SALINITY OF BOREHOLE WATER IN KITUI TOWN

SGL 413: PROJECT IN GEOLOGY

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ABSTRACT

Salinity in boreholes has been a major concern in ASAL and coastal region of Kenya. Most parts Eastern are dry and mostly Kitui County is Semi-arid and most of the boreholes drilled in this area arefound to be saline. Groundwater resources is the only water supply in most parts of the county especially North and central Kitui.

This report outlines approaches that were used to determine possible causes of salinity in boreholes, their levels, and finally recommend possible remedial measures that can be put in place. Several approaches were used in order to achieve objectives of this project.

Data from boreholes spread over the entire project area were analyzed, discussed among colleagues and conclusions made over the results.

The study area is covered by topographic map   having an area of approximately km^2 with a population of about   people. The study area is accessible since there are several newly built tarmac roads in the town and also through the main tarmac Kitui to Syongila where it branches to join Mombasa road and the other Thika road.

Groundwater resource is the main source of water for both domestic and livestock since there are only two major river traversing this vast area (Kalundu river and Mutendea River) which are highly polluted.

The history of boreholes in kitui

The first borehole was made in 1950's and was called the Kitui borehole which was 340ft deep.the pumped groundwater was of good quality and not saline., capacity of the pump was 23-36cubic metres per hour.The storage capacity of kitui aquifer was estimated to be 1000 Million cubic metres, monthly maximum withdrawal estimation is 15,500 cubic metres. According to WatManSup Report no. 2 of November 2006 by A van Loon and P. Droogers.

Groundwater has become the main source of water in the modern world due to high population growth and high demand for water. Since surface water has been over-stretched, the importance of groundwater as a source of water for human consumption, agriculture and industrial purposes is in every country. For the safety of groundwater users, tracing and identifying sources of pollution which pose a contamination threat to subsurface waters is very vital. Groundwater is multidimensional concept and is characterized by location, occurrence over time, size, aquifer properties and accessibility.

Seasonal rivers are not reliable since most of them dry up immediately after the rain season.

This is due to encroachment on catchment areas and destruction of natural forest for charcoal burning.

Also climate variability has caused unreliable rainfall causing most of the seasonal rivers to permanently dry up.

Climate variability due to global warming has contributed to decline of surface water resource in the study area.

Demand on groundwater resources have increased in the recent past in the study area which has posed a challenge to Water Resources Managers in the region in meeting the Millennium development goals and Vision 2030.

Water is obtained through scooped holes from the beds of seasonal rivers and drilled boreholes during dry seasons, sand dams store water which lasts few more weeks or months after rains stop.

One of the major issues affecting this source in the study area is high salinity rate above WHO standard threshold that render it unsuitable for human consumption and sometimes even for livestock use.

Considering high costs of borehole drilling and scarcity of surface water resources in the study area, there is need to study causes of salinity in borehole and address remedial measures that can be put in place to alleviate the problem.

ACKNOWLEDGEMENT

DEDICATION

I dedicate this project report to the Regional Surveyor of a certain region in Nyanza, my Father who has always been my immediate mentor, thank you for believing that I can do better than you somehow.

Thank you for cracking jokes when I want to give up, they kept me going.

1. INTRODUCTION

Groundwater resource is becoming the main alternative water source especially in ASAL areas which experience low rainfall annually.

Surface water is not reliable since most of streams dries up during dry seasons or if available are highly polluted.

The high rates of population growth in the county have contributed to the encroachment and destruction of the catchment areas which have caused the drying up of water sources.

Climatic variability caused by human activities on the environment has also affected the rainfall patterns in the project area. The destruction of forests for charcoal burning is rampant in the entire area.

Demand on groundwater resource in the recent past has increased.

This has posed a major challenge to Water Resources Managers in the region in achieving the Millennium Development goals.

Most of the boreholes drilled in the project area are saline.

1.0 Background information

Standards for groundwater include quantitative (water flow, amount, recharge and discharge) and qualitative (water quality) standards. The main focus of this study is the Quality. Groundwater quality is the composition of constituents dissolved or contained within the water in the functioning of natural processes and human activities. Chemical composition is the most common factor invoked to characterize water quality; however, biological, physical, and radiological factors should also be considered when describing water quality. According to the Guideline on Groundwater Monitoring for General Reference Purposes of IGRAC, the interest in these parameters differs with the objectives of the analysis. These objectives may be of a general type, for instance "general groundwater characterization" related to the actual situation and the potential for use, or may be more specific, such as conducting studies of groundwater quality under the influence of contamination or remedial measures.

Numerous tests can be run to analyse ground water for its major and trace constituents or pathogenic viruses and bacteria that can occur in groundwater. Several factors are therefore considered in characterization of groundwater quality (see table 1) below.

Table 1 showing chemical and physical characterization ingroundwater quality

Chemical Factors	unit	Physical Factors	Unit
Hardness (Ca^{+2} and/or Mg^{+2})	mg/L	Turbidity	FTU (Formazin Turbidity Unit)
Total Dissolved Solids	mg/L	pH	$pH = -log [H^+]$
Nitrogen (NH_3,NO_3^- NO_2^{-2})	mg/L	Radiological factors	Becquerel (Bq)
Iron (Fe^{+2} and/or Fe^{+3})	mg/L	Temperature	
Sulfur (S^{-2} and/or SO_4^{-2})	mg/L		
Silicates (SiO_2)	mg/L		
Salinity[1]	ppm		

2. PROBLEM STATEMENT

The study area has a number of water yielding boreholes which have been drilled over the years due to the continued demand for water in the area which is caused by high growth of population in the area. This has led to an over-abstraction of the aquifer resulting to lowering of water table. This is evident from lowering of water rest level of the boreholes. This phenomenon has affected the yielding capacity of highly productive borehole to the extent that the upper aquifer level drops.

Water supply to the inhabitants is both insufficient and unreliable. It is being restricted only to domestic use. This has resulted into an acute water shortage with groundwater as the only alternative. Insufficiency and unreliability in groundwater in the area is associated with a substantial change in groundwater quality and quantity (Omole, 2003).

Growing number of aquifer abstraction is seen to exceed recharge.

