ANTHROPOGENIC INFLUENCE ON SURFACE AND GROUND WATER QUALITY IN LAKE NAKURU BASIN, CENTRAL KENYA RIFT VALLEY

By

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Reg No: I56/8527/06

Dissertation submitted in partial fulfillment of the requirements for the degree of Master of Science in Geology (Environmental Geology and Management).

August 2012

DECLARATION

I hereby declare that this dissertation is my original work and has not been presented for a degree to any other university or for any other award.

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ABSTRACT

Lake Nakuru basin is located in Nakuru district in the Central Kenya Rift. The study area extends between the bounds of 35° 50' 35'' E to 36° 15' 47.5'' E and 0° 09' 21.8'' S to 0° 42' 56.5'' S The study area is divided into three sub basins namely Nakuru West, Nakuru East and Nakuru North. Nakuru West is generally endowed with a lot of streams traversing it and it contributes a large part of the catchment area that drains into Lake Nakuru. The hydrology of the study area is dependent on the catchment supply through rivers.

The objective of this study was to determine spatial variation of chemical (Na, K, Mg, Ca, NO_3 SO_4, Cl and HCO_3) and physical characteristics (pH, TDS and Conductivity) of surface and groundwater quality and the sources of pollutant (SO_4, Cl and NO_3) in relation to human activities/, soil and geology of Lake Nakuru basin. The approach involved chemical and physical analyses of major ions. A total of 51 deep boreholes, 3 shallow boreholes, 3 springs and 21 river samples were collected and analyzed for the major ionic composition. The data was analyzed and interpreted using SPSS, AquaChem and ArcGis computer programs.

The results indicate that chemical composition of dissolved ions are in the increasing order of Na^+, K^+,Ca^{2+}, Mg^{2+} (cations) and HCO_3^-, Cl^-, SO_4^{2-}, NO_3^- (anions) for both surface water and groundwater. Groundwater is characterized by average mean of 403.99 mg/l TDS, 823.20 µS/cm conductivity and 7.68 pH. Surface water on the other hand is characterized by mean 287.85 mg/l TDS, 577.67 µS/cm and 7.65 pH.

From the results it is deduced that there is spatial variation in composition of water resources in the study area. Surface water is Na-HCO_3 to Na-Cl facies whereas groundwater is Na-HCO_3 to Na-Cl-SO_4 type in the study area. Both surface water and groundwater are fresh and alkaline. Anthropogenic sources of pollution have greatly affected surface water as compared to groundwater. The origin of major ions in groundwater is mostly attributed to weathering of silicate rocks, natural process through precipitaion and anthropogenic contribution is significant. The non-point source of pollution of groundwater in the study area is hydrothermal discharge from hydrothermal zones (Menengai Crater) through sub-surface faults and fractures. Sewage discharge points and outlet of industrial waste are infered to be the point source whereas surface run off of

loose soils adsorbed with nitrate compounds during rainy seasons from agricultural farms are the non point source of pollution of surface water.

It is recommended that interconnection between surface and groundwater should be determined. This will be helpful in future monitoring by giving information on how pollutants move in the environment and extent of water pollution. This is done by injecting a trace element into one of the rivers (e.g river Njoro at its source) in the study area whose flow is structurally controlled. The point along the river into which the element is injected acts as a reference point. The movement of the tracer element to groundwater will be monitored by analyzing samples from the boreholes. Samples that will be found to contain the tracer element in their composition are likely to be interconnected. The above process can be repeated to the other rivers one at a time until the interconnection is determined.

ACKNOWLEDGEMENT

This study would have not been possible without the full scholarship awarded to me by the International Center for Training and Exchanges in the Geosciences (CIFEG - France) through MAWARI project. I sincerely appreciate opportunities to participate in trainings and attachments organized through MAWARI Project without which I could not have come this far.

I deeply appreciate the assistance and continued guidance I have received from my supervisors, Dr. D. Olago and Dr. C. Nyamai. for the relentlessly guidance during fieldwork planning, data analyses and write-up of the dissertation. Your patience, guidance and constructive inputs greatly added value to this study. I am also deeply grateful to Prof. Barongo, the chairman of MAWARI Kenya for being there for me during planning and implementation of the fieldwork schedule. My sincere gratitude to Geology Department fraternity, teaching and non-teaching staff, for training me in this discipline of Geology.

Lastly but not least, I offer my sincere regards to all those who supported me in any aspect during the compilation of this dissertation. To my family, you gave me the motivation and love that i greatly needed during this time. And above all, praise be to God for giving me sound health to accomplish this Msc. Dissertation.

DEDICATION

To my husband (Nehemiah), parents (Dismas and Ann), sisters and brother.

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LIST OF ACRONYMS

µS/cm	Micro Siemens per Centimeter
BH	Borehole
CDN	Catholic Diocess of Nakuru
CIFEG	Centre International pour la Formation et les Exchange on Geosciences
COD	Chemical Oxygen Demand
DDT	Dichloro Dephenyl Trichloro-ethane
EDTA	Ethyl Diamine Tetra Acetic
EU	European Union
EPA	Environmental Protection Agency
GPS	Geographic Positioning System
ITCZ	Inter Tropical Convergence Zone
MAWARI	Management of Water Resources in the East African Rift system.
Mg/l	Milligram per litre
MPN	Most Probable Number
N	Number of variables
NEMA	National Environment Management Association
TDS	Total Dissolved Solids
US EPA	United States Environmental Protection Agency
WHO	World Health Organization
WWF-LNCDP	World Wide Fund for Lake Nakuru Conservation and Development Project.

CHAPTER 1 : INTRODUCTION

1.1 Background Information

Lake Nakuru catchment basin is a closed drainage system covering an area of 1800km^2. Menengai crater lies to the north, Bahati highlands to the north east, Mau escarpment to the west and Eburru crater to the south.

Fresh water lakes in Kenya namely Lake Victoria, Lake Nakuru and Lake Baringo basins are threatened due to increased encroachment of human population on the catchment areas and the associated socio-economic activities.

The increasing human population in both urban and peri-urban regions of Nakuru catchment has led to diverse farming activities to satisfy food requirements Another trend towards food satisfaction is the conversion of forests to agricultural lands underlying aquifers. As a result there is a net increase in eroded particles to surface waters. Rivers mobilize dissolved substances, suspended particles and organic matter from terrestrial systems to lakes (Allan, 1995). Agricultural land use without environmental safeguard to prevent over application of agrochemicals is causing widespread deterioration of water ecosystem. The land use change dramatic in itself has brought even greater social changes in the rise in population of estates laborers and their dependants. There is now an urgent need to accurately measure what is actually happening to the water pollution of the area.

Waste management remains a great challenge to sustainable management of Lake Nakuru watershed. Only a small section of Nakuru Municipality is covered by conventional sewerage systems, where treatment works broke down ten years ago. Therefore, waste disposed from the sewerage system remains a potential source of pollution to both surface and groundwater.

A lot of effort has been directed towards the exploration and exploitation of groundwater in the area. Also the rapid population increase and agricultural activities, which involve intensive use of fertilizers within Lake Nakuru basin is threatening the safety of groundwater and surface water. All these factors are likely to introduce contaminants into the groundwater system thus making it unsafe. This important resource must therefore be protected at all costs.

The wide lake catchment area by contrast comprises land tilled for subsistence and cash crops with rough pasture. There is evidence that land use practices in this wide catchment may compromise the quality of the lake and rivers as well as the long-term viability of this form of small-scale farming. Lakes are influenced by the natural and human characteristics of their catchments. Geochemical surveys of lakes sediments are increasingly being used in environmental investigations in assessments of water quality. It can also provide a geochemical baseline against which any future occurrence may be appraised.

Rising populations and declining environmental concern mean that substantial challenge are posed to water resources due to the increase in anthropogenic activities in such areas. This challenge is heightened in developing nations characterized by fast growing populations and increasing expectations of material quality life. The challenge is nowhere more intense than in vulnerable yet productive wetland areas, such as Nakuru. It is this challenge that the present project intends to address by way of carrying out the water quality study in order to establish the pollution status of Lake Nakuru basin.

1.2 Literature Review

Kulecho and Muhandiki (2005) noted high nutrient loading in the north and south of the lake with a yearly input load of 40401t/yr (Table 1.1). Gichaba et al (2005) found out that river Njoro loaded most suspended solids (70%) to Lake Nakuru followed by Makalia (21%), Nderit (4%), Sewage drain (4%) and finally Baharini Spring brook (1%).

Table 1.1: Selected stream input loads (tons/yr) to Lake Nakuru from 2001 to 2002 (After Kulecho and Muhandiki, 2005).

Stream	Suspended solids	Total Phosphate	COD	Total Nitrogen	Other inputs	Total load
Sewage drain	50	2.98	122	40.48	1164.22	1380
Baharini Spring	3	0.34	248	3.7	640.96	896
R. Nderit	541	1.75	548	25.0	1107.25	2223
R Makalia	1852	10.54	168	56.6	7086.86	9174
R Njoro	200	20.88	712	176	26984.12	28093
Total load	2646	36.49	3096	302	36982.42	40401

The findings on Njoro, Makalia and Nderit are due to the fact that they drain large catchment areas dominated by agricultural activities and urban run-off. Baharini Spring originates from within the Lake Nakuru National Park and therefore does not pass through disturbed areas and hence has very little chance of collecting pollutants.

Changes in climate and land use pattern (massive deforestation and increased habitation in the uplands) have induced the reduction of flows into Lake Nakuru. The proportion of annual precipitation and annual run-off volume of each sub-basin within Lake Nakuru watershed is indicated in Table 1.2. Evapotranspiration from the basin accounts for 96.8% of the annual basin rainfall. Only 3.2% of the annual rainfall is available to recharge the basin (Raini, 2005).

Table 1.2: Annual precipitation and run-off volume of each sub-basin in Lake Nakuru catchment (Data after Raini, 2005)

Sub basin	Annual precipitation (mm)	Annual run-off volume (%)
Njoro	29	39
Nderit	23	13
Makalia	17	21
Ngosur	17	23
Larmudiac	6	1
Lion Hill	8	3

Vareschi (1982) found out that the lake had a mean depth of 2.5m, a maximum depth of 4.5m and a water volume of about 92 x 106 m^3 from 1925 to 2002. This changed to a mean depth of 1.01m, water volume fluctuating between $10m^3$ x 107 when the lake dried almost completely to about $18m^3$ x 107 during the 1997/1998 El Niño floods. The change occurred between 1992 and 2002. Kulecho and Muhandiko (2005) also noted the variation in mean lake level from 2001 to 2004 (Figure 1.1).

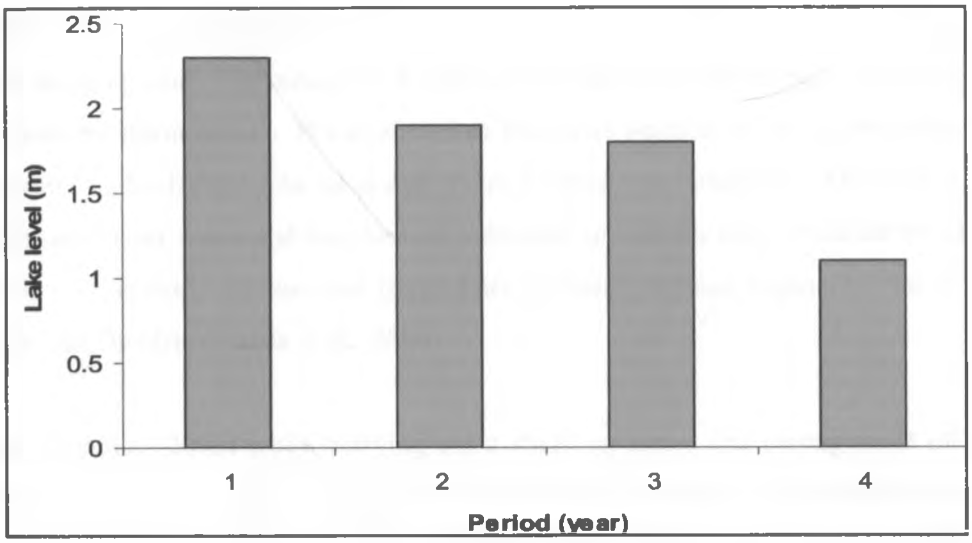

Figure 1.1: Lake levels during 2001 – 2004 (After Kulecho and Muhandiko, 2005) Note: x - axis, 1-4 = 2001 – 2004.

Surveys of benthic macro invertebrate communities in catchment streams of Nakuru indicated a progressive simplification in community structure from river head waters to their discharge point in the lake. This is attributed to alteration of stream flow and river bed substrate as a result of siltation, loss of canopy cover and toxic effects of pesticide residues and heavy metals (WWF – LNCDP, 1998). Greichus et al (1978) cited in Gitahi et al (2002), examined the levels of chlorinated hydrocarbon insecticides and metal in tissues of birds and fish from Lake Nakuru. They concluded that these were very low and that the metals did not present a major problem to the fish and birds. Relative to other Kenyan rift valley lakes, Lake Elementaita, Baringo and Naivasha, the fish in Nakuru had the highest DDT.

Lake basins in developing countries are facing various environmental issues such as deterioration of water quality, reduction of water volume and increased toxicity of inhabiting organisms. These problems largely arise from the cumulative impacts of human activities taking place within the basins in excess of the lakes' capacity to buffer and negate the adverse effects (Odada et al., 2003). Oketch (2005) mentioned that catchments areas in Kenya, Lake Nakuru basin being one of them are threatened due to encroachment of human population and is worsened by the fact that mushrooming industries, towns and institutions have inadequate or non-functioning waste treatment facilities. As a result there is increased discharge of untreated or partially treated waste into the ecosystem.

