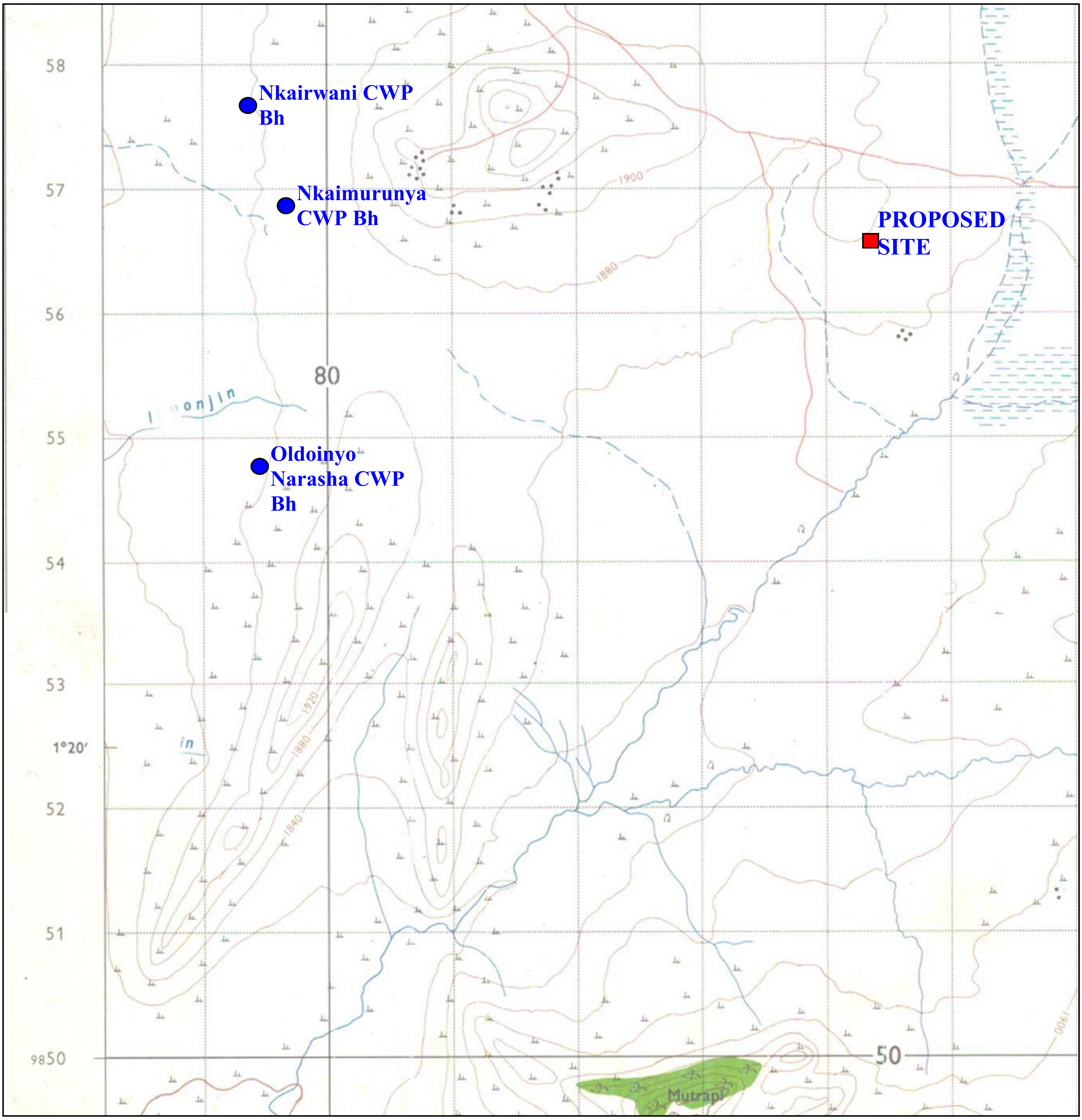
Temperature: *The maximum annual temperature is between 18 and 20 ^{o}C; with a mean maximum of 24 and 26 ^{o}C and the mean minimum of 12 - 14 ^{o}C.*

2.4 Water Demand

Water from the proposed borehole will be used for domestic purposes within the school.

S/No	*Consumer*	*Demand/Day*	*Total Demand*
1.	*200 no. persons*	*100l/day*	*20,000l/day*
Total Demand			*20,000l/day*

Water demand is estimated at 20m^3/day.



<u>LEGEND</u>

Proposed borehole Site

Location of Surrounding Boreholes

Fig 2.1: Map showing the study area and environs, Scale 1: 50,000

3. GEOLOGY

3.1 Regional Geology

The area is entirely underlain by Precambrian rocks of the Basement System. Due to its location on the western shoulder of the Gregory Rift Valley, the original crystalline rocks of the Mozambican Belt have locally been covered by younger volcanic deposits.

The oldest rocks in the area are formed by various types of gneisses, limestones and quartzites. The original rocks of sedimentary origin were presumably laid down in a geosyncline that covers a large part of East and Central Africa. The lower succession consists of relatively coarse psammitic gneisses, probably produced by rapid deposition in relatively deep water. The upper part, the Loita Series, is mainly pelitic (fine-grained) in character, and numerous limestones and quartzites indicate the calmer environment of a relatively shallow basin. Minor igneous activity is represented by amphibolites, which are thin and concordant.

After their deposition, the sediments were metamorphosed and folded. Metamorphosed granite (an intrusive) was formed during this period. The compression and folding led to the formation of mountain chains, which were intensively eroded at a later stage.

The final event was the formation of Recent soils. In the Basement areas, the soils are usually reddish brown and sandy, but black cotton soils may occur in areas of poor drainage. The Basement System in the Rift Valley yields grey sandy soil. Black cotton soil is formed on most of the volcanic rocks.

3.2 Geology of the Survey Area

The study site gently slopes with little dissection. Outcrops are generally poorly exposed within the studied area but more prevalent on the lower slopes and along the stream channels. Most of the area is covered by black soils.

The outcrops on the western side of the area comprise of biotite-hornblende granites and gneisses. This formation is an intrusive body. Some volcanic outcrops composed of porhyritic often vesicular, phonolites with rare tuff partially cover the intrusive metamorphosed body. At the foot of the escarpment are mylonitized gneisses intercalated by bands of amphibolites a sign of tectonic movements.

These soils are imperfectly drained lateritic clays to dark black cotton soils.