This has been caused by limited surface water resources in ASAL (Arid and Semi- Arid Land) areas.

Most parts of the project area are semi-arid and it is characterized by rainy seasons that are highly erratic and unreliable. The rain usually falls in a few intensive storms(Nissen-Petersen 1982) there are two rainy seasons, April to June, these are called long rains and October to December are called short rains. In average precipitation of Kitui town is 900mm, some reports say 800mm per year, it fluctuates with time. The area is also known for high temperatures (average daily temperature in ASAL areas is 30°c).

Virtually all of Kitui county total area belongs to Tana River drainage basin. Only a narrow strip along south and southwest border drains to Athi River.

 The only reliable water source in the area is Groundwater which is sometimes found to be saline making it unsuitable for domestic use.

There is construction of sand storage dams across rivers. These assists Kitui town residents to address household and production water scarcity through the sand storage dam technology. Water trapped in these dams was equally found to be saline. The salinity percentage in these dams and in borehole water may or may not be same but it appeared that it is not just underground water that is saline, river water in Kitui town is saline too. This test was done using the Energy dam water.

3. Justification

  Considering high demand for groundwater resources and costs of borehole drilling, this study will address causes that contribute to salinity in boreholes and recommend possible remedial measures.

Objectives

- To assess and test for levels and possible causes of salinity in boreholes.
- To evaluate the trend of salinity in boreholes in the project area.
- To evaluate the effect of geology of the area on salinity in the boreholes.

Chapter two
LITERATURE REVIEW

This project work is based on several reports that address groundwater vulnerability to salinity in ASAL areas in Kenya.

Specifically, the findings from the World Bank Project; Kenya Water Research Infrastructure gaps- May 2003 by Jacobs Gibbs Ltd. under the Netherlands Water Partnership Program. Which states that: **"Salinity in groundwater increases in north eastern and ASAL areas of Kenya due to evaporate deposits and sea water intrusions".**

I also reviewed a report on Pollution and vulnerability of water aquifers in Mombasa-Kenya by Ministry of water and Irrigation March 2004.

According to Wright, pollution and contamination of streams, lakes and underground sources has greatly impaired the quality of water available for use (Wright, 1956). Ground water occurs below the surface which is why its quality is highly influenced by the quality of its source. The formation of underground water partly takes place when under hydrostatic pressure the permeable rocks get saturated with water (Singh and Dhillon, 1994). The character, quantity and quality of groundwater largely depend on the depth of aquifer, permeability of sediments, chemical makeup of sediments and climate variation. Most aquifers in Kenya have hard water as they are associated with hard water aquifer minerals. Limestone and chalk aquifers contain high concentrations of calcium hydrogen carbonate; dolomite aquifers are often rich in sodium chloride (Grey, 1994).

Abdul-Jaber described water quality as chemical, biological, and physical characteristics of the water. The required water quality is determined by the purpose for which the water to be used (domestic, urban, agricultural, or industrial) (Abdul-Jaber et al., 1999). The evaluation of the water, for any purpose, is based on the characteristics of the water compared to a standard for that use. By "standard" is meant the concentration of constituent which causes to negative effect to the health of the consumer over the life of consumption (WHO, 2006).

Groundwater consists of H_2O molecules, dissolved constituents (inorganics and organics), suspended particles (viruses, bacteria, clay minerals and organic aggregates) and non-miscible phase liquids/non-aqueous phase liquids (NAPLs). The inorganic dissolved constituents are subdivided depending on their abundance into major, minor and trace constituents (Walraevens, 2009). The structure of water enhances the solubility of electrolytes, while it reduces the solubility of many polar organic molecules. In a study by Walraevens, he said that groundwater composition is determined by composition and mixing ratio of end members, hydrodynamics or mass transport processes and chemical reactions (Walraevens, 2009). Infiltration of precipitation influences groundwater quality. Rainwater is a subject to evapotranspiration, increasing concentrations of dissolved constituents as they are related to the temperature conditions in the study area. "Solutes contained in natural water represent the net effect of a series of antecedent chemical reactions that have dissolved material from another phase, have altered previously dissolved components, or have eliminated them from solution by precipitation or other processes" (Hem, 1985).

Heath (1987) described the composition and concentration of dissolved substances in uncontaminated groundwater as being derived from the chemical composition of precipitation, the biologic and chemical reactions on the land surface and in the soil zone, and from the mineral composition of the aquifer matrix and confining layers through which water is transported. The author also explained that the quality of groundwater depends both on the dissolved substances in the water and on some definite properties and characteristics conveyed to the groundwater by the same dissolved substances. Three major cations in natural waters are Ca^{2+}, Mg^{2+} and Na^+ while major anions are HCO_3^-, SO_4^{2-}, and Cl^- with concentrations usually higher than 5 mg/L whose concentration determine water hardness

The mineral composition and physical characteristics of soils and rocks affects the movement of pollutants in many ways (Heath, 1987). He further explains that, the hydraulic characteristic of the soils and rocks defines the pathway and the rate of pollutants transportation within the geological formation. Most groundwater pollution is anthropogenic resulting from the disposal of wastes on the land surface, in shallow excavations and septic tanks, use of agrochemicals, leaks in sewers, storage tanks, and pipelines (Heath, 1987). Appelo & Postma (2005) high F- concentrations in groundwater are notably in Asia and Africa. Fluorite quantities as low as 1.5 ppm to 2.5 ppm attacks the enamel of the teeth of children and, in larger amounts, the teeth of animals (Coster, 1960). The author states that toxic action of fluorine is cumulative and consumption of water with a high fluorine content for shorter period like only six months are less harmful compared to low fluoride concentration in water consumed over a long period of time. Apart from groundwater, grass and other vegetable matter in contaminated areas also contain fluorine and their consumption can be harmful as they too contribute to the body fluoride concentration. Hence, it is difficult to assess the danger of excessive fluorine intake from water in fluorite contaminated areas without stating the figures and facts from other countries in order to establish the truth (Coster, 1960).

