ANALYSIS OF SPATIAL AND SEASONAL VARIATIONS OF WATER QUALITY USING STATISTICAL, CCME-WQI AND GIS METHODS IN NAKURU MUNICIPALITY, KENYA

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DECLARATION

Declaration by the Candidate

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To my father, Francis Keli Maingi, my husband Edward K. Shakala, daughter Sharon Kate and son Absalom Doyo, and above all, GOD the ALMIGHTY.

ABSTRACT

Nakuru Municipality lies in the larger Lake Nakuru basin where the natural chemistry of its watershed is characterized by high levels of inorganic salts posing a significant problem to water resources. River and ground waters are the primary sources of drinking water for the municipalities' population but despite their significance, there are limitations to the availability of a robust database that can describe their quality status in a reliable way. Information that can explain spatial and seasonal variations of river and ground water quality is not sufficient. This study targeted to bridge this gap by adopting a quantitative research design. Stratified random sampling was applied in the study of pH, electrical conductivity, and levels of fluoride selenium, chloride and cadmium. Thirty eight sampling points and three sampling periods/seasons were selected for this study. The seasons were put in three groups: group 1: Transition Period (TP), group 2: Short Rain Period (SRP) and group 3: Dry Period (DP). The data were analyzed, processed and interpreted using SPSS software Version 22.0, Microsoft window Excel tool, statistical, Geographical Information Systems (GIS) and Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) methods. Water quality data were presented as mean values and evaluated based on guideline values to assess its suitability for drinking. Spatial and seasonal variations of examined parameters were descriptively analyzed. The results showed significant spatial and seasonal variations in some of the examined water variables (pH, chloride, fluoride, selenium, cadmium and electrical conductivity). Kruskal - Wallis H test was applied to test for seasonal variation in mean concentration values of water parameters where results were reported at 0.05 level of significance. Seasonally, the results indicated a statistically significant difference between the means of pH ($P = 0.001$) and cadmium ($P = 0.000$) but no significant difference for electrical conductivity ($P = 0.130$), selenium ($P = 0.981$), fluoride ($P = 0.293$) and chloride ($P = 0.228$) in ground water. Post hoc results showed significant existence of mean difference in pH between the TP and DP ($P = 0.000$) and TP and SRP ($P= 0.006$) while for cadmium there existed significant mean difference existed between TP and SRP ($P = 0.001$) and TP and DP ($P = 0.000$). For natural river water samples, Kruskal - Wallis H test results showed existence of significant differences between the means of pH ($P = 0.050$) and electrical conductivity ($P = 0.008$). However chloride ($P = 0.629$), cadmium ($P = 0.122$), fluoride ($P = 0.105$) and selenium ($P = 0.472$) did not show any significant difference. Post hoc results showed existence of significant mean difference in electrical conductivity between TP and DP ($P = 0.004$) and SRP and DP ($P= 0.016$) while for pH significant mean difference existed between TP and DP ($P = 0.034$) and SRP and DP ($P = 0.34$). Spatial distribution maps gave a pictorial representation of the spread of water quality parameters at different sampling points. Based on the CCME-WQI, index values for drinking water quality of river and ground water samples were calculated in a range of 20.94-39.69 and ranked as poor. Selenium, cadmium and fluoride were taken as important parameters impacting water quality as their concentrations were elevated. Aquifer geological formations and water quality characteristics showed spatial variation among the boreholes. Considering all examined variables, correlation results showed that correlation coefficient (r) values ranged from -0.85 to 0.70 in river water and -0.87 to 0.56 in ground water. The study concluded that the quality of river and ground water of the study area was mainly influenced by geological hydrogeological settings of the area, not potable and need proper treatment before consumption.

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LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS

AAS	Atomic Absorption Spectrophotometer
APHA	American Public Health Association
CCME-WQI	Canadian Council of Ministers of the Environment Water Quality Index
DWQI	Drinking Water Quality Index
CDN	Catholic Diocese of Nakuru
DP	Dry period
Ec	Electrical Conductivity at 25°C
GIS	Geographical information system
GISs	Geospatial Information Systems
GoK	Government of Kenya
GPS	Global Positioning System
KDHS	Kenya Health and Demographic Survey
KEBS	Kenya Bureau of Standards
KNBS	Kenya National Bureau of Statistics
NARUWASSCO	Nakuru Rural Water and Sanitation Services Company
NAWASSCO	Nakuru Water and Sanitation Services Company Limited
NEMA	National Environment Management Authority
NTU	Nephelometric Turbidity Units
RVWSB	Rift Valley Water Services Board
SIDA	Swedish International Development Cooperation Agency
SRP	Short rain period

TP	Transition period
UNDESA	United Nations Department of Economic and Social affairs
UNDP	United Nations Development programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational scientific and cultural organization
USEPA	United States Environmental Protection Agency
WWAP	World Water Assessment Programme
WRA	Water Resources Authority
WQIs	Water Quality Indices
WQI	Water quality index
WHO	World Health organization
WASREB	Water Services Regulatory Board
α	Acceptable statistical significance level

DEFINITION OF TERMS

Water supply network: A system of engineered hydrologic and hydraulic components which provide water supply.

Municipal water supply: A public water supply serving a municipality.

Precipitation and dissolution: The transfer of solutes between a mineral in solid phase and ground water.

Public drinking water supply distribution systems: A component of pipes and other conveyances that connect treatment plants to consumers' taps.

Public water supply: The Safe Drinking Water Act defines a Public Water Supply (PWS) as a system that provides water via piping or other constructed conveyances to the public for human consumption.

Public water system: One that serves piped drinking water to at least 25 people or 15 service connections for at least 60 days a year.

Water Quality index (WQI): A numeric expression used to evaluate the quality of water bodies and make it more easily understood by managers.

Water quality standards: A numerical concentration, descriptive statement or objective that is recognized in regulations or enforceable environmental law applicable at the international, trans- boundary, national and/or local level.

Water quality: The composition of constituents dissolved or contained within the water in the functioning of natural processes and human activities.

Water security: The capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability.

Water-quality monitoring: The process of sampling and analyzing water conditions.

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CHAPTER ONE

INTRODUCTION

1.1 Background Information of the study

The quality of drinking water is a powerful environmental determinant of health as well as an important parameter in management of safe water supplies (WHO, 2010). Therefore, appropriate knowledge on the overall status of drinking water quality is necessary for drinking water management and also important in respect to conservation of water ecosystems and sustainable development in a region (Megersa, 2018; Igor *et al.*, 2015; Oyem, 2014; Azrina *et al.*, 2011). In environmental studies, the quality of water is important in its daily use for human consumption and its ability to transport pollutants (Esi *et al.*, 2013).

Together with insoluble materials that are held in suspension, water contains a variety of soluble inorganic and organic compounds (Chapman, 1996). Therefore, in characterisation of water systems, there is need to evaluate major components that include hydrology, physico-chemical and biological characteristics (UNEP/WHO, 1996). Information on physical characteristics and ionic composition of water is important to ascertain its suitability for proposed uses (Abdul *et al.*, 2015; Aris, 2013; Anwar *et al*, 2011; Bartos and Kathy, 2002). In regard to drinking uses, water quality monitoring becomes important in evaluation of water quality problems in order to allow corrective measures to be taken when necessary. Traditionally, conventional methods are applied in data analysis where comparison of physical and chemical characteristics of a water sample are done in line with national and international criteria established for water quality standards (WHO, 2011; 1993; Shmueli, 1999).

One of the greatest challenges in the twenty-first century is availability of adequate supply of safe water to all users (Hongxing *et al.,* 2019; Igor *et al.,* 2015; Huang *et al.*, 2014; Salim *et al.,* 2014). The decline in water quality has become a global issue of concern as climate change causes major alterations to the water cycle, expansion of industrial and agricultural activities increase and human populations grow (UNDESA, 2015). There is also a growing concern on the factors that affect the quality of water for other various uses. Hence, for water quality control it becomes important that the relationship between water quality and health be fully appreciated by the engineers and scientists concerned (Behailu *et al.,* 2017). In addition, many scientists and researchers have opined that the quality of water available to a society is an important factor in determining the quality of life as a whole and measures should be taken inorder to achieve a drinking water quality as safe as practicable (Esi *et al.,* 2013; Vaishali and Punita, 2013; Neha *et al.,* 2013; WHO, 2011; 2004; 1996; 1993; Li and Zhang, 2009; UNDP, 2006; Watkins, 2006; UN WWAP, 2006). For public supply, information on water quality variability at spatial and temporal scales is an important aspect of water quality assessment and future trends prediction (Dixon and Chiswell, 1996).

In sub-Saharan Africa, many countries are considered water scarce when water requirements and the water resources of a country are compared. However, only “blue” water and not “green” water are considered in such analyses (Savenije and Hoekstra, 2000). Changes of water quality across time and space due to various natural and human influences is another issue of concern hence the need to understand the spatial and temporal variability of pollutants within aquatic systems for effective management (Gurjar and Tare 2019; Zhang *et al.*, 2009). This has increased the need for information on spatiotemporal variability of the pollutants and the driving influencing factors. It has also become a subject of water environment research around the world (Maria *et al.*, 2014; Pantelic' *et al.*, 2012).

Surface and groundwater composition are influenced by many similar factors related to natural processes and anthropogenic activities (Brooks, 2003; Van der Aa, 2003). In combination with environmental influence, the major natural factors that influence chemical composition of water are geological, hydrological and climatic as they affect the quantity and the quality of water available (Igor *et al.*, 2015; Rahmanian *et al.*, 2015; Wamalwa and Mutia, 2014; Damo and Icka, 2013; Ramesh and Soorya, 2012; Pink, 2006).

Quality of water varies widely over large regions where the variability is linked to changed concentrations of various physico-chemical parameters at spatial and seasonal/temporal scales (Hongxing *et al.*, 2019; Subramani *et al.*, 2005; Fetter, 1999). The need to identify the extent and underlying causes forms an important part of water quality monitoring. The monitoring process can provide spatially explicit information describing water quality conditions that can help in maintaining a safe and reliable source and gathering information for making decisions on water environment management. It is also important in assessing the levels of pollution and portability for human consumption, probable risk to the environment and for the sustainable management of water resources (Ouyang *et al.*, 2006; Vega *et al.*, 1998).

World-wide, various methods have been used in the field of water quality monitoring in regard to data collection but analysis and visualization methods of water quality data that can draw out meaningful conclusions remains a challenge (Hongxing *et al.*, 2019). Evaluation of long-term water quality changes is also a challenging problem (Biswajeet and Saied, 2011). Data inconsistencies and non-normal distributions make evaluation of water quality and analysis of its spatial temporal trends often difficult (Hongxing *et al.*, 2019). For this reason mixed methods research approaches are being widely used to guide the direction of collection, analysis and interpretation of data in studies that address same objectives to provide a better understanding of the underlying problems for sustainable management of water resources (Cameron and Sankaran, 2015; Salim *et al.*, 2014; Siyue *et al.*, 2009; Leech and Onwuegbuzie, 2008; Creswell and Plano, 2007). Physico-chemical parameters have also been used by many researchers in assessing the water quality status of freshwater systems using mathematical, computational, geostatistics, water quality indices and multivariate statistical techniques (Kitagaki *et al.*, 2019; Igor *et al.*, 2015; Salim *et al.*, 2014; Giriyappanavar and Patil, 2013).

Kenya is ranked a water stress country. The country's water supply and sanitation can be described by low levels of access to water and sanitation. Currently it is categorized as a water scarce country with less than 648 m^3 water supply per person per capital compared to global bench mark of 1000 m^3 per person per year. According to Marshall (2011) the country's per capita available water currently is at 650 m^3 per year which is below the global accepted value of 1000 m^3. Despite the fact that the country's socio-economic development is highly dependent on water, the water resources are scarce and vulnerable to depletion (UN -WWAP, 2006).

In Kenya, water quality possesses an equally great challenge as quantity. Dissolution of geologic materials results to water quality problems especially in ground water, making water unfit for human consumption, especially in areas experiencing high levels of fluoride and manganese ions (Davies, 1996). Other groundwater quality issues include over abstraction with associated problems of water level decline, water quality deterioration and elevated fluoride concentrations which mostly exceed WHO standards in most of the aquifers (Ministry of Water Development, 1992; Pavelic *et al.,* 2012). This is despite the fact that inorganic substances constitute the greatest proportion of chemical contaminants compared to organic substances in drinking water and are very important in water quality studies as they have both adverse effects on human population where the major mode of exposure is through drinking water (WHO, 2011).

Olago *et al.* (2009) observed that significant hydrological changes had taken place in the Central Kenya Rift region over the last 10, 000 years as a result of global, regional and local changes, but the impacts on groundwater resources were still largely unknown. Another challenge as observed by MacDonald *et al.* (2001) is that water resource data are deficient in the country. The problem is attributed to less data on groundwater, low number of gauging stations for rainfall and water levels in surface water bodies and nonfunctional existing stations. In addition, lack of information on the impacts of climate variability and anthropogenic factors on watersheds, significant gaps in climate data, poor hydrometeorological networks and data deficiencies as agencies often do not share data pose another challenge in accurate analysis and solutions. A report in the National water quality management strategy, 2012 -2016 confirms that lack of adequate and reliable information is a major challenge in Kenya in water quality management. A report by Water Resources Authority (WRA), whose mandate is now under Water Act, 2016 (No.43 of 2016) that technically repealed the Water Act 2002, in the management of water resources during the financial year 2012/13 emphasizes challenges in real time data collection that has led to lack of timely data sourcing and modeling.

An Environmental Impact Assessment (EIA) report for Kenya Rift Valley Water Supply and Sanitation project where the study area is located reported that water supply and delivery services suffer from a host of problems including water quality at the sources and along the supply chain. Lack of understanding of water quality problems was also highlighted where the problems were observed to be appreciated when there is a water quality crisis. Other challenges highlighted include; inefficient and ineffective data collection, handling, processing, storage and dissemination of information, lack of coordination, networking and sharing of data per information among all relevant stakeholders. According to the same report, water quantity is the major priority focus of water supply agencies but limited attention is paid to drinking water quality issues. Lack of well-equipped laboratories, water purification systems and the absence of a legal framework for drinking-water quality issues were also observed to have aggravated the situation (Rift Valley Water Supply and Sanitation project Appraisal Report, 2004).

Nakuru Municipality is located within Nakuru County which is known to have water quality problems especially for drinking uses (Madadi *et al.*, 2017; Benson and Isaac, 2017). Findings from previous studies confirm water resources of the area to be highly mineralized where the chemistry is controlled by natural processes, local environmental conditions with input from anthropogenic processes (Oketch, 2012; Kanda, 2010; Olago *et.al*, 2009). At present, the precursors of deterioration of the water-related environment in the larger Nakuru County as well as Nakuru Municipality are apparently posing a significant problem of quality, availability and distribution of this vital resource affecting large proportions of the town's residents. Drinking water access in many estates in Nakuru Municipality is below the required supply standards by NEMA (Onjala, 2002; Kimani and Ngindu, 2007). This forces part of the population to use unsafe drinking water whose quality and quantity is relatively unknown.

As reported by Onjala (2002) water quality problems of the area have reached a level where they impact on poverty levels, as well as the health and livelihood of the people. Besides causing an increase in water borne diseases and the emergence of suppressed demand conditions, the water shortages and poor quality have led to a scaling down of industrial activities.

In light of the above, to ensure clean and safe drinking water supply to Nakuru Municipality residents, sufficient and reliable information on the level of overall mineral content and drinking suitability of the water sources in use, influencing factors, changes over time and space of water quality variables is important hence the backdrop of this study. The focus was on selected river and groundwater drinking water sources that are potable in Nakuru Municipality.

1.2 Problem statement

Nakuru Municipality drinking water supply intakes lies in the larger Lake Nakuru basin and lower Baringo basin. Findings from previous research confirm that geological variations and volcanic activity that characterize the area give rise to high concentration of inorganic salts in water and soils which affects the salt content of surface and groundwaters (Olago, 2018; Kanda, 2010; Olago*et al.,* 2009; Clarke *et al.,* 1990; McCall, 2007). They also deduced a seasonal variability in characteristics of water constituents. Compounding the problem is the areas local geology that makes surface and subsurface flow systems interact resulting in mixing of their water qualities (McCall, 2007; SAPS, 2002; Clarke *et al.*, 1990). There is therefore need to evaluate the nature and the chemistry of surface and groundwater for drinking purposes due to the peculiar natural processes that characterize the area.

The primary sources of drinking water for Nakuru Municipal population among other uses are taps, streams, rivers and boreholes. However, despite their significance, there are limitations to the availability of a robust water quality database that can describe the overall quality in a reliable way due to limitations associated with the existing conventional water quality evaluation methods. In addition, information that can explain spatial, seasonal and temporal trends of river and groundwater quality for drinking purpose in an integrated way is insufficient. In addition, except the traditional water quality assessment methods by existing water agencies, there is not adequate documented work that has evaluated alternative drinking water quality data collection, analysis, processing and visualization of corresponding methods. In addition, according to the National water quality management strategy report 2012 – 2016, problems also exist in water quality management due to lack of adequate and reliable information. Water quality tests are also not regularly done for the public supply sources or not done at all for some private water supply systems. Considering the underlying problems of drinking water quality in the study area, it was necessary to carry out comprehensive research based on modern techniques at mixed scale for example combination of WQI, GIS and statistical methods for evaluation and management of drinking water sources. This can improve the efficiency of water quality monitoring, data analysis, interpretation and reporting protocols to overcome the existing limitations of traditional methods. It can also provide the right tools for water resource management that enable safe access to safe drinking water and effective sustainable management.

1.3 Objectives

1.3.1 General objective

To evaluate the quality of drinking water, spatial and seasonal variations using selected parameters, GIS, CCME-WQI and statistical techniques in Nakuru Municipality;

1.3.2 Specific objectives

1. To determine drinking suitability of untreated and treated river and ground water of the study area.
2. To evaluate and characterize quality of river and groundwater for drinking purposes using the CCME-WQI.
3. To evaluate spatial seasonal variations in river and groundwater quality using statistical methods.
4. To develop a spatial distribution map of examined water quality parameters using GIS techniques.
5. To identify borehole sites with potable water based on aquifer geologic formations and chemical quality of water.
6. To determine the correlation between rainfall trends and chemical quality of the parameters observed.

1.4 Hypotheses

The following hypotheses were tested in the study:

1. There is no difference in quality of treated and natural river and groundwater samples.
2. River and groundwater is not potable.
3. There is no significant seasonal variation in mean concentrations of examined water parameters.

4. There are no significant spatial concentration variations in river and groundwater quality parameters.
5. Chemical quality of groundwater is controlled by underlying aquifer geological formations.
6. Chemical quality of river and groundwater is not affected by rainfall.

1.5 Justification of the study

Despite the fact that the basic requirement for a healthy life of a human being at this moment is the adequate supply of drinking water with safety in its quality, which is the greatest challenge of the twenty-first century is to provide adequate supply of safe water to all users. Water quality as well as quantity have been causes of concern since ancient times and a subject of many recent studies not only for researchers but also for the society as a whole (Klimaszyk *et al.,* 2015; Maria *et al.,* 2014).

In view of the above, protection of water resources has been given topmost priority in the 21st century (USEPA, 2012) as availability safe drinking water is important in many aspects of life. Inorder to achieve sustainable management of safe drinking water supplies, information on water quality status and variability at spatial and temporal scales becomes an important part of water quality assessment and future trends prediction. But as observed by Megersa (2018) and Hongxing *et al.* (2019), suitable methods of water quality monitoring data analysis and information reporting protocols remain a challenge even after many years of world-wide monitoring experience.

