REPUBLIC OF KENYA

MINISTRY OF AGRICULTURE, LIVESTOCK AND FISHERIES
STATE DEPARTMENT OF AGRICULTURE
DROUGHT RESILIENCE AND SUSTAINABLE LIVELIHOODS PROGRAMME (DRSLP)



HYDROGEOLOGICAL SURVEY REPORT

FOR

PORO COMMUNITY

APRIL , 2020

CLIENT:
Principal Secretary,
Ministry of Agriculture, Livestock and Fisheries
P.O. BOX 30028-00100
NAIROBI.

INVESTIGATING HYDROGEOLOGISTS

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EXECUTIVE SUMMARY

Introduction

The Drought Resilience and Sustainable Livelihoods Programme in the Horn of Africa **(DRSLP)** - Kenya Project will cover six arid and semi-arid counties namely Baringo, Isiolo, Marsabit, Samburu, Turkana and West Pokot. The project consists of three components: (i) Natural Resources Management, (ii) Improvement of Livestock Infrastructure and Management and (iii) Project Management and Capacity Building. The project is being implemented by the Ministry of Agriculture, Livestock and Fisheries **(MoALF).** The overall goal of the programme is to contribute to poverty reduction, food security and accelerated sustainable economic growth in the Horn of Africa (HOA) through enhanced rural incomes.

DRSLP through **MoALF** requested for technical support from the Ministry of Water and Sanitation and Irrigation **(MoW&S&I)** to carry out groundwater resources, geophysical and hydrogeological study of **5No** proposed boreholes to serve various targeted communities in **Samburu County** to confirm their suitability for the intended boreholes. This report describes the results of borehole geophysical/hydrogeological investigations carried out for the proposed borehole supply for **Poro Community in Samburu County.** The proposed borehole water source will be used domestic and livestock watering purposes by the community. The water demand is estimated at **70m^3 per day** for domestic use. Livestock demand is about **160m^3/day.** The total demand cannot be met by the borehole. Other sources will supplement the borehole supply.

Objective of Survey

The main objective of the survey/study was to assess the availability of groundwater, recommend a borehole drilling site and comment on aspects of depth to potential aquifers, aquifer availability and type, possible yields and water quality.

Geology

The regional geology of the area comprises of Precambrian Mozambiquian complex overlain by Cenozoic volcanics**.** The volcanic pile is related to the formation of the Great Rift Valley and features volcanic complexes ranging in age from Miocene to Recent lava flows and pyroclastics.

Hydrogeology

Aquifers in this locality are comprised of alluvial sediments on/adjacent to river channels and flood plains at shallow depths, and the relatively deeper weathered and/or fractured zones within the Basement rocks. Aquifer recharge is deduced to occur through regional replenishment and to a limited extend by direct infiltration of precipitation

Water Quality

Water quality is expected to be fairly good for domestic use, but may be slightly mineralized due to nature of underlying rock (Basement System), aridity and high evapo-transpiration rates. It is mandatory to carry out water quality analysis before the supply is put to domestic use.

Geophysics

Geophysical fieldwork was carried out in March, 2022. Both **electrical resistivity** and **EM** methods were employed for the geophysical investigations. **EM** approach was used to rapidly detect weak zones up to **500m** bgl. Vertical Electrical Sounding **(VES)** was used to determine the vertical lithological changes with respect of electrical resistivity to a maximum depth of **320m** bgl. One **EM** profile and one **VES** was carried out in the survey area.

Conclusion

- The study concludes that on the basis of geophysical, geological and hydrogeological evidence, the prospects for sufficient groundwater for domestic and livestock watering purposes are good. The most productive aquifer has been identified to be fractured Basements
- Aquifer recharge occurs directly through fractured and faulted volcanic pile surrounding the area. The aquifer recharge is deduced to be several orders larger than the imposed abstraction, thereby ensuring a reliable long-term water supply.
- Groundwater quality is presumed to be good. Quality analysis should be carried out to qualify the water for domestic use.

Recommendations

- The recommended borehole point **VES-1** is defined by coordinates: **1° 14.327'N, 36° 36.252'E** on topographical sheet **78/3.** It lies at an elevation of **2410m** amsl. The surveyed point is pegged and known to the **Desk Officer DRLSP** Programme, Samburu, **Mr Kinyoi; Tel: 0722482401.**
- It is recommended that the borehole be drilled to a maximum of **300m.** It is difficult to estimate the yield in the absence of nearby borehole data but from overall assessment of yields in Basements terrain the yield is estimate at **4m³/hr**.
- Drilling should first be carried out using a 10" diameter drill-bit to a depth of **10 m** bgl and then continued to the final depth of **300m** bgl with an 8" diameter drill-bit.
- The top **10m** should be sealed off with bentonite and cement grout to prevent surface water from contaminating the groundwater.
- The borehole should be installed with 6" diameter Steel casings and screens with slots of 1mm
- and are recommended.
- As much water as possible should be abstracted from the proposed borehole but should not exceed 60% of the tested yield.
- A well protection box must be constructed at the well head.

Monitoring

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

Drilling Permits

Before drilling commences, the necessary authorizations must be obtained from the Water Resources Authority (WRA).

Borehole Construction

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

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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 (mS/cm)
h	head
hr	hour
K	hydraulic conductivity (m/day)
l	litre
m	metre
N	North
PWL	pumped water level
Q	discharge
sQ/s	specific capacity (discharge – drawdown ratio; in m. cu/hr/m)
Cu	cubic
Sq	square
S	drawdown (m)
S	South
Sec	second
SWL	static water level
T	transmissivity (m.sq/day)
VES	Vertical Electrical Sounding
W	West
WSL	water struck level
mS/cm	micro-Siemens per centimetre: Unit for electrical conductivity
^{o}C	degrees Celsius: Unit for temperature
Wm	Ohm-m: Unit for apparent resistivity
ρ_a	Apparent resistivity
CWP	Community Water Project

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 process, with or without water as an agent. Usually of mixed texture.

Conductivity: Transmissivity per unit length (m/day)

Confined aquifer: A formation in which the groundwater is isolated from the atmosphere by impermeable geologic formations. Confined water is generally at greater 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.

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 lowest head.

Heterogeneous: Not uniform in structure or composition.

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

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

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

Perched aquifer: Unconfined groundwater separated from an underlying main aquifer by an unsaturated zone. Downward percolation hindered by an impermeable layer.

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: The capacity of a porous medium for transmitting fluid.

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

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

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

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

Saprolite: Weathered residual rock in place.

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

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

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

Yield: Volume of water discharged from a well.

1. INTRODUCTION

1.1 Background

The Client requires detailed information on prospects of drilling a production borehole. The borehole is to be used to supply water for domestic and livestock use. A geophysical/hydrogeological survey was subsequently carried out to assess the availability of groundwater, to recommend a borehole drilling site and comment on aspects of depth to potential aquifers, aquifer availability and type, possible yields and water quality. The investigations involved hydrogeological, geophysical field investigations and a detailed desk study in which the available relevant geological and hydrogeological data were collected, analyzed, collated and evaluated within the context of the Client's requirements. The data sources consulted were mainly in four categories:

- Published Master Plans.
- Geological and Hydrogeological Reports and Maps.
- Ministry of Water and Irrigation Borehole Completion records.
- Any Available Technical reports of the area by individual Registered consultants or organizations.

