Hydrogeological/Geophysical Survey Report
for
ONE PRODUCTION BOREHOLE

At

Shankoe Primary School, Shankoe Area, Nainyeny Sub - Location, Shankoe Location, Transmara West Sub County in Narok County

Client

Shankoe Primary School
P.O Box 245 – 40700 Kilgoris

Consultant

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(i) *ABBREVIATIONS*

(NOTE) SI spellings used throughout).

EC	Electrical Conductivity (US/cm)
Km	Kilometres
M	Metres
M amsl	Metres above mean sea level
M bgl	Metres below ground level
Ppm	Parts per million, equivalent to mg/l
SWL	static water level (in m bgl)
TDS	Total Dissolved Solids (ppm)
WSL	water struck level (in m bgl)m metre
T	Transmissivity (m.sq/day)
VES	Vertical Electrical Sounding
µS/cm	micro-Siemens per centimeter: Unit for electrical conductivity
^{0}C	degrees Celsius: Unit for temperature
Ω-m:	Unit for apparent resistivity

(ii) 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.

HERP Horizontal Electrical Resistivity Profile

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

Intercalated Inter-bedded – a lava flow that may occur between layers of sediment or vice-versa

Old Land Surface Old Land Surface (OLS’s) is the term given to ancient erosion surfaces now covered by younger surface material. In hydrogeology OLS’s frequently make good aquifers, especially where the erosion debris left behind is coarse in nature.

Phenocrysts The larger crystals in porphyritic rocks

Porphyritic A rock containing large crystals (>phenocrysts) in a finer groundmass

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)

Unconformable The representation in physical geology (i.e. in the rock record) of a break in the ordered succession of rocks

Volcanics Here used as a general term describing geological material of volcanic origin.

Yield Volume of water discharged from a well

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SUMMARY

The site is situated at Shankoe Primary School, Shankoe Area, Nainyeny Sub -Location, Shankoe Location, Transmara West Sub County in Narok County, Kenya. The coordinates are Latitude 00^{0}58’10.48’’S and Longitude E 34^{0}47’50.59’’E; with an elevation of 1860 meters above mean sea level. UTM 36S :(5700008E, 9892780S. The site is approximately 27 kilometers from Kilgoris town.

Geophysical measurements were conducted at the site to verify hydrogeological conditions and determine optimal drilling locations. This included a Horizontal Electrical Resistivity Profile (HERP) and three Vertical Electrical Soundings (VES), with a maximum separation of AB/2 = 320 meters used to effectively penetrate the granitic formation.

The investigation into the hydrogeological and geophysical conditions of the project area reveals several key findings and recommendations. The area is characterized by a productive aquifer system, primarily located within weathered/fractured old land surfaces of volcanics, which ensures a reliable water supply. Transmissivity (T) and hydraulic conductivity (K) of the aquifer are derived from tested yields and changes in drawdown, indicating the aquifer's capacity to transmit water. The storage coefficient, an important parameter for understanding water storage and release in the aquifer, is estimated to be approximately 4.6 x 10^-5 m³. Recharge mechanisms include direct percolation from rainfall and indirect recharge through potential faults, although no faults have been mapped in the study area. Discharge from the aquifer occurs both naturally and through human activities, with potential risks of physical damage due to uncontrolled abstraction.

The geophysical survey, conducted using Horizontal Electrical Resistivity Profiling (HERP) and Vertical Electrical Sounding (VES), provided insight into subsurface conditions. Resistivity methods, including galvanic resistivity, measured variations in electrical potential to infer geological and hydrogeological features. The HERP identified lateral changes, while the VES helped determine the depth and characteristics of aquifer layers. Upon completion of the hydrogeological and geophysical Survey it is recommended to sink a borehole at **VES 2 GPS (Lat: 00^{0}58’10.48’’S and Long:E 34^0 47’50.59’’E), UTM 36S :(5700008E, 9892780S).** It should be equipped with appropriate casing, screens, and monitoring devices. Further recommendations include regular water quality testing, installation of a master meter and piezometer, and adherence to environmental regulations.

In terms of water quality, attention must be given to fluoride concentrations. Fluoride, if present above recommended levels, poses health risks such as dental and skeletacoul fluorosis. The WHO guideline for fluoride in drinking water is 1.5 ppm. The proposed measures include careful monitoring and potential treatment if fluoride levels exceed safe limits. Overall, the project area holds substantial groundwater potential, but it is crucial to follow recommended practices to ensure sustainable and safe water use.

1. Introduction

1.1 Introduction

The investigation was done in order to assess the subsurface geology and advice the client on the possibility of drilling a production borehole for Shankoe primary School.

The objective of the present study was to assess the availability of groundwater, to recommend a borehole drilling site and to comment on aspects of depth to potential aquifers, aquifer availability and type, possible yields and water quality. For these reasons, all available hydrogeological information of the area has been analyzed, and a geophysical survey has been carried out.

1.2 Reporting Requirements

The format of writing the Hydrogeological Investigations Report, as described out in the Second Schedule of the Water Resources Management Rules, 2007. Such a report must consider the following:

a) Name and details of applicant

b) Location and description of proposed Activity

c) Details of climate

d) Details of geology and hydrogeology

e) Details of neighboring boreholes, including location, distance from proposed boreholes , number and construction details, age, current status, abstraction and use.

f) Description and details (including raw and processed data) of prospecting methods adopted, e.g., remote sensing, geophysics, geological and or hydrogeological cross sections. hydrogeological characteristics and analysis, to include but not necessarily be limited to, the following:

  - ➢ Aquifer transmissivity
  - ➢ Borehole specific capacities
  - ➢ Storage coefficient and or specific yield
  - ➢ Hydraulic conductivity
  - ➢ Groundwater flux
  - ➢ Estimated mean annual recharge, and sensitivity to external factors

g) Assessment of water quality and potential infringement of National standards

h) Assessment of availability of groundwater

i) Analysis of the reserve

j) Impact of proposed activity on aquifer, water quality, other abstractors, including likelihood of coalescing cones of depression and implications for other groundwater users in any potentially impacted areas

k) Recommendations for borehole development, to include but not limited to, the following:

  - Locations of recommended borehole(s) expressed as a coordinate(s) and indicated on a sketch map
  - Recommendations regarding borehole or well density and minimum spacing in the project area
  - Recommended depth and maximum diameter.

- Recommended construction characteristics, e.g., wire-wound screen, grouting depth e. Anticipated yield

l) Any other relevant information (e.g., need to monitor neighboring boreholes

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

The reconnaissance survey was carried out followed by geophysical borehole site investigations through resistivity application. Within the context of resistivity instrumentation, one Horizontal Electrical Resistivity Profile (HERP) spanning a lateral distance of about 30 metres was achieved while three Vertical Electrical Soundings (VES) are carried out at the proposed site.

The maximum separation used was $AB/_2$ = 320 m which was considered effective in delineating the transition into the volcanics.

In addition to the hydro geologic assessment outlined above, a detailed coordinated planning with the Government Authorities [Water Resources Authority} - must be implemented to obtain relevant permits and consent for the project implementation.

1.3 Water Resources

Considering the distances to the other water sources, rainwater harvesting and the pumped water from River Mara could be an essential strategy for the school. Implementing or improving roof catchment systems would help ensure a more reliable and clean water supply.

Understanding the proximity and accessibility of these water resources is vital for developing sustainable water management strategies for the school and the surrounding community. This knowledge can guide decisions on infrastructure investments, such as improving well systems, enhancing rainwater harvesting, or potentially developing pipelines from the river if feasible to supplement the borehole water for effective water demand.

1.4 Water Demand

The proposed development of a borehole water source will cater for the needs of the school and the Shankoe Area at large, groundwater exploitation is viewed as the most feasible option for the area. Although the area is blessed with both seasonal and permanent rivers like River Mara, the prospect of developing piped water supply schemes is costly in both the capital and the recurrent costs.

1.5 Project Location

The site is situated at Shankoe Primary School, Shankoe Area, Nainyeny Sub -Location, Shankoe Location, Transmara West Sub County in Narok County, Kenya. The coordinates are Latitude 00058’10.48’’S and Longitude E 34047’50.59’’E;, with an elevation of 1860 meters above mean sea level. UTM 36S :(5700008E, 9892780S. The site is approximately 27 kilometers from Kilgoris town.

The expected yield for a borehole drilled at this site is expected to be moderate. The quality and the quantity of groundwater at the proposed site are expected to be fair and are bound to conform to specific national standards and WHO standards guidelines.

At the site, geophysical measurements were carried out to confirm the hydro geological conditions and identify optimum and suitable site locations. This was done through resistivity application where one

Horizontal Electrical Resistivity Profile (HERP) and three Vertical Electrical Soundings (VES) were carried out at the site.

The maximum separation used was AB/2 =320m which was considered effective; in deep penetration of the volcanic formation.