Being generally a dry country with humid climate, Kenya endures severe water crisis and has been categorized as a water scarce country. Supply of clean water is one of the current struggles the country is facing and close to half of its population lacks access to safe drinking water. This despite the fact that several acts and reforms have been put into motion to aid Kenya's situation (GoK, 2009; KNBS, 2010).

Where natural water is not affected by human activities, the fundamental control on its quality are the types of organic and geologic materials it comes in contact with and the duration of this contact (Vandas *et al.*, 2002). Generally, without human influence, naturally occurring chemicals in form of mineral constituents are of special concern in drinking water from a health standpoint and also environmental health, therefore understanding their levels and variation in drinking water supplies is important. Studies by Alper and Orhan (2017) confirm geogenic factors to be the primary factors responsible for controlling the natural chemistry and thereby the quality of water resources.

Nakuru Municipality is not an exception to the challenges facing the country in regard to problems of water quality and quantity for various purposes (Madadi *et al.*, 2017; Benson and Isaac, 2017). Its water resources are also both scarce and unequally distributed through time and space. Geological formations of the area with input from anthropogenic influences have been confirmed to influence surface and groundwater quality, recharge, storage and availability (Olago, 2018; Oketch, 2012; Kanda, 2010; Olago *et al.*, 2009). According to Daniel *et al.* (2009), Kanda (2010) and Oketch (2012), the geological processes and variations that characterize Nakuru area together with secondary inputs for example, climatic, hydrological and geomorphological factors have undoubted impacts on surface and groundwater quantity and quality.

Considering the underlying water quality issues of the study area, knowledge of chemicals of natural origin and spatial seasonal trends becomes important for sustaining usable water supplies with respect to drinking uses. This is due to the fact that overall contaminants in basin-fill aquifers and surface water reservoirs from geologic sources are of great concern with respect to water for drinking. Their concentration continuously changes in response to various factors.

1.6 Scope of the study

The scope of this research involved assessment of Nakuru municipal drinking water supply intake points managed by NAWASSCO, private borehole owners and also along River Njoro, data collection, analysis and processing. In accomplishment of this scope; 1. Selected parameters (pH, fluoride, electrical conductivity, chloride, selenium and cadmium) were analyzed. 2. GIS, WQI and statistical methods were applied in data processing.

1.7 Significance of the study

Since not much research has been done in the area, the findings can be used as a baseline of representative and reliable information for the area concerning the status in drinking water quality. The findings can also be used as a baseline in marking out the best safe drinking water sources available and non-potable points. In addition the findings can be used as reference for predicting the quality of water for Nakuru Municipality in future and lay a baseline that is evidence based for water quality risk management and implementation of sustainable water use management strategies and supporting subsequent scientific research.

1.8 Location and description of the study area

Nakuru Municipality/Town is located in Nakuru County which lies in the central Rift Valley. The Municipality has an area of about 300 km^2 and Nakuru is the fourth largest town and one of the fastest growing metropolitan urban areas (ROSA project, 2007). It is located at latitude $0^0$15’ and $0^0$28’ South and longitude 36^0 0’ and $36^0$10’ East, 160 km north-west of Nairobi. The largest part of the town lies at an altitude of about 1700 meters above sea level. However the, altitude rises to about 1850 meters on the slopes of the Menengai Crater which is located in the northern part of the town. The Municipality boundary lies at latitude $0^0$15’30” and $0^0$30’15” South and longitude 36^0 0’ and $36^0$10’0” East (Figure 1.1).

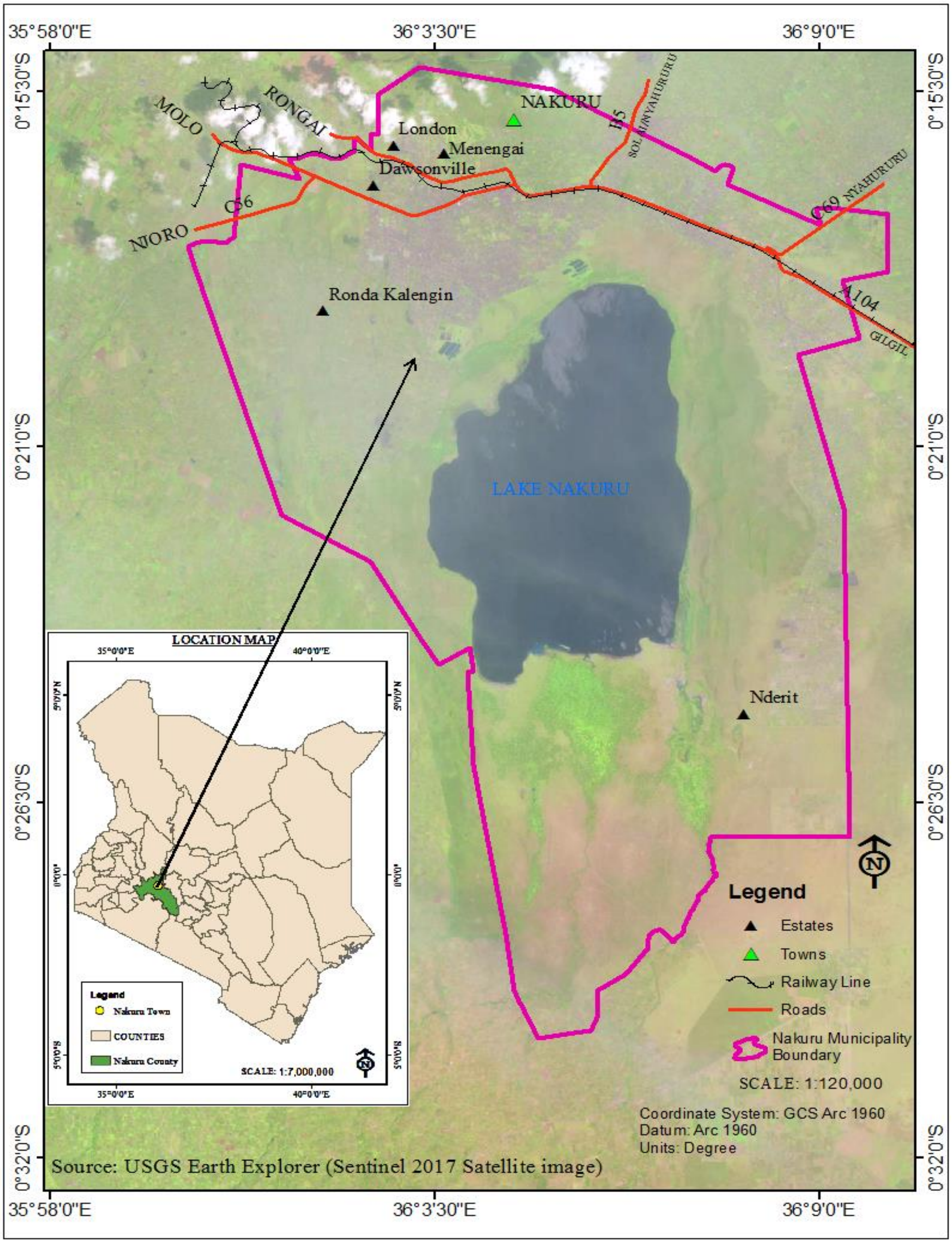

Figure 1.1: Location of the study area.

Source: USGS Earth Explorer (Sentinel 2017 satellite image)

The municipality is located in an environmentally sensitive area that is in the midst of a concentration of geographical features. To the south is Lake Nakuru National Park. To the North is the Menengai Crater and its associated volcanic landscapes. To the northeast are Bahati Highlands which forms the western fringe off the Aberdares Escarpment. To the south are Eburu Hills and Lake Nakuru and to the southwest is Mau Escarpment (Government of Kenya, 2009; 1997).

1.8.1 Temperature and rainfall

Nakuru County where the municipality is located has predictable weather patterns with annual temperature that ranges approximately from 8^{o}C to 30^{o}C. Weather data obtained from Nakuru Meteorological Weather Station during the period of study showed that the driest months are February, July and December. The lowest temperatures occur in July and August while the highest temperatures are from December to March. It experiences two rainy seasons that occur in April, May to August (long rains) and October to December (short rains). Rainfall has a tri- modal distribution with peaks centered in April, August and November. April peak being highest followed by August and November. The county receives between 700 mm and 1200 mm of rainfall annually with average annual rainfall of 960 mm. Evaporation is about 1736mm per year.

1.8.2 Population

Nakuru Town and its peri urban areas has been growing relatively faster in recent years in area size and population wise (NEMA report, 2011). According to available reports in

Eastern Africa, it is categorized as one of the fastest growing urban centers (Kimani and Ngindu, 2007). Report of the 2019 Kenya Population and Housing Census shows that it has a population of 570,674 inhabitants (KNBS, 2020). The population density was 974 persons per square kilometer with average household size of five persons (NDPP, 2010). Nakuru Municipality has four administrative locations namely Bahati, Kaptembwo, Lanet and Central, five sub-locations and 20,000 households (KDHS, 2010).

1.8.3 Geology and soils

The geology of Nakuru area comprises mainly volcanic soils and rocks (lava and pyroclastics) of Tertiary – Quaternary age, that have been affected by a series of faulting and are overlain by recent sediments (Kanda, 2010; McCall, 2007). The volcanic rocks are associated with the Rift Valley system and sediments of various ages. The volcanic rocks are silica rich, including much ash and pumice (Clarke *et al.,* 1990). Unstable geological zones experiencing frequent local geological faulting characterize the western zone of the town. The most affected areas of the municipality include the Central Commercial District which is located on the western side around Ngata, Kiamunyi and the Rift Valley Institute of Science and Technology. Soils are of volcanic origin, young, poorly developed, porous, light and poorly structured. The area is characterized by very low run-off due to the porous nature of the soils. As a result of the geological instabilities and the associated faulting, the Nakuru area and the Rift Valley region as a whole are highly vulnerable to earthquakes, land subsidence and land sliding (Raini, 2005). The volcanic formations consist of basalt, phonolite, phonolitic trachyte and trachyte flows, together with intercalated tufis and reworked tufts containing abundant water-rounded fragments. There is a further form of volcanic rock, widespread throughout the area, which may best be described as welded tuff (Olago, 2018; kanda, 2010, McCall, 2007; Alamirew *et al.*, 2007). Figure 1.2 shows geological map of Nakuru area and its environments.

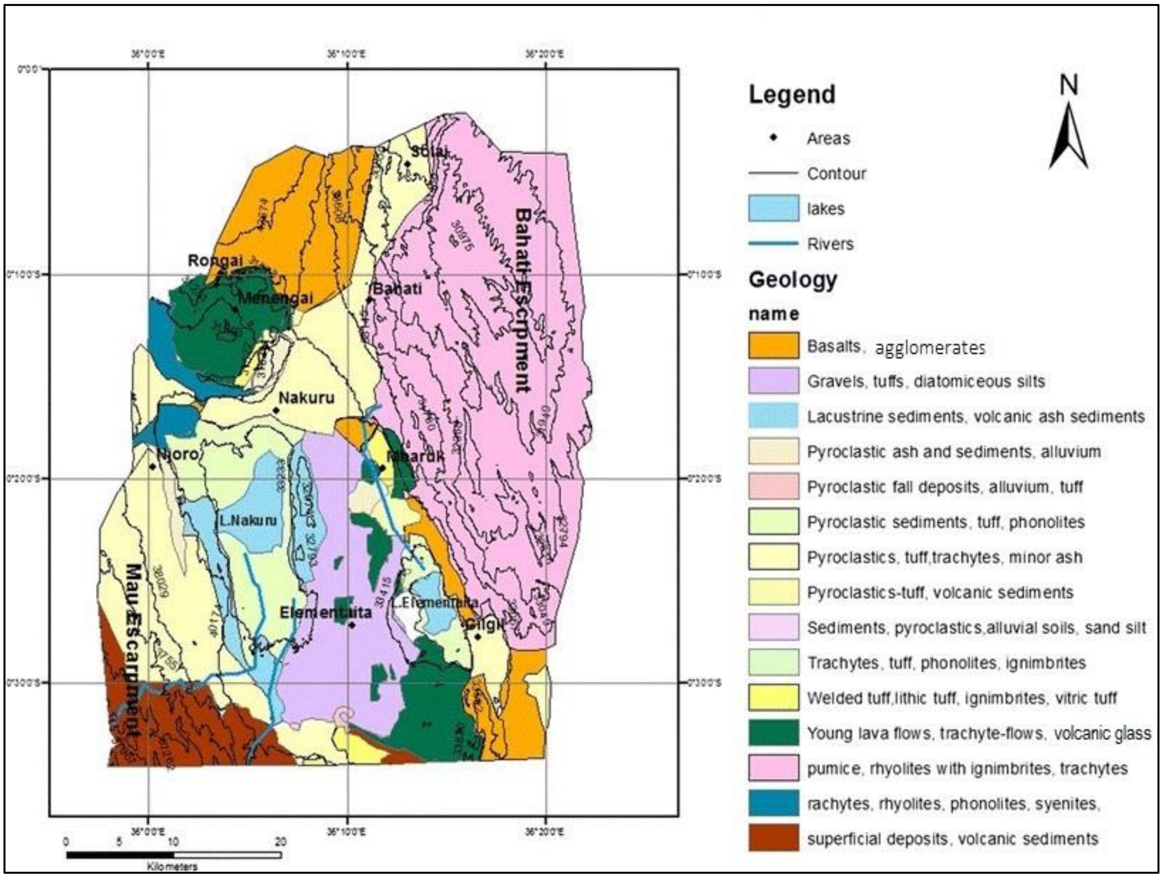

Figure 1.2: Geological map of Nakuru area and its Environments.
Adopted from Alamirew *et al.* (2007).

1.8.4 Aquifer types in Nakuru area

Types of aquifers in Nakuru area have been studied and characterized using driller's log data, groundwater flow maps and vertical sounding among other tools (Alamirew *et al.*, 2007; Kanda, 2010, Sosi 2010; 2019; Olago *et al.*, 2009). According to Kanda (2010) classification of aquifer distribution varies from single to three aquifer systems with three major aquifer lithologies which include fissured trachyte, volcano-sediments and pyroclastics. Rock types of aquifers in Nakuru area that encompass Nairobi, Leitmann and Nakuwell boreholes were categorized into pumice-tuff, tuff, trachytes and phnopholites (Kanda, 2010). Aquifer borehole geo-logs in Olobanita, Kabatini and Baharini (next to Lake Nakuru on the north-eastern side) areas indicate that the top brown soils and sediments are on the order of 10 m thick or more. Below them are lava flows of rhyolites, basalts, trachytes or phonolitic trachytes, with varying thicknesses, from thin (10 m or less) to thick (sometimes 30–40 m), that alternate with consolidated pyroclastic materials such as tuffs, agglomerates, ashes and their derivatives comprising loose tuffaceous sands or pumiceous gravels. These also comprise layers that are thin (5 m or less) to thick (>50 m). This series occurs up to depths exceeding 200 m (Olago, 2018; Sosi, 2010).

1.8.5 Geomorphological features

One of the major features is Lake Nakuru which is shallow, alkaline and saline with extremely high fluoride concentrations. The lake is located within the Nakuru National Park. Another major volcanic feature is the Menengai Crater which is also as a result of volcanic activity (Oketch, 2012; Kanda, 2010; Clarke *et al.*, 1990; McCall, 2007).

1.8.6 Hydrogeology

Water catchment of the lake is a component of an array of small, seasonal rivers, including the Enjoro and Ng'ossor which flow through the town. The areas hydrogeology is controlled by the local geology, tectonic processes, topography and climatic aspects. The geology in the Nakuru watershed does not have any large-scale aquifer formations hence ground water resources are marginal and expensive to exploit. The area is of medium ground water potential and aquifer yields generally vary with depth (Pavelic *et al.*, 2012; Ministry of Water Development, 1992). The recharge of the aquifers is mainly from local sources, by percolation of rainfall downward through fissures until porous stratum is reached (Pavelic *et al.*, 2012). Formations of depressions in the ground, disappearance of surface water into fissures and alignment of some rivers and springs along faults have been confirmed (McCall, 2007). The fault zones influence the groundwater strongly, each fault acting like ruble-filled drain and causes trough-like depression of water table along its length. Hence the rivers and streams lose water in the fault zones.

1.8.7 Surface and ground water recharge

McCall, (2007); SAPS, (2002) and Clarke *et al.* (1990), confirm that the areas ground water recharge is mainly through seepage from the bottom of lakes, rivers and streams. Recharge of lakes and rivers is through groundwater inflow and direct rainfall. The recharge varies with rainfall (altitude) and geological variations. Secondary phenomena include structures/cavities, soil, vegetation type, rock mineralogy and degree per end product of weathering.

1.8.8 Nakuru Town drainage system

The town’s drainage system is a component of man-made and natural drains but part of it is discharged to underground reservoirs slowly through normal seepage and rapidly through the geological faults. Further, when heavy rains occur, natural drains becomes the means through which runoff is discharged to Lake Nakuru. The natural drains are numerous and in many instances they run into physical developments especially in high-density low-income areas. Problems of surface drainage are common in the town where there is no elaborate drainage system. Physical development between the Menengai crater and Lake Nakuru has further complicated the storm water drainage situation by reducing the amount of normal ground seepage. Generally, there is inadequate storm water drains and poor maintenance of the existing networks results to flooding and damaging of roads (NDDP, 2010; ROSA Project, 2007; MCN, NAWASSO, KWS and JICA, 2009). Access to improved sanitation facilities is low such that out of the existing toilets, 51% are unimproved pit latrines. Due to the sandy soils that characterize the area, pit latrines contaminate ground water through faecal sludge and urine that percolate to the ground water table (Kihumba, 2007).

1.8.9 Nakuru Municipal drinking water supply

Intakes of Nakuru Municipality drinking water supplies are located in the larger Lake Nakuru basin that has an area of 1800 km^2 and in the lower Baringo basin in a sub basin area of 6.25 km^2. Untreated and treated piped water from rivers and boreholes are mainly the primary drinking water sources in Nakuru Municipality. Other water supply sources include rainwater, several springs, water pans and shallow wells where the drinking suitability of the water cannot be ascertained (Olago, 2018; CDN, 2005). Several agencies responsible for water quality exist and they target areas concerning water supply, sewerage system, industrial effluent, rivers and the lake. These agencies have clear objectives for water quality monitoring (NEMA, 2011). Among them is NAWASSCO the water provider of treated water to the town and its peri-urban areas which the municipality has given the role to provide clean and reliable safe drinking water supply to all users. The company's service area extends beyond the municipality's boundaries (NAWASSCO, 2007). The total target service area is 320 km² (270 km² - municipality service area and 50 km² peri–urban areas). The current water supply system, however, only covers an estimated 250 km². Piped water is limited to urban areas at Nakuru Municipality but the operational section of the company entails all of Nakuru Town, including both high and low income areas. The company produces approximately 40,000 cubic meters of water per day against the current water demand of 70,000 cubic meters. Therefore, only 57% of the Municipality's water demand is met and part of the population has to rely on other water supplies that are usually not treated (Andati, E. personal communication, June, 2014). According to Andati, E. (personal communication, June, 2014), NAWASSCO gets water from two water sources (several rivers and boreholes which are spatially distributed) among the boreholes, the Kabatini boreholes supply are the main supplies of the water required for Nakuru Municipality. Private and community borehole providers supplement inadequate supply where people buy water or directly get water from rivers or boreholes/wells. Other sources of water are rainwater and run-off water.