1.2 Reporting Requirements

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

1. Name and details of applicant
2. Location and description of proposed Activity
3. Details of climate
4. Details of geology and hydrogeology
5. Details of neighbouring boreholes, including location, distance from proposed borehole or boreholes, number and construction details, age, current status and use, current abstraction and use.
6. 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:
    a. Aquifer transmissivity
    b. Borehole specific capacities
    c. Storage coefficient and or specific yield
    d. Hydraulic conductivity
    e. Groundwater flux
    f. Estimated mean annual recharge, and sensitivity to external factors
7. Assessment of water quality and potential infringement of National standards
8. Assessment of availability of groundwater
9. Analysis of the reserve
10. 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
11. Recommendations for borehole development, to include but not limited to, the following:
    a. Locations of recommended borehole(s) expressed as a coordinate(s) and indicated on a sketch map
    b. Recommendations regarding borehole or well density and minimum spacing in the project area
    c. Recommended depth and maximum diameter
    d. Recommended construction characteristics, e.g. wire-wound screen, grouting depth
    e. Anticipated yield
12. Any other relevant information (e.g. need to monitor neighbouring boreholes during tests).

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.

2. BACKGROUND INFORMATION

2.1 Details of Applicant

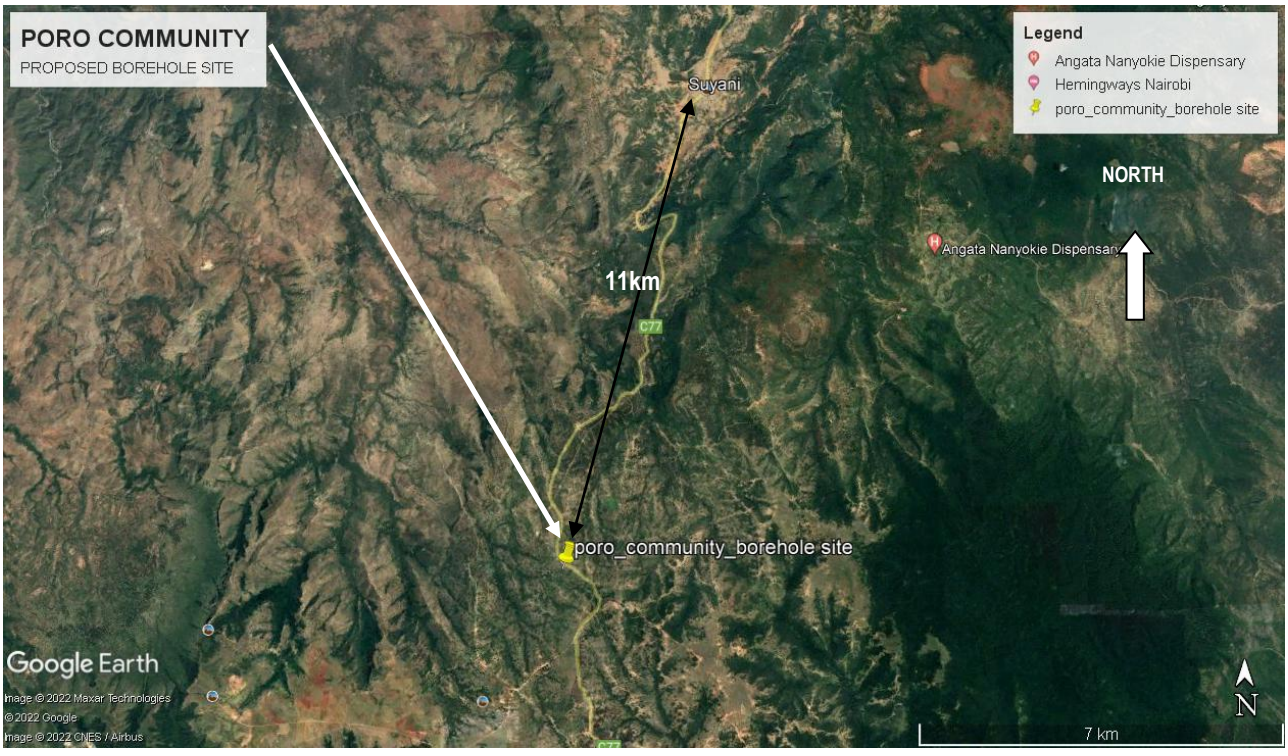
The **Drought Resilience and Sustainable Livelihoods Programme *(DRSLP)*– Samburu County** commissioned the hydrogeologists from the Ministry of Water and Sanitation & Irrigation to carry out a hydrogeological and geophysical survey for the proposed borehole for Poro Community in Samburu North Sub-County in Samburu County. The contact details of the Client are:- ***Ministry of Agriculture, Livestock and Fisheries, (DRSLP), P.O. BOX 30028-00100, NAIROBI.*** The Contact Person for **DRSLP** is the **Project Coordinator**, based at Hill Plaza, **P.O Box 30028-00100, Nairobi,**

2.2 Location

The investigated site is situated about **11km** south of Suiyan shopping centre and about **24km** north of Maralal. The site requires an access road of about **50m** for ease of access by a drilling rig. It is located on coordinates defined by: **2° 14.327'N, 36° 36.252'E** and lies at an elevation of **2410 m** a.m.s.l. on topographic sheet **No 78/3.** Administratively, the site is located in Lp*orokwai village, Malaso Sub-Location, Poro Location, Malaso Division, Samburu Central Sub-County, Samburu County.*

A Googlemap© map extract showing the location of the site is shown on **Figure1.**

***Figure 1** : Location of the Project Area.*



2.3 Proposed Activity

The activity to be undertaken is mainly to drill, construct and equip a borehole to abstract groundwater.

2.4 Water Demand

The investigated area is not covered by the local water services provider and faces an acute shortage of portable water for both domestic use and livestock watering. Available water sources are unsanitary and pose a health risk to both the local community. Water supply comprises scoop holes in **Leseepei seasonal river 2km away** Poro dam about **4km** away. Water demand is reckoned from the table below:-

Demand unit	Number	Remarks
Human population	1,400	Total demand is approx. **70m^3/day**
Shoats	3,000	Livestock demand is about **160m^3/day**
Cattle	2,000	
Donkeys	100	

Water demand for domestic use by the local populace is estimated at **70m^3/day**. Livestock watering demand exceeds the anticipated borehole yield hence the borehole can only supplement other sources for livestock watering.

As much water as possible should be abstracted from the borehole, but the pumped amount should not exceed 60% of tested yield.

2.5 Physiography, Drainage

The relief of the county has a north-south oriented ridges on the flanks of the Rift Valley running from Mount Nyiro Ndoto (2752 m.) through Baragoi, Maralal (2531 m.) and Suguta and another ridge on the east running from Aguru, Mathews Range and Wamba (2688 m.).The ridges form the major drainage divide. The project area lies about 2410m amsl.

The drainage of the study area is dominated by Suguta-Baragoi-Nanganyamonyen river system . The drainage is sub-ordinate to Suguta River. The study area is drained by Leseepei seasonal river.

2.6 Climate and Vegetation

The climate of Samburu County is semi-arid with temperature, rainfall and evaporation strongly influenced by altitude. Two distinct climatic zones are can be distinguished. The semi-arid type over the lowlands and highland sub-tropical on the highlands.

