STRUCTURAL AND GEOLOGICAL CONTROL OF FLUORIDE LEVELS IN GROUNDWATER AND DEFLUORIDATION IN ELEMENTAITA, NAKURU COUNTY, KENYA

SGL 413 PROJECT IN GEOLOGY

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ABSTRACT

The study assesses the influence of geology and geological structures such as faults, joints and fractures on elevated fluoride levels in groundwater around Elementaita area, Nakuru County, Kenya. It also documents defluoridation methods of water treatment in the area. The Elementaita area is located in the central rift of Kenya within the geographical co-ordinates 35° 45' -36° 20' E, 1° 00' - 0° 15' N. The local geology lies in the Naivasha Elementaita-Nakuru watershed. It's characterized by the following rocks: Alluvium, reworked water lain sediments, Quaternary lucustrine deposits, diatomite deposits, reworked sediments, tuffs, agglomerates and acid lava, trachytes, rhyolites, comendite and obsidian. The area is dominated by faults and voluminous fissural volcanic eruptions since Lower Miocene. The water catchment within the area is composed primarily of basic volcanics. It experiences high fluoride level in its groundwater which leads to major problems such as dental and skeletal fluorosis among its residents. Studies have shown that the area's geological and structural setup is responsible for the high fluoride levels. High fluoride levels are common in deeply drilled boreholes than surface water. A guideline value of maximum 1.5 ppm fluoride concentration in groundwaters is recommended by World Health Organization (WHO). Several fluoride removal methods have been documented in literature and are consequently applicable in the area of study. The project discusses the bone char method and its applicability in the area of study.

Key words:

Geological controls, Structural controls, Fluoride levels, Defluoridation, Elementaita area, Kenya

DECLARATION AND APPROVAL

Declaration by candidate

I declare that the report is my original work and has not been presented for a

Degree in any other university.

Name……………………………………Date………………………………………

Signature……………………………………………………

Approval by Advisor

I declare that this report has been submitted for examination with the approval as an official university advisor

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Approval by supervisor

I declare that this report has been submitted for examination with the approval as an official university supervisor

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

1.0 INTRODUCTION

1.1 Background information

A wide range of different chemical elements can be dissolved in groundwater as a result of the interaction with the atmosphere, surficial environment, soil and bedrock. Groundwater tends to have higher concentration than surface water (Rao, 1964). Deep groundwater that has been in contact with rocks for a long time tends to have higher chemical element concentration than shallow young waters (Marieta, 2007). The parameters that defines groundwater geochemistry include: $N0_3^-$, K^+, Na^+ ,Mg^{2+}, $S0_4$, $HC0_3^-$, F^- and others.

Fluoride concentration in groundwater is an aspect of the hydrochemistry of the water. The evolution of fluoride rich natural water results from leaching of rocks hence the concept of leach ability. The leachability of elements in rocks depends on the strength of bonding forces. The more the element is held up to the silicate lattice, the less is it vulnerable to weathering. However, the solubility product of a mineral is also an important aspect that determines the concentration of fluoride in any natural water under a given environment.

Fluoride is widely distributed in the environment hence all living organisms are extensively exposed to it and tolerate it to some amounts (WHO, 2004). In humans, overexposure of fluoride results in the accumulation of the element in the mineralizing tissues of the body. In young children too much of fluoride in drinking water causes teeth to become mottled with dark spots, a condition called dental fluorosis. Dissolved fluoride in water is also believed to store osteoporosis, a bone degeneration that accompanies aging.

For many years, in several developing countries, research on fluoride in groundwater has been established. In Kenya, extensive studies have been carried out by different researchers on distribution, sources of fluoride and incidences of fluorosis. However most of this data is archival since most of it was carried out between 1960-1990 (KEBS, 2010).

1.2 Study area

The Elementaita area lies between latitude 35° 45' -36° 20' E and longitudes 1° 00' - 0° 15' N (Figure 1.1).The area lies in the central rift basin generally comprised of Lakes Nakuru, Elementaita and Naivasha located in step faulted portion of the Rift valley. Administratively, it's located in Nakuru County in the former Rift valley province and is about 150 km northwest of Nairobi. The area is accessed via Nairobi-Nakuru highway. The main line of the old Uganda Railway passes 5km from the area of study.

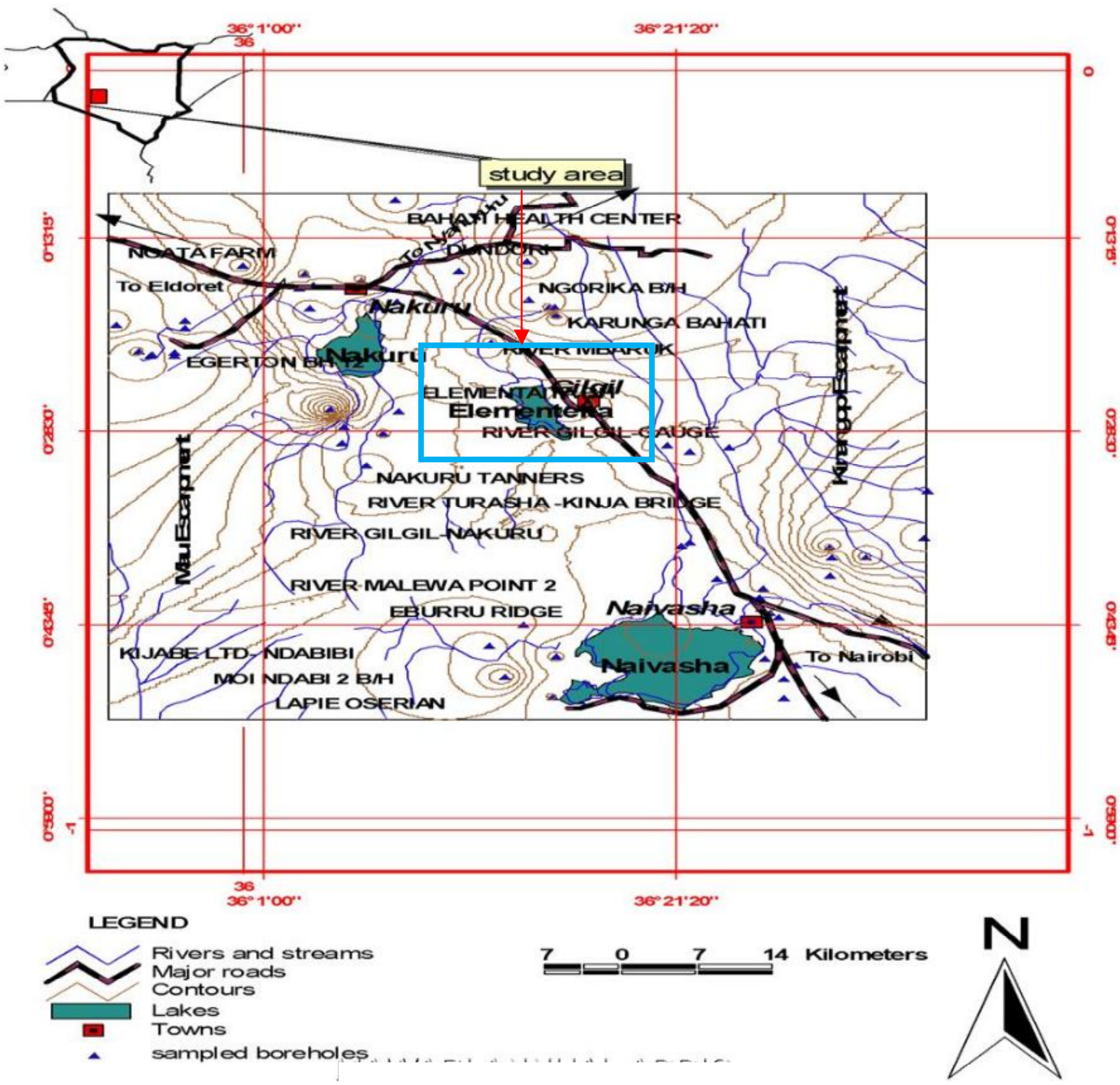


Figure 1. 1: Location of the Study Area (After Ogalo, 2007)

