

**CONCENTRATION LEVELS AND PATTERNS OF FLUORIDE IN  
GROUNDWATER RESOURCES FROM KENDU BAY AREA,  
KENYA**

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## Declaration

This is my original work and has not been presented for a degree in any other university.

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**Dedication**

To my children Huxley Scott, Ryan Roy and Rose Aquiline

## Abstract

Water samples from twenty eight boreholes and twenty six wells were sampled in Kendu Bay area which lies between longitudes  $34^{\circ} 35'$  and  $34^{\circ} 40'$  E and latitudes  $0^{\circ} 21'$  and  $0^{\circ} 27'$  S. The sampling was done in two seasons: dry season in the month of January 2006 and rainy season in the month of April in the same year. Defficiency or excess of fluoride in drinking water may be harzadous causing dental caries or dental fluorosis respectively. The samples were therefore analysed for fluoride and pH in the laboratory with the aim of determining the concentrations of fluoride in the study area, comparing these concentrations in the rift zone with those outside the rift, hence establish the factors controlling fluoride concentrations in the study area. Ion selective electrode method was used for the fluoride and pH determination in the laboratory. Temperature determinations were done in the field on site of each sampling point and an average of three temperature readings were taken on fresh sample of each sample using a  $-10^{\circ}\text{C}$  - $100^{\circ}\text{C}$  range mercury thermometer. Using computer techniques the overall distribution of fluoride levels, temperature and pH values in the study area in different seasons were plotted. The distribution patterns have been explained in terms of geology. These patterns do not change but the concentration changes.

The field and results obtained from the study area were subjected to statistical analysis. The regression curves and values of moment correlation coefficients indicate that there is significant relationship between fluoride and pH in both seasons. Temperature has slight effect on fluoride concentration while there is no relationship between fluoride concentrations and depth. Component factor analysis results show that pH is the

parameter that has the highest significant control of fluoride in the study area. Q-Q plot results and the descriptive statistics reveal that fluoride concentrations in the dry season are higher than rainy season, also fluoride concentrations in the lowland are higher than in upland, hence a general pattern in the decrease in the fluoride level from dry season to rainy season. This same pattern applies to temperature and pH. Topographical corrections were done and the elevations obtained in metres were used to determine the groundwater level above sea level. This was used to draw groundwater contours. The groundwater flow within the area of study has been determined by the use of groundwater contours. The flow direction of groundwater is roughly SE-NW-N direction and is the same direction as the surface water. The recharge and discharge areas have also been established from the groundwater contour map. In relation to groundwater flow direction the concentration levels of fluoride are higher in the discharge areas and lower in the recharge areas. Fluoride concentration levels increase with the direction of flow of groundwater. Quality aspect of the groundwater resources in relation to domestic use has been discussed. From this it is established that the waters are not suitable for domestic use.

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## CHAPTER ONE

### 1.1 Scope of the work

The area under study falls within the Nyanza Rift system which is partly a volcanic terrain. Volcanic terrains are well known for their fluoride content which then leads to higher fluoride concentrations in ground water. There is prevalence of dental fluorosis in the study area and groundwater is extensively used for water supply especially in the dry season when most streams dry up. In this study twenty eight boreholes and twenty six wells have been sampled to evaluate fluoride concentration in groundwater resources in Kendu Bay area. The water samples have been analysed for fluoride and pH in the laboratory. From the concentration levels of fluoride in the groundwater it is possible to state the water quality and to ascribe the factors that influence the water quality. The laboratory results were subjected to statistical analysis to establish the factors controlling fluoride concentrations in the study area. Fluoride concentrations were also compared on spatial basis, i e, the concentration in the upland (outside rift zone) and lowland (within rift zone). Groundwater contour maps were drawn and changes in the concentration levels of fluoride in relation to groundwater flow have been discussed. Contribution by the geology was inferred by comparing the concentration of fluoride in waters in different rock units. Concentration levels and patterns of fluoride in the dry and rainy seasons were briefly investigated and further insights were inferred by drawing fluoride distribution maps for the different seasons, and also by the use of statistical Q-Q plots. The relationship between fluoride and the physico-chemical (pH depth and temperature) parameters was done by calculating moment correlation coefficient and drawing regression curves..

## **1.2 Literature Review**

### **Background information**

Groundwater is an important source of water supply throughout the world whose use in irrigation, industries and drinking has increased. The quality of water is of equal importance as quantity (Todd, 1980). Chemical, physical and bacterial characteristics of groundwater determine its usefulness for various purposes. Continual use of groundwater combined with the re-use of water deteriorates its quality if consideration is not given to proper protection. Groundwater quality naturally varies widely from one geological formation to another and even within a particular formation largely as a result of the interaction between percolating rain water and the soil and subsoil material (Ward, 1967). Various human activities on the ground will therefore change soil conditions and therefore its percolating water, so the variation in various human activities and their influence on groundwater quality is important.

Water is an excellent solvent (Heath and Trainer, 1968). All groundwater contains salts in solution that are derived from the rock forming the aquifer and past movement of the water. However, the kinds and concentrations of dissolved salts depend on the movement of water, time of residence, the rock types, temperature and the concentration of the recharge in a given environment. Water quality analyses, sampling procedures, interpretation of water analyses, problems of water quality and factors controlling the quality have been discussed by different researchers. Climate, topography, geology, soils, relative mobility of elements, chemistry of rain and biology on the quality of water by

controlling the concentration of different elements in water (Gorham, 1961; Levinson, 1974; Todd, 1980).

Handa (1975) from his studies of geochemistry of groundwater in India contends that among the factors which control the concentration of fluoride are climate and presence of the accessory minerals fluorite and apatite in the rock mineral assemblage through which groundwater is circulating. He further noted that regional and tectonic factors also play some part in affecting the fluoride concentration of groundwaters.

Organic chemicals introduced by man into environment as the ultimate contaminator of groundwater originating from various sources include, the spills and the infiltration of polluted surface waters, leachates from dump sites, leakage from chemical plants and organic pesticides in agriculture and forestry (Matthess 1982).

Falkenmark (1982) considers agriculture as a heavy polluter, producing organic pollution from domestic animals, press juice from 'silos' and nutrient salts constituting surplus fertilizers leached from the soil by percolating water which is very toxic in drinking water.

### **Overview of Groundwater Quality in Kenya**

Ongwenyi (1973) has carried out systematic description of the occurrence and quality of groundwater over the whole of Kenya. He divided the country into four zones (Fig 1.1 which he summarized as follows (Table 1.1):



**Table 1.1 Modified after Ongwenyi (1973).**

Zones	Areas covered	Conclusion
I	Parts of Nyanza, Central, Rift Valley and Nairobi Provincial	Groundwater resources are of excellent quality and are suitable for most purposes, which include stock rearing, irrigation, industry and general household. He observed that there are cases of high fluoride concentrations (over 1.5 ppm) where defluoridation is necessary before the water can be used for drinking purposes.
II	Eastern half of Kenya and parts of the southern portion of the Rift Valley	The ground water resources have high fluoride concentrations
III	Semi arid areas of Kenya lying mainly in the north eastern and north western parts of Kenya	The groundwater has high concentrations of Total Dissolved Solids mainly because of chloride and possibly sodium ions.
IV	Extends parallel to the Indian ocean	Has a high chloride and sodium concentration. The water is hard for most uses while the concentration of fluoride was found to be generally within the acceptable limits

He further observed that the zones were meant to be a base for water resource development and further detailed research.

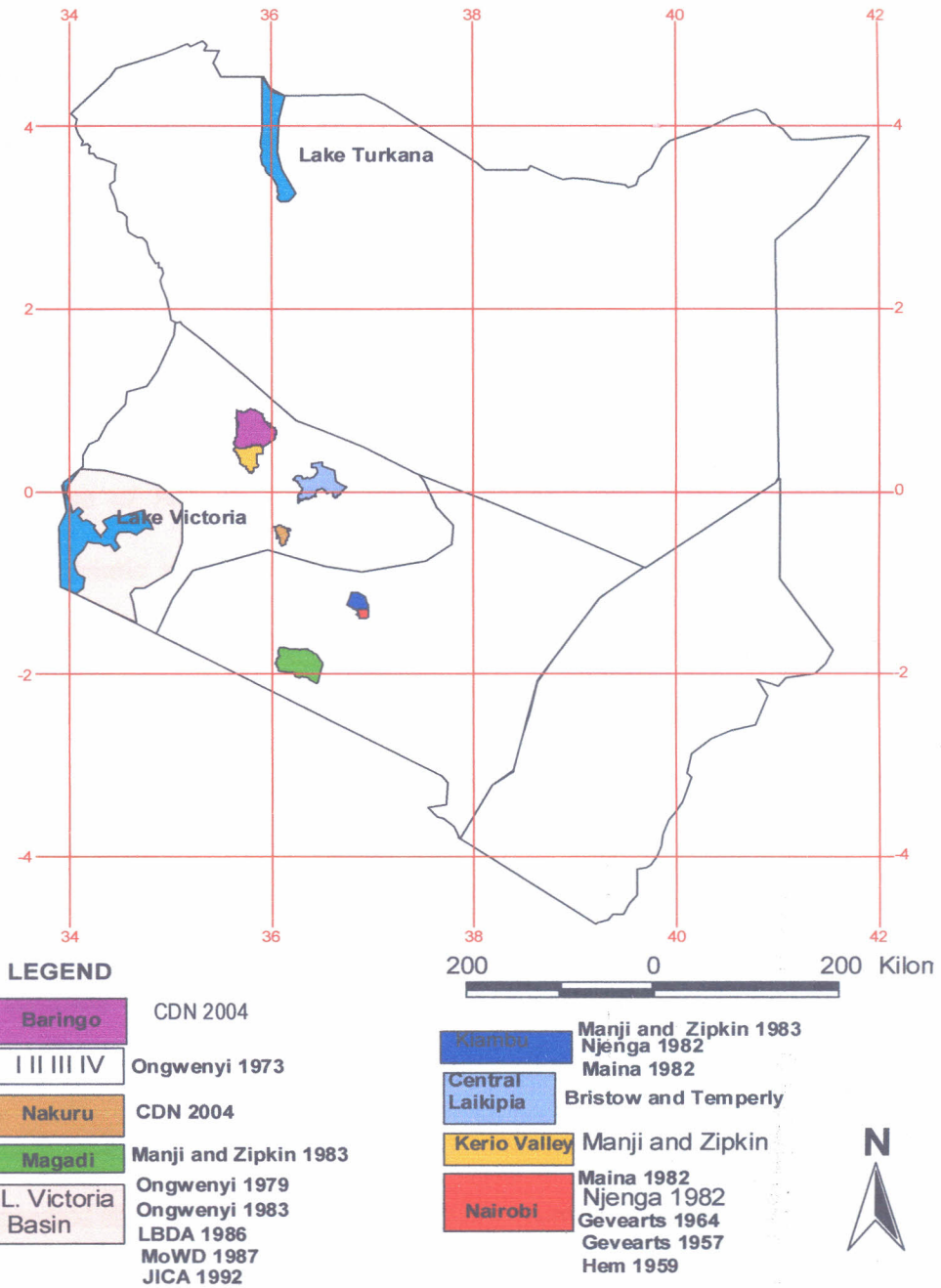


Figure 1.1 Study areas by previous researchers in Kenya (modified from Ongwenyi 1973)

Gevearts (1957, 1964) has done pioneering work by assessing not only the quality but also the quantity of groundwater in various geological units in the Nairobi area. He concluded that groundwater in Nairobi area was of good quality except for the fluoride content which was in excess of the desirable limit of 1.5ppm over a large part of the area and the water quality varies not only in space and time but also in depth as well as within geologic units examined.

The Catholic Diocese of Nakuru (CDN) has since 2004 been doing some work on defluoridation of borehole waters in Nakuru. From their research on the groundwaters from Baringo and Nakuru region (in Rift Valley Province) it has been established that fluoride dissolves readily from the rocks into the ground water in areas with volcanic rocks or sediments of calcium phosphate, hence contributing to high fluoride content in the Rift Valley (CDN, 2004).

Njenga (1982) sampled waters from some boreholes in Kiambu, Nairobi and Rift Valley areas and observed that out of the 24 boreholes sampled; most had fluoride concentrations above 5ppm, with higher concentrations of up to 36ppm in the Rift Valley. She suggested that "the fluoride concentrations were not related to the geological formations since boreholes which were close and penetrating identical formations had different fluoride concentrations although being close to each other". She also found that the fluoride concentrations in the rift system increases with depth of the bore hole.

Hem (1959) observed that fluoride is frequently found in igneous rocks, a component of amphiboles such as hornblende and certain other minerals. Alkaline rocks are also high in fluoride content than most other igneous rocks. However from his study of the Nairobi area (Figure 1.1), there are high fluoride concentrations of more than 1.5ppm.

Extensive work of fluoride content in groundwater has been carried out by Manji and Kapila (1983) in Kiambu, Magadi and Kerio Valley (Figure 1.1). The fluoride concentration of groundwater in these areas was found to be above 10ppm. They also noted high prevalence and severity of the dental fluorosis in the communities living in these areas.

Maina (1982) in her study of the area immediately to the north of Nairobi (Fig 1.1) noted that fluoride concentrations generally increased with the general flow direction of groundwater.

Bristow and Temperly (1964) in their work on the geology and groundwater conditions in central Laikipia (Figure 1.1) mention that the water in the area is of good quality, is soft and contains sufficient mineral matter. Their observation was based on samples from few boreholes; the analyzed fluoride content from eight bore holes had an average concentration of 1.9ppm. The sample size is so small for the area under consideration that their results may not be a reliable representative of the area.

The Ministry of Water Development has since its inception either singly or in collaboration with other ministries and /or international agencies like WHO, UNEP etc. been trying to safe guard the countrys' water bodies from any kind of pollution and mismanagement and their conservation besides provision of clean water. Chemical analysis of water records kept by Ministry of Water Development (1987) show that the quality of water in the study area is good except for the higher concentrations of fluoride of up to 10ppm recorded in some boreholes. The Ministry therefore recommends that the waters be demineralized before being used for human consumption.

Studies done in the Lake Victoria drainage basin outlines the state of surface and groundwater resources, its quality and quantity. Ongwenyi (1979) in a paper on Lake Victoria Development Authority (LBDA) outlines both surface and groundwater resources of the lake basin in terms of runoff, rainfall, evapotranspiration amounts, land use changes, hydrogeology, sediment transport, geology and the potential uses of the water. More information and knowledge on the groundwater quality is vital in groundwater resource management and exploitation.

Meadows (1979) has examined the quality of the Lake Victoria basin water and conclude that the water is excellent with minor departures such as high fluoride concentrations. He then related the quality to the potential developments within the basin such as industry and irrigation. Ongwenyi (1983) observed that although the Lake Victoria basin (Figure 1.1) is well endowed, the water has not been fully developed for effective and rational utilization for domestic, urban, rural and industrial uses. This is because knowledge on

the amount and quality of such water should be available to enable proper use of the water.

JICA (1992) from their research in Lake Victoria basin (Figure 1.1) observed that the water resources are of good quality except for the fluoride content. The high fluoride is related to the geology particularly volcanic rocks and the sedimentary rocks.

Extensive work on groundwater supply has been carried by Lake Basin Development Authority (LBDA) since 1986 in Kendu Bay area by drilling boreholes for the communities living in the area. From this work the water in the study area is of good quality and that the fluoride concentrations in the area are generally low except for a few cases where concentrations of up to 10ppm have been recorded. It was also found that high fluoride concentrations in some parts of the study area are related to the direction of flow of groundwater, that is lowlands have higher fluoride concentrations than the uplands. Also the hydrogeological work by LBDA showed that most of the areas with higher fluoride concentrations (above 1.5ppm) are underlain mainly by rhyolites and rhyolitic tuffs that are overlain by superficial deposits and alluvium. Therefore it is important to carry chemical analyses of groundwater from the current boreholes in different rock units to ascertain the concentration levels of fluoride (LBDA 1986)

### **1.3 Statement of the problem**

Many chemical analyses have been made of the fluoride concentration levels in different parts of the country for groundwater but very little information is known about the

fluoride concentrations in the Kendu Bay area. The geological processes such as faulting and volcanic activities are similar to most parts of the Rift Valley which are well known for higher fluoride content. Groundwater is extensively used for water supply in the region especially during the dry season when most streams dry up. A complete chemical analysis of these waters is necessary to establish whether their concentrations are within the recommended ranges set by WHO (1985) but for the case of this study chemical analysis is done for fluorides only due to prevalence of dental fluorosis in Kendu Bay. Deficiency or excess of fluorides in drinking water may be hazardous; causing dental caries or dental fluorosis respectively. The concentrations of fluorides from some borehole waters reported by the contractors immediately after completion of drilling might not give a true reflection of the fluoride concentration patterns in the area since different boreholes are drilled at different seasons. Therefore there is a dire need for the chemical constituents particularly fluoride concentrations of these groundwaters to be known.

#### **1.4 Objectives and Rationale**

##### **Rationale**

The quality of groundwater in the study area has been evaluated in terms of fluoride concentration because of the extensive use of groundwater for drinking purposes in the study area. By comparing the concentrations of fluoride in upland and lowland, it will be possible to assess the factors (such as pH, depth, temperature) that contribute to high or low fluoride concentration levels and establish which areas are prone to high fluorosis

incidents. Contribution by geology can be inferred by comparing the concentration of the fluoride in water over different rock units, hence the controlling factors contributing to different fluoride levels in different rock units. Groundwater flow is important in establishing the relationship between fluoride concentrations in the recharge and discharge zones. To meet this challenge the objectives and the expected output include:

### **Objectives**

- Determine the fluoride concentrations in the groundwaters in the study area and then compare these concentrations to other groundwater within the Nyanzian rift and outside the rift to ascertain the factors controlling the concentrations
- To determine the effects of groundwater flow on fluoride concentrations.
- To establish the relationship between geology and fluoride concentrations
- To establish the effects of the physico-chemical (depth, pH and temperature) parameters on the fluoride concentrations



## CHAPTER TWO

### STUDY AREA

#### 2.1 Location

The study area is located in Kendu Bay area of Rachuonyo District, Nyanza province (the topographical map sheet 116/3). It lies between longitudes  $34^{\circ} 35' E$  and  $34^{\circ} 40' E$  and latitudes  $0^{\circ} 21' S$  and  $0^{\circ} 27' S$ . The study area covers an area of about  $132\text{km}^2$  (Figure 2.1). Although tarmac roads are absent, a network of all weather roads connects all market centres in the area. Kendu Bay Township, which is the major centre in the study area, is connected by a murrum surface road to Homa Bay to the west, Pap Onditi to the east and Oyugis to the south east.

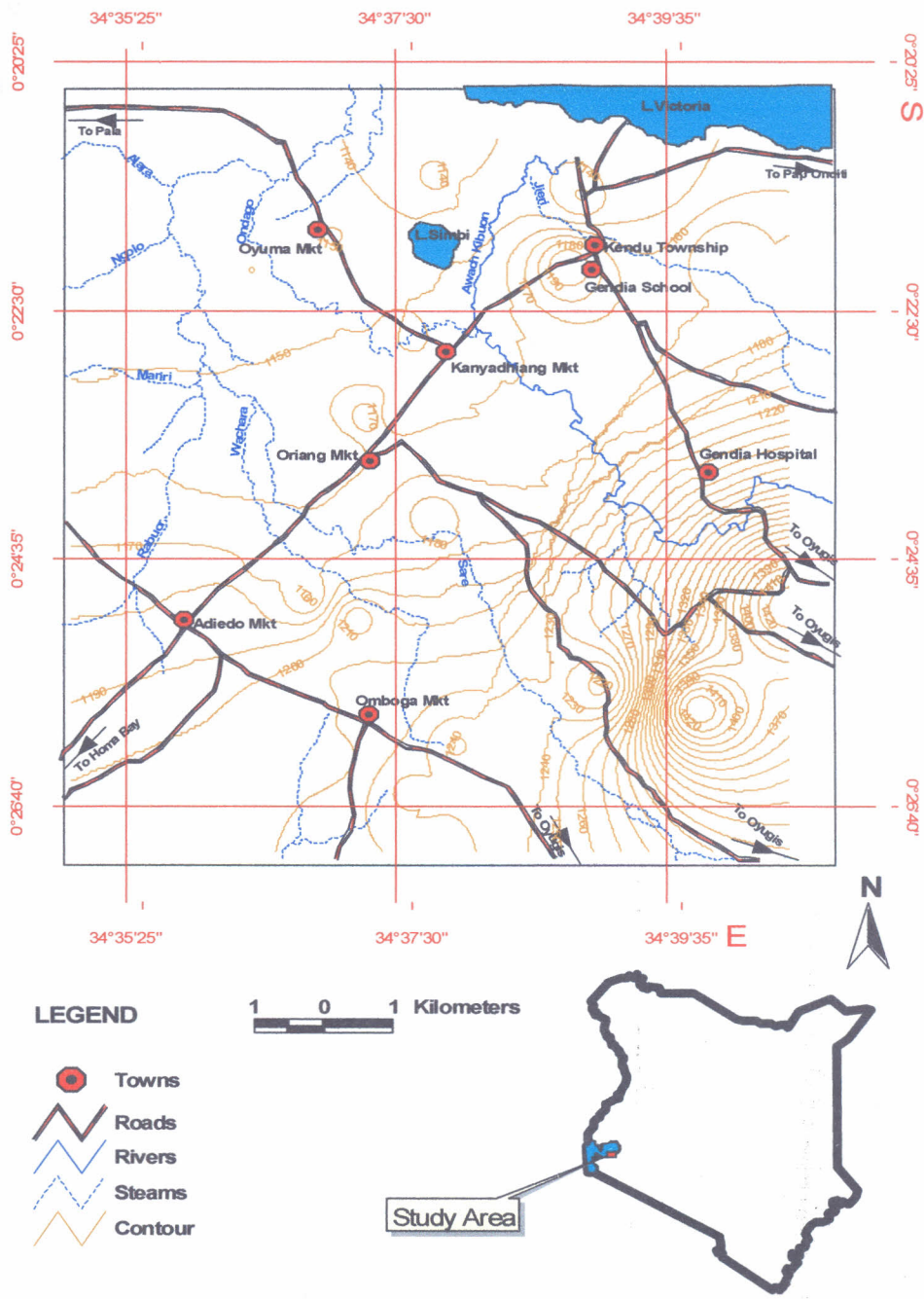


Figure 2.1: Map showing the study area

## **2.2 Climate and Vegetation**

According to Survey of Kenya (1970), the area is classified as sub-humid tropical type with an annual temperature range of 20°- 34°C and the maximum temperatures are in the months of February and early March. The average annual rainfall is approximately 1200mm. The southern part receives about 1300mm and the northern part about 1050mm per year. Two rainy seasons are recognized; the long rains from March to June with maximum precipitation in the month of April and the short rains from September to November. Therefore, rainfall in the area is concentrated over a relatively short time period and is of convectional type (Survey of Kenya, 1970). The climate of the study area is primarily influenced by altitude while cloud conditions and vegetation cover are secondary factors (LBDA 1986). Temperatures are greatly modified by the altitude and are therefore moderately high up to 34°C.

The area has lost most of its original vegetation due to deforestation, however, it is generally covered by savannah grassland, with scattered or grouped trees and shrubs.

## **2.3 Physiography and Drainage**

The topography of the Kendu Bay area is highly determined by the Nyanzian rift system and its geological history (Saggerson, 1952). The area is separated into lowland (Nyanza rift zone, altitude of 1123m to 1190m) and upland (outside the rift, altitude of 1170m to 1400m) by Kendu Escarpment, an extensive fault system which is a part of the Nyanza Rift system. This fault system runs from north-east to south-west and to the north it is parallel to the shore of Lake Victoria (Figure 2.2; LBDA, 1986; Saggerson, 1952). The upland forms the central, east and north-eastern part of the study area while the lowland

is to the north of the Kendu Escarpment, trending in the north east south-west direction between Homa hills and the uplands. The lowlands are slightly above the lake level (1120m). Also within the study area to the north is Lake Simbi which is an old Crater Lake containing non-potable alkaline (bitter) water. The area is also bordered by Lake Victoria to the north, a fresh water lake, and by Homa Hills to the north-west which has an elevation of 1750m Wire Hills to the south east (LBDA, 1986).

The area of study is generally served by one major river namely Awach Kibuon and several seasonal streams such as Wachara, Rabuor, Ondago, Sare, Mariri, among others (topographical sheet 116/3 Survey of Kenya 1970). All of these drain their waters into Lake Victoria in a northern direction (Figure 2.2). The drainage pattern in the eastern half of the study area is characterized by many small streams flowing from the escarpment into Lake Victoria. Due to advanced deforestation of Homa Hills and the escarpment (LBDA 1986), all these streams are seasonal, and occasional discharges cause deep erosion and damage to roads.

Further the water in these volcanics is variable both in quantity and quality (Ojany and Ogendo, 1988).

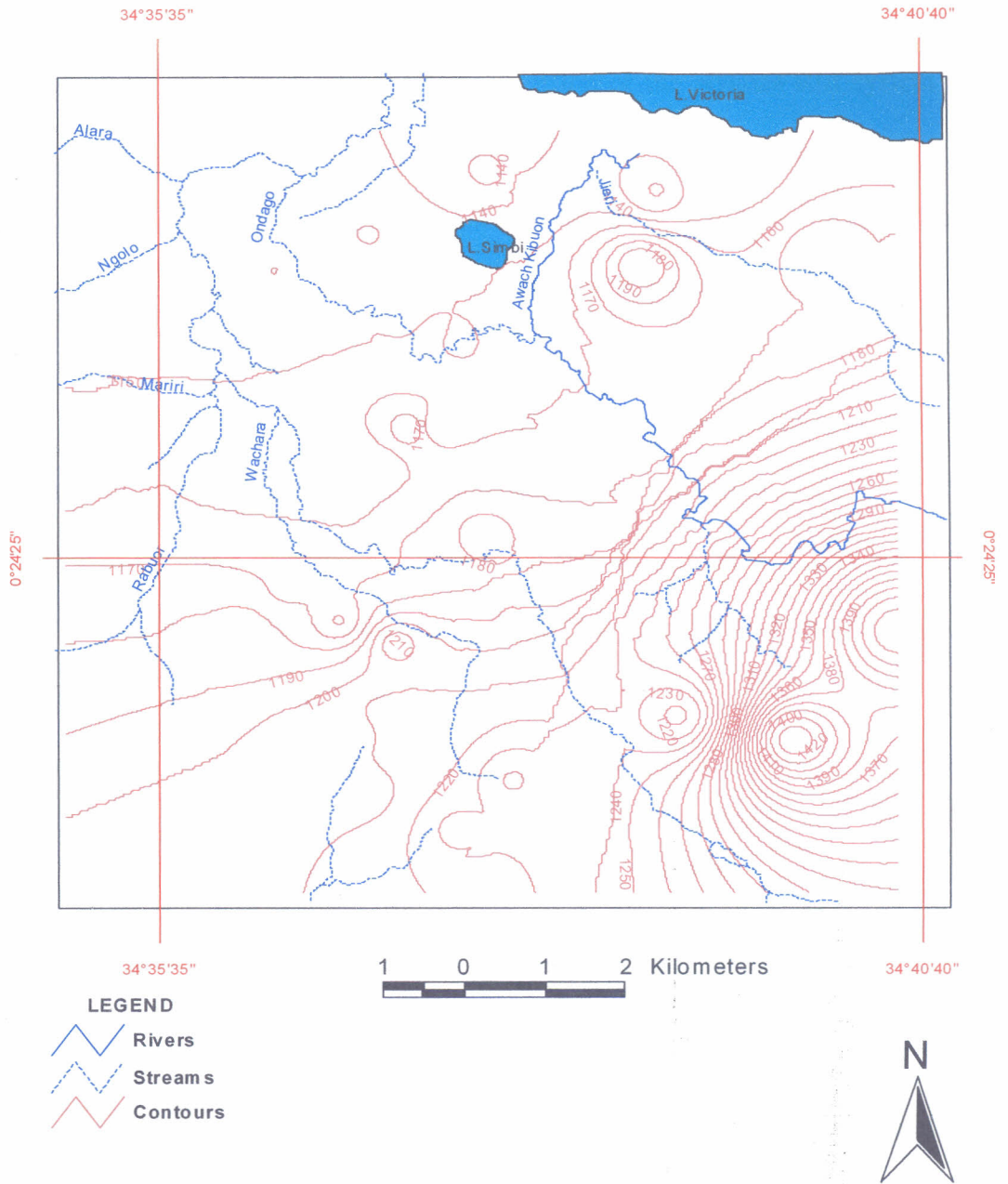


Figure 2.2 Drainage map of the study area

## 2.4 Geological setting

The morphology of the study area is determined by landscapes of igneous and sedimentary rocks (Figure 2.3). The area covers a portion of the Nyanza Rift system as shown in the geological map of the area. The morphology of the study area is volcanic origin. The area is separated into uplands and lowlands by Kendu Escarpment, an extensive fault (Kendu fault and Samanga fault) system which is a part of the Nyanzian Rift system.