The formations likely to be encountered during drilling are:

- *Recent soils (both elluvial and weathered products: in situ).*
- *Slightly weathered Biotite-Horneblende granite*
- *Moderately weathered Biotite-Horneblende granite*
- *Fractured/weathered Basement (Quartzo-feldspathic gneiss)*
- *Massive/compact Basement (Biotite-horneblende granite)*

4. HYDROGEOLOGY

4.1 Background

The area and its environs groundwater is found in Basement rock deposits. More attention is given to the Basement aquifers owing to the underlying geology (Biotite-hornblende granite) covered by tertiary volcanics;

a. ***In Basement System rocks***

Groundwater can occur in the regolith (the weathered, decomposed and fragmented part of the Basement rock), or in faults and fractures that are interconnected.

b. ***Sedimentary aquifers***

Consist of erosion debris from volcanic or Basement rocks. Their suitability for aquifer development depends on parent material, thickness and recharge.

4.2 Existing boreholes

Some boreholes have been drilled in the project area. Available records were studied for 4 boreholes within a radius of about 5.1-km from the present site. Results of the data inventory are presented in Table 4.1 while the approximate location of the boreholes has been indicated in Figure 4.1.

Table 4.1 - Boreholes in the Vicinity of the Site

BH NO.	OWNER	Bearing	TD	WSL	WRL	T.Y	PWL
Ref:	**Olomanira Pri Sch Site**						
-	Empora Community WP	3.8 NE	140	-	-	4.0	-
-	Oldoinyo Narasha Community WP	5.1 SW	180	80, 120	59.11	2.7	162
-	Nkairwani Community WP	5.0 NW	183	18, 122	-	10.0	-
-	Nkaimurunya Community WP	4.7 NW	180	74, 127	-	2.0	-
-	Ilmonchin Pry school		-	-	-	-	-
Range			**140 - 183**	**18 -127**	**-**	**2.0 – 10.0**	**-**

4.2.1 *Borehole Data Analyses*

From the geological logs of the boreholes, water struck levels correlate with fractured/ weathered basement.

4.2.2 *Impacts to Abstraction Trends and Analyses of Boreholes within 800-m from the Proposed Site*

From the records, there is NO borehole which is located within 1000m radius. Thus there is no any foreseen interference with the existing boreholes or the groundwater abstraction trends. The boreholes have good yields which is an indication of underlying productive aquifers.

4.3 Recharge

The recharge mechanisms (and the rate of replenishment) of the local aquifers has not been fully established. The two major processes are probably direct recharge at surface (not necessarily local) and indirect recharge via faults and/or other aquifers. However, except for a fault to the east of the area down the escarpment, no other faults have been mapped in the study area.

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 weathering 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 mechanism is direct infiltration of the rainfall. Rainfall in the region is low to moderate (800 mm). The occurrence of thin layers of clayey soils in the area of study inhibits infiltration of rainwater.

4.3.1 *Mean Annual Recharge*

Although rainfall within the study area is low, regional recharge is of great essence in this area. Much of regional recharge occurs within the eastern flanks of the rift valley followed by base flow within the thick volcanic sheets and faults which characterise the region. ***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

800mm x 5%

Mean Annual Recharge = 40mm

However, this recharge amount is probably estimation due to the possibility of influent local recharge through local rivers and rainwater percolation through faults into the weathered/fractured basement rock system.

4.4 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 few number of boreholes in the area this is 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 formations and faults/ interconnected fractures.

4.5 Aquifer Properties

4.5.1 *Calculation of Aquifer Properties*

To calculate the area Aquifer Properties, testing pumping data of Oldoinyo Narasha CWP borehole was adopted.

***In summary**, the borehole has a total drilled depth of 180m, yield of 2.7m^3/hr, Water Rest levels of 80 & 120m and Pumped Water Level of 162m. The borehole has fairly penetrated the productive aquifers and thus will be fair enough to deduce the aquifer properties of the project Area. It had a drawdown of 102.89m.*

4.5.2 *Estimation Aquifer Transmissivity*

*The raw test Pumping Data of the above boreholes in Table 4.1 were not available to assist in calculation of Aquifer Transmissivity using **Jacob's formula (Driscoll 1986):***

*Thus, in absence of proper pump test data, the **Logan method of approximation** has been employed (Logan, 1965). This method however has errors of 50% or more and is thus used for estimation purpose only. The derivation of the aquifer properties is based on the data of **Oldoinyo Narasha CWP** borehole.*

Aquifer Transmissivity (T) is thus estimated as follows:

$T=1.22Q/\Delta S$ Where: Q = Yield per day

ΔS = Draw down

$T = 1.22/102.89 \times 64.8 =$ **0.77m^2/day**

4.5.3 *Hydraulic Conductivity*

The Hydraulic Conductivity (K) is estimated as follows:

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

Based on the geological logs of the boreholes in the area, the cumulative aquifer thickness for the purpose of this calculation has been estimated at 8m. Thus,

K = 0.77/8
K = 0.1m/day

4.5.4 *Specific Capacity*

The aquifer Specific Capacity (S) = Q/Δs.

Where: ***Q = Discharge (m^3/day) = 64.8m^3/day***
D = Drawdown (m) = 102.89m).
S= 0.92m^2/day

4.5.5 *Groundwater Flux*

The Groundwater Flux (F) is estimated based on Oldoinyo Narasha WP and Nkaimurunya WP boreholes which more or less share the same aquifers.

F = K.i.h.w Where K- Hydraulic Conductivity = 0.1m/day
i – Slope = 16 /9800
h- Aquifer Thickness =8m
w- Arbitrary distance, 7100m

Thus;

F = 0.1m (16/9800). 8. 7100
*F =**9.27m^3/day***

4.6 Water Quality

Water quality strongly reflects aquifer type and geometry, recharge and abstraction periods, and original geology. Practically all types of water, i.e. runoff water, groundwater and even rainwater, contain some dissolved salts and impurities. If certain elements are present in high concentrations, the application of the water for domestic use or any other purpose may be limited.

Groundwater in the study area is actually not known though locals say that water got from the seasonal spring is good for domestic use and for their livestock.

W.H.O. and EC guideline concentrations are included for reference in appendix section.

4.7 Impacts of the Proposed Activity to Water Quality, Wetlands

The Proposed drill 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 drill site that can be contaminated by waste waters generated during drilling. The entire drilling, borehole construction, pump tests, and completion works will be done under supervision to professional standards. Entry of any foreign material until completion will be avoided to avoid any entry of foreign material into the borehole and only inert materials will be used in construction. The borehole will be properly developed 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.