About 9000m^3 of sewage is generated each day in Nakuru town, only 60% of this sewage is moved to approved dumping sites. The remainder accumulates in the environment and eventually ends up in lakes and rivers by storm waters. Pre-treatment of industrial waste is an exception rather than a rule and storm water is discharged into lakes and rivers without prior treatment (Mbagwa et al., 1998). Recent analysis of river water and lake bottom sediments in Nakuru basin revealed enrichment with heavy metals and pesticide residues and farmers are still using banned organochlorine pesticide e.g. DDT, Aldrin and Dieldrin (Odada et al., 2006).

Junjiro and Masahisa (2005) while carrying out a study on status and management of world lake basins mentioned that major anthropogenic activities that are potential lake environmental stressors in upper basin areas are deforestation associated with timber harvesting or land use conversion and agricultural practices including grazing. These activities induce alteration of hydrological processes (i.e. reduction of ground water recharge), excessive soil erosion and runoff of agro-chemicals applied to cultivation fields. He found out that Lake Nakuru basin was threatened by deforestation, agriculture and water abstraction (Table 1.3).

Table 1.3: Co-occurrence of activities in basin areas identified for 27 lakes (modified after Junjiro and Masahisa, 2005)

Identified human activities in basin areas	Percentage (%)	Number of lakes (n)
a, b and c	25.9	7 [1,2,3,4,6,10,11]
a and b	48.1	13 [7,8,9,14,15,16,17,20,21,22,23,24,27]
b and c	0	0
a and c	0	0
Only a	0	0
Only b	25.9	7 [5,12,13,18,19,25,26]
Only c	0	0

NB: Table 1.3 shows Co-occurrence of activities in basin areas identified for 27 lakes; the processes are a-deforestation, b-agriculture, and c- water abstraction. Superscript numbers denote the lakes for which respective sets of activities were identified [1]Nakuru, [2]Baringo, [3]Naivasha, [4]Malawi, [5]Kariba, [6]Chad, [7]Victoria, [8]Tanganyika, [9]Xingkai, [10]Dianchi, [11]Toba, [12]Tonle Sap, [13]Bhoj wetland, [14]Chilika Lagoon, [15]Laguna de Bay, [16]Aral Sea, [17]Baikal, [18]Biwa, [19]Titicaca, [20]Cociboica, [21]Ohrid, [22]Peipsi, [23]Issyk-kul, [24]Sevan, [25]Constance, [26]Champlain, [27]Great Lakes (Laurentian), (after Junjiro and Masahisa, 2005).

A water quality monitoring programme conducted by Raini (2005) in Lake Nakuru and its influent streams indicated mean high water temperature, pH, dissolved oxygen and conductivity in the lake and at the mouth of the influent streams (Table 1.4).

Table 1.4: Mean values of water quality variation at influent streams to Lake Nakuru for the period 1993 – 2003 (modified after Raini, 2005).

Sampling site	pH	Temperature (°C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/l)
Lake shore gauge	10.0	25.9	30.2	7.2
Lake shore drum	10.2	27.6	44.0	9.4
R Njoro mouth	9.8	26.9	33.0	6.9
R Makalia mouth	10.1	27.4	32.1	10.2
R Nderit mouth	10.0	27.2	27.6	8.0
Kampi ya Nyati	10.3	26.9	44.7	8.7
Baharini spring	9.0	25.6	0.5	7.6
R Njoro	8.1	20.2	0.7	9.3
R Makalia	8.2	20.3	2.6	7.3
R Nderit	8.0	22.4	0.5	7.5
Town sewage	8.0	23.0	1.1	11.2
Njoro sewage	8.8	21.7	1.9	7.5

1.3 Problem statement

Anthropogenic activities results in habitat modification which impact on hydrological regimes, resulting more often in degradation of water quality and quantity. This impairs the health of the aquatic system. Settlement in the catchments has resulted in extensive problems following accelerated nutrient inputs (Thornton, 1987).

Land use in Nakuru watershed has been changing since the beginning of the last century following large scale settlement on the middle reaches of the watershed by colonial farmers and later in the 1970's and 1980's by Kenyan farmers on former white settler farms and adjacent forest reserves in the upper reaches. The effects of these land uses on water quality have never been investigated (Shivoga et al., 2005). Groundwater and surface water in Lake Nakuru basin have a large variation in their physical and chemical attributes. Analyzed samples from some boreholes and rivers have several faecal and general coliform bacteria. Gore and Shields (1995) stated that running water ecosystems are intimately tied to physical, chemical and biological processes that occur throughout the catchments. Therefore it is important to use physical, chemical and biological measurements to characterize water quality (Simon, 2003).

In the recent past the catchments areas of Lake Nakuru basin have experienced a lot of deforestation (Mau and Bahati forests) due to fertility of the areas that has attracted agriculture. Karanja et al. (1995) mentioned that catchment areas of Nakuru are located in high potential agricultural areas and most of the rivers in the basin originate from these forests. The earth is left bare to be easily carried away by rain in form of run-off. Run-offs are enriched in phosphorus and nitrogen as the commonly used chemical fertilizers in these farms.

Lake Nakuru is increasingly becoming degraded through expansion of agriculture and industrialization to sustain the requirements of population growth. Expansion of agriculture and industrialization is slowly technologically driven. As dependence on technology increases, likewise is the contribution to pollution (Alloway and Ayres, 1997). There is extensive use of fertilizers in order to increase agricultural productivity to meet population demands for foods and industrial products need, (Gitahi et al., 2002). The demand for organochlorine pesticides has been increasing in some developing countries in Africa, Latin America and Asia (Tanabe et al., 1993). There has been widespread use of pesticides in Kenya in the last four decades because agriculture has been the mainstay of Kenya's economy.

Organochlorine has been extensively used and particularly, DDT and Endosulfan for the control of maize and cotton pests (Munga, 1990). Lindane, Dieldrin, Aldrin, Endrin and Heptachlor have also had wide usage in Kenya, which has made their presence ubiquitous in the environment (Wandiga, 1996). Dregne (1990) and Downing et al (1990) agree that a sustainable level of food production is possible only by achieving better agricultural yield with current land resources and not by extending cultivation on marginal lands. This means that an increase in agricultural yield is possible only if pathways of phosphorus cycling are changed by a greater phosphorus uptake by crops. A study of major sources and sinks of phosphorus and other nutrients in different agro-ecological zones in Kenya (Smaling, 1993) suggested that human intervention in nutrient cycles in modern Africa may be a cause of excessive enrichment in surface waters.

Some industries situated along rivers in Nakuru district empty their partially treated effluents into the rivers thereby changing their chemistry. One of the effects of effluent in water is eutrophication. The nutrients in these effluents cause a detrimental aesthetic effect and increases excessive growth of algae which cause depletion of dissolved oxygen (Twort et al., 2000).

Adverse development in catchments is widely recognized as a major contributor to degradation of water quality (Everard et al., 2002). This is a major concern in lake basins like Lake Nakuru whose simple ecosystem can easily be shifted into a new equilibrium that may not be sustainable. Since Lake Nakuru basin is a closed hydrologic system, pollution tends to accumulate there, and once water is polluted, it is difficult to improve the water quality.

1.4 Justification and Significance

Water must be in a sound condition in every aspect. Strong evidence exists to demonstrate that the ecological integrity of Lake Nakuru is dependent on the rationale and sustainable utilization of resources within its catchment basin (Mavura and Wangila, 2000). Water quality is a critical aspect of lake management that must be monitored and managed. Therefore reliable information on the status of the catchment and its water resources need to be known for decision making.

Rapid population growth, urbanization and agricultural activities in Nakuru basin have put enormous pressure on its resources and the catchment area. In a drainage basin scale, downstream movement of water from high elevation mountains, through settled and agricultural land, link the terrestrial and aquatic ecosystems resulting in a net downstream movement of materials. Since running waters integrate watershed characteristics and receive pollutants from land and the air, water quality measurements are good indicators of changing environmental and ecosystem conditions in a watershed. Recent analysis of river water and lake bottom sediments in Nakuru basin revealed enrichment with heavy metals and pesticide residues and farmers are still using banned organochlorine pesticide e.g. DDT, Aldrin and Dieldrin (Odada et al., 2006).

Suspended solids from terrestrial systems are good scavengers for heavy metals and are likely to be transported together from industrial sources and solid waste dumping sites (Arruda et al., 1988). In order to protect water resources we need to understand the activities on the watershed and the state of surface water bodies.

Raw sewage is discharged into lakes and rivers. Agricultural activities, industrial process and service providers are major polluters of the environment resulting in high levels of waterborne and respiratory diseases.

Past researches have concentrated in the lakes environment. This is a departure from the past trend. The efficient management of lakes entails taking into cognizance processes occurring beyond its littoral fringe (Raini, 2005). Strong evidence exists to demonstrate that the ecological integrity of lakes is dependent on the sustainable utilization of resources within its catchment basin. Water quality is a critical aspect of lake management that must be monitored and managed. Reliable information on the status of the catchment and its water resources needs to be made available to decision makers and the community on a timely and regular basis.

This study will assist in understanding the current environmental status of the catchments of Lake Nakuru basin and further come up with maps and charts that can be useful in future monitoring programs.

1.5 Aim

The aim of the study is to determine the degree or extent of impact of human activities on the surface and groundwater in Lake Nakuru basin.

1.6 Objectives

The specific objectives are:

- Determine the spatial variation in chemical (Na, K, Ca, Mg, NO_3, SO_4, Cl and HCO_3) and physical (TDS, pH and conductivity) characteristics of surface water and groundwater quality.
- To determine the sources of anthropogenic pollutants (Cl, SO_4 and NO_3).

CHAPTER 2 : DESCRIPTION OF THE STUDY AREA

2.1 Location

Lake Nakuru basin is located in Nakuru district in the central Rift Valley. The study area extends between the bounds of 35° 50' 35" E to 36° 15' 47.5" E and 0° 09' 21.8" S to 0° 42' 56.5" S (Figure 2.1).

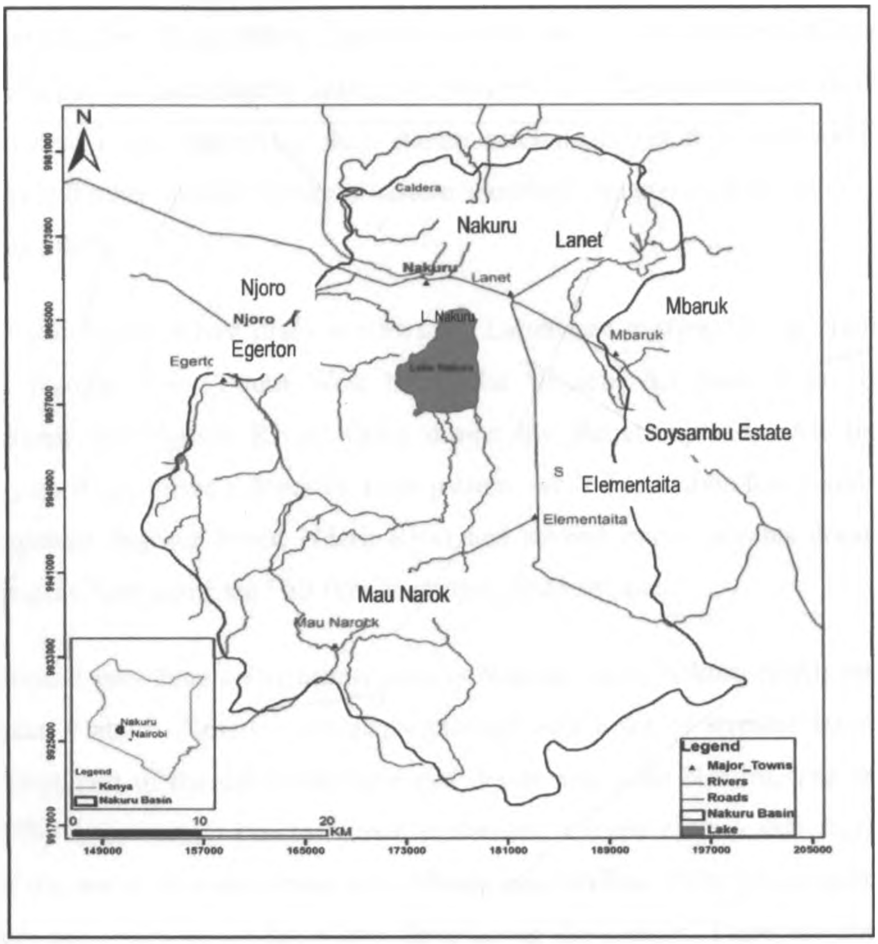

Figure 2.1: Location map of the study area

Lake Nakuru basin is a closed drainage system covering an area of 1800km^2. To the western side the basin is bounded by east dipping normal faults of Mau escarpment. To the east, the basin is bordered by west dipping faults that separate the intra-rift Bahati – Kinangop plateau from the eastern rift shoulders. The northern boundary comprises the Menengai caldera. To the south, Eburru volcano separates the Nakuru-Elementaita from the Naivasha basin.

2.2 Hydrology

The Nakuru basin is characterized by very poor run off due to the porous nature of the formations which mantle the older rocks surfaces. Its hydrology is dependent on the catchment supply through rivers (Figure 2.2).

Seasonal rivers (Njoro, Ngosur, Makalia, Naishi, Larmudiac and Nderit) drain into the lake and some of these rivers (Njoro, Ngosur and Naishi) become influent, disappearing along the fault lines to recharge deep aquifers. River Nderit disappears into a swampy area covered by acacia trees near the lake but recharges the lake directly during wet seasons. The Baharini springs also feeds the lake, where it is believed to be originating from Bahati catchment area through underground stream. Baharini springs and other springs along the eastern shoreline (emanating from Lion's Hill ridge) are perennial (Raini, 2005).

Makalia River and Nderit River drain northwards, Larmudiac eastwards and Njoro River south eastwards and Ngosur River South West into Lake Nakuru. All these rivers drain the Mau Escarpment except the Ngosur River which drains the Bahati uplands. All these rivers are intermittent. Njoro River forms a dendritic river pattern, while Larmudiac River and Makalia River have a trellis pattern. Ngosur River, Nderit River and several minor streams draining the Bahati uplands, Menengai Crater and Lion Hill flow in straight lines streams.