Samburu County falls within arid to semi arid region with annual mean annual rainfall of 200mm to 250mm on low lying areas. The relatively higher altitude of Maralal town raises the mean annual rainfall to 700 mm to 1000 mm which occurs in two rainy seasons and in 49 rainy days. The long rains occur in March to May while the short rains occur from October to December. The rainfall distribution shows spatio-temporal variation with altitude and may be up to about 1500mm per annum. The lowest rainfall is observed in the eastern part of Maralal Town while the highest rainfall occurs at elevated areas such as Lpartuk Forest and in the forested highland area.

The mean temperatures range from 25^{o}C during the coldest month (June-July) and 35^{0}C during the hottest months of January to March. Mean annual temperatures are 30^{0} to 34^{0} C. High temperatures also raise evapo-transpiration rates to range from 1800 mm to 3000 mm per annum. Over the hills, evapo-transpiration rate of 1800mm per annum has been recorded.

All ground below 1500m amsl supports a poor thorn scrub , mainly species of acacia with succulents and larger trees only along water courses. Above 1500m and with increasing rainfall, patches of indigenous forest still remain. These are interspersed with rolling grassy plains, which have resulted from forest clearing though some may have been original. In forested areas, soil cover is thick, however in the lower areas, soil is thin or absent due to poor vegetation cover due to aridity and overgrazing. Soil erosion on the lower areas has been accelerated by this state of affairs. The project area lies about 1100m amsl and is largely covered by indigenous thorn scrub and a host of other flora.

3. GEOLOGY

The geology of the area is described in **" Geology of the Maralal area", Report No. 105,** published by the Ministry of Environment and Natural Resources; Mines and Geological Department in **1986.** The area covered by the geological mapping is bounded by latitudes **1^{0}** and **2^{0} N** and longitudes **36^{0}** and **37^{0} E** covering an area of approximately **12,182 sq. km.** In the following sections, the geology of the project area is discussed both in regional and local context

3.1 Regional Geology

The undulating topography dotted with several sinusoidal hills reflect the general geology of Samburu County. The area stands at an average altitude of 2051m a.s.l. within a steep-dipping terrain punctuated with several hills and flood plains both on the south eastern and north western flanks. The County lies on the eastern shoulder of the Rift Valley and can be subdivided into two major geological divisions. The eastern side covered mainly by the Mozambiquan rocks interspersed with occasional igneous outliers which occupies roughly two thirds of the county. The western side constituting one-third of the county, on the other hand, is covered by basic lava of Paleogene-Neogene volcanics of the Rift Valley.

The lithology may be classified into four major groups, namely, metamorphic rocks of the Neo-Proterozoic Mozambique Belt, igneous intrusives, Paleogene-Neogene volcanics and Quaternary volcanic and sediments. The sediment deposits were altered by tectonothermal events to form gneisses, schists, quartzites and marbles with large areas underlain by migmatites. These events were followed by successive stages of uplift and erosion, lasting until the Paleogene when lavas flooded Mozambiquan rocks, producing basalts in the early stages and phonolites and trachytes in later stages. Recent deposits which consist of alluvium and colluvium, calcareous and lacustrine sediments, agglomeratic ash and residual soils have formed from weathering of the Mozambiquan rocks and the Paleogene volcanics with subsequent deposition on the lower regions and river valleys.

The igneous rocks are mainly granodiorites and granites but also include relatively small outcrops of pegmatites, quartz reefs, aplites and diorites. Only the major outcrops consists of foliated granitoids which often form inselbergs and hills, and granodiorites outcrop east of the Mathews Range. Locally, underneath the volcanics, subvolcanic deposits of probably Lower Miocene age consisting of well rounded pebbles are fluvial erosion products of the Mozambiquan rocks.

In the west, on the Rift Valley shoulder, the lower layers are more basaltic while the upper ones more phonolitic and trachytic. Volcanicity began in the area with the extrusion of an extensive series of basaltic pyroclasts and lavas, the Samburu basalts, followed by plateau phonolite and tuffs. Late Miocene to recent basalts and trachytes erupted over the western and northern extremities of the eastern shoulder. In the east, volcanicity began in the middle Miocene with the deposition of plateau phonolites and basalts [4]. The Mozambiquan rocks and volcanic species have surface joints and fractures, alluding to intense forces of fracturing, faulting, minor

cracking, pneumatolysis and plate tectonics in the Precambrian orogeny and the Quaternary vulcanicity episodes.

The Quaternary sediments include alluvial infill and overspill to most water courses, calcareous deposits, Kunkar limestone, lacustrine deposits, agglomeratic ash, residual soil and colluvium passing laterally into talus at the bases of major hills. Sinuous and braided shallow channels related to sporadic flow after the last heavy rains are marked by medium grained sands with gravel bars which top the alluvium.

Soils in the study area are mainly erosion products of parent rocks which are either of volcanic or metamorphic origin. The volcanic rocks include basalts, phonolites and trachyte. The metarmorphic rocks are those of the Basement System comprising of various gneisses, migmatites and quatzites. The extend of soil development is influenced by vegetation cover and altitude with thick humus-rich topsoil occurring over deeply weathered rock common at higher altitudes with forest cover. Residual soils are rarely more than 2m thick and are mostly red-brown sandy loams with local variations related to underlying bed-rock and are found on the project area. Geology of the area is shown on **Figure 2.**