5. GEOPHYSICAL INVESTIGATION METHODS

A great variety of geophysical methods are available to assist in the assessment of geological subsurface conditions. In the present survey resistivity (also known as the geo-electrical method) has been used.

5.1 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.

5.2 Basic Principles

The electrical properties of rocks in the upper part of the earth's crust are dependent upon the lithology, porosity, the degree of pore space saturation and the salinity of the pore water. Saturated rocks have lower resistivities than unsaturated and dry rocks. The higher the 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 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 certain material is directly proportional to its length L and cross-sectional area A, expressed as:

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

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

$$R = dV/I \qquad (Ohm) \qquad (2)$$

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:

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

5.3 Horizontal Electrical Profiling (HEP)

Resistivity profiles are usually carried in Wenner configuration, i.e. an electrode set-up with a uniform distance between potential and current electrodes. The entire array is moved across the area of interest. By doing so, lateral changes in apparent resistivity are measured, which reflect variations in the lithology, the depth of weathering or the water content.

It must be noted that resistivity differences in a single profile array may largely reflect variations at the surface rather than underground. For this reason, it is usually not sufficient to carry out single-spaced profiles. Moreover, by repeating the same profile at a different configuration, it will become clear if the observed resistivity patterns are caused by surface phenomena or underground features.

5.4 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 strength and 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 against depth on double logarithmic paper, a resistivity graph is formed, which depicts the variation of resistivity with depth.

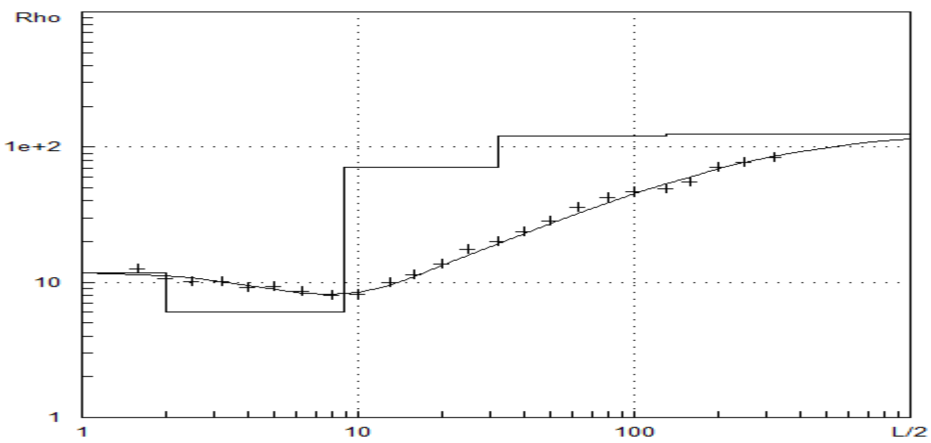
This graph can be interpreted with the aid of a computer, and the actual resistivity layering of the subsoil is obtained. The depths and resistivity values provide the hydrogeologist with information on the geological layering and thus the occurrence of groundwater.

6. FIELDWORK AND RESULTS

Field work was carried out on 29th of September and 21st of December, 2022. Six Vertical Electrical Soundings (VES) were executed. The aim of the sounding was to determine the prevailing hydrostratigraphy at the site.

6.1 Results

Control VES (Ilmonchin) Sounding Curve, Geoelectrical model and Data set.



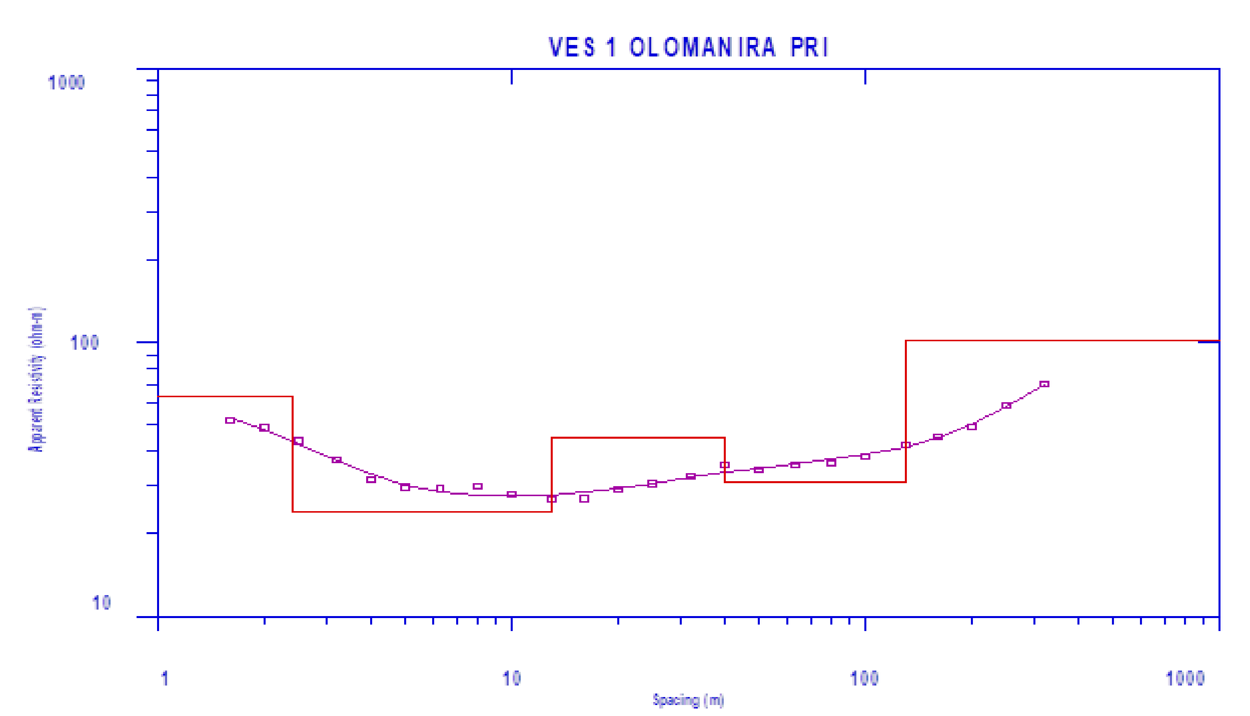
Layer	Resistivity (Ohm)	Thickness (m)	Depth (m)
1	11.80	2.00	2.00
2	6.00	6.90	8.90
3	70.80	23.10	32.00
4	120.30	98.30	130.30
5	125.20		
Station No.	**AB/2**	**MN**	**Resistivity (ohm)**
1	1.6	0.5	12.5
2	2.0	0.5	10.7
3	2.5	0.5	10.1
4	3.2	0.5	10.1
5	4.0	0.5	9.1
6	5.0	0.5	9.3
7	6.3	0.5	8.5
8	8.0	0.5	8.0
9	10	0.5	8.2
10	13	0.5	10.0
11	16	0.5	11.4
12	20	0.5	13.7
13	25	5	17.5
14	32	5	20.0
15	40	5	23.5
16	50	10	28.5
17	63	10	35.8
18	80	10	42.6
19	100	10	46.8
20	130	25	49.5
21	160	25	55.6
22	200	25	71.3
23	250	25	76.9
24	320	25	83.2