Water supply is mainly by rationing and the frequency is skewed. The low income neighbourhoods which NAWASSCO refers as pro-poor, are not connected to the water supply system (KNBS, 2010; ROSA PROJECT, 2007). The company (NAWWASCO) has a special department which focuses on these pro-poor areas inorder to make water available through alternative methods, like water kiosks and pre-paid water meters. The areas include Kaptembwo, Rhoda and Lanet settlements. In Rhoda regular water supply is only accessible to 4% of the residents but 50% rely on river water and 46% on water vendors where the cost of water is Kshs. 20 per 20 liters (Onjala, 2002). More so the cost of the water is relatively high compared to the water supplied to dwellings by NAWASSCO.

Other alternative water providers include donkey carts, water bowers (water tanks), water bikes or community based water kiosks. Some of the residents fetch water for domestic use from Ndarugu River, which is highly polluted, risking infection from water-borne diseases.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

2.1.1 Water supply

Water is the most abundant natural resource on the surface of the earth and is classified as one of the most essential needs of human beings. However, access to adequate, clean and safe drinking water supplies remains a challenge to most of the population (WHO, 2006). World-wide, in respect to public health safety, safe drinking water supply and access is a significant aspect hence a key objective of water supply systems (Jayyousi, 2001). In addition, quality of drinking water is a powerful environmental determinant of health and maintenance of safe drinking water remains a key requirement for public health (WHO, 2011; 2006; 1993). Quality of water at source and also contamination throughout its way to the user and practices related to purification and sanitation determines the availability of safe drinking water (Mishra and Nandeshwar, 2013).

Various physical, chemical and biological parameters affect water quality in regard to various uses (*Bediet et al,*. 2012; Hanaa *et al.,* 2000; Chapman, 1996). In regard to drinking water, these parameters are of serious concern. However, concerns on health issues associated with drinking water, chemical constituents are most important as compared to those associated with microbial contamination as they can cause adverse health effects after prolonged periods of exposure (WHO, 2011; 2006).

In examination of the top-priority problems of water quality, economic, human health, ecosystem and geographical influence as well as duration of the influence are some of the most important aspects taken into consideration (Dalmacija and Tumbas, 2004; Demayo and Steel, 1996).

Many physical and human factors influence water supply and water composition in time and space. Therefore it becomes important to test water before use. Different physical and chemical variables are taken in to consideration in testing of water depending on the purpose of use, extent of quality and purity (APHA, 2012; WHO, 2006). Physicochemical parameters with respect to drinking water quality play important roles as indicators of surface and groundwater contamination. In addition, reliable analytical measurements of water quality parameters are required in assessment and improvement in the quality of water used for human consumption and agriculture (WHO, 1996).

The types and concentration of dissolved constituents determine the suitability of water for various uses (Mirribasi *et al.*, 2008; Hanaa *et al.*, 2000). The status of water quality can be described based on the concentration and state (dissolved or particulate) of some or all of the organic and inorganic material present together with certain physical characteristics of the water. Water quality can be determined by in situ/on-site measurements and laboratory methods. Analytical results for each single water sample are only valid for the particular location and time at which a sample was taken (Chapman, 1996; UNEP/WHO, 1995; 1996; 2002; 2008). In regard to monitoring of water resources and for ensuring sustainability, criteria and guidelines established for water quality standards at national and international are used (Behailu et al., 2017; WHO, 1993; 2006). Also for maintenance of good health, water for drinking uses should be safe and meet the local and international standards of taste, odour and appearance.

2.1.2 Components of water supply systems

Mainly, a water supply system consists of three basic components: the source of supply, the processing or treatment of the water and the distribution of water to the users. Water from the source is conveyed to the treatment plant by conduits or aqueducts, either by pressure or open-channel flow. Following treatment, the water enters the distribution system directly or is transported to it via supply conduits. Quality of water depends on many factors at the point of consumption which include conditions of the raw water source and its watershed, seasonal variations, treatment system and the storage practices at the household and consumer level (Behailu *et al.*, 2017; Mkandawire and Banda, 2009; Suthar *et al.*, 2009; Pritchard *et al.*, 2008; Ibe *et al.*, 2002).

Jordaan *et al.* (1993) articulated water quality problems as causing a great strain on water supply systems as all water supplies vary in the type and concentration of mineral substances. Therefore, monitoring of water quality parameters in a catchment can generate important information for water management as the composition of water quality is a function of hydrogeochemical processes acting within the catchment.

2.2 Surface and groundwater quality

2.2.1 Groundwater quality

Groundwater is highly variable in chemical composition and the variation occurs both spatially and seasonally (Oyem *et al.,* 2014; Ocheri and Idoko, 2012; Venkatesharaju *et al.,* 2010). Its quality and quantity determines its uses such as for drinking, domestic, agricultural, industrial and touristic purposes (Pazand *et al.*, 2011). Naturally, its quality is influenced by the geological formation in which the aquifer occurs. The underlying geology (rock types) of the basin determines the chemistry of the watershed with respect to water and soil and ultimately its streams and lakes (Damo and Icka, 2013; Oketch, 2012; Kanda, 2010; Olago *et al.,* 2009; SAPS, 2002; Davies, 1996; Edmunds and Smedley, 1996). Therefore, the chemistry of groundwater can directly be rated with the source of water, climate and geology of the region.

Practically, water mixes with a variety of dissolved and particulate materials as it travels through the rocks and soils in a watershed, flowing down the stream channel. Groundwater mainly contains more dissolved minerals than surface water as it is always in contact with rocks and minerals and moves more slowly than surface water—centimeters per day instead of kilometers per hour (Swarna and Nageswara, 2010; Weight, 2008; van der Aa, 2003).

Groundwater in some regions contains specific ions like fluoride, toxic elements like arsenic and selenium in quantities that are harmful to health, while in other area it contains elements that cause other problems (Hoko, 2008). The most measured dissolved inorganic constituents of groundwater includes major components (calcium, magnesium and sodium which are cations, bicarbonate, sulphate and fluoride which are anions and dissolved silica), minor components (boron, carbonate, iron, nitrate, potassium, strontium) and trace components (aluminium, arsenic, barium, beryllium, bromide, cadmium, chromium, cobalt, copper, lead, lithium, manganese, nickel, phosphate, selenium, zinc and others). Groundwater commonly exhibits several characteristic of quality attributes such as variable salinity, low pH, dissolved metals and a degree of hardness (Desalegn, 2014).

2.2.2 Surface water chemistry

Climate (evaporation-crystallisation processes), geological formations, soil and soil forming processes, fluvial processes, atmospheric deposition and humans activities are some of the factors that influence surface water chemistry (Howari and Banat, 2002; Zare *et al.*, 2011; Chapra, 1997). Under the influence of major environmental factors for example climate, vegetation and rock composition, the concentrations of many water elements are liable to change at spatial and seasonal scales. At periods of base flow conditions in streams, dissolved solids concentrations are high since most of the source water is from groundwater which often has higher levels of dissolved solids. However, when stream flows are high due to recharge from rain or snowmelt, levels of dissolved solids are typically low (Mirrabasi *et al.*, 2008).

2.3 Ions and dissolved solids in water

2.3.1 Weathering

Weathering of sedimentary rocks and the erosion of the earth's surface are the major sources of dissolved solids in water. Other types of dissolved solids may originate in rain. The types of dissolved ions in water are mainly related to the mineral assemblage of the underlying or surrounding rock (Appelo and Postma, 1993). The solubility and rate of dissolution of minerals is high where the climate is warm and wet. pH also affects the rate of weathering reactions such that a decrease in pH increases the weathering rates and increase in pH decreases the weathering rates. Dissolved carbon dioxide, the presence of organic acids and the extent of weathering determines the pH of weathering solutions.

2.3.2 Atmospheric pollutants

Sources of gases emitted to the atmosphere include burning of fossil fuels, metallurgical processes and other anthropogenic activities. Other sources are from biochemical processes in soil and water as well as volcanic and geothermal activity. The presence of these gases in the atmosphere can affect the chemical properties of rainwater and eventually the quality of surface and groundwater through precipitation (Zhang *et al.*, 2007; Safai *et al.*, 2004).

Natural sources of particulate matter in the atmosphere include terrestrial dust carried by the wind or dust emitted from volcanoes and salt that is picked up from wind agitation of sea water. Other sources include anthropogenic processes like discharge from industrial plants and vehicle emissions (Ahmed *et al.*, 1990; Pink, 2006; Hogan, 2010). Particulate matter in the atmosphere forms nuclei for the condensation of water, which are also sources of solutes in precipitation and influence surface-mediated chemical reactions.

2.3.3 Effects of atmospheric deposition on surface and groundwater quality

Atmospheric deposition involves removal of pollutants (gases and particulates) from the atmosphere. It provides a pathway of the pollutants to aquatic and terrestrial ecosystems. The compounds (dust, trace elements, organic compounds, acids, gases) can have negative effects to the quality of surface water depending on types of soils and rocks in a given water basin (Wetang'ula and Wamalwa, 2015). In regard to aquatic ecosystems it can cause problems of acidification and eutrophication (WMO, 2021). Where soils have little capacity to buffer acids in water, response of natural ecosystems to acidic precipitation can be a problem. This is because the infiltrating acidic water can increase the solubility of metals resulting in the flushing of high concentrations of dissolved metals into surface water. In addition, acid deposition can accelerate the mobilization of some trace elements in soils for example aluminum, impacting on the soil water solution (Wetang'ula and Wamalwa, 2015).

2.3.4 Trace Element Enrichment Factor Calculation

Enrichment factors are very good indicators of natural or anthropogenic pollution and they have increasingly been used to identify geogenic and anthropogenic element sources in environmental sciences (Chabas and Lefevre, 2000). Together with natural sources and anthropogenic influencing factors, various enrichment factors influence concentrations of metals and ions in the environment. The enrichment factors are normally used in identification of origin of an element in precipitation (Zhang *et al.*, 2011). Their determination can show the degree of enrichment of a given element compared to the relative abundance of that element in crustal material.

2.4 Spatiotemporal variability of water quality

Being a dynamic medium, water has a high degree of natural variability where the quality varies at spatial and temporal scales. The concentration and variation of water quality parameters can be linked to natural processes and anthropogenic activities (Huang *et al.*, 2014; Cooke *et al.*, 2005; Subramani and Damodarasamy 2005; Bartram and Ballance, 1996). The intrinsic features of a given environment are also important factors that affect the state of chemical composition in water (Chaudhry and Malik, 2017; Klimaszyk *et al.*, 2015).

Temporal changes in chemistry of surface water bodies vary with time. The variations can be explained by the processes that control the supply of solutes available for leaching. The dynamics, variations with climate and season of hydrological processes that support the generation of runoff within a catchment are also important factors in temporal variability in surface water quality (Dan *et al.,* 2014; Chapman, 1996). In addition, spatiotemporal variability in quality of river and groundwater can be explained in terms of periodical changes and origin of the water recharge, climate variability, geomorphology, weathering processes and contamination from surface drainage together with anthropogenic inputs (Behailu *et al.,* 2017; Barakat *et al.,* 2016; Ayanew, 2008). Types of temporal variabilities in water can be described as minute to minute or day to day variability that results from water mixing and fluctuations in inputs mostly linked to meteorological conditions and capacity of different water bodies. Diurnal variability (24 hour variations) as applies to biological cycles, light per dark cycles (for example O_2, nutrients, pH) and to cycles in pollution inputs (for example domestic wastes). Days-to-months variability where climatic factors are the major controls (river systems, lake ecosystems, point’s sources of pollution for example industrial wastewater and run-off from agricultural land). Seasonal and biological cycles mainly as influenced by climatic factors. Year to year trends.

Spatial variability entails geographical locations of sites where samples are collected from. Geographical variations of sampling sites creates spatial variations for example where the subject of study is streams, lakes, reservoirs and groundwater aquifers (Dan et *al.,* 2014; Chapman, 1996).

2.4.1 Hydrological variability and sampling frequency

Stream flow types and cycles in seasons can have influences on quality of various water reservoirs. For good representation of quality where the subject is water reservoirs, sampling requires an account of a range of hydrologic conditions because the quality of water responds rapidly to short-term changes in flow (Mahesh and Bandela, 2016). For stream flows, variability in water quality mainly results from changes and relative contributions in the sources of water (storm flows containing catchment runoff verses base flows). Groundwater is an important contributor to flows in many rivers and wetland systems and as compared to surface flows, it is a relatively constant and stable source of water (Brooks, 2003). Groundwater flows can maintain water levels in ecosystems during extended dry periods though its quality varies and can often contain higher salinity levels, dissolved nutrients and metals than surface water runoff. Therefore, water quality in river systems and wetlands can vary depending on the relative proportion of groundwater contributions to surface inflows.

Other factors like weather conditions, sample type, analytical errors, land use and land management practices also contribute to variation in water quality data (Bartram and Ballance, 1996).

2.5 Water quality indicators

The quality of a water source is usually described by physical, chemical and biological indicators (Edmunds and Smedley, 1996; Pharino, 2007). A number of criteria are used in general assessment of water quality (mineral content, dissolved metals and turbidity). The procedure of water quality testing involves sampling of water and taking the samples to laboratories to measure the concentrations of potential contaminants.

This study focused on chemical quality and spatial seasonal variability of variables that are some of the most important parameters of water quality in regard to drinking uses (WHO, 2002). Parameters considered included, pH, Conductivity, fluoride, selenium, chloride and cadmium.

2.5.1 pH

pH measurement relates to the acidity or alkalinity of the water. Acidity in a given sample is considered where the pH is below 7.0, neutral if at 7.0 and alkaline if above 7.0. The permissible limit value of drinking water pH range is between 6.5 and 8.5 (WHO, 2011; NEMA, 2006). Values of 9.5 and above indicate high alkalinity while values of 3 and below indicate acidity. Acidic water can lead to corrosion of metal pipes and plumping system. Low pH values help in effective chlorination but cause problems with corrosion. Values below 4 generally do not support living organisms in the marine environment. Careful attention to pH control is necessary at all stages of water treatment to ensure satisfactory water clarification and disinfection (WHO, 2011).

2.5.2 Electrical conductivity

Electrical conductivity is a measure of the capacity of water to conduct current and it is also one of the most useful and commonly measured water quality parameters. Its sources can be natural or man made dissolved substances and its concentration reflects the level of dissolved ions in water (Lenntech, 2014; Odiyo *et al.,* 2012; Dallas and Day, 2004). Electrical conductivity can alter the taste and also cause hardness in water. In aquatic studies, its measurements can give information on the level of dissolved ionic matter. Low values of conductance are characteristic of good water quality but high levels can be an indicator of salinity problems and increased amounts of plant nutrients (Facklam and Collins, 1990). WHO (1998) permits 500 µS/cm as maximum allowed for drinking water. Inorganic dissolved solids that include chloride, nitrate, sulfate and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron and aluminum cations (ions that carry a positive charge) affect the level of conductivity in water. Organic compounds like oil, phenolics, alcohol and sugar are poor conductors, therefore have a low conductivity when in water (Dallas and Day, 2004). Temperature affects conductivity by increasing ionic mobility as well as the solubility of many salts and minerals. Temperature also affects ionic concentration of conductivity such that the warmer the water, the higher the degree of conductivity which increases by 2-3% for an increase of 1^0C of water temperature. Many conductivity meters nowadays automatically standardize the readings to 25^0C. Practically, conductivity is reported as conductivity at 25 degrees Celsius (25^0C) (APHA, 1998). The total salts content or specific cations and anions content are expressed as electrical conductivity (EC) at 25°C.

Lenntech (2014) reports that its concentration does not provide any information about the ion composition in the water despite being a good indicator of the total salinity. Its units of measurement are micromhos per centimeter (µmhos/cm) or microsiemens per centimeter (µS/cm). The equation is expressed as;

conductivity = conductance X probes cell constant (K)

$$\text{or Conductivity} = \frac{\text{electrical current}}{\text{voltage}} \times \frac{\text{distance}}{\text{area}}$$

2.5.3 Temperature

Temperature is considered a critical parameter in analysis of chemical and physical quality of water (WHO, 2008). The suitability of water for many purposes is influenced by the level of earth’s temperature or chemical reaction. In groundwater, temperature tends to increase with increasing depth to the aquifer. In general, temperatures of shallow ground water show some seasonal fluctuation whereas temperatures of ground water from moderate depths remain near or slightly above the mean annual air temperature of the area. In deep wells, the water temperature generally increases 1^{o} C for each 18.28 m to 30.48 m of depth. Temperature is a reflection of climate except where there are thermal discharges.

Water of low uniform temperature is a prevalence for many consumers but an aesthetic objective is set for maximum water temperature to aid in selection of the best water source or the best placement for a water intake (WHO, 1993). Since palatability of water is enhanced by its coolness, it is accepted that the temperature of drinking water should not exceed 15^{o}C, WHO (1996) recommends water with a temperature between $19\text{-}32^{o}$C as ideal for human use.

2.5.4 Fluoride

Fluoride is present in many types of waters but higher concentrations usually occur in underground waters. Variability in its levels occurs in dry and rainy seasons depending on degree of interaction of ground water with volcanic rocks. Its presence in river water is mainly associated with various human activities. Depending on several factors, its levels in drinking water vary very much at large and small scales. The dissolution of fluoride ions in ground water is determined by the chemical composition of the water, the presence, accessibility of fluoride ions to water and the contact time between the source mineral and water (Jha *et al.*, 2011). Though concentration of fluoride in water is limited by fluorite solubility, warmer temperature results into increased solubility, evaporation and fluoride concentration (Chae *et al.*, 2006). Presence of sodium hydrogen carbonate and alkaline volcanic rock with minerals containing fluoride increases the solubility of fluoride ions and removes aluminum which could have formed precipitate complexes. Also, where concentrations of calcium and magnesium are low, precipitation of fluoride complexes tends to diminish (Cotruvo and Bartram, 2009). Presence of easily leachable fluoride in water bodies usually occurs in areas experiencing explosive volcanic eruptions with ash and lahar (Jarvis *et al.*, 2013).

Elevated fluoride levels are usually in areas with calcium-poor aquifers and fluoride-bearing minerals. The levels may also increase where cation exchange of sodium for calcium occurs especially in groundwater. Other areas with elevated levels include geographic belts with sediments of volcanic rocks, granitic and gneissic rocks and marine origin in mountainous areas (Edmunds, 1996). Well documented areas associated with volcanism follows the East African Rift system from the Jordan valley down through Sudan, Ethiopia, Uganda, Kenya and the United Republic of Tanzania. Also, most of the soda lakes in the Rift Valley system have extremely high fluoride concentrations that ranges from 1,640 mg/1 to 2,800 mg/1 (Allen and Daring, 1992). In Kenya, Lakes Elementaita and Nakuru have been noted to have fluoride concentrations of up to 690 mg/1.

In regard to water for drinking purposes, maximum permissible limit of 1.5 mg/l has been recommended (WHO, 2011; 2006; 2004; 1993). Small to minute quantities of fluoride reduce the incidence of tooth decay when the water is consumed during a child’s period of tooth enamel calcification. However, elevated levels as compared to the set guideline value can lead to skeletal fluorosis and increase the risk of dental fluorosis (Dhar and Bhatnagar, 2009).

