HYDROGEOLOGICAL/GEOPHYSICAL SURVEY REPORT

FOR

MAKILA COMMUNITY BOREHOLE

SITED AT

MR. NZIVWAFAARMLU MUSALU
PARCEL OF LAND (PRIVATE LAND)
P.O BOX 451-90119
MATUU.

LOCATED IN

MAKILA VILLAGE, KIKUMINI SUB-LOCATION,
KANGONDE LOCATION, MASINGA CENTRAL WARD,
MASINGA SUB-COUNTY,
MACHAKOS COUNTY.
RK/GOV/SY/2019

DECEMBER 2019

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DECEMBER 2019

Consulting Hydro-geologist: 0728 541-402
SUMMARY

This detailed report is presented as a technical site investigations report for the groundwater Survey for one productive community borehole within Makila Village, Kikumini Sub-location, Kangonde Location, Masinga Central Ward, Masinga Sub-County, Machakos County. The actual hydrogeological survey was sited at Mr. Nziwvalu Musalu plot of land on 29th November 2019. The objective of this study is to assess the availability of groundwater in the project parcel of land, comment on aspects of depth to potential aquifers, possible yields and water quality in addition to recommending an optimum drilling site for a productive borehole.

The report gives an outline of the hydrogeological studies carried out in order to arrive at the conclusions and recommendations given at the end of the report. The report is based on desk-top studies, examination of the geological conditions at the site and an analysis, evaluation and interpretation of the available hydrogeological data of the existing boreholes in the vicinity.

The climatic condition of the project area can be termed as semi-arid. Thus, the region in general has no reliable water supply as the available piped water line is Limited in extend (normally serve those near the road and town centers) and is normally characterized by periodic water rationing to help meet the high demand in the region. Mainly, the community depends on perennial stream and springs, roof catchment and buying water from water vendors and sometimes women and children have to walk long distances in search of this precious commodity as water connection lines are limited in extend.

This particular Hydrogeological Survey was commissioned by Small Scale Irrigation and Value Addition Project (SIVAP) through the ministry of Agriculture, Livestock and Fisheries in collaboration with County Government of Machakos, Ministry of Agriculture, Food security and Co-operative development; Department of Agriculture and food security, directorate of crops. The exercise mainly covered Kivaa Ward and Masinga Central Ward with the major aim of determining and establishing the best ideal location to sink/drill a Borehole which, would serve the general community and encourage Small-scale irrigation for food production.

The Project area is situated in a metamorphic terrain of the basement system. Generally, the project area has low-medium groundwater potential. Groundwater occurs at the contact zones between the different rocks lithology, at the old land surfaces and at the weathered and the fractured zones of the basement rocks.

The climatic conditions of the area, can be summarized as semi humid fairly to very hot in some seasons especially December to March with mean annual temperature ranging between 24º to 30ºC. The average annual evaporation is 2200mm whilst the mean annual precipitation is approximated at 1100mm. In addition, the surveyed site lies on a gentle sloping topography. Ground water to a great extent follows the topography of the area and is also very closely related to the surface water movement.

Based on hydrogeological survey, chances of striking suitable aquifers at the selected site are fairly good. The actual study site is underlain by alternating lithologies of basement rock. Borehole yield within the study area (Based on available data) occurs in the range of 2-10 m³/hr and similarly
the proposed borehole is expected to be about the same range with proper drilling, installation and well development.

Having considered all the possible options towards improving the water supply to meet the available demand, it is (in the opinion of the Consultant) advisable to sink a borehole to a **maximum depth of 250 metres**. The proposed borehole drill site is known by the Sub-County Agricultural officer and Masinga Central ward Vice Administrator (Mr. Boniface Kisilu-0725-815-661) and the drill site is also pegged on the ground for ease of identification.

By employing geophysical measurements within the School Parcel of land, one suitable site was located where the rock is found to be deeply weathered and fractured to greater depth (beyond 100 metres below ground level).

Below is a tabulation of the construction summary to be adopted to realize the project objectives:

**Table 1.1: Summary of the proposed site**

<table>
<thead>
<tr>
<th>Site coordinates</th>
<th>VES No. &amp; ranking in Yield Potential</th>
<th>Recommended depth in meters</th>
<th>Construction Requirements.</th>
<th>Anticipated Yield m³/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>37M E 358864 UTM S 9886663 Elev. 1242m</td>
<td>VES 1 Mr. Musalu Farm</td>
<td>250</td>
<td>216mm/153mm</td>
<td>Over 5</td>
</tr>
</tbody>
</table>

The report based on the assessment findings, is quite detailed and includes amongst others quantifiable recharge and discharge groundwater flux evaluations, statistical aquifer data evaluations Vis computed values of aquifer transmissivities and the typical specific capacities of the aquifers based on available test data.