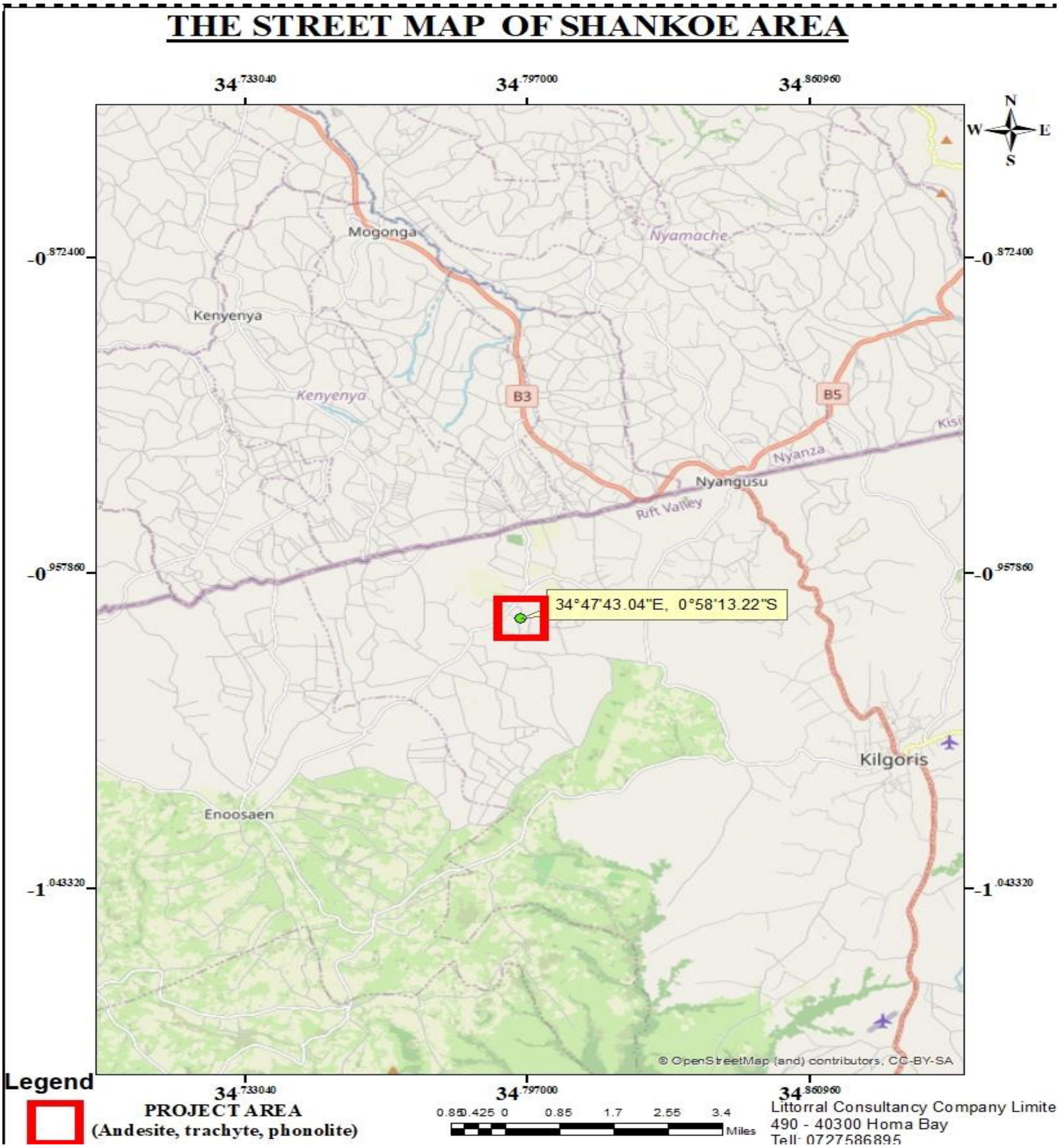


Figure 1: Project area

2 Climate

2.1 Climate:

The area experiences a semi-humid climate typical of the highland regions of Kenya. The area has two rainy seasons: the long rains from March to May and the short rains from October to December. Rainfall amounts vary, with annual precipitation averaging between 1000 mm to 1500 mm, supporting agriculture and livestock farming. Temperatures in Shankoe range from 10°C to 26°C, with cooler nights and mornings due to the area's altitude. The dry season, particularly from June to September, is marked by sunny days and cool breezes, while the region can experience occasional droughts during prolonged dry spells.

2.2 Drainage:

The drainage in Shankoe, like much of Narok County, is influenced by its hilly and gently rolling terrain. The area is part of the Mara River Basin, with numerous small streams and seasonal rivers flowing toward the larger Mara River, which is a crucial waterway for both human activities and wildlife. These streams and rivers generally have a dendritic drainage pattern, which is common in regions with varied terrain. During the rainy seasons, water flow in these rivers increases significantly, contributing to the local agricultural activities. However, during the dry seasons, many of the smaller streams may dry up, leading to reduced water availability. Soil erosion and surface runoff are common in sloped areas, particularly where vegetation cover is sparse.

2.3 Topography:

Topography is characterized by gently rolling hills, interspersed with valleys and flat plains, typical of the highland areas in Narok County. The elevation ranges between 1,500 to 2,000 meters above sea level, contributing to the area's relatively cool climate. The terrain is well-suited for pastoralism and mixed farming, with the valleys often serving as drainage points for seasonal rivers and streams. The hilly sections offer scenic views of the surrounding landscapes, while the plains support grazing for livestock. In some areas, the slopes can be moderately steep, contributing to soil erosion, especially during heavy rains.

2.4 Vegetation Cover

The vegetation cover is a mix of savannah grasslands, shrublands, and patches of forested areas, typical of the highland regions in Narok County. The grasslands are predominant and support extensive livestock grazing, a key economic activity in the region. Shrubs and small trees are scattered throughout the area, with acacia trees being common. Along riverbanks and in valleys, there are pockets of denser vegetation due to the availability of water. During the rainy seasons, the grasslands flourish, providing ample fodder for livestock, while in the dry seasons, much of the vegetation becomes sparse, with grasses turning brown and dry. Deforestation and overgrazing in some areas have led to a reduction in vegetation cover, increasing the risk of soil erosion.

Given that the region is predominantly agricultural, parts of the area around the school may be cultivated with crops such as maize, beans, and millet. This cultivation impacts the natural vegetation, reducing the density of native plants. The vegetation condition varies seasonally, with lush green grasses and foliage during the rainy season and a more sparse, dry appearance during the dry season. Droughts can lead to significant vegetation stress, with reduced plant cover and increased soil erosion. Moreover, Human activities, such as farming, grazing, and deforestation, have affected the natural vegetation, leading to a more fragmented landscape with reduced biodiversity.

3.GEOLOGY, SOIL COVER

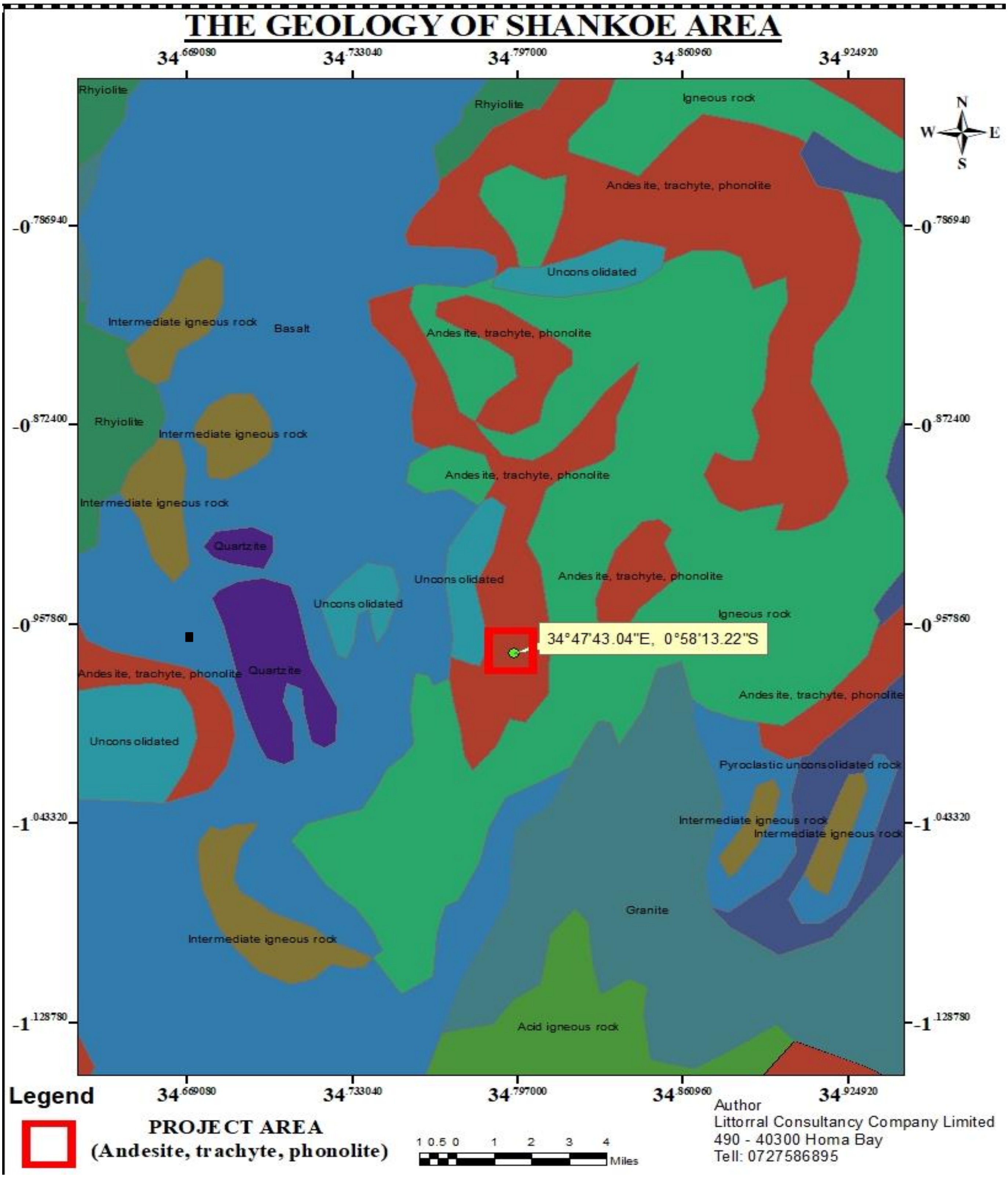


Figure 2: Geology of the area

3.1 Regional Geology

The geology is dominated by volcanic rocks, particularly those associated with the greater Rift Valley volcanic system. These include andesites, trachytes, and phonolites. These rocks were primarily formed during the Miocene to Pleistocene epochs, associated with the tectonic activity in the Rift Valley. Basalt are the most common rock type in the region, characterized by their dark color and fine-grained texture often exhibiting columnar jointing, which is indicative of cooling and solidification processes. Trachytes and Phonolites are more evolved volcanic rocks, typically lighter in color and less dense than basalts. They often occur as lava flows or dykes, cutting through the older basaltic formations. Tertiary sediments in addition to volcanic rocks, the region has some sedimentary deposits from the Tertiary period. These sediments are usually found in low-lying areas and valleys, consisting of clays, silts, and gravels deposited by ancient rivers and lakes.

The most recent geological deposits in the area are from the Quaternary period, consisting of alluvial and colluvial deposits. These include unconsolidated materials like sands, gravels, and soils, often found along river valleys and floodplains.