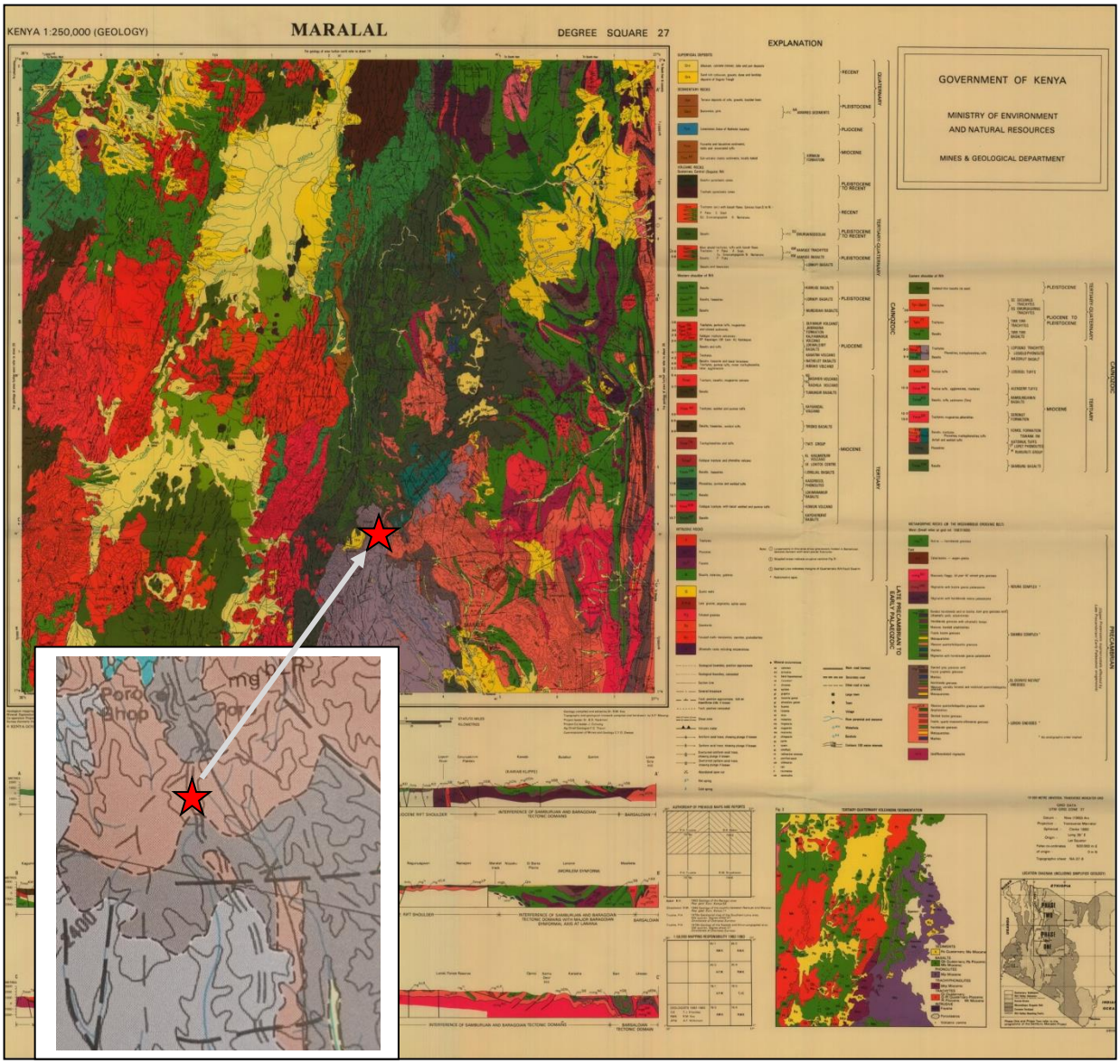


Fig 2. Geology of the area (Inset shows detail)

3.2 Structural Geology

The Basement System of rocks on which the proposed project lies, have been affected by tectono-thermal events. These involved mainly the following events:-

(i) E-W warping and fracturing
(ii) NNW-SSE shearing, fracturing and faulting
(iii) NW-SW shearing fracturing and faulting

The project area is situated on th+e eastern side of the Rift Valley hence its structural evolution is intimately related to its formation. On regional scale the structure of Samburu country is controlled by a complex fault pattern with numerous faults of different magnitudes and orientation. Shear zones oriented approximately NW-SE occur mainly on the western side and the south-eastern parts of the. Faultlines, fracture zones and shear zones are important in formation and storage of groundwater. The study area is located on an intensely folded and faulted area east-west tectonic transport. South Horr valley is an anticline.

3.3 Geology of the investigated Area

The rocks exposed in the study area are classified under Loroki gneisses and comprise mainly of well banded, commonly garnetiferous, biotite gneisses with Marbles & Calc-Silicate gneisses, Garnet-Silimanite gneisses, meta-quarzites, graphite gneisses, Quartz-Feldpar gneisses, Biotite gneisses, hornblende gneisses and amphibolites.

4. HYDROGEOLOGY

The geology of Samburu consists of two major units: the basement System and the Tertiary Volcanics. Groundwater is found in both units and in the shallow alluvial sediments on top of these units. The Basement System has localized aquifer system, which means that groundwater is found in significant quantities only in small areas within the unit. The tertiary Volcanics form regional aquifer system, which means that groundwater may be found in significant quantities over large areas within the unit. Borehole siting is therefore much more critical in the basement rocks than in the volcanics.

The characteristics of zones regarding the availability of groundwater are:

(a) Medium to high groundwater availability (Alluvial Sediments)
(b) Medium groundwater availability (Tertiary volcanics of Leroghi and Merti plateau)
(c) Low to medium groundwater availability (Basement System)
(d) Low groundwater availability (Tertiary volcanics between Leroghi plateau and Lake Turkana)
(e) Very low groundwater potential (Mountain ranges, inselbergs and basalt caps

The Mozambiquan rocks and the young volcanics are fairly fractured and hold groundwater in fractures, faults, as well as the contact zones between the volcanics and the metamorphic rocks or in the weathered zones. However, fractures and faults are of limited extent and therefore groundwater quantities are low. The groundwater in the upper sediments receives an annual rainfall recharge through direct infiltration while the deep-seated zones may be recharged via regional flow aided by the faulted channels. In order to attain the maximum yield for optimum recharge of the groundwater, boreholes are sited near rivers or laggas where the yield is on average **1.4-2.5 m^3 /hr**

Tertiary (Paleogene-Neogene) volcanics occur generally over large relatively continuous areas and have relatively high infiltration capacity and hydraulically interconnected fissures. Lineaments within the volcanics are more easily discerned on the basaltic rocks, while the ones on the phonolites are covered by red and loamy

soils formed from weathered rocks. The recharge potential in this terrain is generally good with boreholes yielding on average **4 m^3 /hr**.

4.1 Hydrogeology of the Investigated Area

Groundwater resources in the project area occur near major rivers where the adjoining aquifer-in the form of fractured Basement or alluvial flats-are recharged from the river. Here shallow water may occur near the rivers where water struck levels may be as shallow as 2m.

4.1.1 Specific Capacity

This is a crude indication of the efficiency of the borehole as an engineered structure, and is calculated by dividing the discharge rate (as m^3/day) by the total drawdown. High specific capacities generally indicate high transmissivities; the converse being true. Rock types remarkably influence aquifer characteristics. Kenya is simplified to consist of three major rock types: basement rocks, volcanic rocks and sedimentary rocks. In The Study of the National Water Master Plan, aquifer characteristics have been determined by rock type and the now defunct province. The investigated area lies on Basement hydrogeological environment whose aquifer characteristics are summarized in the table below.

Borehole data in the investigated area is not sufficient to calculate specific capacity. The estimates below are extracted from the National Groundwater Master Plan.

Table 1:- Borehole specific capacities

Rock type/County	Average Depth (m)	WSL	WRL (m)	Yield (m^3/hr)	Drawdown (m)	Specific Capacity (m^2/day)
Basement/ Samburu	96.8	64.1	30.9	4.2	33.2	3.03614

Source: The Study of the National Groundwater Master Plan-1992 (pp CT-63)

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4.1.2 Transmissivities

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 developed a relationship between specific capacity and transmissivity based on a reworking of Thiem's steady-state groundwater flow equation.

4.1.3 Calculations

To determine the expected T (transmissivity) and K (hydraulic conductivity), test-pumping data from a nearby boreholes is used.

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 Jacobs formula (Driscoll 1986):

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

Table-2: Transmissivities of Nearby Boreholes

	Specific Capacity (m^2/day)	Transmissivity (1.22Q/ Δs)	Remarks
Basement rock type boreholes	3.03614	3.704096	This value is indicative of sustainable aquifer recharge

Aquifer thicknesses are not given in the Ministry of Water database. Hydraulic conductivity therefore, cannot be calculated without making assumptions that make the derived value of little technical value.