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

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1. INTRODUCTION

1.1. Background Information

This detailed report is presented as a technical site investigations report for the groundwater Survey for one productive community borehole within Makila Village in Kikumini Sub-location, Masinga Central Ward, Masinga Sub-County, Machakos County. The objective of this study is to assess the availability of groundwater in the project parcel of land, comment on aspects of depth to potential aquifers, possible yields and water quality in addition to recommending an optimum drilling site for a productive borehole.

The Project area is situated within a complex metamorphic terrain of the basement system.

The borehole water is expected to serve the general populate within Makila Village. In Terms of Hydrogeology in reference to the project area Mr.Musalu plot offers a good location for the proposed borehole and also for easy distribution of the borehole water.

The main objective for this survey is to develop a borehole water source supply for the community in view of the constrained water supply from the various sources. The above survey program was envisaged and commissioned by an Organization for Small Scale Irrigation and Value Addition Project (SIVAP). In Machakos County the Program mainly covered Kivaa Ward and Masinga Central Ward with the major aim of determining and establishing the best ideal location to sink/drill a Borehole which, would serve the general community and encourage Small-scale irrigation for food production. About 20-50 m³ borehole water is required per day.

1.2. Scope of Works

The Scope of works for the execution of the Hydro-geological assessments/ Borehole site investigations within the premise, include but not limited to:

i. Undertake comprehensive feasibility study of the groundwater occurrence within the plot.
ii. Optimize an ideal —survey location for the proposed borehole project,
iii. Integrate reconnaissance survey data with Geophysical borehole data obtained in the conduct of the surveys and assimilate the borehole data to define the recharge/discharge boundaries for the project site i.e. calibrate the exploration data against known geological settings.
iv. Undertake comprehensive assessments of the existing borehole facilities located in the neighboring areas with a view to quantify the inherent potential; and confirm the actual development of other boreholes subsequent to development of Borehole.
v. Compilation/documentation of all the additional available hydro-geological, geological, geophysical, hydrological data and the subsequent provision of a comprehensive report on the groundwater exploration program for the project area.
1.3. Project Site Location

The project site is located at Mr Musalu Plot of land within Mukila Village in Kangonde location, Masinga Central Ward on the far North east part of Machakos County. (Sketch map appended). The project area lies on topographical map for Kangondi/Matuu- Sheet No. 150/1 on scale of 1:50,000. The approximate coordinates of the project site is 37N 358864; UTM 9886663 at an average elevation of 1242 metres above mean sea level.

Fig 1.1: Showing Mr. Musalu Plot (location of proposed borehole) within Makila shopping center.
Figure 1.1: Google Earth Image showing the location of the proposed borehole site
Water Supply Situation

Basically, Makila area is not entirely serviced by piped water from local water Company (Masinga Piped Water) or the Village Syndicate. Other water supply is mainly from shallow wells, rainfall harvesting, fetching from nearby rivers and vending from existing neighboring boreholes.

In the context above, the investigation was to establish the optimum location of a borehole to act as a source of water supplement for the Surrounding Community. Below is a table on the water requirement needs of the client.

Table 1.2: Water requirement needs for the client

<table>
<thead>
<tr>
<th>Population to be supplied with water</th>
<th>Approx. 1000 persons</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 households with an average of 3 persons per household</td>
<td></td>
</tr>
<tr>
<td>Expected Rate of water use (Litres/day) per persons</td>
<td>50 Litres/day</td>
</tr>
<tr>
<td>Total Water Required 50 m$^3$/day</td>
<td>10 m$^3$/hour</td>
</tr>
</tbody>
</table>

1.4 Climate

The climate is semi-arid, being dry for most of the year. Rainfall is bi modal (March May and October December). Mean annual rainfall is approximately 530 mm. Temperatures are highest in the months January to March; Annual mean daily minimum and maximum temperatures are 13 to 26°C (TAMS, 1980). Potential evaporation is between 1,800 and 2,000 mm per year and these losses are exacerbated by frequent high winds in the area.

1.5 Drainage

The drainage is characterized by the streams that originate at the base of the surrounding Hills forming tributaries of small stream and rivers. The general direction of flow for the system is in a South-North trend. Generally most rivers in the region exhibit a dendritic type of flow hence structurally controlled.