1.3Literature review

The following are some of studies carried in the area on fluoride levels and defluoridation methods:

Nair and Gitonga (1984) found out that fluoride content of groundwater in Kenya ranged from 0.1ppm to over 34ppm in majority of parts of the country. They documented that fluoride levels were high around Gamblian lakes such as L. Elementaita and Naivasha.

Manji *et al.*, 1982 in their journal records that the fluoride concentration between the highest levels in areas around L.Elementaita was about 1640ppm and suggests other sources which includes foods and drinks as well as dust in some of the lake region.

Kahama *et al.,* (1997) in their project to determine the fluoride levels in milk around L.Elementaita noted very high fluorosis levels in the region and designed a study to establish the sources of fluoride and the severity of fluorosis in the area.

Naslund (2005) courtesy of the Catholic Diocese of Nakuru (CDN) established that the areas in Nakuru County and Baringo had elevated fluoride level in their groundwater. The study was confined to groundwater from deep boreholes, rivers lakes and natural springs. It was established that the Dundori springs and L. Elementaita water had high levels of fluoride.

Recent work by Wambu and Muthakia (2011) courtesy of the International Society for Fluoride Research identified high mean Fluoride levels of about 7.69 ppm in borehole water around Elementaita area. This study reveals that the level of water F increased with proximity of the source to the lakes in the region.

1.4 Occurrence and distribution of fluorides in Kenya

Fluoride is often associated with volcanic activity and fumarolic gases (Marieta, 2007). It is found in all natural waters at some concentration. Sea water contains typically contains about $1mgL^{-}$ while rivers and lakes generally exhibit concentrations of less than 0.5mgL. In groundwater, low or high concentration of fluoride can occur depending on the nature of the rock and occurrence of fluoride-bearing minerals (Emeleus and Tatlow, 1971). Fluorides are found at significant levels in a wide variety of minerals including fluorspar, rock phosphate, cryolite, apatite, mica, hornblende and others.

The geographical distribution of Fluoride in water from drilled boreholes indicates that 96% of the boreholes in the lake region, western and coastal regions of Kenya have fluoride values of less than 1.5ppm (KEBS, 2010).

Areas in Kenya with at least 50% of boreholes with fluoride levels greater than 1.5ppm are Baringo, Kajiado, Kericho, Laikipia, Nairobi, Narok, Nakuru and Thika (Naslund, 2005). Figure (1.2) represents distribution of boreholes with F^- levels greater than 1.5mg/l in Kenya.

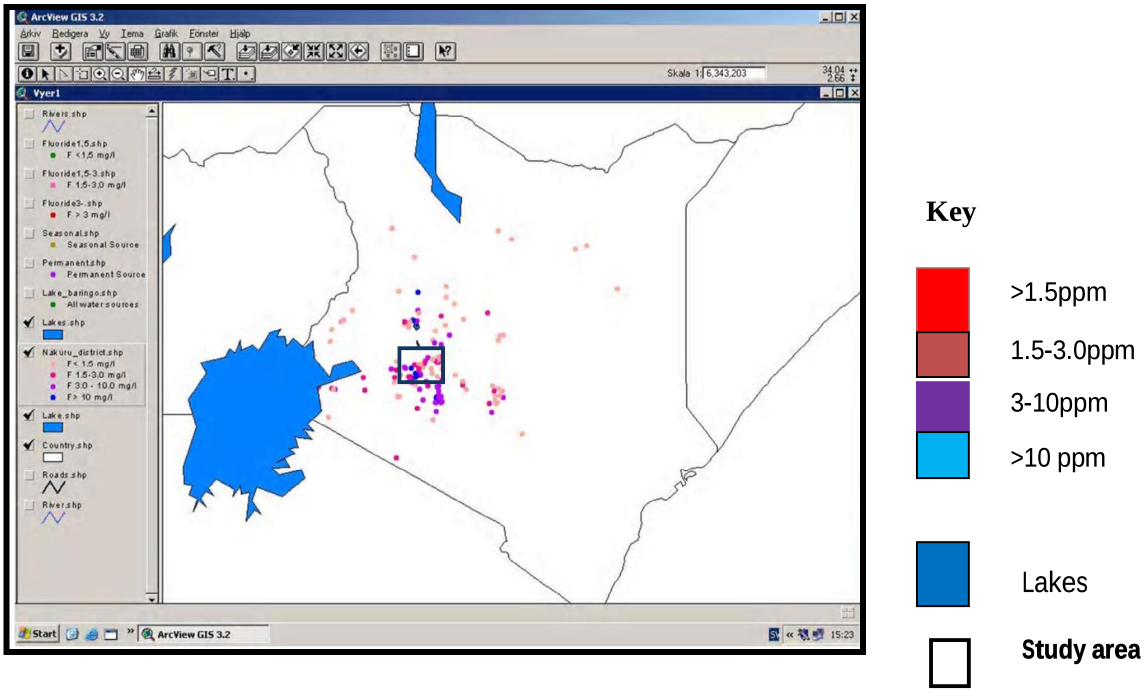


Figure 1. 2: GIS Map of Kenya Showing Water Source with F^->1.5mg/l (Modified after Naslund, 2005)

1.5 Statement of the problem

The World Health Organization (WHO) has recommended a guideline value for drinking water of 1.5ppm. In Kenya, the Kenya Bureau of Standards follows the WHO guidelines value and recommends a maximum of 1.5ppm for drinking water (Gikunju *et al*., 2002)**.** Increased fluoride levels in the water around Elementaita area and consequent drinking water with concentrations above this value carries an increasing risk of dental fluorosis. Much higher concentration leads to skeletal fluorosis evidenced by browning and blackening and pitting of teeth and deformities especially among children. Few attempts have been date to delineate the area's geology and faults and to determine their influence on fluoride levels in groundwater in the area (KEBS, 2010).

Awareness of problems associated with high fluoride level in the area is necessary. Knowledge about geological and structural controls in the area is lacking hence the project purposes to tackle the problem from this perspective.

1.6 Objectives of the study

The following were the objectives of the study:-

- Review the geology of the area with an aim of establishing the relationship between fluoride concentration and geological formations.
- Delineate spatial distribution of fluoride ions in groundwater and relate it to structures such as faults, joints and fracture in the study area.
- Determine the effects of physio-chemical parameters (depth and PH) on fluoride concentration in groundwater in the area.
- Document defuoridation techniques applicable in the area of study.

