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HYDROGEOLOGICAL/ GEOPHYSICAL SURVEY REPORT FOR

ONE PRODUCTION BOREHOLE

ON

LAND PARCELS NO:

WITHIN

BARAKA JEMBE AREA, ADU LOCATION, MAGARINI SUB-COUNTY, KILIFI COUNTY.

CLIENT: BARAKA JEMBE PRIMARY SCHOOL

PROJECT: INSTITUTIONAL BOREHOLE

MAY 2020

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EXECUTIVE SUMMARY

This report describes the results of hydrogeological and geophysical investigations for a production borehole Baraka jembe primary school borehole's parcel of land located in Baraka Jembe area, Adu Location, Magarini Sub-County and Kilifi County.

The aim of the investigations was to locate a suitable borehole drilling site within the school's parcel of land. To accomplish this, detailed hydrogeological and geophysical investigations were executed.

Locally, L.A.J Williams (1953-1956) shows that the site lies on Marafa Beds which are poorly consolidated river gravels and sands (Lower Pleistocnene) of Pleistocene age coded **Pl**. The water bearing formation is expected within the wet sands and wet clays. The area overlies the Fundisa limestone which is yellow limestone, fine grained calcareous sandstone and marls of the Miocene age. An excerpt from L.A.J Williams (1953-1956) geological map is seen below.

Geophysical measurements were used to determine the thickness of the underlying layers, their potential as aquifers, and the expected quality of groundwater in these formations. Two profile survey were conducted using the AIDU ADMT-300S machine.

In view of the geophysical results and hydrogeological nature of the area, if a borehole is to be sunk it is recommended a borehole to be sunk at a depth of **220m bgl** at the location of **VES 1** which was pegged on the presence of Mr. Bendera. Though the survey shows that there is water at shallow depth of 50m bgl but drilling should be done to the recommended depth. It should be noted that the water struck is expected to be saline; hence an Electrical conductivity meter should be at the site to curb any increment in salinity with progressive depth once water has been struck. Drilling method to be adopted is mud drilling though air drilling could be used too. The water prospects are fair.

Regular monitoring should be instituted and maintained in the well 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 borehole.

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

A drilling permit must be applied from the Water Resources Management Authority Regional office in Mombasa under the Ministry of Water and Irrigation.

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LIST OF ABBREVIATIONS

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
Ωm	Ohm-m: Unit for apparent resistivity
ρ	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

Radiator Geohydrotech Ltd were commissioned to carry out hydrogeological investigation at a parcel of land located in Baraka Jembe area, Magarini Sub-County and Kilifi County. The borehole will be used to supply water for the school and community within the area.

The main source of water in the area is from rain water harvesting as tanks and gutters were seen during the time of survey but the supply is unreliable hence the client requires detailed information on prospects of drilling a production borehole.

1.2 Objectives of this Study

The objective of the study was to assess the availability of potable groundwater and to advice on the viability of drilling a productive borehole to be equipped with a pump to supply water for use by the client. The investigations involved include

- A desk study
- Reconnaissance survey of the project area
- Hydrogeological study and geophysical field investigations in which the available relevant geological and hydrogeological data was collected, analyzed, collated and evaluated within the context of the client's requirement.
- Assessment of existing water supply with respect to demand, current land use around the project area, and the general compound set up.

The data sources consulted were mainly in four categories:

a) Published Master Plans.
b) Geological and Hydrogeological Reports and Maps.
c) Ministry of Water and Irrigation Borehole Completion records.
d) Technical reports of the area by various organizations.

1.3 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 Location

The surveyed site is in Baraka Jembe Area, Magarini Sub-County of Kilifi County. The project area is located approximately 5km from Adu Centre, 24km from Kibaoni Junction . It lies within the 1:50,000 Survey of Kenya topographic sheet for leaving the Malindi- Graeni Highway. Its defining coordinates are S 2.832778° E 39.944362° Alt 142m

Figure 1: Location of the Investigated site on a Google Map of the Area

2.2 Physiography

The site lies at an altitude of about 142m amsl. Kilifi County can be divided into four major physiographic units with altitude ranging from sea level to 576m in the Mackinon Road on Tsavo East national park bordering Taita Taveta District.

2.3 Climate

The average annual rainfall ranges from 300mm in the hinterland to 1,300mm at the coastal belt. The coastal belt receives an average annual rainfall of about 900mm to 1,100mm with marked decrease in intensity to the hinterland. Areas with highest rainfall include Mtwapa and to the north of the coastal strip around the Arabuko Sokoke Forest. Evaporation ranges from 1800mm along the coastal strip to

2200mm in the Nyika plateau in the interior. The highest evaporation rate is experienced during the months of January to March in all parts of the county.