2.5.5 Cadmium

Cadmium is carcinogenic in nature, water soluble, more mobile compared to other heavy metals and a minor component of surface and groundwater (Stewart, 2003; WHO, 1992). Natural and anthropogenic processes influence its release to the environment. Natural factors include volcanic eruptions, weathering of rocks and to a lesser extent through atmospheric deposition (Geerke and Gabriela, 2012). Anthropogenic sources include incineration of waste and mining, smelting, and refining sulphide ores of zinc. Sources of cadmium in water environments include eroded soils, weathered bed rock, atmospheric deposition and directed discharges from industrial processes (electroplating, paint-making, manufacture of plastics), leakage from landfills, contaminated sites, dispersive use of sludge and fertilizers in agriculture. Sediment materials are also significant sinks for cadmium emitted to the aquatic environment for example through industrial discharges (WHO, 1992; 1993). Its effects on health and environment are acute and chronic that may exist in water as hydrated ions or inorganic complexes.

2.5.6 Chloride ions

Chloride ions occur in water combined with calcium, magnesium or sodium. They have high mobility in connection with the very high solubility of chloride salts of sodium, magnesium and calcium. Chloride salts are mainly water soluble where the concentration ranges from 10 to 100 mg/l. In natural waters, presence of chlorides can be attributed to dissolution of salt deposits in the form of ions (Cl^-) and the atmosphere (Fetter, 1999). Other related processes include leaching from minerals, rocks and saline deposits (Panno et al., 2006). Atmospheric precipitation, industrial and municipal wastes are also important sources. Generally, chloride ions occur in all types of water in concentrations from parts of mg/l to hundreds of g/kg^{-1} (in brines).

Suggested maximum contaminant level (SMCL) for chloride is 250 mg/l which is due strictly to the objectionable salty taste produced in drinking water (USEPA, 1994). The standard is not health-related, but set to avoid taste and corrosion potential. Chloride levels in water with respect to drinking uses can be decreased by treating water or finding another water supply.

2.5.7 Selenium

The source of selenium is mainly from weathering of rocks and soils. It is often present in association with sulfur containing minerals in the earth's crust. Increased concentrations are associated with volcanic, sedimentary and carbonate rocks (Stillings et al., 2017). In soils, there is wide variation of selenium concentrations as sited in literature but usually higher in soils of more recent volcanic origin (Geerke and Gabriela, 2012; UK EGVM, 2002). Low levels of selenium can end up in soils or water through weathering of rocks (USEPA, 1992). Selenium inputs into soils and waters increases as a result of atmospheric deposition and direct discharge from waste that tends to end up in the soils of disposal sites (Philip *et al.*, 1993). Selenium in soils remains fairly immobile where there is no reaction with oxygen hence cannot dissolve in water becoming less of a risk for organisms. However, there is leaching of selenium in areas with well-aerated alkaline soils that favour its oxidation. In high concentrations, selenium acts as an environmental contaminant.

It is an essential biological requirement needed in very small concentrations. High amounts can be toxic and can cause a variety of illnesses. Effects of selenium toxicity are similar to those of arsenic where the toxic effects of long term exposure in humans are manifested in nails, hair and liver. In concentrations of up to 400 µg/day, selenium is important in human and animal nutrition but a moderate excess > 400 µg/day may be harmful or potentially toxic if ingested for a long time (WHO, 2004).

2.6 Drinking water quality

In any water supply planning, quality of water for drinking uses is more important compared to quantity. The aspects of water quality that define its fitness for particular kind of use are the components of its chemical composition (WHO, 2011; UNEP/WHO, 1996). Practically, determination of water quality involves comparison of physical and chemical characteristics of a water sample with water quality guidelines values or given standards (Shmueli, 1999).

At international and national level, water regulations become important in provision of drinking water that is sufficient in quantity, safe, accessible, acceptable, affordable and reliable to all users. The regulations are important in control of water supply systems.

Each country regulates its drinking water differently depending on the quality of water source. Standards for water quality have been developed to manage the known chemical and microbial risks to human health. Safe drinking water does not mean risk free but simply denotes risks that are very insignificant such that they cannot result in serious health problems (Chapman, 1996). Drinking water quality standards are therefore the references that ensure the delivered water will not pose any threat or harm to human health. Water quality standards can be described as a framework against which a water sample can be considered satisfactory or safe for use (Megersa, 2018).

Generally, guidelines and standards for drinking water quality are designed to enable the provision of clean and safe water for human use, in reference to aesthetic quality and health significance of selected chemical parameters (UNDESA, 2015; USEPA, 2012). The terms quality criteria, concentration standards, maximum allowable concentrations (MAC) and maximum allowable levels (MAL) are used to represent standards of pollutant concentrations adopted in various countries.

In monitoring and ensuring sustainability of water resources, national and international criteria guidelines established for water quality standards are used (WHO, 2011; 2004; NEMA, 2006). Though each country has its own guideline values which relate to the WHO standards, natural quality of the water and the capacity of the chemicals that water provider's use guide the design of national standards.

The constituents which are indeed of concern can be determined by carrying out a water quality assessment by referring to natural water quality, human health and intended uses (Gazzaz *et al.*, 2012). In addition, identification of the types of drinking-water systems in place in a country (piped water supplies, non-piped water supplies, vended water) and the quality of drinking-water sources and supplies is important. Table 2.1 shows drinking water quality standards set by WHO and NEMA.

Table 2.1: WHO and NEMA Drinking Water Quality standards

Parameter	**Category of parameter**	**Units**	**WHO Acceptable limit (2004)**	**KEBS/NEMA guideline value (Maximum permissible) (2006)**	**WHO Maximum permissible limits (2011)**
Ph	Chemical	pH scale	6.5 – 8.5	6.5 – 8.5	5.5 – 9.5
Conductivity	Chemical	(25^oC) µS/cm max	500	-	2500
Chloride	Chemical	mg/l	250	250	250
Fluoride	Chemical	mg/l	1.5	1.5	1.5
Selenium	Chemical	mg/l	0.01	0.01	0.0
Cadmium	Chemical	mg/l	0.003	0.01	0.003

Source: adopted from NEMA (2006), KEBS (2007) and WHO (2011)

2.7 Methods of water quality data analysis

The limitations associated with the conventional water quality evaluation methods makes it difficult to determine the overall suitability of water against various uses. Also the separate interpretation of water quality parameters is usually a difficult task for the general public as well as decision and policy makers. Evaluation of water quality becomes difficult when there are a large number of samples, each containing concentrations for many parameters (Ahmad *et al.,* 2012). Description of water quality data, analysis and presentation in a simple and consolidated way still remains a challenge for researchers and scientists.

Many researchers in the field of environmental water research have adopted alternative techniques in a move towards solutions that can enable effective reporting on the state of water quality to managers and the public in a consistent manner without losing its scientific basis. Another aim is to turn complex water quality data into information that is understandable and useable by the public (Hongxing *et al.,* 2019; Salim *et al.,* 2014; Siyue *et al.*, 2009; Leech and Onwuegbuzie, 2008; Creswell and Plano, 2007).

2.7.1 Water Quality Index (WQI) methods

WQI combines multiple water-quality factors into a single number by normalizing values to subjective rating curve and gives comprehensive information on quality of a given water sample at certain time and locations that are acceptable. It can also be used to model and interpret water quality data into information that is easily understandable and useable by the general public and decision makers. Therefore, its calculation is very important as it evaluates the quality of water in a better and understandable way and provides possible uses of a given water body (Megersa, 2018; Sureja *et al.,* 2018).

Many agencies responsible for water supply and water pollution control have strongly alluded to its use (Satish *et al.,* 2017; Sureja *et al.,* 2018; Lai, 2011; Cude, 2001). Other researchers have concurred that based on important water parameters, WQI can be a very useful and efficient method which can provide a simple indicator of water quality (Abbasi and Abbasi, 2010). The index has also been widely utilized in surface and subsurface water quality evaluation (Wu *et al.*, 2018).

Globally, WQI methods present till now being used to estimate the quality of water include; 1. National Sanitation Foundation Water Quality Index (NSFWQI). 2. Canadian Council of Ministries of the Environment Water Quality Index (CCME-WQI). 3. Oregon Water Quality Index OWQI). 4. Weighted Arithmetic Water Quality Index Method (WAWQI) (Satish *et al.*, 2017; El-Shaarawi & Kwiatkowski, 2011). Although many WQIs are being used in water quality evaluation, aspect of temporal and spatial components of the data has not fully been incorporated. With respect to the steps for developing a WQI, there is no worldwide accepted method. In regard to developing countries, approaches of simplified WQIs have been suggested for quick assessment of water quality to address the limitations associated with the conventional methods and to develop accurate WQIs that suit local or regional area.

The Canadian Council of Ministries of the Environment Water Quality Index (CCME-WQI) model has some advantages over other WQIs which include;

i. Calculation of index values over an index period, typically a season or a year.
ii. The use of a benchmark to compare observations with respect to the specific end use of water where benchmark can be derived from international or national water quality standards or may be a site specific background concentration.

iii. With little modification, it can be applied by water agencies in different countries.

Other advantages associated with the index is that it does not normalize observed values to subjective rating curves and weighted factors for index calculations (Lai, 2011; CCME, 2005; CCME, 2001). It is also calculated on annual basis allowing for overall rating for each station per year thus allowing examination of water quality spatial and temporal dimensions.

Parameter selection is an essential step in development of an index because they are the main constituents of a WQI. The indices have different numbers of selected parameters where the required standard number for CCME-WQI should range from four (Abbasi and Abbasi, 2012) to twenty-six (Dojlido *et al.,* 1994). At least 4 parameters are needed in development of WQI using the CCME-WQI method.

2.7.2 GIS and statistical methods

Other researchers have alternatively used GIS and statistical methods to analyze, interpret and reduce dimensionality of water quality data. According to Chapman (1996), GIS is an important tool that can be applied in water quality monitoring to present data geographically and also relate it to various human activities.

Despite the use of many different analytical methods in water quality data analysis and interpretation, statistical techniques have provided effective ways of analyzing large amounts of water quality data. Many researchers have applied statistical methods in identifying the major variables that influence water quality spatially, seasonally and temporally within a particular catchment (Khound and Bhattacharyya, 2016; Juahir *et al.*, 2010). In regard to multiple interaction of water parameters, multivariate statistics have been applied in many studies to establish the correlation of spatiotemporal variability and water quality (Kitagaki, 2019; Gurjar and Tare 2019; Dan *et al.*, 2014; Singh *et al.*, 2004).

2.7.3 Statistical correlation analysis

Correlation establishes the statistical linkage between variables. Correlation coefficient (r) is a common tool used to assess the relationship between two variables and how well one predicts the other (Mukaka, 2012; Bahar and Reza, 2010; Howell, 2002). It indicates the extent to which two or more variables fluctuate (Jothivenkatachalam *et al.*, 2010). High correlations indicate that the variables are derived from the related sources (Edet *et al.*, 2011). It is a unit free measure of relationship between two variables and takes values (-1, +1). According to Hirsch *et al.*, (1991), Helsel, (1992) and Donald *et al.*, (2011), statistical trend analysis can be applied in test for trends specific to various water quality parameters.

Measures of correlation have the characteristics of being dimensionless and scaled to lie in the range $-1<r<1$. When there is no correlation between two variables, $r = 0$. When one variable increases as the second increases, ‘r’ is positive. When they vary in opposite directions, ‘r’ is negative. If the correlation coefficient value of two variables is closer to zero, the variables are not correlated or the weaker the correlation. When one variable is a measure of time or location, correlation becomes a test for temporal or spatial trend.

Statistical correlation techniques have been alluded to as effective tools in finding relationships between numerous physico-chemical parameters and as a unique step ahead towards the water quality management (Tajmunnaher and Chowdhury, 2017).

2.8 Previous studies on assessment of water quality

The protection of water resources has been given topmost priority in the 21st century due to the global deficit in freshwater resources and the role anthropogenic activities and natural processes play in the deterioration of water quality (Salim *et al.,* 2014). According to Pink (2006), appraisal of water resource policies that can regulate, manage and support development of water resources is needed to counter water pollution problems that has now become a global issue.

Several methods that include remote sensing and GIS based techniques, WQI tool, physico-chemical and micro-biological parameters have been used in a variety of studies around the world in water quality monitoring (Huang *et al.,* 2010; Machado *et al.,* 2017; Mahesh and Bandela, 2016; Lobina and Mercy, 2015).

Spatial WQI maps have also proved to be very useful and effective tools in evaluation of the quality of water in a given area (Igor *et al.,* 2015). WQI tool has the ability to compress large volumes of data to a simplified expression of the water quality (Sureja *et al.,* 2018). It has been used by many researchers in assessment of spatial and temporal changes, classification of river and ground water quality. WQI also finds its application in conversion of complex or complicated water quality data into information that is understandable and usable by public (Cude, 2001). Based on several water quality parameters, WQIs tools become important to characterize water suitability for various uses based on existing standards at a certain location and time.

Research-wise, an important stage in the protection and conservation of water resources is the spatiotemporal analysis of water and sediment quality of the aquatic systems caused by natural and anthropogenic processes (Al- Mutairi *et al.,* 2017; Venkatesharaju *et al.,* 2010; Siyue *et al.,* 2009). According to Vaishali and Punita (2013) evaluation of seasonal changes in surface and ground water quality is an important aspect for evaluating temporal variations of pollution due to natural or anthropogenic inputs. Research on spatiotemporal variability of ground and surface water quality has been conducted in many river basins. Studies by Igor *et al.* (2015) scrutinized different spatiotemporal tests of water quality from a statistical point of view, in order to understand their behavior and help to generate water decontamination designs in a more efficient way. Ocheri and Idoko (2012) and Dan *et al.* (2014) observed that change in season can have influence in concentrations of physico-chemical properties of ground water in their studies on temporal variability of ground water supply of Benue State, Nigeria. Results on assessment of spatial variation of the major ions composition of surface and ground water systems by Tenalem (2005) in the Ethiopian volcanic terrain and associated Plio-Quaternary sediments show wide hydrochemical variations that were attributed to geological, geochemical, geomorphological and climatological factors.

Barakat *et al.* (2016) investigated spatial and seasonal variation of water quality in Oum Er Rbia River and suggested that the changes in water compounds’ concentration are mainly related to point source contamination (domestic and industrial wastewater), non-point source contamination (agriculture activities), as well as natural processes (weathering of soil and rock, climatic factors).

Findings from study on seasonal variation of ground water quality in India by Gorthi and Mohan (2015), Pakistan by Anwar *et al.* (2011) and Iran by Shamsi and Moussavi (2003) confirm that comprehensive evaluation of groundwater is vital requirement for developing countries with rural based economy as most water resources may be unsuitable for human health due to micro-biological and physical chemical issues. They also reported that water quality cannot be measured in only one location within a water body but may require a grid or network of sampling sites. They also suggested the need for evaluation of natural and anthropogenic condition of water resources to create baseline information for comparison, monitoring and informed decision-making on a timely and regular basis for utilization together with sustainable management.

Alper and Orhan (2017) reported that water–rock interactions in geological units with altered zones usually cause changes in physical and chemical properties of water resources on their studies on the effect of geogenic factors on water quality and its relation to human health around Mount Ida, Turkey. They also recommended that such areas should be considered because of important factors that affect the quality of drinking water resources which are mostly responsible for a variety of health related issues.

Research efforts have been made in identification of trends relevant to the deterioration of drinking water quality in water supply distribution systems and to establish and prioritize issues of greatest concern both in urban and rural settings (Mkandawire and Banda, 2009; Suthar *et al.*, 2009; Pritchard *et al.*, 2008; Hoko, 2005; 2008;Kruawala *et al.*, 2005). Other

studies on hydrochemistry of ground water by Abdul et al. (2015), Panagopoulos et al. (2014), Srinivasamoorthy *et al.* (2012), Biswajeet and Saied (2011), Kanda (2010), Mattas *et al.* (2005), Appelo and Postma (1993) confirm that the composition of water is guided by lithological influences on water chemistry through weathering processes, ion exchange and along with effect of chloride ions from anthropogenic impact.

GIS methods have been applied in solving problems where spatial data are important and in developing solutions for water resources problems to assess water quality, determine water availability and understand the natural environment on a local or regional scale. Also it has many applications in hydrology that use spatial analytic tools to a greater or lesser extent on evaluation of water quality. The spatial component serves to place the water quality results in their geographic context (Silberbauer, 1997). Water quality data can be processed in GIS using different interpolation techniques to give an overall picture about its spatial variation and identify areas of concern in a given area (Swarna and Nageswara, 2010). Application of GIS as a database system to carry out spatial statistical analysis of water quality data and to create maps of water quality according to concentration values of different constituents has been alluded to by many researchers. According to Hongxing *et al.* (2019), GIS based spatial interpolation methods combined with spatial analysis and WQI have broadly been used in analysis of geographical variation of water quality characteristics and in estimating parameter values of unsampled sites from measurements made at point locations within the same area.

In Kenya, volcanic processes associated with tectonic activity within the rift valley zone have been reported to exert important controls on its geology, topography, climate and hydrology (Olago, 2018; Olago *et al.,* 2009; GOK, 1997; Gaciri and Davies, 1993). The municipality of Nakuru is located within the East African Rift valley. Previous studies have reported that geological variations and volcanic activity that characterize the area yield elevated concentrations of inorganic salts in water bodies and soil materials (olago *et al.,* 2009). The geology of the area has been confirmed to have a great potential to pose a risk to the regional ground water variably depending on its elemental composition due to persistent interaction with the water. The areas rocks and soils have been reported to cause high salinity which affects the salt content of sub-surface and surface waters (Olago, 2018; Kanda, 2010). The alkaline volcanic sequence has given rise to a predominantly sodium bicarbonate composition for both the surface waters and groundwater (Odero and Peloso, 2000; Oketch, 2012).

Rivers Meroronyi and Malewa which are major surface drinking water sources to Nakuru Municipality drain volcanic basins. In addition, several streams in the Lake Nakuru water catchment such as the Njoro, Ngosur and Naishi have soils in the catchments which are predominantly of volcanic, clay-loam in nature except near the lake where silt clay is found. The streams are also highly influent with characteristic of disappearing along the fault lines to recharge deep aquifers (Kanda, 2010; Raini, 2005).

Findings from other studies in the wider Rift Valley where Nakuru Municipality lies confirm that geological, geochemical, geomorphological and climatological factors control hydrochemical variations in respect to surface and ground water bodies (Tenalem, 2005; Clarke *et al.,* 1990). McCall (2007) reported that the headwaters section of the water basin is characterized by wide valleys and steeply rising mountain ranges. The variable climatic zones with steep land slopes and valleys provides a major path way for interaction between sub-surface and surface water enhancing chemical transfer between terrestrial and aquatic systems. Piezometric plots and isotopic evidence suggest that groundwater along the rift is mainly derived from rainfall on the flanks of the rift, both to the east and west (Allen and Darling, 1992).

In their studies on the larger Lake Nakuru basin water chemistry, Olago *et al.* (2009), Oketch (2012) and Kanda (2010) observed that geological formations and soil-water-rock interactions had significant influence in the occurrence of chemical elements in groundwater resources of the area. Natural processes through precipitation, anthropogenic activities and hydrothermal discharges associated with hydrothermal zones of Menengai Crater were also confirmed to be key factors likely responsible for the observed chemical changes in ground water (Oketch, 2012). Oketch (2012), Kanda (2010) and Olago *et al.* (2009) deduced a seasonal variability in composition of water sources and parameters in the area but they attributed the geographical variabilities to land use, soil and geology of the area. Pollution sources associated with human activities were confirmed to greatly affect surface water as compared to ground water.

Mwangi (2002) carried a study in Maai Mahiu Division, Nakuru County to address causes of water scarcity and reported that problems that affect water resources of the region (surface and ground waters) are related to human factors, environmental factors and the effect of climate change.

Kirianki *et al.* (2018) assessed levels of selected physical chemical parameters in drinking water samples in Njoro area and reported high levels of turbidity, iron, fluoride, manganese and nitrate as compared to WHO recommended quality standards for safe drinking water.