Interpretations of Control VES (Ilmonchin)

Depth (m)	***Resistivity (Ohmm)***	***Interpretation***
0.0 – 2.0	*11.80*	*Top Soils*
2.0 – 8.9	*6.00*	*Highly weathered sub-surface soils*
8.9 – 32.0	*70.80*	*Slightly weathered tuffs*
32.0 – 130.3	*120.30*	*Top- slightly Fractured Welded tuffs; Middle- Fractured phonolites*
Below 130.3	*125.20*	*Slightly weathered to fresh phonolites*

The results of control VES measurements show that the site is covered at the surface by top soils to a depth of about 2.0m and are underlain by highly weathered sub-surface soils to a depth of 8.9m. These are underlain by a layer with a higher resistivity interpreted as slightly weathered tuffs to a depth of about 32.0m. These are in turn underlain by a higher resistivity layer which is interpreted to be slightly weathered/ fractured phonolites to a depth of about 130.3m. Beyond 130.3m is a zone with an increasing resistivity comprised of slightly weathered to fresh phonolites

VES 1 Sounding Curve, Geoelectrical model and Data set.



MODEL: VES 1 OLOMANIRA PRI

LAYER	RESISTIVITY	THICKNESS	DEPTH
1	63.0	2.4	2.4
2	24.0	10.6	13.0
3	45.0	27.0	40.0
4	31.0	90.0	130.0
5	101.0		

DATASET: VES 1 OLOMANIRA PRI

NUMBER	AB/2	MN	RESISTIVITY
1	1.600000	0.500000	51.776848
2	2.000000	0.500000	48.824654
3	2.500000	0.500000	43.601547
4	3.200000	0.500000	37.167294
5	4.000000	0.500000	31.490007
6	5.000000	0.500000	29.597580
7	6.300000	0.500000	29.219093
8	8.000000	0.500000	29.824673
9	10.000000	0.500000	27.856546
10	13.000000	0.500000	26.721090
11	16.000000	0.500000	26.872484
12	20.000000	0.500000	28.992004
13	25.000000	0.500000	30.505947
14	32.000000	0.500000	32.474075
15	40.000000	10.000000	35.792595
16	50.000000	10.000000	34.370369
17	63.000000	10.000000	35.674076
18	80.000000	10.000000	36.266666
19	100.000000	10.000000	38.400002
20	130.000000	10.000000	42.299999
21	160.000000	25.000000	45.200001
22	200.000000	25.000000	48.900002
23	250.000000	25.000000	58.599998
24	320.000000	25.000000	70.599998

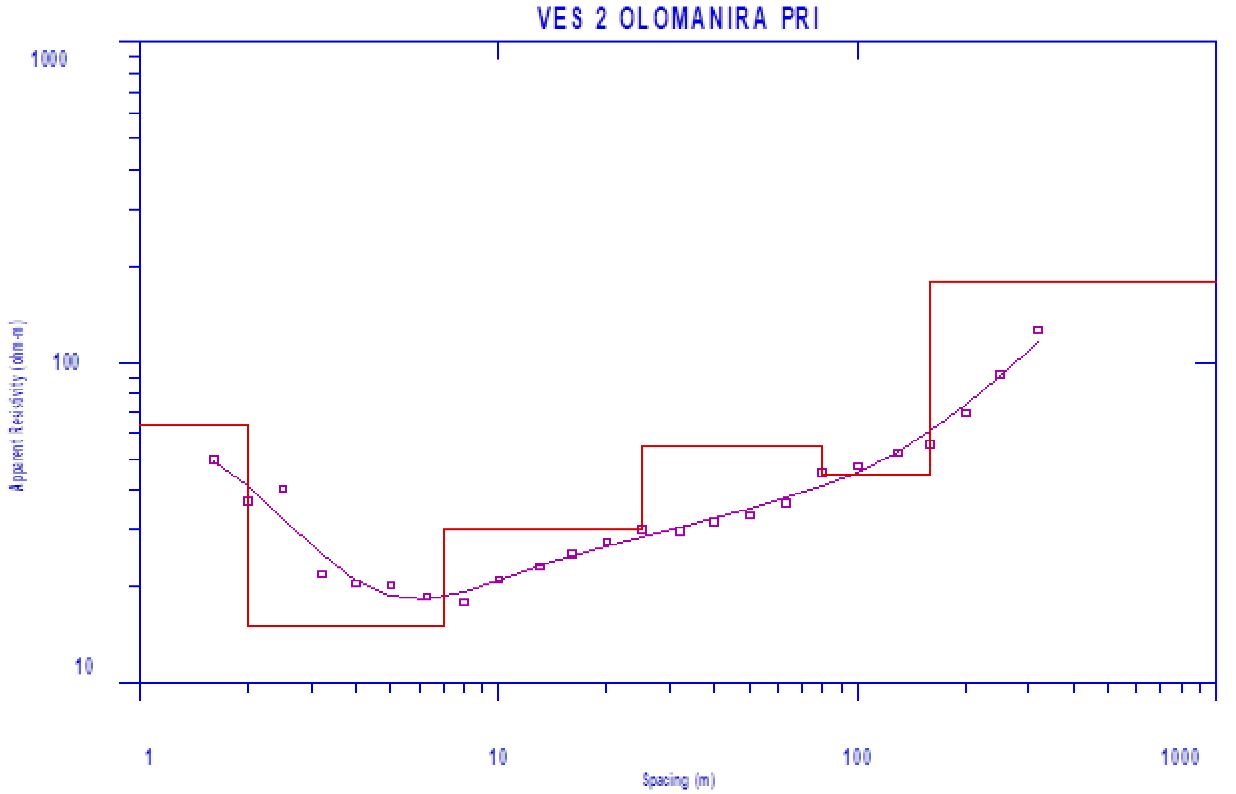
Interpretations of VES 1

Depth (m)	***Resistivity (Ohmm)***	***Interpretation***
0.0 – 2.4	*63.0*	*Dry top soils*
2.4 – 13.0	*24.0*	*Highly weathered sub-soils*
13 – 40.0	*45.0*	*Compact regolith*
40 – 130.0	*31.0*	*Highly weathered/fractured basement (Aquiferous)*
Below 130.0	*101.0*	*Weathered to fresh basement*