1.6 Topography

The site lies at an altitude of about 1200-1500m and it’s covered by reddish grey-Brownish sandy soils.

Physiographically, it can be described as undulating land, which steep towards the south with even summit levels and flat-topped ridges. The streams have a marked concave gradient in the upper parts of the catchments (Baker, 1952), which could be in response to isolated resistant Basement hill complexes and small ridges prevalent in the area.

The topography of the area is influenced by THATHA hills. The wider area is traversed by numerous streams that form a perfect dendritic drainage pattern, all flowing in a SW-NE direction.
2. GEOLOGY

2.1. Regional Geology

The study area is largely underlain by rocks of the Basement Complex. These are mainly metamorphosed as well as granitized rocks of sedimentary origin and include migmatites, granitoid gneisses and paragneisses. These occur in fairly regular belts which are common in the vicinity of this area mainly undifferentiated banded pelitic gneisses and schists.

The sediments were predominantly argillaceous with numerous intercalated arenaceous layers. Conglomeratic sediments do not appear to have been deposited and limestones are rare as only a few thin beds of impure marble have been found.

The superficial deposits mainly include gravels, crossbedded sands and soils. The gravel beds, seldom over twenty feet thick, are ill composed of ill-sorted sub-rounded to angular fragments in a sandy or calcareous matrix. The soils of the region, with the exception of the black soils are the products of semi-arid weathering conditions and are of an immature type. Laterization are extensive over the flat lying part of the area.

2.1.1 Summary of the Geological History

The oldest rocks in the area consist of metamorphic banded semi pelitic and pelitic mica-ampibole-quartz-felspar schists and gneisses with interbanded psammitic types of the Basement System, which are overlain by younger sedimentary rocks or unconsolidated material of Permian to Recent age.

During Precambrian times, vast successions of sediments accumulated in a geo-synclinal structure covering most of the present eastern Africa. Towards the end of this era, a period of regional folding and metamorphism of sediments occurred. The rocks were subjected to high temperatures and pressures during mountain building processes, resulting in (partial) melting and subsequent recrystallization and growth of new minerals. Depending on the parent material and the prevailing pressures and temperatures, various types of gneisses and schists were formed. The metamorphosed sediments were intensely folded and tilted. In addition, granitization processes acted upon the Basement rocks, resulting in granulites and migmatites.

The Precambrian was followed by a period of more than 300 million years during which the Basement rocks were lowered by erosion processes. As a result, a plain-like terrain was formed, with a smooth easterly gradient towards the coast. Regional down-warping and fluctuations in the sea level gave rise to vast successions of sediments in the coastal belt. The age of the sedimentary succession decreases towards the Coast.

During Tertiary and Pleistocene times, extensive faulting and vertical displacements of large blocks of rock took place. It is likely that many of the structures date from the final phases of Pleistocene rift valley faulting. As a result of this block-faulting, many of the formation boundaries are fault bounded.

In Recent times soils developed, covering most of the rocks in the area. The soils also reflect to a certain extent the nature of the underlying formations.
2.2. Geology of the Project Area.

The investigated site is covered with alluvial soils derived from decomposed, undifferentiated Basement rocks. The presence of granitic gneisses in the area indicates the intrusive activities in the Archean. Within the project area especially in road side and river valleys, extensively weathered pelitic quartz-felspar rocks are exposed. Outcrops of Psammitic quartzite bands are evident in the area. The metamorphic Basement is overlain by a moderately thick weathered soils sequence.

2.2.1. Basement System Rocks

The Pre-Cambrian Basement rocks are the oldest rocks in the area. They comprise various types of sediments which were transformed by regional metamorphism into gneisses, schists and quartzites. These rocks outcrop in most of the north-eastern and south-eastern parts of the area.
3. WATER RESOURCES

3.1. Surface Water Resources

The general area is drained by tributaries of river Mikuyuni which merge together with other tributaries thus draining their waters to River Luuma. Due to the semi-arid climatic conditions in the area, these tributaries are mainly seasonal therefore of little use for the intended purposes.

3.2. Groundwater Resources

The hydrogeology of an area is determined by the nature of the parent rock, structural features, weathering processes and precipitation patterns. Especially in the Precambrian shields, metamorphic rocks are highly compact and have virtually no intergranular (or primary) porosity. While mostly solid, non-porous, and absolutely impervious at the scale of a hand specimen, these rocks have a type of porosity that can be termed as fracture (or secondary) porosity. This implies that they can hold water in a network of fissures, cracks, joints, fractures or faults.