Kitui first borehole was made in the 1950's and is 340ft deep. In November 2006 the capacity of the pump was23-26 cubic meters per hour. The pump operated 22hours a day, so 400-500 cubic meters was pumped daily except when electricity failed. The storage capacity of kitui aquifer was estimated at 1000 million cubic meters , monthly maximum withdrawal being 15,500 cubic meters and an estimate

natural recharge based on precipitation data for Kitui . the aquifer surface area was/is 200000ha, depth 5meters, specific yield 0.10 and a storage capacity of 1000 million cubic meters, according to an internet report Water Evaluation and Planning System, Kitui-Kenya Report No. 2. The same report states that the first borehole in Kitui known as the Kitui Borehole described above had water of good quality- NOT SALINE.

So going through the data available and all sources I will figure out what changed over the years.

2.1 WHO water drinking standard

WHO's Guidelines for Drinking-water Quality as it was set up in Geneva, 1993, and the recommended international reference point for standard setting and determination of drinking water safety requirement determined. The standards are used in evaluating the sample chemical analysis results and in establishing whether the wells in the study area are suitable for human consumption. WHO drinking water standards of 1993 guidelines enacted in Geneva provides the recommended concentrations of ions in water suitable for drinking purposes. In the guideline, Asbestos, Berillium, dissolved oxygen, TDS and others indicated in the (table 2 below) didn't have specific required concentrations (WHO, 2008).

Table 2 showing WHO standard guidelines on drinking water

Element/substance	Formula	WHO Guidelines
Ammonia	NH_4^-	<0.2 up to 0.3mg/l
Cadmium	Cd	0.003 mg/L
Chloride	Cl	250 mg/L
Chromium	Cr^{3+}, Cr^{6+}	0.05 mg/L
Fluoride	F^-	1.5 mg/L
Lead	Pb	0.01 mg/L
Manganese	Mn^{2+}	0.5 mg/L
Nitrate and nitrite	NO_2^-, NO_3^-	50 mg/L total nitrogen
Sodium	Na	200 mg/L
Sulphate	SO_4^{2-}	500 mg/L
Uranium	U	1.4 mg/L
Iron	Fe	0.5 - 50 mg/L
Arsenic	As	0.01 mg/L
Mercury	Hg	0.001 mg/L

CHAPTER THREE: DATA AND METHODOLOGY

3.0 Research design

The data approach and methodology applied during the research enabled collection of both primary and secondary data. The research design was experimental and involved the use of borehole data to map the probable salinity and trend of salinity of groundwater in the study area.

3.1 Equipment

The research was dependent on both primary and secondary data (geochemical and borehole data).The primary data was obtained from the Ministry of water and irrigation, Kenya while secondary data was acquired through library research. Computer hardware and software such as GIS: Arc map10.1 software, Surfer software, Microsoft word and excel was used in data arrangement, processing and analysis.

3.2 Data acquisition

The data used in this study were acquired from the ministry of water and irrigation, Kenya by Dr. Patrick Kariuki. The data included borehole data and geochemical data sampled from selected boreholes available in the study area.

3.2.0 Borehole data

Borehole data used comprised: Borehole number (BH No.); Borehole depth; Water struck level (WSL) and Water rest level (WRL), drawdown, yield, borehole location coordinates, and elevation which was obtained from Ministry of water and Irrigation, Kenya. Borehole data was processed and analyzed using Surfer 11, Arc Map 10.1 and Excel softwares. These data together with topographical and geological map were used in preparing hydrogeological maps, profiles and graphs used in analysis and interpretation of results.

3.2.1Geochemical data

Geochemical analysis of water sample collected from respective boreholes in the area was done by geochemists and laboratory results of their chemical composition given to the ministry of water and irrigation from which they were obtained for processing and analysis in this project work. The results obtained from the analysis of the processed geochemical data was interpreted and used in classification of the area groundwater quality of the area. The geochemical data was processed and produced using Excel 2010 software to give the graphical representations used in the interpretation.

3.3 Data processing

The materials and software used in data process include:
  - Personal computer hardware.
  - Microsoft Excel 2010 software.
  - Arc GIS: Arc map10 software.
  - Surfer 11 software
  - Microsoft word 2010 software

3.3.0 Digitization

A scanned topographical map of the area was uploaded in Arc map10.1 software, which enables it to be visualized on the screen of a computer. Firstly, the map was geo-referenced and then secondly digitized by obtaining X, Y and Z readings. The X and Y readings are the coordinate values of borehole locations at every intersection between the grid and the contour while the Z readings are borehole depth, transmissivity and mean surface elevation in some cases. These readings were inserted into a spread sheet and uploaded in Arc map10.1 for interpolation and contouring to produce a digital copy of the maps used in this project.

3.3.1 Borehole sampling and analysis

The boreholes were sampled on the basis of accessibility/and availability of well-sites data in Kitui town and its environment. About ten borehole data were collected, with most of the boreholes located lower aquifer whose geological setting is of Neo Proterozoic age, composed of Mozambiquan sediment (lateritic gravel mixed with clays) Limestone is a common mineral in the area. The data were therefore analyzed using appropriate softwares.

3.3.2 Presentation of groundwater analysis

Surfer 11software was used in production and presentation of piezometric and hydrogeological map of the area. Arc map10.1 presented transmissivity map and groundwater distribution map within the aquifer.Microsoft Excel 2010 helped in graphical representation of hydrogeological profile.This was done by creating a post map from the excel sheet data of which parameter of choice is picked and plotted respectively and presented for discussion where it was deemed fit for interpretation. Tabular and graphical presentation of geochemical data analysis was also employed in this work.

3.3.3 Groundwater dynamic

Surfer software program was used in plotting and producing piezometric map. The potentiometric surface map for the lower/deeper semi-confined aquifer was plotted with those of shallow wells/ upper unconfined aquifer and modified manually to fit into almost real ground state, where the river level was incorporated to achieve a realistic discharge system and for understanding the groundwater flow direction by deducing the flow lines.