The results of VES 1 measurements show that the site is covered at the surface by dry top soils to a depth of about 2.4m and are underlain by highly weathered sub-soils to a depth of 13m. These are underlain by compact regolith to a depth of about 40m which are then underlain by highly weathered/ fractured basement to a depth of about 130m and its aquiferous. Beyond 130m is weathered to fresh basement layer with increasing resistivity and its aquiferous on top zones.

Drilling is not recommended at this site.

VES 2 Sounding Curve, Geoelectrical model and Data set.



MODEL: VES 2 OLOMANIRA PRI

LAYER	RESISTIVITY	THICKNESS	DEPTH
1	64.0	2.0	2.0
2	15.0	5.0	7.0
3	30.2	18.0	25.0
4	55.0	55.0	80.0
5	45.0	80.0	160.0
6	180.0		

DATASET: VES 2 OLOMANIRA PRI

NUMBER	AB/2	MN	RESISTIVITY
1	1.600000	0.500000	49.827461
2	2.000000	0.500000	36.950703
3	2.500000	0.500000	40.449825
4	3.200000	0.500000	21.834507
5	4.000000	0.500000	20.434860
6	5.000000	0.500000	20.294895
7	6.300000	0.500000	18.615318
8	8.000000	0.500000	17.915493
9	10.000000	0.500000	20.994719
10	13.000000	0.500000	23.234156
11	16.000000	0.500000	25.333628
12	20.000000	0.500000	27.573065
13	25.000000	0.500000	30.232395
14	32.000000	0.500000	29.812500
15	40.000000	10.000000	31.830576
16	50.000000	10.000000	33.481731
17	63.000000	10.000000	36.417114
18	80.000000	10.000000	45.498459
19	100.000000	10.000000	47.700001
20	130.000000	10.000000	52.400002
21	160.000000	25.000000	55.500000
22	200.000000	25.000000	69.699997
23	250.000000	25.000000	92.000000
24	320.000000	25.000000	126.500000

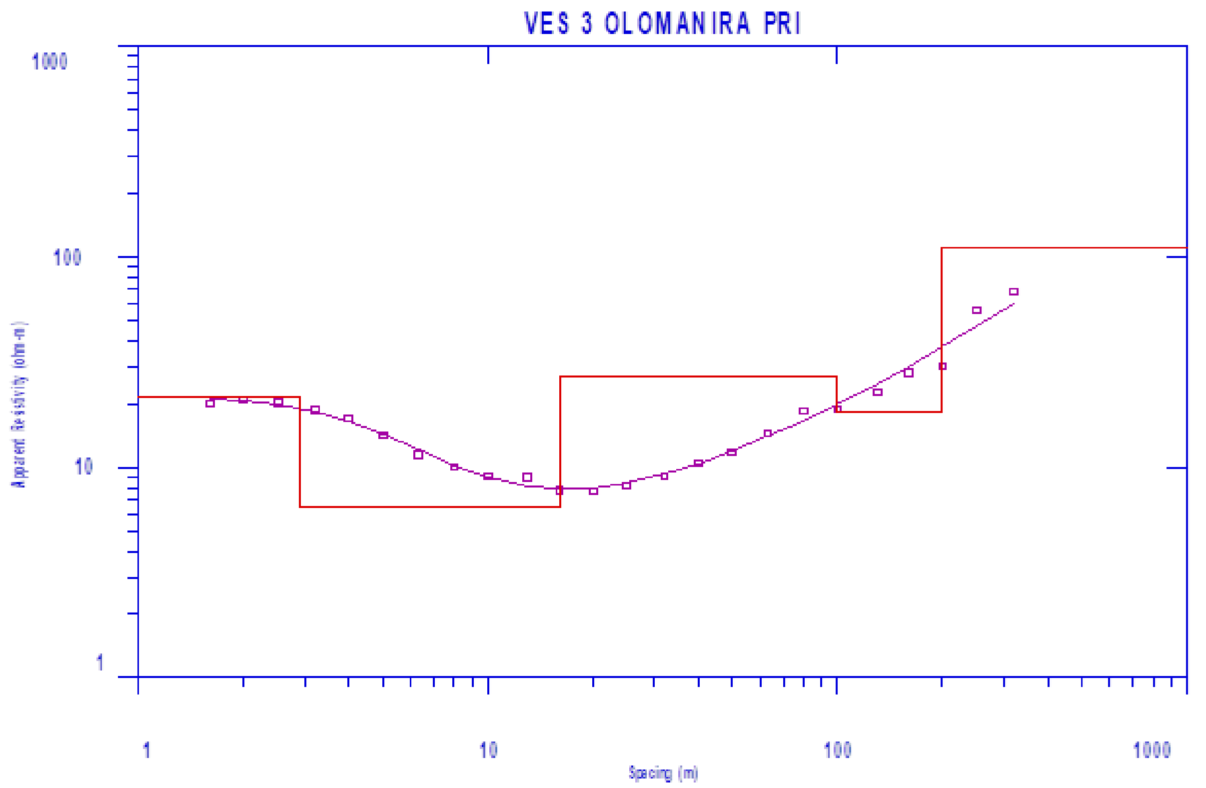
Interpretations of VES 2

Depth (m)	***Resistivity (Ohmm)***	***Interpretation***
0.0 – 2.0	*64.0*	*Dry top soils*
2.0 – 7.0	*15.0*	*Highly weathered sub-soils*
7.0 – 25.0	*30.2*	*Weathered regolith*
25 – 80.0	*55.0*	*Compact regolith*
80 – 160.0	*45.0*	*Highly weathered/fractured basement (Aquiferous)*
Below 160.0	*180.0*	*Weathered to fresh basement*

The results of VES 2 measurements show that the site is covered at the surface by dry top soils to a depth of about 2m and are underlain by highly weathered sub-soils to a depth of 7m. These are underlain by compact regolith to a depth of about 80m which are then underlain by highly weathered/ fractured basement to a depth of about 160m and its aquiferous. Beyond 160m is weathered to fresh basement layer with increasing resistivity and its aquiferous on top zones.