Generally, in the larger Nakuru County, elevated concentrations of fluoride ions in waters in use in the area are well documented and this is one of the major water-related health problems. In the Rift Valley, major water quality concerns revolve around high fluoride and salinity concentrations hence fluoride is a major recognized problem (Naslund and Snell 2005; CDN, 2005; Gikunju, 2002).

Most of the studies on assessment of fluoride levels in ground water along the Kenyan Rift Valley shows that high concentrations are found in Nakuru, Gilgil, Elementaita and Koibatek-Baringo area which are fluorspar deposits regions (Wambu and Muthakia, 2011; Naslund and Snell, 2005; Naslund *et al.*, 2005; Gikunju, 2002). Evaluation of fluoride occurrence and distribution on ground and well water in kenya classified Nakuru District as having the highest maximum levels of fluoride ion concentrations (ppm) of 57 of all districts in Kenya. Its manifestation is in dental public health among others (Gikunju, 2002).

Groundwater in the study area has been confirmed to have high fluoride concentration in many parts linked to the volcanic terrain (Gaciri and Davies, 1993; Odero and Peloso, 2000; Oketch, 2012; CDN hand out, 2005; CDN, 2009). Brunt *et al.* (2004) observed that fluoride and conductivity values increase in the direction of ground water flow from recharge areas at higher elevations towards the valley center. Sodium ions (Na^+) concentration has been reported to be high in the larger Nakuru watershed with low magnesium and calcium ions. High-fluoride ground waters are mainly associated with a sodium-bicarbonate water type and relatively low calcium and magnesium concentrations and high silica content. Such water types usually have alkaline pH.

Nationally, a detailed survey in ground water samples showed fluoride concentration levels exceeding 8 mg/l. Maximum concentration of fluoride (30–50 mg/1) in groundwater were noted in Nairobi, Rift Valley and Central Provinces in areas characterized by volcanism. Dental fluorosis was noted to be common in the most of the affected areas where the sampled wells and boreholes were providing drinking water.

Other studies by Wambu and Muthakia (2011) in Gilgil-Elementaita area and part of the Nakuru municipality in Nakuru County, Njoro division, Kenya reported elevated fluoride concentrations in drinking water from boreholes and low fluoride in surface waters. They attested that in the region, proximity of the water source to the lakes influenced the levels of fluoride in water. Other studies on fluoride levels for drinking water sources in Menengai and Gilgil-Elementaita area have reported a distinct increase in concentration of fluoride in borehole piped water compared to the water at source. The causes have been attributed to the spatial extent of evaporation during treatment and storage of water (Benson and Isaac 2017; Wambu and Muthakia, 2011). However for river water, piped river water has the lowest mean fluoride concentration (<0.1 ppm) (Wambu and Muthakia, 2011).

Studies by Benson and Isaac (2017) and Wamalwa and Mutia (2014) around Menengai geothermal field in Nakuru also confirmed high concentration of fluoride (7.51 mg/l) in borehole water used for drinking at source and points of use. Wetang'ula and Wamalwa (2015) reported presence of selenium and cadmium among other trace elements in precipitation concentrations in their studies in Menengai area, Nakuru. Mavura *et al.* (2003) reported fluoride concentration of 0.78 mg/l in river water to 110 mg/l in borehole water samples collected from 18 sources in Njoro Division, Nakuru District.

Fluoride is therefore a recognized major problem in Kenya. Awareness of problems associated with fluoride levels and different parts of the country affected is high. Many studies have been carried out by different researchers on distribution, sources of fluoride and incidences of fluorosis. However, most of these data are archival since most of them were carried out from 1960-1990 (KEBS, 2010). Most of the accessible published information on fluoride levels and ground water hydrogeology is in areas within the Rift Valley where Nakuru Municipality lies.

Generally, in Nakuru region, an elevated concentration of fluoride mineral is one of the major water-related health problems. Problems of high fluoride levels in waters in use in the area are well known but information on its level and distribution in individual water sources is not known. Knowledge about the fluoride level of a specific water source is also lacking and literature on comprehensive studies done recently is lacking (Gikunju, 2002). In Nakuru region, research has established that ground water sources, mainly boreholes have high fluoride levels of even 50 mg/l hence the greatest threat (source) of fluoride in drinking water (KEBS, 2007; 2010). Existing literature on past research in the area confirm that water obtained from groundwater by NAWASSCO for Municipality supply tends to have higher levels of fluoride than that obtained from rivers. NAWASSCO control options for fluoride contamination include blending of fluoride-rich groundwaters with river waters which is of low fluoride content (Mutai, 2014).

Other studies on physical, chemical and bacteriological quality of drinking water in Nakuru County reported high contamination of surface and borehole water but tap water was found to be safe (Madadi *et al.,* 2017; Waithaka *et al.,* 2015). Most parameters examined were found to be above the recommended drinking water guidelines as set by the World Health Organization (WHO, 2011) and the National Environment Management Authority of Kenya (NEMA, 2006).

Nyanchaga and Tiffani *(*2002) and kirianki *et al.* (2017) reported contamination by different microbial parameters in various sources of water for drinking and in household storage containers in five locations in Njoro Sub-County. Other studies in the general Nakuru area on suitability of ground water for drinking uses was carried out by Ngotho (2014) from different sites. The physio-chemical parameters investigated were; pH, TDS, TSS, TS, electrical conductivity, lead, and microbial (E. coli and coliforms). The results showed variation in the concentration of parameters from different sources where most of the parameters except pH, had elevated concentration levels compared to permissible limits (WHO, 2011 and NEMA, 2006) for quality of drinking water.

2.9 Knowledge gap

In reference to the reviewed literature on previous researches concerning the area of study, it is clear that local geology and hydrogeology control water balance and natural chemistry of its watershed. Geological formations also lead to surface water and groundwater interactions through their flow systems. Inputs of anthropogenic and natural factors on chemical composition of water resources in different areas has also been confirmed.

The present concern was lack of strong database that can explain the linkages between geological factors and surface and ground water chemistry and spatiotemporal dynamics of various water quality variables. Fluoride levels in ground water in use are well documented but quantitative information on the level of overall mineral content in water sources in use and suitability for various uses to set standards is lacking (Gikunju, 2002).

In addition, an important challenge arises in the existing drinking water quality data collection methods, analysis, interpretation and information reporting protocols that do not provide a robust database.

2.10 Conceptual framework

The research concept was built on the concept of water cycle where climatic factors, geology, surface water, groundwater are all linked. In addition, science of the chemical composition for untreated waters in surface and underground reservoirs plus methods used in hydrochemical investigations were also considered (Weight, 2008). All natural water contains dissolved mineral matter but the type of rocks or soils and the length of contact time determine the quantity of the dissolved mineral matter (Chapman, 1996).

Natural water chemical composition is derived from many different sources of solutes that include gases and aerosols from the atmosphere, weathering and erosion of rocks and soils, solution or precipitation occurring below the land surface and cultural effects resulting from human activities. Poor quality of water limits the uses that can be made of it even when available in adequate quantities (Damo and Icka, 2013; UNEP/WHO, 1996). Other factors are chemistry of atmospheric precipitation, topography and climate (Aris *et al.*, 2013).

Evaluation of water quality in relation to source, geology, climate and use is determined through chemical analysis (Raghunath, 1995). In management framework of water quality, conceptual models can be used to characterize the water way important features in reference to how the system works, underlying drivers and causal relationships among significant components for the issue of interest.

This study used a conceptual model to determine quality of river and ground water and analyzed spatial seasonal variations of water quality parameters for drinking purposes in Nakuru Municipality. In order to select, collect the required data, analyze and get output database for characterizing the conditions of drinking water supplies of the study area, a conceptual model was designed with a component of appropriate important independent variables, influencing variables and dependent variables. Procedures and methods of data collection and data analysis are presented in methodology.

Independent variables considered were; selected drinking water sources, spatial and seasonal trends, intervening variables included primary and secondary contaminant factors, while dependent variable was water quality (Figure 2.1 below).

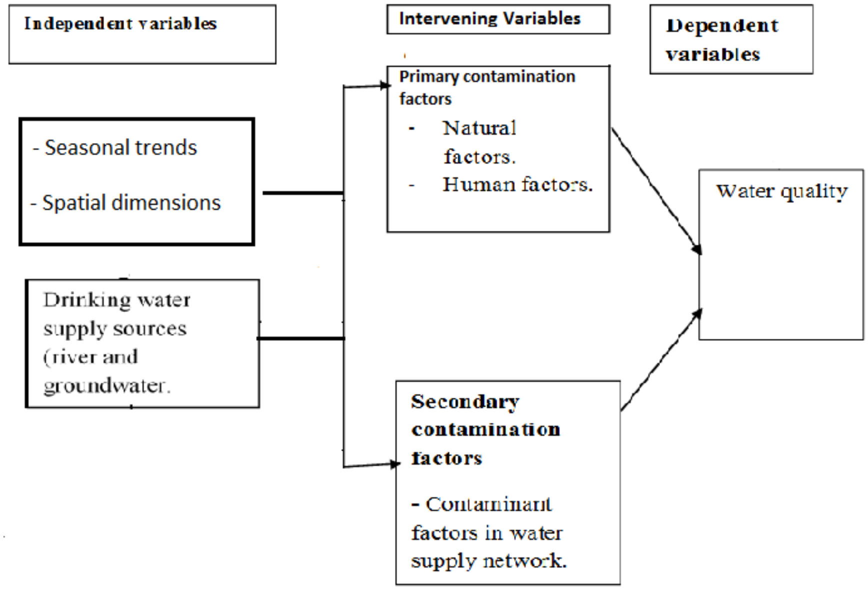

Figure 2.1: A conceptual model of drinking water quality supply assessment

Source: Author

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter gives a detailed description of Nakuru Municipality drinking water supply in terms of water types, location, intake points, quality, spatial and seasonal variations. Methods of data collection, sampling, preservation and analysis are explained. GIS, WQI and statistical techniques and their applications in water quality data analysis, interpretation and information reporting are also explored.

3.2 Study Design

A quantitative research design with a component of cross-sectional survey, field geospatial survey, stratified random sampling method, statistical and WQI methods was applied in this study.

3.2.1 Data collection

Both primary and secondary data were used for this research. Methods of primary data collection used included field data collection and geospatial surveys, observations, informative interviews with key government officers in NAWASSCO, and literature review.

Secondary data were obtained from government resources, libraries, research reports, internet, international and national journals in the field of water resources management and sustainable safe drinking water supplies, media tools, referred text books in water quality and related influences and academic studies conducted in the related areas for the purpose of building thorough literature review.

Mean monthly precipitation data for the study area was obtained from Kenya Meteorological Department in Nakuru for a period of 38 years (1980 to 2018) (Station number: 9036261). The thirty eight year period represented a substantial data set that could be used to determine rainfall variability in the study area. Mean monthly precipitation data for the area of study covering the study period June 2014 to March 2015 was also considered.

3.2.2 Sampling points

The sampling was based on selected treated and natural drinking water sources from boreholes, rivers and taps within Nakuru Municipality. Field geospatial and cross sectional surveys were carried out to delineate the study area and to identify sampling points and their accessibility problems.

Cross sectional survey design employed observation methods, informative interviews with key government officers in NAWASSCO, personal communication and literature review. Direct interviews from selected informants involved collection of information on location, quantity, quality, treatment and distribution of each drinking water source.

Field geospatial survey design work involved identification and geographical location of sampling points. Thirty eight sampling points were carefully selected within Nakuru

Municipal drinking water sources while ensuring complete representation of the entire system. To fully represent the components of Nakuru Municipal drinking water supply, sampling points were chosen at supply sources and points of water use at tap outlets.

Description of sampling points, identification ID, geographical location of the sampling site, sampling site and water category, water sample type and stakeholder are presented in Appendix I page 190.

Field geospatial survey also involved collection of precise coordinates and elevations of sampling points using hand held GPS (Global Positioning System)-Garmin etrex-10 GPS where the data were processed using ArcView 10.1 software. The projection of the GPS was set to World Geodetic System 1984 (WGS 84) since the google earth image maps are set in the same projection. The data were imported in GIS platform and exported in Bitmap format to create map of the locations of the sampling points (Figures 3.1 and 3.2).

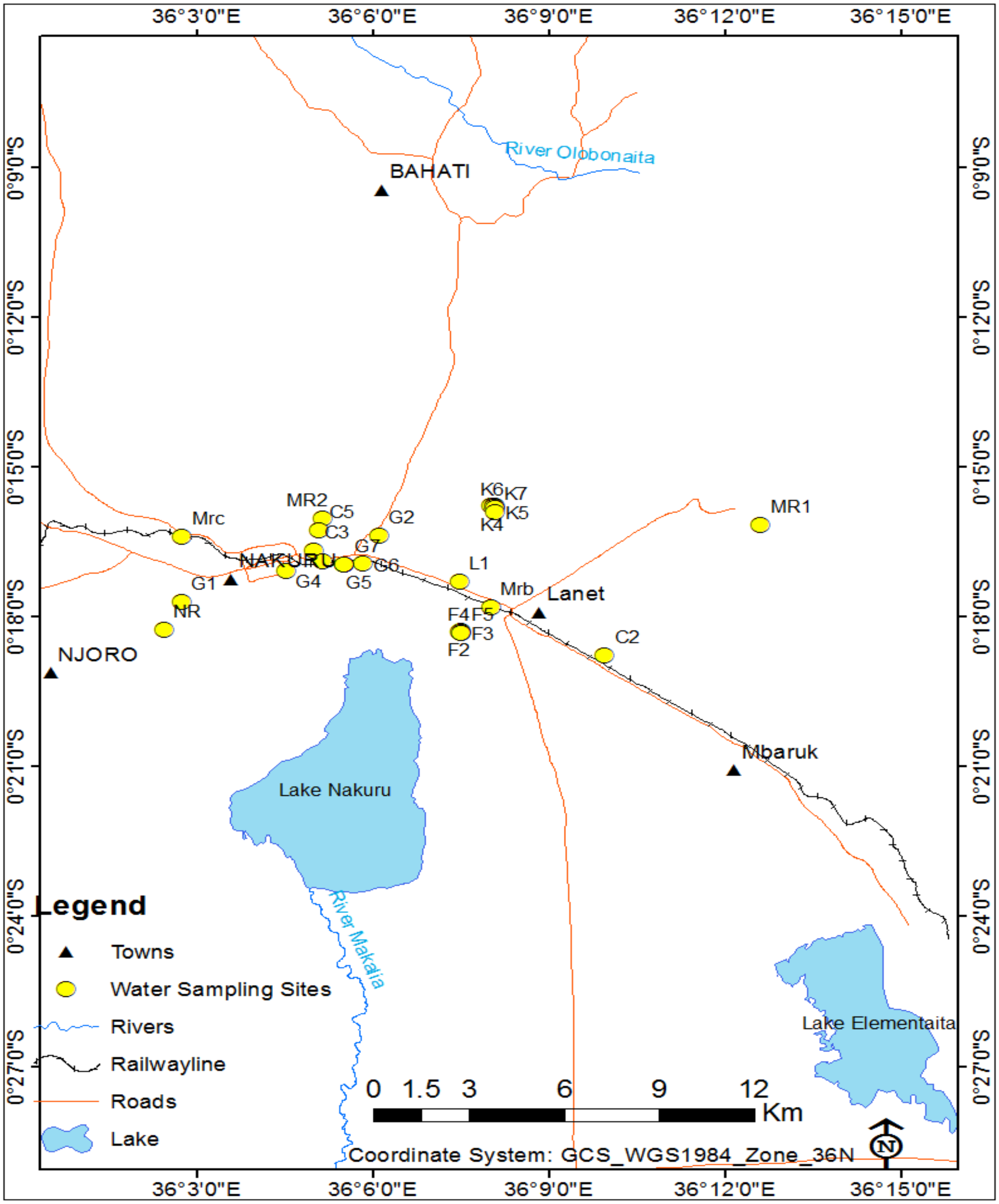

Figure 3.1: Location map of sampling points representing river and ground water intakes in the larger Lake Nakuru Basin.

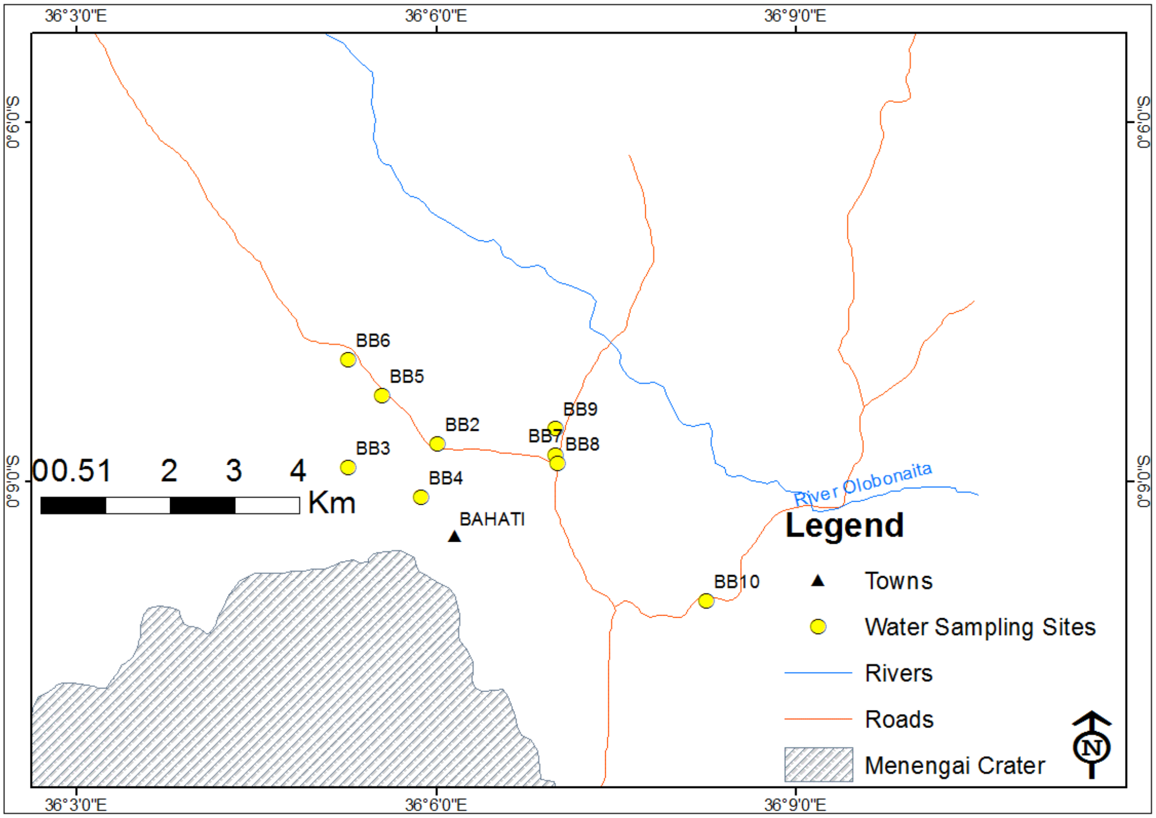

Figure 3.2: Location map of sampling points at Lower Baringo sub Basin (BB2 to BB10).

3.3 WQI based assessment of drinking water quality

3.3.1 Introduction

For this study, the Canadian WQI (CCME, 2001) model framework was adopted to compute relative water quality for drinking uses from selected sources. The index simplifies the reporting of water quality data and has been used by different authors to rate water quality in other countries (Giriyappanavar and Patil, 2013). UNEP (2007) also endorsed the CCME WQI model as globally appropriate for evaluation of water quality against various uses.