The basin is divided into three water basins namely Nakuru West, Nakuru North and Nakuru East. Among the three, Nakuru West is generally endowed with a lot of streams traversing it and it contributes a large part of the catchment area that drains into Lake Nakuru. The area is seriously being affected by deforestation due to human settlement. On the eastern side there are very few rivers. Most of the water sources consist of boreholes and shallow wells. In the northern side there are few streams and rivers which have little flow during dry season. There are about 360 drilled boreholes in the area (CDN, 2005).

Enormous amount of groundwater exists on the floor of the rift valley. Its abstraction is influenced by the ramps of faults and fractures on the floor. The marginal rift faults and the system of grid faulting on the Rift floor undoubtedly have a substantial effect on the groundwater flow systems of the area. In general faults are considered to have two effects on fluid flow. They may facilitate flow by providing channels of high permeability, or they may prove to be barriers to flow by offsetting zones of relatively high permeability.

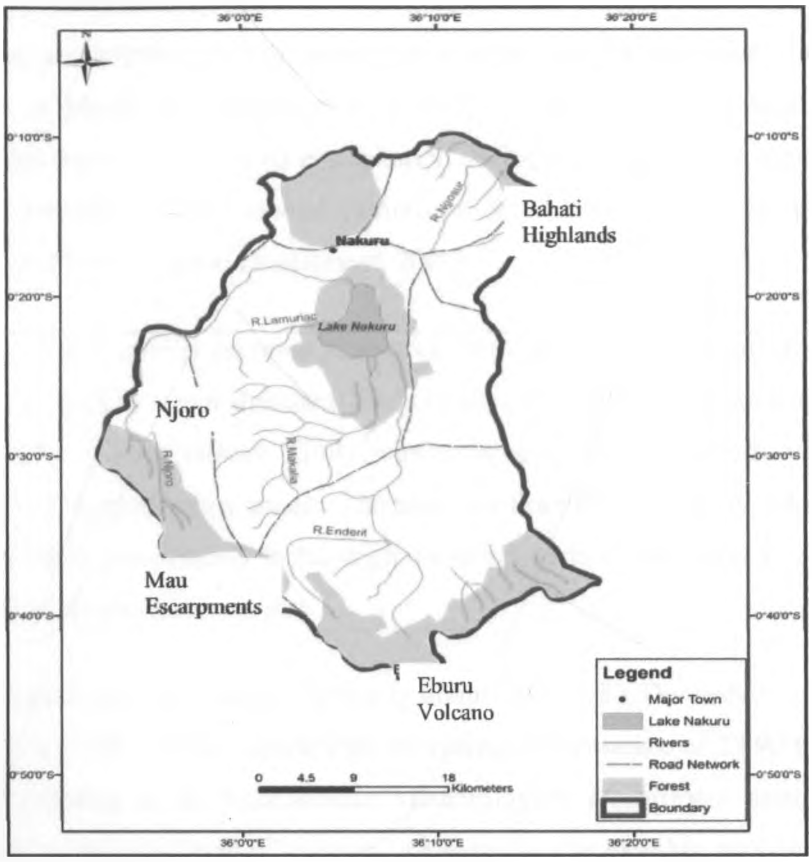

Figure 2.2: Map showing Lake Nakuru Drainage Basin

Groundwater flows are generally directed towards the lakes. Some flow away from the area to the North West, North East from the Mau Escarpment, South West from the Bahati escarpment and North Ward from Eburru. It is also probable that there is some southerly flow from Menengai towards Lake Nakuru. However at depth it is likely that flow occurs to the North East away from the Nakuru and Elementaita catchment towards the lower lying catchment around Lake Bogoria.

Porous and permeable surfaces provide for percolation of runoff, leading to potentially high ground water storage such as swampy depressions of Solai, Olobanita, volcanic centres of Eburru and fault blocks of Subukia. These influence the movement and accumulation of surface and sub surface waters, and subsequently groundwater flow patterns. Plains around Lake Nakuru (Kiwi and Kwa Rodha) have very low drainage density.

2.3 Climate and Rainfall

The climate ranges from cold and humid to arid and semi-arid typical of the Rift Valley floor. Climate is strongly influenced by seasonal migration of Inter Tropical Convergence Zone, (ITCZ) and the coinciding precipitation pattern. Rainfall associated with the transition of the ITCZ follows the highland sun in March and September with a lag of three to four weeks (Nicholson, 2000). Therefore the basin receives most of its precipitation during the long rains in April to May and the short rains in November. Mean annual rainfall is 920mm/yr whereas evaporation is about 1736mm/yr (Kenya Meteorological Department, 2000)

Isohyetal analyses show general decrease in rainfall from the crest of the catchment towards Lake Nakuru, which is located in a rain shadow (Odada et al., 2006). The rainfall occurs in the afternoon as heavy storms and is quite erosive. Gully erosion is rampant in the north western part of the catchment and newly opened forest zones. The amount of rainfall is strongly linked to topography. Thus, the highest rates are obtained in the high elevation parts of the basin in the west and east, whereas the lower areas are relatively dry.

The maximum temperature in Nakuru district is about 30°C with December to March being the hottest months. July is the coldest month with an average temperature of 23.90°C (Government of Kenya, 1997). According to the East African Meteorological Department there is a temperature decrease of 0.56°C for every 100 m of increase in elevation. The monthly maximum, minimum and mean temperature data for the Nakuru ranging from 1994 to 1997 is presented in the Table 2.1

Table 2.1: Maximum, minimum and mean temperatures in Nakuru area for the period 1994 -1997 (After Graham, 1998).

Nakuru	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Mean Max	28.12	28.92	27.56	26.29	26.53	25.89	25.02	24.59	27.36	27.18	26.63	25.83
Mean Min	10.36	10.89	11.52	12.15	12.56	12.49	12.19	10.79	11.72	12.42	13.08	11.53
Mean	19.95	20.27	19.08	18.13	17.97	17.37	16.96	17.58	17.65	17.46	17.08	16.70
Highest Max	28.76	29.31	29.87	30.42	30.98	31.53	32.09	32.65	33.20	33.76	34.31	34.87
Lowest Min	9.69	9.67	9.26	11.36	11.40	11.86	10.87	5.87	9.42	10.24	10.93	6.05

2.4 Land use

Nakuru town has grown as a major commercial and industrial centre. Some of the industries include those engaged in the assembly of farm machineries, pyrethrum and food processing factories. This has seen a rapid increase of urban and peri-urban population brought about by rural to urban migration of largely young adults in search of employment.

Agricultural and dairy farming activities also take place in Nakuru. Both large and small scale agricultural activities involving cultivation of such food crops as wheat, maize, potatoes and beans are practiced (Figure 2.3). Farming of cash crops such as pyrethrum, coffee and sisal also take place in the area. Dairy farming involving rearing of grade cattle is practiced as well.

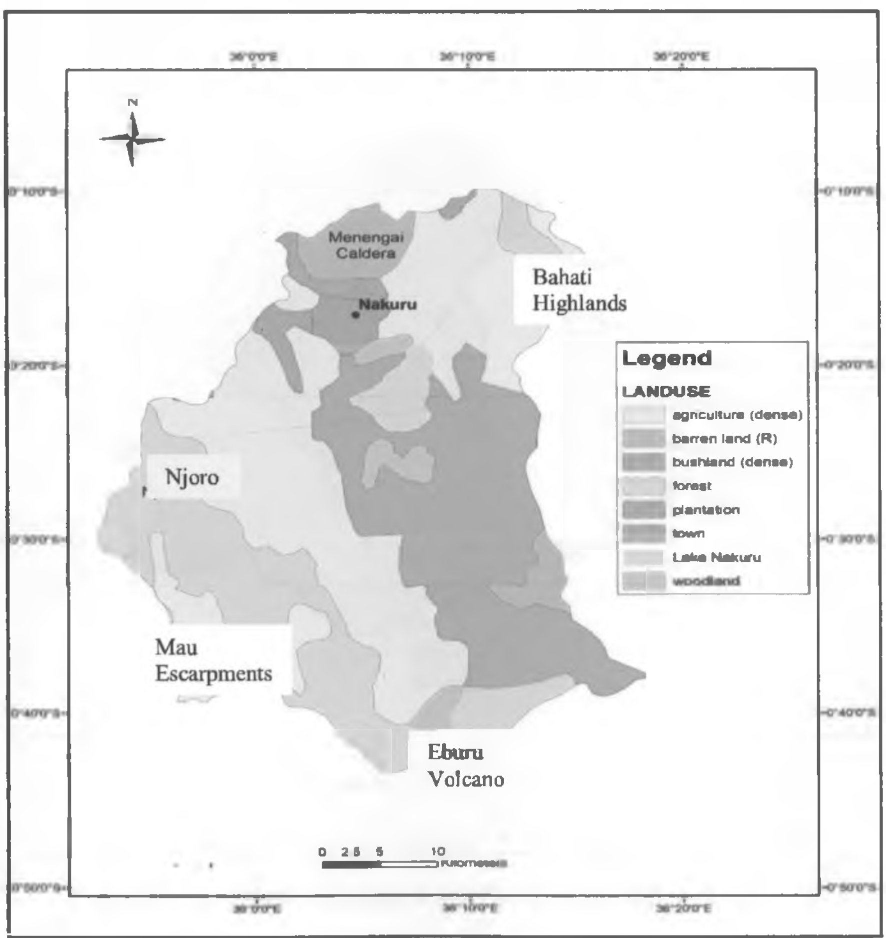

Figure 2.3: Map showing land use within the basin.

2.5 Geology

The geology of the basin poses a great risk to water quality variably depending on its chemical constituents. This can have negative impacts on the sustainable development of the resource, and can result to negative impacts on long term social and economic development. The geology consists of volcanic rocks (lava flows and pyroclastics) of the Tertiary Quaternary age, which has been affected by a series of faulting (Thompson and Dodson, 1963). The major volcanic rocks include trachytes, phonolites, pyroclastics and basalts, occasionally intercalating with volcano sediments and organic sediments (Figure 2.4).

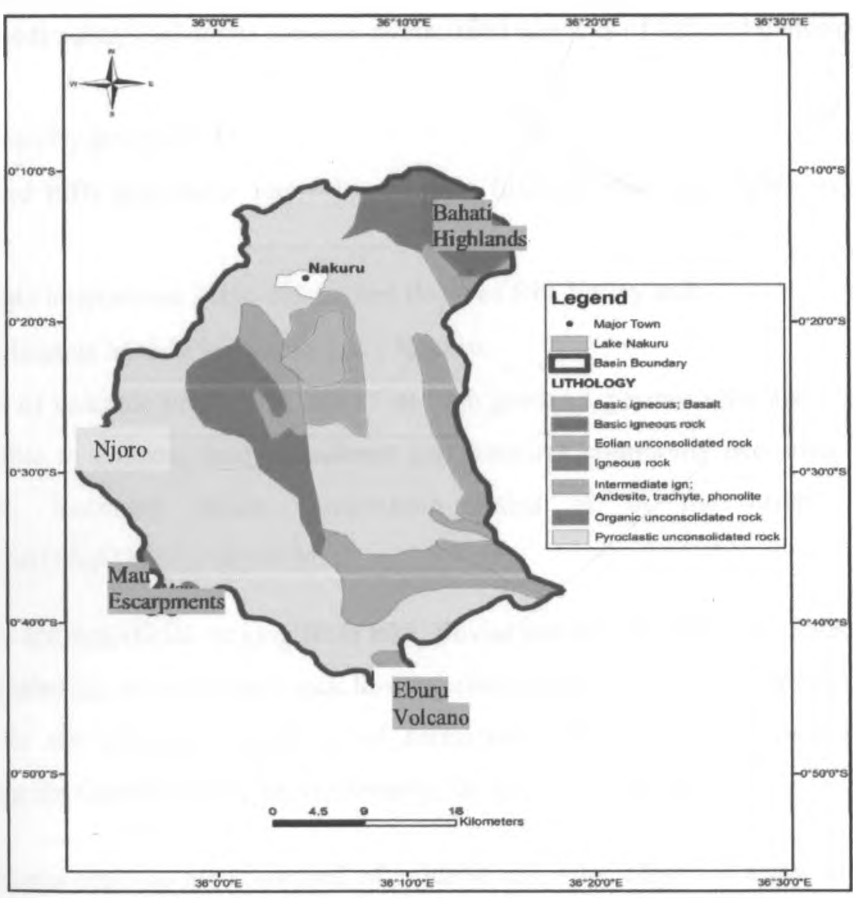

Figure 2.4: Map showing geology of the study area

Andesite, basalt, phonolite and trachyte flows are exposed in the Bahati Escarpment to the North of Mbaruk and also to the East of Lake Nakuru. The basalt often occurs with picrites. Within the basalts are minor intercalations of pumiceous tuffs, inter layered with diatomite beds which is part of the Older Miocene formation.

Phonolite and trachyte lava flows and sheets overly the Mbaruk basalt. Some of these lava sheets are exposed to the west of Lake Nakuru and those forming the Lion Hill are composed of phonolytic trachyte and are of the same age as those of Menengai (Kuria, 2002).

2.6 Soil

The next succession within the Pliocene period and overlying the phonolite and trachyte are tuffs. There are three types: welded tuffs found around Menengai crater, agglomeratic tuffs and graded tuffs with lake sediments. Sediments are seen as stratified deposits of tuff and diatomaceous silts.

The sediments can be grouped into:

- Reworked tuffs and clays, intercalated in the tuffs of Mau and Bahati exposed North of Mbaruk;
- Sediments intercalated in the old-faulted flows of Rift Valley and;
- Lake sediments of the Pleistocene Lake Nakuru.