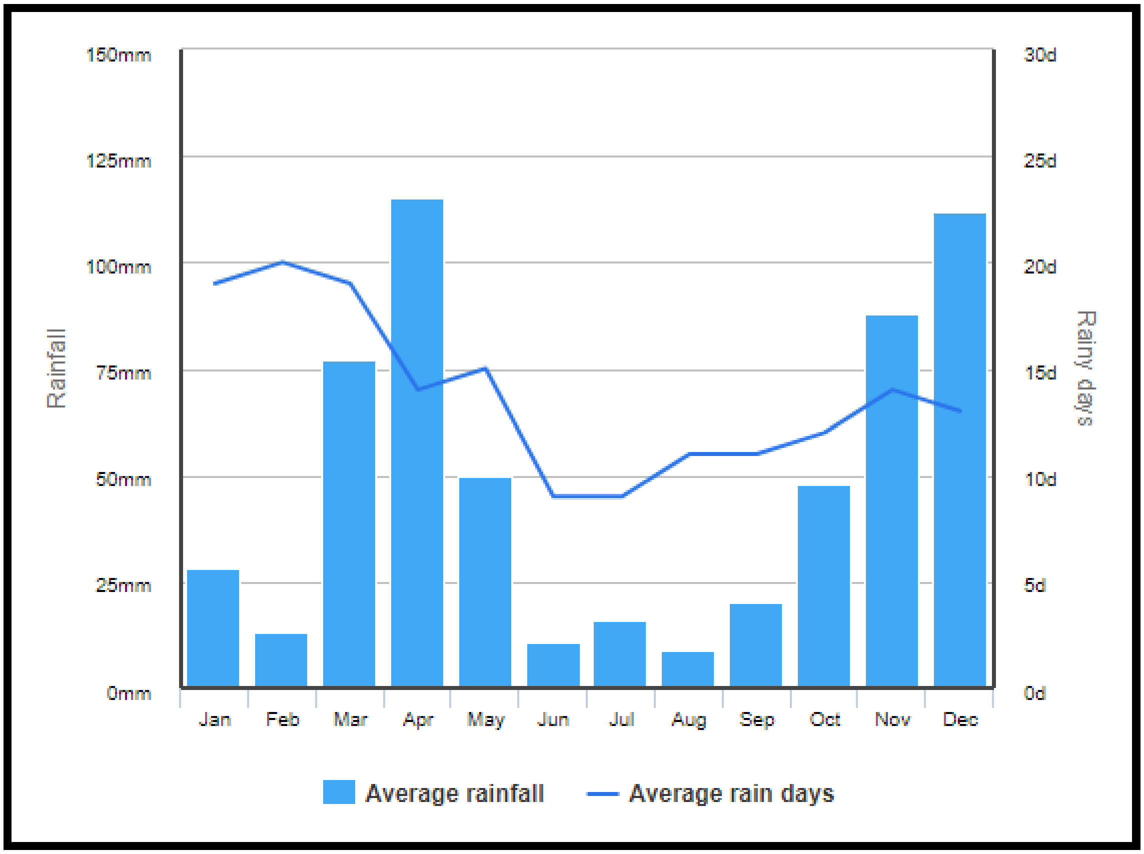


Figure 2: Climate Graph of Kilifi

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mm	28	13	77	115	50	11	16	9	20	48	88	112
Days	19	20	19	14	15	9	9	11	11	12	14	13

2.4 Water Supply and Demand

Currently the locals depend on water bowsers and rain water harvesting. The already drilled borehole by NGO is quite far thus making it unreliable hence the need for an alternative source: borehole.

3 GEOLOGY

The geology of Kenya's Coastal strip was determined by the rifting and break-up of the Palaeozoic Gondwana continent. Jurassic rifting of a Permo-Triassic basin filled with terrestrialclastic materialinto a pre-marine basin on the eastern edge of the African plate. These clasticsare generically the same as Southern Africa's Karoo sediments. Reworking and uplift led to the deposition of marine and Peri-marine sediments, culmination in an erosive hiatus from Cretaceous to mid-Neogene times (the Pliocene). Fresh uplift led to the deposition of fluviatile pebble beds, gravels and sands of the Magarini Formation on older competent sediments. At Pleistocene times, sea level changes led to transgressions and regressions, leaving behind raised sands and fossil coral limestones (Horkel et al., 1984).

Locally, L.A.J Williams (1953-1956) shows that the site lies on Marafa Beds which are poorly consolidated river gravels and sands (Lower Pleistocnene) of Pleistocene age coded **Pl**. The water bearing formation is expected within the wet sands and wet clays. The area overlies the Fundisa limestone which is yellow limestone, fine grained calcareous sandstone and marls of the Miocene age. An excerpt from L.A.J Williams (1953-1956) geological map is seen below.

It is the second and youngest epoch of the Neogene Period in the Cenozoic Era. The Pliocene follows the Miocene Epoch and is followed by the Pleistocene Epoch. Prior to the 2009 revision of the geologic time scale, which placed the four most recent major glaciations entirely within the Pleistocene, the Pliocene also included the Gelasian stage, which lasted from 2.588 to 1.806 million years ago, and is now included in the Pleistocene

Table 1: Geological Time Scale

ERA	PERIOD			LOCAL REPRESENTATIVE	LITHOLOGY AND THICKNESS	ENVIRONMENT OF DEPOSITION
CAINOZOIC	QUATERNARY	RECENT		River Deposits	Alluvium	-
		PLEISTOCENE		Coral Reef Lagoonal Deposits	Reef Limestone Calcareous Sands Quartz Beds	Marine and lagoonal
	TERTIARY	PLIOCENE		Magarini Sands	Sands and Gravels	Deltaic and continental
		MIOCENE				
		OLIGOCENE				
		EOCENE				
MESOZOIC	CRETACEOUS		UPPER			
			LOWER	Freretown Limestone	Limestone and Shales	Marine
	JURASSIC			Changamwe Shale Coroa Mombasa Limestone Miritini Shale	Limestones, Sandstones and Shales	Marine and (?) estuarine
			MIDDLE	Kibiongoni Beds Kambe Limestone		
			LOWER			
	KAROO	TRIASSIC	UPPER	DURUMA SANDSTONES: Shimba Grits Mazeras Sandstone	Grits and Arkosic Sandstones	Continental and deltaic
			LOWER	Mariakani Sandstones Maji-Ya-Chumvi Beds	Thin Sandstones and Shales	Lacustrine; one marine intercalation
PALAEOZOIC		PERMIAN	UPPER	Taru Grits	Grits and Arkosic Sandstones	
			LOWER			
		CARBONIFEROUS	UPPER			
ARCHEAN	BASEMENT SYSTEM			ARCHEAN	Gneisses and Shales	ARCHEAN