3.3.2 WQI designations

The score of CCME WQI index ranges from 0 to 100 where 0 represents poor water quality and 100 indicates excellent water quality. Designations have been specified by CCME (2005) to classify water quality as poor, marginal, fair, good or excellent within the range of 0 to 100. For this study, the designations (Table 3.1) were adopted to create WQI values to evaluate portability of river and ground water of the study area. In computation of WQI values, 23 sites representing drinking untreated borehole water and five sites representing untreated river water, WHO (2011) and national water regulations (NEMA, 2006) for drinking water, CCME guidelines, analytical water quality data sets of the examined variables (pH, electrical conductivity, fluoride, cadmium chloride and selenium)were taken into consideration .

Table 3.1: Water Quality Index values

CCME WQI values	Rating of water quality	Description
95-100	Excellent	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels.
80-94	Good	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
60-79	Fair	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
45-64	Marginal	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
0-44	Poor	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

Source: CCME (2000)

3.3.3 CCME-WQI computation

The given equation was applied in calculation of the CCME-WQI

$$CCME\_WQI = 100 - (\frac{\sqrt{(F1^2 + F2^2 + F3^2)}}{1.732})$$

Based on root mean square aggregation, three factors which are measures of variance from selected water quality objectives (F1, F2 and F3) were used in computation of the equation.

F1 describes the scope that is the number of variables which do not meet the objectives at least once during the time period under consideration ("failed variables"), relative to the total number of variables measured and is expressed as;

F1 = (Number of failed variables /total number of variables) × 100

F2 describes the frequency that is percentage of individual tests that do not meet guideline values where;

F2 = (Number of failed tests/ total number of variables) × 100

F3 describes the amplitude which represents the amount by which failed test values do not meet their guideline values (CCME, 2001).

F3 = nse/ 0.01nse + 0.01

In calculation of F3, three steps are used as outlined below.

1. When the test value must not exceed the objective:

   $excursion_i$ = failed test $value_i$/ $objective_j$) − 1

2. where the test value must not fall below the objective:

   $excursion_i$ = ($objective_j$/ failed test $value_i$) – 1

3. nse = (∑ (excursions)/ (Total number of tests)

where; nse (normalized sum of excursions) represents the collective amount by which individual tests are out of compliance and a failed test can be greater or less than its objective.

3.4 Geospatial assessment of river and ground water quality parameters

A geodata base containing spatial data base (geographical location of all sampling points representing water types and sources) and non-spatial data (water quality data base containing average mean values for each measured quality parameter over the sampling period) were integrated with Arc GIS software to develop spatial distribution maps of river and groundwater quality of observed parameters as applied in other studies by Hongxing *et al.* (2019); Bangalore, 2018; Sapna *et al.* (2018), Kamal and Al-Paruany, (2018), Kiplangat and Mutua, (2016), Huchhe and Bandela, (2016), Ahmad *et al.* (2012), Venkatesharaju *et al.* (2010) and Zheng *et al.* (2009). The water parameters examined included pH, electrical conductivity, cadmium, selenium, chloride and fluoride.

To visualize the distribution of observed water quality parameters within the created maps at different sampling points over the study period, specific colour signature derived from Arc GIS HSV colour model was employed as applied in other studies by Brewer (2015).

3.4.1 Assessment of aquifer geological formations and water quality

Geological map of Nakuru area by Alamirew *et al.* (2007) (Figure 1.2) was digitized using GIS ArcMap tool to delineate locations of sampled boreholes. Data of Kabatini, Baharini and Olbanita boreholes lithologic logs and drillers' logs around Nakuru town where other sampled boreholes are located were used in determination of aquifer lithology based on rock matrix at water rest and water struck level of the sampled boreholes. Levels of examined water parameters in each borehole were also evaluated.

3.5 Assessment of spatiotemporal variations in river and groundwater quality parameters

3.5.1 Sampling period

To investigate spatiotemporal characteristics of selected water quality parameters, the sampling period (June 2014 to March 2015) was put into three groups covering three hydrological periods of the monitoring months (June 2014 to March 2015) that corresponded to the dry, transition from wet to dry season and short rain period of the study area. The following three groups were created; group 1; transition period (June 2014 to September 2014), group 2; short rain period (October 2014 to December 2014) and group 3; dry period (January 2015 to March 2015).

The selected sampling groups for this study represent the hydrology and climate of the area thus considered most appropriate to study possible hydrochemical variations. The sampling period was considered to provide required information that can provide enough data to confirm the study reliability (Rahmanian *et al.,* 2015). In addition, Bartram and Ballance (1996) and Zare *et al.* (2011) agree that collection of samples should be done at equally spaced time intervals in determination of spatial seasonal trends in water quality parameters of interest. Data are also required to be collected regularly from the same locations inorder to establish changes in water quality over time.

3.6 Water sampling, frequency and preparation method

3.6.1 Sampling method

Stratified random sampling technique was employed systematically in conjunction with point and line techniques to create stratas/sampling components while ensuring each water cluster was represented through the sampling process. The stratification was based on water components (natural and treated) representing drinking water sources in Nakuru Municipality. David *et al.* (2000) and Burns (2008) confirm that stratified random sampling approach allows explicit estimation of the error due to sampling and its application in distribution systems like water supplies is effective and of higher statistical precision. Stratified random sampling method also has a spatial and temporal component that allows for statistical methods to be applied in estimating population means and confidence limits for water quality metrics (Janicki, 2003). It is amendable in spatial interpolation analysis, important when interviewing people and during field work. To minimize bias and variance in results. Sampling was done at regular intervals (systematically) throughout the sampling period to obtain the required sample size.

3.6.2 Water sampling

Before start of the exercise, a courtesy call was made to the water provider to Nakuru Municipality (NAWASSCO) on the purpose of the study. At the same time permission and technical support for the whole process was sought. Consultation was also made on all the necessary requirements.

All samples collected were labeled to enable correct identification in the field and also for tracking in the laboratory. The samples had pre assigned, identifiable and unique numbers. At a minimum, the sample labels contained the following information:

1. Sample number.
2. Date of collection.
3. Time of sampling.
4. Analytical parameter.
5. Method of sample preservation.
6. Source and type of water sample.

Thirty eight (38) sampling points representing river and ground water were selected. A total of 320 ground water and 240 river water samples were collected from June 2014 to March 2015. The size of the sample was based on the geochemical principle that the more the samples and well distributed they are, the more representative they are of the study area (Clesceri *et al.,* 1995).

Three groups of water quality data sets covering three hydrological periods were generated by analyzing 240 river water and 320 ground water samples at 38 sampling points. Each data set consisted of six selected water quality parameters (pH, electrical conductivity, chloride, cadmium, selenium and fluoride).

Parameters selected for this study included pH, electrical conductivity, fluoride, chloride, selenium and cadmium. Their selection was based on being; some of the most important water quality chemical variables of natural origin, effective in detecting water quality changes in space and time, some of the conventional variables of special concern from a health standpoint and environmental health (Hongxing *et al.,* 2019; Alper and Orhan, 2017; Abbasi and Abbasi, 2012; WHO, 2011; 2006; 2004; 1993; Chapman, 1996).

Twenty three groundwater and five river water sampling points represented water sources (untreated) covering the study area. All the sampling points formed 84 groups. Nine sampling points represented piped and chlorinated water (treated water) while one sampling point represented river treated water forming 30 groups.

Collection of ground water samples was done manually on monthly basis whereas the river water samples were collected on weekly basis for nine months (June 2014 to March 2015). The samples were collected in the morning between the hours 7.00 am and 11.00 am when water had not been adversely disturbed. The method of water sample collection, preparation and preservation were similar to those reported in previous studies (Behailu *et al.,* 2017; Clesceri *et al.,* 1995) and approved by American Public Health Association (APHA, 2012).

Collection of samples was from river intakes and outlet points, borehole outlet (tap) points, at inlet and outlet points of treatment plants, outlet points of water storage reservoirs and at points of water use.

To ensure representative sampling, collection of ground water samples was based on good representation of the aquifer at the borehole location, proper sample handling precautions, calibration of all sampling and field measurement equipment. Sampling was done using existing boreholes. All the sampled boreholes were well equipped with pumps and in continuous pumping during the sampling time. Water samples were collected at the borehole heads at the point of discharge.

The borehole tap outlet was turned on before the water samples were collected. This was to allow water to flow out for at least five minutes to cool the metal pipe, eliminate the influence of the water temperature with that of the metal pipe and prevent any standing water retained in the borehole piping system being taken as a sample (Behailu *et al.*, 2017; Rosen *et al.*, 1999). This was also to enable collection of water samples with a constant temperature and pH, representing that from the aquifer. For onsite measurements (pH and electrical conductivity), the borehole water outflow was sustained. Water samples were collected and measurements taken every two to three minutes after recording three consistent measurements in a row.

Tap water samples were taken close to the pump, before the water went through the treatment system, outlet and of water storage tanks, at customer water tap use points and other taps that were most frequently used at the sampling site. The tap was turned on to a steady stream and left to run for at least 2-3 minutes to remove any stagnant water in the plumbing network before taking the water sample according to the standard sampling procedure (APHA, 1992;1998). The sampling bottle was held near the base of the tap to get the sample and capped immediately.

For river water, grab sampling was applied where water samples were taken at selected location (at the center of the main flow). The samples were collected by dipping the sampling bottle into the river facing upstream into the flow of the water at a depth of 15 to 30 cm and tilted such that it pointed slightly upwards towards the surface, allowing the container to be filled. Each sampling site was selected and sampled in a manner that minimizes bias caused by the collection process and that best represented the intended environmental conditions at the time of sampling as applied in other studies by Bhushan and Basu, (2017).

Clean acid-washed 500 ml and 2 litre polyethylene bottles were used in collection of water samples. Prior to taking of the samples, the bottles were washed thoroughly with water from the exact site point of sampling inorder to prevent sample contamination. The samples were then labeled with an identification number where the number of the bottle was recorded on the sampling datasheet in line with the sampling location. For the inorganic compounds under study, the sampling bottles were washed with 10 % v/v nitric acid, and then rinsed several times with deionized water. During sample collection, the containers were rinsed several times with water at the sampling site to ensure sufficient flushing before collection.

To avoid the effects of light, temperature and contamination, the samples meant for cadmium, selenium, chloride and fluoride analysis were kept in an ice-chest at 4^{o}C (cool box) until transport for analysis to Chemistry laboratory, Egerton University. At the laboratory, samples were stored in a refrigerator at a temperature of 4^{o}C (APHA, 1998). The sample preservation and analyzing techniques were in accordance with the standard test procedures (UNESCO/WHO/UNEP, 1996; APHA, 2012; 1998; 1995). To ensure quality assurance, precautionary measures were observed from sample collection to analysis period.

3.7 Physiochemical determination

Measured drinking water parameters were analyzed using certified national and international standard methods and CCME-WQI method. The analysis methods were both field (pH and conductivity) and laboratory (selenium, chloride, fluoride and cadmium) based. Field measurement instruments were fully calibrated before starting sampling (pre-field) and again after all the sampling had been completed (post-field).

For pH and electrical conductivity, JENWAY digital portable water analyzer kit with probes for each parameter was used. Three buffer standard solutions (pH 4.0, 7.0, and 10.0) were used in calibration of pH meter prior to taking of the measurements. In measurement of pH, the probe was submerged into the water sample and held for a couple of minutes to achieve a stabilized reading. The probe was then rinsed with deionized water to avoid cross contamination among different samples after the measurement of each sample.

For electrical conductivity meter was standardized with 0.01N potassium chloride solution and set at 25ºC with a cell constant of 10 before any measurement. The probe was submerged in the water sample and the reading was recorded after the disappearance of stability indicator. After the measurement of each sample, the probe was rinsed with deionized water to avoid cross contamination among different samples (APHA, 1998).

During laboratory analysis, a detailed chemical analysis was carried out for each sample in the laboratory according to standard methods for examination of water and waste water (APHA, 1998). Water quality observations and methods employed for analysis are given in Table 3.2.

Table 3.2: Analytical instruments and methods adopted for water quality analysis

Quality Parameter	Abbreviation	Instrument used for determination	Analytical method	Units for analytical results
Fluoride	F	Spectrophotometer	Spectrophotometry	mg/l
Cadmium	Cd	AAS	Spectrophotometry	mg/l
Chloride	Cl	Titration (burette)	Titration using K_2CrO_4 as an Indicator	mg/l
Selenium	Se	AAS	Spectrophotometry	mg/l

Source: APHA, (1998)

3.8 CCME-WQI

CCME-WQI model conceptual framework (Table 3.1) was used to calculate index values and ranks by analyzing the integrated influence of the observed parameters in order to evaluate average water quality for drinking purposes from river and groundwater (CCME, 2001). The analysis was based on integrating the three index periods (transition period, short rain period and the dry period).

3.9 Calibration curves for selenium and cadmium

For the analysis of selenium and cadmium samples, the samples were digested to capture both the elements. For selenium a total of six standard solutions were prepared at concentrations of 0, 2, 4, 6, 8, 10 ppm. For cadmium, concentrations were made at 0, 0.25, 0.5, 0.75, 1, 2 ppm. Using the standards, concentration of each element in each sample was determined directly using AAS method.

3.10 Measure of quality control

For reliable and precise data collection, analysis and use, the aspect of quality assurance and control of data becomes important (USEPA, 2012; Dalmacija and Tumbas, 2004; APHA, 1992).

Measures that were taken to ensure and maintain quality of data in this study included;

1. Data collection network design was ensured in line with study objectives to comply with condition that the sample represented the water source or point condition being measured.

2. To eliminate sources of error in the data interpretation and data management, quality control measures were put in place during sampling and analysis.
3. For laboratory equipment used in analysis, calibration procedures were ensured for preparing standard solutions and detection limits in form of standard curve were specified for all samples before commencing analysis. This included for example the minimum number of different dilutions of a standard to be used, method detection limit (MDL), range of calibration and verification of the standard curve during routine analysis.
4. Errors of natural variability were controlled when taking the samples.

3.11 Data analysis and interpretation methods

3.11.1 Water quality parameters

Water quality data sets of observed parameters were subjected to normality test by use of normal Q-Q plots to explore their distribution characteristics. The data were then analyzed using descriptive statistical methods, CCME-WQI model and non-parametric test. SPSS software, Version 22.0, Microsoft window Excel tool, GIS and WQI tools were applied in processing and interpretation of results.

To produce meaningful information from raw data (magnitude of variables, their variability and trends) initial statistical analysis of the data and indication of the confidence in statistical outputs is required (Boddy and smith 2009; Burns, 2008; Howell, 2002; Chapman, 1996; Demayo and Steel, 1996). Descriptive statistical methods were used to provide statistical description of the data and to identify spatial patterns and seasonal variations of the observed water parameters. Summary statistics using maximum, minimum, mean and standard error of selected variables were used to represent the analytical data. Graphical methods were also used. Standard error was used as a characteristic variable to assess the variation of the data around the mean values inorder to confirm the reliability of the calculated sample mean (Stephanie, 2018; Statistics solutions, 2013; Rosner, 2006). According to Helsel and Hirsch, 2002 it would be useful to describe the rate of spatial changes in observed water parameters in terms of changes in the distribution with respect to a central value. The mean concentration values for the observed parameters were compared to WHO (2011) guideline values and national water quality regulations (NEMA, 2006) for drinking water.

Normality test confirmed that the data were not drawn from a normal distributed population (not normally distributed) hence did not meet parametric test requirements. Therefore Kruskal-Wallis test which is nonparametric version that does not assume normality, was applied to determine if there were seasonal significant variations in the mean values of water quality parameters. The results were reported at 0.05 level of significance. P values < 0.05 were considered as significant (Zar, 2009).

CCME-WQI model was used to compute index values and ranks to rate river and ground water quality on the basis of drinking uses over the sampling period at different sampling points.

Correlation analysis was applied to test the relationship between rainfall trends and concentration levels of measured water quality parameters in river and groundwater samples for natural water (June, 2014 to March 2015) as applied in other studies by Tajmunnaher and Chowdhury, (2017).

By use of graphical methods, analysis of trends and seasonality in rainfall data of the study area was carried out using rainfall data for a period of 38 years (1980 to 2018) and another data set of total mean monthly precipitation of the area covering the study period (June 2014 to March 2015).

GIS techniques were used as applied in other studies by Venkataraman and Manikumari, (2019), Hongxing *et al.* (2019), Sadat *et al.* (2014), Lai, (2011), Li and Zhang, (2009) UNEP, (2007) and CCME, (2001) to assess spatial distribution patterns of water parameters based on their concentration values at different sampling points over the study period.

Spatial spread of water quality parameters at different sampling points over the sampling period was evaluated based on the distribution of the colours. The colour was derived from a single hue scheme of different quantities which produce varying brightness and shades. Colour contrast was used as a specification for representing different ranges of concentrations for observed water parameters at different sampling points on the map as applied in other studies by Venkataraman and Manikumari, (2019). Light colours signify locations of low values (excellent water quality), light dark colours signify locations of average values (good water quality) and dark colours signify locations of high values (poor water quality) in line with WHO (2011) set guidelines for drinking water.

Sampling points representing ground water and their underlying geology were delineated in the generated aquifer map to delineate areas of potable and non-potable drinking water in terms of quality. Classification of the boreholes was done based on underlying lithological units as applied in other studies by Kanda (2010).

CHAPTER FOUR

RESULTS

4.1 Introduction

Analytical results of measured water quality parameters of potable natural and treated river and ground water from selected sites in Nakuru Municipality are presented based on research objectives, hypotheses, data analysis, interpretation and presentation methods of combined GIS, WQI and statistical methods.

Description of all the sampling points is presented in appendix 1, page 190. Results of summary statistics of pH, cadmium, fluoride, chloride, selenium and electrical conductivity in ground and river water for the three sampling periods (transition, short rain and dry period) at different sampling points are presented respectively in Appendices II and III on pages 195 and 227 respectively. As the important beneficial use of water under investigation in this study was for drinking purposes, criteria for water quality evaluation was based on set guidelines by WHO (2011) and NEMA (2006). Results of calculated WQI values are presented in Appendix V page 237 and rainfall data and correlation analysis in Appendix IV page 233. Spatial distribution maps for observed river and ground water quality parameters (Figures 4.15 to 4.38) and aquifer map delineating the sampled boreholes (Figure 4. 39) are also presented.

4.2 Analytical results of water quality parameters for natural and treated river and ground water samples

Analytical data sets for each water quality parameter were statistically analyzed in order to determine the chemical quality and drinking suitability of natural and treated river and ground water in Nakuru Municipality across the three sampling periods. The results are presented (Tables 4.1 and 4.2). Mean values for concentration of each parameter considering all the sampling points and each sampling season/period representing natural and treated river and ground water were compared to WHO, (2011) and NEMA, (2006) guideline values for drinking water. The results show variation in concentration of each parameter across the three sampling periods (transition, short rain and dry period) in natural and treated water samples.