3.2 Structural Geology

Shankoe, located within the broader Rift Valley region of Narok County, is influenced by several major tertiary faults associated with the East African Rift System. Key faults in the area include the Suswa Fault System, which extends from Mount Suswa to the surrounding regions, and the Mau Escarpment Faults, which lie to the north and significantly shape the landscape. Additionally, the Nguruman Fault, part of the Nguruman Escarpment to the south, plays a role in defining the region's topography. These faults contribute to the tectonic activity in the area, influencing landforms, drainage patterns, and seismic characteristics, while shaping the highlands and valleys typical of the region.

3.3Site Geology

The site geology of the Shankoe area in Narok is dominated by a mix of volcanic rocks and sedimentary deposits, characteristic of the broader geological context of the Mau Escarpment and the Great Rift Valley region. The area is underlain by volcanic rocks, including andesites, trachytes, and phonolites, which were deposited during various volcanic eruptions that shaped the Rift Valley. These volcanic formations are often interbedded with sedimentary layers, such as tuffs, clays, and alluvial deposits, resulting from the erosion and weathering of volcanic materials over time. The presence of ash falls and pumice layers from past volcanic activity also influences the soil structure and mineral content. Additionally, the region has localized faulting and fracturing, which affect both the topography and groundwater movement. The combination of volcanic and sedimentary geology gives rise to a complex landscape that supports diverse ecosystems and agricultural activities.

3.4 Soil

The area has soil that includes scree from the hilly terrain. A thin grey soil with pebbles and boulders from the steep landscape of the hill range have been deposited here below. On the upper higher grounds brown grey soils and outcrops are prevalent while on the lower sections such as depressions black cotton soils predominate.

3.4.1 Soil Formation

soil formation is largely influenced by the area's volcanic origins, topography, and climate. The parent material consists of weathered volcanic rocks, which break down into fertile soils rich in minerals. The region's semi-humid climate, with distinct rainy and dry seasons, accelerates weathering processes and organic matter accumulation, particularly during the rainy seasons when vegetation flourishes. The hilly terrain also affects soil formation, as slopes are prone to erosion, while valleys collect more fertile alluvial soils. Biological activity from livestock and vegetation further contributes to soil development through nutrient cycling. Over time, this combination of factors has resulted in soils that vary from shallow and rocky on the slopes to deeper, more fertile soils in the valleys and flatlands, suitable for agriculture and grazing.

3.4.2 Soil Cover

The soil cover in Shankoe is characterized by a diverse mix of fertile volcanic soils and less productive sandy or clayey soils, influenced by the region's topography and land use. In the valleys and low-lying areas, the soil is generally deep and rich in nutrients, supporting lush vegetation and agricultural activities, including crop farming and grazing. These fertile soils are predominantly clayey, which helps retain moisture during the dry seasons. In contrast, the steeper slopes feature shallower, stonier soils that are more susceptible to erosion due to runoff during heavy rains. Overgrazing and deforestation in some areas have led to reduced soil cover, increasing the risk of erosion and degradation. Overall, the soil cover in Shankoe plays a vital role in sustaining local agriculture and pastoralism, although it faces challenges from human activities and environmental factors.

4. HYDROGEOLOGY

4.1 Background

The study of the distribution and movement of groundwater in the soil and rocks of the Earth's crust. It encompasses the investigation of aquifers, the geological formations that can store and transmit water, as well as the interactions between groundwater and surface water. Understanding hydrogeology is essential for effective water resource management, pollution control, and land-use planning, particularly in regions where water scarcity is a concern. Factors such as geology, climate, and land use significantly influence groundwater availability, recharge rates, and the quality of water resources, making it critical to assess and manage these resources sustainably.

4.2 Hydrogeology of the Project Area

Hydrogeology is characterized by the presence of volcanic rock formations that create a complex aquifer system. The region's topography influences groundwater flow, with the hilly landscape directing water movement toward valleys and lower elevations, where aquifers are often more saturated. The volcanic soils and underlying basalt rock can store significant amounts of water, while fractures and weathered zones within the rock enhance water movement and storage capacity. Shankoe experiences seasonal variations in groundwater recharge, primarily during the rainy seasons, when increased precipitation replenishes aquifers. However, challenges such as over-extraction for agriculture and livestock, coupled with limited recharge during prolonged dry periods, can affect the availability and quality of groundwater in the area, necessitating careful management practices to sustain this vital resource.

4.3 Water Quality

Important water quality parameters for rural and community water supplies are Electrical conductivity, iron and fluoride concentrations. The permissible levels are 750 micro-S/cm, 1.5 ppm and 1ppm respectively (Groundwater Master Plan-1992).

The integrated drinking water risk taking into account the above parameters for the area is classified as good. Groundwater quality for the area is hence generally good. However, this risk analysis is not uniform in time and space hence the potential to infringe on the National Standards on localized scale.

Quality of groundwater is controlled by: -

I. Geology of aquifer
II. Length of time water is stored in the ground
III. Climate
IV. Nature of recharge
V. Contamination

- Geology of the aquifer determines the type and amount of dissolved solids it will contain.
- The longer the period water is stored in the good; the more dissolved solids it will contain.
- Climate determines the rate of evaporation from aquifers and also recharge into the aquifer. In hot and dry climate region, the salt content of groundwater is high due to high evaporation. More recharge to the aquifer lowers the salt content of the groundwater. Groundwater contamination due to poor sanitation is the major process of groundwater quality degradation.

5. AQUIFER PARAMETERS

5.1 Mean Annual Recharge

The rainfall within the study area is medium and regional recharge is of great essence in this area. 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

1000mm x 5%

Mean Annual Recharge = 50mm

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 and overlaying OLS.

5.2 Groundwater Flux/ recharge and Discharge Dynamics.

The slope of the land affects the direction and rate of groundwater flow. The undulating terrain means that groundwater typically flows from higher elevations to lower elevations. The gradient of the water table, which is the slope of the groundwater surface, drives the horizontal flow of groundwater.

5.3 Specific Capacity

This is defined as the yield (Q) per unit drawdown (s). Specific Capacity generally varies with duration of pumping; as pumping time increases, specific capacity decreases. Also, specific capacity decreases as discharge increases in the same well.

5.4 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 the aquifer. Strictly speaking, transmissivity should be determined from the analysis of a well test, but here we use the Logan method to estimate it; 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 (Thiem 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 (m3/day), Δs = increase in drawdown over 1 log cycle of time.

5.5 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. For the analysed boreholes, the hydraulic conductivity of fractured rocks depends largely on the density of the fractures and the width of their apertures.

K=T/Aquifer Thickness

5.6 The Storage Coefficient

The storage coefficient 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 the storage coefficient cannot be determined from test data collected from pervious drilling programmes in the area, as aquifer test data is not available. In an aquifer test, a borehole is pumped at a known discharge rate and water levels in one or more neighboring observation boreholes, and the shape and type of drawdown curve in the observation borehole(s) is used to calculate the storage coefficient.

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" estimates of the storage coefficient (Lohman 1972 cited in Todd et al 2005) can be made from:

S = 3 x 10-6 x D, where D is aquifer thickness.

S =3 x 10-6 x50

15x10-4

On this basis, the aquifer under investigation has a storage coefficient of approximately 4.6 x10-5m3

5.7 Recharge

The recharge of aquifers is primarily influenced by seasonal rainfall patterns and the geological characteristics of the region. During the long and short rainy seasons, which occur from March to May and October to December, respectively, precipitation rates increase significantly, allowing surface water to infiltrate into the ground. The volcanic soils in the area have good permeability, facilitating efficient water infiltration and enhancing the recharge of underlying aquifers. Additionally, the hilly topography directs runoff water into lower-lying areas, where it can contribute to aquifer replenishment.

The recharge process is further supported by the presence of fractures and weathered zones in the underlying basalt rock, which create pathways for water to move downward into the aquifers. However, the recharge rates can vary based on land use practices, such as agriculture and livestock grazing, which can affect soil structure and infiltration capacity. In periods of prolonged dry weather, the lack of rainfall can lead to reduced recharge, impacting groundwater levels. Overall, the combination of seasonal rainfall, geological formations, and land management practices plays a critical role in the recharge dynamics of the aquifers in the area.

5.8 Discharge

The discharge of groundwater in the Shankoe area occurs primarily through natural outlets such as springs, river systems, and wells, as well as through evaporation and transpiration processes. Springs often emerge at lower elevations where aquifers intersect with the surface, providing a vital water source for both local communities and wildlife. The regional topography, characterized by rolling hills and valleys, facilitates the movement of groundwater towards these discharge points, especially during the rainy seasons when the water table is higher.

Surface water bodies, such as rivers and streams, are also significant discharge areas, where groundwater contributes to overall water flow, particularly in times of high recharge. Additionally, human activities, such as irrigation and water extraction for domestic use, play a role in groundwater discharge, often leading to lower groundwater levels over time if extraction rates exceed natural recharge. The balance between recharge and discharge is crucial for maintaining sustainable water resources; hence, monitoring these processes is essential to prevent over-exploitation and ensure the availability of groundwater in the area. Factors such as seasonal variations in rainfall, land use practices, and climate change can also influence the rates of discharge, impacting both the quantity and quality of water resources available to the local population.

6.0 GEOPHYSICS

In order to map out geological subsurface conditions, a variety of methods are used. In the present survey galvanic Resistivity method was used, and included Horizontal Electrical Resistivity Profiles **(HERP)** and Vertical Electric Soundings **(VES)** to establish vertical sub-surface resistivity

6.1 Basic Principles

The electrical properties of the upper parts of the earth's crust depend upon the rock type, porosity, pore-space saturation and interconnectivity and the level of salinity of the pore water. Saturated rocks have lower resistivity than dry or unsaturated rocks. Both higher porosities and salinity of saturated rocks mean higher conductivities respectively.

Clays and conductive minerals also increase the conductivity of the rocks leading to ambiguity of interpretation in some cases.

The resistivity of earth materials can be studied by measuring the electrical potential distribution produced at the earth's surface by injection of low frequency electric current. Two basic considerations are the basis of the theory behind galvanic resistivity methods viz:-

(*1) Ohm's law* :

$$\mathbf{E} = \rho \mathbf{i}$$

Where: **E** = Potential gradient (**Volts per meter**)

i = Current density (**Am^{-2}**)

ρ = Resistivity of the earth medium(**Ω-m**)

(2*) The divergence condition for the current flux into the ground:*

$$\mathbf{DIVi} = 0$$

It follows from above that the potential function **V** for a single point source at a distance of **r** meters on the earth's surface is given by:

(i) $$V_r = \rho I / 2\Pi r \quad \text{(Volts)}$$

In hydrogeological field surveys using galvanic Resistivity methods the quantities measured are current **I**, flowing between two electrodes **A&B** and potential difference **ΔV** between two measuring points **M & N.** The following generalized relationship applies to various electrodes configurations.

