REPUBLIC OF KENYA

MINISTRY OF WATER & SANITATION AND IRRIGATION

HYDROGEOLOGICAL SURVEY REPORT

SAWAITI COMMUNITY

LOCATION:-

ARARAE VILLAGE, SAIWATI SUB-LOCATION, KAPKECHUI LOCATION, MOGOTIO SUB-COUNTY
BARINGO COUNTY

SURVEYED & PREPARED BY:-

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WITH

DRSLP PROJECT TEAM
For
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STATE DEPARTMENT OF AGRICULTURE
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EXECUTIVE SUMMARY

Introduction
This survey was supported by the Ministry of Agriculture, Livestock and Fisheries under Drought Resilience and Sustainable Livelihoods Programme (DRSLP) funded by the African Development Bank.

This report describes the results of borehole site investigations carried out for Sawiti community water supply in Ararae area in Mogotio Sub-County. The proposed borehole point is defined by coordinates: 36M 831280E, 6864N on topographical sheet 104/4. It lies at an elevation of 1514M asl. The proposed borehole water source will be used for both domestic and livestock watering purposes. The water demand is estimated at 50m³ per day.

Geology
The regional geology is comprises mainly of Tertiary volcanics (intimately related to the formation of the Great Rift Valley) overlying Precambrian Basement rocks. The Tertiary volcanics are overlain by sub-ordinate recent sediments. The local geology of the investigated site comprises Pleistocene undifferentiated sediments and alluvium, basalts and trachyphonolites.

Hydrogeology
Aquifers are expected within the inter-volcanic old land surfaces and at the base of the volcanic rocks overlying weathered and/or fractured zones within the Basement rocks. Aquifer recharge is deduced to occur through regional replenishment and direct infiltration of precipitation through porous sections of the volcanics and faults.

Water Quality
The quality of water is expected to be good for domestic use except for fluoride levels which may occasionally exceed the WHO guideline values in aquifers located in volcanic rock suites. This will be established once water quality analysis is carried out.

Geophysics
Geophysical fieldwork was carried out October, 2019. Electrical resistivity method was employed for the geophysical investigations. Vertical Electrical Sounding (VES) was used to determine the vertical lithological changes with respect of electrical resistivity. One VES was carried out in the survey area.

Conclusion
- The study concludes that on the basis of geological and hydrogeological evidence, the prospects for sufficient groundwater for livestock watering and domestic purposes are good. The most productive aquifer has been identified to be intervolcanic erosional/depositional surfaces and paleosols at the Basement volcanics interface.
- The aquifers in the study area are deduced to be adequately replenished through subsurface recharge channels comprising of pervious zones, faults and fractures in the catchment areas. The aquifer recharge is deduced to be several orders larger than the imposed abstraction, thereby ensuring a reliable long-term water supply.
- Groundwater quality in the area is good for human consumption. However the fluoride concentration may exceed the maximum recommended level of 1.5 ppm by the WHO guide level. Water quality analysis is mandatory before the water is put consumed domestically.
**Recommendations for Drilling**

- The hydrogeological conditions are presumed to be uniform all over the area. Drilling to a minimum depth of 280 mbgl and Maximum depth of 300 mbgl would give the applicant yields in the order of about 8m³/hr of water or even higher.
- 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 280 mbgl with an 8” diameter drill-bit.
- The top 10 m should be sealed off with bentonite and cement grout to prevent surface water from contaminating the groundwater.
- The surveyed point is well marked, known to **Area Chief Mr. Peter Titomet: 0720-179161** and members of the community.
- The borehole should be installed with 6” diameter Steel casings and screens with slots of 1mm and are recommended.

**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, a drilling permit has to 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.
# TABLE OF CONTENTS

EXECUTIVE SUMMARY ........................................................................................................ 1
LIST OF FIGURES .................................................................................................................... IV
LIST OF TABLES ....................................................................................................................... IV
ABBREVIATIONS (ALL SI UNITS UNLESS INDICATED OTHERWISE) .................................. V
GLOSSARY OF TERMS ............................................................................................................. VI

1. INTRODUCTION ................................................................................................................... 1
   1.1 BACKGROUND ................................................................................................................. 1
   1.2 REPORTING REQUIREMENTS .......................................................................................... 1

2. BACKGROUND INFORMATION ........................................................................................... 3
   2.1 DETAILS OF APPLICANT ............................................................................................... 3
   2.2 LOCATION ...................................................................................................................... 3
   2.3 PROPOSED ACTIVITY .................................................................................................... 3
   2.4 WATER DEMAND ........................................................................................................... 3
   2.5 PHYSIOGRAPHY, DRAINAGE ........................................................................................ 4
   2.6 CLIMATE AND VEGETATION ....................................................................................... 4