The soil is also of volcanic origin and, due to its high porosity, permeability and loose structure, is highly susceptible to erosion, land subsidence and fractures commonly occurring during or after heavy rainfall. Sediment oxide composition ratios is in the order SiO_2 >Al_2O_3> Fe_2O_3>Na_2O>CaO>K_2O>TiO_2>MgO>MnO.

Recent deposits are superficial ranging from lake, fluvial and alluvial deposits. Soils normally result from *in-situ* weathering of the country rock forming residual deposits. The composition of these soils is controlled by the physical conditions of formation. The most widespread sediments were deposited during the Gamblian lake period towards the end of the Pleistocene.

The Gamblian Lake deposits are composed of volcanic ash, silts, clays and a few beds of diatomite. The river and lakes deposits largely comprises of reworked volcanic material or sub-aqueously deposited pyroclastics besides clay and silt (McCall, 1966).

2.7 Structures

The structural pattern of Nakuru is complex owing to the number and variety of orientation (McCall, 1966) due to numerous tectonic events and the resultant morphological features. Major faults display large scale structural domains with consistent structural style. These are associated with large accumulations of pyroclastics and trachyte lavas, intercalated with tuffs and welded tuffs (Morley et al., 1990).

Buried faults and other tectonic structures are inferred from the alignment of volcanic vents, cones, sinkhole structures seen on the satellite imagery as aligned patterns of vegetation (Figure 2.5). They often indicate the path of the drainage lines, linear fractures or permeable lithology alternating with impermeable lithology (Onywere, 1997).

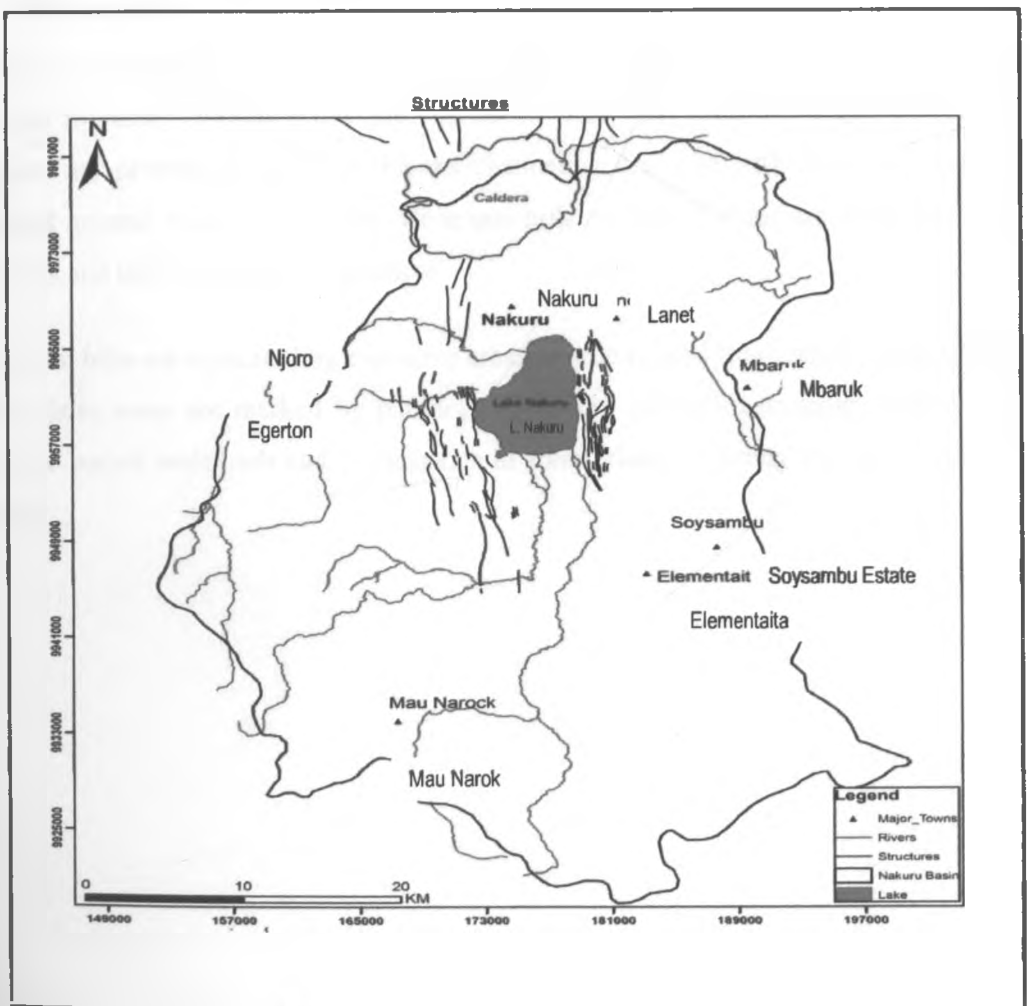

Figure 2.5: Structural map of the study area.

2.8 Vegetation

The vegetation cover is dominated by forests on the steep slopes of the higher fault scarps and in some areas of the higher parts of the escarpment. About three main types of vegetation are recognized; dense near tropical forests and bamboo vegetation of the Mau hills, clumped trees in the grassland areas of the plains and shrub or thicket at the valley bottoms of the stream lines.

Locally natural forests have given way to cultivated forests of eucalyptus and cyprus. The forested areas of the catchment basin consist of Eastern Mau, Eburru and Dondori forest. Eburru forest is composed of indigenous forests that have been progressively excised. The vegetation that remains now is restricted to the crest of the escarpment and consists of bamboo.

2.9 Physiography

The marginal escarpments on the eastern and western sides of the area are characterized by high ground, up to nearly 4000m above the rift floor. The Mau hills, Kinangop plateau and Bahati escarpment are prominent fault-fault blocks channeling drainage with structural controls on both surface and ground water. Eburru and Menengai hills on the rift floor are formed of volcanic ash, pyroclastics and tuff with layers of trachyte.

The volcanic hills are separated by extensive areas of step faulted topography culminating in narrow grabens. These areas are marked by parallel structurally controlled drainage patterns. The narrow grabens are buried under ash and pyroclastics in some places, forming flat plains such as Ndabibi and Bahati.

CHAPTER 3 : METHODOLOGY

3.1 Introduction

This section presents an overview of the method used in the study area and the various sources where data were obtained.

3.2 Data Gathering

3.2.1 Materials and Methods

Preparation for surface and groundwater sampling trip was done to save time and reduce the number of difficulties that commonly occur with field works. Sampling procedures began in the laboratory before sample collection by thoroughly cleaning sample bottles and protecting them from any contamination during sample collection, preservation and shipment to assure high quality samples. Filtering equipments were rinsed to remove any mineral and the rinsed sample bottles air dried under the laboratory exhaust hood. Computer programs used include SPSS, Microsoft Office Excel, ArcGIS and AquaChem.

3.2.2 Field Work

Fieldwork was conducted between 27th April and 10th May, 2008, in Lake Nakuru basin. The objective of collecting surface and ground water samples for chemical and physical analysis was to collect new data in order to fill the gaps in information and knowledge about the drainage basin. Powell (1954) notes 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.

3.2.3 Desktop studies

The study gathered data from various databases in the country;

- Geological map covering the entire basin acquired from the Geology Department, University of Nairobi. The map was at a scale of 1:50,000 and was digitized in the Geographic Information System (GIS).
- Topographical maps (Sheet No. 119/3 Nakuru, 119/1 Menengai, 118/4 Njoro and 118/2 Rongai) were used to acquire location of towns, land cover information and drainage network.

- Surface water and Groundwater analytical data

3.2.4 Sampling

A total of 75 water samples were collected from rivers and boreholes. Routine sampling was employed to collect river upstream and downstream (Figure 3.1) and borehole water samples (Figure 3.2) within the basin to determine physical parameters (pH, TDS, temperature and conductivity) and laboratory analysis for major ions.

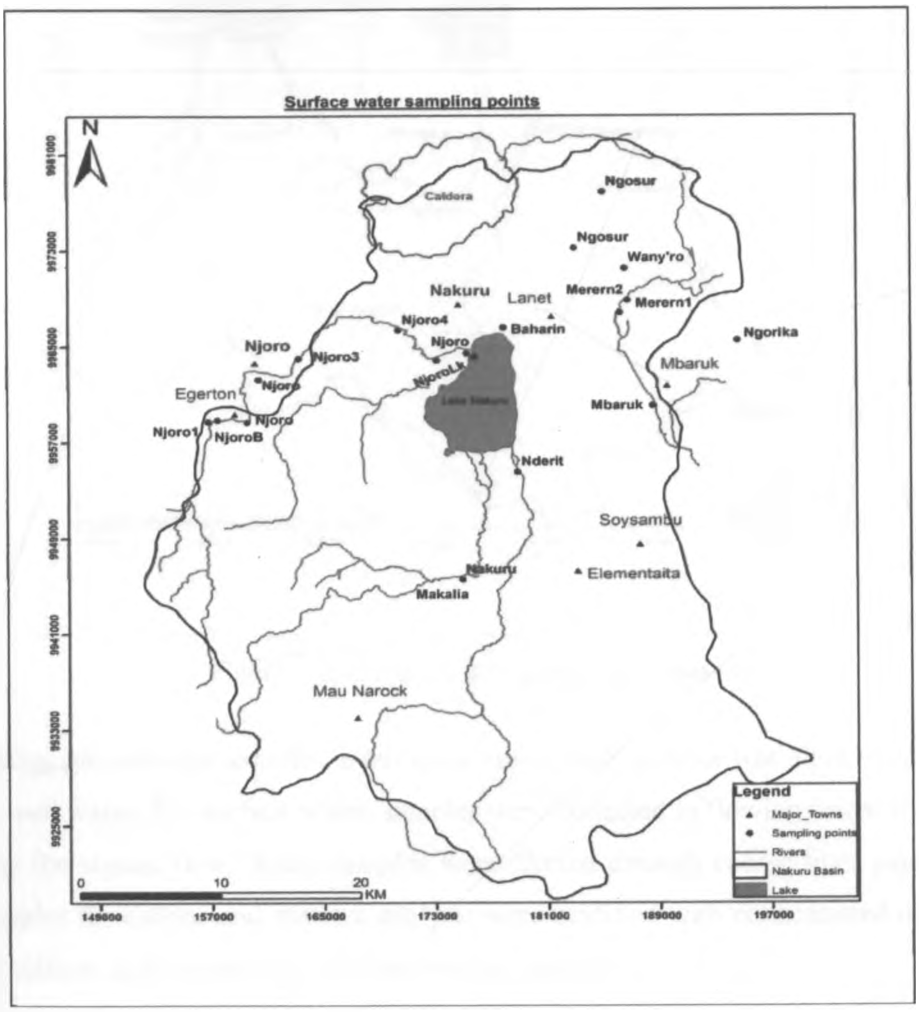

Figure 3.1 : Surface water sampling points

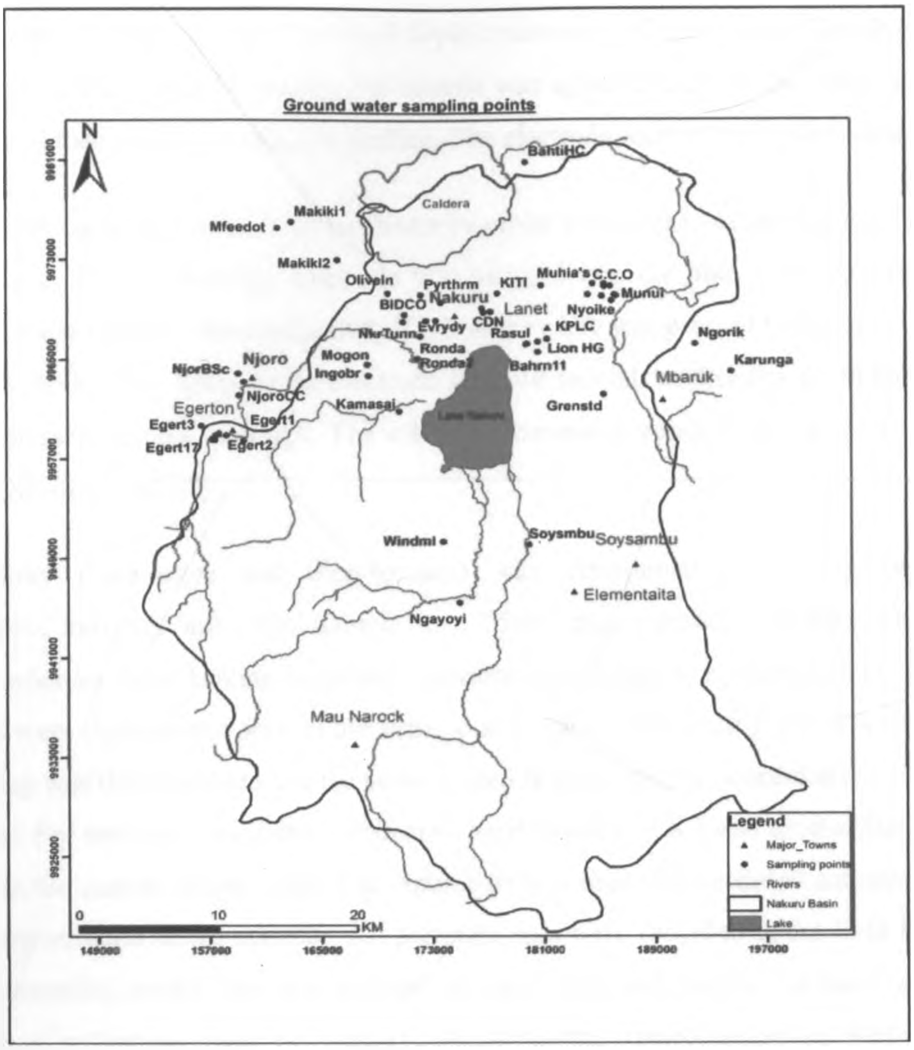

Figure 3.2: Groundwater sampling points

Before collecting groundwater samples, a pumping time of half an hour was allowed to avoid filling of stationary well water. For surface water, samples were collected in flowing water with the bottles placed against the stream flow. Water samples were filtered through coarse filter paper to remove particles. Samples for cations and nutrient analysis were acidified with concentrated nitric acid and concentrated sulfuric acid respectively for preservation purpose.