The lowland is highly faulted and is underlain by Quaternary sediments and Tertiary volcanic deposits covered by superficial volcanoclastics of Recent age (Saggerson, 1952). Bordering the area of study to the north-west is Homa Hills, a site of active volcanic activities in the Tertiary and Pleistocene. According to Saggerson (1952) the rock types are divided into four divisions as in Table 2.1

**Table 2.1 Generalized geological succession. (Saggerson 1952).**

Geological Age		Stratigraphy
Quaternary	Recent	Alluvial and lacustrine sediments, soils and clay deposits
	Pleistocene	Tuffs, lake sediments and coarse agglomerates
Tertiary	Miocene Kisingiri lavas	Nephelinites and phonolitic nephelinites
Precambrian	Intrusives	Dolerites Granite
	Nyanzian System	Rhyolites Andesites Basaltic lavas

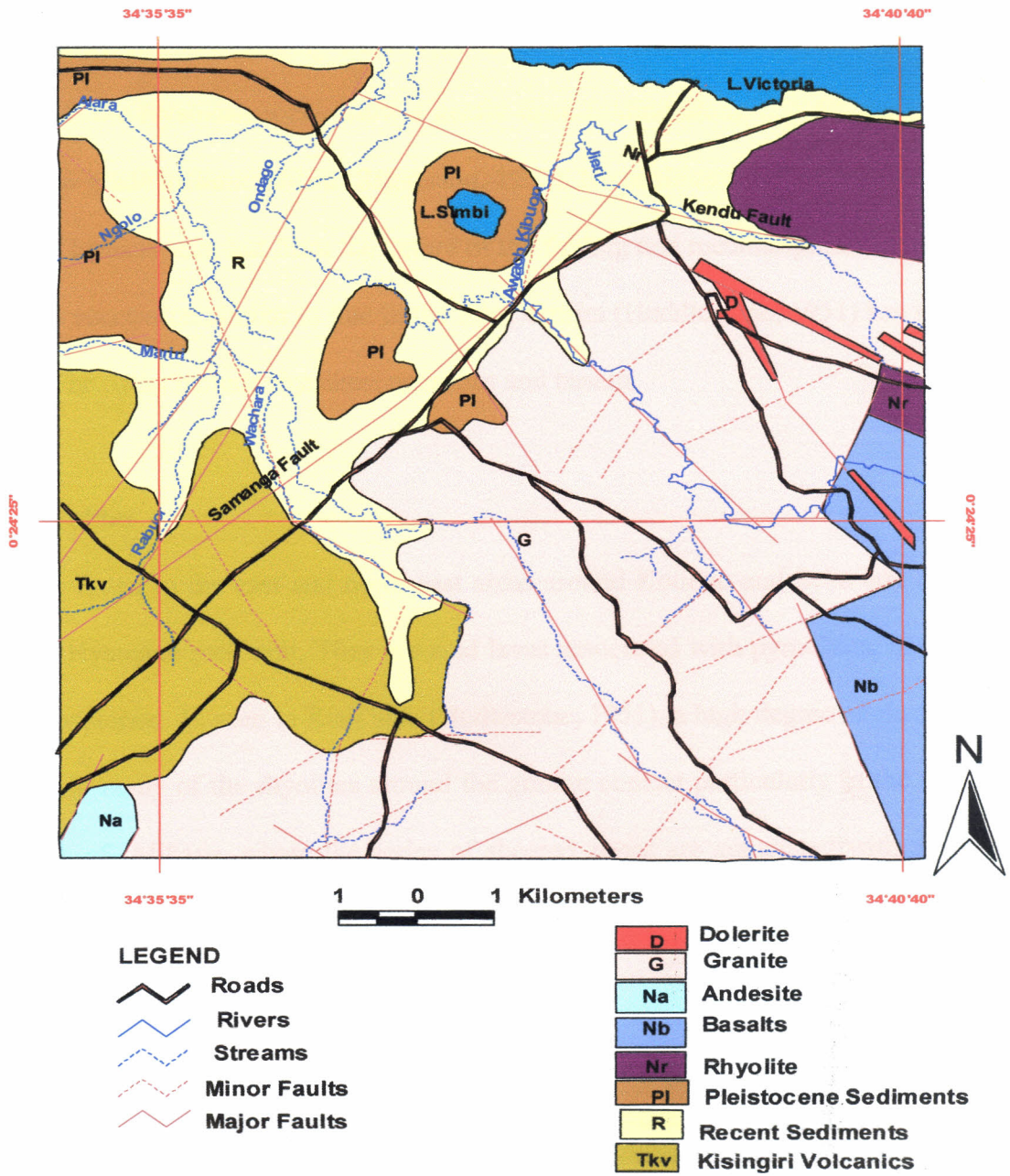


Figure 2.3: Geological map of the study area (Source: DHV Consulting Engineers 1986).

## **2.4.1 Precambrian Rocks**

### **2.4.1.1 Nyanzian system**

These are mainly volcanic ranging from basic to acid in character. Being of extrusive volcanic origin the Nyanzian rocks show a gently open folding along NW-SE axes and underwent low grade metamorphism (Saggerson, 1952). No positive proof of the order of succession of lavas is seen but from the nature of the folding and metamorphism of some of the rocks a succession similar to that in the Kisii district (Huddleston, 1951) has been established. The rocks include rhyolites, andesites and basalts.

#### **2.4.1.1.1 Rhyolites**

Rhyolites are found to the east and north east areas around Kotieno and Seka and form the youngest Nyanzian rock unit. They are acid lavas associated with pyroclasts, banded cherts and ironstones. As seen in Kisii area (Huddlestone, 1951), a high degree of shearing is noticeable in many of the rhyolites around the granite contact particularly in the river Awach, north of Mikaye, where the series of sheared zones are associated with much younger faulting.

#### **2.4.1.1.2 Andesite**

Andesite has a minor development, appearing as narrow lenticular bands exposed to the south-west, Kobila area. Near the granite contact they have been sheared and altered. They are porphyritic with feldspar and ferromagnesian minerals (Saggerson, 1952).



#### **2.4.1.1.3 Basalts**

Basalts form the oldest Nyanzian rock unit and consists of highly weathered closely packed pillow lavas of varying length. The pillows are somewhat irregular in shape and usually flattened. Unweathered outcrops are completely absent (Saggerson, 1952; Hudleston, 1951). South east of the study area is a tuff intercalated in the metabasalts. The chief minerals are albite, calcite, epidote, chlorite, quartz, hornblende and actinolite.

#### **2.4.1.2 Oyugis Granite**

This forms almost half of the rock system in the study area. The Oyugis granite outcrops between Kendu and Oyugis extending to Omboga area to the south west. The rock unit is highly fractured and sheared. The granites that form the Kendu Escarpment are more of the granodiorite type containing considerable amounts of mafic minerals. Feldspathic minerals are common and are associated with apatite needles. At the immediate contact between granite and Nyanzian basalts the rock is macrogranodioritic. The granodiorites are highly jointed and fractured with increasing intensity towards Kendu Escarpment. The fractures have a NW-SE trend (Saggerson, 1952).

#### **2.4.1.3 Dolerites**

Dolerites occur as sheet like masses often of considerable size or smaller dykes and sills. They are emplaced in the basalts and rhyolites rocks to the eastern region. These dykes and sills follow the dominant NW-SE fracture trend (Saggerson, 1952).

## **2.4.2. Tertiary volcanics**

### **2.5.2.1 Kisingiri Lavas**

These occur in the western region. Based on their origin, the Kisingiri lavas are identified. These are fissure eruptions that originated from Kisingiri volcanic centre in Mbita. The lavas are nephelinites and phonolitic nephelinites, similar to phonolites except that they are more massive and rarely porphyritic. The nephelinites form very prominent isolated conical hills, Rabuor and Samanga being typical examples. The rocks are characterized by their phenocrysts of pyroxene set in felted groundmass containing pyroxene, nepheline and in the case of phonolitic nephelinites, feldspars. Apatite, magnetite and rarely cossyrite are accessories. Apatite forms microphenocrysts and is prominent in the groundmass. Calcite forms euhedral microphenocrysts (Saggerson, 1952).

## **2.4.3 Quaternary deposits**

These are the youngest rocks in the study area and are found at the foot of the Escarpment, and along the shores of Lake Victoria. They are sediments of lacustrine origin consisting of Pleistocene deposits which were laid down when the Homa Volcano was still active, and Recent deposits which contain mainly gravels and loam deposited after all volcanic activity had ceased (Saggerson, 1952).

### **2.4.3.1 Pleistocene deposits**

The Pleistocene beds are found in the western area, Alego School, areas around Lake Simbi and as a small outcrop at Nyakongo area (Saggerson, 1952). Kanjera beds are

identified in this area and consist of alternating tuffs and lake sediments such as clay, sand, gravel and limestone. The beds consist of a three fold division identified by Kent, (1942) as follows:

- a) Basal greenish tuffs and ash which consist of thin bedded to coarse gravelly green and yellow brown tuffs and limestones.
- b) Middle group of clays, limestone, tuffs and agglomerates. The coarse agglomerates are found intercalated indicating contemporaneous volcanic events during the deposition of sediments.
- c) The upper group consists of transgressive beds of brown and greenish clay.

The Kanjera beds have gently folded and faulted (Kent, 1944). At the north- west of Lake Simbi, current bedded sandstones are identified (Oswald, 1914). These beds dip to the north-north east while slightly further south they dip south-west indicating the presence of a low anticline.

#### **2.4.3.2 Recent Sediments**

These include alluvial and lacustrine sediments as well as hill wash gravels soils and clay deposits. They occur along the Lake Victoria shore line and at the foot of the Kendu Escarpment and form more than 50% of the lowland. (LBDA, 1986, Saggerson, 1952).

#### **2.4.4 Structures**

The present major geological structures found in Kendu Bay area are caused mainly by the development of the Nyanzian rift and associated volcanism during the Tertiary. These structures include faults and dykes. Kendu and Samanga fault form the Kendu escarpment. The faults have two dominant trend directions: NW-SE and NE-SW direction. The dolerite dykes also follow the NW-SE fault direction which implies that this structural trend is of Precambrian age (LBDA, 1986; Saggerson, 1952).

#### **2.5 Soils**

The soils in the study area are divided into black cotton soil, red lateritic soil and the granitic soils (Figure 2.4). Black cotton soils comprise of black clay and grey sandy loam.

Lateritic soils include hill wash and grey calcareous gravelly soils.

Granitic soils include reddish brown clay loam and reddish brown sandy clay.

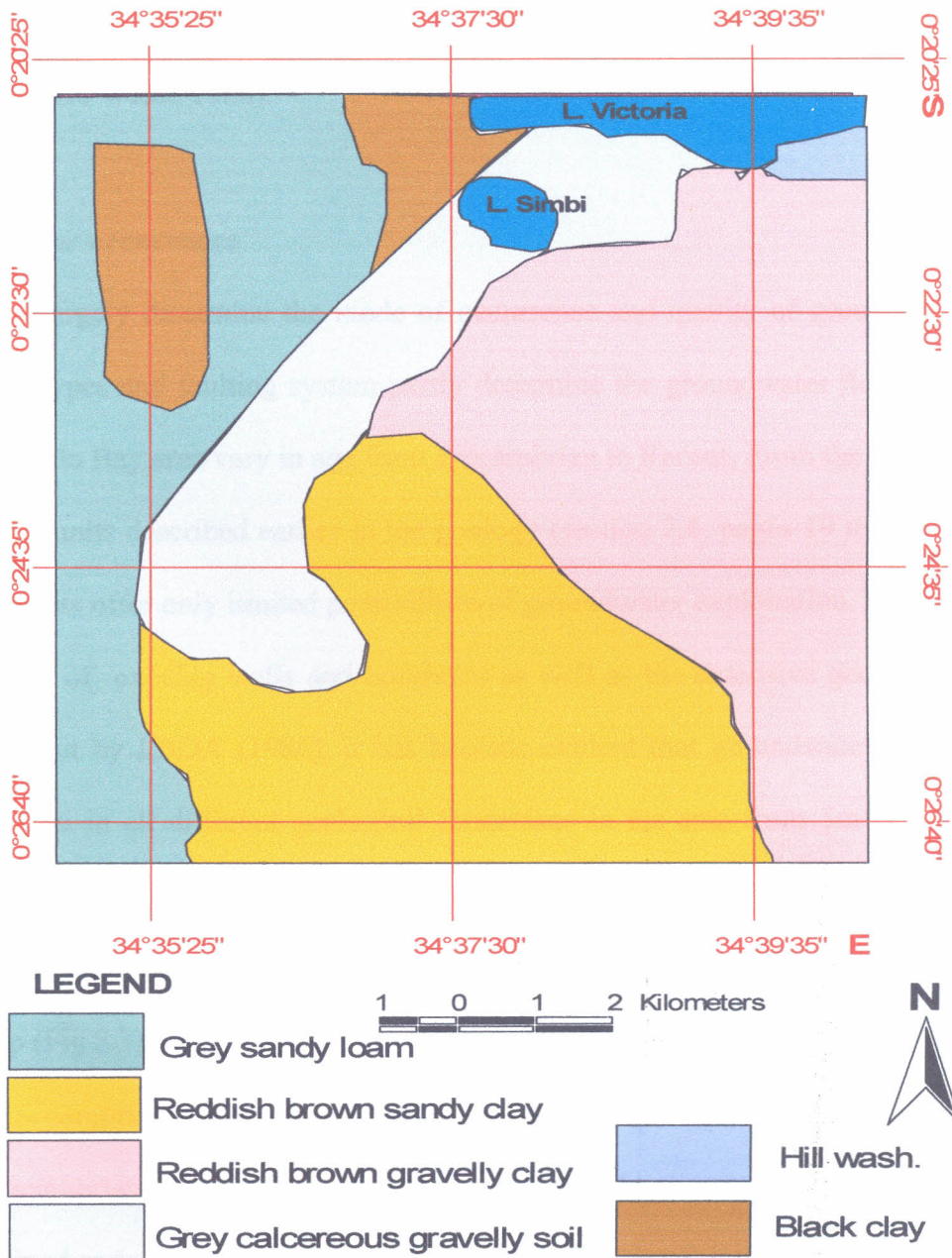


Figure 2.4: Map of soils in the study area (Source: Soil Survey of Kenya 1980)

## **2.6 Hydrogeology**

Factors such as rainfall, evaporation and inland and outflow, rock types and the extensive and well developed faulting system characterize the hydrogeology of the area (LBDA, 1986; Davies and De Wiest, 1966).

### **2.6.1 Groundwater occurrence**

The rock types largely determine the mode of occurrence and quality of groundwater, while both rock types and faulting system partly determine the groundwater flows. The rock types in Kendu Bay area vary in age from Precambrian to Recent. From the different lithostratigraphic units described earlier in the geology (section 2.4, pages 19 to 23), the Quaternary deposits offer only limited possibilities of groundwater exploitation. From the inventory records of existing wells and boreholes as well as the extensive geophysical surveys carried out by LBDA (1986), it has become evident that groundwater occurs almost everywhere in all different geological formations in the area from 5m to 130m depth (Tables 2.2 and 2.3).

Three hydrogeological zones related to rock types are identified as seen clearly on the geological map (Fig 2.3):

- Zone 1:- comprises the uplifted, elevated eastern part of Kendu area underlain by the Precambrian granites and volcanic rock types. In this zone, the aquifer is unconfined and the groundwater occurs mainly in the weathered zones. The quite pronounced sub-vertical fault zones provide larger storage.
- Zone 2:- comprises the down faulted lowland areas, south-west of Kendu and around the shore of Lake Victoria; underlain by Recent sediments and Pleistocene

deposits. The groundwater in this zone is found practically everywhere occurring in sand, silt or gravel in unconfined aquifers. The water is of poor quality hence offers limited possibilities of exploitation.

- Zone 3:- This zone is sandwiched between Precambrian granites in the east and Pleistocene deposits in the west, exclusively underlain by Tertiary volcanics. Groundwater occurs throughout the zone in the weathered rocks in unconfined aquifers.

**Table 2.2 Borehole data of the study area (Source: Ministry of Water Development 1987).**

Bore hole No	Bore hole register No	Source/owner	Latitude	Longitude	WRL in meters	WSLin meters	Total depth	Water elevation above sea level in meters
B1	-	Muslim Pri	-0.3589	34.6484	52	40	60	1077
B2	-	Tawakal Mosque	-0.3565	34.6545	-	-	-	-
B3	-	SimbiSsch	-0.3550	34.6251	-	-	-	-
B4	-	Francis Opondo	-0.3541	34.6263	-	-	-	-
B5	-	Ongalo sec	-0.3589	34.6168	-	-	130	-
B6	-	Osika Pri.	-0.3594	34.6099	-	-	-	-
B7	-	James Amayo	-0.3695	34.6061	-	-	-	-
B8	-	Kital Comm..	-0.3695	34.6070	48	-	53	1100
B9	C6651	Otok Sec	-0.3901	34.5824	81	-	90	1099
B10	-	Manywanda	-0.4039	34.6135	-	-	-	-
B11	-	Oula	-0.4065	34.6178	-	-	-	-
B12	C11486	Soko	-0.4183	34.6194	33.7	-	55	1182.3
B13	C7561	Omboga Pri	-0.4309	34.6209	27.5	-	52	1189.5
B14	C12743	Kakoko B	-0.4298	34.6153	45.65	-	67	1161
B15	C11487	Kakoko A	-0.4319	34.6116	27..13	-	46	1181.87
B16	C7776	Kogeta mult	-0.4167	34.6026	49.1	-	90	1137.9
B17	C7582	Bwanda	-0.4151	34.6135	64.43	-	70	1094.57
B18	C7766	Sanda w. group	-	-	79.85	-	83	1075.15
B19	-	Alego Kamser	-	-	-	-	-	-
B20	C7563	Kobila sch	-0.4509	34.5879	46	-	85	1174
B21	C12746	Kibugu	-	-	49.5	-	61	1156.5
B22	-	Omboga Sec	-0.4424	34.6262	35.5	-	60	1197.5
B23	-	Yanja w. project	-0.4068	34.6214	-	-	-	-
B24	-	Katuola	-0.4040	34.6288	-	-	-	-
B25	C7568	Kendu H Centre	-	-	49.68	-	60	1150.32
B26	C7774	Kowuor sch	-0.4276	34.6505	88.37	-	100	1129.63
B27	C7779	Liera sch	-0.4308	34.6635	51.3	-	53	1375.5
B28	C7778	Kideshwa sch	-0.4166	34.675	63.5	-	75	1364.5

**Table 2.3 Borehole data of the area study (source: field observation data and LBDA).**

Bore hole No	Borehole register No	Source/Owner (LBDA)	Griding (Field)		Altitude (Field)	Acqifer type (LBDA)
			Latitude	Longitude		
B1	-	Muslim pri	-0.3589	34.6484	1129	Sandstone/siltstone
B2		Tawakal	-0.3565	34.6545	1149	-
B3		Simbi Sch	0.3550	34.6254	1132	-
B4	-	Francis Opondo	0.3541	34.6263	1134	-
B5	-	Ongalo Sec	0.3589	34.6189	1141	Sandstone
B6	-	Osika Pri Sch	0.3594	34.6099	1143	-
B7		James Amayo	0.3695	34.6061	1138	Sandstone
B8		Kital Comm	0.3695	34.6070	1148	Sandstone
B9		Otok Sec	0.3901	34.6209	1180	Sandstone
B10		Manywanda	0.4039	34.6135	1160	Weathered granite
B11		Oula Wateri	0.4065	34.6187	1168	Weathered granite
B12	C11486	Soko	0.4183	34.6194	1216	Weathered granite
B13	C7561	Omboga Pri	0.4309	34.6209	1217	Weathered volcanic
B14	C12743	Kakoko B	0.4298	34.6153	1207	Weathered volcanic
B15	C11487	Kakoko A	0.4319	34.6116	1209	Weathered volcanic
B16	C7776	Kogeta Mult	0.4167	34.6026	1187	Weathered volcanic
B17	C7582	Bwanda	0.4151	34.6130	1159	Weathered volcanic
B18	C7766	Sanda W Group	0.3814	34.5824	1155	Sandstones
B19	-	Alego Kamser	0.3510	34.6090	1156	-
B20	C7563	Kobila Sch	0.4509	34.5879	1220	Weathered andesite
B21	C12746	Kibugu	0.4373	34.6161	1206	Weathered granite
B22	-	Omboga Sec	0.4424	34.6262	1233	Weathered granite
B23	-	Yanja W. Project	0.4068	34.6214	1174	Weathered granite
B24	-	Katuola	0.4040	34.6288	1186	Weathered granite
B25	C7568	Kendu H. Centre	0.3688	34.6467	1200	Weathered granite
B26	C7774	Kowuor Sch	0.4276	34.6505	1218	Weathered granite
B27	C7779	Liera Sch	0.4308	34.6635	1427	Weathered granite
B28	C7778	Kideshwa Sch	0.4169	34.6752	1428	Weathered basalts



**Table 2.4 Well Data of the study area (source: Field observation data).**

Well No	Latitude	Longitude	Elevation	Depth	WRL(m)	Water elevation above sea level (m)
1	-0.3676	34.6669	1180	23	13	1167
2	-0.3561	34.6568	1142	18	16	1126
3	-0.3518	34.6267	1132	10	8	1124
4	-0.3559	3.06287	1144	10	8	1136
5	-0.3548	34.6228	1136	10	7	1129
6	-0.3578	34.6231	1140	10	8	1132
7	-0.3564	34.6144	1143	12	11	1132
8	-0.3566	34.6150	1143	10	8	1135
9	-0.3600	34.6166	1146	-	-	-
10	-0.3646	34.6163	1144	15	9	1135
11	-0.3676	34.6130	1143	10	8	1135
12	-0.3710	34.6068	1149	13	11	1138
13	-0.3725	34.6076	1148	12	10	1138
14	-0.3697	34.6194	1148	10	8	1140
15	-0.3750	34.6202	1147	7	6	1141
16	-0.3772	34.6235	1152	33	28	1124
17	-0.3782	34.6267	1147	12	11	1136
18	-0.3764	34.6305	1155	16	14	1141
19	-0.3897	34.6238	1152	7	5	1147
20	-0.3948	34.6174	1153	6	3	1150
21	-0.3941	34.6127	1151	6	4	1147
22	-0.3949	34.6050	1150	8	6	1144
23	-0.3996	34.6136	1156	10	7	1149
24	-0.4113	34.6071	1169	5	2	1167
25	-0.4280	34.6188	1216	8	7	1209
24	-0.3460	34.6322	1241	12	9	1232

### 2.6.2 Groundwater Quality

The quality of the water in the study area (as has been discussed in literature review, chapter 1, pages 3-9) is generally good except for the fluoride concentrations which are higher than the recommended WHO (1985) standards. An appraisal of physical and

chemical quality of groundwater has been done by drillers but no proper past records on groundwater quality has been kept by Ministry of Water Development.

### **2.6.3 Groundwater path flow**

Groundwater is always in motion where the movement is from recharge area to discharge area (Chorley, 1974 and Chow, 1964). The path of groundwater flow and the rate at which water moves are not only determined by the geological conditions already discussed but also the topography which further determines the hydraulic conditions. According to Chow (1964) and Fitts (2002), movement of groundwater is influenced by lithology thickness and structure of rocks, porosity and permeability and that these structures also have a strong bearing on the storage of water. These structures (such as joints, bedding planes and faults) act as flow channels for groundwater in the study area. Todd (1959) cites joints as an example of some permeable zones in volcanic rocks. He further states that clay and coarser material mixed with clay are generally porous, but their pores are so small that they may be regarded as relatively impermeable. Thus, where free from clay-infillings, fissured zones along the faults as well as joints in the weathered zones along the faults such as the Oyugis granite and the rhyolites to the east provide the least resistance to flow of water and may provide temporary storage of water and or traps before it infiltrates and percolates into the ground storage. The groundwater flow in the area is towards north-northwest (Figure 2.5), corresponding with the northwest trend of the faults. These structures (faults) facilitate recharge in groundwater to be tapped through boreholes. Flow may also be concentrated in the relatively large, well connected faults in the area.

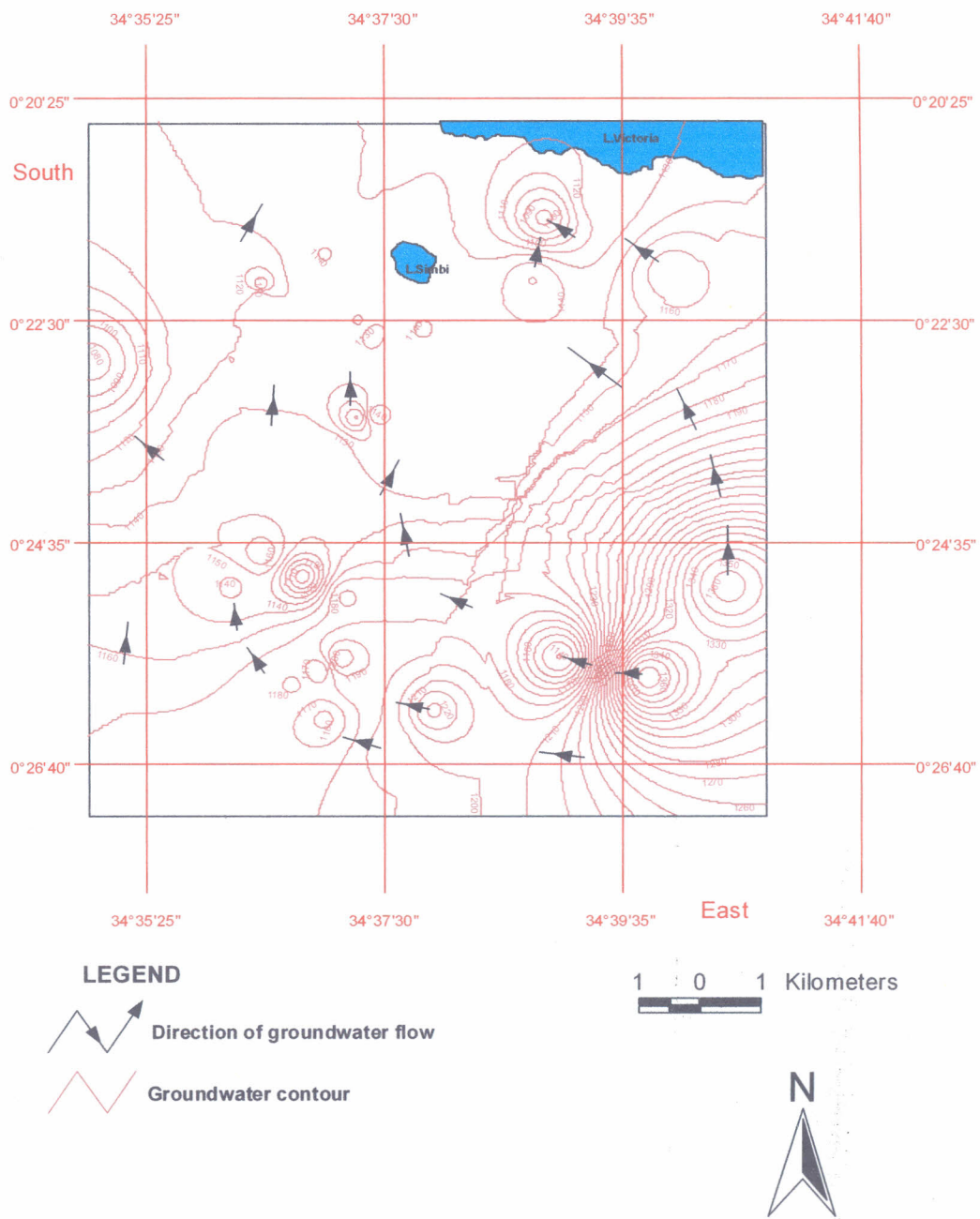


Figure 2.5 Map showing direction of groundwater flow

#### **2.6.4 Groundwater recharge and discharge**

Recharge areas are usually in topographically high places while discharge areas are located in topographically low areas (Fetter, 2001). The recharge of groundwater in the area of study is from infiltration and percolation of rain water on higher slopes of Homa Hills, infiltration from rivers and streams and also from inflow of groundwater from other areas such as Oyugis area and Wire Hills in the south east (LBDA, 1986). Regional groundwater flow patterns in the rift valley have evolved on the basis of high flanks providing recharge areas and the rift floor the discharge zones (Odero, 1993). In this respect, part of the study area lies in Nyanza rift floor, therefore the groundwater is recharged from the precipitation on the south-eastern zones which form the uplands while it is discharged in the lowlands which form the floor of the Nyanza rift. Bouwer (1978) states that the principle source of groundwater in unconfined aquifers is precipitation that has infiltrated into the soil above the aquifers either directly as it fell on the ground or indirectly via surface runoff and seepage from the streams. Ponding of rainwater on surfaces may allow recharge to continue long after rainfall event. Groundwater in this area is encountered between 5 to 130m below the surface. Generally groundwater in discharge zones tend to have higher mineral concentration levels compare to that at the recharge areas because of the longer residence time and prolonged exposure to geological factors (Walton, 1970; Todd, 1980). The same principle applies to the area of study where the discharge zones are having higher fluoride concentrations than the recharge.

## CHAPTER THREE

### METHODOLOGY

#### 3.1 Introduction

The methodology adopted to ensure the objectives of the study were achieved were in three phases. The first phase involved desk study in which all the relevant information was gathered before the actual field work was carried out. The second phase was marked by actual field work which was conducted in two seasons (Table 3.1):

- Dry season: field work conducted between 02/01/2006 to 09/01/2006 and
- Rainy season: field work conducted between 23/04/2006 to 28/04/2006.