(ii) $$\rho = K \times \Delta V / I_{AB} \quad (\Omega\text{-m})$$

Where K is defined as the geometrical factor derived from electrode configuration adopted. The most common field arrays are the Schlumberger and Wenner configurations.

Data obtained is normally subjected to modeling analysis using a digital computer. This is combined with data from existing boreholes to come up with a more realistic interpretation and recommendations.

6.2 Field Work

Field work for the project area was carried out on 27th September 2024. The exercise was undertaken with the aim of: -

a) Carrying out an on-site examination and constructing a conceptual model which would form a baseline for more elaborate investigations in the study.
b) Delineating the area for proposed borehole away from possible contamination from pit latrines or any other liquid/solid waste sites
c) Conducting geophysical investigations to determine geological layout and consequently the optimum depth of drilling to reach the potential water bearing formation where applicable.

The geophysical survey method employed the Werner HERP and the Schlumberger Vertical Electric Sounding (VES).

6.2.1 Horizontal Electrical Resistivity Profiling

This method is a quick and qualitative application that is geared towards the delineation of the lateral changes in the sub surface. This method will unfurl the lateral changes as may be due to the presence of fractures/faults, lithology, the moisture content and the weathering variations.
In this study, the depth was set at 300m bgl with a frequency of 40. The interval between the measuring points was kept at 1m (N-N1/M-M1) for all the profiles investigated. The machine measures and stores the data automatically, curve graphs 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 anomalous points were made the candidate points for further investigations by VES.

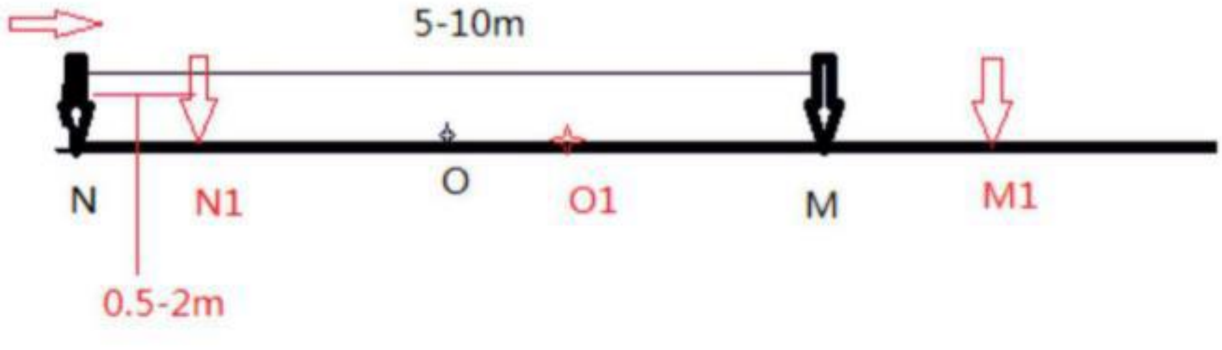


Figure 3:Illustration of Equipment Arrangement (After PQWT - TC300 Manual 2027)

6.2.2 Resistivity Sounding Method

When carrying out a resistivity sounding, also called vertical electrical sounding (VES), an electric current (I) is passed into the ground through two metal pegs, the current electrodes. Subsurface variations in electrical conductivity determine the pattern of current flow in the ground and thus the distribution of electrical potential.
A measure of this is obtained in terms of the voltage drop (ΔV) between a second pair of metal pegs and the potential electrodes placed near the center of the array. The ratio (V/I) provides a direct measurement of the ground resistance and from this and the electrode spacing, the apparent resistivity (ρ) of the ground is derived.

A series of measurements made with an expanding array of current electrodes (Schlumberger Array), allows the flow of current to penetrate greater depths, providing information on the vertical variation in resistivity. The calculated apparent resistivity is plotted against current electrode half separation on a bi-logarithmic graph paper to constitute the so-called sounding curve. The curve depicts a layered earth model composed of individual layers of specific thickness and resistivity.
Interpretation of the sounding curves is can be achieved by computer software.
In addition, the VES is used to predict the thickness of different layers and depth to the aquifer as well as the lithologies encountered.

6.3 Results

6.3.1 Horizontal Electrical Resistivity Profile (HERP)

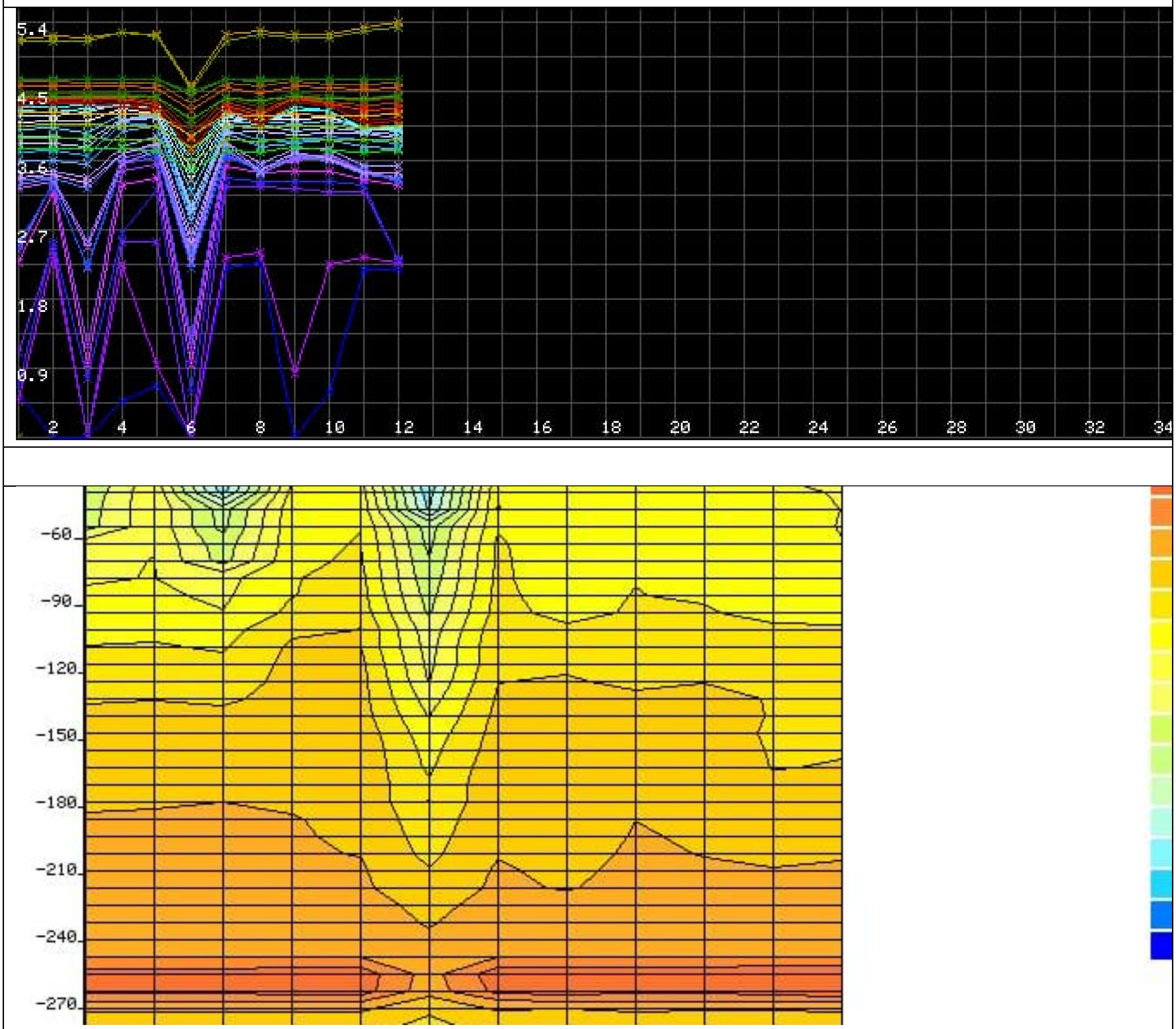
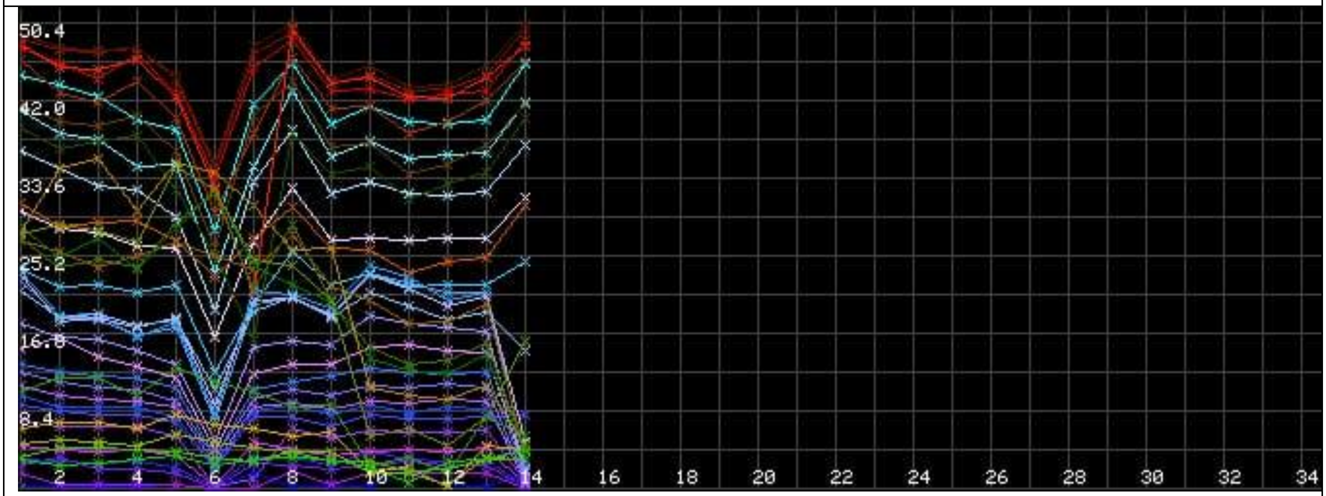