4.1.4 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 neighbouring 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 5×10^{-5} to 5×10^{-3} (Todd et al 2005).A "rule of thumb" estimate of the storage coefficient (Lohman 1972 cited in Todd et al 2005) can be made from $S = 3 \times 10^{-6} \times D$, where D is aquifer thickness. Aquifer thicknesses are not known in this area hence storage coefficient may not be objectively derived.

4.1.5 Annual Recharge Estimation

Due to the complexity of the geology of the area and lack of adequate borehole drilling data, it is difficult to estimate the recharge in the project area. But the recharge regime for groundwater is deduced to be sustainable with the available precipitation on the highland areas.

4.1.6 Ground Water Movement

Ground water in this region is supplied by a number of aquifers either in fluviatile or paleosol (OLS) deposits intercalated in most formations or between the principal lava flows. In addition faults, fissures and joints all may carry water to the discharge areas.

4.1.7 Safe Yield

The apparent transmissivity of the aquifer system is indicative of sustainable aquifer regime based on **National Ground Water Master Plan data.** It is assumed that at the expected pumping of the borehole, both the drawdown and the gradient of the cone of depression will be small. Thus, even when no recharge of the aquifer from the precipitation takes place, the proposed amount of water can be abstracted without changing the groundwater level dramatically. During dry periods, the natural lateral groundwater flow into the aquifer is estimated still to be higher than the proposed groundwater abstraction.

4.1.8 Groundwater Quality

Water quality is expected to be good for domestic use.

The water quality guideline values for water are those published by WHO. In the case of rural and community water supply, the WHO guideline values have to be often considered as long-term. Taking into account the local geographical, socio-economic , dietary and industrial conditions in the country , the following water quality parameters should be used to measure and assess the quality of water intended for water supply:

(1) Bacteriological aspects
(2) Chemical and physical aspects:-

- Turbidity
- Colour
- Taste &odour
- Electrical conductivity
- Fluoride
- Iron

The basic requirements of drinking water should be:-

1. Free from pathogens
2. Containing no compounds with an adverse acute or long term effect on human health.
3. Fairly clear (low turbidity or little colour)
4. Non-corrosive and non-staining.

The bacteriological quality of water is absolutely essential and should be tested before the selection of any source and during the operation of the supply. Table 4 below details the bacteriological guideline values for drinking water:-

Table:3 :- Bacteriological Guideline values for drinking water

Colliform Count (No. per 100ml)	Remarks
0-50	Disinfection only
50-5000	Full treatment
5000-50000	Heavily polluted, requires extensive treatment
>50000	Extreme pollution requiring special treatment; unacceptable source unless no alternative exists.

(Source:- Groundwater Master Plan-1992; Design Manual for Water Supply in Kenya-1986)

When more than 40% of the coliforms are found to be of faecal group, then the water source should be considered to fall under the next higher category with respect to the treatment required.

4.1.9 Borehole Data

No drilling records for boreholes in the area are available. It was thus not possible to carry out correlative studies. Conclusions arrived at were based on ground geophysics hydrological and hydrogeological site evaluation.

5. GEOPHYSICS

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.

5.1.1 Basic Principles

Geophysical techniques in soil-water research form an important component of Water Resources Development and Management. It is the logical and compulsory approach not only to explore and assess the available resource in the light of its withdrawal, but also to ensure social acceptance of its different components e.g. Economic, environmental, legal, political etc. for a given area such as river basin, catchment, watershed, dry land and so on.

Geophysical techniques work on the basic concept of determining and understanding the physical contrasts in the soil-water systems. These contrasts are expressed as measurable physico-chemical parameters such as electrical resistivity or conductivity, dielectric constant, propagation velocity, attenuation coefficient, isotope content etc. of the subsurface configuration. Information on the general geology and hydrogeology conditions are essential to arrive at meaningful conclusions from the geophysical data at a given location.

Geophysical techniques are used to obtain more accurate information about sub-surface conditions such as type and depth of materials, depth of weathered or fractured zone, depth to groundwater, depth to bedrock, and salt component of groundwater.

In order to map out geological subsurface conditions, a variety of methods are used. In the present survey galvanic Resistivity method is used, and includes vertical electric sounding (VES) to establish vertical sub-surface resistivity layering and horizontal electric profiling (HEP) to detect lateral charges in electrical conductivity.

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 in the sub-surface present low resistivities.

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 fundamental 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:

$$\nabla \times \mathbf{i} = 0$$

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) $V_r = \rho I/2\Pi r$ **(Volts)**

In hydro-geological 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) $\rho = K \times \Delta V/I_{AB}$ (Ω-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.

5.1.2 Data Interpretation

The interpretation of resistivity data is done in two stages:-

1. Processing of data to get physical parameters in terms of resistivities and depths.
2. Using these parameters to infer the nature of sub-surface formations on the basis of geological knowledge and correlative studies.

Data obtained is normally subjected to modeling analysis using a digital computer. Correlation with data from existing boreholes complements the modeling analysis to come up with the most realistic conclusion.

5.2 Magnetotelluric Current method

The magnetotelluric (MT) method is a passive surface geophysical technique that uses the earth's natural electromagnetic fields to investigate the resistivity structure of the subsurface. The resistivity of geologic units is largely dependent upon their fluid content, porosity, fracturing, temperature, and conductive mineral content (Keller and Frischknecht, 1966). Saline fluids within the pore spaces and fracture openings can reduce resistivities in a resistive rock matrix. Also, resistivity can be lowered by the presence of conductive clay minerals, graphitic carbon, and metallic mineralization. It is common for altered volcanic rocks to contain authigenic minerals that have resistivities ten times lower than those of the surrounding unaltered rocks (Nelson and Anderson, 1992). Increased temperatures cause higher ionic mobility and mineral activation energy, reducing rock resistivities significantly.

Unaltered, unfractured igneous rocks are normally very resistive (typically thousands to tens of thousands of ohm-m), whereas fault zones will show low resistivity (less than 100 ohm-m) when rocks in the zones are fractured enough to have hosted fluid flow and consequent mineralogical alteration. Carbonate rocks are moderately to highly resistive (hundreds to thousands of ohm-m) dependent upon their fluid content, porosity, fracturing, and impurities. Marine shales, mudstones, and clay-rich alluvium are normally very conductive (a few ohm-m to tens of ohm-m). Metamorphic rocks(non-graphitic) are moderately to highly resistive (hundreds to thousands of ohm-m). Tables of electrical resistivity for a variety of rocks, minerals and geological environments may be found in Keller (1987) and Palacky (1987).

The MT method allows us to probe the crust from depths of tens of meters to depths of tens of kilometers (Vozoff, 1991). The Earth's natural electromagnetic fields that are measured include the magnetic and electric field due to world-wide lightning activity at frequencies of 10,000 Hz to 1 Hz and geomagnetic micro-pulsations at frequencies of 1 Hz to 0.0001 Hz. The natural electric and magnetic fields propagate vertically in the earth because the very large resistivity contrast between the air and the earth causes a vertical refraction of both fields transmitted into the earth (Vozoff, 1972). The method can determine resistivity variations at different depths because the different frequency fields propagate to different depths (Vozoff, 1972).