This provided raw data that was to be used on the basis of the study. The samples from the field were then transported to the laboratory on 10/01/2006 and 30/04/2006 where chemical analyses were done. Finally statistical analysis of the data was done and this marked the third phase.

**Table 3.1 showing dates of sampling**

Dates of sampling			Dates of sampling		
Dry season	Rainy season	Sample	Dry season	Rainy season	Sample
03/01/06	24/04/206	B1	06/01/06	27/01/06	B9
		B2			B18
		W1			B16
		W2			B10
04/01/06	25/04/06	B25	07/01/06	28/04/06	W20
		B5			W21
		B6			W22
		W10			W24
		W11			W23
		W17			B22
		W18			B13
		W16			B15
		W15			B14
		W14			B21
W7	B12				
05/01/06	26/04/06	W9	08/01/06	29/04/06	B14
		W6			B11
		B3			B23
		B4			B24
		B8			B20
		7B			W25
		B19			W26
		W8			B26
		W12			B27
		W5			B28
W3					
W4					
W13					

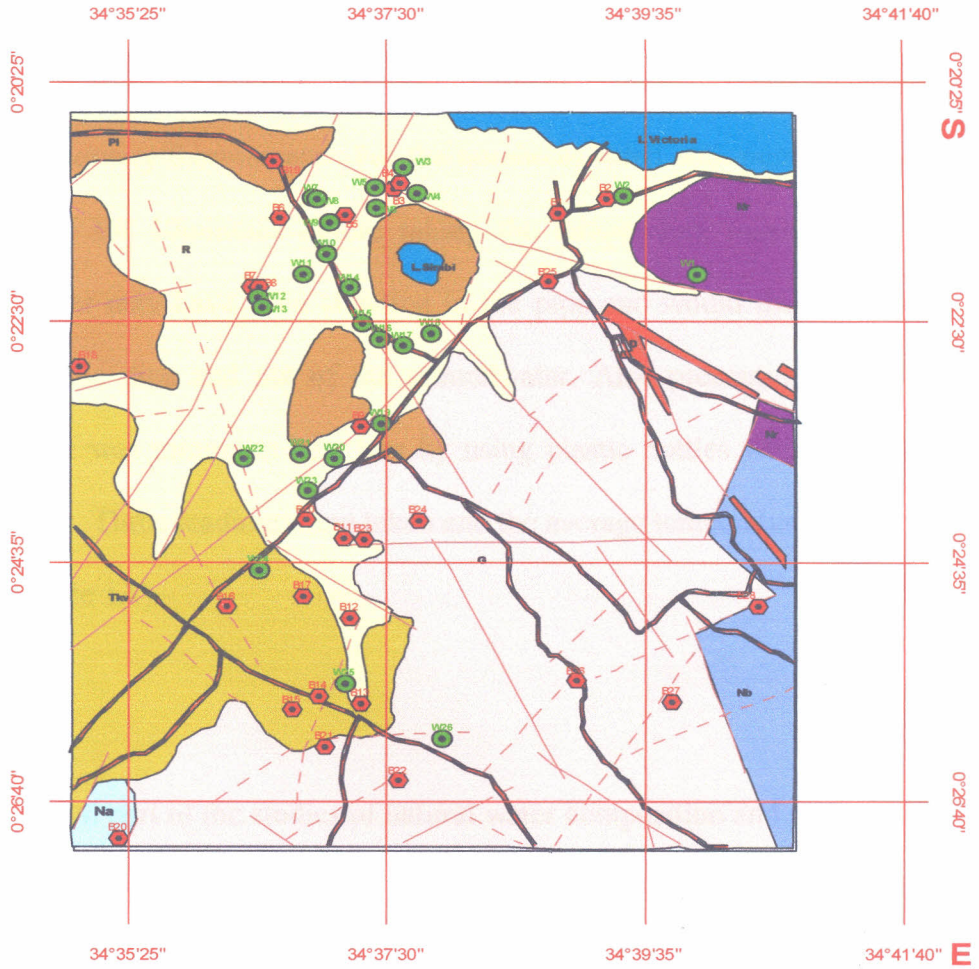
### 3.2 Desk Study

This involved study of journals, reports, theses and maps (soil, geological and topographical). It also included gathering of field data on bore holes from Ministry of Water and Irrigation, Kenya and also from the LBDA with respect to previous work done

in the area (from 1986-1987). The hydrogeological data included aquifer depths, water rest levels and water struck levels. Water quality data was based on fluoride concentrations in the waters. And finally the geological data has put emphasis on stratigraphic, lithological and structural factors that control occurrence and quality of groundwater.

### **3.3 Field Observation Sampling and Measurement methods**

Twenty eight boreholes and twenty six wells were sampled in the study area (Figure 3.1). Temperature determination was done in the field using a -10°C – 100°C range mercury thermometer. Altitude, longitude and latitude of the sampling sites were also measured using GPS (UTM 84).



**LEGEND**

- Wells
- ◆ Bore holes
- D Dolerite
- G Granite
- Na Andesite
- Nb Basalts

1 0 1 2 Kilometers



- Nb Rhyolite
- PI Pleistocene Sediments
- R Recent Sediments
- IKV Kisingiri Volcanics



Figure 3.1 Groundwater Sampling points



### **3.3.1 Field observation**

#### **Temperature**

The temperature of the waters was measured on site at the time of sampling using a -10°C - 100°C mercury thermometer. For the boreholes fitted with pumps the water was allowed to flow for 10 minutes before taking the temperature measurement. This is because the water may have been standing in the pipe and would therefore reflect the temperature of the pipe and not of the groundwater. Also precautions were taken to ensure that there was minimum heat loss by using plastic bottles which were wrapped with tissue paper. Three readings were taken and the average temperature was determined (Appendix I Table IA).

### **3.3.2 Sampling**

Sampling is a vital part of the studies of natural water composition and perhaps the major source of errors in the whole process of obtaining water quality information (Ilem 1959; Horowitz et al. 1994). Powel (1954) notes that the basic consideration in determining the water quality characteristics of a water supply is obtaining a sample or series of samples which is representative of the area. Due to the effect of change in season on water quality, sampling was done in two seasons; dry and rainy. The dry season sampling was done in January (peak of dry season) whereas the rainy season sampling was done in April (peak of rainy season) 2006. Random sampling was adopted where twenty-eight boreholes and twenty-six wells were sampled (Figure 3.1) based on the principle that the more the samples the more they are representative of the area (Ilem, 1959; Ongwenyi, 1973). Sampling was done using clean plastic bottles which had screw cap stoppers ringed to

prevent leakage during transportation. To ensure accuracy, the sampling plastic bottles were cleaned with a metal free nitric acid of concentration 2M then rinsed several times with distilled water and finally deionised water. When collecting the water samples in the field, the plastic containers were rinsed at least three times with the water about to be sampled. Plastic bottles are advantageous to use because:

- Breakage is minimized
- No contamination of metals dissolved from the walls of the container.

The samples were taken close to the point source of discharge from the boreholes and wells. In cases of boreholes fitted with pumps, the water was allowed to flow for sometime before taking the sample because the water may have been standing in contact with the iron pipe which could add to iron content in the sample (Todd, 1959; Todd, 1980; Hem, 1959). The sample bottle was then tightly closed for transportation to the laboratory. Tightly closing the bottles helps in maintaining the pH value of the water as close to field conditions as possible. The pII value of water represents the overall balance of a series of equilibrium existing in solution and may be altered by loss of carbon dioxide as soon as the borehole/well water is brought to the surface. Thus the pH obtained in the laboratory may not represent the actual conditions within the aquifer even if the bottles were tightly closed since some of the carbon dioxide is lost from the water before it is sampled. However, it should be noted that values for pH determined in the laboratory may better represent conditions under which the water will be used than would field determinations (Hem, 1959). Hence any loss of carbon dioxide that may have occurred in this case is not considered critical to the evaluation of water quality with respect to fluoride.

### **3.4 Laboratory and Analytical Technique for F<sup>-</sup> and pH**

The choice of analytical techniques is influenced by the standard of accuracy and precision required. The laboratory procedures considered generally acceptable and in widest use for water analysis are compiled in many publications: American Public Health Association (APHA) et al (1992), Hcm (1959). The analytical technique adopted for the determination of fluoride and pH in this study is Ion Selective Electrode.

#### **a) The apparatus and reagents used:**

Apparatus (Figure 3.2):

Fluoride electrode

Specific ion meter

Sleeve type reference electrode

Magnetic stirrer with TFL coated stirrer bar

Stop-watch

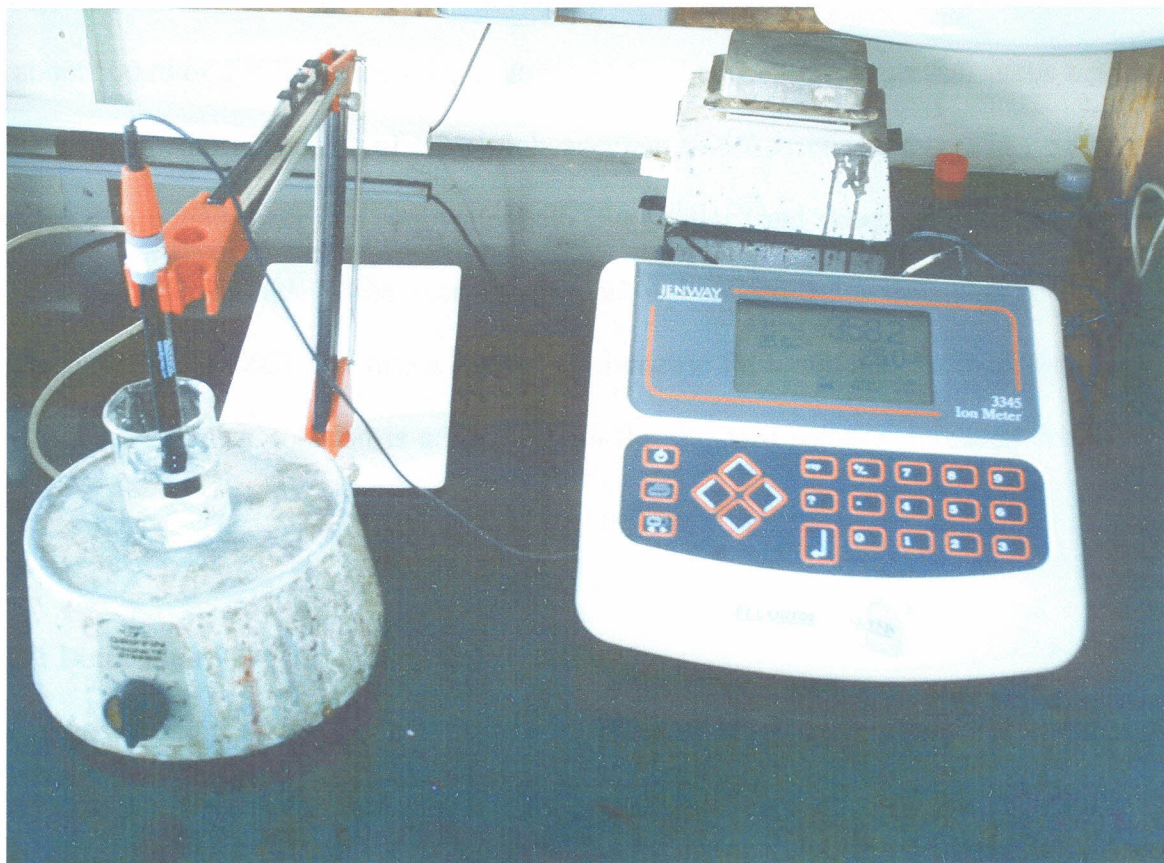


Figure 3.2 Set up of Fluoride electrode, Specific Ion Meter, and magnetic stirrer

**Reagents:**

Stock fluoride solution

Dissolve 221.0 mg anhydrous sodium fluoride in distilled water and dilute to 1000ml;

1.00ml=1.0 $\mu$ gF<sup>-</sup>

**b) Standard fluoride solution**

Dilute 100ml stock fluoride solution to 1000ml with distilled water; 100ml=10.0 $\mu$ gF<sup>-</sup>

### c) Fluoride buffer; TISAB

To about 500ml of distilled water in a beaker, add 57ml concentrated (glacial) acetic acid, 58g of sodium chloride and 4g of 1,2-cycloheanediamine-tetraacetic acid (CDTA). Stir to dissolve. Place the beaker in a cool water bath (for cooling) and slowly add about 120ml of 6M sodium hydroxide while stirring until pH is between 5-5.5 then cool to room temperature (20°C-25°C). Put into a one litre volumetric flask and add distilled water to the mark. This buffer solution is added to both the standard solution prepared and the sample.

### d) pH Determination

For the determination of the pH the reference electrode is immersed in a solution containing a fixed concentration of hydrogen ions. A position which allows the electric current to pass separates the reference solution from the solution in which the electrode is immersed to determine the pH value. Buffers of pH value 4.00 and 7.00 were used for calibrating the instrument.

In both the cases, that is fluoride and pH determinations, sample analyses was carried out after establishing appropriate curve using the standard for each of the two cases.

Instrument specification ( source: Ion Meter Operating Mannual)

Range:	-2 to 19.999pH
Resolution:	0.1/0.01/0.001pH
Accuracy:	±0.003pH

## **Concentrations of ions**

Range:  $1 \times 10^{-9}$  to  $9.99 \times 10^9$

Units: Activity ppm, %, mg/l, M or none

Resolution: 3 significant digits

Accuracy :  $\pm 0.00\text{px}$  for monovalent ions

### **e) Ion Selective Electrode Method**

Ion selective electrode (Figure 3.2) is defined as an indicator or measuring electrode with relatively high degree of specificity for a single ion or class of ions. It is used together with a reference electrode. The electrodes have a potential which varies with the concentration of a particular ion and is of invariant potential with negligible variation in the liquid junction. These electrodes are essentially membranes mounted at the end of glass or plastic tubes. The nature of the membrane determines the ion to which the electrode responds. 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 depends on the concentration of the activity to which the electrode responds. The relationship between ion activity and the electrode potential is logarithmic. Measurements of the potential against the fixed potential of the reference electrode provides a measure of concentration. An Orion Model 3345 specific ion meter (Ion analyser Orion Operating manual) with expanded scale was used for the determination fluoride ion concentration and pH values.

The fluoride ion electrode is a selective ion sensor. The key element in the fluoride electrode is the laser-type doped lanthanum trifluoride crystal across which a potential is established by fluoride solutions of different concentrations. The fluoride ion activity electrode can be used to measure the activity or concentration of fluoride in aqueous samples by use of an appropriate calibration curve. The fluoride activity is dependent upon the total ionic strength of the sample and the electrode does not respond to fluoride which is bound or complexed. Total Ionic Strength Adjustment Buffer (TISAB) is therefore added in equal amount to both the sample and each of the standards used in the calibration curve. TISAB has two functions:

It adjusts the ionic strength of the samples and standards of solutions (samples) to be equal. This helps in using a single calibration curve for a wider range of samples. The ionic strength of the samples is fixed by adding a much larger level of ions than that found in drinking water. It also helps eliminate the interfering ions and will buffer the solution at a pH range which avoids the hydroxide ion or hydrogen ion and will complex with most cations.

### **3.5 Statistical methods**

A Microsoft Window Excel package together with SPSS for Windows version 12.00 were used for correlation analysis, regression analysis, descriptive statistics (i.e. mean variance and standard deviation), Q-Q Plot and Principle Components Analysis. All these statistical methods were applied to establish the relationships between the measured parameters and how they influence fluoride concentrations in the study area.

### 3.5.1 Statistical Correlation Coefficients, Regression analysis Q-Q Plot and Principle Components Factor Analysis.

#### Correlation

Correlation assesses the degree of relationship between the variables measured from the field and laboratory analyses. The variables include fluoride, pH, temperature and depth. The product moment of coefficient of linear correlation  $r$  is used to assess the linear relationship between these variables and the concentration of fluoride.

Values of  $r$  which are dimensionless measure can vary between +1 and -1.

If  $r = +1$  it shows perfect correlation between  $x$  and  $y$ , that is one variable increases as the second increases.

$r = -1$  shows there is a negative correlation between  $x$  and  $y$ , that is one variable changes inversely with relation to the other.

$r = 0$  shows there is no relationship (Till, 1974; Helsel and Hirsch, 2002).

Therefore the correlation equation is expressed as follows:

$$r = \frac{\sum xy - (\sum x)(\sum y)/n}{\sqrt{\sum x^2 - (\sum x)^2/n} \sqrt{\sum y^2 - (\sum y)^2/n}}$$

where  $r$  = moment correlation coefficient

$x, y$  = variables

$n$  = number of observations



## Regression

Regression allows for the quantification of the relationship between a pair of variables so that the other is predicted. This deals with the relationship between one continuous variable of interest, called the response variable and one other variable, the explanatory variable.

Therefore linear regression equation is:

$$y_i = b_0 + b_1 X_i$$

Where  $y_i$  is the  $i$ th observation of the response (or dependent) variable

$X_i$  is the  $i$ th observation of the explanatory (or independent) variable

$b_0$  is the intercept

$b_1$  is the slope

In performing regression the value of  $R^2$  are evaluated. Values of  $R^2$  close to 1 are an indicator of a good model. (Davis, 2002; Helsel and Hirsch 2002).

## Q-Q plot

The Q-Q plot (or quantile-quantile plot) is the comparison made between two data sets by graphing the quantiles. If two data sets came from the same distribution the quantile pairs would plot along a straight line. The data sets are ranked in ascending order and the Q-Q plot is simply a scatter plot of the ordered data pairs  $x_1 y_1, \dots, x_n y_n$ . When sample sizes are not equal consider  $n$  to be the sample size of the smaller data set and  $m$  to be the sample size of the larger data set. The data values from the smaller data set are its  $p$ th quantiles where  $p = (i-0.4)/(n+0.2)$ . The  $n$  corresponding quantiles for the larger data set

are interpolated values which divide the larger set into n equally spaced parts. To compute the corresponding quantiles for the second data set  $p = (j-0.4)/(m+0.2)$  therefore j must be

$$\frac{(j-0.4)}{(m+0.2)} = \frac{(i-0.4)}{(n+0.2)} \quad \text{or}$$

$$j = \frac{(m+0.2) * (i-0.4)}{(n+0.2)} + 0.4$$

$Y_j = Y_1 + p * (Y_n - Y_1)$  where  $Y_j$  are the interpolated values,  $Y_1$  is the first value of the larger data set,  $Y_n$  is the  $n_{th}$  value of the larger data set and p is the  $p_{th}$  percentile

For example the first value of  $Y_j$  will be:

$$Y_j = Y_1 + 0.05 * (Y_2 - Y_1)$$

The interpolated values of  $Y_j$  are then plotted against  $X_i$ . the interpretation is based on the slope/gradient of curve:

Gradient/slope >1: y values are greater than x values.

If <1: then y values are less than x values.

Gradient=1:  $y = x$  (Helsel and Hirsch 2002).

### **Principle Component Analysis (PCA)**

Principle component analysis starts with the covariance matrix describing the dispersion of the original variables (measured parameters and extracting the eigenvalues and eigenvectors). An eigenvector is a list of coefficients (loadings or weights) by which it is multiplied with the original correlated variables to obtain new uncorrelated (orthogonal) variables, called principle components (PC), which are weighted (linear combinations of

the original variables). A principle component is the product of the original data and an eigenvector; the result of projecting the data on to a new axis is a new variable. The main purpose of Factor Analysis is to reduce the contribution of less significant variables in order to simplify the data structure coming from PCA. During the computation of PCA a Varimax rotation (raw) of the PCs from the original standardized variables is done in order to reduce the contribution of variables with minor significance. The number of principle components considered for each situation is mainly decided on the basis of the percentage of explained variance. Then all factors with eigenvalues higher than one are extracted (Davis, 2002).

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## CHAPTER FOUR

### FIELD AND LABORATORY RESULTS AND INTERPRETATION

This chapter summarizes the field, laboratory and statistical analysis results of the collected data. The analytical results of fluoride levels, pH, and field determination of temperature results for groundwater in the study area in the dry and wet seasons have been summarized in Table 4.1 and 4.2 respectively.

#### 4.1 Temperature

Groundwater temperature can almost be constant except when very shallow (Robert 1986), however this is generally exceptional. The groundwater temperatures ranged from 25°C - 31°C in both the dry and rainy season (Table 4.1). In the dry season the lowest temperature of 25°C was recorded at W8, W14, W15 and W17 (Fig 3.1) whereas the highest temperature was recorded at station W19 and W20. In the rainy season, the lowest temperature of 25°C was recorded at stations W8, W14, W16, W17 and W24 whereas the highest temperature of 31°C was recorded at station B1 (Muslim Primary School).

**Table 4.1 Temperature, pH and fluoride levels of groundwater in Kendu Bay area**

both in dry and wet season (D = dry season, W = rainy or wet season)

BH No/ well No	Name/ Source	Dry season			Wet/rainy season		
		F <sub>D</sub> (ppm)	F <sub>W</sub> (ppm)	T <sub>D</sub> (°C)	T <sub>W</sub> (°C)	pH <sub>D</sub>	pH <sub>W</sub>
B1	Muslim Pri School	24.50	36.00	29.00	31.00	8.56	8.57
B2	Tawakal	7.40	6.40	30.00	29.00	8.53	8.42
B3	Simbi School	3.40	2.00	30.00	29.00	7.69	7.60
B4	Francis Opondo	2.40	2.30	28.00	29.00	7.46	7.50
B5	Ongalo Sec School	2.98	2.90	28.00	27.00	7.96	7.90
B6	Osika Primary School	2.35	2.00	28.00	28.00	7.14	7.10
B7	James Amayo	4.60	4.10	26.00	26.00	7.61	7.62
B8	Kital Community	12.00	10.8	29.00	28.00	7.80	7.74
B9 (c7776)	Otok Sec.School	4.80	3.20	29.00	28.00	7.74	7.28
B10	Manywanda Oriang	2.30	2.00	28.00	27.00	7.35	7.47
B11	Oula Wateri	2.75	2.50	28.00	27.00	7.50	7.60
B12)	Soko Omboga	10.50	10.00	29.00	28.00	8.03	7.98
B13 (c7582)	Omboga Primary School	4.20	3.90	29.00	28.00	7.79	7.77
B14 (C12743)	Kakoko B	2.50	2.10	28.00	27.00	7.82	7.82
B15 (C11487)	Kakoko A	1.97	1.90	27.00	27.00	7.52	7.54
B16 (C7776)	Kogeta	3.80	3.60	29.00	28.00	7.76	7.76
B1 (C7582)	Bwanda	6.80	5.90	29.00	28.00	7.57	7.66
B18 (7766)	Sanda Women Group	2.70	2.20	29.00	28.00	7.56	7.63
B19	Alego Kamser	2.20	1.90	28.00	26.00	7.62	7.52
B20 (C7563)	Kobila School	3.50	3.00	29.00	28.00	7.48	7.34
B21	Kibugu	3.50	3.40	28.00	28.00	7.64	7.92
B22 (c7561)	Omboga Secondary School	3.40	2.80	28.00	27.00	7.43	7.40
B23	Yanja Water Project	4.10	3.60	28.00	27.00	7.46	7.71
B24	Katuola	4.40	3.60	28.00	26.00	7.70	7.71
B25 (c7778)	Kendu Health Centre	5.00	4.30	28.00	26.00	7.41	7.20
B26 (7774)	Kowuor School	2.60	2.50	27.00	27.00	7.11	7.26
B27 (C7779)	Liera School	2.40	2.00	27.00	27.00	7.76	7.72
B28	Kideshwa School	1.80	1.40	27.00	27.00	7.51	7.36

**Table 4.1 continued**

W1	Kasat	5.80	4.80	28.00	26.00	7.44	7.12
W2	Juma Mashoud	7.60	10.50	28.00	27.00	7.53	7.95
W3	Agnes Chialo	0.28	1.10	28.00	30.00	6.43	7.77
W4	Ouru Kagumbo	4.20	3.80	28.00	30.00	7.62	8.20
W5	Dan Omollo	0.32	0.21	26.00	26.00	7.54	6.46
W6	Joshua Ogutu	0.58	0.60	26.00	26.00	7.13	7.44
W7	Konyina	4.40	3.90	28.00	27.00	7.35	7.82
W8	Owino Yienya	1.10	0.84	25.00	25.00	7.39	7.68
W9	Ongalo Secondary	12.00	12.00	27.00	26.50	7.70	7.94
W10	Barrack Okull	7.00	5.90	29.00	28.00	7.72	8.04
W11	Lwala	12.00	4.30	29.00	27.00	7.84	7.86
W12	Omollo Miser	3.80	3.20	27.00	26.00	8.27	7.85
W13	Kital	9.00	8.30	29.00	28.00	7.75	7.84
W14	Joshua Agwa	0.33	0.45	25.00	25.00	6.31	6.78
W15	Mboya	0.94	0.88	25.00	26.00	7.32	7.65
W16	Kambogo	1.15	1.20	26.00	25.00	6.90	7.42
W17	Kamaguti	0.115	0.11	25.00	25.00	6.21	6.21
W18	Kanyakogelo	0.84	0.77	27.00	27.00	7.03	7.35
W19	Richard Odiwa	8.20	7.30	31.00	27.00	7.88	8.13
W20	Ogola Onguru	6.20	5.40	31.00	27.00	8.08	8.37
W21	Ogembo Ogonda	2.15	1.65	29.00	27.00	7.31	7.89
W22	Ogal Aono	13.5	12.9	27.00	26.00	8.23	8.10
W23	Okun	7.80	4.10	30.00	28.00	7.99	7.98
W24	Achuth Primary School	1.71	1.45	28.00	25.00	7.83	7.67
W25	Kaseto	4.60	4.20	27.00	26.00	7.43	7.40
W26	Wang Magwe	0.84	0.66	26.00	26.00	6.81	6.87

## 4.2 pH

The pH values for the groundwater in the study area ranged from 6.21 to 8.56 in the dry season and from 6.21 to 8.56 in the rainy season (Table 4.2). In the dry season the lowest pH value of 6.21 (Figure 3.1) was recorded at station W6 whereas the highest pH value of 8.57 was recorded at station B1 (Muslim Primary School). In the rainy season the lowest pH value of 6.21 was recorded at station W6 whereas the highest pH value of 8.57 was recorded at station B1.

**Table 4.2 Descriptive statistics for temperature, pH and fluoride for groundwater in the study area (D = dry season, W = wet season).**

	Fluoride (ppm)		Temperature (°C)		pH	
	F <sub>D</sub>	F <sub>W</sub>	T <sub>D</sub>	T <sub>W</sub>	pH <sub>D</sub>	pH <sub>W</sub>
Range	0.12 - 24.50	0.11 - 36.00	25.00 - 31.00	25.00 - 31.00	6.21 -8.56	6.21 -8.57
Mean	4.65	4.33	27.89	27.12	7.55	7.62
Standard deviation	4.31	5.23	1.42	1.31	0.46	0.44
Variance	18.60	28.42	2.03	1.31	0.21	0.19

The large variance of fluoride is due to the very high fluoride concentrations in some borehole (B1 B2, B8, and B12) and wells (W9, W19, W22, W23). Fluoride levels in B1 (24.5ppm and 36ppm in the dry and rainy season respectively) were extremely high compared to the data obtained in the study area.

### 4.3 Fluoride

Concentration levels of fluoride in groundwater from the study area ranged from 0.115ppm -24.5ppm in the dry season and 0.11ppm to 36ppm in the rainy season (Table 4.1 and 4.2). In both the dry and the rainy season the lowest fluoride levels of 0.115ppm and 0.11ppm respectively was recorded at station W6 whereas the highest fluoride levels of 24.5ppm and 36ppm respectively were recorded at station B1 (Figure 3.1).

#### 4.4 Relationship between fluoride, temperature pH and depth in groundwater in the study area

##### 4.4.1 Correlation

The moment correlation coefficients of fluoride temperature, pH, and depth in the water resources of the study area were computed. Fluoride was positively or negatively correlated to temperature, pH, and depth of groundwater (Table 4.3a, b, and c).