Figure 4: VES 1 Herp

Was conducted at point 11.5 along profile



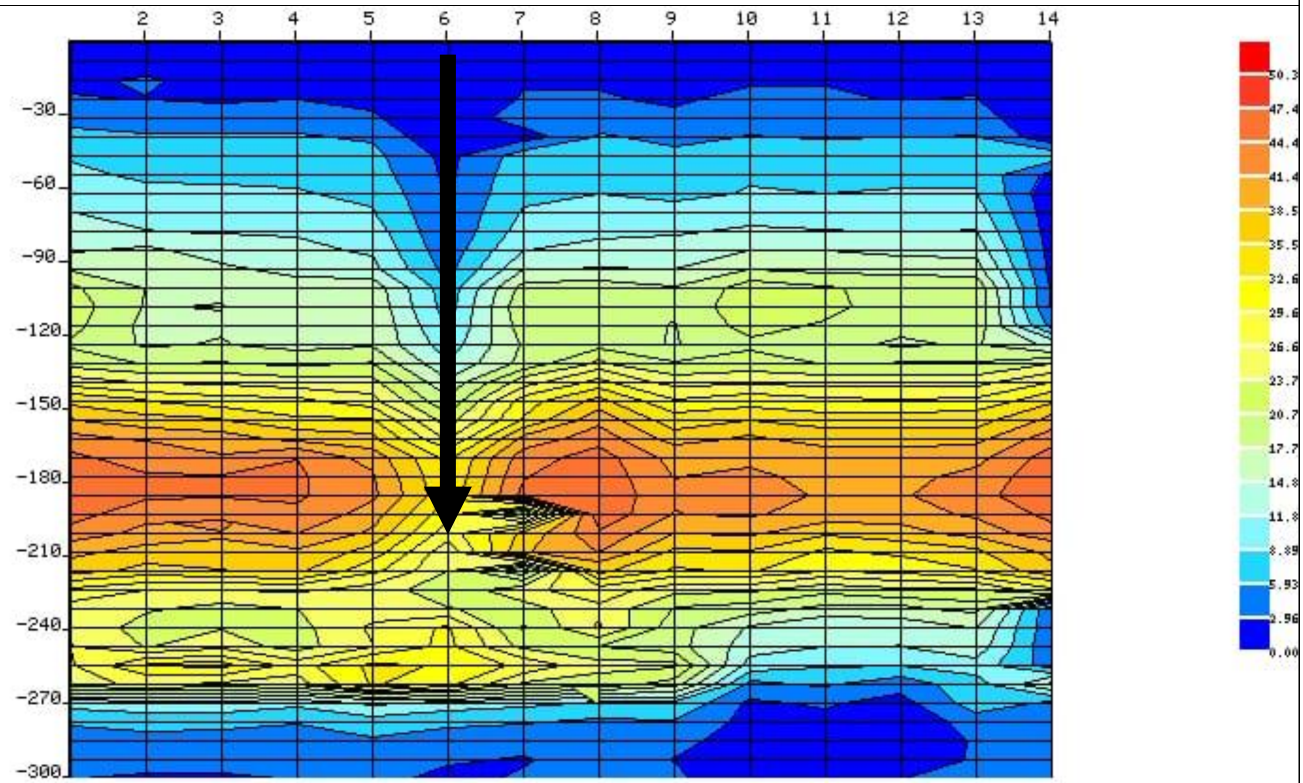


Figure 5: VES 2 Herp

Was conducted at point 6 along profile

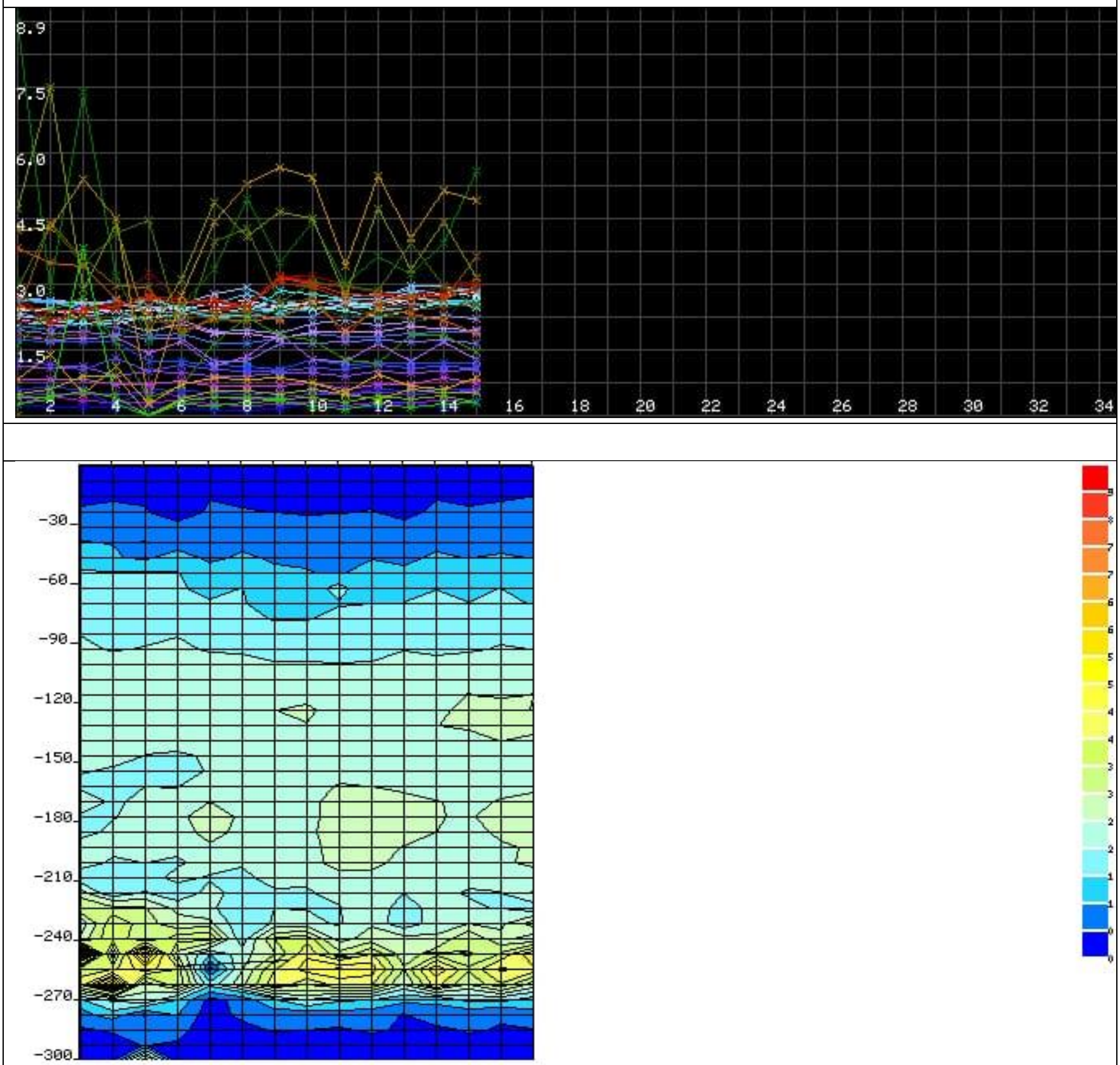


Figure 6: VES 3 Herp

Was conducted at point 8 along profile

6.3.2 Vertical Electrical Sounding

A deep probe resistivity **meter Model No. SSR-MP-AT** was used to acquire data after which interpretation was done by means of a **PC** and **Nile software GeWIN Version-4.**
The figures below illustrate the results.

VES 1

Meas. #	L/2 in m	R in Ohm.m	don't use	Meas. #	L/2 in m	R in Ohm.m
1	1.60	221.40		21	160.00	810.02
2	2.00	213.80		22	200.00	956.18
3	2.50	230.10		23	250.00	1256.36
4	3.20	215.70		24	320.00	1610.00
5	4.00	200.50			.00	.00
6	5.00	166.50			.00	.00
7	6.30	137.10			.00	.00
8	8.00	123.80			.00	.00
9	10.00	125.50			.00	.00
10	13.00	157.90			.00	.00
11	16.00	187.10			.00	.00
12	20.00	208.30			.00	.00
13	25.00	232.90			.00	.00
14	32.00	299.80			.00	.00
15	40.00	353.40			.00	.00
16	50.00	370.20			.00	.00
17	63.00	404.32			.00	.00
18	80.00	498.00			.00	.00
19	100.00	563.16			.00	.00
20	130.00	689.04			.00	.00