The secondary porosity is caused by systems of "macro pores" and "micro pores". Macro pores are fissures and fractures of structural origin. Micro pores are interstices created by weathering. These two types of secondary porosity are usually closely related, as cracks and fissures facilitate the percolation of water and hence more intensive weathering. The aquifers in the metamorphic rocks are characterized generally by a very low primary and (depending on the degree of fracturing) highly variable secondary porosity.

The thickness and mineral characteristics of the weathered layer play an important role in the amount of groundwater it can hold and the hydraulic conductivity (i.e. the ability of water to flow). Topography, drainage pattern, rainfall and evaporation are some of the major factors, which determine the occurrence of groundwater.

3.3. Recharge Considerations

Recharge is the process through which water is added to the groundwater reservoir. As a result, the aquifers identified are indirectly recharged by underground drainage of water falling some distance from their present locations.

Individual aquifers formed exclusively within the weathered layer rarely produce yields in excess of 2-3 m³/hr. Higher yields (say >5 m³/hr) can be achieved from boreholes located in "open" faults and fissure zones. The potential of structurally altered rocks is two fold:

- Along faulted or fissured rocks weathering can penetrate much deeper, thus creating sub-vertical zones filled with relatively coarse, weathered material. These zones generally have a much higher transmissivity than their surroundings.

- Recharge occurs over large areas: major faults may extend well beyond the surface catchment, thus intercepting adjacent aquifers or surface sources.

Although faults are often associated with water bearing zones, it should be noted that they might also act as impermeable barrier zones ("closed faults"). In this case the structure acts as a
"groundwater dam" and significant storage may build up on its upstream side. Drilling inside such a closed fault system, however, would in most cases be futile.

Thirdly, there are faults or fissure zones that, despite having all the properties of a water bearing zone, are not productive due to a lack of recharge (dry, open fractures)

3.4. Previous Groundwater Development/Hydrogeology

There are hardly any borehole in the vicinity of the project area and only very few boreholes have been developed in similar geological conditions and indeed in the vicinity of the project area. These boreholes (Table 1) exhibit varying degree of success and this can be attributed to their total depth, topographical location, construction and development, as well as depth of pump-intake.

Figure 5. 1 Topographic map extract sheet (150/1 – Kangondi/Matuu) indicating the existing borehole sites in the vicinity of the project plot.

**LEGEND**
- **Proposed Site**
- **Location of Surrounding Boreholes**
The borehole data indicate that potential aquifers are encountered between 50 and 70 meters. It should be noted that the depth alone is not the sole determining factor controlling the yield, but also the design, construction and development of the boreholes.

Basically this area seems to indicate potential groundwater at a depth of between 30 - 150 metres.

The consultant was unable to get data of any boreholes in the near vicinity of project site. The available Boreholes C-11855 was found out to be dry borehole other data only shows productive borehole on the lowland area in reference to our project area, this was considered to be in a different geological and hydrogeological set up.

To use such a data for correlation would only result in misplaced analysis of boreholes productivity and aquifer properties. The consultant finds it inappropriate to provide false information as much as the aquifers are concerned and there is hardly any documented information to this effect.

### 3.5 Discharge

Discharge from aquifers is either through natural processes as base-flow to streams and springs, or artificial discharge through human activities. However considering the few number of boreholes in the area this is form of discharge is not much pronounced.

The total effective discharge from the aquifers via either of the above means is not known, and should in fact be studied. The main form of discharge is through flow along formations and faults/interconnected fractures.

### 3.7 WATER QUALITY:

In the area the quality of groundwater is generally good. It is however mandatory to get a full chemical analysis of the water from the borehole before any use is commenced.

Generally, groundwater chemistry from the Metamorphic terrain varies from place to place due to mode of recharge and how long water has interacted with rocks. Water quality from the proposed borehole is expected to meet the WHO standards but with some slight modification due to the increased amounts of minerals.

Consumption by humans of waters with concentrations somewhat above the standard limits is not necessarily harmful. Still, the best possible quality should be targeted, and the identified sources should have chemical properties within and/or to the WHO norms. Appropriate technological solutions must be considered in areas where adverse types of water are likely to have hazardous effects on man and livestock. However, for toxic substances, a maximum permissible concentration limit has been established. The constituents for which these standards have been set (e.g. heavy

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**Table 1.** Below gives data for boreholes drilled in the vicinity of the project site. The data has been obtained from the consultant’s data base and from information gathered from the existing borehole owners.