**Table 4.3a Correlation coefficient values calculated for the parameters in boreholes/wells in dry season.**

		Boreholes			Wells		
	F <sup>-</sup> (ppm)	pH	Temp (°C)	Depth	Temp (°C)	pH	Depth(m)
F <sup>-</sup> (ppm) r	1.00	0.520	0.503	0.200	0.675	0.820	0.017
Significance (p-value)	-	0.006	0.008	0.416	0.000	0.000	0.935

**Table 4.3b Correlation coefficient values for the parameters in boreholes/wells in rainy/wet season.**

		Boreholes			Wells		
	F <sup>-</sup> ppm	pH	Temp (°C)	Depth(m)	Temp (°C)	pH	Depth (m)
F <sup>-</sup> (ppm) r	1.00	0.470	0.210	0.180	0.405	0.810	0.022
Significance (p-value)	-	0.012	0.293	0.463	0.040	0.001	0.917



**Table 4.3c Correlation coefficient values calculated for three parameters in different rock units in dry season.**

		Boreholes						Wells	
		Granite		volcanic		Recent sediments		Recent sediments	
	F <sup>-</sup> (ppm)	Temp (°C)	pH	Temp (°C)	pH	Temp (°C)	pH	Temp (°C)	pH
F <sup>-</sup> (ppm) r	1.00	0.954	0.588	0.871	0.234	0.371	0.682	0.684	0.840
Significance (p- value)	-	0.001	0.165	0.129	0.765	0.235	0.014	0.000	0.000

**Table 4.3d Correlation coefficient values calculated for three parameters in different rock units in rainy/wet season.**

		Boreholes						Wells	
		Granite		volcanic		Recent sediments		Recent sediments	
	F <sup>-</sup> (ppm)	Temp (°C)	pH	Temp (°C)	pH	Temp (°C)	pH	Temp (°C)	pH
F <sup>-</sup> (ppm) r	1.00	0.090	0.116	0.920	0.080	0.337	0.505	0.420	0.795
Significance (p- value)	-	0.840	0.805	0.081	0.920	0.283	0.094	0.053	0.000

#### 4.4.2 Regression

Best fit curves were drawn based on the adjusted  $R^2$  as shown in the curves below. The bigger the adjusted  $R^2$ , the better the model. The non linear curves are the best fit curves in most cases since water quality data are lognormally distributed. pH values are often a measure of the solvent power of water or an indicator of the chemical behavior certain solutions may have towards rock minerals, hence a means of stating the balance of certain chemical equilibrium in water solutions (Hem, 1959). Difference in pH values of the groundwater depends on chemistry of the water which could be reflected by the composition of the aquifers, human activities, chemical and biological processes occurring during infiltration (Garrels and Christ, 1965).

At pH values less than 7.5 (Figure 4.1a, b), the fluoride concentrations are less than 4ppm and also there is a slow increase in fluoride levels both in the dry season and the rainy season. As the pH increases, that is, a pH value of 7.5 and above there is also rapid increase in fluoride concentration. This is because lower pH relatively reflects low solvent power of these waters due to dilution from recharge (compared to Matthes 1982) whereas higher pH reflects high dissolution of the fluoride bearing minerals from the rocks into the waters. At pH value of about 7.7 and above the rate of increase of fluoride in wells are higher than in boreholes. Dissolved minerals from the weathered rocks readily flow into the wells but take a longer time to flow into the boreholes.

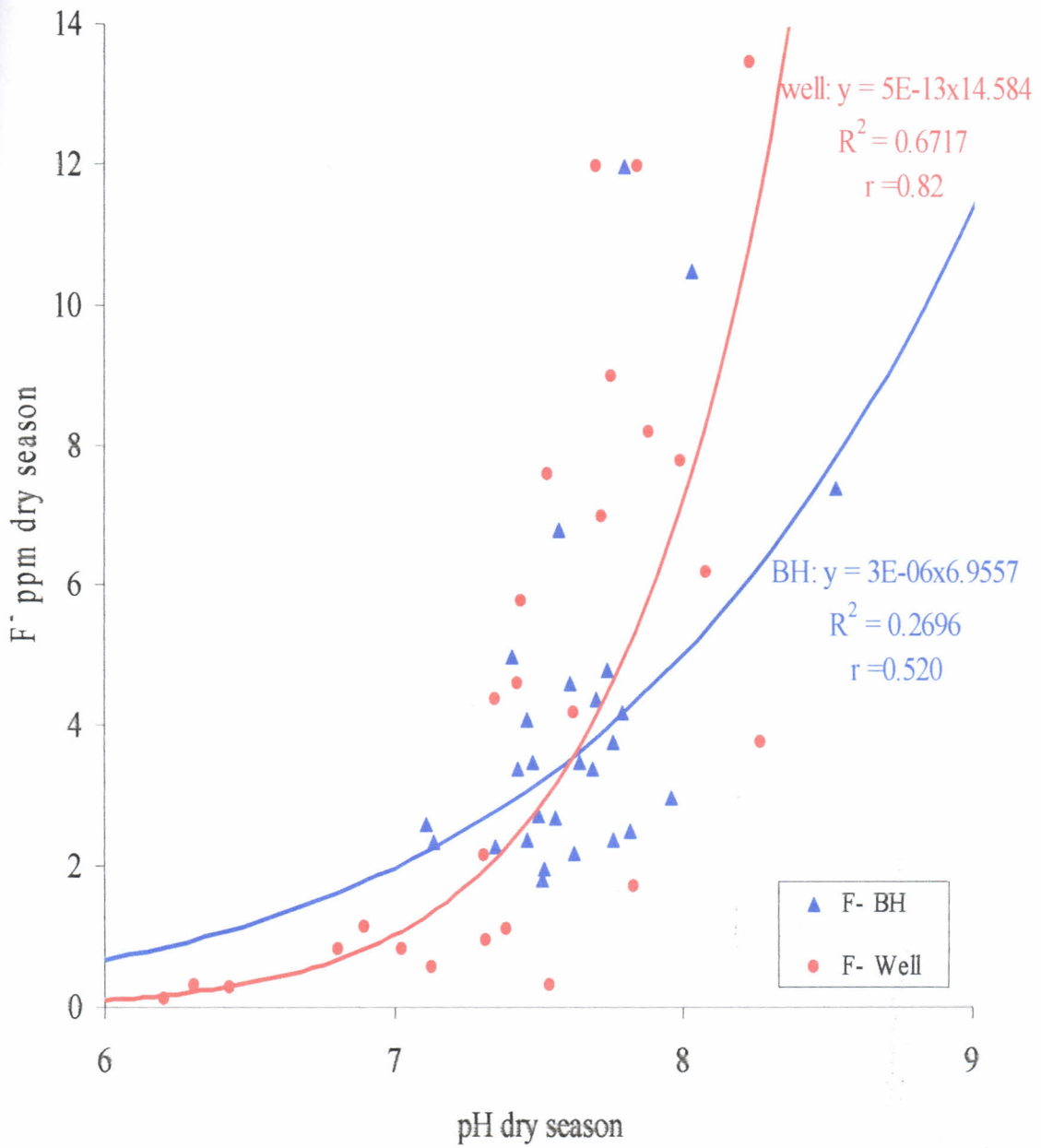


Figure 4.1a: Regression curve of fluoride in ppm against pH in dry season

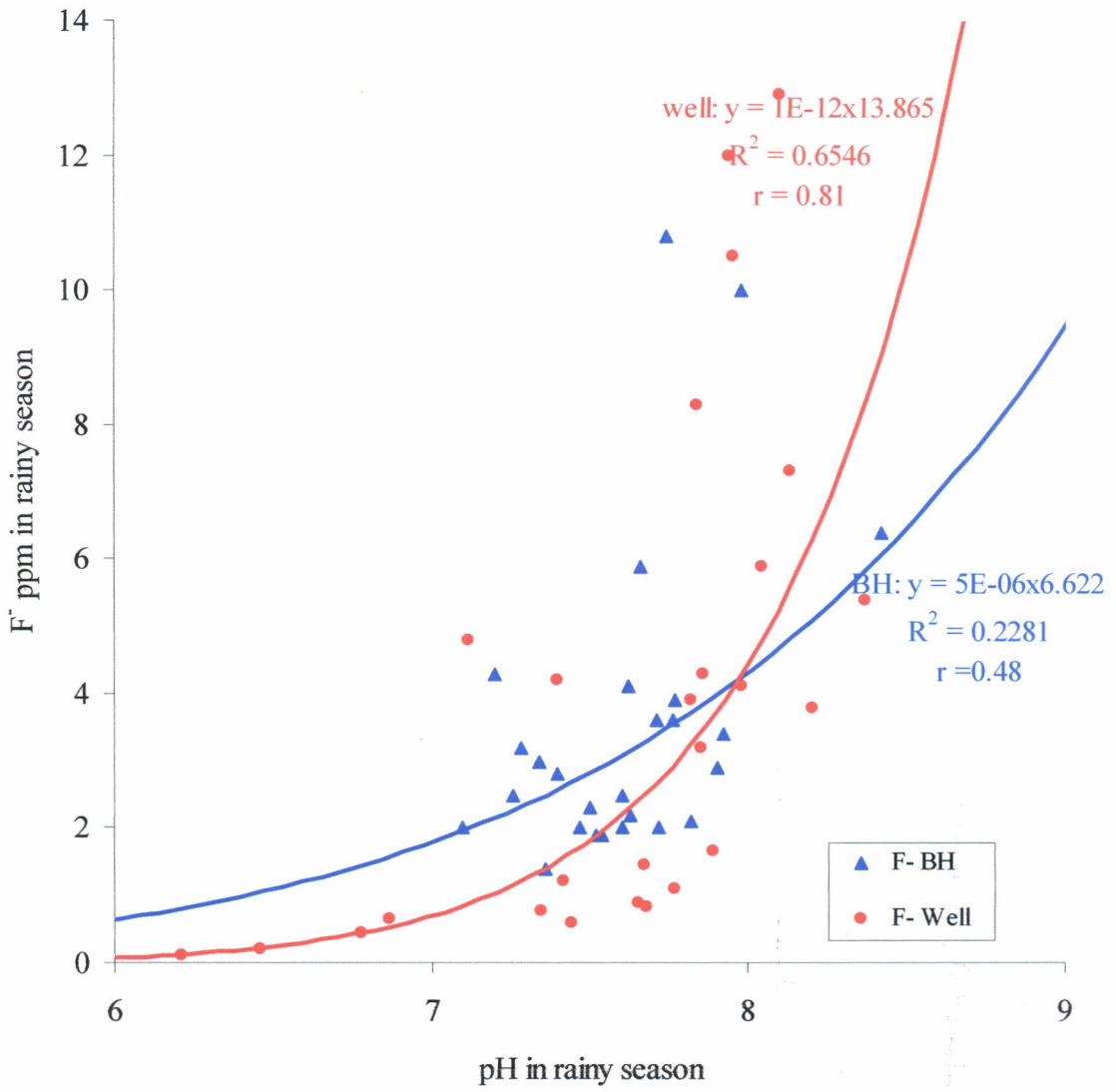


Figure 4.1b: Regression curve of fluoride concentration against pH in rainy season

Groundwater temperature is the result of heat exchange on the earth's surface under the control of incoming and outgoing radiation, heat of conduction, convection, evaporation and chemical and thermonuclear processes in the rocks. Temperature change can also be due to frictional heating during water flow through rocks, exothermic and endothermic chemical reactions such as oxidation or reduction, heat of solution and heat of sorption. High temperature increases the dissolution of fluoride bearing minerals into the groundwater (Matthess 1982).

There is rapid increase in fluoride concentration in wells at a temperature of 27°C and above in both seasons (Figure 4.2a, b). Rocks at or near surface weather easily at high temperatures hence the weathered minerals dissolve and are recharged into wells faster than in the boreholes. Boreholes do not show much increase of fluoride with increase in temperature but has significant correlation with fluoride in dry season (Table 4.3a). Wells are shallow and so, the temperature change can be due surface radiation from the sun. High temperature increases the solute content of water thereby increasing the dissolution of fluoride bearing minerals from the rocks into the groundwater.

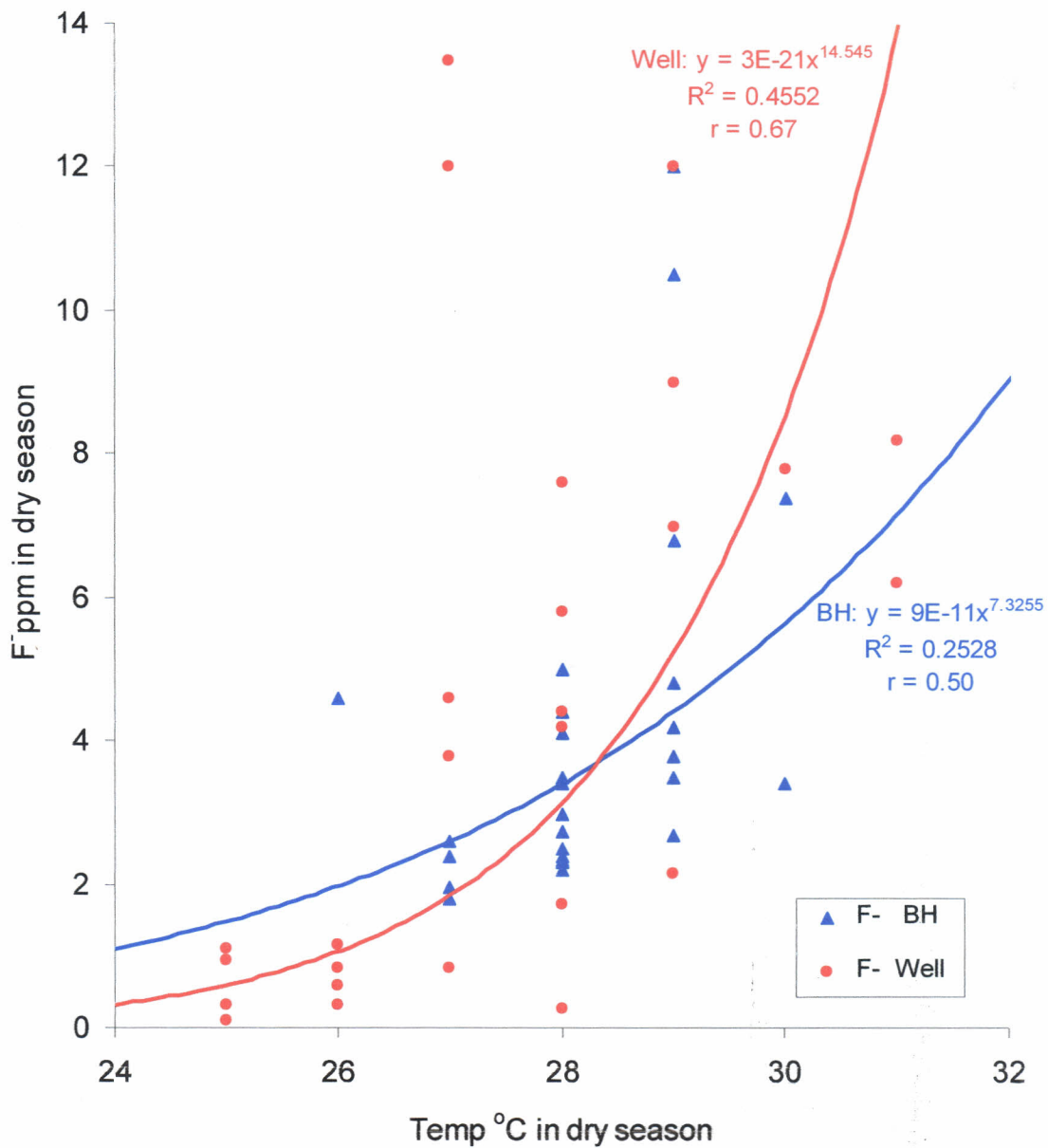


Figure 4.2a: Regression curve of F<sup>-</sup> concentration against Temperature in dry season

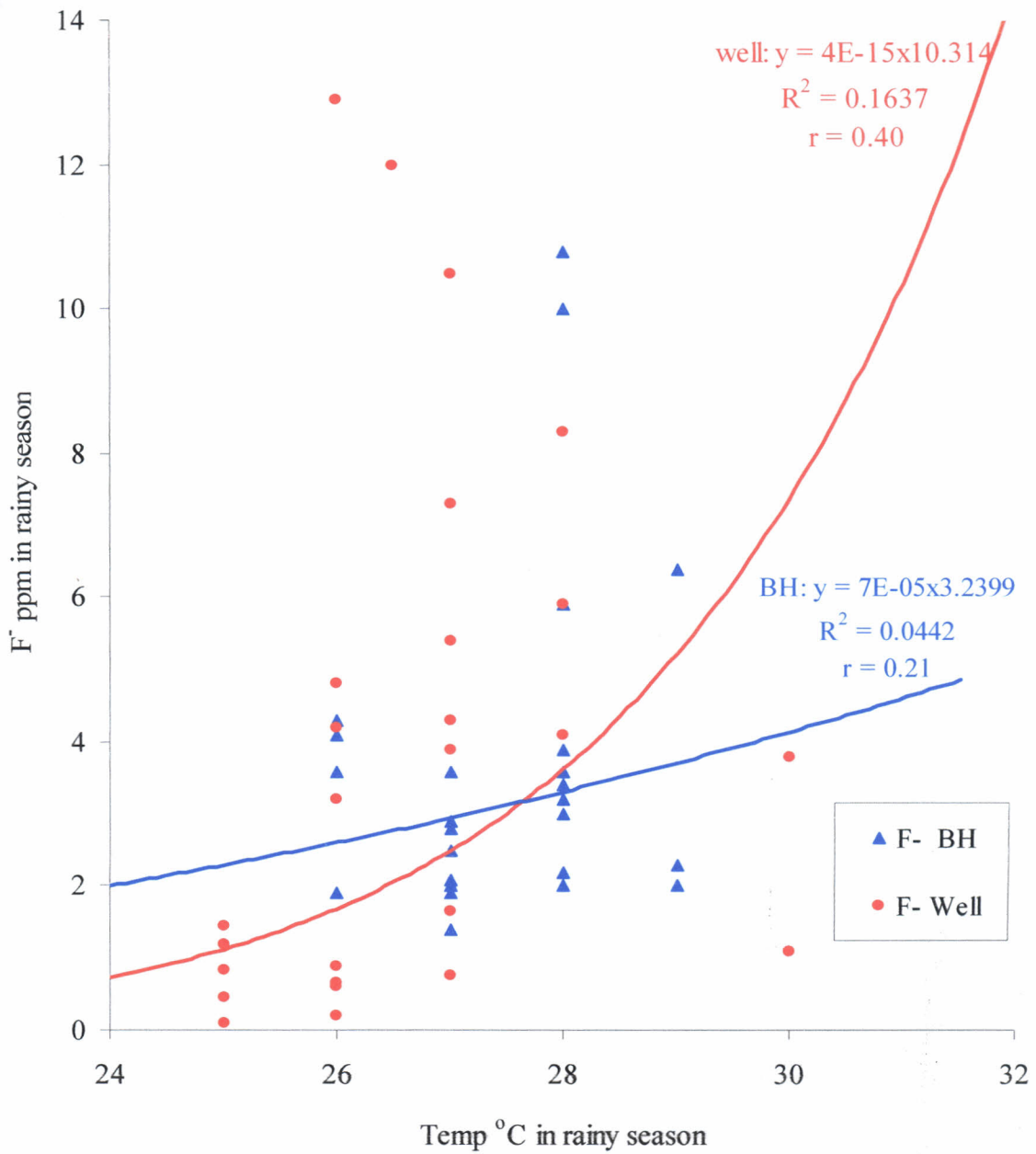


Figure 4.2b: Regression curve of F<sup>-</sup> concentration against Temperature in rainy season

Fluoride concentration are higher in boreholes at shallow depths and decreases as the depth increases whereas for the wells it slightly increases with depth (Figure 4.3a, b, c, d) but the correlation is not significant (Table 4.3a, b).

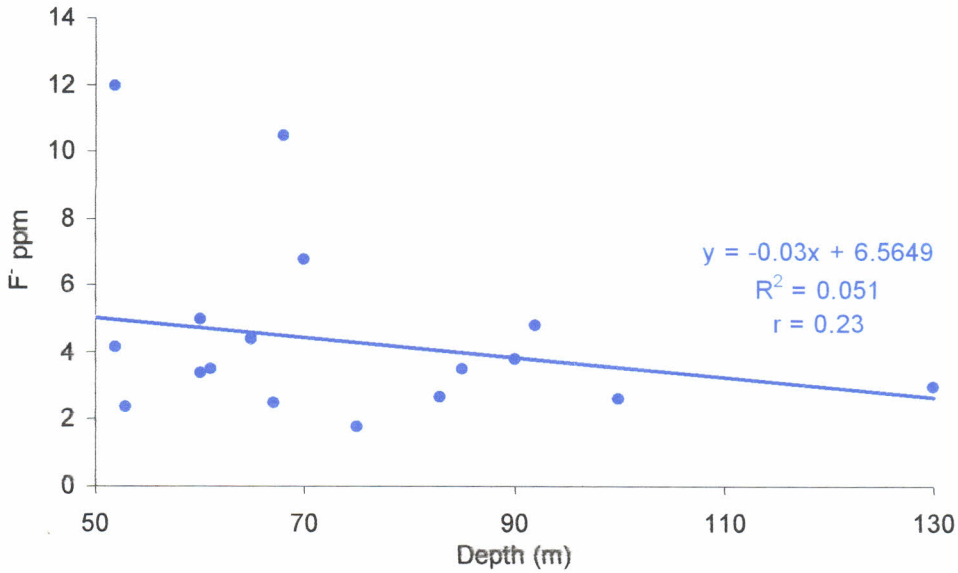


Figure 4.3a: Regression curve of F<sup>-</sup> concentration against depth in boreholes in dry season.

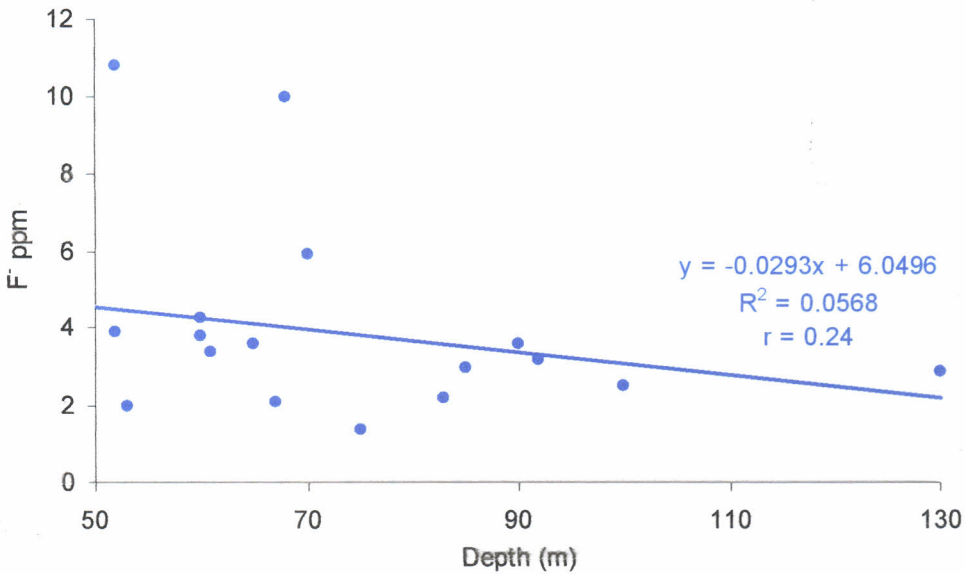


Figure 4.3b: Regression curve of F<sup>-</sup> concentration against depth in boreholes in rainy/wet season.



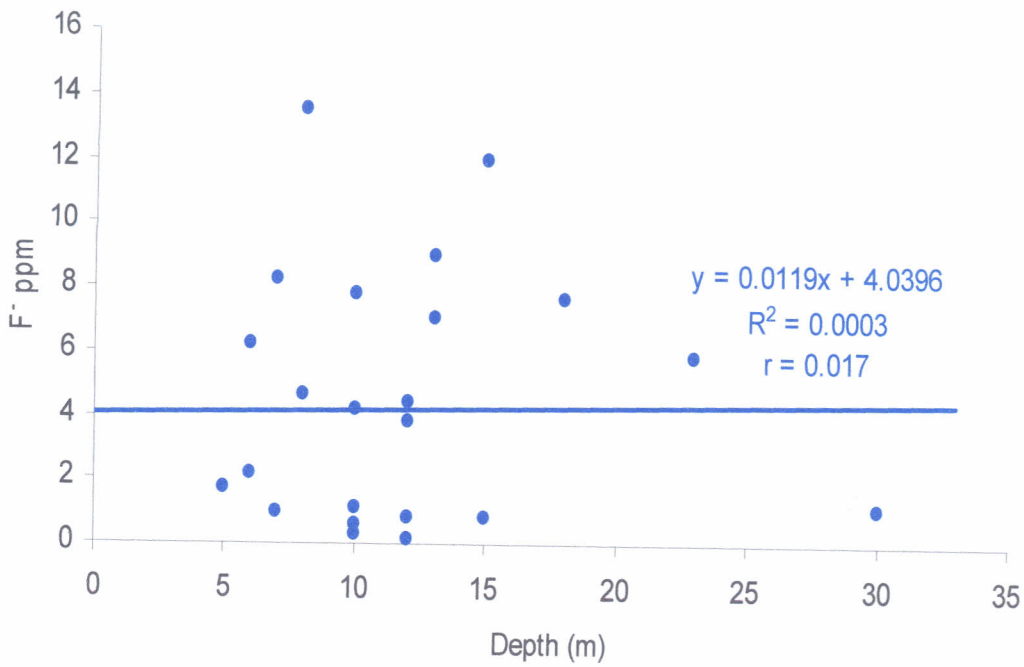


Figure 4.3c Regression curve of  $F^-$  against depth in wells in dry season.

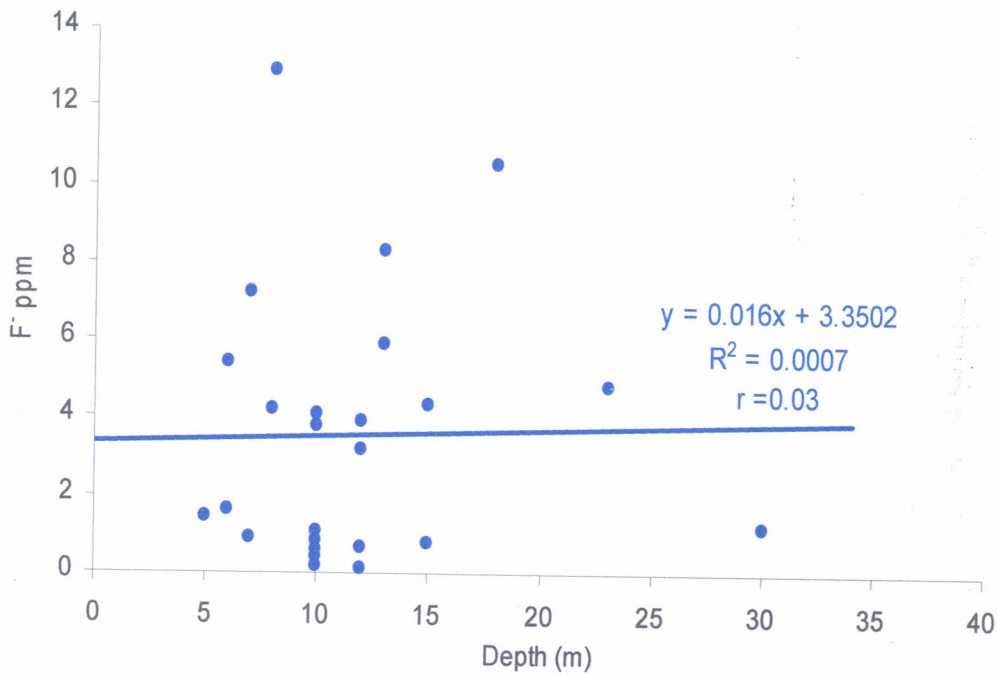


Figure 4.3d Regression curve of  $F^-$  against depth in wells in rainy/wet season.

Granite shows significant linear relationship between temperature and fluoride in dry season, but not rainy season (Figure 4.5a, b) this means that the dissolution of fluoride bearing minerals in granite increases with increase in temperature. The curve (Figure 4.4 a,) shows increase in fluoride concentration with increase in pH in granite in dry season but the correlation is not significant (Table 4.3c).

Higher pH increases the solubility of fluoride bearing minerals from the rocks. Sediments weather easily and are more soluble than igneous rocks (compared to Matthes 1982). The curves (Figure 4.4a, b) show an increase in fluoride concentrations with increase in pH in sediments and the correlation is only significant in dry season (Table 4.3c). Fluoride concentrations decrease with increase in temperature in rainy season and slightly increase with increase in temperature in rainy dry in sediments.

Volcanic rocks show a decrease in fluoride with increase in pH in dry season whereas a slight increase in rainy season but the relationship between fluoride and pH is not significant (Table 4.3c, d). At temperatures above 26°C there is a rapid increase in fluoride concentrations with temperature in both seasons but has no significant correlation with fluoride (Table 4.3c, d).