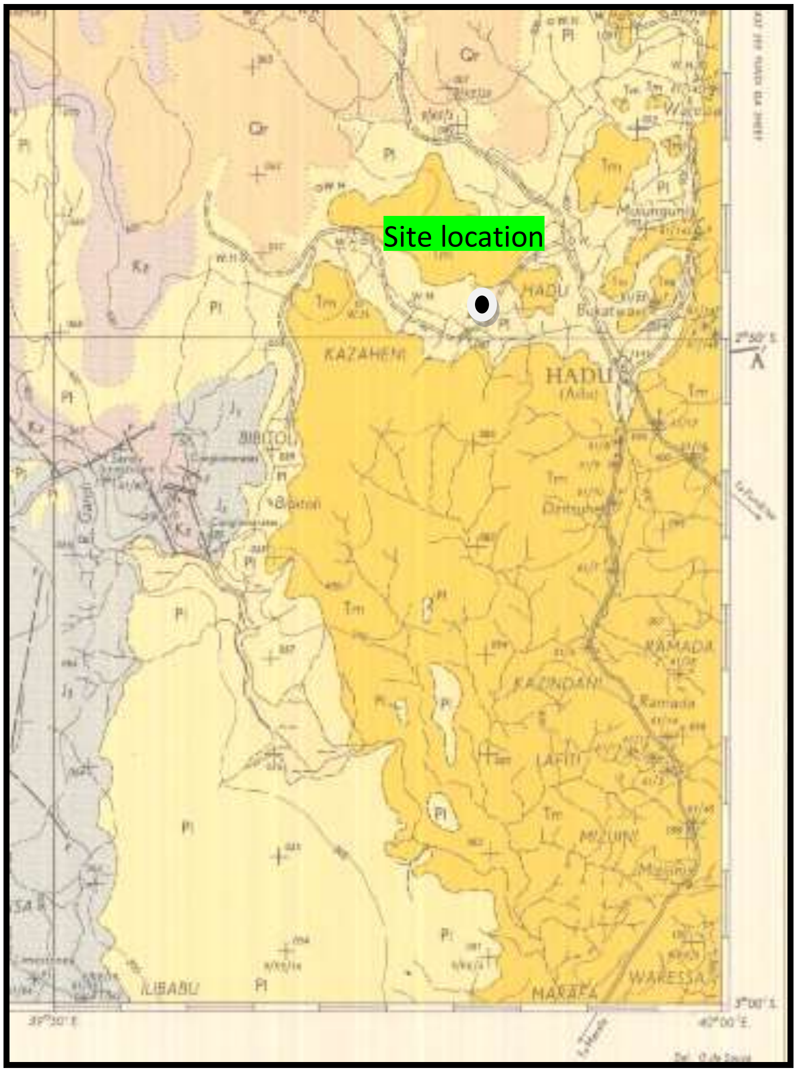


Figure 3: Geology of Investigated Site and surrounding areas

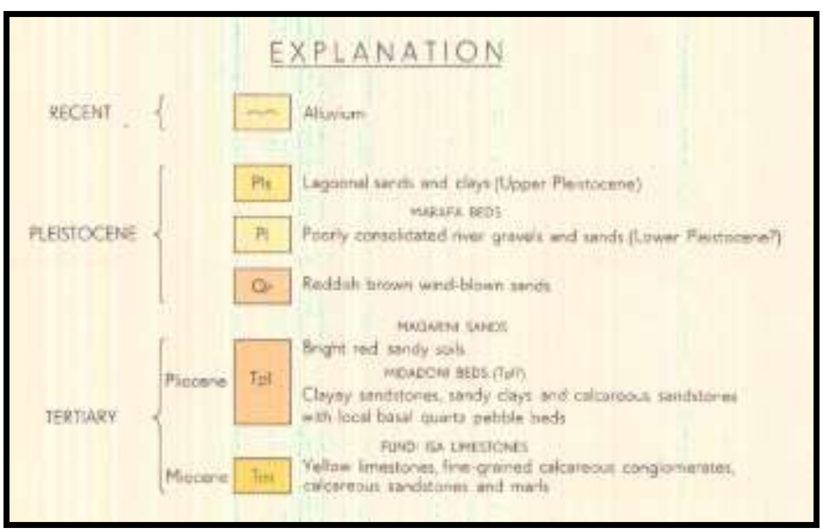


Figure 4: Legend

4 HYDROGEOLOGY

4.1 Background

The hydrogeology of an area is determined by the nature of the parent rock, structural features, weathering processes and precipitation patterns. Within sedimentary beds, lithological contacts and Old Land Surfaces (OLS) which characterize periods of erosion are potential aquifers. In most sedimentary beds, groundwater occurs within the **pores**.

4.2 Regional Hydrogeology

Within the area, the clays are characterized by poor interconnectivity of pores which subsequently results into low permeability hence poor discharge and recharge of the aquifers in this region. With a mean rainfall figure close to 800mm, and a geology marked by sediments, the general potential for groundwater development can be termed as fair. Potential aquifers thus occur within

- Wet sands
- Wet clays

4.3 Boreholes in the Immediate Vicinity of the Area.

There are no documented boreholes around the area. Though there are boreholes that have been drilled recently but details are missing.

Description of columns

A. Ministry of Water Resources Identification Number (lowest numbers represent oldest holes)
B. Owner
C. Distance in km from selected BH site
D. Total drilled depth in meters below ground level (m bgl)
E. Water Struck Level 1, 2 and 3, depth at which the aquifer was encountered, in meters below ground level (m bgl)
F. Water Rest Level, depth of piezometric surface, or water table, in meters below ground level (m bgl)
G. Tested yield in m^3/hr

4.3.1 Borehole Data Analyses.

From the boreholes drilled in Adu,(which details were not present during the time of survey), the aquifers are located wet sands

4.3.2 Impacts to Abstraction Trends and Analyses of Boreholes we there wiithin 800-m from the Proposed Site

Since there are no analyzed boreholes which is located within 800m radius, thus no hydraulic interference in abstraction trends to the existing boreholes is envisaged.

4.4 Recharge

The recharge mechanisms (and the rate of replenishment) of the local aquifers has not been fully established. The two major processes are probably direct recharge at surface (not necessarily local) and indirect recharge via faults and/or other aquifers.

Direct recharge is obtained through downward percolation of rainfall or river water into aquifer. If the infiltration rate is low due to the presence of an aquiclude (such as clay), the recharge to the aquifer is low. Percolation will depend on the soil structure, vegetation cover and the state of erosion of the parent rock. Rocks weathering to clayey soils naturally inhibit infiltration and downward percolation. Aquifers may also be recharged laterally if the rock is permeable over a wide area.

In the present study area, the principal recharge is through direct recharge at surface (percolation) through the pores of the existing sand formation. The investigated area probably receives high rainfall.

4.4.1 Mean Annual Recharge

Rainfall within the study area is average (300 mm) and regional recharge is of great essence in this area followed by base flow within the porous sands that characterize the region.

At the present location, water also percolates directly into the faults, fractures, local rivers and streams (via fractures) thus deeper and adjacent units are recharged over time.

Mean Annual Recharge has therefore been estimated as follows:

The Recharge is estimated as 5% of the Mean Annual Rainfall of the recharge area

300mm x 5%

Mean Annual Recharge = 15 mm

However, this recharge amount is probably estimation due to the possibility of influent regional recharge through the pores of the characteristic sand formation.

4.5 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 as form of discharge is not much pronounced.

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

4.6 Aquifer Properties.

4.6.1 Problems Associated With Calculation of Aquifer Properties.

Very little information is available concerning the aquifer characteristics in this area. It is not possible for example to determine if proper pump test were carried out on the existing borehole since some data of the analyzed borehole are missing.

Thus, in absence of proper pump test data, the **Logan method of approximation** has been employed (Logan, 1965). This method however has errors of 50% or more and is thus used for estimation purpose only.

4.6.2 Estimation Aquifer Transmissivity

Aquifer Transmissivity (T) is estimated as follows:

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

4.6.3 Hydraulic Conductivity

The Hydraulic Conductivity (K) is estimated as follows:

K = T/Aquifer Thickness

4.6.4 Specific Capacity

The aquifer Specific Capacity (S) = $Q/\Delta s$.

Where: **Q = Discharge (m^3/day)**
Δs = Drawdown (m)

4.7 Water Quality Considerations

When deposition occurs in a land-locked basin under conditions of semi-aridity, evaporation of the connate water occurs with the consequent precipitation of mineral salts, mainly carbonates, chlorides, and sulphates. These are disseminated throughout the succession with varying degrees of concentration and, being partly soluble, are readily re-dissolved by meteoric groundwater; hence the water derived from these beds is liable to be saline.

Groundwater may be classified based on salinity as shown in Table 4.3 below.