1.7 Significance of the study

The study should help to delineate spatial distribution of fluoride so as to come up with preferred zones of alternative safe groundwater.

Results form the study will be extremely useful to the Ministry of Water and Irrigation and other agencies that are involved in the formulating water policies, planning and implementing water to development programs as well as providing social and health services fluorosis affected communities and regions.

1.8 Justification of the study

World Health Organization (WHO) recommends a maximum of 1.5ppm fluoride content in water used for cooking or drinking. Residents of Elementaita area suffer from dental fluorosis as a result of consumption of groundwater whose fluoride levels exceed this limit. Existing theories and literature in the area have been confined to availability, quantity and pollution of groundwater but none has dealt with the influence of structures and geological formations on fluoride in the groundwater in the area (Ogalo, 2007). The study therefore aims to highlight the this perspective. This in essence permeates delineation of potential sites for safe groundwater for the local population.

2.0 GEOLOGY, HYDROGEOLOGY AND STRUCTURES

2.1 Geology

The study area embraces two flanks of the Gregory rift valley with the Kinangop plateau on the Eastern side and the Mau escarpment on the western side. The main faulting stages of the rift valley occurred during the Miocene or early Pliocene and in the Pleistocene-Holocene epochs (Ase *et al*. 1986). The regional geology of the area is characterized by volcanic rocks and Quartenary lucustrine deposits from ancient lakes.

The volcanic rocks consist of tephrites, basalts, trachytes, phonolites, ashes tuffs, agglomerates and acid lavas rhyolite comendite and obsidian (Thompson and Dodson, 1963).Much of the eastern highland areas are composed of a varied assortment of vitric pumice tuffs, Rumuruti phonolites, Mbaruk porphyritic olivine basalt and Gilgil trachyte (McCall,1967). The regional geology of the area is characterized by volcanic rocks and Quartenary lucustrine deposits from ancient lakes. The volcanic rocks consist of tephrites, basalts, trachytes, phonolites, ashes tuffs, agglomerates and acid lavas rhyolite comendite and obsidian (Thompson and Dodson, 1963). Much of the eastern highland areas are composed of a varied assortment of vitric pumice tuffs, Rumuruti phonolites, Mbaruk porphyritic olivine basalt and Gilgil trachyte (McCall, 1967).

Locally, the geology is composed of the following: Rhyolites, comendite, comendites, tephrites, syenites, trachyte, phonolite, pyroclastic deposits, lava flows, volcanic sediments, pyroclasic falls and pyrclastic ash lacustrine deposits, diatomaite deposits, reworked sediments tuffs and rare scoriaceous basalt. The beds of L. Elementaita is mainly composed of volcanic materials and subsequently deposited and pyroclastics and organic matter produced locally.

The sediments are composed of sand, pebbles as well as gravels made of rounded pumice clasts (Stuttard *et al*., 1995). Sediments are seen as stratified deposits of tuff and diatomaceous silts. Volcanic rocks especially amorphous rocks like pumice, tuffs, pyroclastics and porphyry and other easily weathered materials like volcanic ash or sediments of salt lakes are concerned with washing out the fluoride component into the surface and groundwater. This was the case in the area (Figure 2.1).

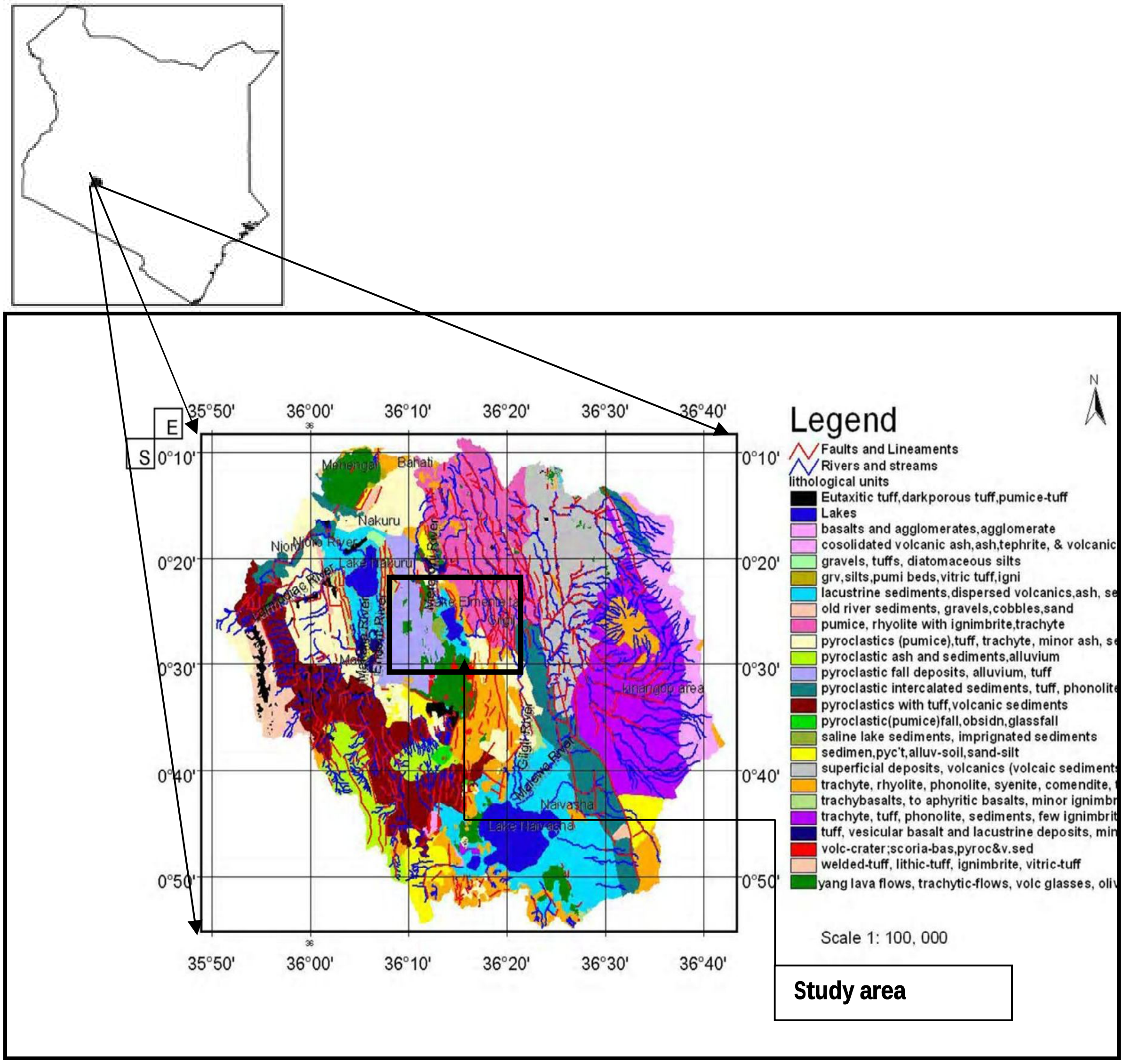


Figure 2. 1: Geology of the Study Area and its Environs (After Alamirew *et. al.*,2007)

2.2 Hydrogeology

The factors affecting hydrogeology include: Rainfall, evaporation, inland and outflow, geology and faulting system. Four hydrogeological zones related to geology are identified in the area as follows.