Figure 7: VES 1: Raw Data

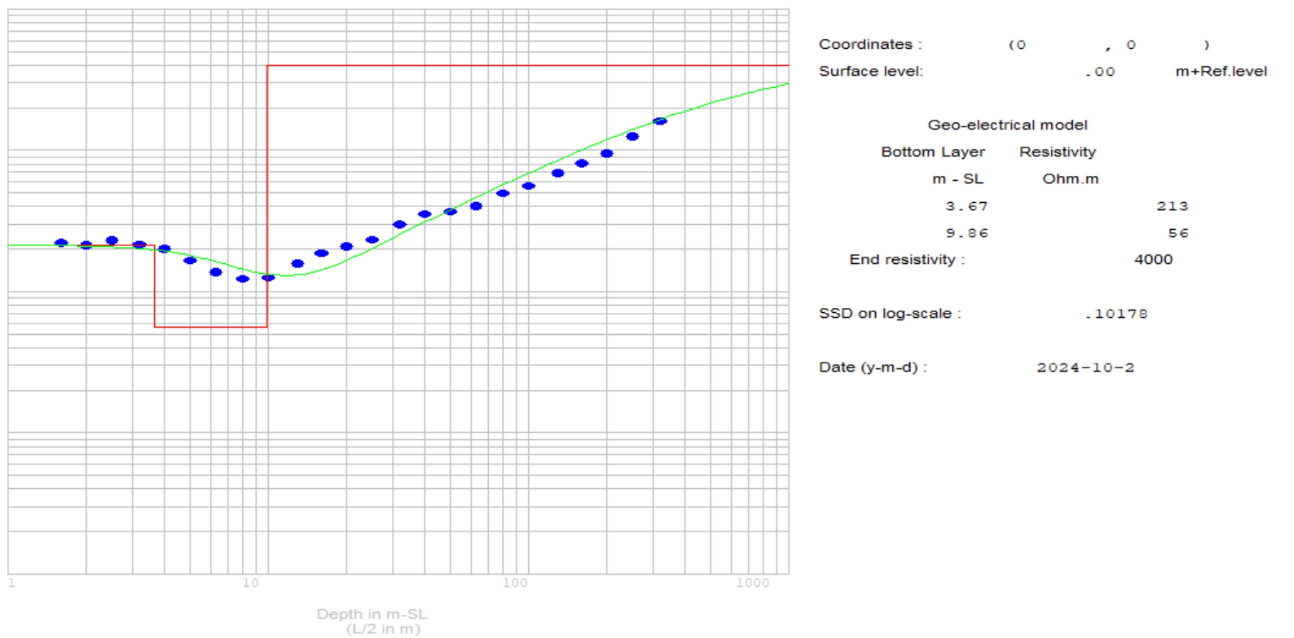


Figure 8: VES 1 INTERPRETATION CURVE

VES 2

Input measured curve

Meas. #	L/2 in m	R in Ohm.m	don't use	Meas. #	L/2 in m	R in Ohm.m
1	1.60	145.20		21	160.00	285.91
2	2.00	141.95		22	200.00	415.07
3	2.50	146.45		23	250.00	555.66
4	3.20	139.73		24	320.00	795.34
5	4.00	106.43			.00	.00
6	5.00	83.57			.00	.00
7	6.30	66.22			.00	.00
8	8.00	58.80			.00	.00
9	10.00	62.91			.00	.00
10	13.00	74.73			.00	.00
11	16.00	80.30			.00	.00
12	20.00	89.00			.00	.00
13	25.00	99.26			.00	.00
14	32.00	102.99			.00	.00
15	40.00	117.50			.00	.00
16	50.00	124.79			.00	.00
17	63.00	140.45			.00	.00
18	80.00	160.48			.00	.00
19	100.00	192.35			.00	.00
20	130.00	256.61			.00	.00

Figure 9: VES 2 Raw Data

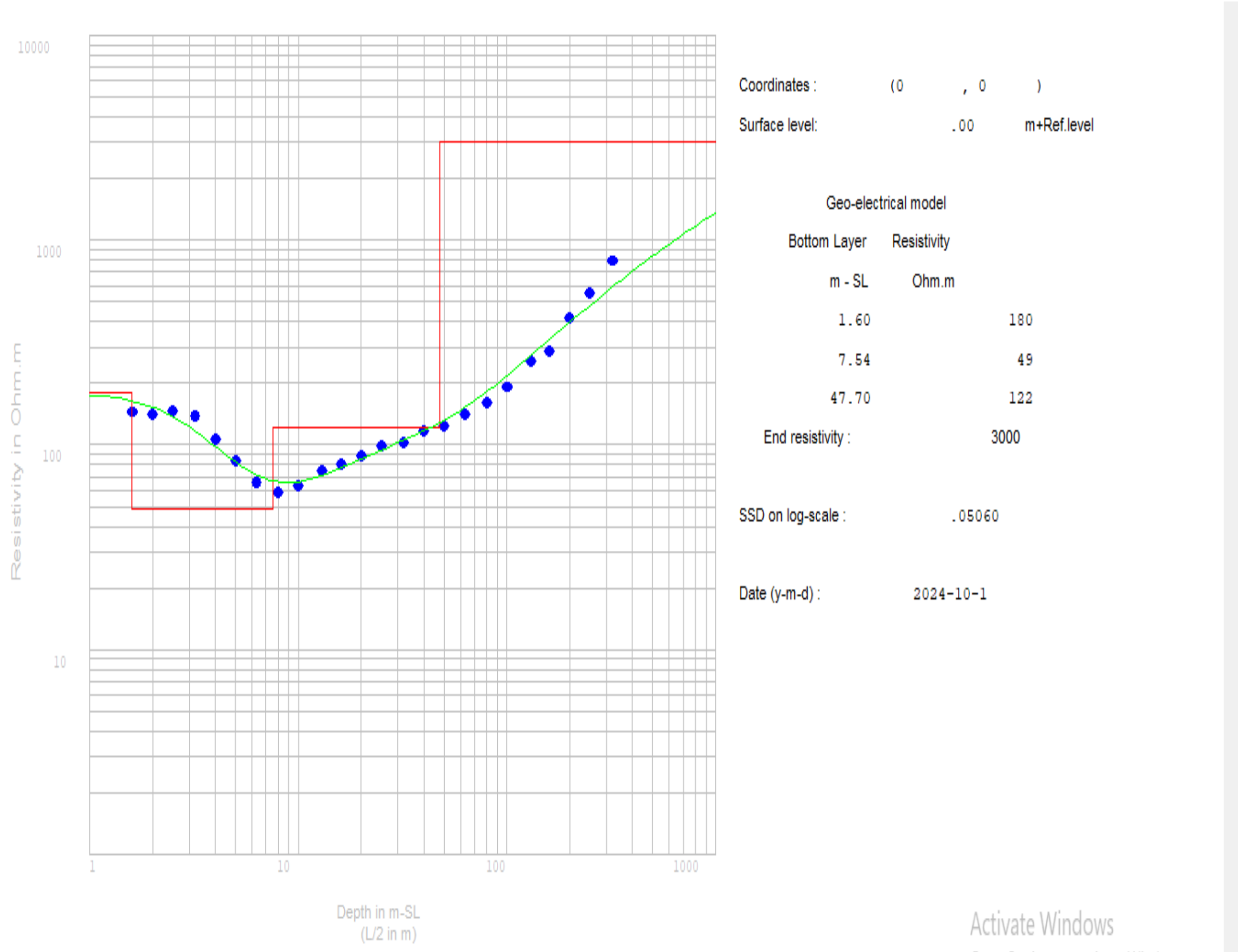


Figure 10:VES 2 INTERPRETATION CURVE

VES 3

Meas. #	L/2 in m	R in Ohm.m	don't use	Meas. #	L/2 in m	R in Ohm.m
1	1.60	13.38		21	160.00	300.35
2	2.00	9.52		22	200.00	421.34
3	2.50	7.80		23	250.00	559.58
4	3.20	7.57			.00	.00
5	4.00	7.87			.00	.00
6	5.00	8.71			.00	.00
7	6.30	9.85			.00	.00
8	8.00	11.48			.00	.00
9	10.00	14.55			.00	.00
10	13.00	18.82			.00	.00
11	16.00	22.56			.00	.00
12	20.00	25.00			.00	.00
13	25.00	24.63			.00	.00
14	32.00	32.94			.00	.00
15	40.00	42.00			.00	.00
16	50.00	58.06			.00	.00
17	63.00	78.19			.00	.00
18	80.00	107.51			.00	.00
19	100.00	149.60			.00	.00
20	130.00	222.04			.00	.00

Figure 11: VES 3 Raw Data

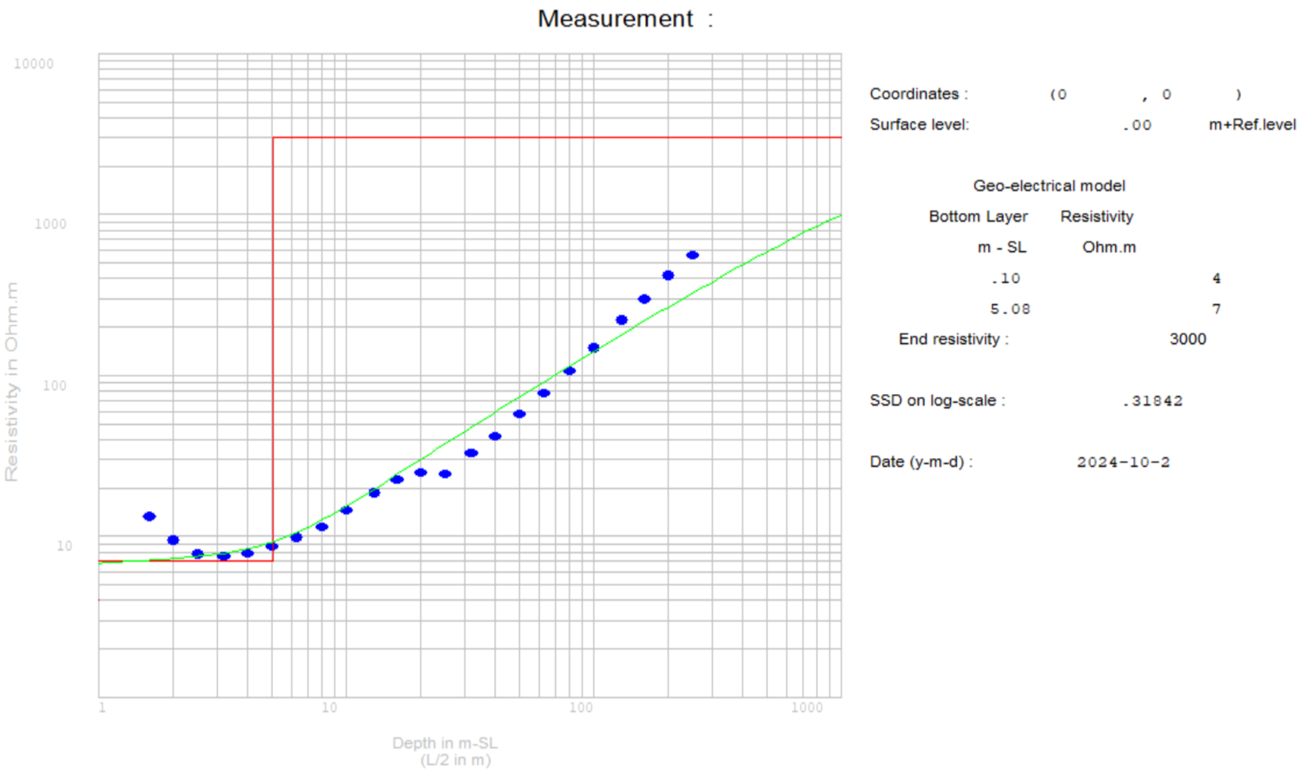


Figure 12: VES 3 INTERPRETATION CURVE

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusion

The hydrogeological site investigations on the project area indicate that the area is located in a hydrogeological zone that is characterized by good groundwater potential as deduced from geophysical modeling, geology and hydrogeological information. The most productive aquifer has been identified to be the weathered/Fractured Old Land Surface of volcanics. A borehole drilled in this area will supply an adequate amount of water to the school to meet the expected demand. The yields are expected to increase with depth.