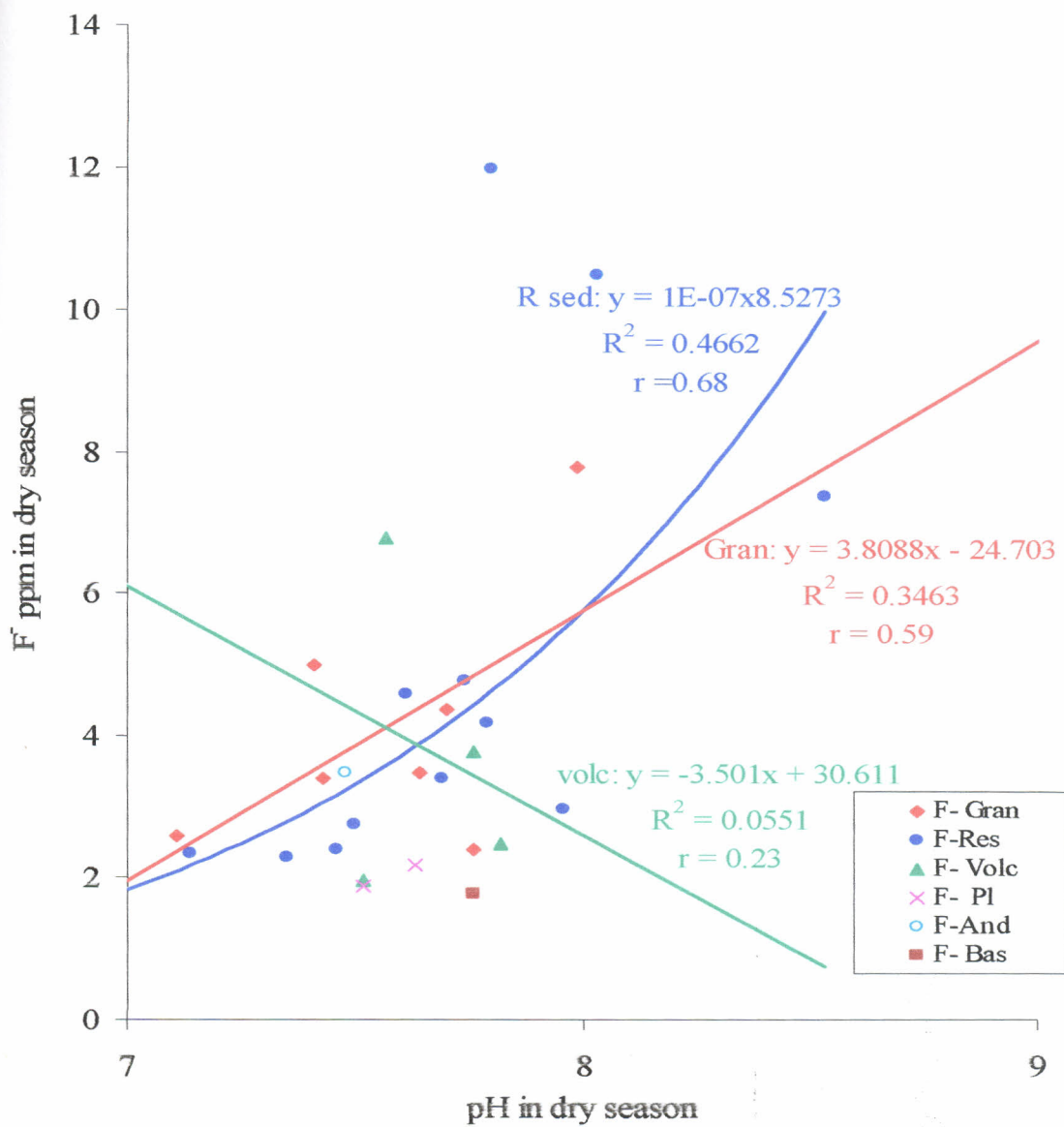


Figure 4.4a Regression curves of fluoride against pH in dry season in different rock units.

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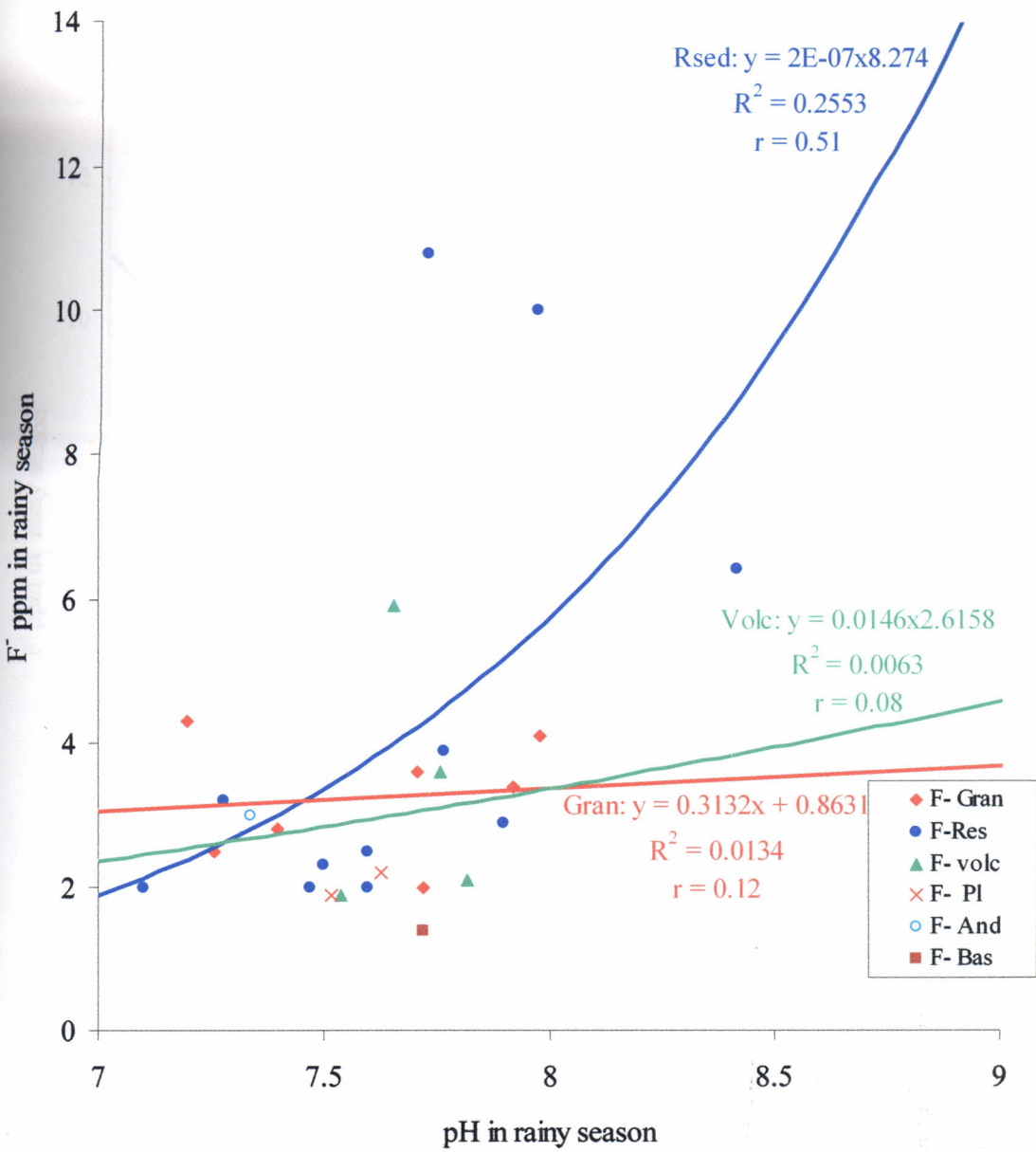


Figure 4.4b Regression curves of fluoride against pH in rainy season in different rock units.

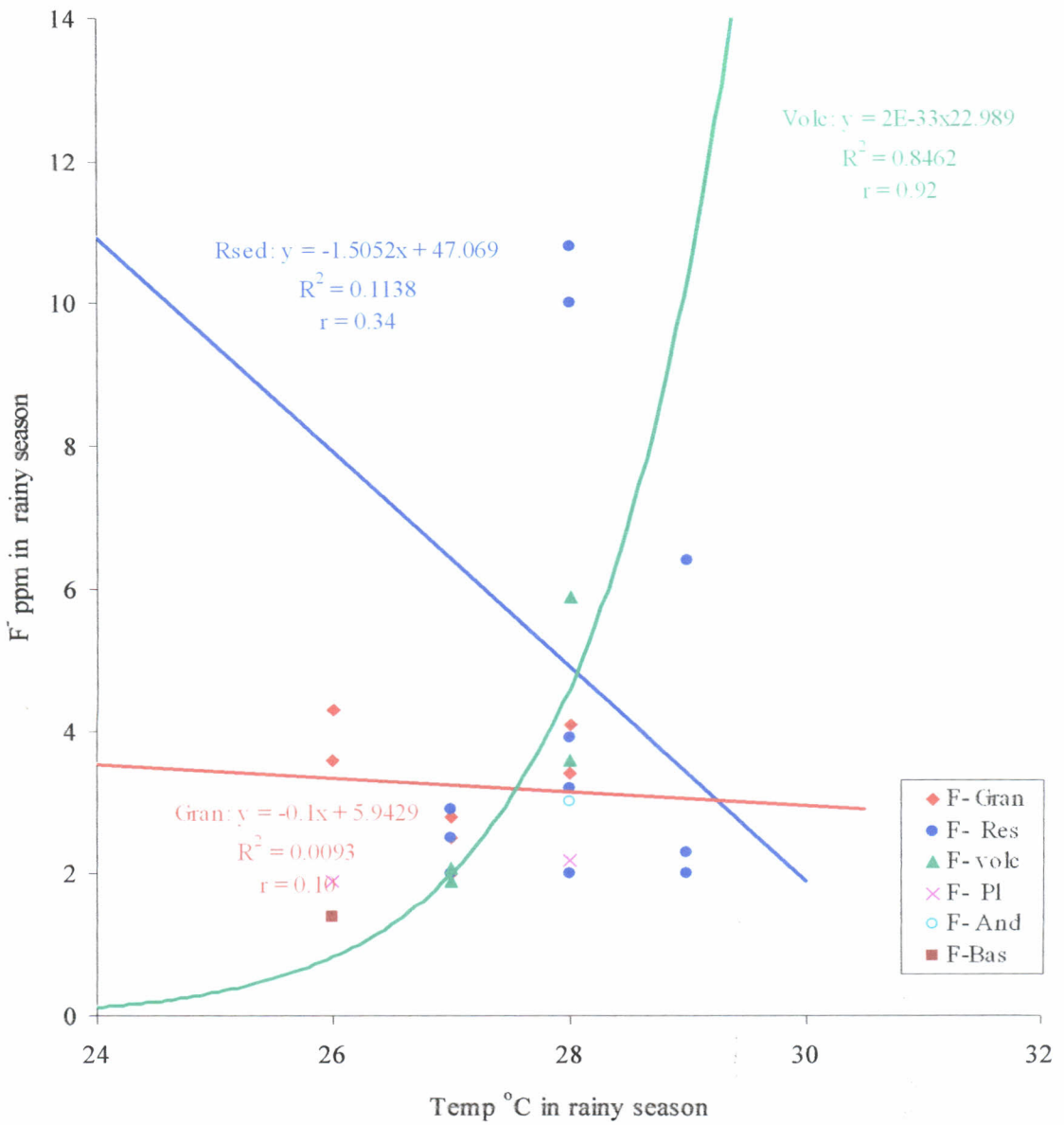


Figure 4.5a Regression curves of fluoride against temperature in rainy season in different rock units.

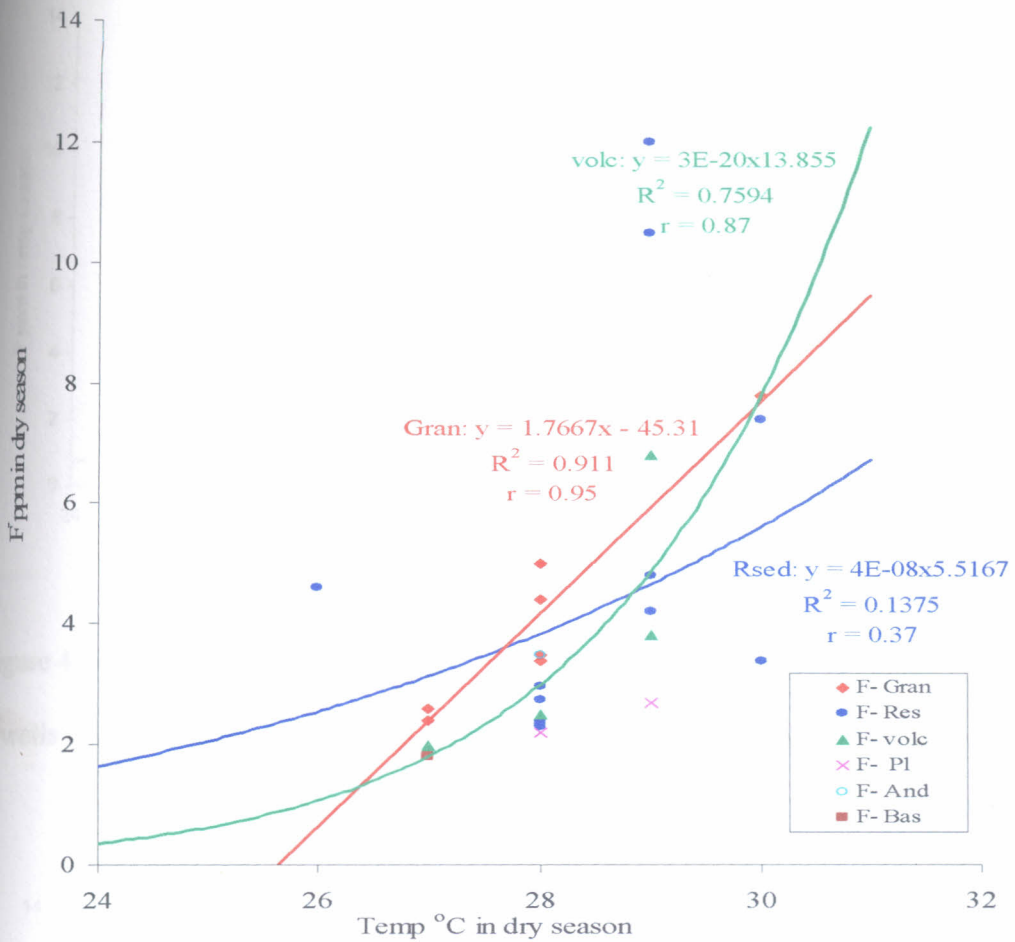


Figure 4.5b Regression curves of fluoride against temperature in dry season in different rock units.

In wells, regression curves have been drawn only for fluoride in Recent sediments (Figure 4.6a, b, c, d). At pH values of 7.5 (Figure 4.6c, d) and above there is rapid increase in fluoride concentrations in both the dry and rainy season due to increased dissolving power of the water. At temperatures of 26°C (Figure 4.6a, b) and above there is also a rapid increase in fluoride concentrations in both the dry and rainy season. High temperatures increase solubility of minerals into groundwater. Sediments weather and also dissolve easily.

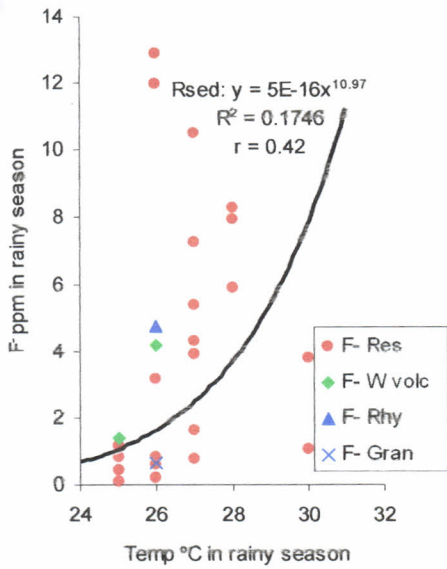


Figure 4.6a  $F^-$  against temperature in wells in rainy season in sediments

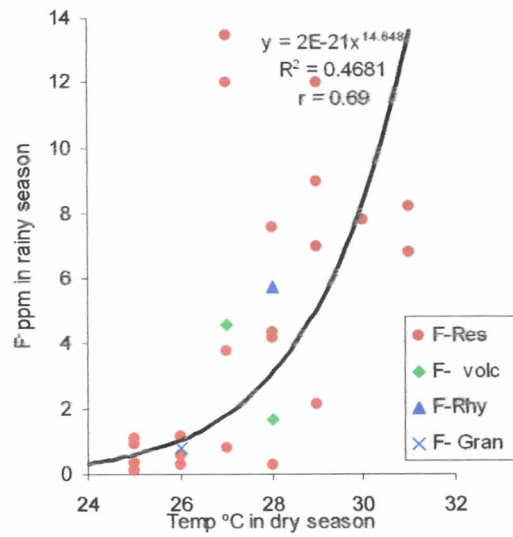


Figure 4.6b  $F^-$  concentration temperature in wells dry season in sediments

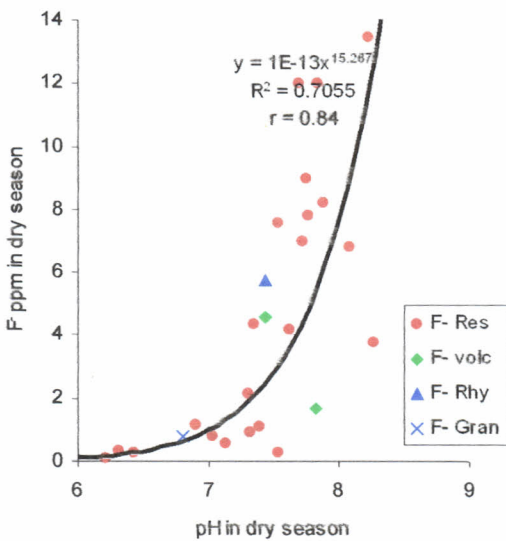


Figure 4.6c  $F^-$  concentration against pH in wells in dry season in sediments.

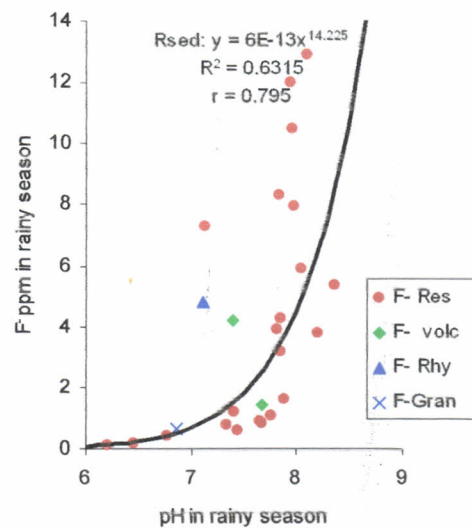


Figure 4.6d  $F^-$  concentration against pH wells in rainy season in sediments.

#### 4.4.3 Q-Q Plots

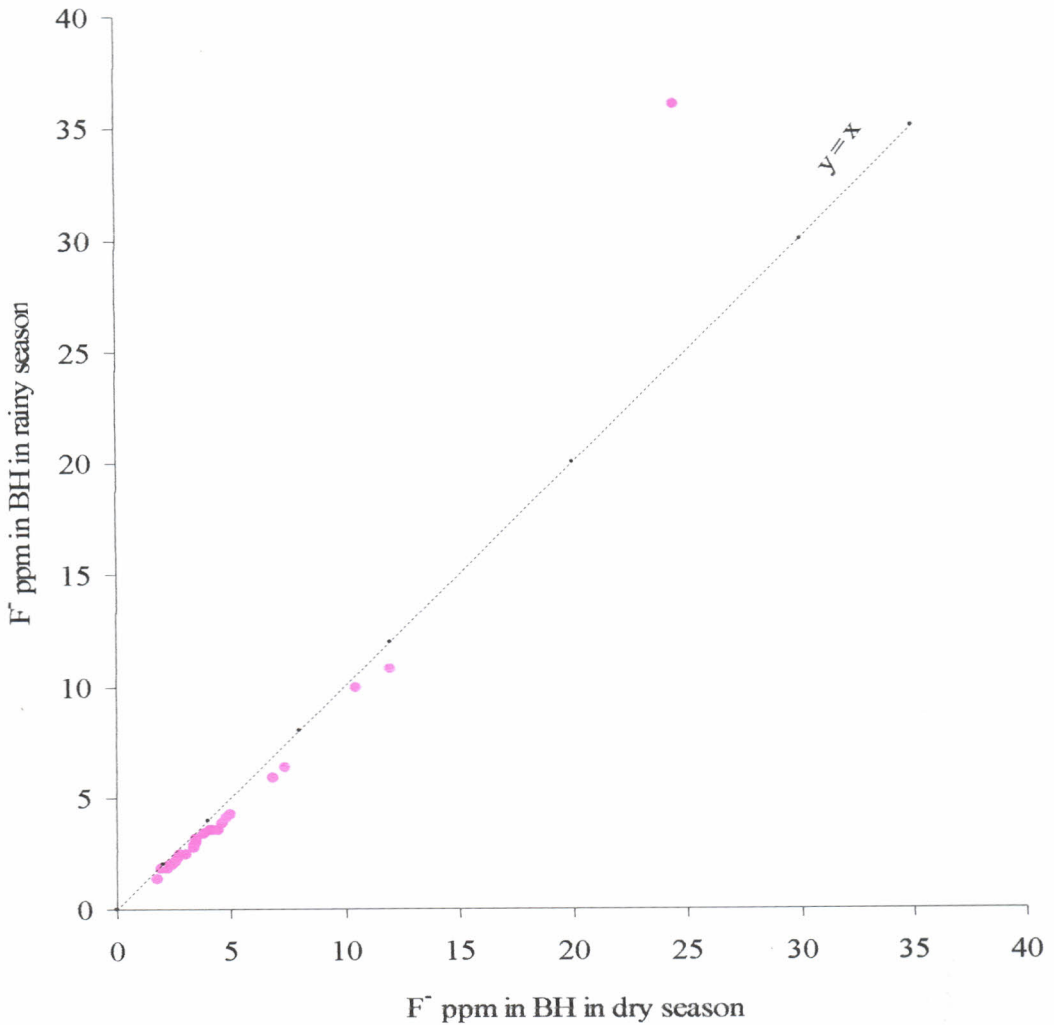


Figure 4.7 Q-Q Plots for fluoride in boreholes in dry and rainy season

Fluoride concentrations in the boreholes in the dry season are 1.08 times higher than in the wet season except for borehole B1 which had higher concentrations in the rainy season than dry season. This borehole receives fluoridised recharge from fracture zones and also from the dissolution of fluoride bearing mineral from the surrounding sedimentary rocks (see Appendix I Tables B1, B2 for data on Q-Q plot).

during the rainy season.



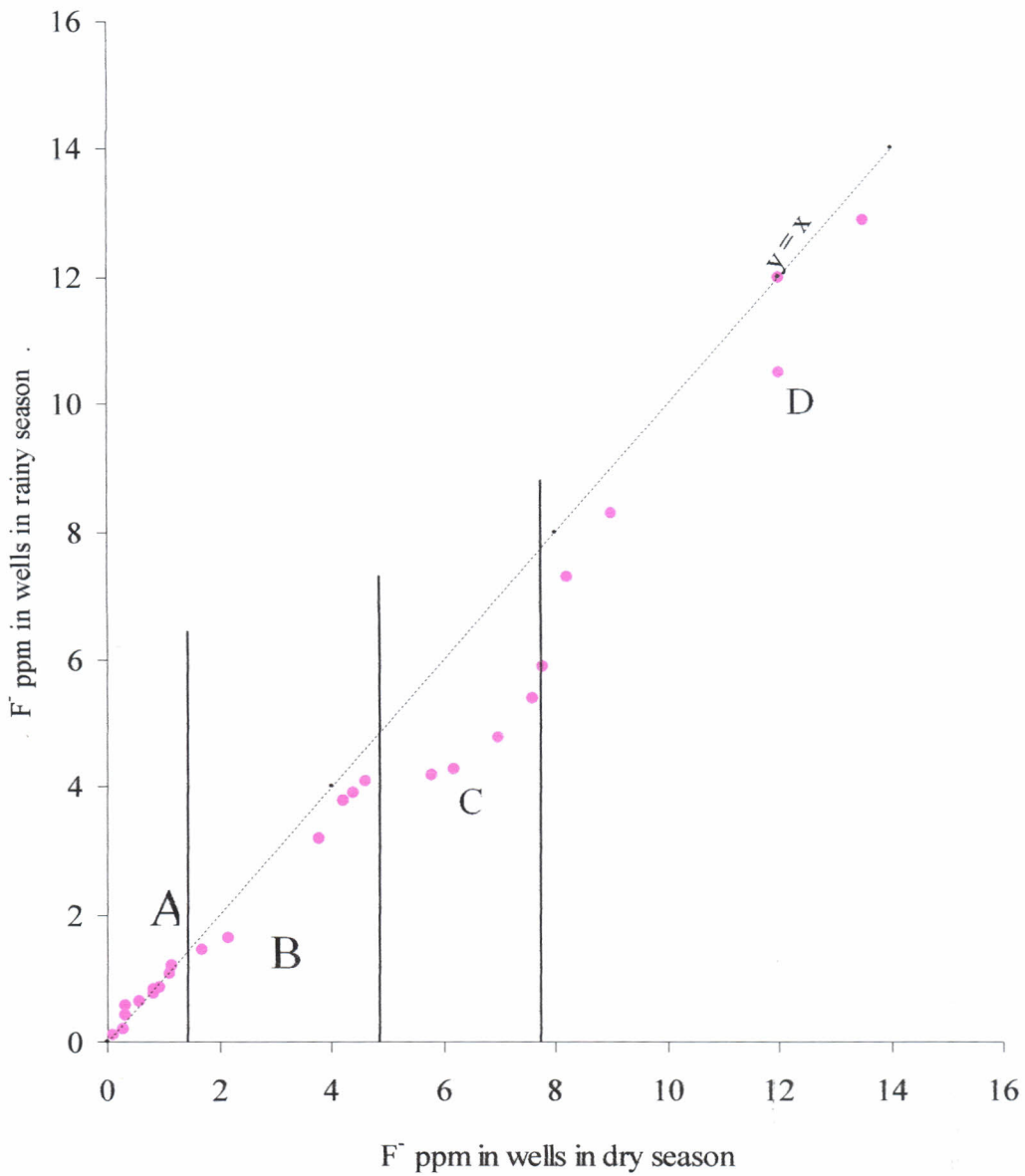


Figure 4.8 Q-Q Plots for fluoride in wells in dry and rainy season

Fluoride concentrations for lower (zone A) quantile (have very low concentrations) are equal for both lowland and upland (Figure 4.8). As the concentrations increase wells in the dry season tend to have higher fluoride concentrations than the rainy season. In zone B (1.7ppm to 4.6ppm) fluoride in dry season is 1.05 times higher than in the wet season.

In zone C (5ppm to 7.8 ppm) fluoride in dry season are 1.15 times higher than wet season and in zone D (7.97.9ppm and above) the fluoride concentrations are 1.03times higher in dry season than rainy season. The high temperatures in dry season increases evaporation and decreases flushing process suggesting that the water has sufficient time to come into contact with the rock forming mineral thereby increasing solubility of the minerals into groundwater.

Fluoride concentrations in boreholes in lowland are equal to upland for the lower quantiles upto approximately 3.6ppm (Figure 4.9 zone A). For higher quantiles (zone B), fluoride concentrations in the lowland are 3.08 times and 3.14 times higher than upland in dry and rainy season respectively (Figure 4.9).

Fluoride concentrations in wells for very low concentration of approximately 1ppm and below (zone A) are higher in upland than lowland in both seasons (Figure 4.10). For concentrations of 2ppm and above (zone B) the concentrations in the lowland are 1.32 times and 1.84 times higher in lowland than in upland in dry and rainy season respectively.

The lowland is in a discharge zone and also consists of sediments which are highly soluble whereas upland is in recharge zone and consists of mainly igneous rocks which are less soluble.