- Aquifer group 1-The gravely sand sediments
- Aquifer group 2-The contact zone of basic and acidic volcanic
- Aquifer group 3-The intercalation zones of basalts and tuffs
- Aquifer group 4-Fissures in the acidic volcanic

Figure 2.2 illustrates the four aquifer groups found in the area.

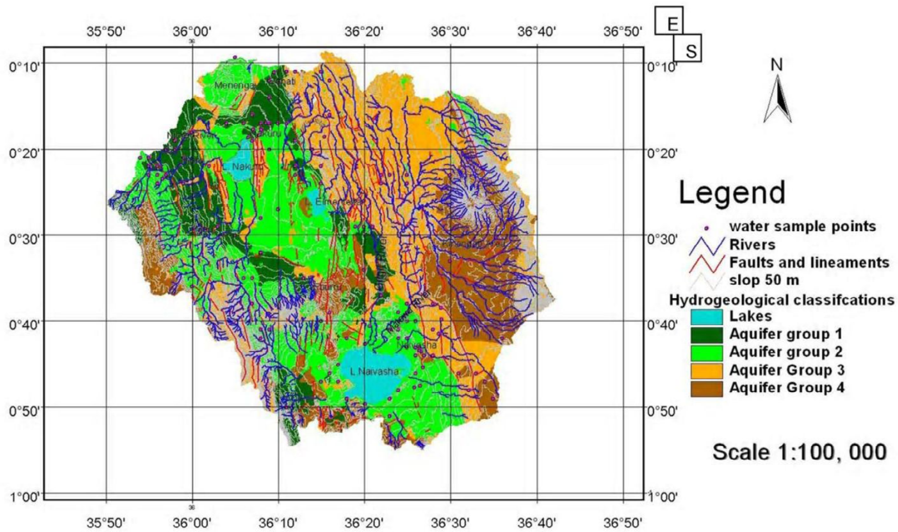


Figure 2. 2: Hydrogeology of Elementaita and its Environs (After Alamirew *et. al.*,2007)

The area is of medium groundwater potential and yields generally vary with depth (Alamirew *et al.*, 2007). The recharge of the aquifers is mainly from local sources, by percolation of rainfall downward through fissures until porous stratum is reached. Some rivers and springs in the area are aligned along faults (McCall, 1967). Here the fault zones influence the groundwater strongly, each fault acting like ruble-filled drain and causes trough-like depression of water table along its length. Hence the rivers and streams lose water in the fault zones. Generally, there are about 20 boreholes in the study area but the sampled ones are illustrated in Figure 2.3.

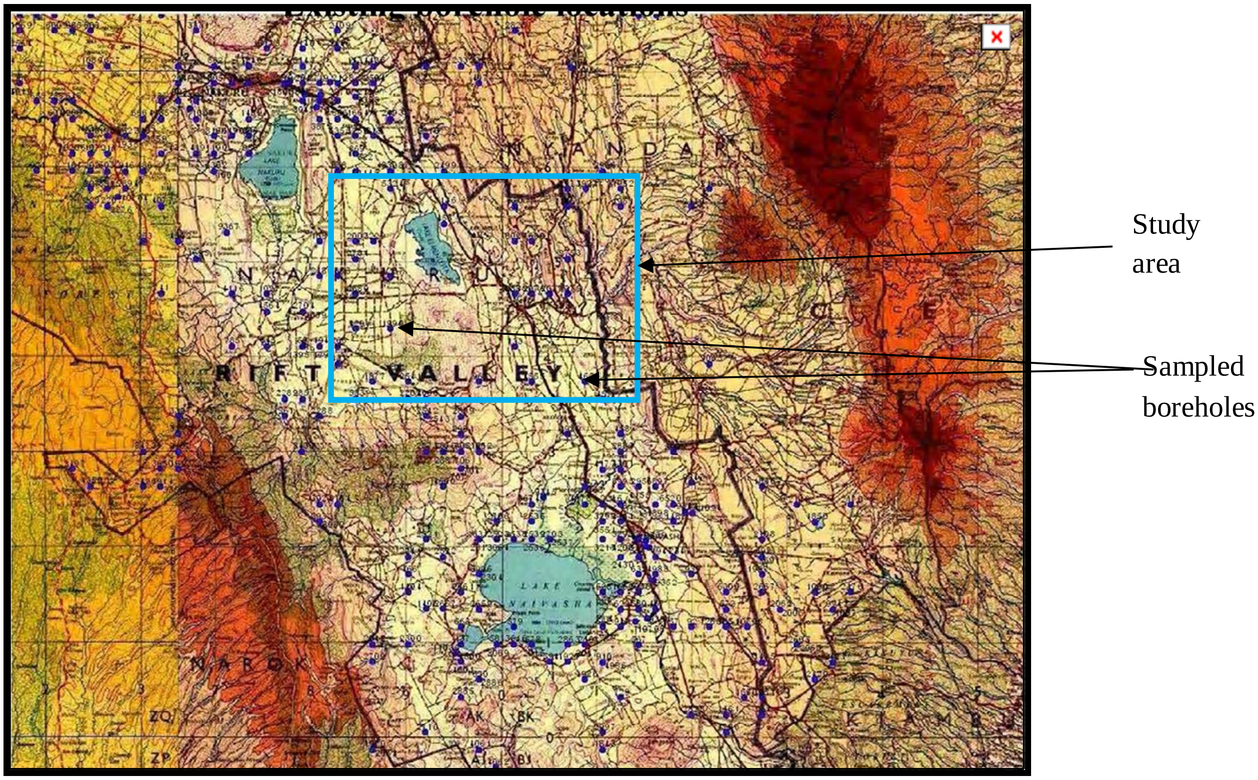


Figure 2. 3: Sampled boreholes in the study area and its environs (After Marieta, 2007)

2.2.1 Hydrology

Primary sources of water for population in the study area include: rivers, streams, springs, and boreholes. Piped water is limited to urban areas at Gilgil town and the neighboring Nakuru Municipality. Water for domestic consumption in the area is obtained from Dundori springs which is channeled and transported to Kariandusi Diatomite plant. This water is consumed without treatment thus recent studies have proposed that more F^- surveys should be conducted to establish the risk posed by increasing F^- exposure in the area.

2.3 Structures

The structural pattern of the area is complex owing to the number and variation of orientation

(McCall, 1967) due to numerous tectonic events and the resultant morphological features. There's a confused jumble of fault blocks near Gilgil which represents a central volcano developed during the middle Pleistocene period (McCall, 1967). Areas north of L. Elementaita have the highest density of faults (Figure 2.4).