3. GEOLOGY .................................................................................................................................. 4
   3.1 REGIONAL GEOLOGY ..................................................................................................... 5
   3.2 STRUCTURAL GEOLOGY ................................................................................................. 5
   3.3 GEOLOGY OF THE INVESTIGATED AREA ...................................................................... 5

4. HYDROGEOLOGY ................................................................................................................. 7
   4.1 HYDROGEOLOGY OF THE INVESTIGATED AREA ............................................................ 7
      4.1.1 Specific Capacity ........................................................................................................ 7
      4.1.2 Transmissivities ......................................................................................................... 8
      4.1.3 Calculations ............................................................................................................... 8
      4.1.4 The Storage Coefficient ........................................................................................... 9
      4.1.5 Annual Recharge Estimation .................................................................................... 9
      4.1.6 Ground Water Movement ....................................................................................... 9
      4.1.7 Safe Yield .................................................................................................................. 9
      4.1.8 Groundwater Quality .............................................................................................. 9
      4.1.9 Borehole Data .......................................................................................................... 10

5. GEOPHYSICS ....................................................................................................................... 12
   5.1 RESISTIVITY METHOD ................................................................................................. 12
      5.1.1 Basic Principles ........................................................................................................ 12
      5.1.2 Data Interpretation ................................................................................................... 13

6. FIELDWORK AND RESULTS ............................................................................................ 14
   6.1 FIELDWORK ................................................................................................................. 14
   6.2 RESULTS ....................................................................................................................... 14
   6.3 RESULTS ....................................................................................................................... 15

7. CONCLUSIONS AND RECOMMENDATIONS .................................................................... 17
   7.1 CONCLUSIONS .............................................................................................................. 17
   7.2 RECOMMENDATIONS .................................................................................................... 17

REFERENCES .......................................................................................................................... 18
APPENDICES ............................................................................................................................ 19
List of Figures

Figure 2.1: Map Showing the Location of the Project Area .......................................................... 3
Figure 3.1: Geological Map of the Area .................................................................................. 6
Figure 6.1: Photo showing site location within the plot .............................................................. 16

List of Tables

Table 1: Borehole specific capacities .......................................................................................... 8
Table 2: Transmissivities of Nearby Boreholes ......................................................................... 8
Table 3: Bacteriological Guideline values for drinking water ..................................................... 10
Table 4: Listing of Boreholes Close to the Investigated Site ..................................................... 10
Table 6: Interpretation of Results for the Survey .................................................................... 15
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)
I  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
°C  degrees Celsius: Unit for temperature
Wm  Ohm-m: Unit for apparent resistivity
ρa  Apparent resistivity
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 Management 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

This report describes the results of geophysical/hydrogeological investigations carried out at the proposed borehole site for SAWAITI COMMUNITY WATER PROJECT of P.O. Box 115-20105, MOGOTIO.

2.2 Location

The investigated site lies some 10 km off Nakuru-Mogotio-Kabarnet Road North-East of Mogotio town. The UTM coordinates of the investigated point are 831280E, 6864N at an elevation of 1514M amsl (taken with a GPS) on topographical Sheet No 104/4 (1:50,000). Administratively, the site is located in Ararae Village, Mukuyuni Sub-Location, Kapkechui Location, Mogotio Sub-county, Baringo County.

![Map Showing the Location of the Project Area](image)

**Figure 2.1:** Map Showing the 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. The water will be used for domestic and livestock watering.

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 and livestock.
SAWAITI COMMUNITY WATER PROJECT is intended to serve a population of 2500 people, 2000 head of cattle and 4500 shoats. The only available source of water is Rongai river which is seasonal. Additionally the water is utilized raw and untreated posing health hazards to the community. A borehole to supply about 50m$^3$ per day will suffice.

It is against this background that a hydrogeological survey was carried out to explore the possibility of sinking a borehole.

2.5 Physiography, Drainage

The area can be divided into the following physical units: (1) the eastern edge of the Uasin Gishu Plateau in the west, followed eastwards by (2) the Kerio Valley, (3) the Kamasian Hills and (4) the floor of the Rift valley proper. The high ground of the south-west is a continuation of both the Uasin Gishu Plateau and the Kamasian Hills, around the head of Kerio Valley.