<table>
<thead>
<tr>
<th>BH</th>
<th>NAME</th>
<th>DEPTH</th>
<th>WSL</th>
<th>WRL</th>
<th>Q</th>
<th>PWL</th>
</tr>
</thead>
<tbody>
<tr>
<td>11855</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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metals, pesticides, bacteria) all have a significant health hazard potential at concentrations above the specified limits. Hence, the specified limits should not be exceeded in public water supplies.

Check appendix 3.

3.8 IMPACTS OF THE PROPOSED ACTIVITY TO WATER QUALITY, WETLANDS

The Proposed drill site and related works are expected to pose no impact on water quality, either Surface or groundwater resources. There is no any surface water body near the drill site that can be contaminated by waste waters generated during drilling. The entire drilling, borehole construction, pump tests, and completion works will be done under supervision to professional standards. Entry of any foreign material until completion will be avoided to avoid any entry of foreign material into the borehole and only inert materials will be used in construction. The borehole will be properly developed to open up the aquifers and clean the borehole water. Monitoring of ec during drilling will be done to detect and seal any aquifer with elevated mineralization.

The site is not located within a wetland and has no negative impacts on biodiversity.
4. FIELD EXPLORATION PROGRAM

4.1. Prospecting Methods

4.1.1. Resistivity (Basic Principles)

The electrical properties of rocks in the upper part of the earth’s crust are dependent upon the lithology, porosity, and the degree of pore space saturation and the salinity of the pore water. Saturated rocks have lower resistivity than unsaturated and dry rocks.

The higher the porosity of the saturated rock, the lower is its resistivity, and the higher the salinity of the saturating fluids, the lower the resistivity. The presence of clays and conductive minerals also reduces the resistivity of the rock. The resistivity of the earth materials can be studied by measuring the electrical potential distribution produced at the earth’s surface by an electric current that is passed through the earth.

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

$$ R = \rho \times L \times A \quad (1) $$

Where $\rho$ is known as the specific resistivity, characteristic of the material and independent of its shape or size, With Ohm’s Law;

$$ R = \Delta V / I \quad (2) $$

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

$$ \rho = (A/L) \times \Delta V / I \quad (3) $$

4.2. Survey Design

Two categories of field techniques exist for conventional resistivity analysis of the subsurface. These techniques are vertical electric sounding (VES), and Horizontal Electrical Profiling (HEP).

4.2.1. Vertical Electrical Sounding (VES).

The object of VES is to deduce the variation of resistivity with depth below a given point on the ground surface and to correlate it with the available geological information in order to infer the depths and resistivities of the layers present.

In VES, with wenner configuration, the array spacing “a” is increased by steps, keeping the midpoint fixed ($a = 2, 6, 18, 54, \ldots$).

In VES, with schlumberger, the potential electrodes are moved only occasionally, and current electrode are systematically moved outwards in steps

$$ AB > 5 \text{ MN} $$
4.2.2. **Horizontal Electrical profiling (HEP)**

The object of HEP is to detect lateral variations in the resistivity of the ground, such as lithological changes, near-surface fault.

**In the wenner procedure of HEP**, the four electrodes with a definite array spacing “a” is moved as a whole in suitable steps, say 10-20 m. four electrodes are moving after each measurement.

**In the schlumberger method of HEP**, the current electrodes remain fixed at a relatively large distance, for instance, a few hundred meters, and the potential electrode with a small constant separation (MN) are moved between A and B.

When carrying out a resistivity sounding, current is led into the ground by means of two electrodes. With two other electrodes, situated near the centre of the array, the potential field generated by the current is measured. From the observations of the current strength and the potential difference, and taking into account the electrode separations, the ground resistivity can be determined.

While carrying out the resistivity sounding the separation between the electrodes is step-wise increased (in what is known as a Schlumberger Array), thus causing the flow of current to penetrate greater depths. When plotting the observed resistivity values against depth on double logarithmic paper, a resistivity graph is formed, which depicts the variation of resistivity with depth.

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

![Diagram of Horizontal Electrical Profiling](image)
4.3. FIELD WORK

A detailed exploration program was carried out on the 29\textsuperscript{th} November 2019, and it entailed both reconnaissance (comprised observation of general topography, drainage, geological set up, etc), hydrogeological and geophysical surveys. Two Vertical Electrical Soundings were carried out to a maximum electrode spacing of $AB/2 = 250$ m. The eventual selection of the drill also took into consideration the accessibility, geophysical results and proposed infrastructure.