The **PQWT** instrument is an automated data-acquisition and processing system, in which the natural electric and magnetic fields are recorded in two orthogonal, horizontal directions (the vertical magnetic field is sometimes recorded as well). The recorded time-series signals are used to derive earth tensor apparent resistivities and phases. This is achieved by first converting them to complex cross-spectra using FFT (fast-Fourier-transform) techniques. Least-squares, cross-spectral analysis (Bendat and Piersol, 1971) is used to solve for a tensor-transfer function that relates the observed electric fields to the magnetic fields under the assumption that the Earth consists of a two-input, two-output, linear system with the magnetic fields as input and the electric fields as output (Rodriguez and others, 1996). Prior to their conversion to apparent resistivity and phase, the tensor is normally rotated into principal directions that usually correspond to the direction of maximum and minimum apparent resistivity.

For a two-dimensional (2-D) Earth, the MT fields can be de-coupled into transverse electric (TE) and transverse magnetic (TM) modes; 2-D modeling is generally done to fit both modes. When the geology satisfies the 2-D assumption, the MT data for the TE mode is assumed to represent the situation when the electric field is along the geologic strike, and the data for the TM mode is assumed to represent the situation when the electric field is across strike. The MT method is well suited for studying complicated geological environments because the electric and magnetic relations are sensitive to vertical and horizontal variations in resistivity. The method is capable of establishing whether the electromagnetic fields are responding to subsurface rock bodies of effectively 1-, 2-, or 3-dimensions (Appendix). An excellent introduction to the MT method and references for a more advanced understanding are contained in Dobrin and Savit (1988) and Vozoff (1991).

The propagation and magnitude of the **EM-field** is subject to **Maxwell's equations**, especially relating the AC impendance to frequency, magnetic and electric field components:

(1) $\rho_s = E_x/5fH$ where;

ρ_s: AC impendance
f: Frequency
H: Magnetic field component
E_x: Electric filed component

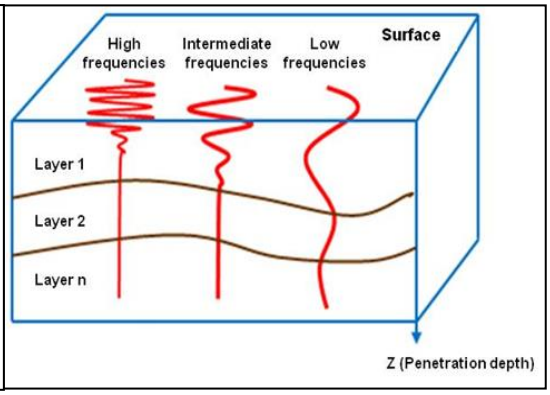
When the EM field interacts with ground medium, the depth of penetration depends upon the attenuation caused by the skin effect given by:

(2) $\delta = 503.3\rho F$

Following from (2) above, lower frequencies mean higher penetration and the vice versa.

Fig 3 Relationship between depth of penetration and frequency

***NB**: EM wave is heavily damped (attenuated) whereas lower frequency achieves higher penetration. Notably, higher penetration is achieved at the expense of resolution.*



The basic **PQWT** instrument measures the electric field component on the earth's surface by means of a pair of electrodes. This field is as a result of a sheet of direct current flowing through conductive layers of rocks. Two conditions apply here:

(i) The total current through the geological formation is conserved hence the current density is inversely proportional to the thickness of the conductive formation

(ii) The electric field measured at the surface will be proportional to the resistivity of the conductive geological formation and inversely proportional to its thickness.

The MT equipment takes measurements in multi-frequency mode depending upon the depth of penetration. The values recorded are in (millivolts)**mV** and need to be calibrated through electric sounding technique. The instrument is invaluable in picking out the anomalous zones.

Fig 4 PQWT EM- instrument used in this survey

The instrument measures the vertical component of electric field generated by telluric currents



The approach used in the field was that, the EM equipment was utilized for rapid and deep profiling to pick anomalies which were subsequently confirmed by means of vertical resistivity sounding.

6. FIELDWORK AND RESULTS

6.1 Fieldwork

Fieldwork was carried out in **March 2022,** using both MT-equipment **(PQWT S-500)** and deep probe resistivity meter **model No. SSR-MP-AT.** One **20m** profile and one Vertical Electric Sounding were carried out with **AB/2** varied from **1.6m to 320m**. This way, subsurface anomalies picked by the MT instrument were subjected to vertical electric sounding whence distinct changes in resistivity with depth were recorded and subjected to modeling analysis with a digital computer using **IPI2Win (Lite)** hydrogeology software.

The results of analysis are summarized below:-

Fig 5 EM profile

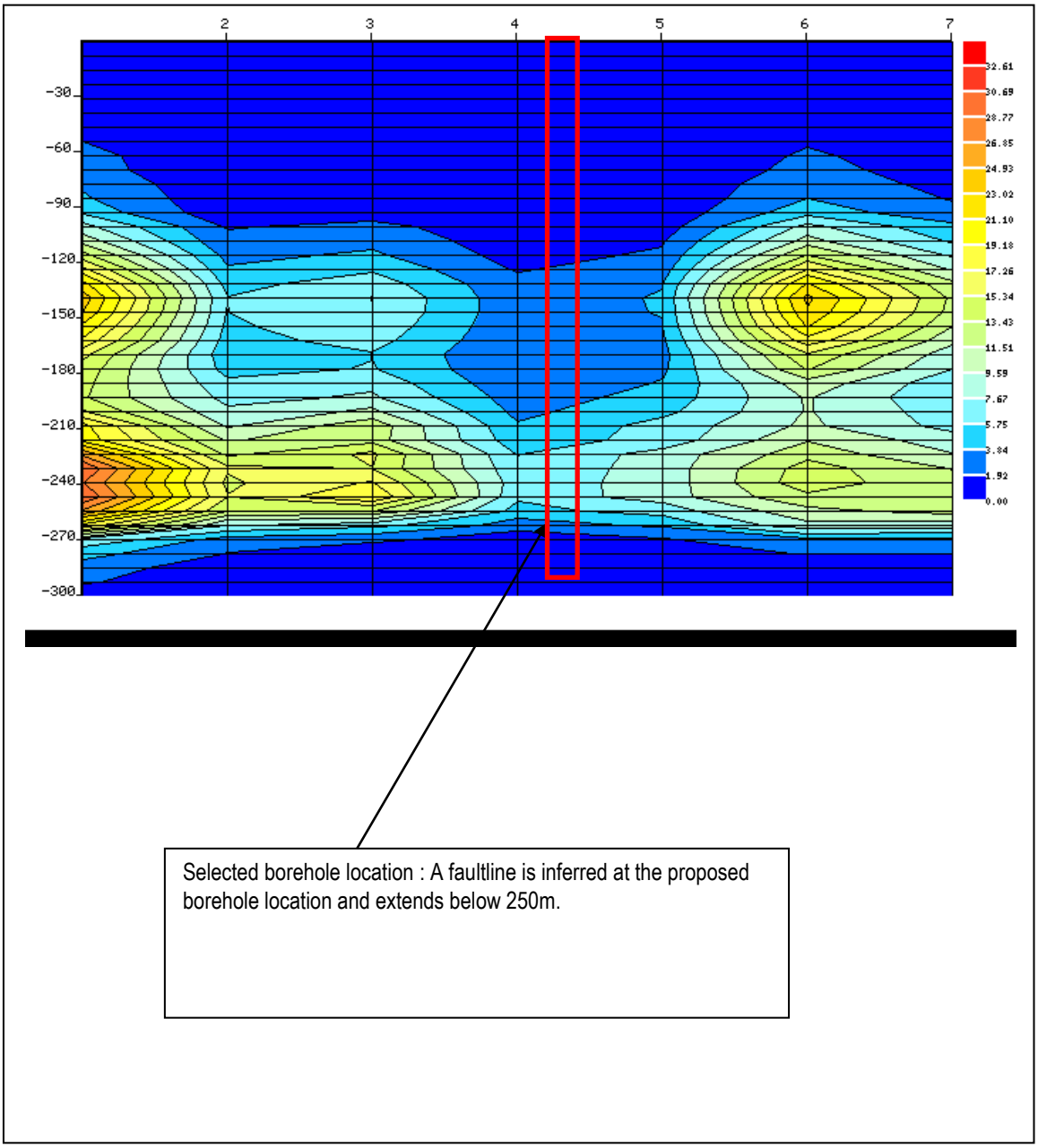
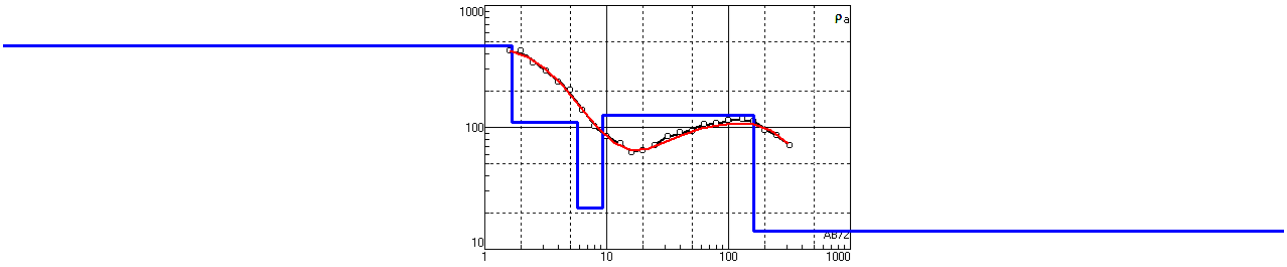