5.0.1 Processes causing parameter concentrations

#### *5.0.1.0 Origin of F- in groundwater samples*

"Groundwater with low Ca^{2+} content is sub-saturated with respect to fluorite, and fluorite will have the tendency to dissolve" (Coetsiers et al., 2008). He explained that the weathering of feldspar consumes protons and causes a rise in pH making it impossible to attain equilibrium with CO_2 hence more HCO_3^- and CO_3^{2-} is produced while more CO_2dissolves. The precipitation of calcite due to increase in CO_3^{2-} causes a drop in Ca^{2+} making the solution to be sub-saturated compared to fluorite. This leads to fluorite dissolving and its concentrations gets elevated in groundwater. Below is the kind of chemical reactions which may have taken place or which can be used in explaining the processes which led to the concentration of various parameters in the samples analyzed. Dissolution of alumno-silicates with Na-feldspar (albite) as typical representative:

$$2NaAlSi_3 O_8 + 2H^+ + 9H_2 O = Al2Si_2 O_5 (OH)_4 + 2Na^+ + 4H_4 SiO_4,$$ (Appelo & Postma, 2005).
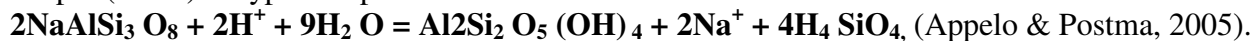
Due to consumption of H^+ by the above reaction, pH is raised thus more CO_2 is dissolved in groundwater. Raising HCO_3^- and CO_3^{2-} concentration in groundwater helps in keeping the equilibrium with constant partial pressure of CO_2.

$$CO_2 = CO_{2(aq)} + H_2 O = H_2 CO_3 = HCO_3^- + H^+$$

$$HCO_3^- = CO_3^{2-} + H^+$$
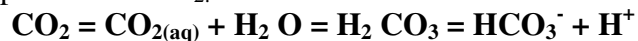
Therefore, at a certain moment, SI of calcite will be exceeded (> 0) (SIcalcite = (Ca^{2+}) (CO_3^{2-})) and calcite will precipitate. Coetsiers et al. (2008) stated that the Ca^{2+} concentration in groundwater is regulated by the calcite equilibrium. The authors further explained that the increase in pH and alkalinity in groundwater deters equilibrium to be attained with calcite and calcite precipitating according to the reaction below.

$$Ca^{2+} + CO_3^{2-} = CaCO_3$$
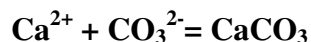
This precipitation of calcite lowers Ca^{2+} in groundwater. This impact heavily on attaining equilibrium with fluorite, hence leading to dissolution of fluorite as the groundwater SI of calcite is < 0. The solubility of fluorite is shown by the following reaction:

$$CaF_2 = Ca2+ + 2 \ F^- \ (1)$$
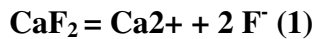
The dissolution can be affected by temperature, pressure, ionic strength, particle size, polymorphism, complexing capacity of the solution and kinetic barriers (Nordstrom & Jenne, 1976). For the simplification of the problem, the authors proposed an assumption of equilibrium conditions with no particle size effects. The negative log of the equilibrium constant, *K,* for reaction (1) is;

$$pK = -log \ K = -log \ (a_{Ca},^{2+}) \ (aF^-)^{\,2}$$

Where the equilibrium concentrations are expressed in terms of the activities of dissolved calcium (aCa^{2+}) and dissolved fluoride (aF^-), and because the activities are used instead of concentrations, ionic strength effects are taken into account (Nordstrom & Jenne, 1976).

According to Nordstrom & Jenne (1976) complexing is time and again the single most important factor which determines the total concentration of fluorite dissolution. The authors further stated that upon the dissolution of fluorite, the ions may associate with themselves to form a mono-fluoride complex:

$$Ca^{2+} + F^- = CaF^+$$

Observation made on (figure 3 below) shows that Ca^{2+} concentration is low on deep wells compared to shallow wells while F^- concentration is randomly distributed but higher in shallow wells compared to deep wells.**Figure 1 plot of Ca^{2+} against F^-**
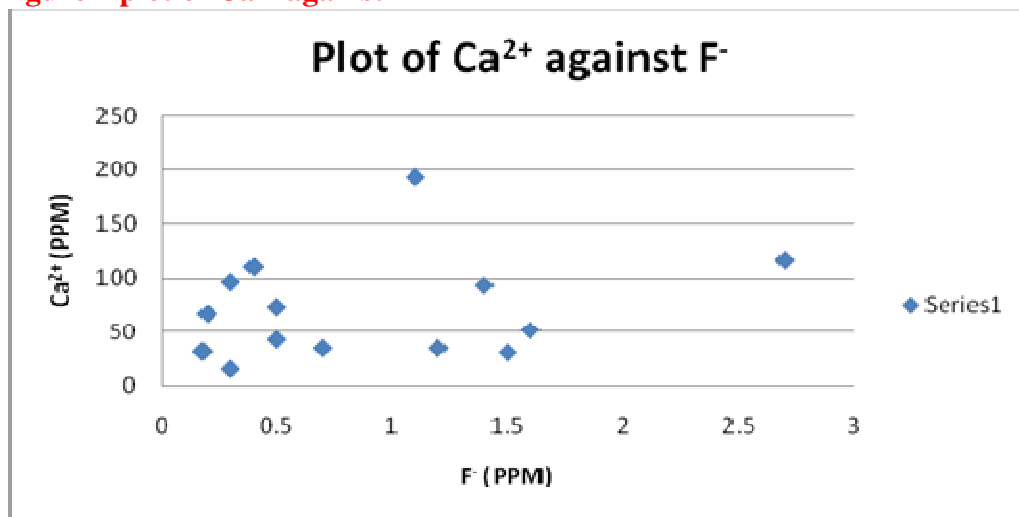
Ca^{2+} and F^- have an inverse linear relation, such that when one is higher the other is low, this so because fluorite will precipitate from solution where both exist in high concentrations. The solubility product of CaF_2 is the upper limit for the concentration of Ca^{2+} and F^- in water. Due to abundance of carbonate bearing rocks like limestone in the area, which commonly is the major source of Ca^{2+}, there's absence of F^- in the region as compared to central region of Kenya where it is abundant which resulted from the volcanic activities associated with the Rift valley formation, this results in conditions of F^- deficit leading to the development of the $NaHCO_3^+$ water type as more Na^+ are released through alumino-silicate weathering.