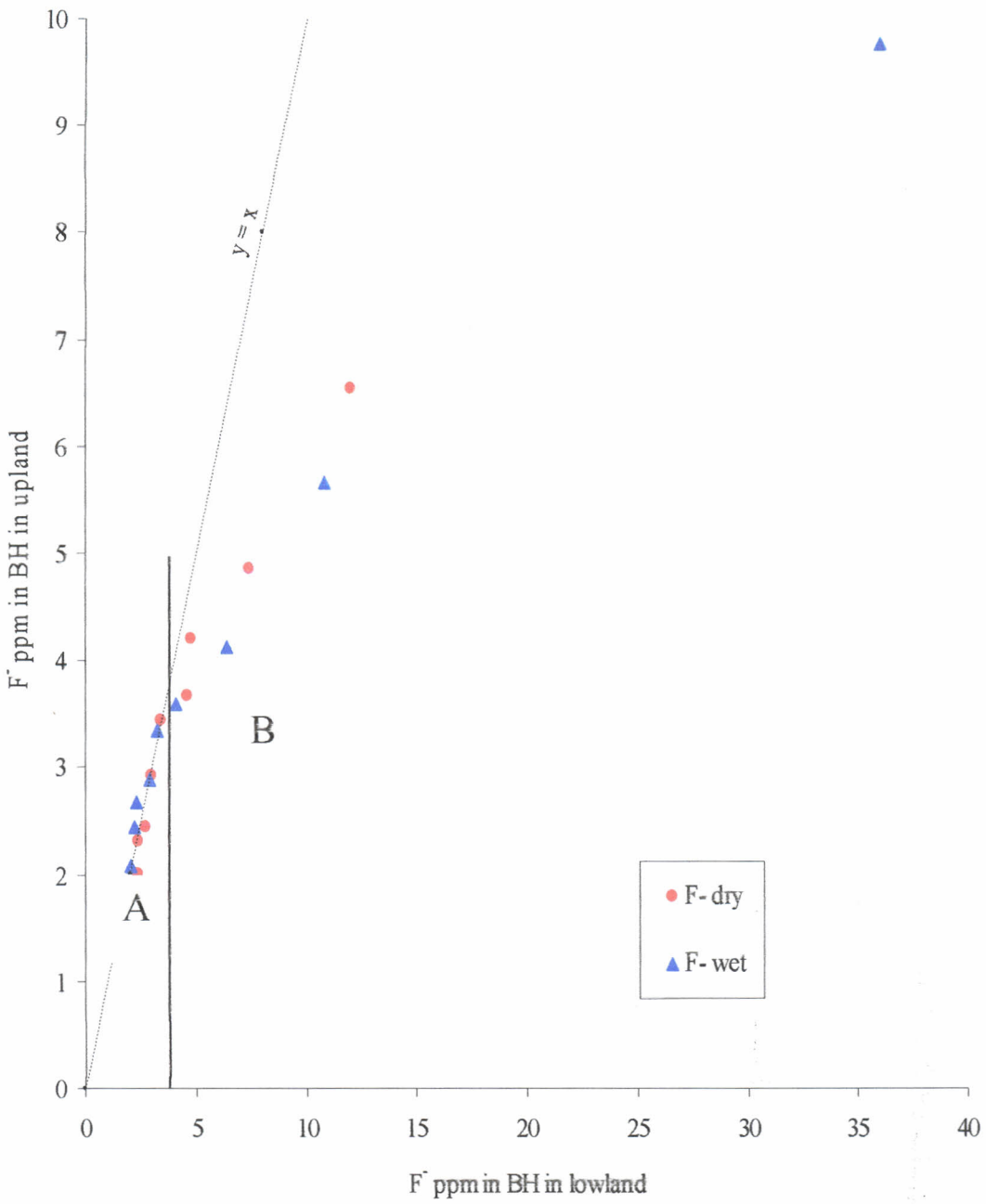


Figure 4.9 Q-Q Plots for fluorides concentrations in boreholes in uplands and lowland

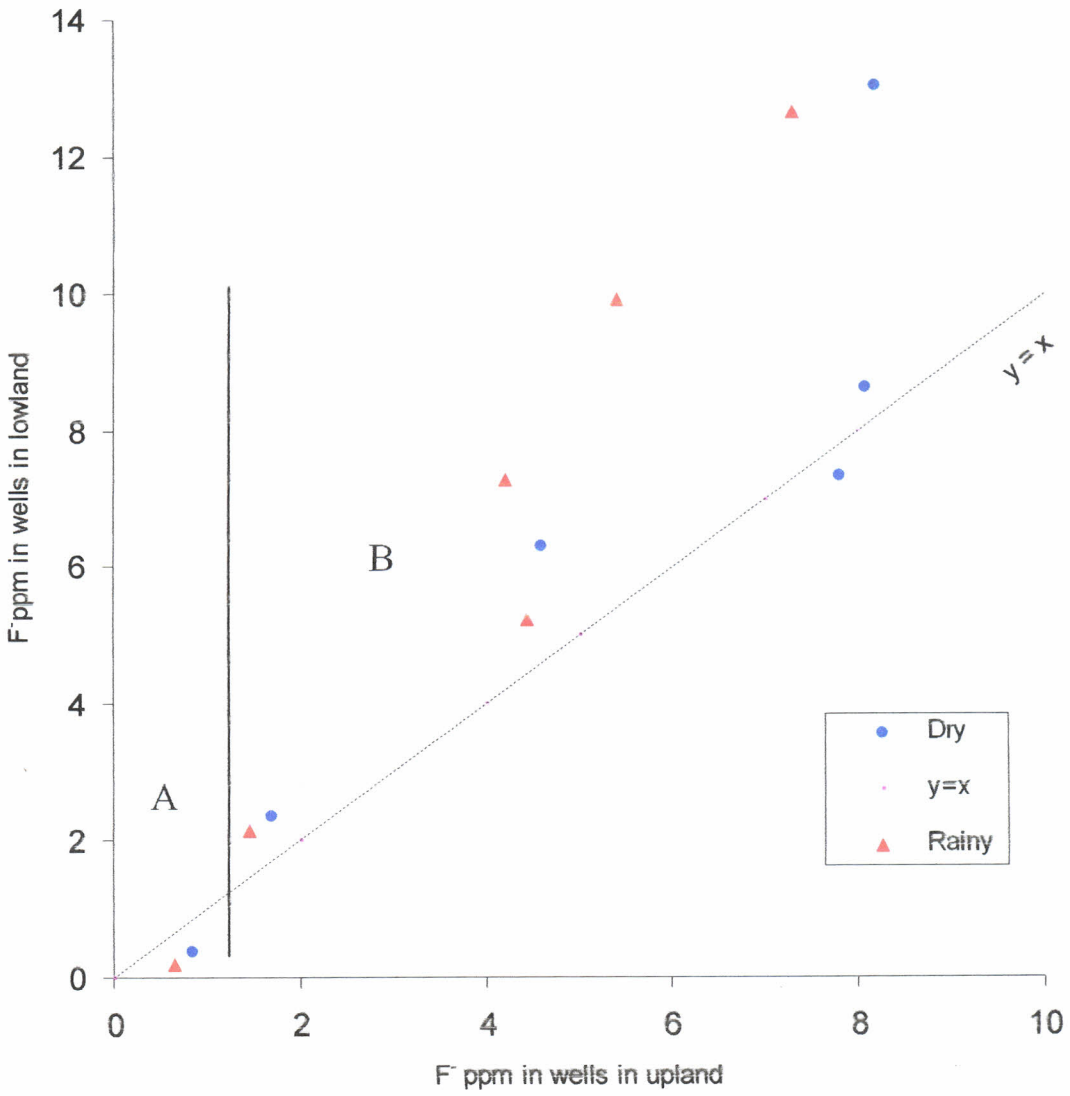


Figure 4.10 Q-Q plots for fluoride concentrations in wells in uplands and lowland

#### 4.4.4 Principle Component Factor Analysis

Two factors were derived (Appendix I Table C1, C2, C3, C4, C5, C6 and C2) after the data reduction. One factor was for fluoride concentrations in boreholes and the other for fluorides in the wells. These factors were the dependent variable; temperature and pH are independent variables. These factors were then linearly correlated with the dependent variables and the results are shown in Table 4.4

Table 4.4 Correlation result of component analysis. P-value greater than 0.05 is not significant.

BH/WELL	Factors and Significance ( $\rho$ - value)	pH		Temperature °C	
		Dry	Rainy	Dry	Rainy
Boreholes	Factor 1 boreholes				
	r	0.65	0.74	0.318	0.64
	p- value	0.008	0.012	0.853	0.531
	Factor 2 BH lowland				
	r	0.343	0.361	0.432	0.321
	p- value	0.332	0.306	0.212	0.366
Wells	Factor 3 BH upland				
	r	0.503	0.422	0.631	0.356
	p- value	0.034	0.091	0.006	0.161
	Factor 1 Wells				
	r	0.600	0.662	0.515	0.250
	p- value	0.0002	0.0012	0.0071	0.2300
Wells	Factor 2 well lowland				
	r	0.679	0.5681	0.504	0.197
	p- value	0.001	0.009	0.023	0.403
	Factor 3 well upland				
	r	0.685	0.802	0.853	0.742
	p- value	0.133	0.055	0.031	0.440

From the results: pH in the dry season has significant control (effect) on fluoride concentration in the boreholes, while temperature has little or no effect at all.

pH in both dry and rainy season has significant control on fluoride concentration in the wells. Temperature in the dry season also has significant control on fluoride concentrations in the wells while in the rainy season has no effect.

In the lowland pH and temperature do not have significant control on fluoride in bore holes while in the wells; temperature in dry season, pH in both dry and rainy season has significant control on fluoride concentration in the wells. In the upland pH and temperature in dry season has significant control on fluoride concentration in boreholes while temperature has significant control of fluoride in wells.

## CHAPTER FIVE

### DATA INTERPRETATION AND DISCUSSION

#### 5.1 Over view of hydrogeochemistry

Geochemical properties of groundwater generally depend on those of recharge water and on the subsurface geochemical processes. These control the quality during the course of its underground movement by raising or lowering the amount and kind of the dissolved constituents. The scale of these changes is dependent on the chemical properties and physical properties of the surrounding rock. Chemical (fluoride) analyses carried out in the study area were all on groundwater from mainly from boreholes and wells. The waters were analyzed for fluorides. The data obtained for these waters in the study area were complete and reliable as the researcher carried the analysis specifically for this study. The overall parameter that has the highest and the least influence on fluoride concentration in the area is shown in Table 4.4.

#### Fluoride

Fluorine forms 0.078% of the earth's crust and thus more abundant than chlorine (Simons, 1950; Matthes, 1982) and ranks thirteen in abundance in the earth's crust. In areas with volcanic and sedimentary rocks (such as in the study area) it dissolves from fluoride bearing minerals in the rocks and the soils into the groundwater (CDN 2004). The principle independent fluoride mineral in igneous rocks is fluorite (calcium fluoride). This mineral is a source of fluoride in water but its solubility is low (Hem 1959). Fluoride is the most electronegative of all elements and forms a number of complexes with sodium, aluminium, beryllium calcium and iron and a series of mixed fluoride-hydroxide

complexes with boron (Hem 1967). The most important of these complexes is apatite (calcium fluorophosphates). Fluoride is found in igneous rocks and sedimentary rocks as a component of amphiboles, such as hornblende, and of micas and a number of other silicate minerals (Elrashidi and Lindsay 1986). In these minerals it replaces part of the OH-groups in the mineral structure (Rankama and Sahama 1950). Fluoride is an important constituent of drinking water because it is taken up by the human body and incorporated into teeth and bones. Excessive fluoride concentrations are, however, toxic.

A recent aspect of fluoride problem is the accumulation in the surface soils through fertilizers and insecticide applications (Evans et al 1971; Drury and Ensminger 1980) and also from industrial sources which include brick making and pottery (Duncan et al 1973; Robinson et al 1973): such application of fertilizers and brick making activities are common in the study area. Depending on the minerals (Table 5.1) in the rock bearing waters the groundwater may contain high or low concentrations of fluoride. Quality standards for human drinking water have been developed by among others AWWA (1971) U.S Public Health Service (1962), U.S. Environmental Protection Agency (1975), and WHO ( 1971, 1973a&b and 1985) as 1.5ppm as the optimum limit. Waters having concentrations of 10ppm or more are rare (Hem 1959 and Cox 1964), but were recorded in some waters in the study area and in particular, the sample from Kendu Muslim Primary (B1) to the north of the study area recorded the highest concentration of 36ppm. Apatite, a fluoride bearing mineral occurs in association with feldspars, quartz, muscovite and as an accessory mineral in nephelinite (Table 5.1). Fluorite also occurs in association with quartz and calcite, and so, fluoride is released in groundwater during the weathering



process of these minerals. The weathering product of orthoclase and pyroxene are clay minerals (mica) in which Fluoride replaces part of the OH<sup>-</sup> groups in the mineral structure (Table 5.1).

**Table 5.1 Minerology of the rock units in the study area**

Rock type	Mineral	Formula	Weathering product
Rhyolite	Orthoclase	$KAlSi_3O_8$ ,	Clay minerals: Kaolinite, Halloysite montmorillonite
		$(Na,K) AlSi_3O_8$	
	Oligoclase	$n NaAlSi_3O_8$	
hornblende	$(Ca,Na)_2(Mg,Fe,Al)_5(Al,Si)_8O_{22}(OH)_2$		
Andesite	Oligoclase	$n NaAlSi_3O_8$	
	Pyroxene	$Ca(Mg Fe) Si_2O_6$	
	Andesine	$n NaAlSi_3O_8$	
	Hornblende	$(Ca,Na)_2(Mg,Fe,Al)_5(Al,Si)_8O_{22}(OH)_2$	
Basalts	Andesine	$n NaAlSi_3O_8$	
	Labradorite	$mCaAl_2Si_2O_8$	
	pyroxene	$Ca(Mg Fe) Si_2O_6$	
Granite	Apatite	$(CaF)Ca_4(PO_4)_3$	
	Quartz	$SiO_2$	
	Orthoclase	$KAlSi_3O_8$ ,	
	hornblende	$(Ca,Na)_2(Mg,Fe,Al)_5(Al,Si)_8O_{22}(OH)_2$	

**Table 5.1 continued**

<p>Tertiary volcanic</p>	<p>Pyroxene Nepheline Magnetite Orthoclase Accessory minerals are apatite, biotite and analcite</p>	<p><math>\text{Ca}(\text{Mg Fe}) \text{Si}_2\text{O}_6</math> <math>\text{Na AlSiO}_4</math> <math>\text{FeO} \cdot \text{Fe}_2\text{O}_3</math> <math>\text{KAlSi}_3\text{O}_8</math>,</p>	<p>Ferric oxide and Clay minerals: Kaolinite, Halloysite, montmorillonite</p>
<p>Pleistocene sediments (rocks include: sandstones, lacustrine tuffs, mudstones, siltstones and gravels)</p>	<p>Calcite Boitite Muscovite</p>	<p><math>\text{CaCO}_3</math> <math>\text{K}(\text{MgFe})_3(\text{AlSi}_3)\text{O}_{10}(\text{OH})_2</math> <math>\text{KAl}_2(\text{AlSi}_3)\text{O}_{10}(\text{OH})_2</math></p>	
<p>Recent Sediments (rocks include sandstone mudstones gravels claystone siltstones limestone and soils)</p>	<p>Calcite Muscovite Biotite Paragonite</p>	<p><math>\text{CaCO}_3</math> <math>\text{KAl}_2(\text{AlSi}_3)\text{O}_{10}(\text{OH})_2</math> <math>\text{K}(\text{MgFe})_3(\text{AlSi}_3)\text{O}_{10}(\text{OH})_2</math> <math>\text{H}_2\text{NaAl}_3(\text{SiO}_4)_3</math></p>	

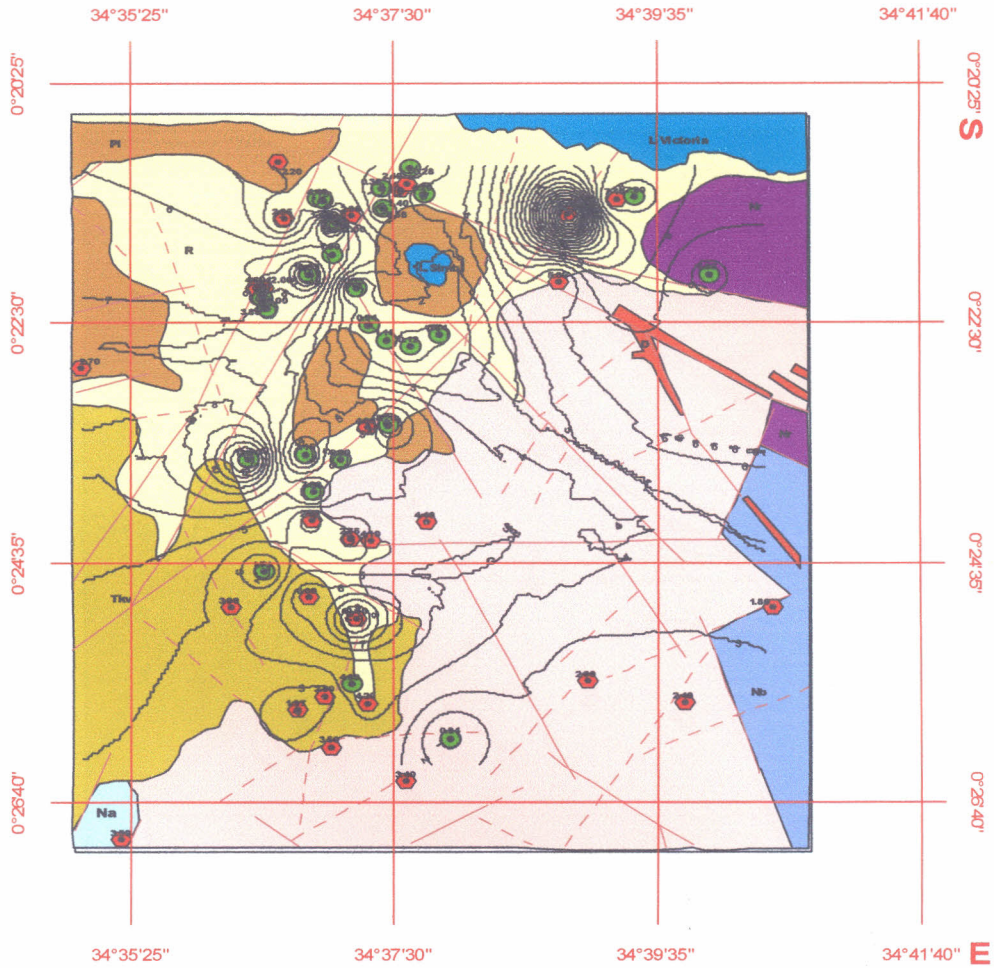
Source Opiyo 1988, Loughnan 1969, Saggerson 1952 and Dana 1932

## **5.2 Discussion**

The things that most affect the water quality are sometimes present only in traces in the rock (Hem 1967). However Ongwenyi (1973, 1975) concluded that the chemical composition of groundwater is as a result of climatic, biologic hydrologic, geologic and chemical processes that are active in any given environment. These processes have played an important role in determining the groundwater chemistry in the present study area.

### **5.2.1 Geology**

Geology plays a major role in determining the groundwater quality and has been found to be reflected in such water although modified by the above mentioned factors that constitute the environmental conditions. The highest and the lowest fluoride levels were in recent deposits (Figure 3.1, Appendix I, Table D1). It is noted from Figure 5.1a and b that fluoride levels in the recent deposits (sedimentary rocks) are generally above 1.5ppm. Very close fluoride distribution contours show there is much higher change in chemical constituents in the groundwater.



**LEGEND**

- Wells
- Bore holes
- Contour
- Major Faults
- Minor Faults

- D** Dolerite
- G** Granite
- Na** Andesite
- Nb** Basalts
- Nr** Rhyolite
- Pl** Pleistocene Sediments
- R** Recent Sediments
- Tkv** Kisingiri Volcanics



Figure 5.1a Distribution of fluoride (ppm) in dry season

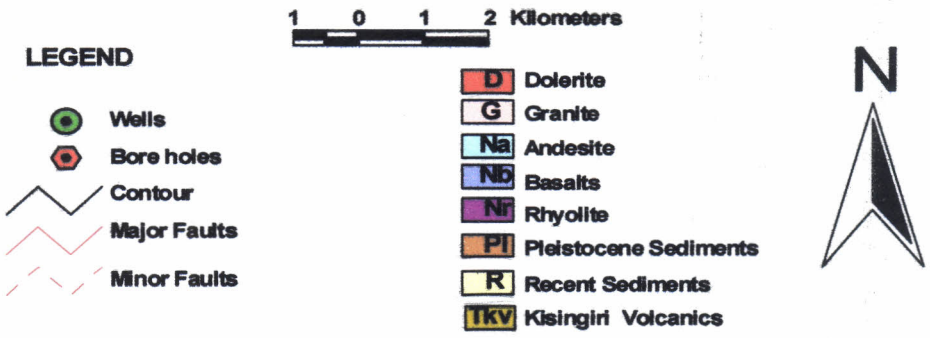
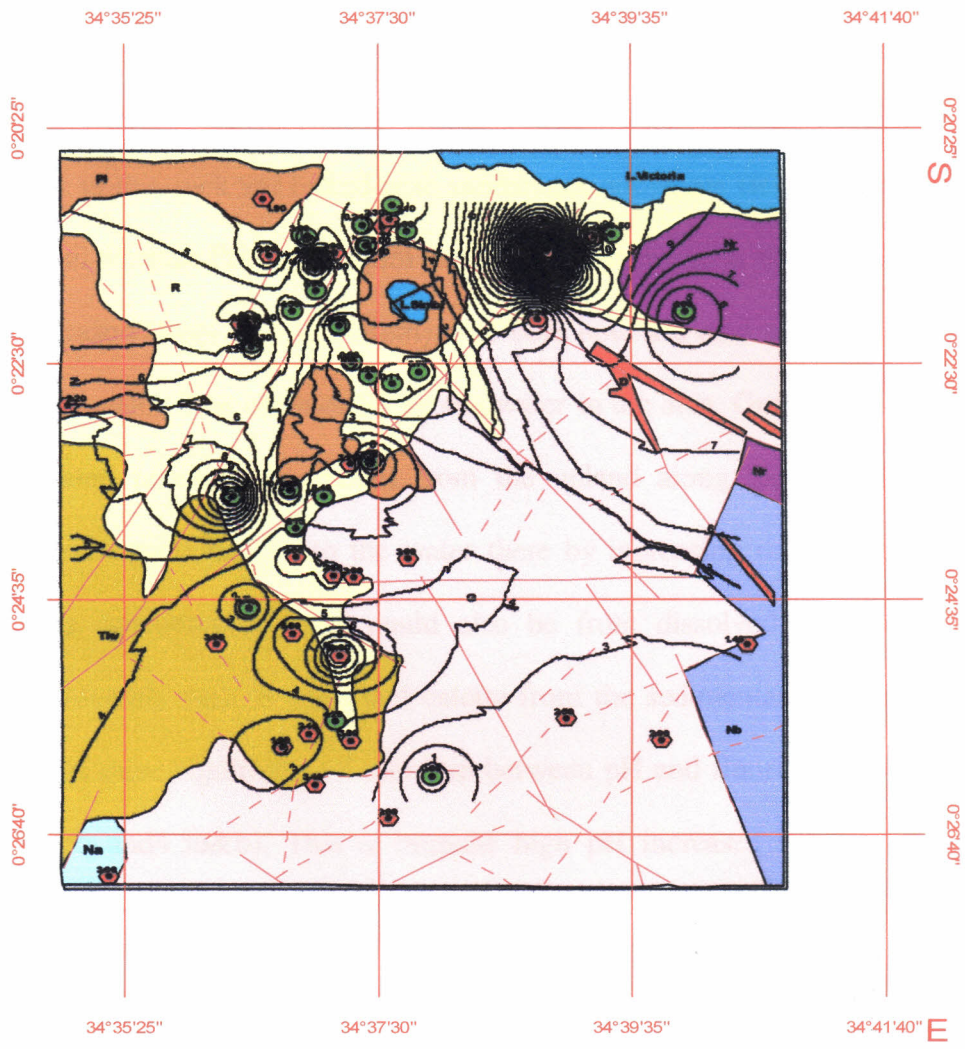


Figure 5.1b Distribution of fluoride (ppm) in rainy season

However, there are isolated pockets of very low levels of fluoride (less than 1ppm) and very high level of 36ppm in the same rock unit (Recent sediments) with a mean of 5.38ppm and 5.78 ppm in dry and rainy season respectively. The high concentration levels of fluorides in this rock are linked with sandstones which are rich in mica (Table 5.1). The station at Muslim Primary School shows a high increase in the fluoride levels during the rainy season (from 24.5 to 36ppm). The bore hole lies on a major fault in the lowland which is a major flow channel for groundwater in the area. Groundwater brings fluoride concentrated residuals (recharge) from the upland along the fracture zones (Samanga fault and Kendu fault) into the water there by increasing its concentrations. The high fluoride concentration level could also be from dissolved constituents of fluoride bearing minerals such as mica and calcite from the sedimentary rocks. Recent sediments show the most significant relationship between pH and fluoride levels (Table 4.3, Figure 4.4a&b and 4.5a&b). This is because high pH increases the solubility of minerals and sediments are highly soluble.

The water from Pleistocene sediments has fluoride concentration levels which are above 1.5ppm which is above the recommended limit for portable water. The fluorides in this rock unit have a mean of 2.45ppm in the dry season and 2.05ppm in the rainy season (Table 5.2a, b). The high fluoride levels are probably due to weathering of calcite bands and mica in the sandstone (Table 5.1). Fluoride concentration levels in the Tertiary volcanics (the Kisingiri ) are also above the recommended limit of 1.5ppm with a mean of 3.43ppm and 3.19ppm in dry and rainy season respectively (Table 5.2a, b). The high fluoride contents are probably from apatite in the nephelinites and feldspars in the

phonolitic nephelinites. Moment correlation coefficient (Table 4.3b) show there is no correlation between pH and fluoride but there is positive correlation between temperatures.

**Table 5.2a Descriptive statistics of fluoride concentration levels in different rock units in dry season**

Rock type	Sample size	Range (ppm)	Mean (ppm)
Precambrian Nyanzian system:			
Rhyolites	1	-	5.80
Andesites	1	-	3.50
Basalts	1	-	1.80
Precambrian intrusives			
Dolerite dykes	Nil	Nil	Nil
Granite	8	0.84 -5.00	3.31
Tertiary volcanics			
Kisingiri lavas	6	1.71-5.90	3.43
Quaternary deposits			
Recent sediments	35	0.12 -24.50	5.38
	34 without B1 (24.5ppm)	0.12 – 13.50	3.97
Pleistocene sediments	2	2.20 -2.70	2.45

Two mean values of fluoride in recent sediments have been calculated. Mean of 5.38 includes 24.5ppm (fluoride concentration in B1). This value is extremely high compared to other fluoride levels in the study area hence raising the mean. When this value is not included then mean lowers to 3.97ppm.

**Table 5.2b Descriptive statistics of fluoride concentration levels in different rock units in rainy season**

Rock type	Sample size	Range (ppm)	Mean (ppm)
Precamrian Nyanzian system:			
Rhyolites	1	-	4.80
Andesites	1	-	3.00
Basalts	1	-	1.40
Precambrian intrusives			
Dolerite	Nil	Nil	Nil
dykes	8	0.66 -4.30	2.86
Granite			
Tertiary volcanics			
Kisingiri lavas	6	1.45 -5.90	3.19
Quaternary deposits			
Recent sediments	35	0.11 -36.00	5.78
	34 without B1 (36ppm)	0.11 – 12.90	3.68
Pleistocene sediments	2	1.9 -2.20	2.05

B1 has fluoride concentrations of 36ppm in rainy season hence raising the mean of recent sediments to 5.78. When this value is not included the mean is lowered to 3.68 in rainy season. 36ppm is a very high level of fluoride compared to the concentration levels of fluoride in the study area.

High fluoride concentration levels in Oyugis granite with a mean of 3.31ppm and 2.86ppm in dry and rainy season respectively are from feldspars (fluoride released during the weathering of feldspars) hornblende and apatite (Table 5.1). In granite there



is significant correlation between fluoride and pH but no correlation with temperature. No statistical data could be obtained from rhyolite, basalts and andesite rock units due to limited number of bore holes. Each of the geological units mentioned had one borehole each. The only sample taken from rhyolite had high fluoride levels of 5.8ppm and 4.8ppm in the dry and rainy season respectively. The possible source of fluoride in rhyolite is orthoclase, oligoclase and hornblende. The sample taken from andesite rock unit had fluoride levels of 3.5ppm and 3.0ppm in the dry and wet season respectively and the possible source of fluoride in it is hornblende and pyroxene. A sample taken from the basalt rock unit had fluoride concentration level of 1.8ppm and 1.4ppm in dry and rainy season respectively. These levels are tolerable. Basalts therefore have the lowest level of fluorides. Fluoride levels in water from different locations may not however be related solely to the geological factors since different boreholes penetrating identical formations had different concentrations although being very close to each other (compared to Njenga1982). The same observation has been made in the study area where neighbouring boreholes (B7 and B8), having their aquifer in the same formation (Figure 3.1, Table 4.1); have different fluoride concentrations. Another example is well W9 with fluoride concentration level of 12ppm in both seasons and borehole B5 with a fluoride level of 2.98ppm and 2.9ppm in the dry and wet season respectively. These are in the same geological unit (Recent sediments) and very close to each other (approximately 50m separation from each other) but show a very big difference in fluoride levels. These two (W9 and B5) also show a very large variation in depth. The borehole (B5) which is the deepest (130m) has very low fluoride concentrations compared to the well (W9). Therefore the real cause of the variation can be assumed to be related to certain fluoride-

bearing minerals, which dissolve and infiltrate into different formations of different depths, whereby water extraction depth changes along these formations which result into the different fluoride levels within neighbouring boreholes.

### **5.2.2 Groundwater flow**

It is clearly apparent that the groundwater follows the direction of the topographical contours (Figure 2.5) and generally flows northward. A limited (slow) flow is evidenced in the lowland due to the presence of faults and almost a flat lying topography. The flow rate is indicated by the closeness of the groundwater contour lines. These contours are closest to each other to the south east of the area implying the groundwater gradient is the highest in this part in contrast to the west and north where these contours are far removed from each other reflecting low gradient. The relatively slow flow rate of the groundwater in this section (west and northern areas) increases the time of contact of groundwater with the surrounding rocks hence increases the solubility of fluoride bearing minerals into the groundwater (compared to Maina 1982). The gradient is high for most areas in the uplands facilitating rapid flow of mineral salts through the aquifers and low rate of leaching of minerals into the aquifer hence show high geochemical gradient. In this respect the concentration levels of fluorides are lower where the contours are very close and this can be noted from the fluoride levels in borehole at Kideshwa and Liera School (Figure 3.1) towards the south east of the area, but higher where the water discharges (for example the borehole at Muslim Primary school which is in the discharge zone has highest concentration levels of fluoride).