Fig 6:

VES-1:- Geo-Electric Model



N	ρ	h	d	Alt
1	467	1.68	1.68	-1.678
2	110	4.03	5.71	-5.712
3	21.6	3.6	9.32	-9.316
4	126	152	162	-161.7
5	14.1			

Table 4: Interpretation of Results for the Survey

Approx. Depth (m)	Approx. True Resistivity (ohm-m)	Geological inference	Prospects
1.7	467	Top sandy soils	Poor
5.6	110	Weathered gneiss	Poor
9.3	22	Highly weathered gneisses	Good
162	126	Weathered gneisses	Moderate
>162	14.1	Fractured gneiss(along a fault-line	Good
			********** **end

R.M.S. Error=3.93%

6.2 Results

Main aquifer comprises of fractured and/or weathered gneiss formation. Aquifers are recharged from facture/fault system connected to higher volcanic covered recharge zones.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

- The study concludes that on the basis of geological and hydrogeological evidence, the prospects for sufficient groundwater for domestic and livestock watering purposes are good. The most productive aquifer has been identified to be fractured Basements.
- It is deduced that aquifers in the study area are adequately and sustainably replenished ensuring a reliable long-term water supply.
- Groundwater quality in the area is fairly good for human consumption. Due to arid nature, low precipitation, high evapo-transpiration rates in the area, groundwater may be slightly mineralized. Water quality analysis must be carried out (and remedial measures to improve quality implemented) before the water is put to domestic use.

7.2 Recommendations

In view of the above it is recommended that:

- An borehole be drilled as summarized on the table hereunder:-

Grid Reference of point to be drilled VES-1	Diameter (mm)	Elevation (m) (amsl)	Minimum Recommended Depth (m)	Maximum Recommended Depth (m)	Amount to be abstracted (m^3/day)
2° 14.327'N, 36° 36.252'E	203.2 (8'')	2410	280	300	80

- The borehole must be installed with a Water Meter and an Airline/piezometer to monitor groundwater abstraction and to 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.
- A copy of the analysis report must be sent to the WRA – Regional Office for record.
- A drilling permit has to be acquired from WRA.
- A well protection box must be constructed at the well head.

In Appendix 1, additional recommendations on the construction and completion of a borehole are given.

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Appendix 1: Drilling

Drilling Technique

Drilling should be carried out with an appropriate tool preferably a rotary drilling machine. Air drilling with mud capacity is recommended. The driller should be prepared to use tempoaray casings to manage collapsing formation.

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 and recorded.

Well Design

The design of the well should ensure that screens are placed against the optimum aquifer zones. An experienced hydrogeologist should make the final design.

Casing and Screens

The well should be cased and screened with good quality material. Owing to the depth of the borehole, it is recommended to use steel casings and screens of high open surface area.

We strongly advise against the use of torch-cut steel well casing as screen. In general, its use will reduce well efficiency (which leads to lower yield), increase pumping costs through greater drawdown, increase maintenance costs, and eventually reduction of the potential effective life of the well.

Gravel Pack

The use of a gravelpack is recommended within the aquifer zone, because the aquifer could contain sands or silts which are finer than the screen slot size. An 8" diameter borehole screened at 6" will leave an annular space of approximately 1", which should be sufficient. Should the slot size chosen be too large, the well will pump sand, thus damaging the pumping plant, and leading to gradual `siltation' of the well. The slot size should be in the order of 1.5 mm. The grain size of the gravel pack should be an average 2 - 4 mm.