It was also noted by Coetsiers et al. (2008) who concluded that the weathering of Na-rich volcanic rocks increases pH which in turn triggers the dissolution of CO_2. The consequent increase in HCO_3^- and CO_3^{2-} causes saturation in the groundwater compared to calcite, leading to the precipitation of this mineral. The authors further explained that this precipitation lowers the F^- concentration in solution and leads to sub-saturation for calcite in the system.

Figure 4 below shows that increasing Na^+ concentrations are accompanied by increasing HCO_3^-. These two ions are the major components of dissolved solids in the study area and form the majority of the water type
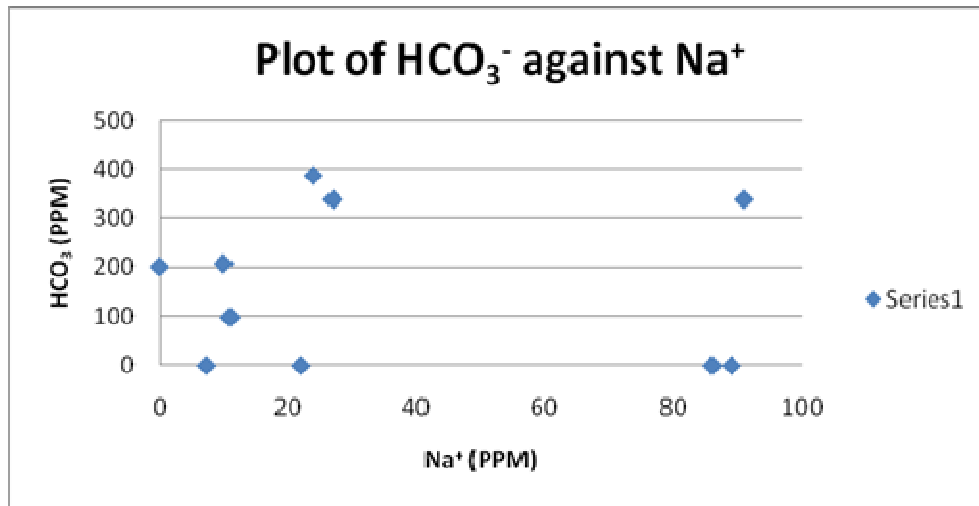

Figure 2 plot of HCO_3^- against Na^2

This figure4 shows a variation which supports the discussion on the possible weathering processes taking place in the study area that, H^+ consumption in the weathering process of alumino-silicate leads to pH increase raising $HCO3^-$ and $CO3^{2-}$ in solution due to CO_2 dissolution in groundwater. Since the weathering produces Na^+ and CO_2 dissolution produces HCO_3^- their linear relation in the study area is justified as both processes are concurrent.

5.0.1.1 Anthropogenic pollution
The quality of groundwater in the area is influenced by human activities. To examine the influence of possible anthropogenic pollution, NO_3^- and Cl^- concentrations are plotted together against each other in figure 5 below.
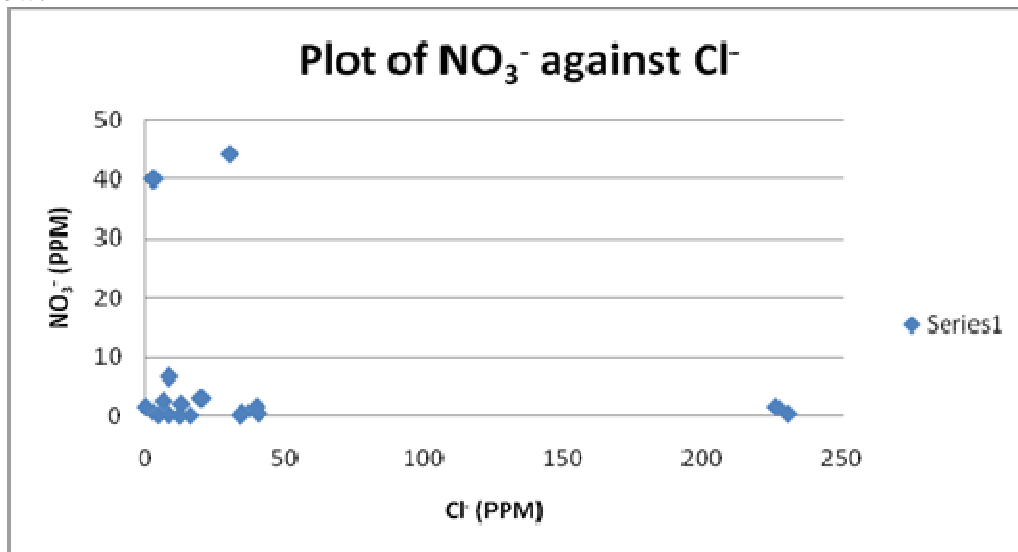

Figure 3 plot of NO_3^- against Cl^-

The concentrations of both anions plotted in figure 5above are high in the upper aquifer/shallow boreholes. The high values of the concentrations indicate pollution. The pollution source may be the pit latrines and sewage which are dug to more or less the same depth as the shallow wells, causing high interaction of the waste with the upper aquifer. Another source may be domestic waste dump site to which in the town are nearly everywhere and animal-waste disposal which infiltrate into the groundwater raising levels of nitrates concentration. This contributes to a high groundwater pollution level in the area through leaching down to the water table.

These causes of pollution can be prevented by proper construction of septic tanks rather than pit latrines and the overflowing fluid dumped into the ground to be collected in sewer systems. Regular inspection and cleaning of sewer lines and septic tanks depending on the nature of the waste and avoiding disposing of household chemicals into the system, banning by the State the use of hazardous cleaning additives for septic systems, use of public sewers when feasible and educating the public concerning the effects and proper construction of septic systems and possible harm from unmanaged pit latrines.