Drilling is not recommended at this site.

VES 3 Sounding Curve, Geoelectrical model and Data set.



MODEL: VES 3 OLOMANIRA PRI

LAYER	RESISTIVITY	THICKNESS	DEPTH
1	21.8	2.9	2.9
2	6.5	13.1	16.0
3	26.9	84.0	100.0
4	18.2	100.0	200.0
5	110.0		

DATASET: VES 3 OLOMANIRA PRI

NUMBER	AB/2	MN	RESISTIVITY
1	1.600000	0.500000	20.081251
2	2.000000	0.500000	20.908127
3	2.500000	0.500000	20.317501
4	3.200000	0.500000	18.781876
5	4.000000	0.500000	17.010000
6	5.000000	0.500000	14.175000
7	6.300000	0.500000	11.458125
8	8.000000	0.500000	10.040626
9	10.000000	0.500000	9.095625
10	13.000000	0.500000	8.977500
11	16.000000	0.500000	7.796250
12	20.000000	0.500000	7.678125
13	25.000000	0.500000	8.150625
14	32.000000	0.500000	9.095625
15	40.000000	10.000000	10.395000
16	50.000000	10.000000	11.812500
17	63.000000	10.000000	14.529375
18	80.000000	10.000000	18.663750
19	100.000000	10.000000	18.900000
20	130.000000	10.000000	22.700001
21	160.000000	25.000000	28.100000
22	200.000000	25.000000	30.200001
23	250.000000	25.000000	55.799999
24	320.000000	25.000000	68.900002

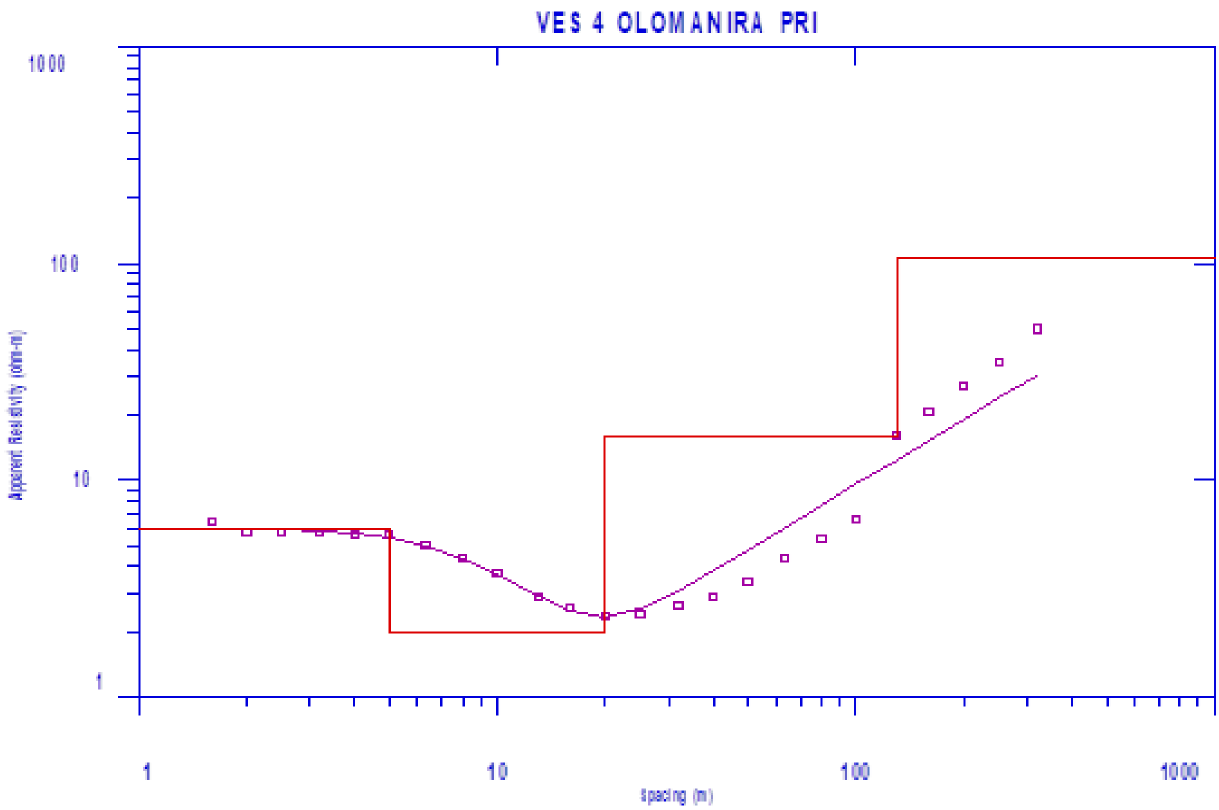
Interpretations of VES 3

Depth (m)	***Resistivity (Ohmm)***	***Interpretation***
0.0 – 2.9	*21.8*	*Dry top soils*
2.9 – 16.0	*6.5*	*Highly weathered sub-soils*
16 – 100.0	*26.9*	*Compact regolith*
100 – 200.0	*18.2*	*Highly weathered/fractured basement (Aquiferous)*
Below 200.0	*110.0*	*Weathered to fresh basement*

The results of VES 3 measurements show that the site is covered at the surface by dry top soils to a depth of about 2.9m and are underlain by highly weathered sub-soils to a depth of 16m. These are underlain by compact regolith to a depth of about 100m which are then underlain by highly weathered/ fractured basement to a depth of about 200m and its aquiferous. Beyond 200m is weathered to fresh basement layer with increasing resistivity and its aquiferous on top zones.

Drilling is recommended at this site to a depth of 220m.

VES 4 Sounding Curve, Geoelectrical model and Data set.