The samples were tightly corked and stored in a cool box with ice before transportation to the laboratory for analysis. GPS was used to locate the exact sampling points. Temperature, Total Dissolved Solids, electrical conductivity, pH and alkalinity were measured on site. A portable multi-parameter meter was used to measure pH.

The pH electrode was plugged into the black 5-pin connector and then placed in the water sample. pH key was pressed to select pH mode. The sample was agitated for 5-10 second to mix well. The enter button was then pressed to take the reading. The electrode measures pH electrochemically.

A portable multi-parameter meter with conductivity probe was used to determine conductivity, TDS and temperature. The conductivity electrode was plugged into the blue 5-pin connector and then placed in the water sample. The conductivity/TDS/salinity key was pressed to select the conductivity mode or TDS mode, after agitating the electrode for 5-10 seconds to dislodge air bubbles. The enter button was pressed to take readings. The electrode measured conductivity at 25°C or TDS and temperature electrochemically.

Total alkalinity (carbonates and bicarbonates) was determined by adding two drops of phenolphthalein indicator into 50ml sample in a 250ml pyrex beaker. Samples with carbonates turned pink whereas those lacking carbonates (bicarbonates present) remained clear. Samples with bicarbonates were then titrated with dilute sulfuric acid until a pH reading of 4.5 was reached. The burette reading was then recorded and the volume used to calculate the concentration of bicarbonates in the sample. For samples containing carbonates, a pH reading of 8.3 was used as the end point for titration when the sample turned clear. The volume of titre used was recorded and used to calculate carbonate concentration in the sample. All pertinent data were recorded in the field book i.e. GPS positions of sampling points, land uses and the measured field parameters. For each sample, sample number, date of collection, place and time of collection were labeled and sealed with cello tape for protection.

3.2.5 Laboratory Analyses

Mohr titration method was used to determine concentration of chloride in the samples. An aliquot of water sample was measured using a pipette then transferred into a conical flask. Two to three drops of potassium dichromate were then added to the sample. A known concentration of silver nitrate was filled in a burette. The sample was titrated against the silver nitrate while stirring the sample with a magnetic stirrer. The end point was indicated by persistence of red coloration. Readings of the burette was taken and concentration of chloride in the sample calculated.

Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) concentrations were determined by complexation reaction with EDTA. A few drops of sodium hydroxide (NaOH) indicator and calcine buffer were added to 25ml of water sample which gave a green fluorescent color. The buffer maintained a pH of 10 for Ca^{2+}. Titration of the sample with EDTA in the burette was done and end point of the reaction was a pink color. The titre from the burette reading was taken. In the second titration pH was maintained at 12 through addition of a buffer solution for Mg^{2+}. The sample turned purple. Titration using EDTA was repeated until the solution turned blue in color. The burette reading was recorded and calculations for both concentrations were done.

Sulfate (SO_4^{2-}) was determined by turbidimetry. 25ml of water sample was measured using a volumetric pipette and transferred into a beaker. 5ml of SulfaVer4 reagent was then added to the sample. Barium in the SulfaVer4 reacted with SO_4^{2-} in the sample to form an insoluble barium sulfate precipitate which was kept in suspension using glycerol. The solution was then passed through a molecular absorption spectrophotometer and the readings recorded.

Cadmium reduction method was employed in the determination of NO_3^-. 25ml of water sample was measured and poured into a beaker. Cadmium metal was then dropped into the beaker to reduce nitrate in the sample to nitrite. The nitrite then reacted in an acidic medium with sulfanitritic acid to form an intermediate diazonium salt. This coupled with gentisic acid formed an amber colored product. The concentration of $NO_3^-$was then determined from absorbance at 400nm using spectrophotometer.

Sodium (Na^+) and Potassium (K^+) were determined by flame emission using a flame photometer with lithium as an internal standard: 1g/l each of KCl and NaCl was used for Na^+ and K^+ as a matrix connector.

CHAPTER 4 : RESULTS

4.1 Introduction

This chapter focuses primarily on the results obtained from the acquired data. These include surface and groundwater chemical and physical characteristics of the study area.

4.2 Physico-Chemical characteristics of surface and groundwater

Surface and groundwater samples were analyzed for major elements alongside pH, conductivity and TDS and the results are as shown in Appendix 1 and 2. The data presentation in Table 4.1 and Table 4.2 is a summary of descriptive statistics of 11 variables of surface and groundwater.

A total of 54 borehole samples were analyzed and variation is evident with HCO_3 ions displaying the highest variance. It is followed by Na., Cl, SO_4, K, Ca, Mg and NO_3 ions in that order. All variables show positive skewness with a mean error of 0.33.

Table 4.1: Descriptive statistics of chemical data and physical characteristics of groundwater samples.

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error
pH	54.00	2.90	6.33	9.23	7.68	0.63	0.39	0.74	0.33
Cond	54.00	3200.00	220.00	3420.00	823.20	729.72	532497.41	2.10	0.33
HCO_3	54.00	773.00	20.00	793.00	165.87	205.56	42256.91	1.77	0.33
Ca	54.00	30.55	0.00	30.55	7.34	6.53	42.58	1.42	0.33
Mg	54.00	10.61	0.00	10.61	4.86	2.66	7.09	0.48	0.33
Na	54.00	739.00	26.00	765.00	155.06	141.16	19925.20	2.54	0.33
K	54.00	43.60	2.40	46.00	18.61	10.05	101.09	0.67	0.33
SO_4	54.00	279.15	0.25	279.40	37.34	52.57	2763.98	2.74	0.33
Cl	54.00	660.00	7.00	667.00	48.76	92.77	8606.06	5.87	0.33
NO_3	54.00	5.98	0.02	6.00	0.58	1.04	1.08	3.55	0.33
TDS	54.00	1640.00	70.00	1710.00	403.99	367.85	135310.03	2.07	0.33

A total of 20 river samples were analyzed. The descriptive statistics show that HCO_3 has the highest range of 296 mg l^{-1} that spans from 14 to 310 mg l^{-1}. It is followed by Na and Cl contents. Variation is as well noted with the other elements but with lower values. NO_3 content gives the lowest range of 20.30 mg l^{-1} that spans from 0.30 to 20.60 mg l^{-1}.

Table 4.2: Descriptive statistics of chemical data and physical characteristics of surface water samples.

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error
pH	20.00	1.22	7.02	8.24	7.65	0.34	0.12	-0.06	0.51
HCO_3	19.00	296.00	14.00	310.00	87.37	72.02	5186.96	1.64	0.52
Ca	20.00	21.20	0.80	22.00	8.69	5.49	30.12	1.29	0.51
Mg	20.00	41.90	0.97	42.87	7.34	8.73	76.21	3.88	0.51
Na	20.00	187.50	12.50	200.00	46.38	43.74	1913.39	2.68	0.51
K	20.00	32.20	1.80	34.00	12.22	7.85	61.56	1.18	0.51
SO_4	20.00	30.75	0.25	31.00	10.21	9.04	81.75	0.84	0.51
Cl	20.00	82.00	3.00	85.00	18.95	19.14	366.26	2.40	0.51
NO_3	20.00	20.30	0.30	20.60	4.10	4.38	19.18	2.99	0.51
Cond	20.00	1933.20	96.80	2030.00	577.67	485.26	235480.92	1.76	0.51
TDS	20.00	966.60	48.40	1015.00	287.85	241.90	58513.39	1.78	0.51

4.3 Chemical variation in groundwater chemistry

Ground water in the study area has two facies namely Na-HCO_3 and Na-Cl-SO_4 type (Figure 4.1). Enrichment through soil-water-rock interactions (intense weathering of alumino-silicate rocks), natural process (precipitation) and hydrothermal discharges coupled with hydrothermal terrain are the two processes likely responsible for the observed chemical variability of the groundwater in the area.

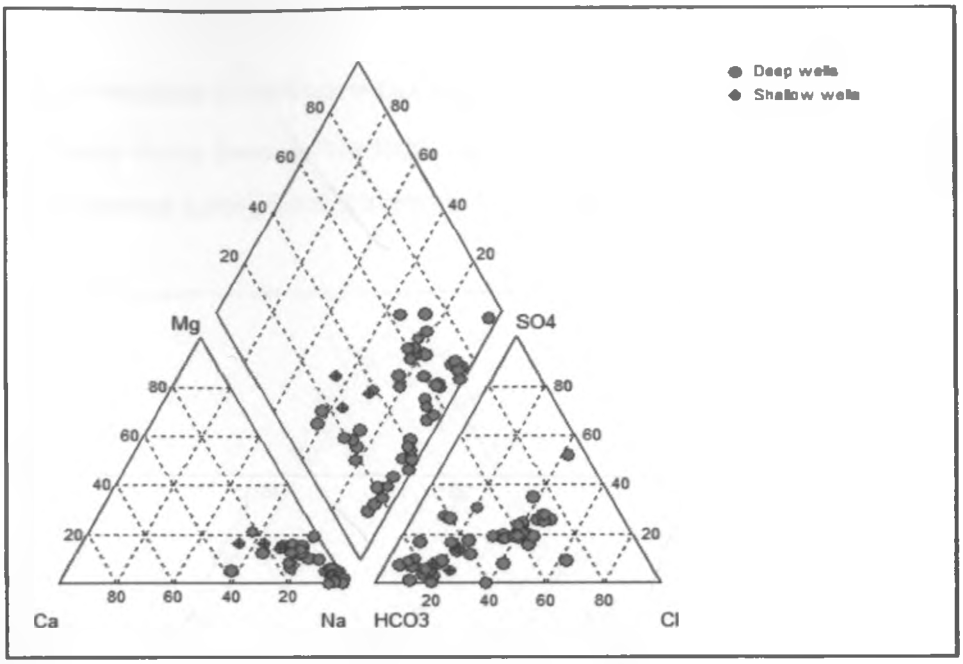

Figure 4.1: Piper diagram showing groundwater type.

4.4 Physical variation of physical properties of groundwater

Groundwater is characterized by TDS concentration of values as low as 70mg/l to as high as 1710mg/l with a mean of 403.99mg/l. All the groundwater samples apart from boreholes in Londra, Soysambu, Pyrethrum Board, Nakuru Tunners, BIDCO and Bontana Hotel have TDS values less than 500mg/l. However the above mentioned boreholes have TDS values greater than 500mg/l signifying dominance of silicate weathering. The pH of boreholes and shallow wells of the drainage basin range between 6.33 to 9.23 with a mean of 7.68. Boreholes at Ngorika and BIDCO Company adjacent to Nakuru Tunnel have low and high pH values respectively. Conductivity of groundwater shows variation from 220 to 3420 μS/cm with an average of. 823.20μS/cm. Tabuga and Ronda boreholes have recorded low and high conductivity respectively. Boreholes adjacent to Lake Nakuru and Menengai crater such as Soysambu, Londra, Olive Inn, Pyrethrum Board, Nakuru Tunnel, BIDCO and Bontana Hotel have high conductivity values. This may be due to addition of more ions in hydrothermal discharge from Menengai Crater.

4.5 Chemical variation in surface water chemistry

Surface water facies varies between Na-HCO_3 and Na-Cl type (Figure 4.2). Weathering of silicate rocks and natural process (precipitation) seems to be the major contributing factor.

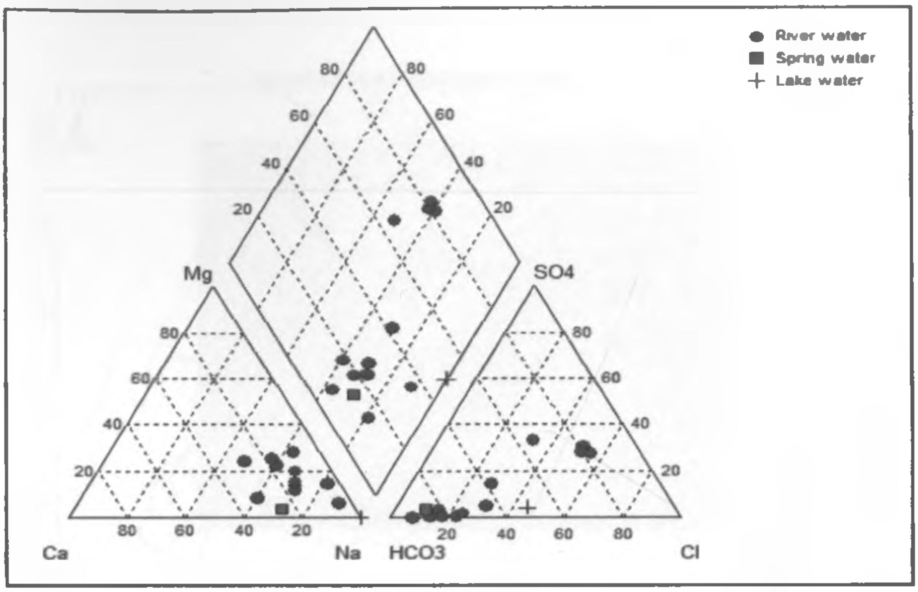

Figure 4.2: Piper diagram showing surface water type

4.6 Physical variation of physical properties of surface water

There is relationship between conductivity and TDS. The more ions present (TDS), the higher the conductivity of water and vice versa. TDS is between 48.5-1015 mg/l with a mean of 287.85mg/l. Conductivity is between 96.5 to 2030 µS/cm with a mean of 577.67 µS/cm. Highest TDS and conductivity is noted at the mouth of River Njoro where it enters the lake. pH range between 7.02 to 10.49 at River Ngosur and Lake Nakuru respectively. Rivers in the drainage basin have pH variation from 7.02 to 8.24 at the upstream and downstream of River Njoro respectively. The mean is 7.65.