5.0.1.2 Dissolution of alumino-silicates

Kinetic dissolution of alumino-silicates is the main chemical reaction in the study area. The weathering of the alumino-silicates can be expressed as:

$$-SiO^- + H+ = -SiOH$$
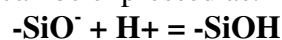
Due to low solubility of alumino-silicates, their contribution to water composition is relatively limited in the presence of carbonates which possess high solubility. In carbonates absence, alumino-silicates determine the ion chemistry of the water hence resulting in low concentrations due to low solubility of the dissolving alumino-silicates (Walraevens, 2009).
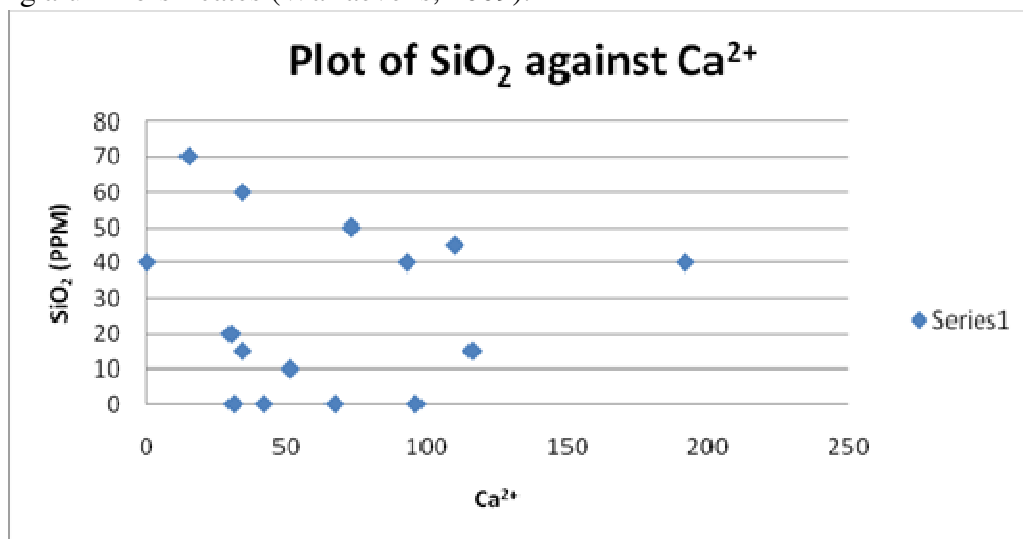
Figure 4 plot of SiO_2 against Ca^{2+}

From figure 6, increasing Ca^{2+} concentrations are indeed accompanied by an increase in SiO_2. It also indicates that dissolved silica concentration is higher in some deeper wells compared to Ca^{2+}. The primary source of dissolved silica in natural water is the chemical breakdown of silicate minerals in rocks and sediments by chemical weathering process (Hem, 1985). It is further explained by Probst (2002) that the silica concentrations are influenced by the amount of precipitation received within the drainage basin and the residence time of groundwater within an aquifer. Silica is not easily dissolved in water but appears in suspension (Probst, 2002). Due to kinetic inhibition, the silica concentration is not

reached as fast as for carbonates. CO_2 from the underground increases the weathering of aluminosilicates through the formation of acid, which aids in the chemical weathering processes. Hence, CO_2 concentrations and longer residence times determine the amount of dissolved silica in the groundwater.

Calcium and magnesium are primarily found in groundwater due to the dissolving of limestone (primarily composed of calcium carbonates). This is the case with the study area. Another possible cas is where the available calcium and magnesium have originated from the weathering of alumino-silicates, comprising feldspars and feldspathoid, from the tertiary phonolites, andesite and granite intrusions of Kitui.

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5.1.0 Problems encountered by samples quality and possible solution

The main problem in the study area is the high concentration of NO_3^-. Nitrate concentrations causes blue babies syndrome when consumed in large quantity. This is made possible by nitrate binding itself with hemoglobin hence inhibiting oxygen transport in babies system as hemoglobin is not made available to bind with oxygen for oxygen to be transported into the body system. When consumed by livestock, it also causes the animals' abdomen to bulge. Nitrate can be treated by filtration process using bio-filters in which nitrate are consumed. This is affordable method and can be practiced in the study area. Reverse osmosis method can also be used though expensive and not affordable by the common people. It is a process where water is forced through a membrane of tiny pores using pressure, water passes through under pressure leaving nitrate particles retained.

The US Environmental Protection Agency (EPA) recommends that domestic water should not exceed 0.3 mg/L of iron (II & III), hence sampled boreholes C2483, C8719, C6828, C8251 and C8973 which have a higher concentration of 1.2 mg/L, 2.5 mg/L, 1.4mg/L, 4.4mg/L and 4.8mg/L respectively should be treated before use to avoid the characteristic reddish staining. Potassium permanganate or "green sand" filters are highly successful in eliminating iron to tolerable levels and the best and cheaper option for the dwellers of the study area is the aeration, the addition of oxygen to the water, can aid in the precipitation of iron, thus removing it from the water. Although dissolved Ca^{2+} and Mg^{2+} causes hardness in water, the study area is not faced with hardness problem. Calcium and Magnesium have no ill effects on humans though hardness caused in water can be an annoyance.

Conclusion

It is important to comment on the salinity of both sand dam water and water from boreholes because it cannot be a mere coincidence.

According to the study and observations made, conclusions were made on the topic as follows.

Major solid waste management problem affects the quality of water in Kitui town, just like any other town in Kenya. Rivers are highly polluted and dumping sites are almost everywhere, even close to town apartments especially in Kalundu it is almost clearly seen from the main road how poor solid waste has been managed. Nappies of young children for example can bring a very unpleasant environment and sometimes create significant health conditions. The sites provide breeding habitats for insect-vectors, pests, snakes and rats that increasethe likelihood of disease transmission. But in my case I focused on the effect of this poor management to water sources especially boreholes.

Poor waste management in Kitui town has polluted river kalundu, whose water is believed to have seeped and infiltrated to the Kitui town aquifers. Polluted water mostly contains of toxic substances which cause major harm to humans when the water is abstracted from boreholes and used for drinking and homestead uses.

The major sources of these wastes was found to be the slaughter opposite Jua Kali area, the wastes are dumped in a small stream next to it. The water may seep underground through the stream or after it joins River Kalundu. Kalundu market can be pointed out as the largest source of pollution, especially solid waste deposition on the course of Kalundu River. Food distribution points, medical centers, domestic areas and feeding areas were other sources of pollution. Wastes from residents of the town however was noted to be highly unhygienic since the environment is untidy and the smells are disgusting.