The Vertical Electrical Sounding [VES] was carried out with an ABEM Terrameter SAS 1000/4000 resistivity instrument.

The results for the soundings are summarized on table 4.1 a-b below.

![VES measurement graph](image)

**Table 4.1 a – VES 1-Mr. Nzivwalu Musalu Plot**

<table>
<thead>
<tr>
<th>DEPTH (in meters)</th>
<th>RESISTIVITY (OHM)</th>
<th>FORMATION</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 – 1.0</td>
<td>130</td>
<td>Surficial Deposits-Sandy Soil</td>
<td>Dry</td>
</tr>
<tr>
<td>1.0 – 6.0</td>
<td>120</td>
<td>Quaternary Alluvium deposits</td>
<td>Dry</td>
</tr>
<tr>
<td>6.0 – 13.0</td>
<td>130</td>
<td>Weathered pelitic schist-Banded</td>
<td>Dry</td>
</tr>
<tr>
<td>13.0-20.0</td>
<td>400</td>
<td>Compact Gneisses</td>
<td>Dry</td>
</tr>
<tr>
<td>20.0-30.0</td>
<td>300</td>
<td>Weathered Basement rocks</td>
<td>Wet</td>
</tr>
<tr>
<td>30.0-50.0</td>
<td>400</td>
<td>Fresh undifferentiated Basement rock</td>
<td>Dry</td>
</tr>
<tr>
<td>50.0-80.0</td>
<td>350</td>
<td>Weathered/Fractured undifferentiated Basement rock</td>
<td>Wet</td>
</tr>
<tr>
<td>80.0-200.0</td>
<td>700</td>
<td>Fresh undifferentiated Basement rock</td>
<td>Dry</td>
</tr>
<tr>
<td>&gt;200</td>
<td>500</td>
<td>Weathered Basement rocks</td>
<td>Wet</td>
</tr>
</tbody>
</table>
Table 4.1 b – VES 2-Mr. Munyau Muindi Plot

<table>
<thead>
<tr>
<th>DEPTH (in meters)</th>
<th>RESISTIVITY (OHM)</th>
<th>FORMATION</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 – 1.0</td>
<td>30</td>
<td>Surficial Deposits-Sandy Soil</td>
<td>Dry</td>
</tr>
<tr>
<td>1.0 – 6.0</td>
<td>70</td>
<td>Quaternary Alluvium deposits</td>
<td>Dry</td>
</tr>
<tr>
<td>6.0 – 16.0</td>
<td>190</td>
<td>Compact pelitic schist-Banded</td>
<td>Dry</td>
</tr>
<tr>
<td>16.0-30.0</td>
<td>90</td>
<td>Weathered Schist-Banded</td>
<td>Wet</td>
</tr>
<tr>
<td>30.0-50.0</td>
<td>150</td>
<td>Fresh Undifferentiated Basement rock</td>
<td>Dry</td>
</tr>
<tr>
<td>50.0-70.0</td>
<td>160</td>
<td>Weathered Basement rock</td>
<td>Dry</td>
</tr>
<tr>
<td>70.0-160.0</td>
<td>340</td>
<td>Fresh undifferentiated Basement rock</td>
<td>Dry</td>
</tr>
<tr>
<td>160.0-200.0</td>
<td>340</td>
<td>Weathered Basement rocks</td>
<td>Wet</td>
</tr>
</tbody>
</table>

4.3.1 Results & interpretation

The geophysical results indicate that the site is covered at the surface by dry top alluvial soils (Sandy Soil) a depth of about 0.8-1m. These are underlain by compact sub-surface regolith to a depth of about 2-6m which are then underlain by weathered banded pelitic schists and gneisses to a depth of 13m. These are underlain by compact basement rocks upto about 20m. Thereafter relatively fractured and weathered quartzo-felspathic gneisses which seem to be aquiferous (first aquifer expect at 20-30m). The Lithology follows with calcareous granulites and granitoid gneisses to a depth of 50m, this formation is compact and dry. Beyond this depth is highly fractured and weathered quartzo-felspathic gneisses and its aquiferious (50-90m) and (>200m) on the upper stratum. This then gradually grade to fresh undifferentiated basement system rocks that is compact though noted with reducing resistivity hence somehow weathered.
5. IMPACTS OF PROPOSED DRILLING ACTIVITY

Within the study area, the formation is characterized by Metamorphic rocks and sediments. There are few number of boreholes that have been drilled in the area.

Withdrawal of water from the proposed borehole will not cause any alarming effect to the aquifer. Generally, the regional aquifer is rich and can supply vast amounts of water. This fact is attributed to encroachment by human leading to destruction of forests that are water catchment system.