4.7 Source of groundwater pollutants

Sulfate levels in groundwater in the study area range from 0.3 mg/l to 279.4 mg/l. Influx of sulfate occur in wells surrounding Nakuru town to the Northwest of the lake (Figure 4.3). This include; Pyrethrum Board, Windmill trough, Bontana, Eveready and Lower Ronda. Bahati borehole recorded the lowest sulfate concentration. Pyrethrum board borehole exceeded the allowable water drinking limit of 250mg/l set by the WHO, EU and EPA. Spatial distribution is biased to the area between Menengai crater and the lake, additionally the area south of the lake extending towards Eburru volcano shows an influx of sulfate in the groundwater. Interestingly, the boreholes to the Northeast and the Western side of the study area in Figure 4.3 have low concentrations of sulfate.

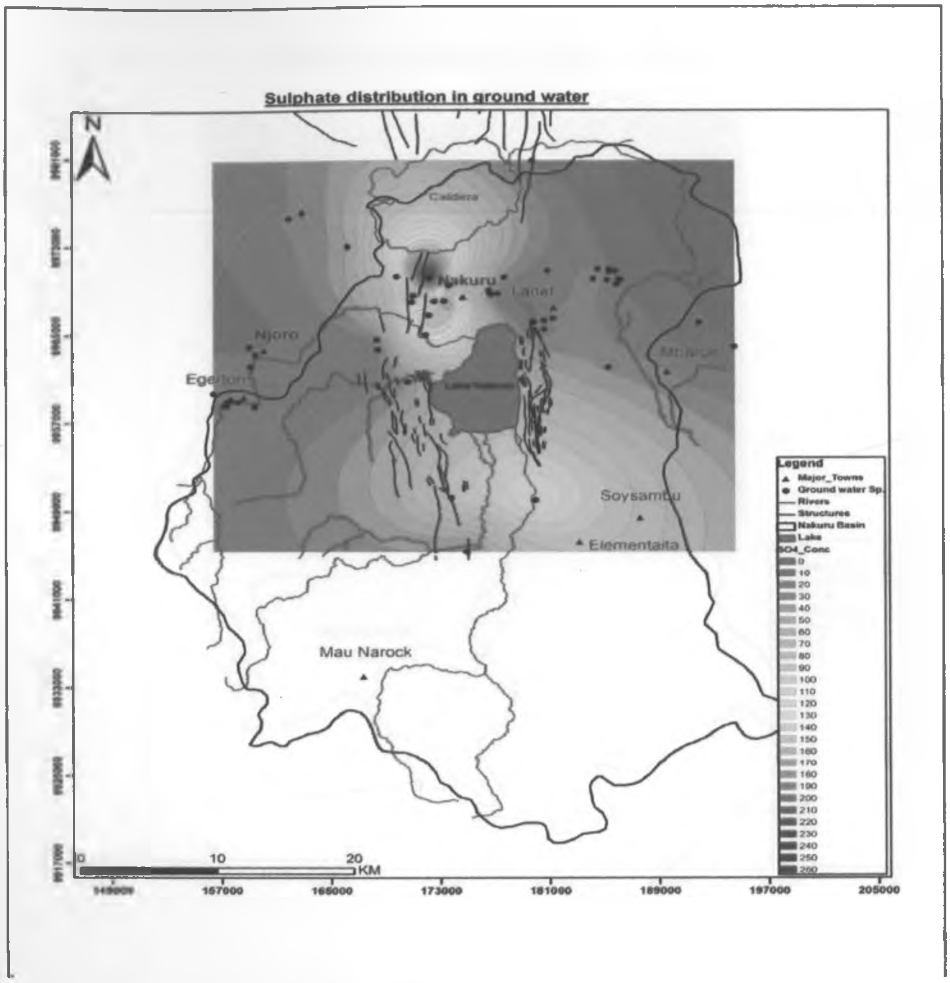

Figure 4.3 : Distribution of sulfate in groundwater

Hydrothermal discharge from Menengai crater is the possible source of sulfate in groundwater and is transported through sub-surface faults and fractures as noted in Figure 4.5.

Borehole with high chloride concentration (667mg/l)) is noted around Nakuru town of the study area (Figure 4.4). The specific area is Ronda with concentrations of 667mg/l. Influx of chloride ion is also noted along river Njoro around the same area in surface water as seen in Figure 4.8. Areas to the

Southwest and Northeast have low concentrations. This could result from natural source mainly rain water from the surface into the groundwater system facilitated by subsurface faults that we see terminate at this point.

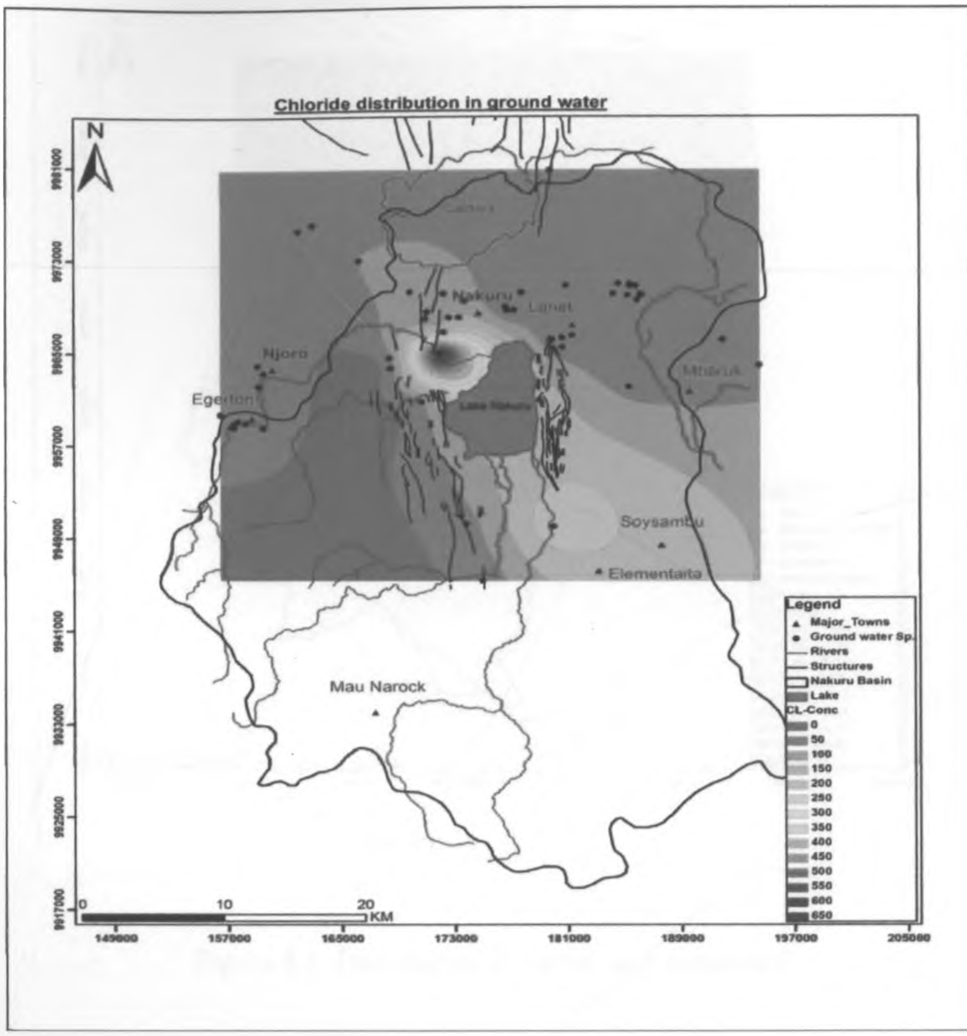

Figure 4.4: Distribution of chloride in groundwater

Nitrate was detected in all samples, with concentration ranging from 0.02 to 6mg/l. Two boreholes to the East (Karunga and Ngorika) in Bahati had samples containing nitrate greater than 3mg/l (Figure 4.5). However nitrate concentration is within the limits as required by WHO, i.e., 50mg/l for drinking water. The possible cause could be infiltration of irrigation water enriched in nitrate compounds into the groundwater system through the porous and permeable soils in agricultural farms in Bahati highlands.

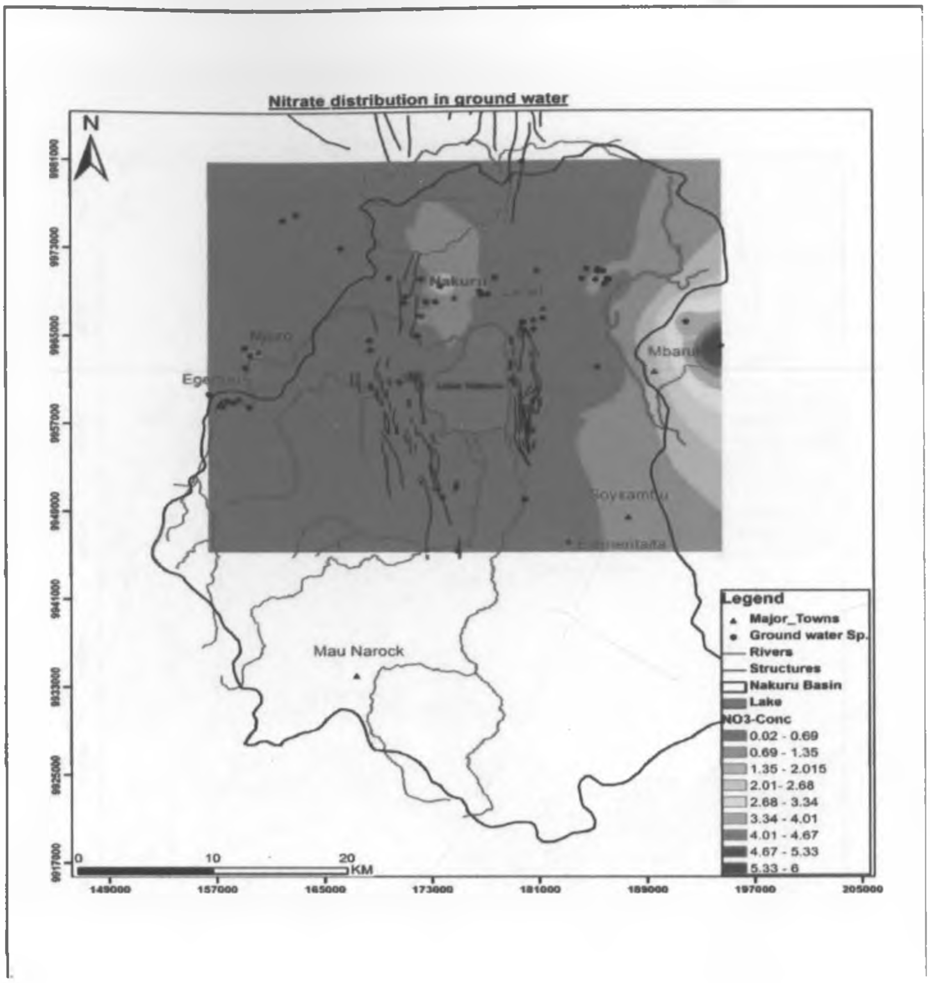

Figure 4.5: Distribution of nitrate in groundwater.

4.8 Source of surface water pollutant.

Influx of Cl^- and SO_4^{2-} (85 and 26 mg/l respectively) is noted along river Njoro at the midpoint and mouth as it drains into Lake Nakuru (Figure 4.6). High value of NO_3^- (20.6mg/l) is only seen along river Njoro at the sewerage discharge point. Njoro area host several industries and farms with dense population. Mineral fertilizers and manure used in agriculture, sewage effluent from the dense population with minimal sanitation facilities and industrial discharges (e.g from Njoro Canning factory) could plausibly explain the observed result of high NO_3^- along river Njoro. The pollutant sources are likely to be outlets of industrial waste, sewerage discharge points and run off of loose soils with adsorbed fertilizers from agricultural farms.

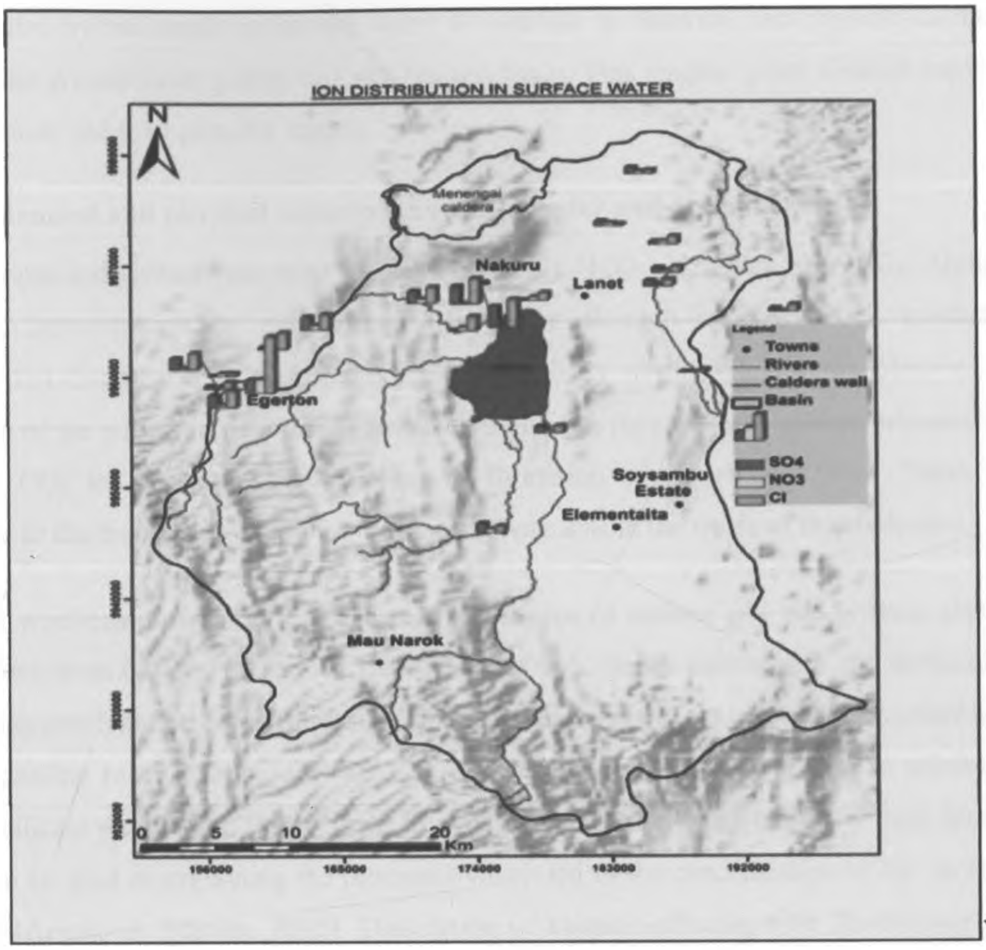

Figure 4.6: Ion concentration map for surface water.