7.2 Recommendations

In view of the above, it is recommended that: -

- The particulars of the borehole be as shown in the table below:

Site Reference	**Grid Reference**	**Elevation**	**Minimum Recommended Depth**	**Maximum Recommended Depth**
VES 2	$34^0$47’50.59’’E; $00^0$58’10.48’’S	1860m	150m	200m

- The borehole should be drilled with a diameter of 8”, installed with 6" diameter Steel casings and screens with slots of 1 mm and high % open surface area.

- The borehole must be installed with a water meter and an airline/piezometer to monitor groundwater abstraction and facilitate regular measurements of the static water level in the borehole.

- Upon drilling completion, a 2-litre water sample from the borehole should be collected for reference to the WRA Testing Laboratory, or any other competent Water Testing Authority for a full physical, chemical and bacteriological analysis before the water is put to any use.

- Water recycling and re-use after treatment be practiced

- Continuous water quality monitoring (pH, EC, TDS) during drilling should be done once the first aquifer is struck to ensure proper separation of aquifers with different water qualities.

- The borehole development should be done until the water is sediment free. This process should be supervised by an experienced hydrogeologist.
- Groundwater quality in the area is good for human consumption. However, the fluoride concentration may be above the maximum recommended level of 1.5 ppm by the WHO guide level.

Additional information on drilling and construction of boreholes are given in the appendices.

Other recommendations to be met include;

a) Installation of a Master meter in the borehole to enable periodic monitoring of abstraction rate.
b) Installation of a piezometer (or airline) in the borehole to enable regular measurement of Static water level.
c) Undertaking full physical, chemical and bacteriological analysis of the water obtained before use for any intended purposes.
d) An E.I.A. must be conducted as per the requirements of Environmental Management and Coordination Act-1999, unless the project is exempted from the same provisions.
e) Drilling may be discontinued before the recommended depth if enough yields are realized and on recommendations of the supervising hydrogeologist

REFERENCES

1. **Rofe Kennard and Lapworth (RKL) (1982**)
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6. **DRISCOLL F. G., 1986:** Groundwater and Wells, 2nd Ed. Johnson Division.

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APPENDIX 1

DRILLING TECHNIQUES

Drilling should be carried out with an appropriate tool. A percussion or rotary drilling machine will be suitable, though the latter is considerably faster. Geological rock samples should be collected at 2 metres intervals. Water struck and water rest levels and if possible, estimates of the yield of individual aquifers encountered, should also be noted.

1. Well Design

The design of well should ensure that screens are placed against the optimum aquifer zones. The final design should be made by an experienced hydrogeologist.

2. Casing and Screens

The well should be screened with good quality screens considering the depth of the borehole; it is recommended that stainless steel casing and screens of 6" diameter be used. Slots should be of maximum 2mm in size.

We strongly advice against the use of torch-lit steel casings for screens. In general its use will reduce well efficiency (which leads to lower yields) increase pumping costs through greater draw down, increased maintenance's cost, and eventually reduction of the potential effective life of the well.

3. Gravel pack

The use of gravel pack is recommended within the aquifer zone, because the aquifer could contain sands or silts which are finer than the screen slot size. An 81/2 diameter borehole screened at 6", which should be sufficient. Should the slot size chosen be too large, the well will pump sand, thus damaging the plant and leading to gradual siltation of the well. The grain size of the gravel pack should be an average 2-4mm.

4. Well Construction

Once the design has been agreed, construction can be proceeded. In installing screen and casing, centralizers at 6 metre 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(2m), 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 and thus prevent contamination.

5. 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 addictives from borehole wall. 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 development and cleaning wells.

Wells 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.

6. 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 a hydro geologist.

A well test consists of pumping a well from measured start (SWL) at a known or measured yield and recording the rate and pattern by which the water level within the well changes. Once as dynamic water level (DWL) is reached, rate of inflow to the well equals the rate of pumping.

The duration of the test should be 24 hours with a further 24 hours for a recovery test or less depending on the rate of recovery during which the rate discovery to SWL is recorded. The results of the test will enable a hydro geologist to calculate the test recorded. The results of the test pumping rate, the installation depth and the drawdown for a given discharge rate.

It is nowadays-common practice to carry out a so-called step draw down test, in which the yield during testing increases stepwise. Each step is continued until hydraulic equilibrium is reached after which the yield is increased wit 50 to 100% towards the end of the test a water sample of 2 litres should be collected for chemical analysis.

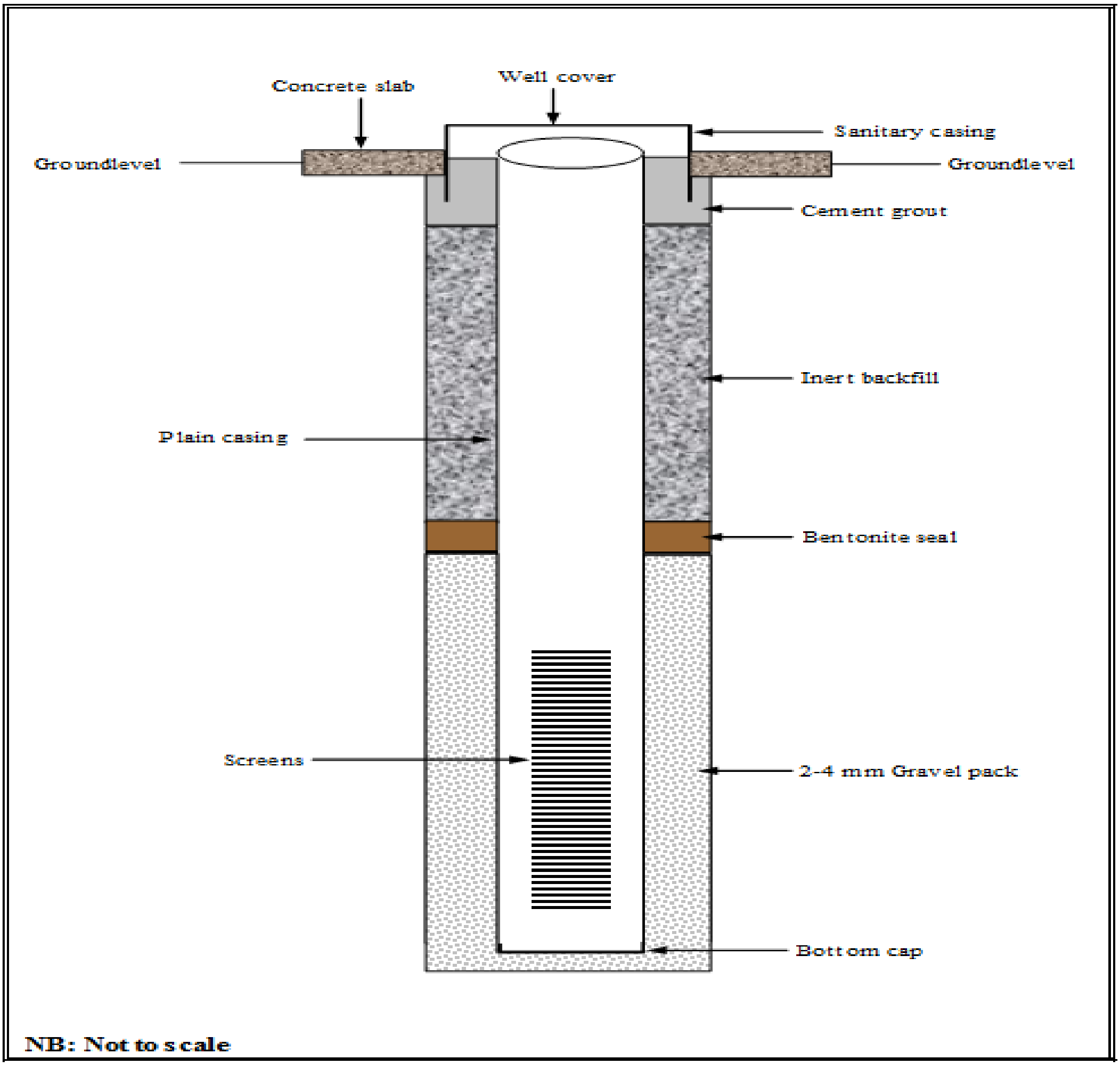


Figure 13: Schematic Design for Borehole Completion

7. Pump Installation

After testing and analysis of the results the pump can be selected and installed. It is important to select the right type of pump, which matches the characteristic of the well. It should have the right capacity to lift the water directly to the storage tank. The pump should never be installed in the slotted section, but at least 2 meters above or below the screened section. The electric submersible pump should be protected with a cut-off switch 2 meters above the pump inlet level.

Appendix 2: Acceptable Ionic Concentrations -Various Authorities

World Health Organization: 1983 Guidelines; 1971 Int. Standards

European Community: EC Directive 1980 relating to the quality of water intended for human consumption:

Substance or Characteristic		Guideline Value (GV	Upper limit (HL),	Guide Level (tentative)	Max. Admissible (GL)	Concentration (MAC)
Inorganic Constituents of health significance;						
Antimony	Sb				0.01	
Arsenic	As	0.05	0.05		0.05	
Cadmium	Cd	0.005	0.01		0.005	
Chromium	Cr	0.05	0.05			
Cyanide	CN	0.10	0.05		0.05	
Fluoride	F	1.5	1.7		1.5	
Lead	Pb	0.05	0.10		0.05	
Mercury	Hg	0.001	0.001		0.001	
Nickel	Ni				0.05	
Nitrates		10 (as N)	45 (as $N0_3$)	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 GL - Guide Level UO - Unobjectionable		IO - Inoffensive			

(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 Institutefor 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 appendixthe 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 (skeletalchanges 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 theTable 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 ofwater 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 materialsare 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 isthe 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:

$$CaSO_42H_2O + 2F^- \text{--->} CaF2 + SO42^- + 2H2O$$

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 concentrationto 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 fluorideis immobilized in the filter medium through the process of ion exchange.