Table 4.1: Analytical results of examined water quality parameters in groundwater for treated and natural water over the study period

		Transition period			**Short rain period**			**Dry period**			**MAX**	
Parameter	Water type	MIN	MAX	**MEAN**	MIN	MAX	**MEAN**	MIN	MAX	**MEAN**	WHO STD (2011)	NEMA (2006)
pH	Natural water	6.66	10.54	**8.60± 1.94**	6.43	9.98	**8.21± 1.78**	5.97	10.53	**8.25± 2.28**	5.5-9.5	6.5-8.5
	Treated water	7.30	9.01	**8.16± 0.86**	6.50	9.83	**8.17± 1.67**	6.00	10.15	**8.25± 2.28**	6.5-8.5	
Electrical conductivity (µS/cm)	Natural water	215	991	**603± 388**	300	978	**639± 339**	205	994	**599.50 ±394.50**	2500	-
	Treated water	121	980	**550.50±429.50**	213	872	**542.50 ±329.50**	212	865	**538.50 ±326.50**	1500	
Selenium (mg/l)	Natural water	0.09	6.75	**3.42± 3.33**	0.50	8.20	**4.35± 3.85**	0.064	7.48	**3.77± 3.71**	0.01	0.01
	Treated water	0.08	6.55	**3.32± 3.24**	0.11	5.70	**2.91± 2.80**	0.07	3.49	**1.78± 1.71**		
Cadmium (mg/l)	Natural water	0.00	0.30	**0.15± 0.15**	0.04	0.29	**0.17± 0.13**	0.04	0.35	**0.20± 0.16**	0.003	0.01
	Treated water	0.00	0.21	**0.11± 0.11**	0.02	0.32	**0.17± 0.15**	0.04	0.30	**0.17± 0.13**		
Fluoride (mg/l)	Natural water	1.21	9.30	**5.25± 4.05**	0.23	14.50	**7.37± 7.14**	0.30	14.00	**7.15± 6.85**	1.5	1.5
	Treated water	0.11	10.60	**5.36± 5.25**	0.30	8.00	**4.15± 3.85**	0.60	9.50	**5.05± 4.45**		
Chloride (mg/l)	Natural water	14.20	28.40	**21.30 ± 7.10**	14.20	28.40	**21.30± 7.10**	14.20	28.40	**21.30± 7.10**	250	250
	Treated water	14.20	21.30	**17.75 ± 3.55**	14.20	14.20	**14.20± 00**	14.20	21.30	**17.75± 3.55**		

Table 4.2: Analytical results of examined parameters in river water for treated and natural water over the study period

		Transition period			**Short rain period**			**Dry period**			**MAX**	
Parameter	Water type	MIN	MAX	**MEAN**	MIN	MAX	**MEAN**	MIN	MAX	**MEAN**	WHO STD (2011)	NEMA (2006)
pH	Natural water	6.74	8.50	**7.62 ± 0.88**	7.41	8.96	**8.19± 0.78**	6.33	9.50	**7.92± 1.59**	5.5-9.5	6.5-8.5
	Treated water	6.93	7.49	**7.21 ± 0.28**	6.84	8.04	**7.44± 0.60**	6.94	8.95	**7.95± 1.01**	6.5-8.5	
Electrical conductivity (µS/cm)	Natural water	93.75	180.50	**137.13± 43.38**	90.00	160.75	**125.38 ± 35.38**	127.75	280.50	**204.13 ± 76.38**	2500	-
	Treated water	91.25	105.00	**98.13± 6.88**	111	138.25	**124.63 ± 3.63**	144.50	175.75	**160.13 ± 15.63**	1500	
Selenium (mg/l)	Natural water	0.01	3.33	**1.67 ±. 1.66**	0.01	3.94	**1.98± 1.97**	0.01	4.37	**2.19± 2.18**	0.01	0.01
	Treated water	0.01	0.03	**0.02 ± 0.01**	0.01	1.19	**0.60± 0.59**	0.08	0.48	**0.28± 0.20**		
Cadmium (mg/l)	Natural water	0.01	0.22	**0.12 ± 0.11**	0.02	0.10	**0.06± 0.04**	0.03	0.31	**0.17± 0.14**	0.003	0.01
	Treated water	0.01	0.03	**0.02 ± 0.01**	0.02	0.06	**0.04± 0.02**	0.08	0.13	**0.11± 0.03**		
Fluoride (mg/l)	Natural water	0.21	4.58	**2.40 ± 2.19**	0.27	1.63	**0.95± 0.68**	0.40	1.89	**1.15± 0.75**	1.5	1.5
	Treated water	0.13	2.35	**1.24 ± 1.11**	0.44	0.81	**0.63± 0.19**	0.38	0.63	**0.51± 0.13**		
Chloride (mg/l)	Natural water	12.40	16.00	**14.20± 1.80**	10.70	16.80	**13.75 ± 3.05**	12.40	17.80	**15.10± 2.70**	250	250
	Treated water	14.20	14.20	**14.20± 0.00**	14.20	14.20	**14.20 ± 0.00**	14.20	14.20	**14.20± 0.00**		

4.2.1 pH

Mean value of pH in natural groundwater samples (Table 4.1) representing all the sampled boreholes varied from 6.66 to 10.54 with a mean value of 8.60±1.94 during the transition period. For the short rain period the level of pH ranged between 6.43 to 9.98 with a mean value of 8.21±1.78 and 5.97 to 10.53 where the mean value was 8.25±2.28 during the dry period. For treated groundwater samples, pH level varied from 7.30 to 9.01 with a mean value of 8.16±0.86 during the transition period to 6.50 to 9.83 with a mean value of 8.17±1.67 in short rain period. The level was 6.00 to 10.15 with a mean value of 8.25±2.28 during the dry period. Compared to WHO (2011) and (NEMA (2006), mean values pH across the three sampling periods remained in the range of set standards for drinking water (6.5 – 8.5) hence no effect on health.

pH level in natural river water samples (Table 4.2) was between 6.74 and 8.50 with a mean value of 7.62± 0.88 during the transition period. The level ranged between 7.41 and 8.96 with a mean value of 8.19±0.78 during the short rain period, 6.33 and 9.50 with a mean value of 7.92±1.59 during the dry period. For treated river water samples, pH level was ranging from 6.93 to 7.49 with a mean value of 7.21±0.28 during the transition period and 6.84 to 8.04 with a mean value of 7.44±0.60 in short rain period. During the dry period, the range was between 6.94 and 8.95 with a mean value of 7.95± 1.01. The mean levels remained in the range of set guideline values for drinking water (WHO, 2011 and NEMA, 2006).

4.2.2 Electrical conductivity

Electrical conductivity for natural ground water samples (Table 4.1) ranged from 215 µS/cm to 991 µS/cm with a mean value of 603±388 during the transition period. For the short rain period, the conductivity varied from 300 µS/cm to 978 µS/cm with a mean value of 639± 339. The range was from 205 µS/cm to 994 µS/cm with a mean value of 599.50±394.50 during the dry period. For treated groundwater samples, the conductivity was from 121 µS/cm to 980 µS/cm with a mean value of 550.50±429.50 during the transition period. The range was 213 µS/cm to 872 µS/cm with a mean value of 542.50±329.50 in short rain period and 212 µS/cm to 865 µS/cm with a mean value of 538.50±326.50 during the dry period. Mean levels of electrical conductivity in some boreholes over the sampling period were above the desirable limit of 500 µS/cm (WHO, 2004) but below the set permissible limits by WHO (2011) indicating that water from all sampled boreholes could be used for drinking purpose in absence of alternate source.

For river water, the level of electrical conductivity in natural river water samples (Table 4.2) varied from 93.75 µS/cm to 180.50 µS/cm with a mean value of 137.13±43.38 during the transition period. During the short rain period the conductivity levels were from 90.00 µS/cm to 160.75 µS/cm with a mean value of 125.38±35.38 and 127.75 µS/cm to 280.50 µS/cm with a mean value of 204.13±76.38 during the dry period. For treated river water samples, mean conductivity values varied between 91.25 µS/cm to 105.00 µS/cm with a mean value of 98.13± 6.88 during the transition period. For the short rain period, the range was from 111.00 µS/cm to 138.25 µS/cm with a mean value of 124.63±3.63 and 144.50 µS/cm to 175.75 µS/cm with a mean value of 160.13±15.63

during the dry period. Mean levels of electrical conductivity during the sampling period were below the set permissible limits (WHO, 2011) for drinking water.

4.2.3 Selenium

From Table 4.2 selenium concentration in natural ground water samples varied from 0.09 mg/l to 6.75 mg/l with a mean value of 3.42±3.33 during the transition period and 0.50 mg/l to 8.20 mg/l with a mean value of 4.35±3.85 during the short rain period. For the dry period, levels ranged between 0.064 mg/l and 7.48 mg/l with a mean value of 3.77±3.71. For treated groundwater samples, the range of concentration in selenium was between 0.08 mg/l and 6.55 mg/l with a mean value of 3.32±3.24 during the transition period, 0.11 mg/l and 5.70 mg/l with a mean value of 2.91±2.80 in short rain period and 0.07 mg/l and 3.49 mg/l with a mean value of 1.78±1.71 for the dry period. Mean levels of selenium during the sampling period were however above WHO (2011) and (NEMA, 2006) guideline values for drinking water.

For natural river water samples (Table 4.2), levels in selenium varied from 0.01 mg/l to 3.33 mg/l with a mean value of 1.67±.1.66 during the transition period and 0.01 mg/l to 3.94 mg/l with a mean value of 1.98±1.97 during the short rain period. During the dry period the range was from 0.01 mg/l to 4.37 mg/l with a mean value of 2.19±2.18. For treated river water samples, selenium concentration ranged from 0.01 mg/l to 0.03 mg/l with a mean value of 0.02±0.01 during the transition period and 0.01 mg/l to 1.19 mg/l with a mean value of 0.60±0.59 during the short rain period. The range was between 0.08 mg/l and 0.48 mg/l with a mean value of 0.28±0.20 during the dry period. Mean levels of selenium during the sampling period were above the permissible limits for drinking water (WHO, 2011 and NEMA, 2006).

4.2.4 Cadmium

From Table 4.1 cadmium concentration in natural ground water samples extended from 0.00 mg/l to 0.30 mg/l with a mean value of 0.15±0.15 during the transition period and 0.04 mg/l to 0.29 mg/l with a mean value of 0.17±0.13 during the short rain period. During the dry period, it ranged from 0.04 mg/l to 0.35 mg/l with a mean value of 0.20±0.16. For treated ground water samples (Table 4.2), concentration in cadmium varied between 0.00 mg/l and 0.21 mg/l with a mean value of 0.11±0.11 during the transition period and 0.02 mg/l and 0.32 mg/l with a mean value of 0.17±0.15 in short rain period. The levels ranged from 0.04 mg/l to 0.30 mg/l with a mean value of 0.17±0.13 during the dry period. Mean levels of cadmium were however above the permissible limits for drinking water (WHO 2011 and NEMA, 2006) for both treated and natural ground water samples in each of the sampling period.

Cadmium concentration in natural river water samples (Table 4.2) ranged between 0.01 mg/l and 0.22 mg/l with a mean value of 0.12±0.11 during the transition period. During the short rain period the levels varied from 0.02 mg/l to 0.10 mg/l with a mean value of 0.06±0.04. During the dry period, the concentration was from 0.03 mg/l to 0.31 mg/l with a mean value of 0.17±0.14. For treated river water samples, cadmium levels ranged from 0.01 mg/l to 0.03 mg/l with a mean value of 0.02±0.01 during the transition period and 0.02 mg/l to 0.06 mg/l with a mean value of 0.04±0.02 in short rain period. During the dry period the range was from 0.08 mg/l to 0.13 mg/l with a mean value of 0.11±0.03. With reference to quality of drinking water, levels of cadmium were above the recommended guidelines (WHO, 2011 and NEMA, 2006) over the three sampling periods.

4.2.5 Fluoride

Fluoride concentration in natural ground water samples (Table 4.1) ranged from 1.21 mg/l to 9.30 mg/l with a mean value of 5.25±4.05 during the transition period and 0.23 mg/l to 14.50 mg/l with a mean value of 7.37±7.14 during the short rain period. The variation was between 0.30 mg/l and 14.00 mg/l with a mean value of 7.15±6.85 during the dry period. For treated ground water samples, the range was between 0.11 mg/l and 10.60 mg/l with a mean value of 5.36±5.25 during the transition period, 0.30 mg/l and 8.00 mg/l with a mean value of 4.15±3.85 in short rain period. During the dry period the concentration varied from 0.60 mg/l to 9.50 mg/l with a mean value of 5.05±4.45. Mean levels in concentration of fluoride were above drinking water guideline values (WHO, 2011 and NEMA, 2006) over the sampling period.

Fluoride concentration in natural river water samples from Table 4.2 ranged from 0.21 mg/l to 4.58 mg/l with a mean value of 2.40±2.19 during the transition period and 0.27 mg/l to 1.63 mg/l with a mean value of 0.95±0.68 during the short rain period. It ranged from 0.40 mg/l to 1.89 mg/l with a mean value of 1.15±0.75 during the dry period. For treated river water samples, the concentration varied from 0.13 mg/l to 2.35 mg/l with a mean value of 1.24±1.11 during the transition period to 0.44 mg/l to 0.81 mg/l with a mean value of 0.63±0.19 in short rain period. The levels during the dry period ranged from 0.38 mg/l to 0.63 mg/l with a mean value of 0.51±0.13. Except during short rain and dry period, concentration of fluoride for natural river water samples was found to be above permissible limits for drinking water (WHO, 2011 and NEMA, 2006).

4.2.6 Chloride

From Table 4.1 chloride concentration in natural ground water samples during all the three seasons (transition, short rain and dry period) ranged from 14.20 mg/l to 28.40 mg/l with a mean value of 21.30±7.10. For treated ground water samples, range of concentration for both transition and dry period extended from 14.20 mg/l to 21.30 mg/l with a mean value of 17.75±3.55 with a constant level of 14.20 mg/l in short rain period. Mean levels of chloride were however below guideline values for drinking water by WHO (2011) and NEMA (2006) over the sampling period.

Chloride concentration values in natural river water samples from Table 4.2 ranged from 12.40 mg/l to 16.00 mg/l with a mean value of 14.20±1.80 during the transition period. During the short rain period, the concentration was between 10.70 mg/l and 16.80 mg/l with a mean value of 13.75±3.05 during the short rain period and 12.40 mg/l and 17.80 mg/l with a mean value of 15.10±2.70 during the dry period. For treated river water samples, chloride concentration remained the same at three periods. The mean levels were below the permissible limits (WHO, 2011 and NEMA, 2006) for drinking water over the sampling period.

4.3 Seasonal and spatial variation of river and ground water quality parameters

4.3.1 Introduction

Mean values and the degree of variability from the sample mean of each examined parameter in river and ground water at different sampling points between the three sampling periods were considered in analysis of variations due to seasonal changes and geographical locations of sampling points. Description of sampling points is given in Appendix 1. The mean values with respect to the three sampling periods and sampling points were presented in form of tables and cluster bar graphs (Appendices II and III, Figures 4.1 to 4.12). Non- parametric test (Kruskal-Wallis H) was applied to test for significant seasonal variations in the mean concentrations of each examined water parameter. Where significant differences existed, post hoc test was applied to explain the correlation in detail for significance. All the results were reported at 0.05 level of significance.

4.3.2 pH

Spatially, mean values of pH in ground water samples during the transition period ranged from 7.14±0.13 at sampling point K2 (Kabatini boreholes) to 8.32± 0.57 at sampling point BB5 (Olobanita boreholes) (Figure 4.1 and Appendix II).

Mean values of pH in river water samples during the transition period varied from 7.5±0.25 at sampling point Mrb (River Turasha) to 7.67±0.25 at sampling point Mrc (River Malewa) (Figure 4.2 and Appendix III). Most of the river and ground water samples did not exceed the recommended levels for drinking water (WHO, 2011 and NEMA, 2006).

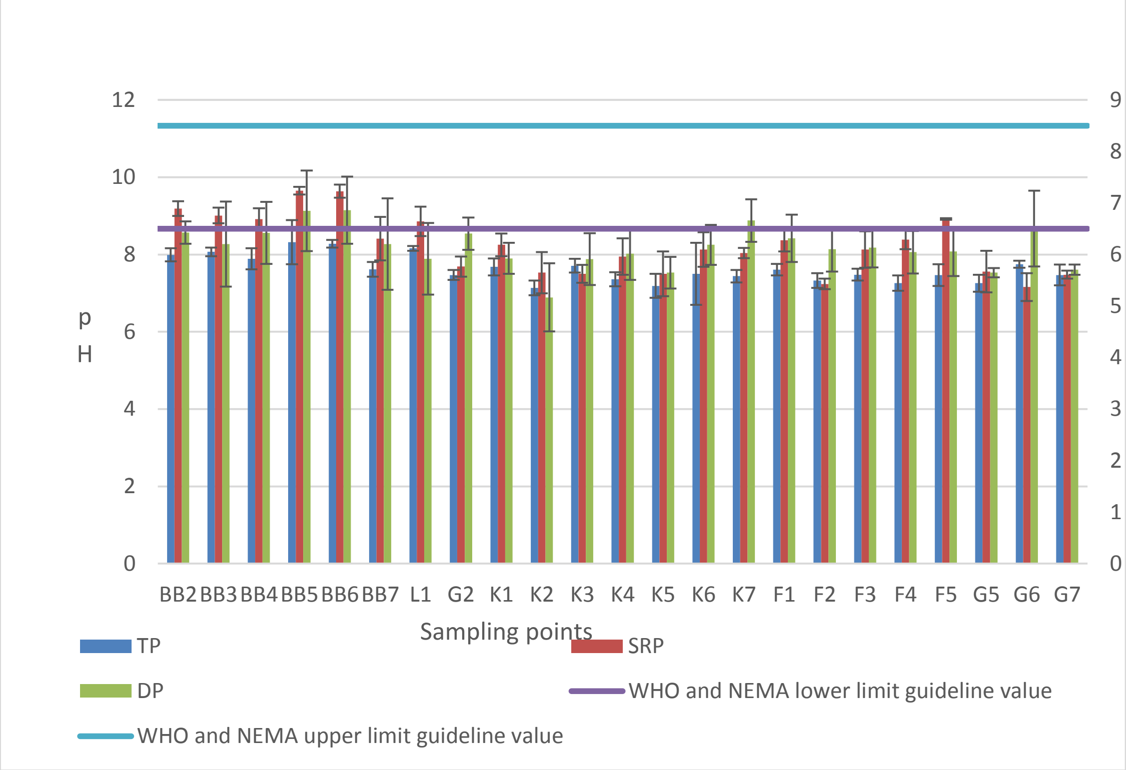

Figure 4.1: Seasonal variation in mean pH values in ground water.

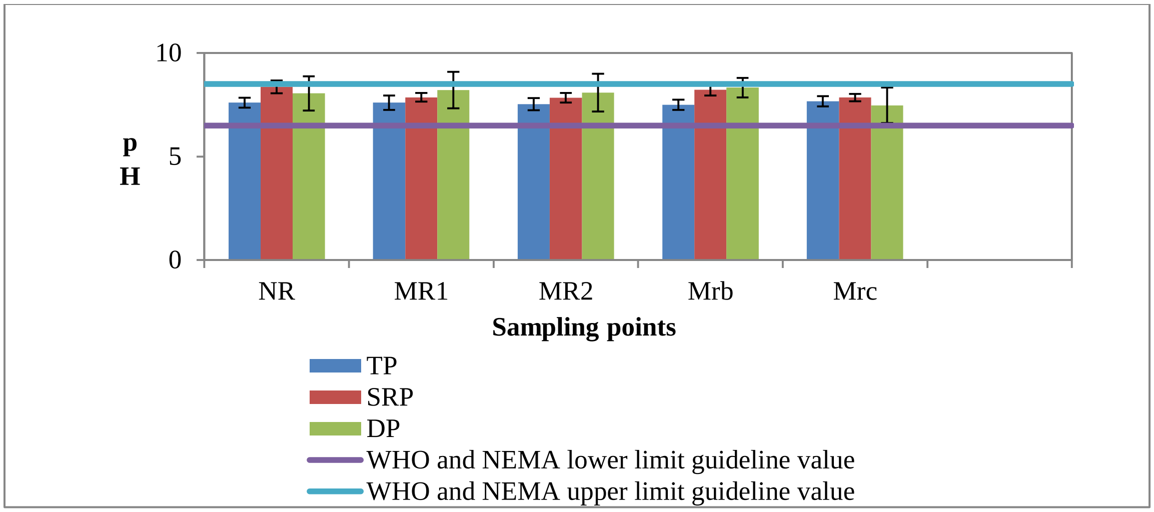

Figure 4.2: Seasonal variation in mean pH values in river water.