Table 2: Groundwater Classification Based on Salinity

Category	TDS (ppm)	EC (µS/cm)
Fresh water	0-1,500	0-2,000
Brackish water	1,500-10,000	2,000-15,000
Saline water	10,000-100,000	15,000-150,000
Brine	>100,000	> 150,000

TDS : Total Dissolved Solids (in parts per million = mg per liter)
EC : Electrical Conductivity in micro Siemens per cm

Table 3: Salinity Limits for Groundwater Use

EC (μS/cm)	TDS (ppm)	Use/Limitation
< 2,000	< 1,500	Potable water
> 2,000	> 1,500	Unsuitable for domestic purposes
2,000-3,000	1,500-2,000	Generally too salty to drink but still fit for livestock
> 3,000	> 2,000	Generally unfit for dairy cattle and young cattle
> 7,000	> 4,500	Unfit for grazing cattle and sheep

4.8 Groundwater Movement

Groundwater will always flow towards the area with the lowest piezometric head. For this area, this base level is ultimately found east of the investigated site.

With respect to the potential for faults to create aquifers and to recharge the aquifers, it is very important to establish whether the faults occurring in the rocks are groundwater barriers or preferential flow paths. The pervious faults have a larger secondary porosity. This macro porosity accounts for a greater mobility of the groundwater. The water stays in contact with the rock for a relatively short period; hence, mineralization stays low. Mobility in the (primary) micropores, on the contrary, is low. The groundwater in these pores will be highly mineralized by dissolved salts.

4.9 Rainfall, Percolation and Recharge

Assuming that suitable storage media exist below the ground, aquifer potential is also affected by the mechanisms of percolation of rainfall or river water down to the aquifer. If the infiltration capacity is low due to the presence of an aquiclude like clay/shale, the recharge to the aquifer is low.

Percolation will depend on the soil structure, vegetation cover and the permeability of the rocks. Clayey/shale formations naturally inhibit percolation. Aquifers may also be recharged laterally if the rock is permeable over a wide area.

5 GEOPHYSICAL INVESTIGATION METHODS

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

5.1 Resistivity Method

It is sometimes referred to as DC resistivity technique. This method measures the earth's resistivity by driving a direct current (DC) signal into the ground and measuring the resulting potentials (voltages) created in the earth. From that data the electrical properties of the earth (the geoelectric section) can be derived and thereby the geologic properties inferred. The diagram below illustrates the basic electrical array for that measurement.

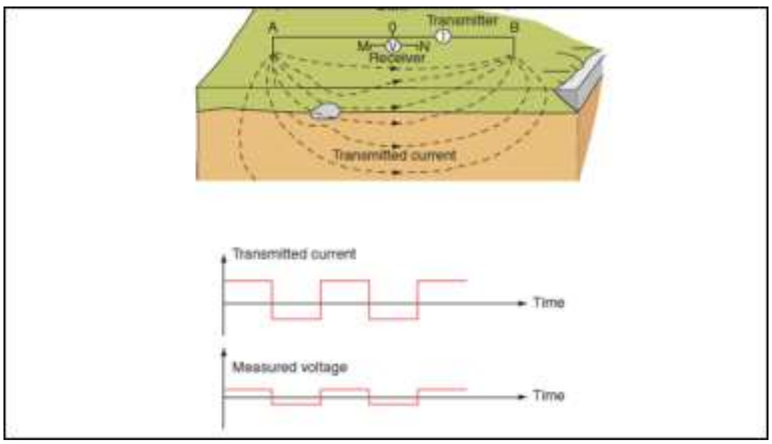


Figure 5: Schematic Diagram of DC Resistivity Method

The figure above is a schematic diagram showing the basic principle of DC resistivity measurements. Two short metallic stakes/current electrodes (AB) are driven about 1 foot into the earth to apply the current to the ground. Two additional potential electrodes (MN) are used to measure the earth voltage (or electrical potential) generated by the current. Depth of investigation is a function of the distance of current electrodes

In this method an electric current is passed into the ground and the potential difference measured to get the Resistivity of the underlying layers

There are many Resistivity arrays used in the field. The one used in this survey was the vertical electrical sounding (VES).

Basic Principles

The electrical properties of rocks in the upper part of the earth's crust are dependent upon the lithology, porosity, the degree of pore space saturation and the salinity of the water. It is imperative to note that:

1. Saturated rocks have lower resistivities than unsaturated and dry rocks.

2. The higher the porosity of the saturated rock, the lower its resistivity.
3. The higher the salinity of the saturating fluids, the lower resistivity of the host media.
4. Clays and conductive minerals also reduce the resistivity of the rock.

The resistivity of earth materials can be studied by measuring the electrical potential distribution produced at the earth's surface by an electric current that is passed through the earth.

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

$$R = Rs * L/A \quad \text{(Ohm)} \quad (1)$$

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

$$R = dV/I \quad \text{(Ohm)} \quad (2)$$

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

$$Rs = (A/L) * (dV/I) \quad \text{(Ohm.m)} \quad (3)$$

5.2 Horizontal Electrical Profile (HEP)

In horizontal Electrical Profile, lateral changes in resistivity are measured at a given depth depending on the values of AB and MN where AB is the distance between the current electrodes and MN is the distance between the potential electrodes. The direction in which a profile is taken is always across the fault line. The profile would therefore detect this regions and a VES would be done at the appropriate areas to confirm the presence of water. In the Wenner configuration, the current and potential electrode pairs have a common mid-point and the distances between adjacent electrodes are equal, so that $r_{AB} = r_{BC} = r_{CD} = a$, and $r_{AC} = r_{BD} = 2a$ (Telford *et al.,* 1990).

$$\rho = 2\pi\frac{V}{I}\left\{\left(\frac{1}{a}-\frac{1}{2a}\right)-\left(\frac{1}{2a}-\frac{1}{a}\right)\right\}^{-1} \text{.................................. (5.1)}$$

$$\rho = 2\pi a\frac{\Delta V}{I} \text{.. (5.2)}$$

5.3 Vertical Electrical Soundings (VES)

Consider an arrangement consisting of a pair of current electrodes and a pair of potential electrodes. The current electrodes A and B act as source and sink, respectively

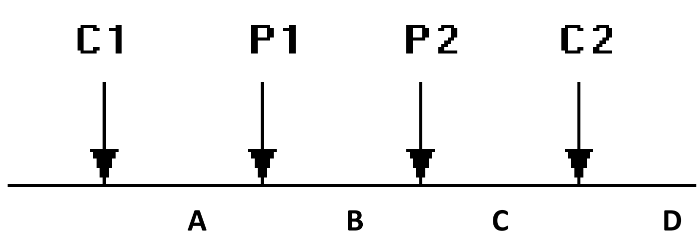


Figure 6: Conventional array with four electrodes to measure the subsurface resistivity.