The investigated area is found within the Rift valley drainage area. The principal perennial rivers are Molo, Perkerra and Kerio. The immediate area is drained by Rongai river, a tributary of Molo river which is sub-ordinate to Perkerra River draining into Lake Baringo.

2.6 Climate and Vegetation

Rainfall is dependent on altitude varying between 600mm on lower altitudes eg. Marigat, to slightly over 1600mm on higher areas. Rainfall is heaviest between March and September, with peaks in April and August, the former month usually having a slightly higher average than the latter. Of the other months, December is the wettest. Like rainfall temperatures are largely controlled by altitude, the highest parts of the area in the west being cooler. The Kerio Valley and the Rift floor in the east, particularly the low ground to the north-east are hot by day and generally warm at night.

All the ground below 1600m O.D. supports poor thorn scrub, mainly acacia species. Along major river courses, more luxuriant vegetation abound. Above 1600m O.D. with increasing rainfall, patches of indigenous forest still remain interspersed with rolling grassy plains some resulting from forest clearing to give way to agrarian parcels and grazing land.

3. GEOLOGY
The area geology is described in "The Geology of the Eldama-Ravine Kabarnet Area" by J. Walsh. (1969). The report describes an area bounded by the equator and 0030°N and meridians 35°30’ and 36°00’E. It is located within Baringo County in the Rift Valley.

3.1 Regional Geology

The regional geology of the area is dominated by Tertiary volcanics consisting of tuffs and lavas overlying Basement System rocks at greater depths. The Volcanics are in turn overlain by Quaternary sediments. Tectonism of the rift valley generated basins and highlands. The basins became sediment troughs for fluviolacustrine sediments besides forming lakes. The volcanics were emplaced in episodes separated by tuffs and sediments.

Metamorphosed sediments of the Basement System (Precambrian) outcrop in the north-west of the area; elsewhere, they are buried under great thicknesses of Tertiary and Quaternary lavas, ranging from basalts (Miocene?) to Pleistocene phonolites. Several tuff and sediment groups are intercalated in the lavas. Recent sediments occur in the north-east of the area, representing sediments of an earlier extension of lakes Baringo and Hannington.

3.2 Structural Geology

Structurally the area belongs to the Rift faulting zone. The most striking structural feature is a multitude of north-south oriented fault system. These fault lines have a huge influence on the groundwater recharge regime.

3.3 Geology of the investigated Area

The local geology of the investigated site comprises Pleistocene undifferentiated sediments and alluvium, basalts and trachyphonolites.
Figure 3.1: Geological Map of the Area
4. HYDROGEOLOGY

Regionally ground water in the investigated site occurs in three hydrogeological environments:

1. Alluvial aquifers in flood plains of major river courses
2. Old land surfaces, between volcanic flow episodes and pre-volcanic land surface (unconformity).

On a regional scale, the investigated point lies on environment (2). The aquiferous formation comprises of ash, lava fragments, and Basement xenoliths. In the volcanics, considerable groundwater amounts may be encountered. Groundwater recharge is deduced to occur regionally by percolation into porous sections of the volcanic masses. The Great Rift Valley terrain is characterised by faults. Direct infiltration of precipitation into the weathered substratum or regional recharge through fracture/fault zones is deduced to be the major form of recharge. Alluvial aquifers are recharged directly from their channels.

4.1 Hydrogeology of the Investigated Area

On a local scale, the investigated area lies in a zone of low-medium groundwater potential. Groundwater occurs in weathered and/or fractured zones in volcanic rocks, interbedded sediments between volcanic flows and in alluvial and torrent wash deposits. Due to considerable variability of geology, structure, physiography and climate, a complex hydrogeological regime has resulted. Lower plain areas are dominated by sediments with low potential and high salinities. Boreholes located on alluvial flats have both better yields and quality. Areas with volcanic rocks and faults have better potential due to expected high permeabilities.

Aquifer recharge is expected to be mainly by regional replenishment under hydraulic gradient from higher grounds such as Rift Valley escarpments and the highland areas around Kabarnet to the west.

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 volcanic hydrogeological environment whose aquifer characteristics are summarized in the table below.

The specific capacity of the surveyed borehole is expected to be high and to decrease gradually at increasing abstraction rates.