CHAPTER 5 : DISCUSSION

5.1 Introduction

As indicated by the results presented, there is variation in chemical and physical composition of surface and groundwater quality in Lake Nakuru basin. This chapter gives detailed explanation on the variations and their possible causes.

5.2 Chemical and physical variation in surface water and groundwater

Surface water and groundwater type varies between Na-HCO_3, Na-Cl and Na- SO_4. Anthropogenic influence, concentration by evaporation, enrichment through soil-water-rock interactions and hydrothermal discharges are the processes that are likely responsible for the observed chemical variability of the waters in the area. Weathering of silicate rocks release sodium whereas rain water dissolves CO_2 in the atmosphere leading to formation of bicarbonate ions. These processes contribute to the dominance of sodium and bicarbonate ions in the water of the study area.

Chemical weathering of trachyte and basalt is a source of sodium and this process also produces bicarbonates from basaltic rocks. The dissolution of CO_2 in the atmosphere and in the unsaturated zone during precipitation and infiltration, imparts the bicarbonate character to the surface and ground water according to Shanyengana et al., (2004) in Chander et al., (2011). Na^+ is released through alumino-silicate weathering. Below is the kind of chemical reactions which may have taken place or which can be used in explaining the processes which led to the concentration of Na^+ in the samples analyzed (Appelo & Postma, 2005). Dissolution of alumino-silicates with Na-feldspar (albite) as typical representative occurs as follows;

$$2NaAlSi_3O_8 + 2H^+ + 9H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 2Na^+ + 4H_4SiO_4 \quad \text{..........} \quad (i)$$

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

Mean TDS concentration in surface water and groundwater is 287.85 and 403.99 mg/l respectively. This variation is influenced by solubility of rock type, pH of infiltrating water and residence time of the groundwater along the flow path from recharge to discharge areas. As such rock mineralogy combined with hydraulic conductivity as controlled by the size and abundance of fractures contribute to the overall TDS concentration along the flow path. From Table 5.1 below both surface water and groundwater in the study area can be categorized as fresh. This can be attributed to surface outlet influence, direct precipitation and recharge of surface water and groundwater

Table 5.1: Water classification based on TDS (after Kovalevsky et al., 2004).

Classification	TDS (mg/l)
Fresh water	0-1000
Brackish	1000-20000
Saline	20000-50000
Brine	>50000

Surface water resources have less conductivity as compared to groundwater as shown in Table 5.2 which summarizes their mean. This variation in conductivity is due to the difference in ion concentration (TDS) in surface water and groundwater. Groundwater has more dissolved ions due to dissolving of ions in the volcanic rocks by infiltrating water which takes longer residence time along the flow paths.

Table 5.2: The mean of conductivity values of water samples from the study area against WHO standards.

Sample	Conductivity (μS/cm)	WHO (μS/cm)
Surface water	577.67	2500
Groundwater	823.20	2500

In Table 5.3 below, both surface water and groundwater are alkaline. The alkalinity could be as a result of weathering of carbonates which produces HCO_3^-.

Table 5.3: The mean of pH values of the water samples from the study area against WHO standards.

Sample	pH	WHO
Ground water	7.68	6.5-8-5
Surface water	7.65	6.5-8.5

5.3 Anthropogenic sources of pollutants in surface water and groundwater.

This involves identification of point and non-point sources of pollution in both surface and groundwater. In natural environment, sources of contamination are always present and usually widespread.

5.3.1 Groundwater

Groundwater to the northern part of the study area seems to be vulnerable to pollution due to the sub surface structures i.e. faults that trend in the North-South direction facilitating surface drainage into the groundwater.

Boreholes with high chloride value noted around Nakuru town could be attributed to either natural sources of weathering or anthropogenic contribution through leakage of effluent from the industries and sewage through the porous and permeable surfaces (terminating faults) as seen in Figure 4.6.

Concentration of nitrate in groundwater is low (0.02 – 6mg/l) and it is within the limits as required by WHO 2003, <50mg/l. Nitrate concentrations in groundwater under natural conditions are usually less than 2mg/l. When nitrate concentrations exceed 3mg/l, non-natural sources are suspected. Two boreholes to the East in Bahati highland had samples containing nitrate >3mg/l as exemplified in Figure 4.5. Since nitrate has high mobility and easily leaches out of the agricultural fields, the possible cause could be infiltration of irrigation water enriched with nirate from agricultural farms into the groundwater system through sub-surface faults. Irrigation and fertilizer use can have profound impacts on the hydrology and quality of water resources in agricultural regions (Johnston et al., 1998; Böhlke, 2002; Gourcy et al., 2009) in (Brown et al., 2011). The authors emphasized in Böhlke (2002) found that excessive infiltration of irrigation water has a high chance of introducing agricultural contaminants like nitrate to shallow aquifers. Low vegetation cover easily causes run-off water to access the aquifer through open fractures and conduits.

Sulfates are a combination of sulfur and oxygen and are a part of naturally occurring minerals in some soil and rock formations that contain groundwater. As water moves through these formations, the minerals dissolve over time and are released into groundwater. Almost all natural waters contain chloride and sulfate ions. Their concentrations vary considerably according to the mineral content of the earth in any given area. In small amounts they are not significant. Elevated concentrations of this element may result from mineral dissolution, domestic and industrial waste. The EPA Secondary Drinking Water Regulations recommend a maximum concentration of 250 mg/l for sulfate ions. High value of sulfate in boreholes to the north of the study area could be attributed to leaching of sulfur from pyrite. This pyrite could be originating from Menengai crater located to the north of the study area as illustrated in Figure 4.3. It is postulated that infiltrating/recharging water rich in oxygen could be reacting with pyrite which is a common hydrothermal alteration mineral. In the presence of water and oxygen, pyrite is oxidized to Fe^{2+} and SO_4^{2-} and releases H^+ as indicated in the equation shown below.

$$FeS_{(s)} + H_2O + O_2 \rightarrow Fe^{2+} + SO_4^{2-} + H^+ \quad \text{................ (ii)}$$

This reaction releases sulfate ion into groundwater through the North-South trending faults in Menengai crater (Figure 4.3). The possible non-point source of pollution in groundwater in the study area is weathering of alumino-silicate rocks and alteration minerals from hydrothermal zones like Menengai Crater that are transported through sub-surface faults and fractures.

5.3.2 Surface water

High concentration of NO_3^- (20.6 mg/l) is noted along river Njoro at the sewerage discharge point. This concentration is above the limit of EPA standards which is 50mg/l. Influx of SO_4^{2-} and Cl^- is also noted at Njoro Bridge and Sewage discharge point along river Njoro (Figure 4.6). The two concentrations (SO_4^{2-} and Cl^-) are within the limit of EPA standards which is 250mg/l. Mau catchment where river Njoro draws its water from, is now occupied by land that has been converted to small scale farms and human settlement. Nitrate enters the environment from fertilizers, sewage and human or farm animal waste. Nitrate has high mobility and is the main cause of high concentration in aquatic systems. It easily leaches out of the agricultural fields and ends up in aquatic environment. Farming activities in these areas involve intense application of fertilizers such as diammonium phosphate and animal manure. These areas were once covered by thick forests. Due to destruction of vegetation by man and his livestock, high concentration of nitrate in surface water may be associated with high run-off from the agricultural fields.

It is possible that fertilizer and manure used in agriculture, sewage effluent from the adjacent settlements with minimal sanitation facilities and industrial discharges (e.g from Njoro canning factory) are washed into the rivers. Therefore sewage discharge points and oulet of waste from Njoro Canning Factory are infered to be the point source whereas run off of loose soils with adsorbed nitrate compounds from agricultural farms are the non point source of pollution of surface water in the study area.

CHAPTER 6 : CONCLUSION AND RECOMMENDATIONS.

Spatial variation in surface water and groundwater is due to land use, soil and geology in the study area. As the rivers flow through areas covered with agricultural land, dense population and industries, fertilizers, effluent and sewage discharge are washed into the river thus changing the chemical composition of surface water. Surface drainage into the groundwater system through disappearing sub-surface fractures and faults occurs as the rivers flow downstream thus polluting the system.

From the examination of both surface water and groundwater chemical composition, anthropogenic sources of pollution has greatly affected surface water as compared to groundwater. The origin of major ions in groundwater is mostly influenced by natural processes through precipitation and geological process through rock and water interaction as indicated by the results. In addition, the geology of Lake Nakuru basin and Menengai Crater also influence the distribution of chemical elements in groundwater in the study area. Geology of Lake Nakuru basin is composed of volcanic rocks and sediments rich in alumino-silicate. Weathering of alumino-silicate and dissolving of CO_2 in the atmosphere by rain water during precipitation contributes to the dominance of sodium and bicarbonate respectively in the water of the study area. Hydrothermal discharge from Menengai crater, through subsurface structures causes chemical variability in groundwater.

Non-point source of pollution of groundwater in the study area are hydrothermal discharge from hydrothermal zones (Menengai crater) along subsurface faults, weathering of silicate rocks and porous and permeable surfaces in agricultural farms through which pollutants enter the groundwater system. Sewage discharge points and outlet of waste from industries like Njoro Canning Factory are infered to be the point source of pollution in surface water. Surface run off of loose soils enriched with nitrate during rainy season from agricultural farms is the non point source of pollution in surface water in the study area.

To mitigate water quality deterioration, there is need for integrated management of the stream system through strict control of effluent volume and nutrient content as well as provision of sanitation facilities and piped water to the communities. Water quality monitoring of surface and ground water from the source to its final user should be practiced. Identification of ways of managing risks and control measures be put in place and effectively used continuously. Monitoring helps to identify the causes of contamination and to establish whether the problem is general (aquifer wide) or restricted to individual water supplies (localized problem). Understanding the extent and nature of pollution is critical to be able to plan and implement remedial actions. Where the problem is aquifer wide, then consideration should be given to whether it is possible to change the design of the water supply. This could involve using a deeper tube well with the contaminated shallow aquifer sealed-off, or by adding treatment to the source, for instance through chlorination of a shallow well. Alternatively, the sanitation system could be changed with a design that is less prone to leaching contaminants into the groundwater or by ensuring that latrine pits are never dug into the water-table. Where a change in design or construction is not possible, an alternative means of water supply (for instance through piped water) could be considered or a household water treatment system promoted. Where the problem is localized, it is necessary to identify the factors causing the contamination, which will help identify how the problem might be rectified. This relies on using both sanitary inspection and water quality data and, unless both are available, it will be difficult to do this analysis.

Quality changes are not only due directly to human impacts but may also be brought about indirectly by pumping that in effect changes the aquifer system hydrodynamics, and this will in the long run degrade groundwater quality integrity. In relation to this, being the chief water consuming part of the basin, the population of Nakuru Municipality and its environ is on the increase, and as a result the need to maintain supply of clean water is a responsibility that should not be overlooked.

It is recommended that interconnection between surface and groundwater should be determined. This will be helpful in future monitoring by giving information on how pollutants move in the environment and the anticipated extent of pollution. This is done by injecting a trace element into one of the rivers (e.g river Njoro at its source) in the study area whose flow is structurally controlled. The point along the river into which the element is injected acts as a reference point. The movement of the tracer element to groundwater will be monitored by analyzing samples from the boreholes. Samples that will be found to contain the tracer element in their composition are likely to be interconnected. The above process can be repeated to the other rivers one at a time until the interconnection is determined.

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APPENDICES

APPENDIX 1: Physical and Chemical data of surface water in the study area.