Alamirew *et al* .(2007) categorized faults in the area as follows based on their orientation:

- NS running old faulting
- The Northeast-southwest running faulting
- Minor EW running faulting (few lineaments)
- The young NS running faulting

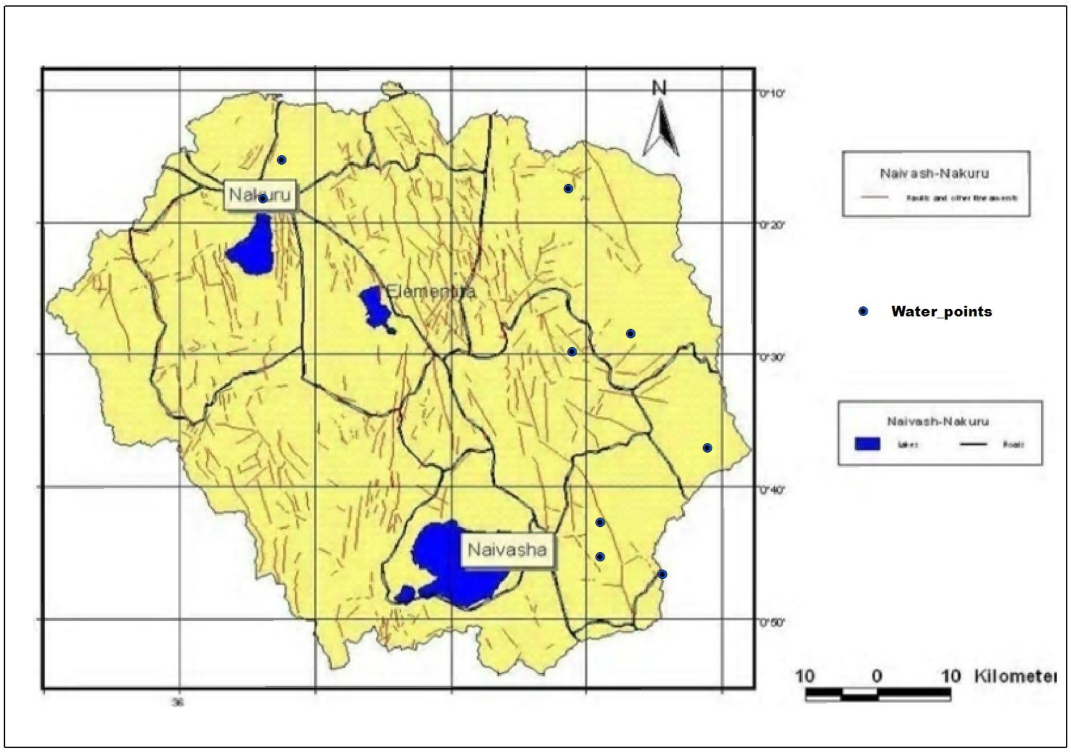


Figure 2. 4: Faults and lineaments in the study area (After Alamirew *et al*., 2007)

3.0 METHODOLOGY

3.1 Desk studies

This involved the study of journals, reports, theses and maps (soil, geological and topographical). It also includes collecting borehole data from the Ministry of Water and Irrigation and from the Kenya Water Institute (KEWI) with respect to previous work done in the area. The hydrogeological data in the area include aquifer depths, water rest levels, water struck levels and water quality data based on fluoride concentration in area's groundwater. Internet was also vital for it provided data based on factors controlling the occurrence and quality of groundwater in the study area.

3.2 Statistical methods

A Microsoft Window Excel package was used for correlation analysis, regression analysis, and descriptive statistics. All these methods are applied to establish the relationship between the measured parameters and how they influence F^- concentration in the study area.

3.3 Other methods

These are methods carried out by previous researchers to estimate fluoride levels in groundwater. They include:

- Field sampling method
- Laboratory analytical method

3.3.1 Field sampling methods.

This technique is done by sampling boreholes from the area of study. The geographical coordinates and altitudes are taken at the point of collection using a Geographical Information system (GPS).This is essential when plotting data using Arc View GIS and other soft wares. Wambu and Muthakia (2011) randomly sampled data from 37 boreholes from the area while Catholic Dioceses of Nakuru (CDN) has been involved in sampling and analysis of water quality data in the area since 2004.

3.3.2 Laboratory and analytical testing for fluoride

The choice of analytical technique is influenced by the standard of accuracy and precision required (Naslund, 2005). The analytical technique adopted for determination of fluoride and PH in the study area is Ion Selective Electrodes (Plate 3.1).

Plate 3. 1: Ion selective electrode (After CDN, 2004)

This is an indicator or measuring electrode with high degree of specificity for a simple ion or class of ions. The body of the electrode contains a reference solution of constant composition. When the electrode is placed in a solution an electric potential develops across the membrane. The magnitude of the potential develops on the concentration of ion activity and electrode potential is logarithmic.

4.0 RESULTS AND INTERPRETATION

4.1 Results

4.1.1 General Hydrochemistry of the study area

The following data represents the overall geochemical data from boreholes within the area of study.

Table 4. 1General hydrochemistry of boreholes in the Elementaita area

Parameter	**Elementaita**	**Majimoto**	**Chamuka**
pH	9.5	8.1	7.2
Conductivity (_S cm−1)	4,300	300	228
Alkalinity (mg L−1)	1,200	144	76
Sodium (mg L−1)	945	44	13
Chloride (mg L−1)	552	8	13
Sulphate (mg L−1)	85	10	5
PO4-P (mg L−1)	0.2	0.08	0.08
NO3-N (mg L−1)	0.01	0.01	0.01
Manganese (mg L−1)	0.1	0.1	0.1
Fluoride (mg L−1)	**2**	**2**	**1.5**
Potassium (mg L−1)	8.1	14	3.6
Magnesium (mg L−1)	0.1	2.4	2.4
Iron (mg L−1)	0.1	0.2	0.7
Calcium (mg L−1)	0.8	8.8	

Source of data: Mwaura 1999; Ministry of water and Irrigation

Kahama *et al* .1997 determined the fluoride levels in boreholes in the area and represented the results as follows.

Table 4. 2Fluoride in water in Elementaita area, Kenya

Borehole number	**Concentration (pg/mL-1)**
1	19.50
2	11.40
3	20.60
4	14.50
5	2.40
6	2.25
7	9.80
8	17.50
9	11.10

Source of data: Kahama *et al*., 1997

From Table 4.2, the average concentration of fluoride concentration in boreholes is 12.16pg/ml^{-1}. This exceeds the recommended 1.5pg/mL^{-} by the World Health Organization (WHO).

4.1.2 Variation of fluoride with borehole depth

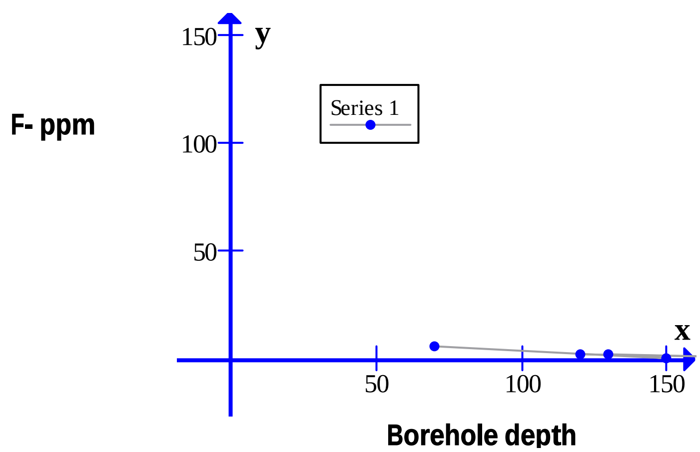
Below is borehole data showing variability of fluoride with depth and PH from the study area.