Vegetation cover provides a check for overland flow of rain water and therefore facilitates its infiltration into the ground storage. This water goes to dilute the chemical constituent in the groundwater. This is evidenced by the levels of fluoride in the rainy season with a mean of 4.36ppm compared to the dry season with a mean of 4.64ppm (Table 4.2, Figure 4.7 and 4.8). The availability of much water further dilutes acids such as carbonic acid and this hinders any increase in chemical constituent in groundwater through chemical weathering of rocks thus favours low levels of fluoride in the area in the rainy season. As result the main dilution effect is in the upland (especially areas covered by granite) which show remarkable decrease in fluoride levels in rainy season.

### **5.2.3 Groundwater Temperature**

The temperatures of the groundwater in the study area are within the range of the atmospheric air that is 25°C - 31°C. The temperature distribution map (Fig 5.2a and 5.2b) show the temperature distribution pattern does not change with change in season.

Higher groundwater temperatures were recorded in the sediments, and the highest temperatures were recorded in sedimentary rocks (Figure 5.2a and b). The correlation coefficients (Table 4.3a and b) indicate that there is slight positive correlation between temperature and fluoride content. The effect of temperature is significant only during the dry season for both wells and boreholes. As the temperature increases the fluoride concentration levels also increase in the dry season. During the rainy season temperature has minimum control on fluoride concentration. Fluoride concentrations in the wells are more dependent on temperature than fluoride in the boreholes (Tables 4.3a and b). This is indicated by the linear regression curve (Figures 4.2a and b).

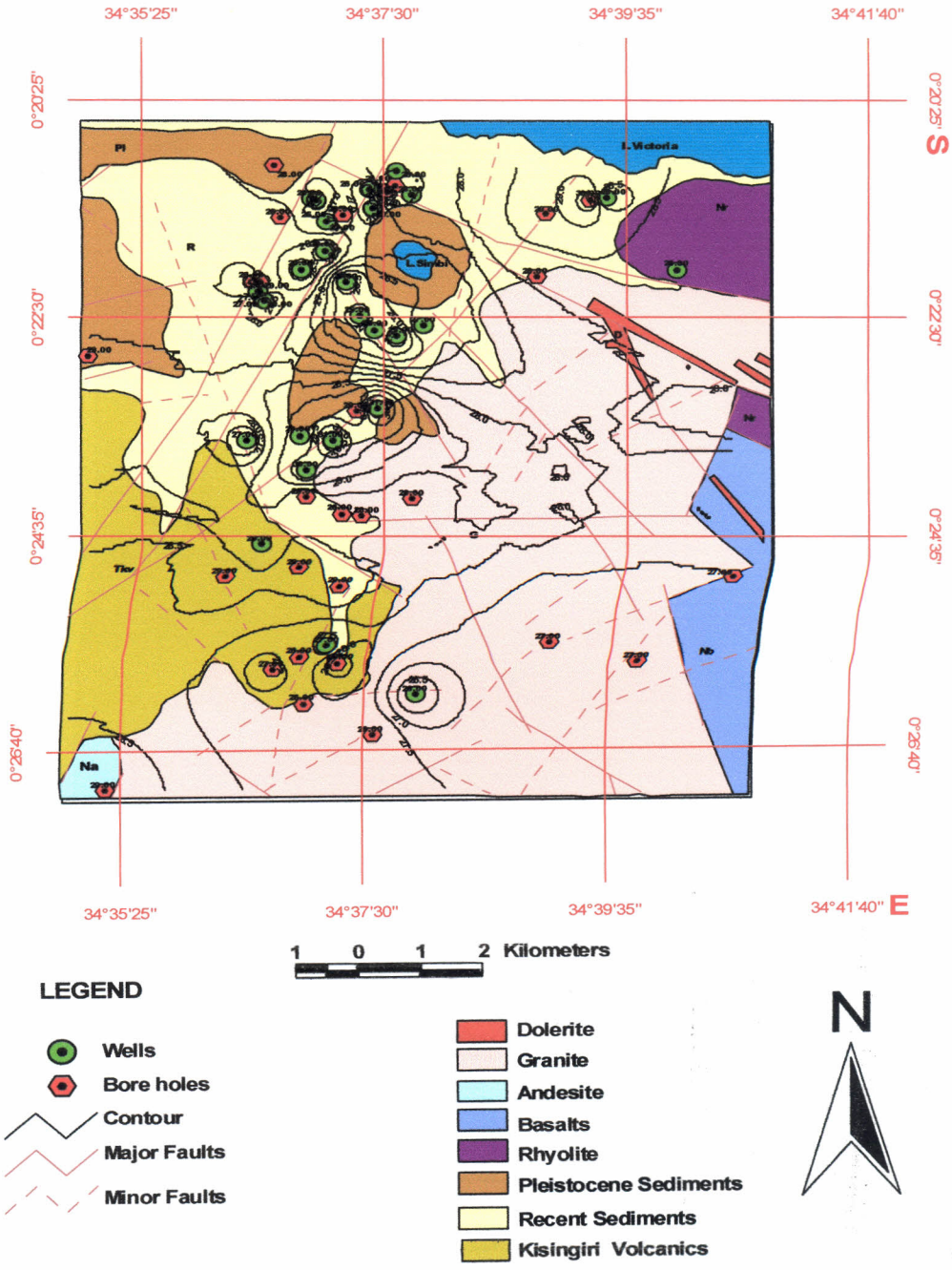
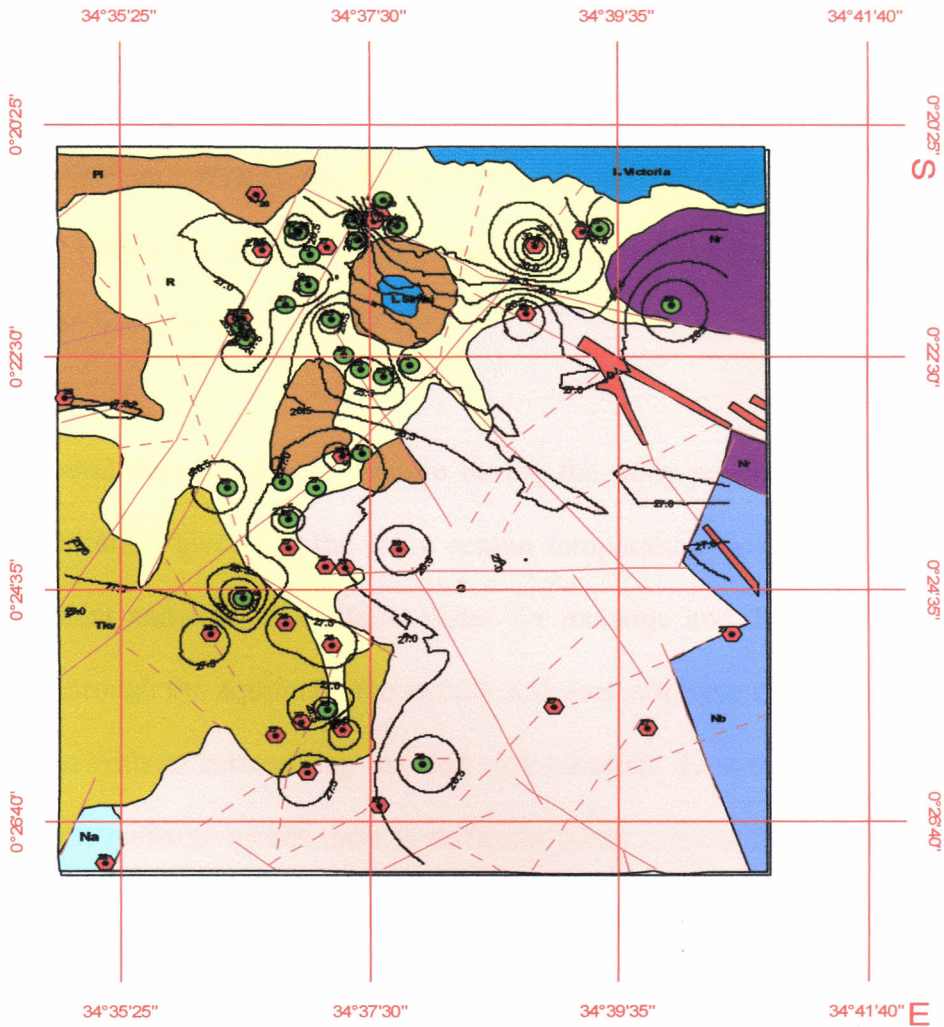


Figure 5.2a Distribution of temperature °C in dry season.



**LEGEND**

- Wells
- Bore holes
- Contour
- Major Faults
- Minor Faults

1 0 1 2 Kilometers

- Dolerite
- Granite
- Na Andesite
- Nb Basalts
- Nr Rhyolite
- Pi Pleistocene Sediments
- R Recent Sediments
- Tkv Kisingiri Volcanics



Figure 5.2b Distribution of temperature °C in rainy season.

Todd (1980) remarks that the insulating qualities of the earth's crust rapidly damp the large range of temperature found at surface so that only shallow groundwaters display any appreciable fluctuations in temperatures. This is noted in the shallow wells such as W3, W6, W5, W16 and W18 (Table 4.1) which have high temperatures but low fluoride levels (Table 4.1 Fig 3.1). From this observation the temperatures could be as a result of surface radiation from the sun.

There is a general decrease in temperature during the rainy season hence decrease in fluoride concentration levels. In the rainy season temperatures are lower (Table 4.1). There is sufficient and readily available water for recharge and dilution of salts. The water leached through the aquifers quite rapidly and does not have enough time to come into equilibrium with its surrounding soil and rock minerals. Low evaporation rates and high groundwater recharge means there is sufficient water percolating into the ground to flush away the soluble fluoride bearing mineral from the ground aquifer thereby reducing the concentration of fluoride. In the dry season the temperatures are higher (Table 4.1) and there is hardly any rainfall. Therefore there is little leaching process suggesting that the water has sufficient time to come into contact with mineral forming aquifer. High evaporation rates and low groundwater recharge means that there is not sufficient water percolating to flush away dissolved mineral salts from the ground aquifer, hence increase in fluoride concentration levels

The rate of the solution of solid is proportional to the saturation deficit which increases with increase in temperature. The easily soluble alkalis and alkaline earth metals are

dissolved by water. The solute content for alkali ions increases with increase in temperature and decrease for alkaline earth ions (Matthess 1982). These alkali rich waters are similarly rich in fluoride. In this respect the groundwaters with high temperatures have high fluoride concentration levels. This is noted at B1 (Muslim primary school) which has the highest temperature with the highest fluoride levels. These levels reduce during the rainy season when there is dilution of groundwater due to increased recharge. There is high temperatures in some groundwaters which occur along the fracture zones such as B1 and consequently have high fluoride content. The difference in temperature values of the borehole and well waters may depend on several factors such as seasonal variations in the heat received from the sun, the movement of heat from the earth's interior; evaporation, chemical and the thermonuclear processes in the rocks and endothermic/exothermic chemical reactions as oxidation, or reduction and heat of solution (Matthess, 1982).

#### **5.2.4 pH**

The pH values of the groundwater samples ranged from 6.21-8.56 in the dry season and 6.21- 8.57 in the rainy season. The pH of natural waters range from 6-9 (Stumm and Morgan 1996 in Fitts 2002). The pH values of all the water samples in the study area fall within the above mentioned range. The pH recommended limits of permissible drinking water range from 6.5-8.5 (WHO 1985). The pH results of the study area (Table 4.1) show that 3 samples fall below the lower limit of WHO range whereas the remaining 51 samples fall within the limited range. The moment correlation coefficient in Tables 4.3a and b shows that there is a significant positive correlation between pH and fluoride levels

in both seasons. pH has the highest impact (greatest control) of fluoride concentration in the study area; wells exhibit the relationship between fluorides and pH better than boreholes (Table 4.4). As the pH increases fluoride concentration levels also increase as shown by the regression curve (Figures 4.1a and b). Cox (1964) recognizes that fluoride concentrations can exceed 10ppm and can reach more than 30ppm. These high concentrations tend to be associated with a high pH. In this respect the highest pH in the study area (Table 4.1, Fig 5.3a and b) were also associated with high content of fluoride. For example B1 has highest pH and highest concentration levels of fluoride (Table 4.1) in both dry and rainy season. Lower pH in the rainy season reflects high leaching rate and therefore the relatively low solvent power of these waters due to dilution by recharge from precipitation. Also higher pH values are in the sediments. Therefore the difference in pH values of the borehole and well water sample may depend on several factors such as the chemistry of the groundwater, which could be reflected by the composition of the aquifers, by human activities, chemical and biological processes occurring during infiltration.



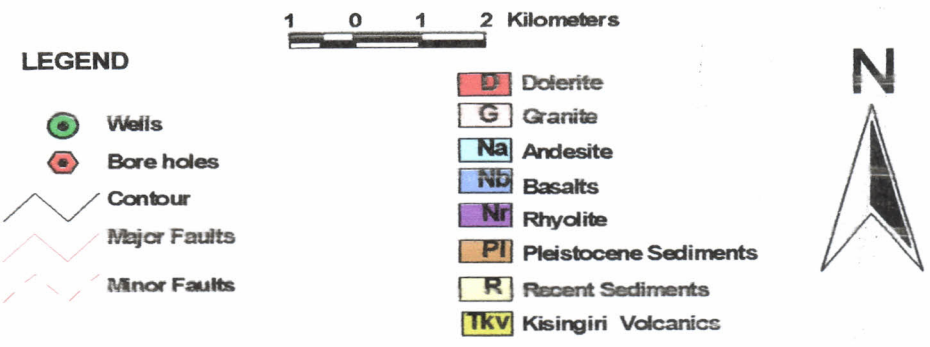
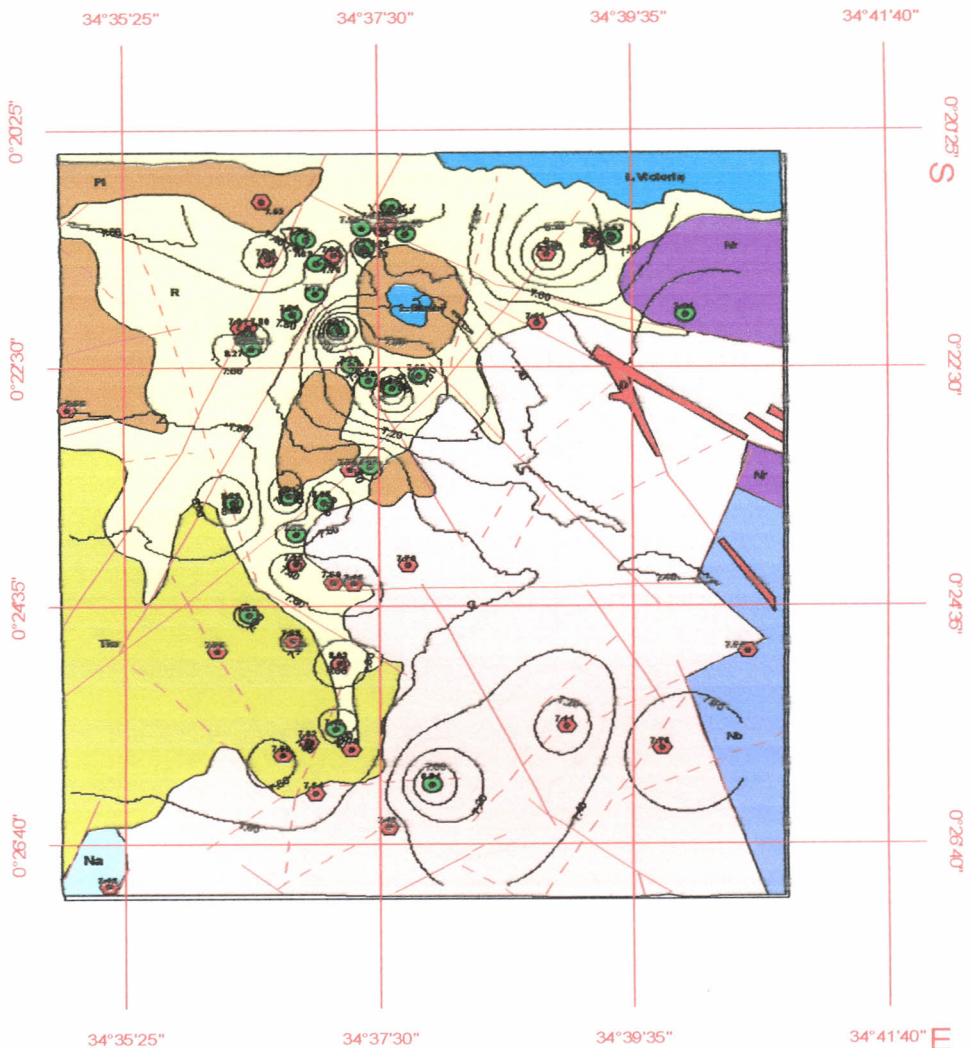


Figure: 5.3a Distribution of pH in the dry season

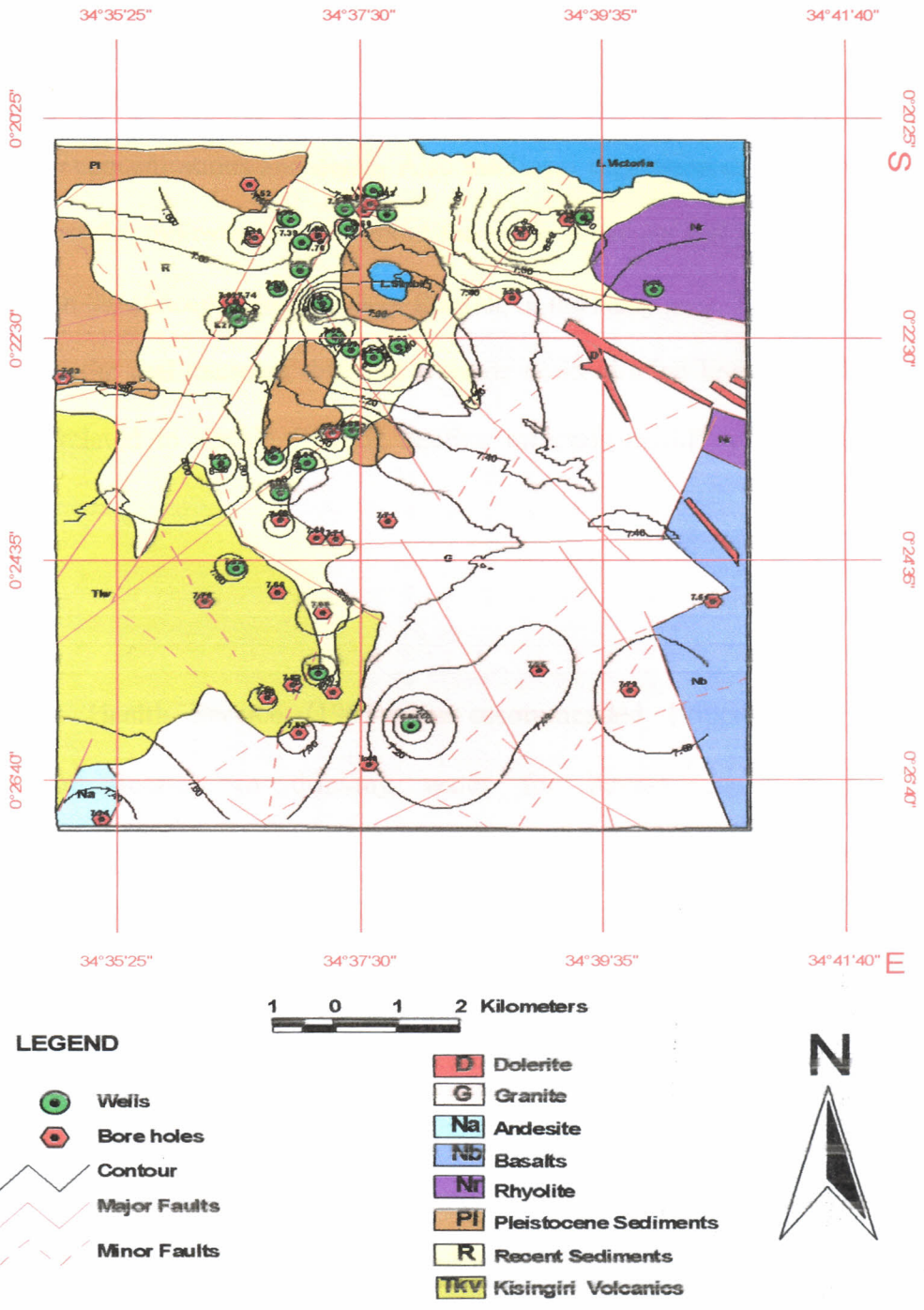


Figure 5.3b Distribution of pH in the rainy season

### **5.2.5 Depth**

The groundwater depths in the study ranged from 5m to 130m (Appendix I Table G1). Moment correlation coefficients (Table 4.3a and b) show that there is no relationship between fluoride concentrations and depth. Also the linear regression curve (Fig 4.3a, b, c, and d) is almost flat indicating scatter about the mean is narrow and hence depth does not have effect on the concentration levels of fluoride in the study area. Therefore it is not easy to point out the real cause of different fluoride concentration levels, but it can be assumed to be related to certain fluoride bearing minerals in different formations at different depths.

### **5.2.6 Fluoride**

The US Public Health Service (1962) has recommended 1.5ppm as maximum concentration of fluoride in drinking water for human consumption. This recommendation has been adopted by WHO (1985). The average fluoride concentration in the groundwaters was found to be 4.654ppm and 4.229ppm (Table 4.2) in the dry and rainy season respectively. Fluoride distribution pattern does not change in both seasons but the concentration levels change (Figure 5.1a and b). The concentration levels are higher during the dry season and lower during the rainy season (Table 4.1, Figure 4.7 and 4.8)

There is a general pattern of decrease in the levels of fluoride in rainy season due to the dilution effect of rain water that infiltrate and percolate into the ground. However there is an isolated pocket at Muslim Primary School where there is an increase in the levels of

fluoride. This borehole lies along a fracture zone in lowland (Figure 5.1a and b), therefore groundwater brings highly concentrated fluoride residuals from the igneous rocks in the upland along the fracture zones (Samanga and Kendu fault) thereby increasing the fluoride content. The high fluoride content could also be from the surrounding fluoride bearing minerals from sedimentary rocks.

### **5.2.7 Comparison of fluoride concentration levels in upland and lowland**

The study area is divided into upland and lowlands by Kendu fault and Samanga fault. Distribution of fluoride, pH and temperature are shown in Appendix I Table E1 and E2. Computed mean of fluoride concentration levels in uplands is 3.43ppm in the rainy season and 4.07ppm in the dry season whereas, the lowland has computed mean of 4.85ppm in the rainy season and 5.05ppm in the dry season (Appendix I Table F1). The mean of fluoride concentration levels are higher in the lowland than in the upland (see also Figure 4.9 and 4.10 in Chapter 4). The low levels of fluoride in the upland are coupled with high groundwater gradient which flushes out fluoride bearing minerals through the aquifer. The groundwater gradient is generally low in the lowlands (Fig 2.5) and therefore groundwater flow rate is very slow allowing enough time for water to come into contact with the surrounding rock minerals forming the aquifer, increasing dissolution of fluoride bearing minerals into the aquifer, thereby increasing the levels of fluoride.

The lowland consist of mainly sedimentary rocks hence the high fluoride concentration levels due to high solubility of fluoride bearing minerals in the sedimentary rocks into the

groundwater (Todd, 1980) whereas upland is mainly covered by igneous rocks particularly granite hence lower fluoride levels due to low solubility of fluoride bearing mineral in granite.

#### **5.2.8 Relationship of water to use**

The suitability of water is governed by the use to which it is to be put. Thus the requirements for drinking water, industrial water and agricultural vary widely (Todd 1980). Measures of chemical constituents are one of the factors that have to be taken into account in establishing quality criteria. Nevertheless standards of permissible amounts of impurity have been laid down by various bodies such as WHO and United States Public Health Service. The acceptable limit is 1.5ppm (WHO 1985), but this can vary from region to region depending on the climate and geographic position (Lloyd and Heathcote 1985), so the set standards can only be considered as a guide.

#### **Water for domestic use**

It is important that water to be used for drinking purposes must meet very high quality standards of physical, chemical and biological purity. Such water must be free from pathogenic micro-organisms, minerals and substances capable of producing adverse physical effects (APHA et al. 1992 and Todd 1980) and also free from colour, turbidity and should have no unpleasant odour or taste.

As per the study the fluoride content of the ground water from the study area do not agree with the recommended limits of 1.5ppm. The range in both dry and rainy season (Table

4.1) does not fit the desirable range of 0.7ppm to 1.5ppm which is essential for drinking purposes as given by WHO (1985). Most of the water samples from the boreholes and wells have fluoride concentrations (Table 4.2) in excess of the recommended limit (1.5ppm). The waters, are therefore not good for drinking purposes and defluoridation can be done as a measure to reduce the fluoride content to acceptable limit (Appendix II).

## CHAPTER SIX

### CONCLUSIONS AND RECOMMENDATIONS

#### 6.1 INTRODUCTION

The various aspects of the groundwater in the study area have been discussed in relation to the fluoride content as stipulated in the objectives. This chapter therefore reviews and summarizes the various conclusions that have been arrived at and further puts forth some recommendations with respect to water quality in this area.

#### 6.2 Conclusion

The geology of the study area is determined by the landscapes of igneous and sedimentary rocks. The area is separated into upland and lowland by the Kendu and Samanga fault. The lowland is highly faulted and is underlain mainly by the Quaternary deposits and Tertiary volcanics covered by volcanoclastics of recent age, while granite forms the larger percentage of the upland. Groundwater occurs almost everywhere in all different geological formations in the area from a depth of 5m to 130m. In areas underlain by the granites and volcanic rock types, groundwater occurs in the weathered zones, and the sub-vertical fault zones provide a larger storage. In the down faulted lowland the groundwaters occur in sands, silt and gravels. Groundwater flow in the area is determined by the geological conditions as well as the topography of the area. Joints, bedding planes and faults act as flow channels for groundwater. The groundwater flow direction is a replica of the topography. The depths of the water as evidenced in the bore hole data indicate the groundwater profile is closely related to topography of the area. The flow direction indicates the groundwater flow varies from recharge to discharge

areas which is controlled by the geology and topography of the area except for cases where faulting may have occurred. The recharge of groundwater is from the infiltration and percolation of rainwater on the higher slopes, as well as infiltration from rivers and streams. The water recharges from the precipitation on the higher slopes in the upland while it is discharged in the lowlands which form the floor of the Nyanza rift.

Groundwater flow controls the fluoride concentrations levels of the water in the area. Fluoride content are higher where flow is slow (discharge zones) and lower where flow is higher. This is because at recharge zones the flow rate is higher and so the water has not enough contact time with fluoride bearing mineral, therefore low solubility. The temperatures of the groundwater were within the range of surface air temperatures. These temperatures were generally lower during the rainy season. The differences in groundwater temperatures could have been due to:

- Seasonal variations in heat received from the sun
- Evaporation, chemical and the thermonuclear processes in the rocks.
- Endothermic/exothermic chemical reactions as oxidation, or reduction; heat of solution and heat of dilution

The statistical analysis results indicate the relationship between fluoride content and temperature is significant only in the dry season and not the rainy season. Fluoride concentrations are dependent on temperature since solute content of alkali ions also rich in fluoride increase with the increase in groundwater temperature. pH of all the waters fall within the range of 6-9 (Stumm and Morgan 1996 in Fitts 2002) hence shows the waters are neutral. Fluoride concentrations are also dependent on pH of water. Moment



correlation coefficients show that the relationship between fluoride and pH in both dry and rainy season is quite significant. Fluoride concentrations increase with increase with increase in pH. pH determines the solvent power of the water. Lower pH reflects relatively low solvent power of these waters whereas higher pH reflects higher dissolution of the fluoride bearing minerals into the waters. Component factor analysis results show that pH has the greatest effect on fluoride concentration levels in the study area. Depth of groundwater in the study area does not influence the fluoride content of the waters. Therefore it is not easy to point out the real cause of different fluoride concentration levels, but it can be assumed to be related to certain fluoride bearing minerals which penetrate different formations at different depths. Fluoride levels in water from different locations may not be related only to the geological factors since in some places different boreholes penetrating identical formations had different concentrations although being very close to each other. It was also noted that concentration levels of fluoride (mean value) were higher than the optimum limit (1.5ppm) in all the rock units, sedimentary rocks having the highest fluoride content. This was because of the high solubility of sedimentary rocks compared to the igneous rocks.

Q-Q plot results show fluoride concentration levels were generally higher in the lowland than in the upland.

This is due to the fact that lowland:

- Is in discharge zones where topographical gradient are low and so is the groundwater flow. This allows for more contact time between the water and fluoride bearing minerals thereby increasing their solubility.

- Consist of mainly sedimentary rocks which have higher solubility.

Upland has low fluoride levels because:

- It is in the recharge zones where the topographical gradient is higher and so is the groundwater flow. This allows for minimum contact time between the water and the rocks therefore low solubility.
- It mainly consists of igneous rocks which have low solubility.

Fluoride concentration levels change with change in season. These levels are higher during the dry season and lower during the rainy season due to dilution from extra recharge from precipitation. The pattern of fluoride distribution does not change in both seasons. The relationship between these parameters (pH, temperature and depth) and fluoride is quite significant in wells than in boreholes.