Solution: key components of solid waste management suggested for Kitui town are discussed below;

1.Storage

After waste is generated, it must be stored properly. This includes keeping discarded materials safely before their disposal. Small containers are used like household and office plastic bins.

Large containers like communal bins for fenced or walled-in areas or shallow pits are used.

2.Collection

How waste is collected to be taken to the final disposal site is very important. The collection plans of the waste should be carefully planned to ensure that storage facilities do not become overloaded. Collection intervals and volumes of collected waste should be estimated carefully.

   3.Transportation

There are various methods adopted but the common one for kitui town waste are lorries/trucks which are mostly overloaded hence dropping the waste right back to the streets again.

4.Disposal

These include land application example burial or landfilling, composting, burning or incineration and recycling. These should all be done very carefully to ensure that toxic substances don't end up seeping in to the aquifers, chemicals and other inorganic and organic but dangerous substances also should be disposed using the right method so that they don't end up increasing pollution of the aquifers.

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By so doing we will reduce pollution of river water hence reduced pollution of the aquifer.

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Appendix/annex
Annex iii Water quality
WHO's Guidelines for Drinking-water Quality, set up in Geneva, 1993, are the international reference point for standard setting and drinking-water safety.

Element/ substance	Symbol/ formula	Normally found in fresh water/surface water/ground water	Health based guideline by the WHO
Aluminium	Al		0,2 mg/l
Ammonia	NH_4	< 0,2 mg/l (up to 0,3 mg/l in anaerobic waters)	No guideline
Antimony	Sb	< 4 µg/l	0.005 mg/l
Arsenic	As		0,01 mg/l
Asbestos			No guideline
Barium	Ba		0,3 mg/l
Berillium	Be	< 1 µg/l	No guideline
Boron	B	< 1 mg/l	0,3 mg/l
Cadmium	Cd	< 1 µg/l	0,003 mg/l
Chloride	Cl		250 mg/l
Chromium	Cr^{+3}, Cr^{+6}	< 2 µg/l	0,05 mg/l
Colour			Not mentioned
Copper	Cu		2 mg/l
Cyanide	CN^-		0,07 mg/l
Dissolved oxygen	O_2		No guideline
Fluoride	F	< 1,5 mg/l (up to 10)	1,5 mg/l

Hardness	mg/l $CaCO_3$		No guideline
Hydrogen sulfide	H_2S		No guideline
Iron	Fe	0,5 - 50 mg/l	No guideline
Lead	Pb		0,01 mg/l
Manganese	Mn		0,5 mg/l
Mercury	Hg	< 0,5 µg/l	0,001 mg/l
Molybdenum	Mb	< 0,01 mg/l	0,07 mg/l
Nickel	Ni	< 0,02 mg/l	0,02 mg/l
Nitrate and nitrite	NO_3, NO_2		50 mg/l total nitrogen
Turbidity			Not mentioned
pH			No guideline
Selenium	Se	<< 0,01 mg/l	0,01 mg/l
Silver	Ag	5 – 50 µg/l	No guideline
Sodium	Na	< 20 mg/l	200 mg/l
Sulfate	SO_4		500 mg/l
Inorganic tin	Sn		No guideline
TDS			No guideline
Uranium	U		1,4 mg/l
Zinc	Zn		3 mg/l

ORGANIC COMPOUNDS

Group	Substance	Formula	Health based guideline by the WHO
Chlorinated alkanes	Carbon tetrachloride	$C Cl_4$	2 µg/l
	Dichloromethane	$C H_2 Cl_2$	20 µg/l
	1,1-Dichloroethane	$C_2 H_4 Cl_2$	No guideline
	1,2-Dichloroethane	$Cl CH_2 CH_2 Cl$	30 µg/l
	1,1,1-Trichloroethane	$CH_3 C Cl_3$	2000 µg/l

Chlorinated ethenes	1,1-Dichloroethene		$C_2 H_2 Cl_2$	30 µg/l
	1,2-Dichloroethene		$C_2 H_2 Cl_2$	50 µg/l
	Trichloroethene		$C_2 H Cl_3$	70 µg/l
	Tetrachloroethene		$C_2 Cl_4$	40 µg/l
Aromatic hydrocarbons	Benzene		$C_6 H_6$	10 µg/l
	Toluene		$C_7 H_8$	700 µg/l
	Xylenes		$C_8 H_{10}$	500 µg/l
	Ethylbenzene		$C_8 H_{10}$	300 µg/l
	Styrene		$C_8 H_8$	20 µg/l
	Polynuclear Aromatic Hydrocarbons (PAHs)		$C_2 H_3 N_1 O_5 P_{13}$	0.7 µg/l
Chlorinated benzenes	Monochlorobenzene (MCB)		$C_6 H_5 Cl$	300 µg/l
	Dichlorobenzenes (DCBs)	1,2-Dichlorobenzene (1,2-DCB)	$C_6 H_4 Cl_2$	1000 µg/l
		1,3-Dichlorobenzene (1,3-DCB)	$C_6 H_4 Cl_2$	No guideline
		1,4-Dichlorobenzene (1,4-DCB)	$C_6 H_4 Cl_2$	300 µg/l
	Trichlorobenzenes (TCBs)		$C_6 H_3 Cl_3$	20 µg/l
Miscellaneous organic constituents	Di(2-ethylhexyl)adipate (DEHA)		$C_{22} H_{42} O_4$	80 µg/l
	Di(2-ethylhexyl)phthalate (DEHP)		$C_{24} H_{38} O_4$	8 µg/l
	Acrylamide		$C_3 H_5 N O$	0.5 µg/l
	Epichlorohydrin (ECH)		$C_3 H_5 Cl O$	0.4 µg/l
	Hexachlorobutadiene (HCBD)		$C_4 Cl_6$	0.6 µg/l
	Ethylenediaminetetraacetic acid (EDTA)		$C_{10} H_{12} N_2 O_8$	200 µg/l
	Nitrilotriacetic acid (NTA)		$N(CH_2COOH)_3$	200 µg/l
	Organotins	Dialkyltins	$R_2 Sn X_2$	No guideline
		Tributil oxide (TBTO)	$C_{24} H_{54} O Sn_2$	2 µg/l