Well Construction

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

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

Well Development

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

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

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

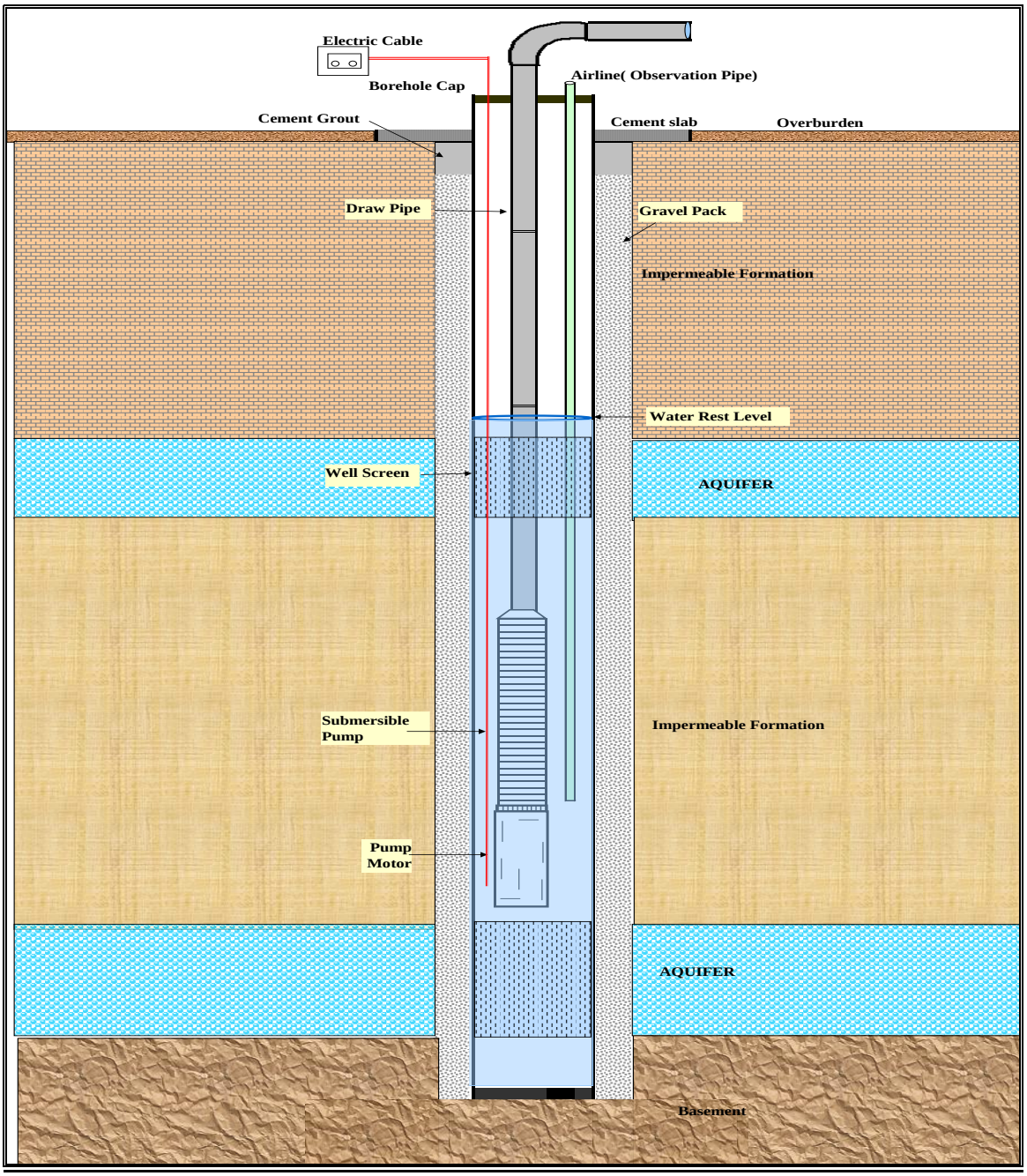
Well Testing

After development and preliminary tests, a long-duration well test should be carried out. Well tests have to be carried out on all newly completed wells, because apart from giving an indication of the quality of drilling, design and development, it also yields information on aquifer parameters, which are vital to the hydrogeologist.

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

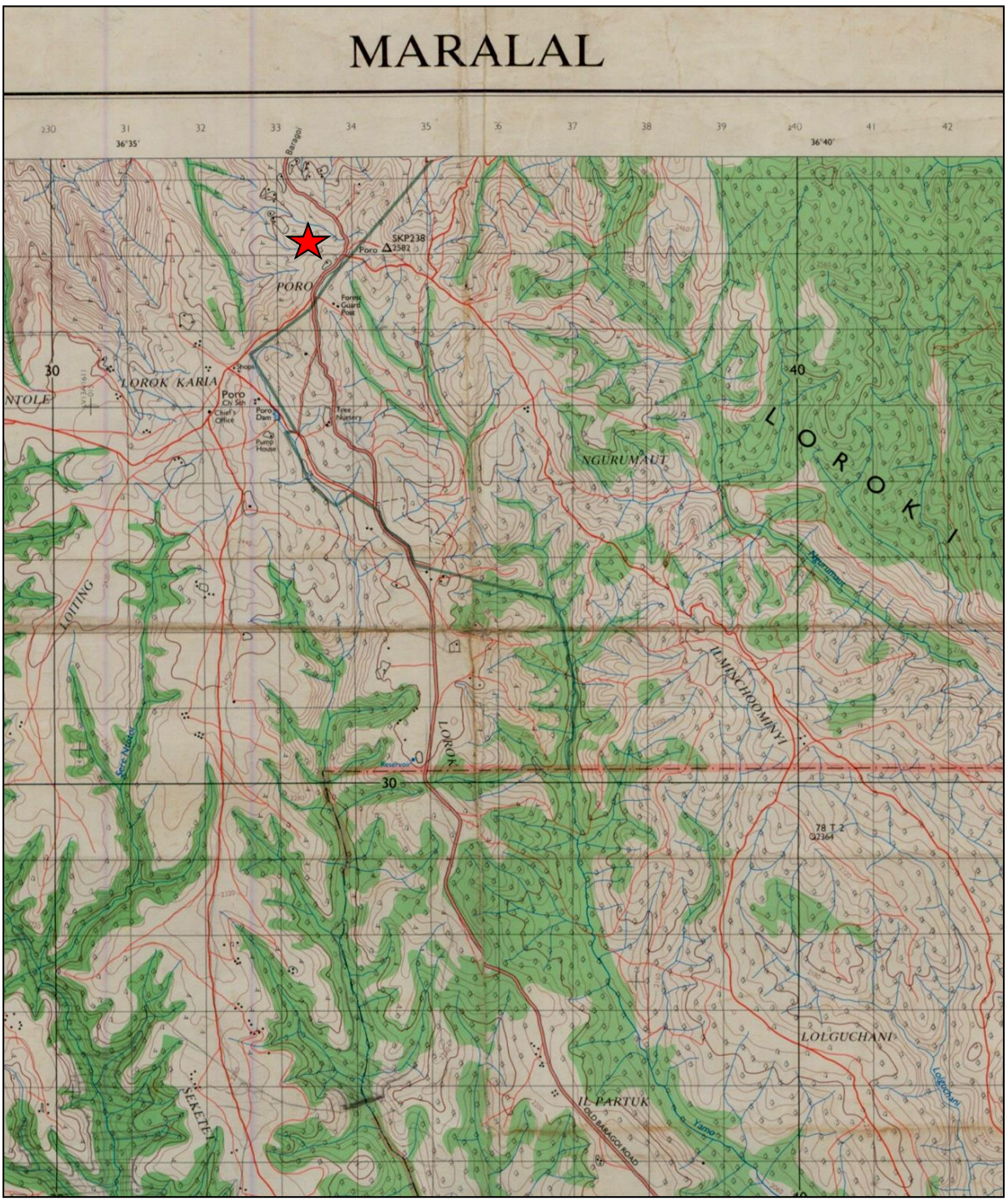
The duration of the test should be 24 hours, followed by a recovery test for a further 24 hours, or alternatively until the initial WRL has been reached (during which the rate of recovery to WRL is recorded). The results of the test will enable a hydrogeologist to calculate the optimum pumping rate,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

Schematic Design for Borehole Completion



Appendix-2

Topographical Map Extract (Topo-Sheet No. 78/3) Showing the Approximate Location of the propose borehole .



Key:

★ Proposed Borehole

Appendix-3: Field data

AB/2	MN	Resistivity (ohm-m)
1.6	2	460
2	2	460
2.5	2	368
3.2	2	319
4	2	255
5	2	220
6.3	2	150
8	2	112
10	2	91.2
13	2	80.8
16	2	67.9
20	2	69.9
20	3	64.2
25	3	70.9
32	3	84.7
40	3	90.6
40	4	97.6
50	4	99.4
63	4	115
80	4	116
100	4	122
100	5	197
130	5	204
160	5	194
200	5	165
250	5	150
320	5	123