It is the responsibility of every citizen to control use, manage and if possible measures be put in place to recycle this commodity. The general region/area requires more than 50,000 litres of water per day that should be abstracted from this borehole.

The proposed abstraction is relatively high-Moderate considering aquifer potential in the region. However, it will unlikely cause serious impact to the cone of depression. The cone of depression is expected be elongated towards the direction of recharge, thus any boreholes drilled near the proposed one can be pumped maximum without causing major hydraulic interference.

Environment issues shall be addressed by conduct of an Environmental Impact Assessment that will be followed by Environmental Audit to ensure recommendations and mitigation measures are adhered to.

Attention is called to ensure groundwater is protected from possible contamination especially during implementation where liquids are introduced into the borehole. Only biodegradable liquids should be used with careful disposal according to manufacturer’s recommendations.

5.1. Impacts of the Local Aquifer Quantity and Quality

The sustainability of the water quantity depends on the level of abstraction and recharge rate. If groundwater is abstracted at a rate greater than its natural replenishment rate, then the project will not be sustainable as there will be dry pumping. Based on the yields of the boreholes, the proposed abstraction of 20m$^3$/day on a 8 hour pumping regime is not expected to have any major impact on the aquifers, as the aquifer is expected to be moderate Yielding.

The water quality will mainly depend on the host rock, construction design and the age of the water. Overall, the expected impacts resulting from the borehole to the environment and their mitigation measures will be adequately addressed in the EIA study to be conducted.

5.2. Impacts of Existing Boreholes in the Area

It’s noteworthy that most of the boreholes drilled within the area are found to be beyond the 800 m stipulated distance, hence no significant impact is expected from abstraction of water from this proposed borehole.
6. CONCLUSIONS AND RECOMMENDATIONS FOR BOREHOLE DEVELOPMENT

Conclusions

Based on the discussions in the previous chapters on hydrogeology, geophysics and existing boreholes, it has been concluded that a water supply borehole is to be developed on the proposed VES 1 point to a recommended maximum depth of 250 m below ground level. This depth is considered ideal considering the number of target aquifer and their thickness that will be penetrated.

Aquifers in the project area occur in the OLS, highly weathered/ and fractured schists and gneisses. The potential aquifer zones are as described in the hydrogeology.

The water from the borehole is expected to be of good quality. However, a water sample from the borehole should be referred to a competent laboratory for physical, chemical and bacteriological analysis before water is available for use.

Based on the available information on geology and existing boreholes, combined with the hydrogeological assessments, the following conclusions can be drawn:-

a) The maximum yield that can be obtained from a borehole which fully penetrates the formation is likely to be in the range of 5-10 m³/hr.

b) The required depth of a fully penetrating hole would be at least 250 metres

The location is shown in the site sketch – (Back pocket map extract of Kangondi/Matuu; Topographical map sheet No.150/1). Below is a tabulation of the construction summary to be adopted to realize the project objectives:

Table 6.1: Borehole Construction Recommendations

<table>
<thead>
<tr>
<th>Site coordinates</th>
<th>VES No. &amp; ranking in Yield Potential</th>
<th>Recommended depth in meters</th>
<th>Construction Requirements.</th>
<th>Anticipated Yield m³/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>37M E 358864 UTM S 9886669 Elev. 1242 m</td>
<td>VES 1</td>
<td>250</td>
<td>216mm/153mm</td>
<td>Over 5</td>
</tr>
</tbody>
</table>

Recommendations

i. The drilling should ideally be carried out with a Rotary drilling plant rotary in order to attain the maximum recommended drill depth of 250 m below ground level unless enough water has been struck or the formation is complicated to continue drilling.

ii. The borehole to be drilled should be of at least 8” diameter. The borehole should be lined with appropriate steel casings and screens following the design recommended by the supervising hydro geologist.

iii. The borehole should be properly gravel packed and sealed to avoid any contamination from shallow sub-surface water, taking particular note of the guidelines given in the accompanying addendum on borehole drilling, design and construction.
iv. A monitoring tube is to be installed in the drilled intake to allow regular measurements of the water levels in the intake wells. This is a requirement for the final pumping equipment installation.

v. The recommendations on well construction cannot be considered complete without the mention of the requirement to test pump the water supply borehole to British standards BS 6316 (1992), which is an industry standard. At least 10 hours of the step test at –2-hour interval followed by a CRT test for 30 hours is recommended. Recovery must be carried out to full Static Water Levels.

vi. In order to maximize yields in this part of the aquifer systems, the proposed borehole will have to be drilled to the recommended depth, very carefully constructed and developed. The drilling, construction and test-pumping of the borehole should be supervised by a qualified hydrogeologist.