Table 4. 3Variability of fluoride concentration with depth

Borehole Number	**OWNER**	**Total depth** (TD)	N/S(longitude)	E/W(Latitude)	PH	F-
D029	St. Peter's Prim	120	00 29' 00	36 17' 40	6.00	1.9
D030	Murera Gilgil	200	00 29' 00	36 17' 40	7.2	1.8
D087	Wamagana	130	00 28' 23	36 55' 30	6.60	2.0
D094	Sosian scheme	150	00 33'57	36 36' 21	8.50	0.8
D344	Marula Estate	70	00 32' 11	36 32' 11	7.70	5.9

Source of data: Ministry of Water and Irrigation

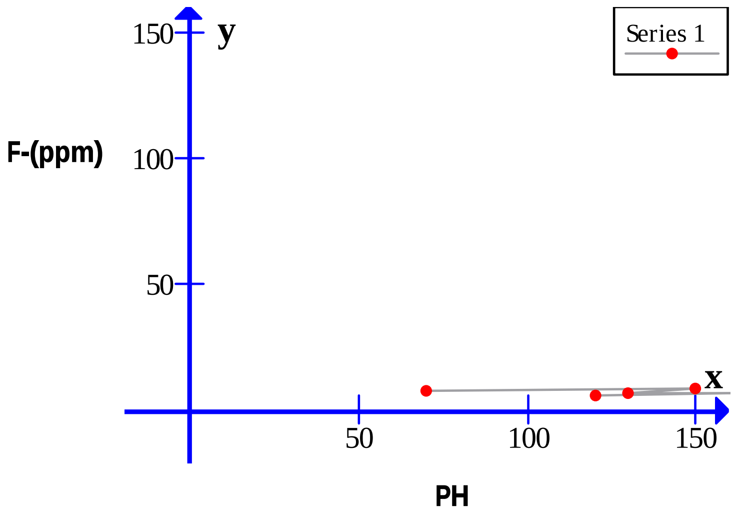
The data was plotted to establish the relationship between borehole depth and fluoride concentration.



From the graph above, no relationship could be established between fluoride concentration and depth of boreholes in the area .It is inferenced that F^{-} concentrations differ considerably at different aquifer depths due to geological formation and mineral content (Marieta, 2007). This contradicts with the hypothesis by (Mjengera and Mcharo, 1990) that the deeper the borehole, the higher the fluoride concentration .Therefore the most important controlling factor of fluoride concentration in groundwater is geological and structural and not depth.

4.1.3 Variation of fluoride with groundwater PH

The data in Table 4.3 was plotted in a graph as follows:



From the graph above, there exist a negative relationship between PH and F^-. This can be attributed to the presence of Fluoride bearing minerals in igneous rocks of the area increases solubility of F^- in groundwater upon weathering (Hem, 1959). Handa (1975) established that the composition characteristics of water in volcanic terrains is alkaline and are rich in Na^+, K^+ as well as HCO_3 (Table 4.1).These species have high solubility in water but Ca and Mg have low solubility and hence are incorporated as carbonates (Eqn 4.1).

$$CaC0_{3(s)} + H^+ + 2F^- CaF_{2(s)} + H^- C0_{3(aq)} \longrightarrow K_{Cal\ -fluo} \frac{aHC03}{aH + x(CaF-)2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn } (4.1)$$

{Equation after Handa (1975)}

From the equation, provided the PH remains constant any decrease or increase in bicarbonate concentration will be accompanied by a corresponding increase in F- as $K_{cal\text{-}fluo.}$

4.1.4 Fluoride distribution map of Elementaita area

The F- concentration shows much variation from area to area as illustrated by Fig 4.1.

Fluoride levels of 18-19ppm have been recorded in areas west of L.Elementaita.

Groundwater around Lake Elementaita has up to 12mg/l and some show up to 20 mg/l.

Highly faulted areas show moderate to high fluoride content in groundwater as is the case in areas west of Elementaita (Figure 4.1).

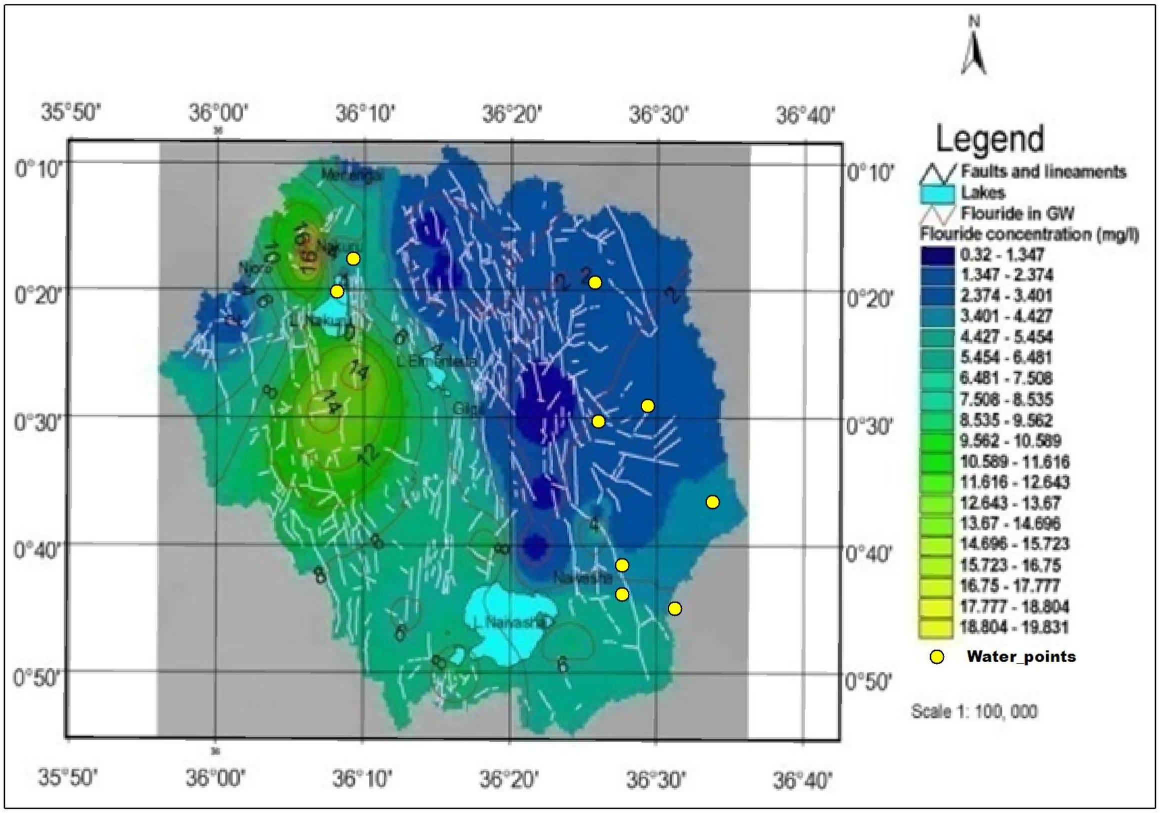


Figure 4. 1: Fluoride distribution in the study area and its environs (After Alamirew *et al.* 2007)

4.2 DISCUSSION

4.2.1 Geological control on Fluoride levels in the area

From hydrogeological data sampled, conditions within the rift i.e. comparatively high temperature and pressures favor effective chemical weathering of rocks (Nanyaro *et al.* 1984). The hydrogeological composition of water reflects partly the lithology of the basin under consideration e.g. the abundance of intermediate plagioclase in these alkaline rocks is considered primary as influences of Ca^{2+} and Na^{2+}. Geologically, the study area is also composed of volcanic rocks such as: Trachytes, phonolites and basalts which when weathered release considerable concentration of fluoride. Koritnig (1978) comparative relationship of fluoride in various rocks is as represented in Table 4.4.