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

<table>
<thead>
<tr>
<th>Rock type/Count y</th>
<th>Average Depth</th>
<th>WSL</th>
<th>WRL</th>
<th>Yield (m$^3$/hr)</th>
<th>Drawdown</th>
<th>Specific Capacity (m$^2$/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volcanics</td>
<td>125</td>
<td>94</td>
<td>49</td>
<td>7.5</td>
<td>37</td>
<td>4.8</td>
</tr>
</tbody>
</table>

Source: The Study of the National Groundwater Master Plan-1992

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

<table>
<thead>
<tr>
<th>Specific Capacity (m$^2$/day)</th>
<th>Transmissivity (1.22Q/Δs)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volcanic rock type boreholes</td>
<td>4.8</td>
<td>5.856</td>
</tr>
</tbody>
</table>

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 complete 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 $5 \times 10^{-5}$ to $5 \times 10^{-3}$ (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. Nevertheless, an estimate can be made as follows. Considering a catchment area of 1000 km$^2$, a mean annual rainfall of 1000 mm and an infiltration rate of 10%, the amount of water being recharged into the groundwater storage is estimated to be 100mm per year. Even when assuming a major groundwater abstraction in the region, the recharge into the groundwater storage is more than enough to supply for domestic use in one year hence, the danger of groundwater depletion is rather remote.

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. In addition faults, fissures and joints all from very important recharge conduits from the higher ground where rainfall is high.

4.1.7 Safe Yield

The apparent transmissivity of the aquifer system is estimated at 5.856m$^2$/day, based on National Ground Water Master Plan data. It is assumed that at an expected pumping rate of 50 m$^3$/day in 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 livestock watering and 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

<table>
<thead>
<tr>
<th>Colliform Count (No. per 100ml)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-50</td>
<td>Disinfection only</td>
</tr>
<tr>
<td>50-5000</td>
<td>Full treatment</td>
</tr>
<tr>
<td>5000-50000</td>
<td>Heavily polluted, requires extensive treatment</td>
</tr>
<tr>
<td>&gt;50000</td>
<td>Extreme pollution requiring special treatment; unacceptable source unless no alternative exists</td>
</tr>
</tbody>
</table>


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

Drilling records have been studied for 4 No boreholes, which is located within a radius of 6km of the proposed borehole. The recordis summarized in Table 4. The approximate borehole location is shown on the topo-map in the appendix.

Table 4: Listing of Boreholes Close to the Investigated Site
<table>
<thead>
<tr>
<th>Bh No. C-</th>
<th>Owner</th>
<th>Dist. (km) /Bearing</th>
<th>Depth (m)</th>
<th>W.S.L (m)</th>
<th>W.R.L (m)</th>
<th>Yield (m³/h)</th>
<th>PWL (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7379</td>
<td>Lomolo Sisal Estate</td>
<td>3.0/SW</td>
<td>188.5</td>
<td>155, 163</td>
<td>137.95</td>
<td>30.0</td>
<td>140.24</td>
</tr>
<tr>
<td>9751</td>
<td>Mogotiya Plantations Ltd.</td>
<td>2.5/WNW</td>
<td>170</td>
<td>158, 162</td>
<td>127</td>
<td>BH Not Tested</td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>Kipkutur bh</td>
<td>6.0/NE</td>
<td>220</td>
<td>....</td>
<td>....</td>
<td>5.0</td>
<td>....</td>
</tr>
<tr>
<td>new</td>
<td>Sisal Estate</td>
<td>2.0 NW</td>
<td>180</td>
<td>-</td>
<td>-</td>
<td>20</td>
<td>....</td>
</tr>
</tbody>
</table>
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 :

\[ E = \rho i \]

Where:

- \( E \) = Potential gradient (Volts per meter)
- \( i \) = Current density (Am\(^2\))
- \( \rho \) = Resistivity of the earth medium (Ω-m)

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

\[ \nabla \times i = 0 \]

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:

\[ (i) \quad V_r = \frac{\rho I}{2\pi r} \text{ (Volts)} \]

In hydro-geological field surveys using galvanic Resistivity methods the quantities measured are current \( I \), flowing between two electrodes A&B and potential difference \( \Delta V \) between two measuring points M & N. The following generalized relationship applies to various electrodes configurations.

\[ (ii) \quad \rho = K \times \frac{\Delta V}{I_{AB}} \text{ (Ω-m)} \]

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 modelling analysis using a digital computer. Correlation with data from existing boreholes complements the modelling analysis to come up with the most realistic conclusion.
6. FIELDWORK AND RESULTS

6.1 Fieldwork

Fieldwork was carried out in **October, 2019**, using deep probe resistivity **Model No. SSR-MP-ATS**. One Vertical Electric Sounding was carried out with AB/2 varied from **1.6m to 320m**. This way, distinct changes in resistivity with depth were recorded and subjected to modelling analysis with a digital computer using **GEWIN** hydrogeology software.