NB: The Client should note that before drilling commence, a groundwater abstraction permit should be obtained from the Water Resources Management Authority.
Appendices

Appendix 1; Geophysical Data Model VES 1 and VES 2

![Graph 1: Munyau-V2 Measurement]

![Graph 2: Munyau-V2 Measurement]

Consulting Hydro-geologist: 0728 541-402
Appendix 11: Drilling Design

Drilling Methodology

Drilling should be carried out with an appropriate tool – comprised of a high-powered rotary machine, which is considerably faster. 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.

Well Design

The design of the well should ensure that screens are placed against the optimum aquifer zones. An experienced works drilling consultant/hydro geologist should make the final design; and should make the main decision on the screen settings.

Casing and Screens

The well should be cased and screened with good quality screens; considering the depth of the borehole it is recommended to use steel casing and screens of 6” diameter. Slots should be maximum 1mm in size. 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” (203mm) diameter borehole screened at 6” (153mm) will leave an annular space of approximately 1”, which should be sufficient. Should the slot size chosen be too large, the well will pump sand, thus damaging the pumping plant and leading to gradual ‘siltation’ of the well. The grain size of the gravel pack should be an average 2-4mm.

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 to insert the artificial gravel pack all around the screen. If installed, gravel packed sections should be sealed off top and bottom with clay (2m).

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

Well Development

Once screen, gravel 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 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 2m 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 on all newly-completed wells, because from giving an indication of the quality of drilling, design and development, it also yields information on aquifer parameters which are vital to the hydrogeologist. A well test consist 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 drawdowns as a function of time. Once a dynamic water level (DWL) is reached, the rate of inflow to the well equals the rate of pumping. Usually the rate of pumping is increased stepwise during the test each time equilibrium has been reached (Step Draw-Down Test). Towards the end of the test a water sample of 2 litres should be collected for chemical analysis. The duration of the test should be 48 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 the project design consultant to calculate the optimum pumping rate, the installation depth, and the draw-down for a given discharge rate.
### Table 3.2: Maximum dissolved constituent limits as per WHO/EU standard

<table>
<thead>
<tr>
<th>Parameter</th>
<th>WHO/EU Guideline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cations (mg/l)</td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td>0.2</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.5</td>
</tr>
<tr>
<td>Calcium</td>
<td>No Guideline</td>
</tr>
<tr>
<td>Magnesium</td>
<td>No Guideline</td>
</tr>
<tr>
<td>Sodium</td>
<td>200</td>
</tr>
<tr>
<td>Potassium</td>
<td>No Guideline</td>
</tr>
<tr>
<td>Anions (mg/l)</td>
<td></td>
</tr>
<tr>
<td>Chloride</td>
<td>250</td>
</tr>
<tr>
<td>Fluoride</td>
<td>1.5</td>
</tr>
<tr>
<td>Nitrate</td>
<td>50</td>
</tr>
<tr>
<td>Nitrite</td>
<td>0.50</td>
</tr>
<tr>
<td>Sulphate</td>
<td>250</td>
</tr>
<tr>
<td>Total Hardness (CaCO₃ mg/l)</td>
<td>Desirable:150-500</td>
</tr>
<tr>
<td>Total Alkalinity (CaCO₃ mg/l)</td>
<td>No Guideline</td>
</tr>
<tr>
<td>Physical Parameters</td>
<td></td>
</tr>
<tr>
<td>PH</td>
<td>Desirable:6.5-8.5</td>
</tr>
<tr>
<td>Colour (Pt mg/l)</td>
<td>Desirable:15</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>Desirable:&lt;5</td>
</tr>
<tr>
<td>Permanganate Value (O₂ mg/l)</td>
<td>No Guideline</td>
</tr>
<tr>
<td>Conductivity (S/cm)</td>
<td>250μS/cm</td>
</tr>
<tr>
<td>Total Dissolved Solids (mg/l)</td>
<td>No Guideline</td>
</tr>
<tr>
<td>Free Carbon Dioxide (mg/l)</td>
<td>No Guideline</td>
</tr>
</tbody>
</table>
Appendix IV. TOPO SHEET MAP

Fig 2.1: An extract of Topographical Map sheet No.150/1-Kangondi/Matuu Showing Proposed Makila Community borehole location.