As per the results of the research study which was based on fluorides as the only ion, groundwater in this area has excess of the desirable limit of 1.5ppm over a larger part of the area. The water quality in terms of fluoride varies not only with season but also with pH, temperature and groundwater flow within the different geologic units but not with depth.

### **6.3 Recommendation**

Most values for fluoride level in the area are above WHO (1985) recommended range of 0.7-1.5ppm for drinking water quality. These high concentration levels pose serious health problems to consumers and require remedial measures to be taken to correct the accepted healthy fluoride levels in the water. Such boreholes and wells where content of fluoride exceed the required optimum level (1.5ppm) need some kind of treatment which is cheap enough (Appendix II) to check the concentration levels of fluoride before it is used for drinking purposes. Excessive fluoride causes mottling of tooth enamel, brittle teeth and if acute may cause skeletal fluorosis. These effects are more evident in children who drink too much fluoridated water while their permanent teeth are still growing (Driscoll 1986).

Quality criteria of water are determined in terms of its chemical, physical and biological properties. Classification of the groundwater from the study area is therefore not complete since only one element was considered. It is therefore my recommendation that further research on quality of groundwater in the study area be done, full chemical analysis putting more emphasis on trace elements.

The study has also established that there are very low and high pockets of fluoride concentration in groundwater. This is important in the planning and development of groundwater resources in the study area. Future groundwater development should therefore be restricted to low fluoride pocket areas for the provision of good quality portable water.

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## APPENDIX I

**Table A1 Average Field Temperature readings °C**

BH/W NO	Dry SEASON				RAINY SEASON			
	1 <sup>ST</sup>	2 <sup>ND</sup>	3 <sup>RD</sup>	AVER- AGE	1 <sup>ST</sup>	2 <sup>ND</sup>	3 <sup>RD</sup>	AVER- AGE
W1	28	28	28	26	26	26	26	26
W2	28	28	28	28	28	27	26	27
W3	28	28	28	28	31	30	29	30
W4	28	28	28	28	30	30	30	30
W5	26	26	26	26	26	26	26	26
W6	26	26	26	26	26	26	26	26
W7	29	28	27	28	27.5	26	27.5	27
W8	25	25	25	25	26	24	25	25
W9	27	27	27	27	27	26.5	26	26.5
W10	29	29	29	29	28	28	28	28
W11	29	29	29	29	27	27	27	27
W12	27	27	27	27	26	26	26	26
W13	30	28	29	29	28	28	28	28
W14	25	25	25	25	25	25	25	25
W15	25	25	25	25	26	26	26	26
W16	26	26.5	25.5	26	25.5	25	24.5	25
W17	25	25	25	25	25	25	25	25
W18	27	27	27	27	27	27	27	27
W19	31	31	31	31	27	27	27	27
W20	32	31	30	31	27	27	27	27
W21	29	29	29	29	27	27	27	27
W22	27	27	27	27	26	26	26	26
W23	30	30	30	30	28	28	28	28
W24	28	28	28	28	25	25	25	25
W25	27	28	26	27	26.5	26.5	25	26
W26	26	26	26	26	26	26	26	26
B1	29	29	29	29	31	31	31	31
B2	30.5	30	29.5	30	29	29	29	29
B3	30	30	30	30	29	29	29	29
B4	28	28	28	28	29	29	29	29
B5	28	28	28	28	27	27	27	27
B6	28	28	28	28	28	28	28	28
B7	29	29	29	29	28	28	28	28
B8	26	26.5	25.5	26	26	26	26	26
B9	29	29	29	29	28	28	28	28

**Table continued**

	DRY SEASON				RAINY SEASON			
	1 <sup>ST</sup>	2 <sup>ND</sup>	3 <sup>RD</sup>	AVER	1 <sup>ST</sup>	2 <sup>ND</sup>	3 <sup>RD</sup>	AVE
B10	28	28	28	28	28	27	26	27
B11	29	28	27	28	27	27	27	27
B12	29	29	29	29	28	28	28	28
B13	29	29	29	29	28	28	28	28
B14	28.5	27.5	28	28	27	27	27	27
B15	27	26	28	27	27.5	27	26.5	27
B16	29.5	29	28.5	29	28	28	28	28
B17	29	29	29	29	28	28	28	28
B18	29	29	29	29	29	28	27	28
B19	28	29	27	28	29	28	27	28
B20	30	29	28	29	28	28	28	28
B21	28	28	28	28	28	28	28	28
B22	28	28	28	28	28	27	26	27
B23	28	28	28	28	27	27	27	27
B24	28	28	28	28	26	26	26	26
B25	29	27	28	28	27	25	26	26
B26	27	27	27	27	27	27	27	27
B27	27	27	27	27	28	27	26	27
B28	27	27	27	27	28	27	26	27

**Table B1 Q-Q plot data for boreholes**

i	Fluoride in dry season				Fluoride in rainy season			
	$X_i$	$P_i$	$Y_j$	upland values	$X_i$	$P_i$	$Y_j$	upland values
1	2.20	0.05	1.81	1.80	1.90	0.05	1.43	1.40
2	2.35	0.14	2.02	1.97	2.00	0.14	1.91	1.90
3	2.40	0.22	2.32	2.30	2.00	0.22	2.09	2.00
4	2.70	0.32	2.46	2.40	2.20	0.32	2.46	2.40
5	2.98	0.41	2.93	2.60	2.30	0.41	2.68	2.60
6	3.40	0.50	3.45	3.40	2.90	0.50	2.90	2.80
7	4.60	0.59	3.68	3.50	3.20	0.59	3.35	3.00
8	4.80	0.68	4.21	3.80	4.10	0.68	3.60	3.60
9	7.40	0.77	4.86	4.40	6.40	0.77	4.14	3.60
10	12.00	0.86	6.55	5.00	10.80	0.86	5.68	4.30
11	24.50	0.95	10.32	6.80	36.00	0.95	9.78	5.90
				10.50				10.00

**Table B2 Q-Q plot data for fluorides in wells**

i	Fluoride in dry season				Fluoride in rainy season			
	$X_i$	$P_i$	$Y_j$	lowland values	$X_i$	$P_i$	$Y_j$	lowland values
1	0.84	0.10	0.37	0.28	0.66	0.10	0.22	0.11
2	1.71	0.26	2.36	1.15	1.45	0.26	2.14	1.20
3	4.60	0.42	6.32	5.80	4.45	0.42	5.26	4.80
4	7.80	0.58	7.35	7.00	4.20	0.58	7.29	5.90
5	8.08	0.74	8.64	7.60	5.40	0.74	9.93	8.30
6	8.20	0.90	13.05	9.00	7.30	0.90	12.66	10.5
				13.50				12.90



**Table C1 Component analysis data for boreholes.****D = dry season, W = wet season.**

BH NO	F <sub>D</sub>	F <sub>w</sub>	T <sub>D</sub>	T <sub>w</sub>	pH <sub>D</sub>	pH <sub>w</sub>	factor1-1
B1	24.50	36	29	31	8.56	8.57	32.77613
B2	7.40	6.40	30	29	8.53	8.42	4.60722
B3	3.40	2.00	30	29	7.69	7.60	-0.36896
B4	2.40	2.30	28	29	7.46	7.50	-0.71829
B5	2.98	2.90	28	27	7.96	7.90	-0.02103
B6	2.35	2.00	28	28	7.14	7.10	-0.93706
B7	4.60	4.10	26	26	7.61	7.62	1.62238
B8	12.00	10.80	29	28	7.80	7.74	9.90802
B9	4.80	3.20	29	28	7.74	7.28	1.15541
B10	2.30	2.00	28	27	7.35	7.47	-0.96412
B11	2.75	2.50	28	27	7.50	7.60	-0.4011
B12	10.50	10.00	29	28	8.03	7.98	8.58518
B13	4.20	3.90	29	28	7.79	7.77	1.27814
B14	2.50	2.10	28	27	7.82	7.82	-0.792
B15	1.97	1.90	27	27	7.52	7.54	-1.20657
B16	3.80	3.60	29	28	7.76	7.76	0.87
B17	6.80	5.90	29	28	7.57	7.66	3.96304
B18	2.70	2.20	29	28	7.56	7.63	-0.61988
B19	2.20	1.90	28	26	7.62	7.52	-1.08213
B20	3.50	3.00	29	28	7.48	7.34	0.32423
B21	3.50	3.40	28	28	7.64	7.92	0.57986
B22	3.40	2.80	28	27	7.43	7.40	0.14231
B23	4.10	3.60	28	27	7.46	7.71	1.03231
B24	4.40	3.60	28	26	7.70	7.71	1.19463
B25	5.00	4.30	28	26	7.41	7.20	1.96662
B26	2.60	2.50	27	27	7.11	7.26	-0.48226
B27	2.40	2.00	27	27	7.76	7.72	-0.91001
B28	1.80	1.40	27	26	7.76	7.72	-1.61809

**Table C2 Component analysis data for boreholes in lowland.****D =dry season, W = wet season.**

NO	F <sub>D</sub>	F <sub>W</sub>	T <sub>D</sub>	T <sub>W</sub>	pH <sub>D</sub>	pH <sub>W</sub>	Factor 1-1
B2	7.4	6.4	30	29	8.53	8.4	0.93888
B3	3.4	2	30	29	7.69	7.6	-0.49185
B4	2.4	2.3	28	29	7.46	7.5	-0.60106
B5	2.98	2.9	28	27	7.96	7.9	-0.40035
B6	2.35	2	28	28	7.14	7.1	-0.66243
B7	4.6	4.1	29	28	7.8	7.7	0.0758
B8	12	10.8	26	26	7.61	7.6	2.46708
B9	4.8	3.2	29	28	7.74	7.3	-0.05144
B18	2.7	2.2	29	28	7.56	7.6	-0.57007
B19	2.2	1.9	28	26	7.62	7.5	-0.70454

**Table C3 Ccomponent analysis data for boreholes in upland.****D = dry season, W = wet season.**

NO.	F <sub>D</sub> (ppm)	F <sub>W</sub> (ppm)	T <sub>D</sub> (°C)	T <sub>W</sub> (°C)	pH <sub>D</sub>	pH <sub>W</sub>	Factor 1-1
B10	2.30	2.00	28.00	27.00	7.35	7.47	-0.72488
B11	2.80	2.50	28.00	27.00	7.50	7.60	-0.49443
B12	10.50	10.00	29.00	28.00	8.03	7.98	3.19817
B13	4.20	3.90	29.00	28.00	7.79	7.77	0.19564
B14	2.50	2.10	28.00	27.00	7.82	7.82	-0.65283
B15	1.97	1.90	27.00	27.00	7.52	7.54	-0.8276
B16	3.80	3.60	29.00	28.00	7.76	7.76	0.02669
B17	6.80	5.90	29.00	28.00	7.57	7.66	1.3062
B20	3.50	3.40	29.00	28.00	7.48	7.34	-0.1932
B21	3.50	3.40	28.00	28.00	7.64	7.92	-0.0938
B22	3.40	3.00	28.00	27.00	7.43	7.40	-0.26649
B23	4.10	3.60	28.00	27.00	7.46	7.71	0.09749
B24	4.40	3.60	28.00	26.00	7.70	7.56	0.16829
B25	5.00	4.30	28.00	26.00	7.41	7.20	0.48383
B26	2.60	2.50	27.00	27.00	7.11	7.26	-0.52983
B27	2.40	2.00	27.00	27.00	7.76	7.72	-0.70128
B28	1.80	1.40	27.00	27.00	7.51	7.36	-0.99196

**Table C4 Component analysis data for wells.****D = dry season, W = wet season.**

Well No	F <sub>D</sub>	F <sub>W</sub>	T <sub>D</sub>	T <sub>W</sub>	pH <sub>D</sub>	pH <sub>W</sub>	factor 1-1
W1	5.80	4.80	28.00	26.00	7.44	7.12	12.3149
W2	7.60	10.50	28.00	27.00	7.53	7.95	21.92181
W3	0.28	1.10	28.00	30.00	6.43	7.77	-0.09226
W4	4.20	3.80	28.00	30.00	7.62	8.20	8.8083
W5	0.32	0.21	26.00	26.00	7.54	6.46	-1.137
W6	0.58	0.60	26.00	26.00	7.13	7.44	-0.28562
W7	4.40	3.90	28.00	27.00	7.35	7.82	9.21569
W8	1.10	0.84	25.00	25.00	7.39	7.68	0.74883
W9	12.00	12.00	27.00	26.50	7.70	7.94	30.01797
W10	7.00	5.90	29.00	28.00	7.72	8.04	15.37801
W11	12.00	4.30	29.00	27.00	7.84	7.86	20.4885
W12	3.80	3.20	27.00	26.00	8.27	7.85	7.49849
W13	9.00	8.30	29.00	28.00	7.75	7.84	21.18449
W14	0.33	0.45	25.00	25.00	6.31	6.78	-0.82579
W15	0.94	0.88	25.00	26.00	7.32	7.65	0.57143
W16	1.15	1.20	26.00	25.00	6.90	7.42	1.26527
W17	0.12	0.11	25.00	25.00	6.21	6.21	-1.55147
W18	0.84	0.77	27.00	27.00	7.03	7.35	0.29348
W19	8.20	7.30	31.00	27.00	7.88	8.13	18.81239
W20	6.20	5.40	31.00	27.00	8.08	8.37	13.62471
W21	2.15	1.65	29.00	27.00	7.31	7.89	3.24031
W22	13.5	12.90	27.00	26.00	8.23	8.10	33.25899
W23	7.80	4.10	30.00	28.00	7.99	7.98	14.28484
W24	1.71	1.45	28.00	25.00	7.83	7.67	2.36882
W25	4.60	4.20	27.00	26.00	7.43	7.40	9.87059
W26	0.84	0.66	26.00	26.00	6.81	6.87	0.15735

**Table C5 Component analysis data for wells in lowland.****D= Dry season Wet/Rainy season.**

	F <sub>D</sub> (ppm)	F <sub>W</sub> (ppm)	T <sub>D</sub> (°C)	T <sub>W</sub> (°C)	pH <sub>D</sub>	pH <sub>W</sub>	Factor1-1
W1	5.80	4.80	28.00	26.00	7.44	7.12	0.28895
W2	7.60	10.50	28.00	27.00	7.53	7.95	1.20738
W3	13.5	12.9	27.00	26.00	8.23	8.10	2.18823
W4	4.20	3.80	28.00	30.00	7.62	8.20	-0.02056
W5	0.30	0.20	26.00	26.00	7.54	6.46	-0.91632
W6	0.60	0.60	26.00	26.00	7.13	7.44	-0.83767
W7	4.40	3.90	28.00	27.00	7.35	7.82	0.01502
W8	1.10	0.80	25.00	25.00	7.39	7.68	-0.74768
W9	12.00	12.00	27.00	27.00	7.70	7.94	1.90273
W10	7.00	5.90	29.00	28.00	7.72	8.04	0.56471
W11	12.00	4.30	29.00	27.00	7.84	7.86	0.94301
W12	3.80	3.20	27.00	27.00	8.27	7.85	-0.14156
W13	9.00	8.30	29.00	28.00	7.75	7.84	1.09493
W14	0.30	0.50	25.00	25.00	6.31	6.78	-0.88525
W15	0.90	0.90	25.00	26.00	7.32	7.65	-0.76118
W16	1.20	1.20	26.00	25.00	6.90	7.42	-0.69703
W17	0.10	0.10	25.00	25.00	6.21	6.21	-0.95247
W18	0.80	0.80	27.00	27.00	7.03	7.35	-0.78644
W21	2.20	1.70	29.00	27.00	7.31	7.89	-0.5254
W22	13.5	12.9	27.00	26.00	8.23	8.10	2.18823

**Table C6 Component analysis data for wells in upland.****D =Dry season W =wet season.**

No	F <sub>D</sub>	F <sub>W</sub>	T <sub>D</sub>	T <sub>W</sub>	pH <sub>D</sub>	pH <sub>W</sub>	Factor1-1
W19	8.20	7.30	31.00	27.00	7.88	8.13	1.2635
W20	6.20	5.40	31.00	27.00	8.08	8.37	0.53798
W23	7.80	4.10	30.00	28.00	7.99	7.98	0.53328
W24	1.71	1.45	28.00	25.00	7.83	7.67	-1.02534
W25	4.60	4.20	27.00	26.00	7.43	7.40	0.02396
W26	0.84	0.66	26.00	26.00	6.81	6.87	-1.33337

**Table D1 showing concentrations of fluoride in different rocks.**

Where R= Rainy season while D = Dry season

Pleistocene sediments			Recent sediments			Tertiary volcanics		
No	D	R	No	D	R	No	D	R
B18	2.70	2.20	B1	24.50	36.00	B14	2.50	2.10
B19	2.20	1.90	B2	7.40	6.40	B15	1.97	1.90
			B3	3.40	2.00	B16	3.80	3.60
			B4	2.40	2.30	B17	6.00	5.90
			B5	2.98	2.90	W24	1.71	1.45
			B6	2.35	2.00	W25	4.60	4.20
			B7	4.60	4.10			
			B8	12.00	10.80			
			B9	4.80	3.20			
			B10	2.30	2.00			
			B11	2.75	2.50			
			B12	10.50	10.00			
			B13	4.20	3.90			
			W2	7.60	10.50			
			W3	0.28	1.10			
			W4	4.20	3.80			
			W5	0.32	0.21			
			W6	0.58	0.60			
			W7	4.40	3.90			
			W8	1.10	0.84			
			W9	12.00	12.00			
			W10	7.00	5.90			
			W11	12.00	4.30			
			W12	3.80	3.20			
			W13	9.00	8.30			
			W14	0.33	0.45			
			W15	0.94	0.88			
			W16	1.15	1.20			
			W17	0.12	0.11			
			W18	0.84	0.77			
			W19	8.20	7.30			
			W20	6.80	5.40			
			W21	2.15	1.65			
			W22	13.50	12.90			
			W23	7.80	7.98			

**Table continued**

Granite			Rhyolite			Andesite			Basalt		
No.	D	R	No	D	R	No.	D	R	No.	D	R
B21	3.50	3.40	W1	5.80	4.80	B20.00	3.50	3.00	B28.00	1.80	1.40
B22	3.40	2.80									
B23	4.10	3.60									
B24	4.40	3.60									
B25	5.00	4.30									
B26	2.60	2.50									
B27	2.60	2.00									
W26	0.84	0.66									

**Table E1 Showing distribution of fluoride, temperature and pH in the upland and lowland in the dry season.**

Upland				Lowland			
No	F <sup>-</sup> (ppm)	Temp (°C)	pH	No	F <sup>-</sup> (ppm)	Temp (°C)	pH
B10	2.30	28.00	7.35	B1	24.5	29.00	8.56
B11	2.75	28.00	7.50	B2	7.40	30.00	8.53
B12	10.50	29.00	8.03	B3	3.40	30.00	7.69
B13	4.20	29.00	7.79	B4	2.40	28.00	7.46
B14	2.50	28.00	7.82	B5	2.98	28.00	7.96
B15	1.97	27.00	7.52	B6	2.35	28.00	7.14
B16	3.80	29.00	7.76	B7	12.00	26.00	7.61
B17	6.80	29.00	7.57	B8	4.60	29.00	7.80
B20	3.50	29.00	7.48	B9	4.80	29.00	7.74
B21	3.50	28.00	7.64	B18	2.70	29.00	7.56
B22	3.40	28.00	7.43	B19	2.20	28.00	7.62
B23	4.10	28.00	7.46	W1	5.80	28.00	7.44
B24	4.40	28.00	7.70	W2	7.60	28.00	7.53
B25	5.00	28.00	7.41	W3	0.28	28.00	6.43
B26	2.60	27.00	2.60	W4	4.20	28.00	7.62
B27	2.40	27.00	7.76	W5	0.32	26.00	7.54
B28	1.80	27.00	7.51	W6	0.58	26.00	7.13
W19	8.20	31.00	7.88	W7	4.40	28.00	4.40
W20	8.08	31.00	8.08	W8	1.10	25.00	7.39
W21	0.84	26.00	6.84	W9	12.00	27.00	7.70
W23	7.80	30.00	7.99	W10	7.00	29.00	7.72
W24	1.71	28.00	7.83	W11	12.00	29.00	7.84
W25	4.60	27.00	7.43	W12	3.80	27.00	8.27
W26	0.84	26.00	6.81	W13	9.00	29.00	7.75
				W14	0.33	25.00	6.31
				W15	0.94	25.00	7.32
				W16	1.15	26.00	6.90
				W17	0.12	25.00	6.21
				W18	0.84	27.00	7.03
				W21	2.15	30.00	7.99
				W22	13.5	27.00	8.23

**Table E2 showing distribution of fluoride, temperature and pH in the upland and lowland in the rainy/wet season.**

Upland				Lowland			
No	F <sup>-</sup> (ppm)	Temp (°C)	pH	No	F <sup>-</sup> (ppm)	Temp (°C)	pH
B10	2.00	27.00	7.47	B1	36.00	31.00	8.57
B11	2.50	27.00	7.60	B2	6.40	29.00	8.42
B12	10.00	28.00	7.98	B3	2.00	29.00	7.60
B13	3.90	28.00	7.77	B4	2.30	29.00	7.50
B14	2.10	27.00	7.82	B5	2.90	27.00	7.90
B15	1.90	27.00	7.54	B6	2.00	28.00	7.10
B16	3.60	28.00	7.76	B7	10.8	26.00	7.62
B17	5.90	28.00	7.66	B8	4.10	28.00	7.74
B20	3.00	28.00	7.34	B9	3.20	28.00	7.28
B21	3.40	28.00	7.92	B18	2.20	28.00	7.63
B22	2.80	27.00	7.40	B19	1.90	26.00	7.52
B23	3.60	27.00	7.71	W1	4.80	26.00	7.12
B24	3.60	26.00	7.56	W2	10.50	27.00	7.95
B25	4.30	26.00	7.20	W3	0.11	30.00	7.77
B26	2.50	27.00	7.26	W4	3.80	30.00	8.20
B27	2.00	27.00	7.72	W5	0.21	26.00	6.46
B28	1.40	27.00	7.36	W6	0.60	26.00	7.44
W19	7.30	27.00	8.13	W7	3.90	27.00	7.82
W20	5.40	27.00	8.37	W8	0.84	25.00	7.68
W21	0.66	26.00	6.87	W9	12.00	26.50	7.94
W23	4.10	28.00	7.98	W10	5.90	28.00	8.04
W24	1.45	25.00	7.67	W11	4.30	27.00	7.86
W25	4.20	26.00	7.40	W12	3.20	26.00	7.85
W26	0.66	26.00	6.87	W13	8.30	28.00	7.84
				W14	0.45	25.00	6.78
				W15	0.88	26.00	7.65
				W16	1.20	25.00	7.42
				W17	0.11	25.00	6.21
				W18	0.77	27.00	7.35
				W21	1.65	27.00	7.89
				W22	12.9	26.00	8.10
				W21	1.65	27.00	7.89



**Table F1 Descriptive statistics of fluoride concentration levels in uplands and lowlands.**

	Sample size	Range ppm	Mean ppm	Standard deviation	variance
Upland					
Dry season	24	0.84 -10.50	4.07	2.48	6.17
Rainy season	24	0.66 -10.00	3.43	2.09	4.37
Lowland					
Dry season	30	0.12 -24.50	5.05	5.32	28.34
Rainy season	30	0.11 -36.00	4.85	6.82	46.51

**Table G1 showing fluoride concentrations at different depths**

	Depth (m)	F DRY (ppm)	F WET (ppm)
B1	64.00	24.50	36.00
B5	130.00	2.98	2.90
B8	52.00	12.00	10.80
B9	92.00	4.80	3.20
B12	68.00	10.50	10.00
B13	52.00	4.20	3.90
B14	67.00	2.50	2.10
B15	46.00	1.97	1.90
B16	90.00	3.80	3.60
B17	70.00	6.80	5.90
B18	83.00	2.70	2.20
B20	85.00	3.50	3.00
B21	61.00	3.50	3.40
B22	60.00	3.40	3.80
B24	65.00	4.40	3.60
B25	60.00	5.00	4.30
B26	100.00	2.60	2.50
B27	53.00	2.40	2.00
B28	75.00	1.80	1.40
W1	23.00	5.80	4.80
W2	18.00	7.60	10.50
W3	10.00	0.28	1.10
W4	10.00	4.20	3.80
W5	10.00	0.32	0.21
W6	10.00	0.58	0.60
W7	12.00	4.40	3.90
W8	10.00	1.10	0.84
W9	-	12.00	12.00
W10	13.00	7.00	5.90
W11	15.00	12.00	4.30
W12	12.00	3.80	3.20
W13	13.00	9.00	8.30
W14	10.00	0.33	0.45
W15	7.00	0.94	0.88
W16	30.00	1.15	1.20
W17	12.00	0.12	0.11
W18	15.00	0.84	0.77
W19	7.00	8.20	7.20
W20	6.00	6.20	5.40
W21	6.00	2.15	1.65
W22	8.00	13.50	12.90
W23	10.00	7.80	4.10
W24	5.00	1.71	1.45
W25	8.00	4.60	4.20
W26	12	0.84	0.66

## APPENDIX II

### **Defluoridation of water**

Defluoridation is the removal of fluoride in water. As discussed earlier most of the waters in the study area contain excessive amounts of fluoride. Several methods have been described in literature by several authors for removal of fluoride from drinking water, but only a few are in practice. This is due to several shortcomings in the treatment when moving from laboratories to the “real world”. The suitability of a method depends on the settings in which defluoridation plants are used. Defluoridation in remote rural settings requires another approach than in a water work for a big city. Factors to consider when selecting defluoridation method are as follows:

- I. Should be efficient that is should reduce fluoride levels to acceptable levels  
(Typically below 1.5ppm).
- II. Should be cheap both with regard to establishing the plant and the running cost.
- III. Running of the plant: level of required supervision, dependency of electricity, complexity of operation e.g. dosing of chemical
- IV. Possible safety hazards: handling of dangerous chemicals, consequences of wrong dosing, inefficient fluoride removal, and possible chemical residual in the treated water.
- V. Supply of chemical for defluoridation

No individual method is the best on all point and the choice of method is therefore dependent on the local possibilities. Various methods of defluoridation have been suggested and these are discussed below:

**a) Blending with low fluoride water.**

This is the mixing of high fluoride concentrated water with low fluoride concentrated water to obtain the optimal limit. It is the cheapest and simplest method where no chemicals or experts are required. River waters have less than 0.5ppm fluoride (Njenga 1982) while borehole waters have more than 1.5ppm. The two can be mixed in appropriate ratios in order to make the fluoride concentration of 1ppm.

**b) Reverse osmosis**

In reverse osmosis the water pass through a membrane that holds back some of the salts (e.g. fluoride) in the water. The efficiency of the process is both  $pH$  and temperature (Rubel 1978, 1983). Commercially available membrane is often cellulose-based; nylon is also used. Practical implementation of this process is more complicated due to the relatively high pressure required to force the water through the membranes. Also it is often required to do the osmosis on several steps. This method must be regarded as quite high tech and are probably only suitable for large water works.

**c) Nalgonda method**

In the Nalgonda method, alum and lime are added to raw water, fluoride is attached to the flocks of aluminium hydroxide, which are formed and can be removed from the water with the precipitated flocks. The method involves adding in sequence sodium aluminate or lime and then filter alum (Nawlkhe1975, Tjiiook1983). The method is cheap and can be implemented for household and large water works.

#### **d) Activated Alumina**

Gravels of activated alumina can be used as a media for an ion exchange of hydroxide and fluoride ions (Singh and Clifford 1979, Choi and Chen 1979). Activated alumina is a special form of acid treated alumina. Control of optimum pH at 5-6 is important. Fluorides are absorbed from water while hydroxide is released into the water. By raising the pH values in water the process can be reversed. Fluoride can be reduced to practically any desired level.

#### **e) Use of synthetic bone.**

The material is made by reacting phosphoric acid with lime to produce tricalciumphosphate and hydroxyapatite (synthetic bone). The use of synthetic bone for defluoridation has been referred to quite often in literature. The mode of action is thought to be that it combines with fluoride to form fluoroapatite. For the formation of this compound the calcium ions must be in excess. Boiling is necessary to increase defluoridation. Njenga (1982) used the method using Lake Elementaita water sample containing 1000ppm fluoride, after the experiment, fluoride concentration reduced to 660ppm. The method is considered successful if it can be used on large scale and with water having low alkalinity (Ndegwa 1980)

#### **f) Treatment with charcoal**

Charcoal is first soaked in 2% alum then left to stand for 12 hours; removed, washed and dried. When water containing fluoride is passed through this media, a considerable amount of fluoride is removed. This method of treatment is not cheap (Njenga 1982).

**g) Bone-char.**

Bone-char or bone-char gravels are bones which have been heated to high temperatures (above 400<sup>0</sup>c) and crushed. In the process all organic material has been removed and only the mineral apatite is left. Due to its porous structure this material is able to absorb high amount of fluoride (Maier 1960). This method is currently being used by the Catholic Diocese of Nakuru water quality program to defluoridise bore hole waters. However presence of arsenic in water interfere with the effectiveness of the bone-char, since arsenic is very readily adsorbed and causes irreversible changes in the structure of the bone-char ultimately rendering it useless (U.S. EPA 1983)