At the detection electrode C the potential due to the source A is

$+\rho I / [2\pi r_{AC}]$………………………………………………………… (5.3)

While the potential due to the sink B is $-\rho I / [2\pi r_{AC}]$ (Lowrie, 2007)……………… (5.4)

The combined potential at C is $U_C = \frac{\rho I}{2\pi}\left(\frac{1}{r_{AC}} - \frac{1}{r_{CB}}\right)$……………………………… (5.5)

Similarly, the resultant potential at D is

$U_D = \frac{\rho I}{2\pi}\left(\frac{1}{r_{AD}} - \frac{1}{r_{DB}}\right)$…………………………………………………… (5.6)

Where,

$r_{AC}, r_{CB}, r_{AD}, r_{DB}$ is the distances from the array centre to the electrodes

The potential difference measured by a voltmeter connected between C and D is obtained by subtracting equation 5.5 from equation 5.6

$$\Delta V = \frac{\rho I}{2\pi}\underbrace{\left[\left(\frac{1}{r_{AC}} - \frac{1}{r_{CB}}\right) - \left(\frac{1}{r_{AD}} - \frac{1}{r_{DB}}\right)\right]}_{G} \quad (5.7)$$

Making ρ the subject of the formula,

$\rho = \frac{2\pi \Delta V}{IG}$………………………………………………………………………………… (5.8)

$\rho = (2\pi / G) \times (\Delta V / I)$…………………………………………………………………… (5.9)

But $(2\pi / G)$ is a constant, k. The substantial formula for apparent resistivity reduces to

$\rho = \kappa \Delta V / I$………………………………………………………………………………… (5.10)

Where:

I=current.

ΔV= potential difference.

ρ = resistivity.

k = is the geometric factor for the electrode array in use and obtained by:

$\kappa = \frac{2\pi}{l}(L^2 - l^2)$ (Lowrie, 2007)……………………………………………… (5.11)

Where:

L is the current electrode separation AB/2 in metres.

l is the potential electrode separation MN/2 metres

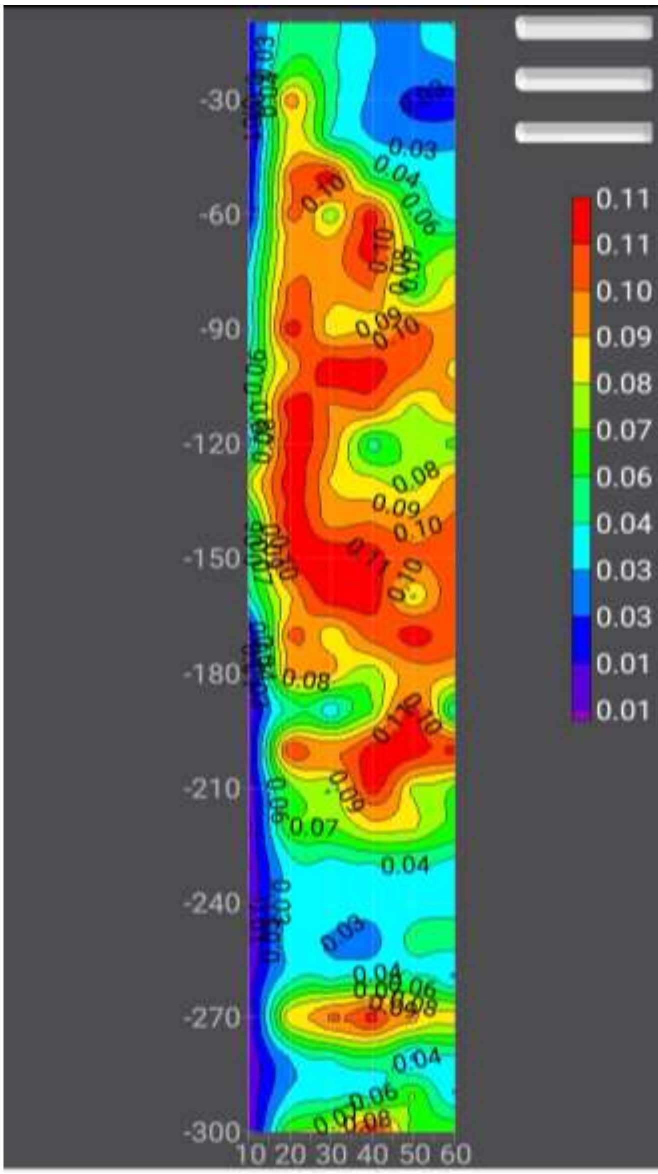
5.4 Principle of ADMT-300S working principle of the instrument

The ADMT series instrument use natural electromagnetic field of the earth as working field source to study the electrical structure inside the earth. According to the principle that different frequencies of electromagnetic waves have different skin depths in the conductive coal, the subsurface is measured high frequency to low frequency Earth electromagnetic response sequence studies the different in electrical variation of geological bodies at different depths in subsurface and determines the occurrence of underground geological bodies.

6 FIELDWORK AND RESULTS

Field work comprising of two Profile survey were carried out on 20th May 2020. The aim of the sounding was to determine the prevailing hydrostratigraphy at the site.