Table 4. 4 Concentration of fluoride in various rocks (After Koritnig, 1978)

Rocks	**Concentration of Fluoride (ppm)**
Granite	850
Gabbro+Basalts	400
Syenite	950
Slate	740
Sandstone	270
Chalk	350
Dolomite	180
Regional metamorphic rocks	80-1110
Contact metamorphic rocks	260-4700

From the above table it is evident that fluoride is high in igneous and metamorphic rocks as is the case of the study area.

(Marieta, 2007) attributes the elevated fluoride concentration to infiltrating rainfall which in the process of percolation through rocks gets enriched in fluorides. The surface runoff accompanying percolation carries substantial amounts of fluorides into shallow groundwater, rivers, ponds and lakes.

Another reason for high fluoride concentration in groundwater is through volcanic ash ejected during Quaternary volcanism which forms part of the unconsolidated sediments in the area. Groundwater seeping through the ash material to lake therefore results in high fluoride concentration, which gets enriched by evaporation especially in lakes of closed basins in the Gregory rift Valley system (Marieta, 2007).

The high temperatures and geothermal activity in the study area raises the temperature groundwater in the area. Consequently the high temperatures increase the solubility and mobility of fluoride ions in groundwater which in effect causes an increase in F^-.

The high fluoride in groundwater in the area can be as a result of the absorption of uprising, subterranean gas containing higher fluoride concentrations in areas where there have been volcanic activities (Gaciri and Davis, 1993.)

The area is covered by mainly alkaline volcanic rocks mainly trachytes, phonolites and basalts which cover large parts of East African System Rift Valley (Mc Call, 1967). These rocks are thought to contribute to high concentration of fluoride ions; when weathered, they dissociate to minerals as micas (phlogopite, adularia, albite), carbonate salts and hydroxide (wollastonite, brucite, dolomite, trona, tremolite) that acts as good sinks for fluoride ions (Marieta, 2007).

Finally, the high fluoride concentration in groundwater in the area could be attributed to localized high contents of mica minerals in aquifer rocks (Ongwenyi, 1975). Fluoride content in micas is represented by Table 4.5.

Table 4. 5Fluoride content in micas (after Dear *et al.*, 1960)

Mica	**Concentration**
Biotites	70-500ppm
Phlogopite	3300-3700ppm
Lepidolite	19000-68000ppm
Muscovite	170-14800ppm

4.2.2 Structural controls on fluoride levels

The geological structures in this category include faults, joints and fractures. The study area is highly faulted (Alamirew *et al.,* 2007). Faults are the major structures that control fluoride content in groundwater in the study area. Theories explaining the origin of faults and their influence on groundwater have been discussed by several researchers as follows.

Nabidi (2001) documents that tectonic movements of the rift valley have important effects on aquifers properties since they create local fracture systems that comprises many aquifers which on a large scale forms regional hydraulic barriers on shatter zones of enhanced permeability. The presence of this complex network of faults and fractures in the area suggests reactivation of tensional oblique to primary rift axis controlled by these structures (Marieta, 2007). The high concentration of fluoride in the area could therefore be attributed to high in situ temperature (manifested by high hydrogeothermal) activity that results from tensional strain that may increase the solubility of mineral containing fluoride ions in the rocks (Onywere, 1997).

5.0 DEFLUORIDATION METHODS

Defluoridation is the process of removal of fluoride ion in drinking water. This Chapter reviews existing fluoride treatment technologies; assesses the level of awareness of each of these in Elementaita area; and makes recommendations regarding which are most suitable in the study area.

5.1 Review of fluoride removal technology

The different methods so far tried for the removal of excess fluoride from water can be broadly classified into the following categories according to KEBS (2010):

- Lime softening (calcium hydroxide)
- Alum plus lime (the “Nalgonda” process)
- Gypsum plus fluorite
- Activated carbon
- Plant carbon
- Zeolites
- Defluoron 2
- Clay pots, earths and clays
- Activated alumina
- Bone char

5.2 Bone char method of defluridation

In the study area, the bone char technique is the main defluoridation method used. Bonechar’s ability to defluoridate water has been known for decades though it has only relatively recently been applied in Kenya (Korir *et al.,* 2009).

5.2.1 Description of the method

Bone char gravels are bones which have been heated to temperature, above 400°C and crushed (Naslund, 2005). The bones are heated to kill microorganisms and make them brittle. Next, the bones are crushed to increase surface area (Plate 5.1). They bone chars are washed in tanks filled with water that contains 10% NaOH to remove dust and color.

Plate 5. 1: Bone char method (a) Bones before heating (b) Bone char gravels (After CDN ,2004)

The process that a lead to immobilization of fluoride on bone char is complicated and a combination of two or more reactions is involved (Naslund, 2005). The reactions involved can be divided into four types mainly: Ion exchange, adsorption, recrystalization and precipitation.

There are two types of ion exchange that take place, either when a fluoride ion changes position with hydrogen ion(OH-) or when it exchanges with a carbonate or hydrocarbonate ion(CO_3^{2-} /HCO_3^-) as illustrated by eqn 5.1.

$BC\text{-}OH + F^- \longleftrightarrow BC\text{-}F + OH^-$ ………………………………………………………………. 5.1

Equation after Bregnhoj (1995)

5.2.2 Advantages of the bone char method

- Effectiveness;
- Simplicity in day-to-day operation;
- Based on materials that are readily available locally;
- Cheap.

5.2.3 Disadvantages of the bone char method

- The use of bone char may be unacceptable to some communities or cultures due to the perception by some groups that the use of animal bone for treating water is contrary to traditional and religious beliefs.
- Water quality – taste and smell – is sometimes reported to be poor; this does compromise the use of the filter

6.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Summary

The area of study lies in the central rift along the Elementaita-Naivasha –Nakuru watershed. It's situated in Nakuru County the Rift valley Province of Kenya. It's bound by latitudes 35° 45' -36° 20' E and longitudes 1° 00' - 0° 15' N. The geology of the area is composed of volcanic rocks consisting of tephrites, basalts, trachytes, phonolites, ashes tuffs, agglomerates and acid lavas rhyolite comendite and obsidian (Thompson and Dodson, 1963). These rocks sandwich lake sediments where diatomite layers occur in thickness of 30metres dipping in a westward direction. The high fluoride concentration in groundwaters of the area exceeds the recommended system value of 1.5ppm by World Health Organization (Kahama *et al*., 1997). Geological and structural factors control the level of fluoride in groundwater in the area. The high fluoride in the area can be attributed to leaching of fluoride rich volcanic rock systems around the lake that enriches the underground drainage (Nair and Gitonga, 1984). High in situ temperatures along faults results in tensional strain that favours the solubility of minerals containing fluoride consequently leading to increased levels of fluoride ions in groundwater (Marieta, 2007). Defluoridation is the process of removal of fluoride ion in drinking water. Successful application of the defluoridation techniques demands innovation of cheap, nontoxic, easily and locally available material. Bone char method has been in the study area because it is readily available and requires less sophisticated processing.