MODEL: VES 4 OLOMANIRA PRI

LAYER	RESISTIVITY	THICKNESS	DEPTH
1	5.9	5.0	5.0
2	2.0	15.0	20.0
3	15.9	110.0	130.0
4	107.0		

DATASET: VES 4 OLOMANIRA PRI

NUMBER	AB/2	MN	RESISTIVITY
1	1.600000	0.500000	6.448854
2	2.000000	0.500000	5.743511
3	2.500000	0.500000	5.693130
4	3.200000	0.500000	5.693130
5	4.000000	0.500000	5.592366
6	5.000000	0.500000	5.592366
7	6.300000	0.500000	4.987786
8	8.000000	0.500000	4.332824
9	10.000000	0.500000	3.677862
10	13.000000	0.500000	2.871755
11	16.000000	0.500000	2.569465
12	20.000000	0.500000	2.367939
13	25.000000	0.500000	2.418321
14	32.000000	0.500000	2.619847
15	40.000000	10.000000	2.922137
16	50.000000	10.000000	3.425954
17	63.000000	10.000000	4.383206
18	80.000000	10.000000	5.390839
19	100.000000	10.000000	6.600000
20	130.000000	10.000000	15.900000
21	160.000000	25.000000	20.799999
22	200.000000	25.000000	26.900000
23	250.000000	25.000000	34.700001
24	320.000000	25.000000	49.799999

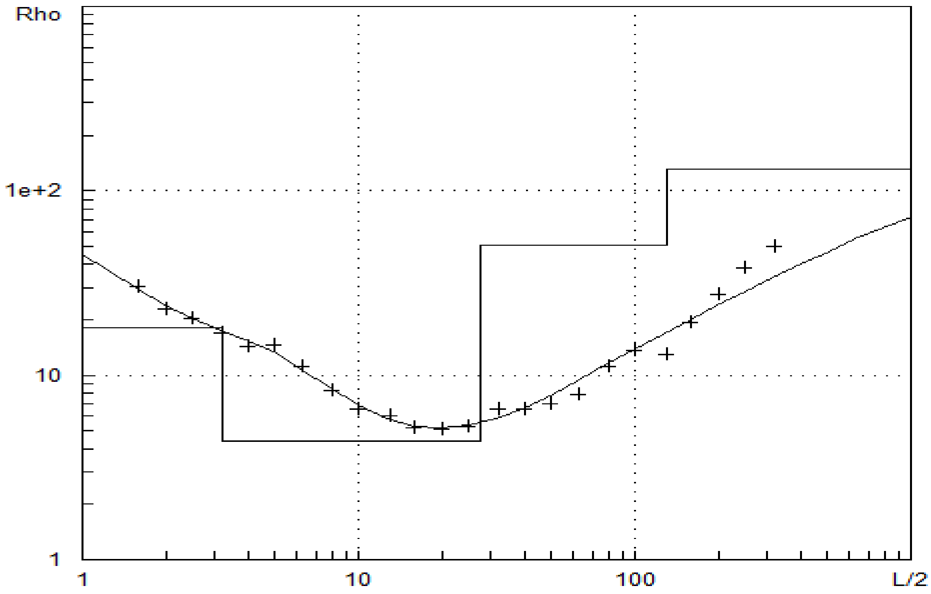
Interpretations of VES 4

Depth (m)	***Resistivity (Ohmm)***	***Interpretation***
0.0 – 5.0	*5.9*	*Dry top soils*
5.0 – 20.0	*2.0*	*Highly weathered regolith*
20 – 130.0	*15.9*	*Weathered basement*
Below 130.0	*107.0*	*Compact basement*

The results of VES 4 measurements show that the site is covered at the surface by dry top soils to a depth of about 5m and are underlain by highly weathered regolith to a depth of about 20m which are then underlain by weathered basement to a depth of about 130m. Beyond 130m is compact basement layer with increasing resistivity.

Drilling is recommended at this site to a depth of 220m.

VES 5 Sounding Curve, Geoelectrical model and Data set.



Layer	*Resistivity (Ohm)*	*Thickness (m)*	*Depth (m)*
1	71.60	0.50	0.50
2	18.10	2.70	3.20
3	4.40	24.50	27.70
4	50.80	102.70	130.40
5	130.90		
Station No.	**AB/2**	**MN**	**Resistivity (ohm)**
1	1.6	0.5	30.3
2	2	0.5	22.9
3	2.5	0.5	20.3
4	3.2	0.5	17.0
5	4	0.5	14.4
6	5	0.5	14.5
7	6.3	0.5	11.1
8	8	0.5	8.3
9	10	0.5	6.5
10	13	0.5	6.0
11	16	0.5	5.2
12	20	0.5	5.1
13	25	0.5	5.3
14	32	10	6.6
15	40	10	6.5
16	50	10	7.0
17	63	10	7.9
18	80	10	11.1
19	100	25	13.7
20	130	25	13.0
21	160	25	19.2
22	200	25	27.3
23	250	25	38.5
24	320	25	50.1

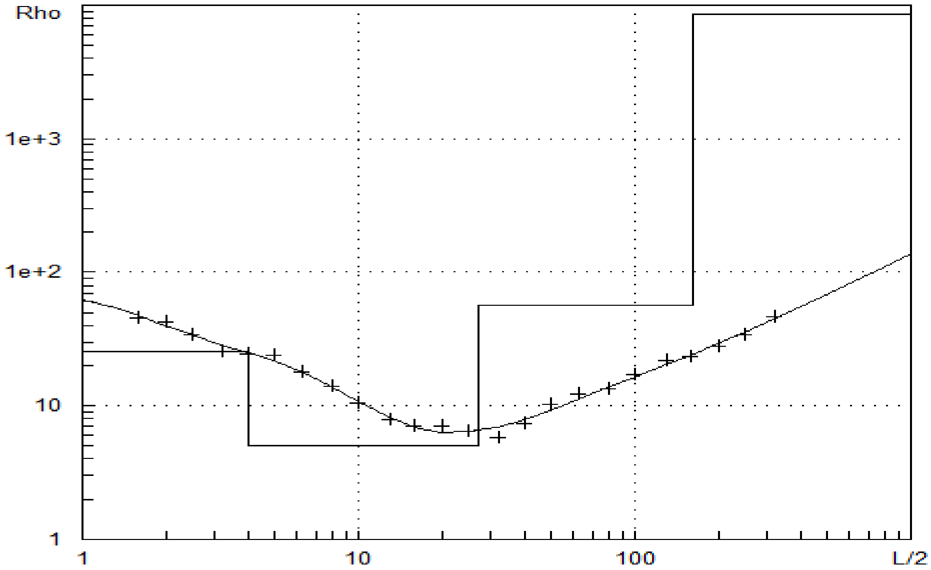
Interpretations of VES 5

Depth (m)	***Resistivity (Ohmm)***	***Interpretation***
0.0 – 0.5	*71.60*	*Dry top soils*
0.5 – 3.2	*18.10*	*Weathered sub-soils*
3.2 – 27.7	*4.40*	*Highly weathered regolith*
27.7 – 130.4	*50.80*	*Weathered/fractured basement (Aquiferous)*
Below 130.4	*130.90*	*Weathered to fresh basement*

The results of VES 5 measurements show that the site is covered at the surface by dry top soils to a depth of about 0.5m and are underlain by weathered sub-soils to a depth of 3.2m. These are underlain by highly weathered regolith to a depth of about 27.7m which are then underlain by highly weathered/ fractured basement to a depth of about 130.4m and its aquiferous. Beyond 130.4m is weathered to fresh basement layer with increasing resistivity and its aquiferous on top zones.