6.1 VES 1 Geo-electric Layers, Sounding curve and Interpretations



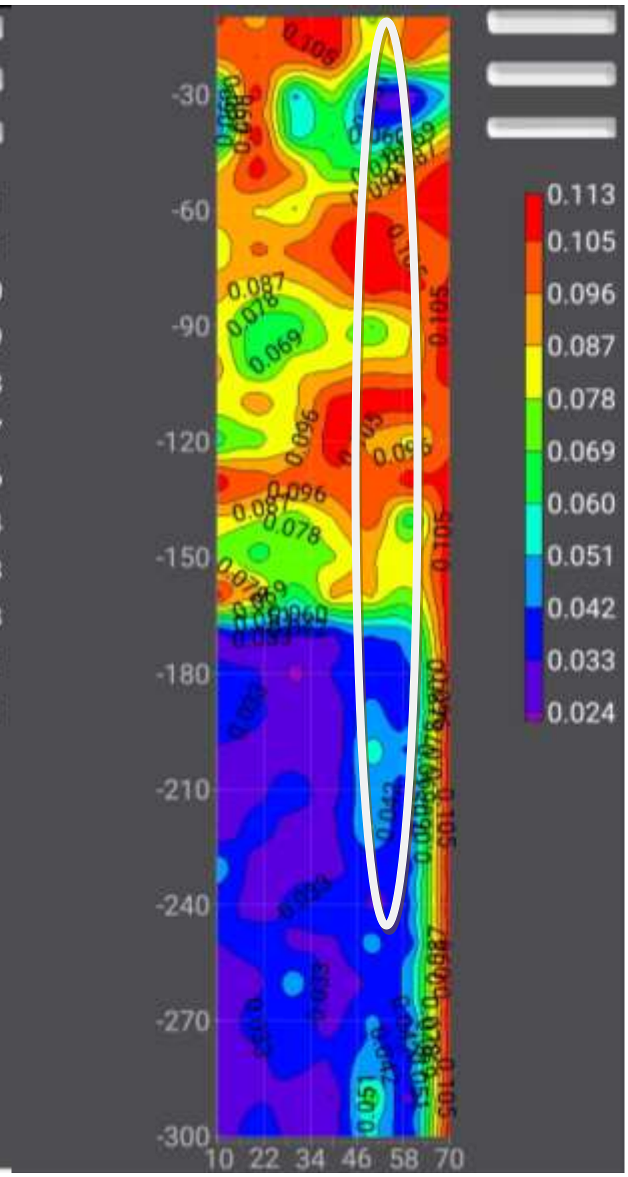


Figure 7:Profile 1

Figure 8: Profile 2

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Based on the available information and the geophysical investigations around the area, it is concluded that the investigated area is located in an area with fair groundwater prospect. Recommendations

- If a borehole is to be drilled, Drilling should be done to **a depth of 220m at VES 1 (circled on white),** though some aquifers may be encountered at shallow depths of 50m as on the survey above , drilling should continue to the final depth of with an 8” diameter drag bit. Mud drilling could be used during drilling. The water is expected to be slightly saline hence Electric Conductivity Metre should be on site during drilling to monitor the salinity levels.

Good quality mild stainless steel casings and screens should be installed to the final depth in order to penetrate sufficiently the deep aquifers. The borehole should be installed with 6” diameter mild stainless steel casings and screens with slots of 1.5 mm and high % open surface area.

OTHER RECOMMENDATIONS

- Geological rock samples should be collected at 2 meter intervals. Struck and Rest water levels and if possible, estimates of the yield of individual aquifers encountered, should also be recorded.
- A piezometer should be installed in the borehole to enable monitoring of the water level.
- 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 are susceptible to fluorosis if they depend on drinking water with high fluoride concentrations (see Appendix 2).
- A master meter should be installed to record the amount of water abstracted from the borehole.
- A water sample should be collected at the end of the test pumping to be taken to a competent lab for a complete water quality test.
- Additional recommendations on the construction and completion of a borehole are given in Appendix 1.

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Appendix 1: Drilling

Drilling Technique

Drilling should be carried out with an appropriate tool - either percussion or rotary machines will be suitable, though the latter are considerably faster. However due to unstable sub ground condition mud drilling is the most suitable method. Geological rock samples should be collected at 2 meter 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. The final design should be made by an experienced hydrogeologist.

Casing and Screens

The well should be cased and screened with good quality material. Owing to the chemistry of the boreholes, it is recommended to use mild stainless 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 metres 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 well head 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.

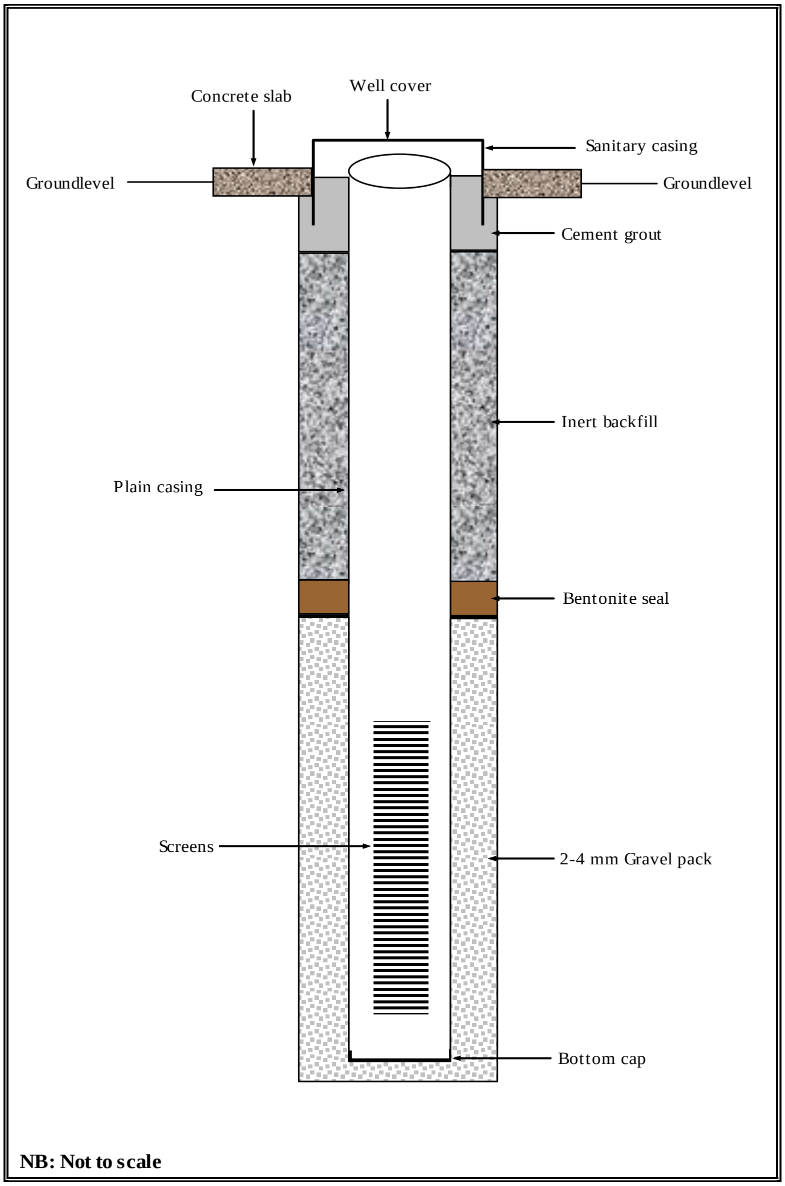
We do not advocate the use of over pumping as a means of development since it only increases permeability in zones which are already permeable. Instead, we would recommend the use of air or water jetting, or the use of the mechanical plunger, which physically agitates the gravel pack and adjacent aquifer 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 step wise during the test. 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:- Acceptable Ionic Concentration – Various Authorities

World Health Organization: European Community: 1983 1971 Int. EC Directive 1980 relating to the quality

Guidelines; Standards; of water intended for human consumption:

Substance or Characteristic	Guideline Value	Upper limit	Guide Level	Max. Admissible	
Inorganic Constituents of health significance;					
Antimony	Sb				0.01
Arsenic As	0.05	0.05		0.05	
Cadmium	Cd	0.005	0.01		0.005
Chromium	Cr	0.05	0.05		
Cyanide CN	0.10	0.05		0.05	
Fluoride F	1.5	1.7		1.5	
Lead Pb	0.05	0.10	0.05		
Mercury Hg	0.001	0.001		0.001	
Nickel Ni			0.05		
Nitrates 10 (as N)	45 (as NO_3)	25 (as NO_3)		50 (as NO_3)	
Selenium	Se		0.01		0.01
Other Substances	GV: Desirable Level:	Highest Permissible Level:	Maximum	GV:	MAC:
Aluminum, Al	0.20			0.05	0.20
Ammonium NH_4				0.05	0.50
Barium , Ba				0.10	
Boron B				1.0	
Calcium, Ca		75	50	100	
Chloride, Cl	250	200	600	25	
Copper , Cu		0.05		0.10	
Hydrogen Sulphide, H_2S	ND				ND
Iron Fe	0.30	0.10	1.0	0.05	0.20
Magnesium Mg	0.10	30	150	30	50
Manganese, Mn	0.10	0.05	0.50	0.02	0.05
Nitrite, NO_2					0.10
Potassium, K				10	12
Silver, Ag					0.01
Sodium, Na	200			20	175
Sulphate, SO_4	400	200	400	25	250
Zinc, Zn	5.0	15	0.10		
T D S	1000	500	1500		1500
Total Hardness as $CaCO_3$	500	100	500		
Colour °Hazen	15	5	50	1	20
Odour Inoffensive	Unobjectionable				2 or 3 TON
Taste Inoffensive	Unobjectionable				2 or 3 TON

Turbidity (JTU)		5	5	25	0.4	4
pH		6.5 - 8.5	7.0 - 8.5	6.5 - 9.2	6.5 - 8.5	9.5 (max.)
Temperature^{o}C					12	25
EC	uS/cm				400	
Notes	ND - Not Detectable		IO - Inoffensive			
	GL - Guide Level	UO - Unobjectionable				

(Based on Table 6.1, in Twort, Law & Crowley, 1985).

APPENDIX 3: Fluoride in Groundwater

(Source: Endemic Fluorosis in Developing Countries, 1991, J.E. Frenken, editor, TNO Institute for Preventive Health Care, The Netherlands)

Introduction

Fluoride is an essential constituent of the human body where it concentrates mainly in bones and teeth. A deficiency as well as an excess of fluorine may have negative effects on someone's health. Excessive intake of fluorine may lead to Fluorosis, a disease associated with dental and skeletal deterioration.

Especially for drinking water purposes these high concentrations form a limitation. In this appendix the aspects of fluoride in groundwater e.g, the source of fluoride, the health hazard of high fluoride concentrations and fluoride removal methods, will be discussed briefly.

Sources of Fluoride

Fluoride (F^-) is an ion of the chemical element fluorine (F). The elemental form does not occur in nature due to the electro-negativity and high chemical reactivity.
The geochemical behavior of fluoride is similar to that of the hydroxyl ion (OH^-).

Fluorine bearing minerals are found in igneous, sedimentary and metamorphic rock. Especially in contact metamorphic rocks high concentrations are found. The main fluorine bearing minerals are listed in the Table below.

Fluorine bearing minerals

Group	Examples
Silicates	Amphiboles, Micas
Halides	Fluorite, Villiaumite
Phosphates	Apatite
Others	Aragonite

The most important mineral containing fluorine is fluorite (CaF_2). Furthermore volcanic gases may contain fluorine; examples are HF, SiF_4 and H_2SiF_6.

Other sources of fluorine are related to pollution caused by agricultural and industrial activity (use of phosphatic fertilizers, processing of phosphatic raw materials).

Furthermore fluoride concentrations in water are determined by weathering processes (CO_2 pressure, hydrothermal activity), evaporation and calcium concentration. At low calcium concentrations (in environments with high alkalinity and when calcite limits calcium concentrations) fluoride can not be equilibrated by fluorite solubility and can reach very high concentrations.

In volcanic areas without hydrothermal activity the fluoride concentrations are mainly determined by the weathering of amphiboles or volcanic glass. Both are important constituents of phonolites. Volcanic tuffs on an average have a higher content of soluble volcanic glass than phonolites.

Health hazard of fluoride

The prevalence and severity of dental and skeletal fluorosis is depending on many factors but the most important risk indicator will be fluoridated drinking water. Results of several investigations show that especially children are susceptible to fluorosis if they depend on (drinking) water with high fluoride concentrations. The results indicate that mild dental fluorosis can occur when concentrations of 0.4 ppm are considered. More serious problems occur at fluoride concentrations of 2.1 ppm (100 % prevalence of dental fluorosis in age group 10 - 15 years) and 3.6 ppm (skeletal changes in 11 - 15 years old). Above 10 ppm skeletal deformities may occur in children.

The World Health Organization uses the guideline limit of 1.5 ppm fluoride. This limit is based on the assumption that people consume only 2 liters of water per day. This assumption seems to be rather low since people, especially in countries with hot climates, consume more than 2 liters per day. The recommended WHO concentration limits together with the possible effects are listed in the Table below.

Fluoride contents in drinking water and possible effects (WHO)

Concentration Fluoride ppm	Possible effects
0.5 - 1.5	Fluoride in water has no adverse effects, incidence of caries decreases
> 1.5	Mottling of teeth may occur to an objectionable degree e.g. dental fluorosis incidence of caries decreases
3.0 - 6.0	Association with skeletal fluorosis
> 10.0	crippling skeletal fluorosis

Results of investigations in tropical areas suggest a maximum recommended level of 0.6 ppm more appropriate for tropical regions. Above this value mottling of teeth may occur.

Some countries however use higher permissible or maximum recommended levels, simply because of the absence of water with lower concentrations. The maximum permissible level in Tanzania is 8 ppm, while the Kenyan maximum permissible level is set at 1.5 ppm.

Removal of fluoride from groundwater

Especially during the last decade several methods have been developed to remove or reduce the fluoride concentration in drinking water. However most of the methods are rather complicated and expensive and are still in the laboratory or experimental stage. The methods are mainly based on:

- Precipitation (use of lime, alum, sulphate, gypsum, etc)
- Adsorption / ion exchange (use of bones, charcoal, clays, etc)
- Osmosis
- Electrochemically stimulated coagulation
- Electrodialysis

Although the methods are still in the laboratory phase, the application potential for the bone char, gypsum / fluorite and clay method are rather good. These methods are simple and the raw materials are often available at the site. The methods can be applied at household and community level.