The equipment used in laboratory and field tests is rather simple. The DE fluoridator, unit consists of a container and a filter. The filter has a bottom layer of 300 gr crushed charcoal for adsorption ofcolor 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 orbone 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^{o}C.For both methods it is advised to treat the bone media with sodium hydroxide before it is used.

he 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.

In areas like Nairobi, boreholes are often used as a standby supply in case of no supply (of non- fluoride water) by the Nairobi City Council. Where high fluoride concentrations occur, it is advisableto obtain safe drinking water for children. It should be noted that drinking of water with fluoride concentrations above the WHO limit during short periods is not harmful to adults.

Appendix 4:

VES 1 HERP DATA

183	1	0.259	0.417	2.178	2.713	3.904
183	2	0.24	0.343	2.109	2.471	3.766
183	3	0.297	2.419	3.144	3.817	4.853
183	4	0.419	1.919	2.575	3.766	6.061
183	5	0.205	0.259	2.057	2.557	4.094
183	6	0.222	0.321	0.486	2.126	3.369
183	7	0.24	0.203	0.047	0.005	2.92
183	8	0.317	0.569	3.196	2.368	3.231
183	9	0.398	0.576	2.074	2.627	3.593
183	10	0.407	0.588	2.005	2.592	3.731

VES 2 HERP DATA

L	N	freq01	freq02	freq03	freq04	freq05
184	1	0.362	1.729	2.609	3.334	4.784
184	2	0.336	0.466	3.489	3.093	4.352
184	3	0.352	0.488	2.178	2.834	4.076
184	4	0.385	0.488	2.281	3.058	4.37
184	5	0.423	0.597	1.781	2.385	3.593
184	6	0	0.037	0.202	0.234	0.236
184	7	1.712	0.035	2.851	3.403	5.198
184	8	0.31	1.971	2.661	3.489	4.301
184	9	0.372	0.55	2.247	2.644	3.731

APPENDIX 5: SHANKOE GOOGLE MAP

APPENDIX 6: RAW FIELD DATA

FIELD DATA (VES 1 & 2) ON THE SAME SCALE

LITTORAL CONSULTANTS COMPANY LIMITED –P.O BOX 490 -40300 HOMA BAY

365 699775
UTM 9892695

SHANKOE PRI. SCHOOL

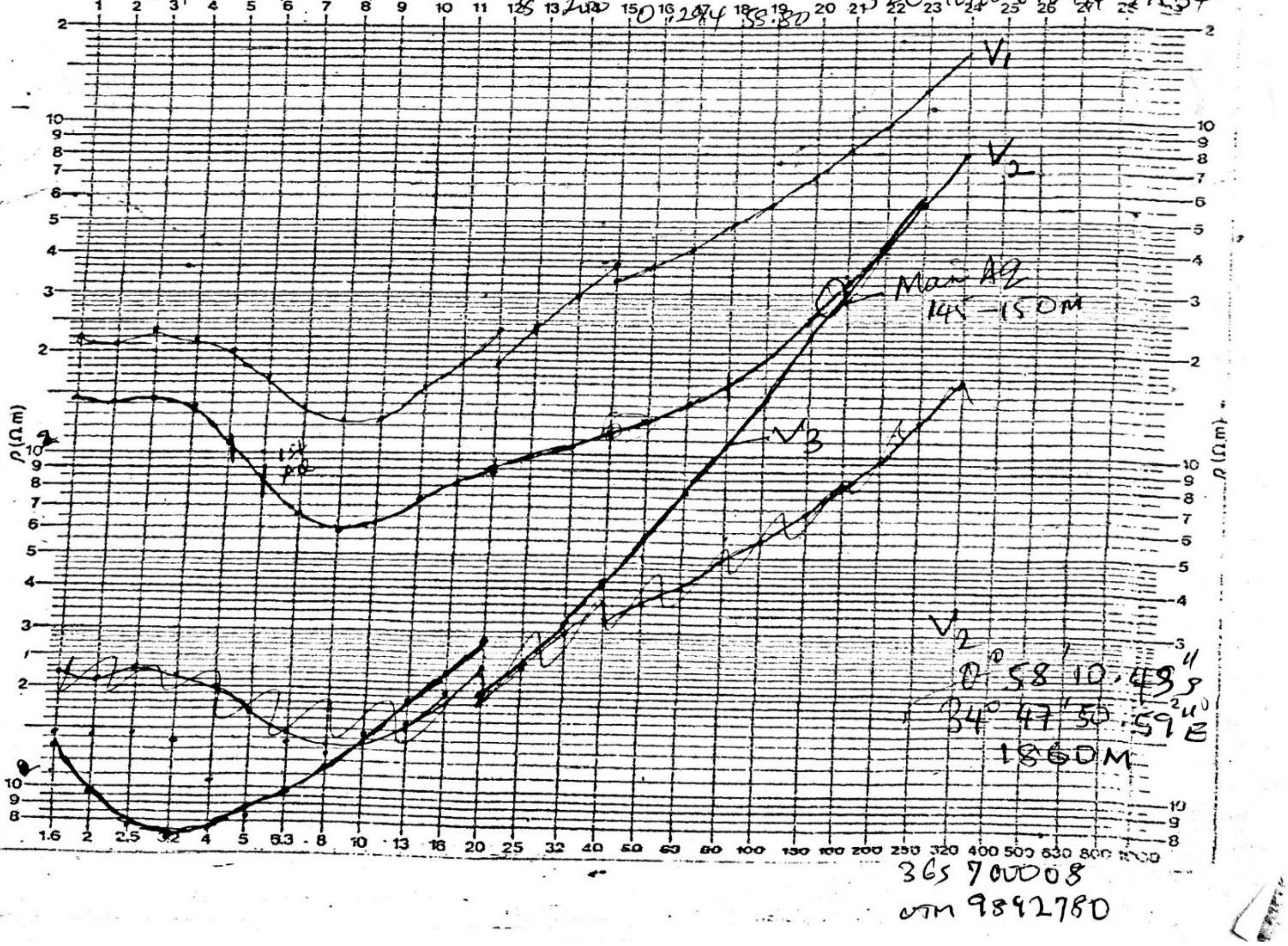
Location: ______ Date: 27/9/2024

Mapsheet: ______ Coord. X: ______ Y: ______ Azimuth: 0°58'13.22"S

VES/Profile Nº: ______ Station interval: ______ m Operator: 34°47'43.04"E

L173 V1 @ 11.5 (Control)

MN/2	AB/2	K	ΔV / I	ρ	MN/2	AB/2	K	ΔV / I	ρ	MN/2	AB/2	K	ΔV / I	ρ	
	1.6	7.26	30.5	221.4		50	377	0.982	370.2		10	313	0.201	62.91	
	[illegible]	11.8	18.12	213.8		63	608	0.665	404.32		13	530	0.141	74.73	5.57
	2.5	18.8	12.24	230.1		80	990	0.498	[illegible]		16	803	0.100	80.30	4.93
	3.2	31.4	6.87	215.7		100	1560	0.361	563.16		20	1260	0.0696	87.70	
	4.0	49.5	4.05	200.5		130	2460	0.261	689.04		20	118	0.767	90.51	3.48
	5.0	77.8	2.14	166.5		160	4010	0.202	810.04		25	188	0.528	99.26	3.48
	6.3	124	1.106	137.1		200	6270	0.1525	956.18		32	314	0.328	102.99	14.33
	8.0	200	0.619	123.8		250	9800	0.1282	1256.2		40	491	0.237	117.32	
	10	313	0.401	125.5		320	16100	0.100	1610		40	236	0.499	117.72	7.63
	13	530	0.298	157.9	L174			V2 @ 10			50	377	0.331	124.79	15.66
	16	803	0.233	187.1		1.6	7.26	20.0	145.2		63	608	0.231	140.45	20.03
	20	1260	0.186	234.4		2	11.8	12.03	141.95		80	990	0.162	160.48	31.87
	20	118	1.544	182.2		2.5	18.8	7.79	146.45		100	1560	0.1233	192.35	64.26
	25	188	1.239	232.9		3.2	31.4	4.45	139.73		130	2460	0.0972	256.61	65.39
	32	314	0.955	299.8		4	49.5	2.15	106.43	(322)	160	4010	0.0713	285.9	93.07
	40	495	0.758	375.21		5	77.5	1.078	83.57		200	6270	0.0662	415.07	140.59
	40	236	1.405	331.5		6.3	124	0.534	66.22		250	9800	0.0567	555.66	
						8	200	0.294	58.80		320	16100	0.0494	795.34	



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UTM 9892780

RAW FIELD DATA OF VES 3

LITTORAL CONSULTANTS COMPANY LIMITED –P.O BOX 490 -40300 HOMA BAY

SHANKOE PRI SCHOOL
Location:
Mapsheet: Coord. X: Y: Date: 27/9/2024
VES/Profile Nº: Station interval: m Azimuth: 0°58'8.09"S
L17S V3 @ 8 Operator: 34°47'52.83"E
1867M

MN/2	AB/2	K	ΔV / I	ρ	MN/2	AB/2	K	ΔV / I	ρ	MN/2	AB/2	K	ΔV / I
	1.6	7.26	1.843	13.38		63	608	0.1286	78.19				
	2	11.8	0.807	9.52		80	990	0.1089	107.81				
	2.5	18.8	0.415	7.80		100	1560	0.0959	149.60				
	3.2	31.4	0.241	7.57		130	2640	0.0841	222.02				
	4	49.5	0.159	7.87		160	4010	0.0749	300.35				
	5	77.8	0.112	8.71		200	6270	0.0672	421.34				
	6.3	124	0.0794	9.85		250	9800	0.0571	559.58				
	8	200	0.0574	11.48									
	10	313	0.0465	14.55									
	13	530	0.0355	18.82									
	16	803	0.0281	22.56									
	20	1260	0.0225	28.35									
a	20	118	0.163	19.33									
	25	188	0.131	24.63									
	32	314	0.1049	32.94									
	40	493	0.0859	42.52									
	40	236	0.175	41.30									
	50	377	0.154	58.06