PESTICIDES

Substance	Formula	Health based guideline by the WHO
Alachlor	$C_{14} H_{20} Cl N O_2$	20 µg/l
Aldicarb	$C_7 H_{14} N_2 O_4 S$	10 µg/l

Aldrin and dieldrin		$C_{12} H_8 Cl_6$/ $C_{12} H_8 Cl_6 O$	0.03 µg/l
Atrazine		$C_8 H_{14} Cl N_5$	2 µg/l
Bentazone		$C_{10} H_{12} N_2 O_3 S$	30 µg/l
Carbofuran		$C_{12} H_{15} N O_3$	5 µg/l
Chlordane		$C_{10} H_6 Cl_8$	0.2 µg/l
Chlorotoluron		$C_{10} H_{13} Cl N_2 O$	30 µg/l
DDT		$C_{14} H_9 Cl_5$	2 µg/l
1,2-Dibromo-3-chloropropane		$C_3 H_5 Br_2 Cl$	1 µg/l
2,4-Dichlorophenoxyacetic acid (2,4-D)		$C_8 H_6 Cl_2 O_3$	30 µg/l
1,2-Dichloropropane		$C_3 H_6 Cl_2$	No guideline
1,3-Dichloropropane		$C_3 H_6 Cl_2$	20 µg/l
1,3-Dichloropropene		$CH_3 CHClCH_2 Cl$	No guideline
Ethylene dibromide (EDB)		$Br CH_2 CH_2 Br$	No guideline
Heptachlor and heptachlor epoxide		$C_{10} H_5 Cl_7$	0.03 µg/l
Hexachlorobenzene (HCB)		$C_{10} H_5 Cl_7 O$	1 µg/l
Isoproturon		$C_{12} H_{18} N_2 O$	9 µg/l
Lindane		$C_6 H_6 Cl_6$	2 µg/l
MCPA		$C_9 H_9 Cl O_3$	2 µg/l
Methoxychlor		$(C_6H_4OCH_3)_2CHCCl_3$	20 µg/l
Metolachlor		$C_{15} H_{22} Cl N O_2$	10 µg/l
Molinate		$C_9 H_{17} N O S$	6 µg/l
Pendimethalin		$C_{13} H_{19} O_4 N_3$	20 µg/l
Pentachlorophenol (PCP)		$C_6 H Cl_5 O$	9 µg/l
Permethrin		$C_{21} H_{20} Cl_2 O_3$	20 µg/l
Propanil		$C_9 H_9 Cl_2 N O$	20 µg/l
Pyridate		$C_{19}H_{23}ClN_2O_2S$	100 µg/l
Simazine		$C_7 H_{12} Cl N_5$	2 µg/l
Trifluralin		$C_{13} H_{16} F_3 N_3 O_4$	20 µg/l
Chlorophenoxy herbicides (excluding 2,4-D and MCPA)	2,4-DB	$C_{10} H_{10} Cl_2 O_3$	90 µg/l
	Dichlorprop	$C_9 H_8 Cl_2 O_3$	100 µg/l
	Fenoprop	$C_9H_7Cl_3O_3$	9 µg/l
	MCPB	$C_{11} H_{13} Cl O_3$	No guideline
	Mecoprop	$C_{10}H_{11}ClO_3$	10 µg/l
	2,4,5-T	$C_8 H_5 Cl_3 O_3$	9 µg/l

DISINFECTANTS AND DISINFECTANT BY-PRODUCT

Group	Substance	Formula	Health based

				guideline by the WHO
Disinfectants	Chloramines		$NH_nCl^{(3-n)}$, where n = 0, 1 or 2	3 mg/l
	Chlorine		Cl_2	5 mg/l
	Chlorine dioxide		ClO_2	No guideline
	Iodine		I_2	No guideline
Disinfectant by-products	Bromate		$Br\,O_3^-$	25 µg/l
	Chlorate		$Cl\,O_3^-$	No guideline
	Chlorite		$Cl\,O_2^-$	200 µg/l
	Chlorophenols	2-Chlorophenol (2-CP)	$C_6\,H_5\,Cl\,O$	No guideline
		2,4-Dichlorophenol (2,4-DCP)	$C_6\,H_4\,Cl_2\,O$	No guideline
		2,4,6-Trichlorophenol (2,4,6-TCP)	$C_6\,H_3\,Cl_3\,O$	200 µg/l
	Formaldehyde		HCHO	900 µg/l
	MX (3-Chloro-4-dichloromethyl-5-hydroxy-2(5H)-furanone)		$C_5\,H_3\,Cl_3\,O_3$	No guideline
	Trihalomethanes	Bromoform	$C\,H\,Br_3$	100 µg/l
		Dibromochloromethane	$CH\,Br_2\,Cl$	100 µg/l
		Bromodichloromethane	$CH\,Br\,Cl_2$	60 µg/l
		Chloroform	$CH\,Cl_3$	200 µg/l
	Chlorinated acetic acids	Monochloroacetic acid	$C_2\,H_3\,Cl\,O_2$	No guideline
		Dichloroacetic acid	$C_2\,H_2\,Cl_2\,O_2$	50 µg/l
		Trichloroacetic acid	$C_2\,H\,Cl_3\,O_2$	100 µg/l
	Chloral hydrate (trichloroacetaldehyde)		$C\,Cl_3\,CH(OH)_2$	10 µg/l
	Chloroacetones		$C_3\,H_5\,O\,Cl$	No guideline
	Halogenated acetonitriles	Dichloroacetonitrile	$C_2\,H\,Cl_2\,N$	90 µg/l
		Dibromoacetonitrile	$C_2\,H\,Br_2\,N$	100 µg/l
		Bromochloroacetonitrile	$CH\,Cl_2\,CN$	No guideline
		Trichloroacetonitrile	$C_2\,Cl_3\,N$	1 µg/l
	Cyanogen chloride		$Cl\,CN$	70 µg/l
	Chloropicrin		$C\,Cl_3\,NO_2$	No guideline