6.2 Results

The results of interpretation of the resistivity soundings data are presented in the following sections. In addition, this section briefly describes the results of the measurements and also presents plots of the interpretation graphs for the resistivity soundings.

The results of analysis are summarized below:-

**VES-1: Geo-Electric Model**
6.3 Results

The results of interpretation of the resistivity soundings data are presented in the following sections. In addition, this section briefly describes the results of the measurements and also presents plots of the interpretation graphs for the resistivity soundings.

Table 5: Interpretation of Results for the Survey

<table>
<thead>
<tr>
<th>VES</th>
<th>Depth (m bgl)</th>
<th>Resistivity (Ohm-m)</th>
<th>Geological Interpretation</th>
<th>Hydrogeologic Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1</td>
<td>2.4</td>
<td>111</td>
<td>Top superficial layer and other volcanic debris</td>
<td>Dry</td>
</tr>
<tr>
<td>Layer 2</td>
<td>6.95</td>
<td>57</td>
<td>Weathered Basalts</td>
<td>moist</td>
</tr>
<tr>
<td>Layer 3</td>
<td>40</td>
<td>302</td>
<td>Fractured Basalts</td>
<td>Dry</td>
</tr>
<tr>
<td>Layer 4</td>
<td>139.7</td>
<td>46.2</td>
<td>Slightly Fractured Trachyphonolites</td>
<td>Dry</td>
</tr>
<tr>
<td>Layer 5</td>
<td>&gt;140</td>
<td>110</td>
<td>Pyroclastics, chert, tuffs, admixed volcanic sediments (OLS)</td>
<td>Major aquifer</td>
</tr>
</tbody>
</table>

**OLS—Old Land Surface**

The VES interpretation results indicate a shallow superficial layer to a depth of 2.4 m bgl with a resistivity of 111 ohm-m. This can be interpreted as the top superficial layer comprising of soils and dry volcanic material. This is underlain by alternation of slightly too highly weathered Basalts/tuffs with intercalations of old land surfaces. The strata is subsequently underlain by a resistive formation to a depth of 140M Consisting of Basalts and Trachyphonolites. Below this layer is a 110 ohm-m resistivity layer interpreted to be an old land surface (OLS) and succession stratas composed of Pyroclastic, chert, tuffs, and admixed volcanic sediments.
The site was marked and shown to the community members and the Assistant Chief, Mr Peter Titomet

Figure 6.1: Photo showing site location within the plot
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 purposes are good. The most productive aquifer has been identified to be sediments and tuffs intercalated between volcanic lava flows and to a lesser extend fractured volcanics.
- The aquifer regime in the area is conducive to sustainable replenishment at several orders larger than the imposed abstraction, thereby ensuring a reliable long-term water supply.
- Groundwater quality in the area is good for domestic consumption. There may be slight hardness due to aridity and high evapo-transpiration rates. Fluoride levels should be checked to ensure compliance to WHO standard.
- The proposed borehole may yield about 8m3/hr or more.

7.2 Recommendations

In view of the above it is recommended that:

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

<table>
<thead>
<tr>
<th>Grid Reference of point to be drilled VES-1</th>
<th>Diameter (mm)</th>
<th>Elevation (amsl)</th>
<th>Minimum Recommended Depth (m)</th>
<th>Maximum Recommended Depth (m)</th>
<th>Amount to be abstracted (m³/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>36M 831280E and UTM 6864N</td>
<td>203.2 (8’’)</td>
<td>1514</td>
<td>280</td>
<td>300</td>
<td>50</td>
</tr>
</tbody>
</table>

➢ 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 WRMA 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.

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

If fluoride concentrations are above 1.5 ppm, it is not recommended to use the borehole as a permanent source for drinking water. Children especially below 5 years are susceptible to fluorosis if they depend on drinking water with high fluoride concentrations.
REFERENCES

DRISCOLL F.G (1986) Groundwater and Wells, 2nd Ed. Johnson Division

APPENDICES

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 temporary 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 gravel pack is recommended within the aquifer zone, because the aquifer could contain sands or silts which are finer than the screen slot size. An 8” diameter borehole screened at 6” will leave an annular space of approximately 1”, which should be sufficient. Should the slot size chosen be too large, the well will pump sand, thus damaging the pumping plant, and leading to gradual `siltation' of the well. The 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.
Appendix-2
Schematic Design for Borehole Completion

NB: Not to scale
Topographical Map Extract (Topo-Sheet No. 104/4) Showing the Approximate Location of the propose borehole site.

Key:

- Proposed Borehole