6.2 Conclusion

The study was generally successful because the preliminary objectives were accomplished.
Geological factors were found to have affected fluoride levels in groundwater in the area.
The area has complicated geology and shows variable vertical and lateral stratigraphic layers of variable thickness and composition. This indicates that the area had gone through repeated (at least 5 visible layers) of periodic volcanism, denudation and associated tectonism. The alkaline volcanic rocks of the area e.g. trachytes, phonolites and basalts when weathered dissociate to minerals such as micas, carbonate salts and hydroxides that act as good sinks for fluoride ions

Fluorides in the area exist naturally in the rocks as components of amphiboles such as hornblende and other materials. Tectonic movements of the rift valley have important effects on aquifers properties since they create local fracture systems that comprise many aquifers which on a large scale forms regional hydraulic barriers on shatter zones of enhanced permeability. High in situ temperature (manifested by high hydrogeothermal) activity that results from tensional strain of surrounding rocks that may increase the solubility of mineral containing fluoride ions in the rocks

The F^- concentration and salinity of the groundwater are more related to depth and highly influenced by young penetrative faults and deeper sediments and partly shallow sediments.

The severity of fluoride contamination of borehole water in the area increases with proximity to the lake and depth of the borehole.

Finally the deep groundwater system that is controlled by faults or young volcanic systems and mixed sediments is saline and with high F^-.

6.3 Recommendations

Boreholes should be sited away from fault zones and highly weathered volcanic rocks. Areas East of L. Elementaita forms the best sites for borehole location because of their geological setting in relative faulted zones as compared to the west.

Alternative water sources such as surface water, rain water and low fluoride groundwater to be used by residents to prevent cases of fluorosis.

GIS and remote sensing to be used in by the Ministry of Water and Irrigation in delineating fluoride levels in water distribution in Elementaita area and the whole Kenya.

Sensitization of the public on the need to use surface water and rainwater as alternative water sources to prevent cases of dental and skeletal fluorosis.

Hydrogeological data from studies undertaken within the country to show consistency and incorporate geochemical data and modification to include structure

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APPENDIX

BOREHOLE DATA TABLE IN NAKURU COUNTY (CDN DATA)

Values used to plot Ph and borehole depth curves in chapter 4

WELL-ID	N/S	E/W	PROJ.NAME	X	Y	PEOPLE	DEPTH	PH	COND	F
D004	00 44' 20	36 29' 10	Mwega Nyakairu	36.4850	-0.7367	960	200	8,20	62	7,0
D007	00 41' 56	36 31' 45	Ngondi II	36.5242	-0.6927	5000	200	7,90	56	4,5
D008	00 43' 30	36 26' 37	Shindano Gituru	36.4395	-0.7217	5000	180	7,40	73	2,4
D009	00 43' 23	36 26' 26	Naivasha TC I	36.4377	-0.7205	5000	150	7,70	75	2,4
D011	00 45' 00	36 31' 12	Maraigushu	36.5187	-0.7500	0	250	8,10	71	1,0
D012	00 04' 30	36 29' 30	Nyamathi	36.4883	-0.0717	3600	247	7,60	24	2,2
D013	00 45' 48	36 31' 45	Karai I	36.5242	-0.7580	2400	210	8,30	73	9,6
D015	00 41' 25	36 28' 40	North Karati	36.4733	-0.6875	4160	160	8,70	55	6,4
D017	00 41' 30	36 27' 30	Nyondia	36.4550	-0.6883	2400	190	9,00	59	6,0
D018	00 39' 45	36 29' 00	New Karati	36.4833	-0.6575	8000	190	8,25	46	6,4
D022	00 47' 30	36 26' 30	D.N Handha	36.4383	-0.7883	1000	100	8,10	95	2,4
D023	00 45' 20	36 26' 50	Naivasha Sec.	36.4417	-0.7533	750	150	8,20	79	7,5
D024	00 46' 00	36 28' 26	Karai II	36.4710	-0.7667	3000	230	8,20	95	18,0
D025	00 57' 57	36 26' 50	Mirera II	36.4417	-0.9595	480	120	8,40	95	3,5
D026	00 16' 12	36 22' 01	OlKalou I	36.3668	-0.2687	300	150	7,60	31	1,3
D027	00 17' 47	36 10' 00	Karigi Ndege	36.1667	-0.2912	400	235	9,20	48	1,0
D028	00 06' 50	36 02' 40	Gichobo	36.0400	-0.1083	340	200	7,70	45	1,8
D029	00 29' 00	36 17' 40	St. Peters Prim.	36.2900	-0.4833	1950	120	6,00	24	1,9
D030	00 29' 00	36 17' 40	Murera Gilgil	36.2900	-0.4833	800	200	7,20	52	1,8
D033			Pastoral Centre			300	126	7,40	43	1,4
D034	00 03' 00	35 43' 00	Mercy Hospital	35.7167	-0.0500	1000	210	7,60	34	1,2
D035	00 22' 19	35 59' 58	Rare Kikapu	35.9930	-0.3698	400	195	8,30	32	4,5
D037	00 12' 40	35 42' 40	Franciscan Bro.	35.7067	-0.2067	300	155	7,60	16	1,6
D038	00 09' 30	36 11' 40	Koiyo Kamosop	36.1900	-0.1550	1000	135	7,90	18	0,2
D040	00 02' 03	36 32' 04	Rumuruti Missio	36.5340	0.0338	300	200	9,30	70	2,0
D059	00 54' 03	36 06' 10	Mary Mt. sec.	36.1017	-0.9005	300	205	7,50	21	1,6
D060	00 54' 03	36 06' 13	MoloTown Sec.	36.1022	-0.9005	300	130	7,50	17	1,0
D061	00 53' 57	36 05' 46	Kapkelek	36.0910	-0.8928	250	200	7,50	30	1,2
D062	00 54' 11	36 05' 34	Nyonjoro	36.0890	-0.9018	1615	87	6,40	56	4,0
D063	00 20' 00	35 06' 80	Njoro parish	35.1133	-0.3333	2100	197	7,00	31	1,8
D065	00 11' 45	36 32' 58	Gatundia	36.5430	-0.1908	1450	165	8,30	54	1,2
D066	00 04' 00	36 27' 00	Pondo	36.4500	-0.0667	1460	105	9,10	61	1,6
D067	00 02' 00	36 27' 30	Mutanga	36.4550	-0.0333	1500	80	7,30	39	1,4