SAMPLID	LOCAT	SITE	X Reduced	X Correcte	Y Correcte	Z	pH	Cond	HCO3	Ca	Mg	Na	K	SO4	Cl	NO3	TDS (mg/l)
Riv	Nakuru	Ngosur	183066.58	851019.58	9973206.45	1953	7.8	460.0	52.0	5.1	5.1	23.0	4.0	7.0	3.0	4.3	230.0
RIV	Nakuru	Wany'ro	186669.94	854622.94	9971528.29	2010	7.9	460.0	34.1	5.7	3.1	28.0	11.0	4.0	12.0	4.8	230.0
Riv	Nakuru	Merem2	186869.67	854822.67	9968817.26	1970	7.6	440.0	42.7	6.1	5.5	24.0	9.0	7.0	9.0	3.2	220.0
Spr	Nakuru	Ngosur	185113.08	853066.08	9977869.02	2100	8.1	600.0	19.4	4.4	4.2	21.0	5.0	9.0	5.0	3.6	300.0
Riv	Njoro	Njoro1	156886.00	824839.00	9958696.00	2307	7.6	560.0	132.2	5.2	7.3	28.0	16.0	17.0	25.0	3.2	280.0
Riv	Njoro	Njoro3	163359.00	831312.00	9963989.00	2139	7.7	700.0	14.0	7.9	6.2	31.0	13.0	19.0	23.0	6.8	350.0
Riv	Njoro	Njoro4	170498.91	838451.91	9966319.51	1814	7.5	1300.0	16.0	7.2	6.4	27.0	14.0	18.0	24.0	6.4	650.0
Riv	Nakuru	NjoroBr	175387.36	843340.36	9964386.49	1767	7.0	1260.0	76.4	20.7	42.9	86.0	18.0	26.0	38.0	0.5	620.0
Riv	Nakuru	NjoroLk	175929.30	843882.30	9964138.13	1777	8.1	2030.0	152.0	22.0	12.1	114.0	26.0	31.0	42.0	0.8	1015.0
Riv	Nakuru	Makalia	175019.29	842972.29	9945555.90	1775	7.3	430.0	18.0	12.6	6.8	25.0	8.0	14.0	10.0	5.6	215.0
Riv	Nakuru	Nderit	178971.41	846924.41	9954526.27	1767	7.7	364.0	18,6	9.7	5.7	46.0	15.0	11.0	12.0	3.4	132.0
Riv	Nakuru	Merem1	186333.95	854286.95	9967785.19	1951	7.5	150.0	109.2	7.3	5.6	20.0	8.0	8.0	10.0	2.6	100.0
Spr	Bahati	Ngorika	194705.41	862658.41	9965485.43		7.4	334.0	140.0	16.0	1.5	52.5	5.4	4.6	10.0	0.4	172.0
RW	BrdgEgt	Njoro	157535.00	825488.00	9958840.00	2296	8.1	254.0	104.0	4.0	7.8	32.5	12.0	0.3	5.0	4.8	127.0
RW	Njoro	Egert.	156886.00	824839.00	9958696.00		8.2	225.0	94.0	4.8	4.8	30.0	11.0	3.4	10.0	2.2	117.0
RW	Marula	Gilgil	205961.85	873914.85	9930410.68	1858	7.6	96.8	40.0	5.6	1.0	12.5	2.2	0.3	5.0	0.8	48.4
RW	Nakuru	Mbaruk	188620.47	856573.47	9960042.25	1886	7.1	104.5	44.0	0.8	1.9	19.5	1.8	0.3	4.0	0.3	48.4
RW	Sew Dis	Njoro	159655.46	827608.46	9958643.25	2287	7.6	1057.0	310.0	8.0	7.8	200.0	34.0	20.2	85.0	20.6	528.2
RW	KARI	Njoro	173232.72	841185.72	9963811.69	2296	7.3	369.0	130.0	11.2	4.9	55.0	16.0	1.1	22.0	5.4	189.5
RW	SlghtrH	Njoro	160505.66	828458.66	9962228.61	2170	7.8	359.0	132.0	9.6	6.3	52.5	15.0	3.1	25.0	2.2	184.5
Lake	Nakuru	Nakuru	175019.29	842972.29	9945555.90	1787	10.5	99700.0	26762.0	0.8	4.9	22676.0	420.0	1828.3	14000.0	1.2	179.5

APPENDIX 2: Physical and Chemical data of groundwater in the study area.

SAMPLID	LOCAT	SITE	Reduced X	X Corrected	Y Corrected	Z	pH	Cond	HCO3	Ca	Mg	Na	K	SO4	Cl	NO3	TDS (mg/l)
BH	Nakuru	Kabatni	180989.0	848942.0	9970878.8	1901.0	7.5	370.0	192.0	8.7	5.2	26.0	12.0	13.0	13.0	0.1	180.0
BH	Nakuru	Bahrin7	179938.3	847891.3	9966220.2	1830.0	7.4	470.0	228.0	14.6	5.1	86.0	17.0	7.0	32.0	0.3	230.0
BH	Nakuru	Bahrin9	179989.1	847942.1	9966201.8	1831.0	7.2	490.0	228.0	11.9	9.8	89.0	20.0	12.0	28.0	0.2	240.0
BH	Nakuru	Bahrn11	179894.6	847847.6	9966169.5	1828.0	7.1	480.0	240.0	10.5	7.9	98.0	15.0	8.0	26.0	0.2	240.0
BH	Nakuru	NrbRd6	176827.2	844780.2	9968751.4	1885.0	7.5	580.0	330.0	3.8	2.2	132.0	22.0	28.0	17.0	0.6	290.0
BH	Nakuru	NrbRd4	176853.7	844806.7	9968737.4	1885.0	7.5	570.0	344.0	3.8	2.8	126.0	26.0	23.0	12.0	0.4	290.0
BH	Nakuru	Bontna	173416.2	841369.2	9968114.1	1846.0	8.5	2670.0	27.0	3.4	3.6	301.0	42.0	186.0	110.0	0.8	1330.0
BH	Nakuru	Londra	172713.1	840666.1	9968098.5	1858.0	7.5	2880.0	240.0	2.5	3.1	258.0	46.0	78.0	112.0	0.5	1430.0
BH	Nakuru	AGRI	173770.9	841723.9	9969538.1	1875.0	9.1	840.0	64.0	0.8	2.9	203.0	36.0	52.0	71.0	2.8	420.0
BH	Nakuru	KITI	177842.0	845795.0	9970262.2	1908.0	7.5	900.0	480.0	2.8	3.8	112.0	33.0	28.0	53.0	0.2	450.0
BH	Nakuru	CDN	177333.1	845286.1	9968778.2	1872.0	8.3	530.0	28.0	2.1	3.7	106.0	24.0	12.0	19.0	0.1	260.0
BH	Nakuru	NRBRd5	176856.0	844809.0	9968748.4	1885.0	7.5	580.0	38.0	4.4	2.4	146.0	31.0	32.0	38.0	0.1	290.0
BH	Nakuru	Wamuyu	185488.2	853441.2	9970806.6	1960.0	6.9	360.0	26.0	11.6	7.2	78.0	22.0	10.0	15.0	0.6	180.0
BH	Nakuru	Tabuga	185488.3	853441.3	9971004.7	1992.0	7.3	220.0	22.0	5.3	5.3	55.0	9.0	8.0	12.0	0.1	110.0
S. Well	Nakuru	Njogu	185924.4	853877.4	9970822.4	1972.0	7.5	360.0	72.0	11.1	6.1	56.0	11.0	13.0	15.0	1.2	180.0
S. Well	Nakuru	Njoroge	186337.1	854290.1	9970076.0	1966.0	7.5	1150.0	94.0	15.4	7.7	56.0	11.0	8.0	12.0	0.1	570.0
S. Well	Nakuru	Munui	186222.1	854175.1	9970130.0	1970.0	7.5	980.0	72.0	19.6	6.9	43.0	8.0	4.0	14.0	1.2	490.0
BH	Nakuru	Nyanjor	186023.8	853976.8	9969648.0	1958.0	7.9	540.0	30.0	8.2	10.6	98.0	6.5	9.4	11.3	0.2	270.0
BH	Nakuru	Nyoike	185334.8	853287.8	9970026.4	1950.0	6.6	300.0	21.0	8.2	6.7	62.0	12.0	15.0	19.0	2.2	150.0
BH	Nakuru	Muhia's	184681.1	852634.1	9971027.1	1956.0	7.5	260.0	20.0	6.3	6.1	52.0	7.0	16.0	19.0	0.0	130.0
BH	Nakuru	C.C.O	184323.5	852276.5	9970147.0	1935.0	7.2	630.0	50.0	30.6	10.4	101.0	17.0	26.0	32.0	0.1	315.0
BH	Njoro	Egert6a	157344.0	825297.0	9958576.0	2308.0	7.5	540.0	50.0	4.2	1.4	130.0	19.0	8.0	10.0	0.2	270.0

SAMPLID	LOCAT	SITE	Reduced X	X Corrected	Y Corrected	Z	pH	Cond	HCO3	Ca	Mg	Na	K	SO4	Cl	NO3	TDS (mg/l)
BH	Njoro	Egert11	157344.0	825297.0	9958576.0	2298.0	7.3	440.0	46.0	1.3	3.6	115.0	20.0	15.0	18.0	0.1	220.0
BH	Njoro	Egert17	157495.0	825448.0	9958558.0	2292.0	7.9	520.0	44.0	1.6	3.6	108.0	18.0	14.0	20.0	0.2	250.0
BH	Njoro	Egert3	157537.0	825490.0	9958912.0	2304.0	7.5	590.0	49.0	1.2	2.5	122.0	22.0	10.0	22.0	0.1	290.0
BH	Njoro	Egert2	157789.0	825742.0	9959088.0	2278.0	7.5	440.0	43.0	1.5	3.9	132.0	25.0	17.0	19.0	0.1	220.0
BH	Njoro	Egert12	159555.0	827508.0	9958494.0	2250.0	7.9	410.0	30.0	3.0	2.6	121.0	23.0	13.0	20.0	0.1	200.0
BH	Njoro	Egert15	156525.0	824478.0	9959678.0	2274.0	7.5	450.0	42.0	5.5	3.9	129.0	17.0	15.0	19.0	0.1	230.0
BH	Njoro	Egert1	158331.0	826284.0	9958922.0	2267.0	6.9	440.0	30.0	3.5	3.3	112.0	19.0	10.0	21.0	0.1	220.0
BH	Njoro	NjorCDF	159199.0	827152.0	9963910.0	2210.0	7.6	290.0	22.0	4.0	5.3	87.0	13.0	8.0	13.0	0.1	140.0
BH	Njoro	NjoroCC	159244.0	827197.0	9962132.0	2160.0	8.6	340.0	28.0	1.5	3.3	92.0	15.0	12.0	18.0	0.1	170.0
BH	Nakuru	Ingobr	168578.3	836531.3	9963706.5	1940.0	7.5	460.0	34.0	7.5	6.0	89.0	24.0	19.0	22.0	0.1	230.0
BH	Nakuru	Grenstd	185441.4	853394.4	9962139.9	1926.0	7.5	610.0	22.0	2.5	4.7	126.0	31.0	28.0	34.0	0.0	70.0
BH	Nakuru	Mfeedot	162055.0	830008.0	9975572.0	2012.0	7.5	560.0	44.0	8.5	10.3	97.0	17.0	22.0	26.0	0.4	300.0
BH	Nakuru	Makiki1	163054.0	831007.0	9976072.0	2012.0	7.5	670.0	46.0	9.9	8.8	102.0	26.0	20.0	27.0	0.1	280.0
BH	Nakuru	Makiki2	166346.1	834299.1	9973013.9	2032.0	7.5	700.0	54.0	3.4	4.0	158.0	28.0	39.0	52.0	0.3	330.0
BH	Nakuru	Oliveln	169957.0	837910.0	9970320.1	1936.0	7.5	1300.0	96.0	2.4	3.1	224.0	42.0	98.0	78.0	0.3	650.0
BH	Nakuru	Lion HG	180740.1	848693.1	9965543.6	1886.0	7.5	560.0	34.0	17.5	5.8	98.0	12.0	15.0	26.0	0.8	280.0
BH	Nakuru	KPLC	181410.8	849363.8	9966579.5	1881.0	7.5	560.0	38.0	24.0	5.5	132.0	23.0	26.0	32.0	0.1	280.0
BH	Bahati	BahtiHC	179898.4	847851.4	9980794.4	2078.0	7.8	316.0	104.0	6.4	5.8	52.5	3.6	9.1	15.0	0.1	108.0
BH	Nakuru	NkrTunn	172305.5	840258.5	9966838.3	1812.0	9.0	2190.0	720.0	4.8	0.0	493.0	9.8	146.7	119.0	0.9	1090.0
Bh	Nakuru	Ngayoyi	175052.6	843005.6	9945387.0	1852.0	8.5	593.0	214.0	17.6	10.4	93.5	5.8	21.1	14.0	0.1	296.5
Bh	Nakuru	BIDCO	171173.1	839126.1	9968588.0	1875.0	9.2	1643.0	614.0	4.8	6.8	348.0	20.0	61.4	96.0	0.2	821.5
BH	Nakuru	Windml	173911.9	841864.9	9950316.3	2442.0	8.6	834.0	248.0	9.6	0.0	171.5	16.0	86.0	31.0	0.4	417.0
BH	Nakuru	Evrydy	171052.2	839005.2	9968010.1	1875.0	8.4	954.0	232.0	0.0	5.3	208.0	2.4	116.6	57.0	0.1	472.0
BH	Nakuru	Pyrthrm	172340.5	840293.5	9970169.5	1875.0	8.6	2500.0	793.0	0.0	5.8	549.0	25.0	279.4	83.0	0.3	1250.0
BH	Nakuru	Soysmbu	180075.5	848028.5	9950091.9	1875.0	8.6	2290.0	716.0	16.8	2.0	490.0	23.0	113.7	190.0	0.5	1145.0
BH	Nakuru	Ronda	172076.2	840029.2	9965047.3	1811.0	8.8	3420.0	522.0	8.0	0.5	765.0	20.0	132.0	667.0	0.4	1710.0
BH	Nakuru	Ronda2	172076.2	840029.2	9965047.3	1811.0	7.1	1528.0	610.0	9.6	2.9	332.0	6.2	3.7	87.0	0.5	764.0
BH	Bahati	Ngonk	192037.3	859990.3	9966205.5	2251.0	6.3	230.0	92.0	16.8	1.5	30.0	7.0	1.1	7.0	3.6	115.0
BH	Njoro	NjorBSc	159610.9	827563.9	9963245.1	2174.0	7.0	351.0	102.0	0.8	7.8	60.0	11.0	12.6	48.0	1.2	175.0
BH	Nakuru	NkrBSc	176723.2	844676.2	9969075.9	2174.0	8.2	649.0	244.0	0.8	3.4	140.0	4.6	43.4	14.0	2.1	324.5
BH	Bahati	Karunga	194624.7	862577.7	9964003.2	2052.0	7.3	345.0	98.0	9.6	6.3	55.0	6.0	0.3	36.0	6.0	172.0