Drilling is recommended at this site to a depth of 220 metres asl.

VES 6 Sounding Curve, Geoelectrical model and Data set.



Layer	*Resistivity (Ohm)*	*Thickness (m)*	*Depth (m)*
1	76.10	0.70	0.70
2	25.30	3.30	4.00
3	5.00	23.30	27.30
4	56.30	135.50	162.80
5	150.90		
Station No.	***AB/2***	***MN***	***Resistivity (ohm)***
1	1.6	0.5	45.2
2	2	0.5	42.9
3	2.5	0.5	34.3
4	3.2	0.5	25.5
5	4	0.5	24.2
6	5	0.5	23.7
7	6.3	0.5	17.7
8	8	0.5	14.0
9	10	0.5	10.4
10	13	0.5	7.8
11	16	0.5	7.0
12	20	0.5	7.0
13	25	0.5	6.4
14	32	10	5.8
15	40	10	7.4
16	50	10	10.2
17	63	10	12.2
18	80	10	13.5
19	100	25	17.2
20	130	25	21.6
21	160	25	23.1
22	200	25	28.0
23	250	25	34.0
24	320	25	46.4

Interpretations of VES 6

Depth (m)	***Resistivity (Ohmm)***	***Interpretation***
0.0 – 0.7	*76.10*	*Dry top soils*
0.7 – 4.0	*25.30*	*Weathered sub-soils*
4.0 – 27.3	*5.00*	*Highly weathered regolith*
27.3 – 162.8	*56.30*	*Weathered/fractured basement (Aquiferous)*
Below 162.8	*150.90*	*Weathered to fresh basement*

The results of VES 6 measurements show that the site is covered at the surface by dry top soils to a depth of about 0.7m and are underlain by weathered sub-soils to a depth of 4.0m. These are underlain by highly weathered regolith to a depth of about 27.3m which are then underlain by highly weathered/ fractured basement to a depth of about 162.8m and its aquiferous. Beyond 162.8m is weathered to fresh basement layer with increasing resistivity and its aquiferous on top zones.

Drilling is recommended at this site to a depth of 220 metres asl.

6.2 Site Identification

The study thus recommends that the borehole be drilled at VES 5 or 6 ***to a depth of about 220m bgl or until fresh basement is struck.***

Figure 6-1 – Google Earth Image showing the proposed site

7. CONCLUSIONS AND RECOMMENDATIONS

On the basis of all the information gathered in the field, geological, geophysical and hydrogeological evidence,

*A borehole is recommended to be drilled at the site of **VES- 5 or 6 to a depth of about 220 m bgl depending on the choice of the host community**. This will ensure that the deeper aquifer is fully penetrated.*

The yield of a borehole drilled at the plot is expected to be good, but careful construction and development will lead to maximum borehole productivity, efficiency and long life.

Water quality is expected to be good for human and livestock consumption.

It is thus recommended that:

- ✓ ***The borehole should be drilled at VES 5 or 6 position at a minimum of 8-inch diameter and to a depth of about 220m bgl depending on the choice of the host community.***
- ✓ *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 Resources Management 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.

8. REFERENCES

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Exploratory Soil Map and Agroclimatic Zone Map of Kenya, 1980, Kenya Soil Survey.

9. APPENDICES

APPENDIX I - Acceptable Ionic Concentration - 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		GuideLevel	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 N03)		25 (as NO3)		50 (as NO3)				
Selenium	Se		0.01				0.01				
Other Substances		GV:		Highest	Maximum		GV:		MAC:		
			Desirable	Permissible							
			Level:		Level:						
Aluminium	Al	0.20						0.05		0.20	
Ammonium	NH4								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	H2S	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	NO2										0.10
Potassium	K							10		12	
Silver	Ag										0.01
Sodium	Na		200						20		175
Sulphate	SO4		400		200		400		25		250
Zinc	Zn				5.0		15		0.10		
Total Dissolved Solids		1000		500		1500				1500	
Total Hardness as CaCO3			500		100		500				
Colour	^{o}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	^{o}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 - Water Supply, Edward Anorld, London).

APPENDIX II; DRILLING AND DEVELOPMENT PROCEDURES

1. Drilling

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

2. Well Designs

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

3. Casing and Screens

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

4. Gravel Pack

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

5. Well Construction

Once the design has been agreed upon, construction can proceed. In installing screen and casing, centralizers at 6 metre intervals should be used to ensure centrality within the borehole. This is particularly important if an artificial gravel pack is to be installed as it ensures an approximately even annular space. If installed, gravel packed sections should be sealed off top and bottom with clay. It is normal practice nowadays to gravel pack nearly the total length of the borehole but seal off the weathered/topsoil zone at the top.

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

6. Well Developments

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

a) It repairs the damage done to the aquifer during the course of drilling by removing clays and other additives from the borehole walls, and

b) It alters the physical characteristics of the aquifer around the screen and removes fine particles.

We would not advocate the use of 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, which physically agitates the gravel pack and adjacent aquifer material. This is an extremely efficient method of developing and cleaning wells. Well development is an expensive element *in the completion of a well but it is usually justified in longer well life, greater efficiencies, lower operational and maintenance costs and a more constant yield.*

7. Well Testing

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

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

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

8. Well Maintenance

Once the well has been commissioned and a pump installed at the correct depth, the maintenance schedule should be established. Checks on discharge (m3/day), pumping water level (metres below a leveled and immovable bench mark), and static water level (if for any reason the well is not used for a 24-hour period) should be taken as part of a regular, routing process. This will enable the evaluation of all known conditions should reduction in the yield or other problems occur in the future, and recommend the most appropriate action.