The *gypsum / fluorite* method can reduce the fluoride concentrations to 4 ppm only. More advanced steps are necessary to reduce the concentrations below 1.5 ppm. The basic principle of the method is the dissolution of gypsum in drinking water with high fluoride concentrations. Fluoride concentrations will be reduced due to the precipitation of fluorite according the following reaction:

$$CaSO_42H_2O + 2F^- \text{--->} CaF_2 + SO4^{2-} + 2H2O$$

Fluorite will precipitate as soon as the water is saturated with fluorite. The equilibrium constant for fluorite:

$$CaF_2 \text{<---->} Ca^{2+} + 2F^- \qquad K = 10^{-10.7}$$

The water is saturated as soon as:

$$SI = \log ([Ca] * [F]^2 / K) ³ 1$$

Bone media has been used successfully to remove fluoride. Reductions of the fluoride concentration to less than 1.0 mg/lit are reported.

The principle of the method is based on the fact that the bone media is reacting with fluoride in a similar way as bones and teeth of the human body. The fluoride is immobilized in the filter medium through the process of ion exchange.

The equipment used in laboratory and field tests is rather simple. The defluoridator unit consists of a container and a filter. The filter has a bottom layer of 300gr crushed charcoal for adsorption of color and odor. The middle layer consists of 1000gr bone media. At the top 200gr of pebbles are used to prevent the middle layer of floating. The bone media can be either granulated bone media or bone char. In both cases the material has to be pretreated carefully to optimize the results. For the granulated bone media, the bones selected have to be clean, non porous and crushed into chippings of 1 to 2 mm. For the bone char the bones have to be activated by heating to a temperature of 600^{o}C. For both methods it is advised to treat the bone media with sodium hydroxide before it is used.

The time over which the filtering material remains active depends on the amount of water which has been treated and the initial fluoride content. In experiments in Argentine (contact time necessary to allow fluoride to chemically combine with granulated bone media amounted to 0.5 hours) the filter had to be replaced every 3 months at a production of 20 l/day and an initial concentration of 10 ppm.

Different *types of clay* have been used in laboratories to reduce the fluoride contents. Kaolinite, serpentinite, china clay and clay pot are used as natural adsorbents. Reductions from 10 ppm to 1.5 ppm and lower are reported.
For this methods Ph, temperature and/or salt content should be maintained at a level predetermined through laboratory experiments.

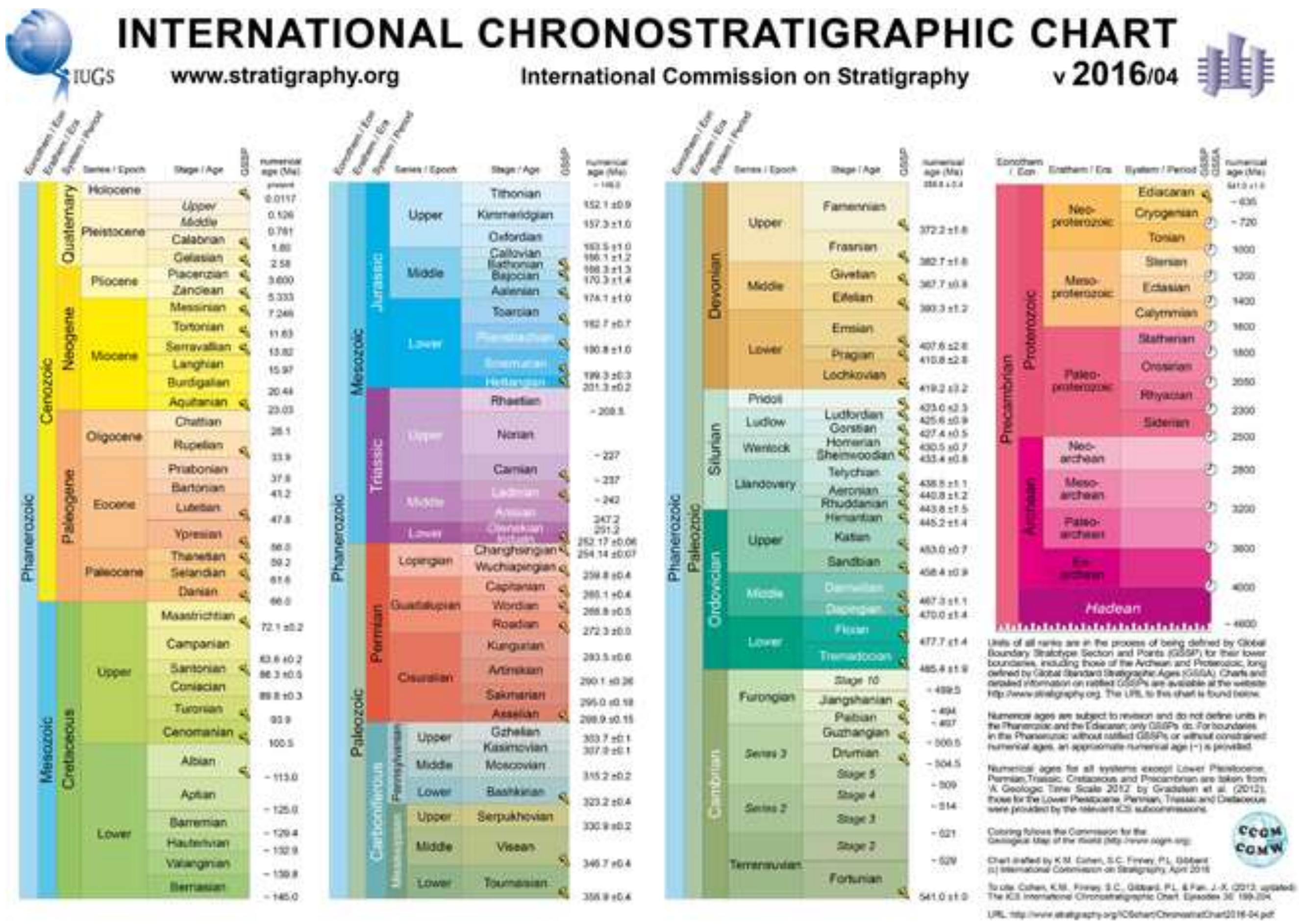
Conclusions and recommendations

High fluoride concentrations in drinking water may cause dental and / or skeletal fluorosis. The maximum recommended levels differ per country; the recommended WHO limit is 1.5 ppm. In fact the maximum advisable level depends on factors such as diet, climate and age.

Nevertheless it can be concluded that especially children are susceptible to fluorosis. Therefore it is recommended not to use borehole water with fluoride concentrations exceeding 0.5 ppm as drinking water for children. The recommended maximum level for adults is 1.0 ppm. These levels only have to be considered when the borehole water is used as a permanent source for drinking water.

The equipment for the removal of fluoride from drinking water is not yet available for domestic purposes but future prospect are good.

7.1.1.1 Geological Time Scale1



[1] Cohen KM, Finney SC, Gibbard PL and Fan JX 2013: **The ICS International Chronostratigraphic Chart**. *Episodes* 36(3), 199-204. September 2013.