Mean values of pH in ground water samples during the short rain period ranged from 7.16±0.36 at sampling point G6 (Nairobi road boreholes) to 9.65 ± 0.10 at sampling point BB5 (Olobanita boreholes) (Figure 4.1).

Mean values of pH in river water samples during the short rain period varied from 7.84±0.23 at sampling point MR2 (River Meroronyi sampling point 2) to 8.36±0.31 at sampling point NR (River Ndarugu) (Figure 4.2). In river pH level remained within the permissible drinking water limits of 6.5 – 8.5 (WHO, 2011; NEMA, 2006) however, in ground water it was higher.

Mean values of pH in ground water samples during the dry period ranged from 6.89±0.42 at sampling point K2 (Kabatini boreholes) to 9.15±0.87 at sampling point BB6 (Olobanita boreholes) (Figure 4.1). In ground water the level of pH exceeded the required permissible limits for drinking water (WHO, 2011; NEMA, 2006).

Mean values of pH in river water samples during the dry period ranged from 7.47±0.86 at sampling point Mrc (River Malewa) to 8.33±0.47 at sampling point Mrb (River Turasha), (Figure 4.2). The pH value remained within the standard range (WHO, 2011; NEMA, 2006) for drinking water.

Kruskal-Wallis H test results showed a statistically significant difference in mean values of pH in ground water samples between the three sampling periods at significance level of $p<0.05$ H (2) = 14.087, P = 0.001). Post hoc test results showed a significant mean difference in pH values between transition period and dry period ($p = 0.000$), transition period and short rain period (0.006) in ground water. However, there were no significant mean differences between short rain and dry period (0.423).The null hypothesis of this study that pH mean values in ground water between the three sampling periods is not statistically significant was therefore rejected.

For river water samples, Kruskal-Wallis H test results showed that statistically significant difference existed in mean values of pH across the three sampling periods at significance level of $p<0.05$ (H (2) = 6.011, P = 0.050). The null hypothesis of this study that pH mean values in river water between the three sampling periods are not statistically significant was therefore rejected. The level of pH was noted to be good across the three sampling periods during the research period as per guideline values for drinking water (WHO, 2011; NEMA, 2006).

4.3.3 Electrical conductivity

Spatial variation in mean values of electrical conductivity in river and groundwater samples were observed at different sampling points among the sampling periods. In groundwater, wide spatial variations among the sampling points were observed as indicated by standard error of the sample mean (Appendix II). Electrical conductivity in ground water during the transition period ranged from 242.50±16.65 μS/cm at sampling point K7 (Kabatini boreholes) to 938.75±19.48 μS/cm at sampling point BB4 (Olobanita boreholes) (Figure 4.3). Mean values of electrical conductivity in river water during the transition period ranged from 113.38±8.74 μS/cm at sampling point Mrc (River Turasha) to 144.38±14.09 μS/cm at sampling point NR (River Ndarugu) (Figure 4.4).

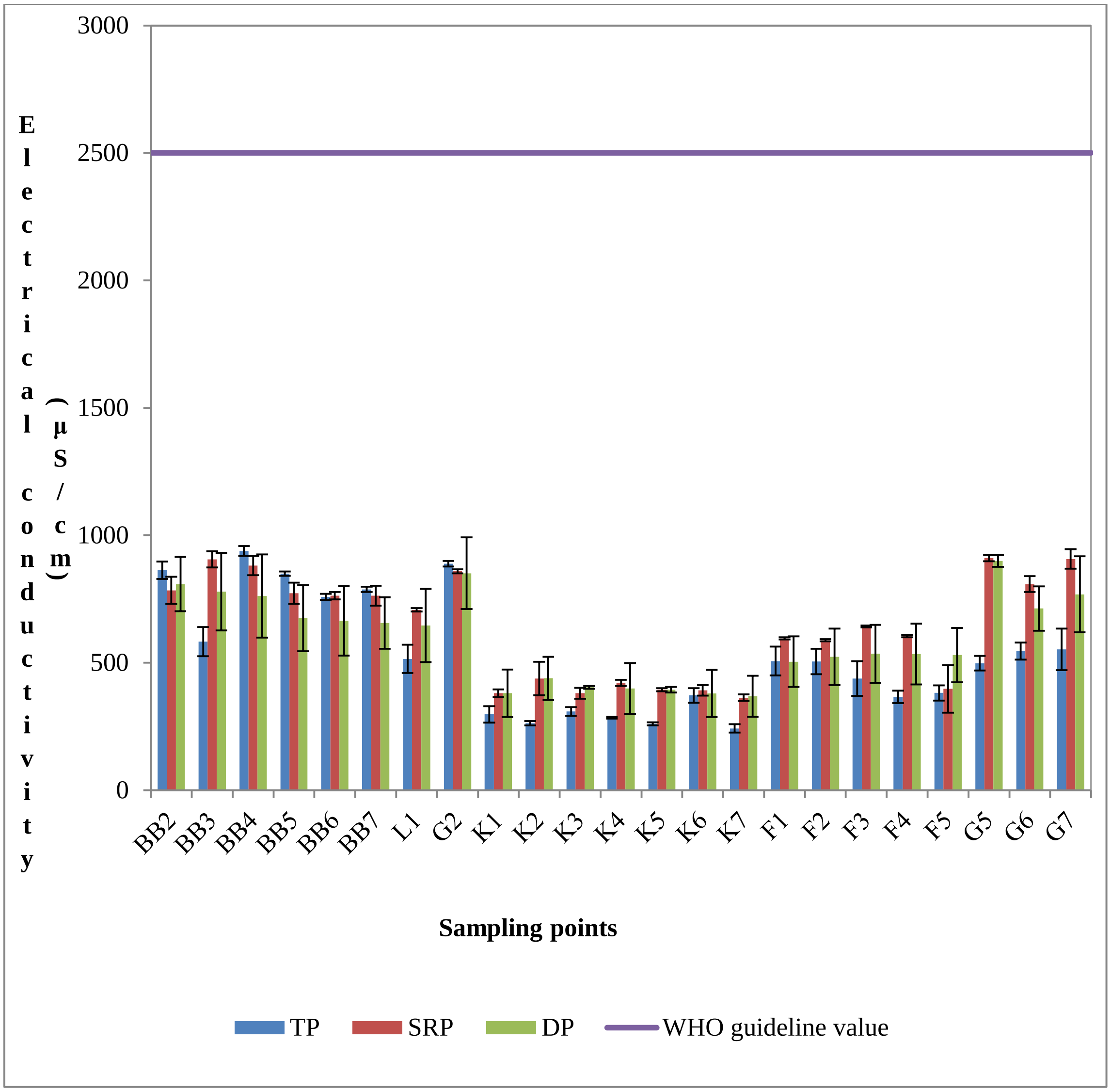

Figure 4.3: Seasonal variation in mean electrical conductivity in ground water.

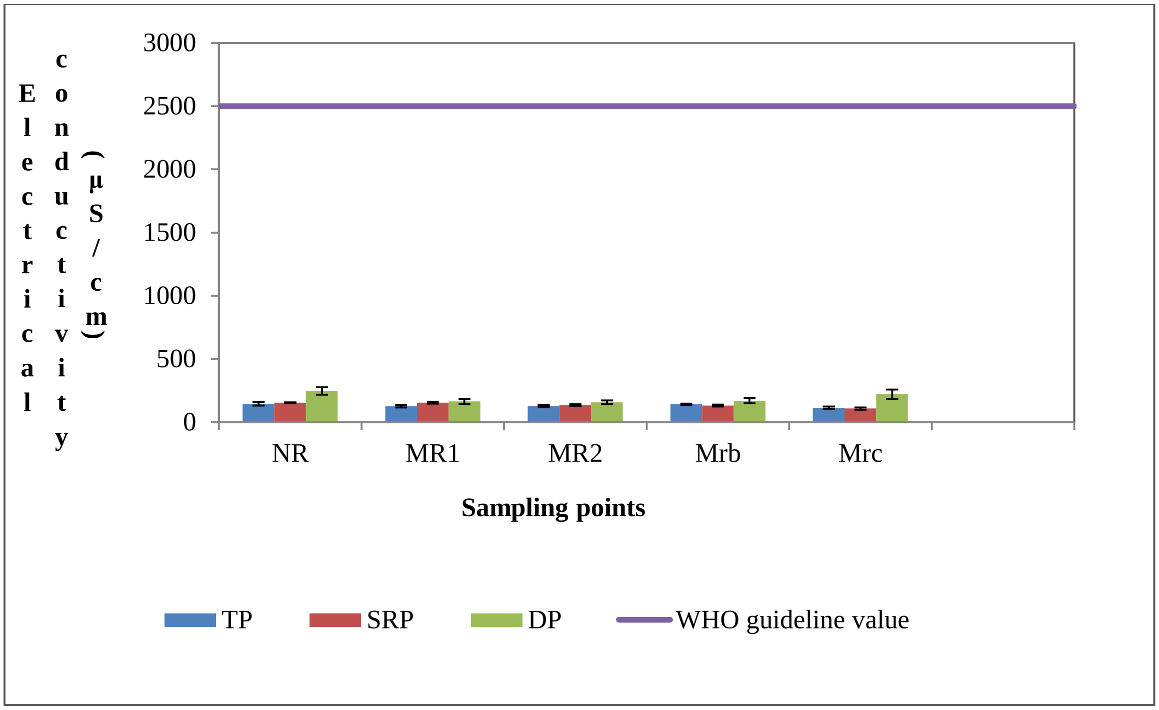

Figure 4.4: Seasonal variation in mean electrical conductivity in river water.

Mean values of electrical conductivity in ground water samples during short rain period ranged from 363.00±12.77 µS/cm at sampling point K7 (Kabatini boreholes) to 910.67±12.13 µS/cm at sampling point G5 (Nairobi road boreholes) (Figure 4.3).

Mean values of electrical conductivity in river water samples during the short rain period ranged from 107.33±9.56 µS/cm at sampling point Mrc (River Malewa) to 152.83±7.67 µS/cm at sampling point MR1 (River Meroronyi sampling point 1) (Figure 4.4).

Mean values of electrical conductivity in ground water samples during dry period ranged from 368.33±12.77 µS/cm at sampling point K7 (Kabatini boreholes) to 899.67±23.24 µS/cm at sampling point G5 (Nairobi road boreholes) (Figure 4.3).

Electrical conductivity mean values in river water samples during the dry period ranged from 156.08±14.22 μS/cm at sampling point MR2 (River Meroronyi sampling point 2) to 246.67±29.09 μS/cm at sampling point NR (River Ndarungu), (Figure 4.4). Compared to river water, the values of electrical conductivity for all of the samples in ground water (Figure 4.3) were below the maximum permissible limit (WHO, 2011).

Seasonally, Kruskal-Wallis H test results showed no significant variation in mean values of electrical conductivity in ground water samples with respect to the three sampling periods at significance level of $p<0.05$ (H (2) = 4.085, P = 0.130). Therefore, the null hypothesis of this study that no significant differences existed in mean concentration of electrical conductivity levels in ground water samples between the three sampling periods was accepted.

For river water samples, mean values in electrical conductivity showed a statistically significant difference at significance level of $p<0.05$ (H (2) = 9.620, P = 0.008) between the three sampling periods. The post hoc test results showed a significant mean difference in mean values of electrical conductivity between transition and dry periods (p = 0.004), as well as between dry period and short rain period (p = 0.016). However, there were no differences between transition and short rain period (p = 0.621). Thus the null hypothesis of this study that no statistically significant difference existed in mean electrical conductivity values in river water samples between the sampling periods was therefore rejected.

4.3.4 Fluoride

Mean fluoride concentration in samples representing ground water over the transition period ranged from 1.65±0.06 mg/l at sampling point F5 (Baharini borehole) to 4.51±1.60 mg/l at sampling point BB6 (Olobanita borehole) (Figure 4.5).

Mean fluoride concentration in river water samples during the transition period were 0.97±0.36 mg/l at sampling point MRI (River Meroronyi) and 2.95±0.88 mg/l at sampling point Mrb (River Turasha) (Figure 4.6).

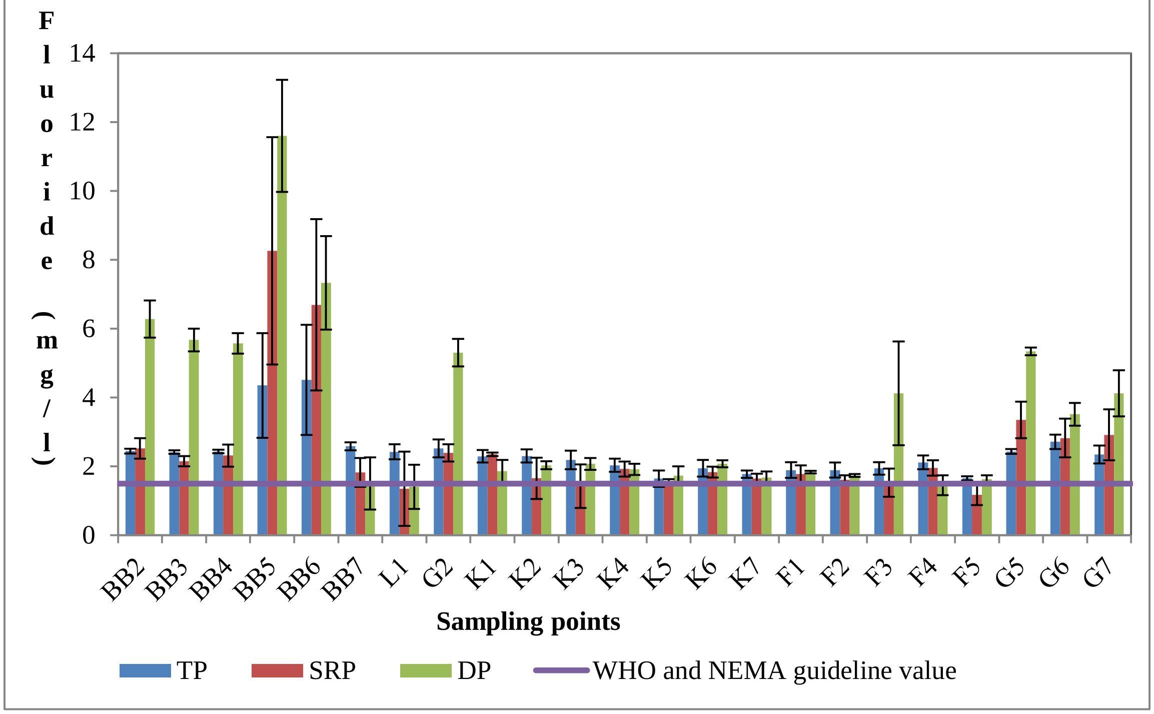

Figure 4.5: Seasonal variation in mean concentration of fluoride in ground water.

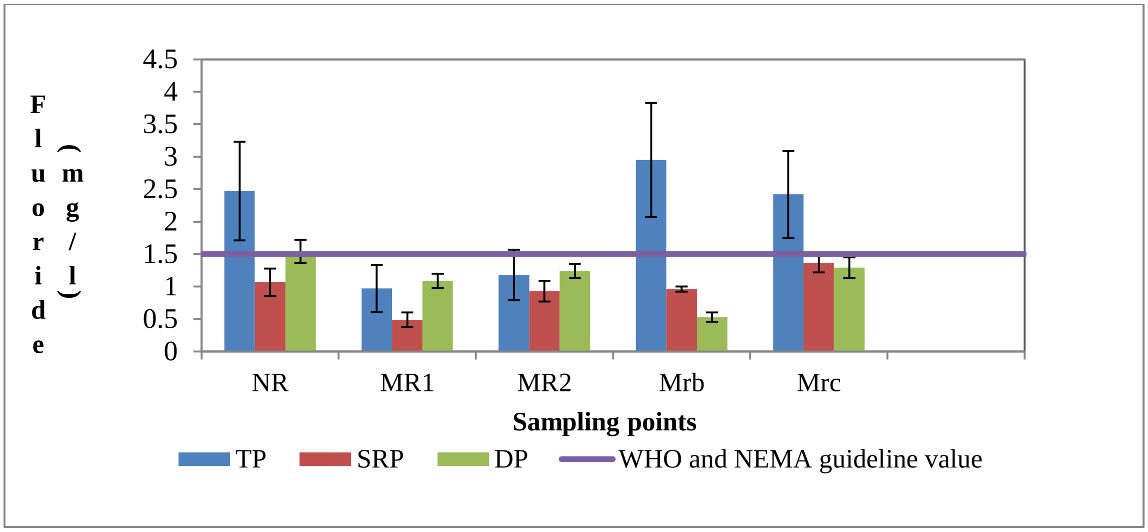

Figure 4.6: Seasonal variation in mean concentration of fluoride in river water.

Fluoride mean concentration values for ground water samples during the short rain period ranged from 1.56±0.07 mg/l at sampling point k5 (Kabatini boreholes) to 8.26±3.30 mg/l at sampling point BB5 (Olobanita boreholes) (Figure 4.5 above).

In river water samples, mean values of fluoride concentration during the short rain period were 0.49±0.11 mg/l at sampling point MR1 (River Meroronyi) and 1.36±0.14 at sampling point Mrc (River Malewa) (Figure 4.6 above).

Mean fluoride concentration for ground water samples during dry period ranged from 1.40±0.64 mg/l at sampling point L1 (Leitmann borehole) to 11.60±1.63 mg/l at sampling point BB5 (Olobanita boreholes) (Figure 4.5 above).

Concentration of fluoride in river water samples over the dry period varied from 0.53±0.07 mg/l at sampling point Mrb (River Turasha) to 1.54±0.18 mg/l at sampling point NR (River Ndarungu) (Figure 4.6 above).

The results generally showed a big difference in range of fluoride concentration at different sampling points and sampling periods. The level of fluoride was noted to be elevated in ground water over the sampling period as per WHO, (2011) guideline values for drinking water. In river water, concentration of fluoride was noted to be below the guideline values for drinking water quality by WHO (2011) and NEMA, (2006) except for transition period in NR, Mrb and Mrc (Figure 4.6).

Kruskal-Wallis H test results showed no statistically significant difference in mean concentration of fluoride in groundwater samples between the three sampling periods at significance level of $p<0.05$ (H (2) = 2.455, P = 0.293). Therefore, the null hypothesis of this study that no statistically significant difference existed in mean concentration of fluoride in ground water across the sampling periods was accepted.

For river water samples, Kruskal-Wallis test results showed no significant seasonal difference in mean concentration of fluoride at significance level of $p<0.05$ (H (2) = 4.500, P = 0.105). Post hoc test was not performed as the overall test did not show significant difference in mean levels of fluoride between the three sampling periods.

4.3.5 Cadmium

Mean cadmium concentration in ground water samples during the transition period varied from 0.01±0.01 mg/l at sampling point G7 (Nairobi road boreholes) to 0.16±0.06 mg/l at sampling point K3 (Kabatini boreholes) (Figure 4.7 below).

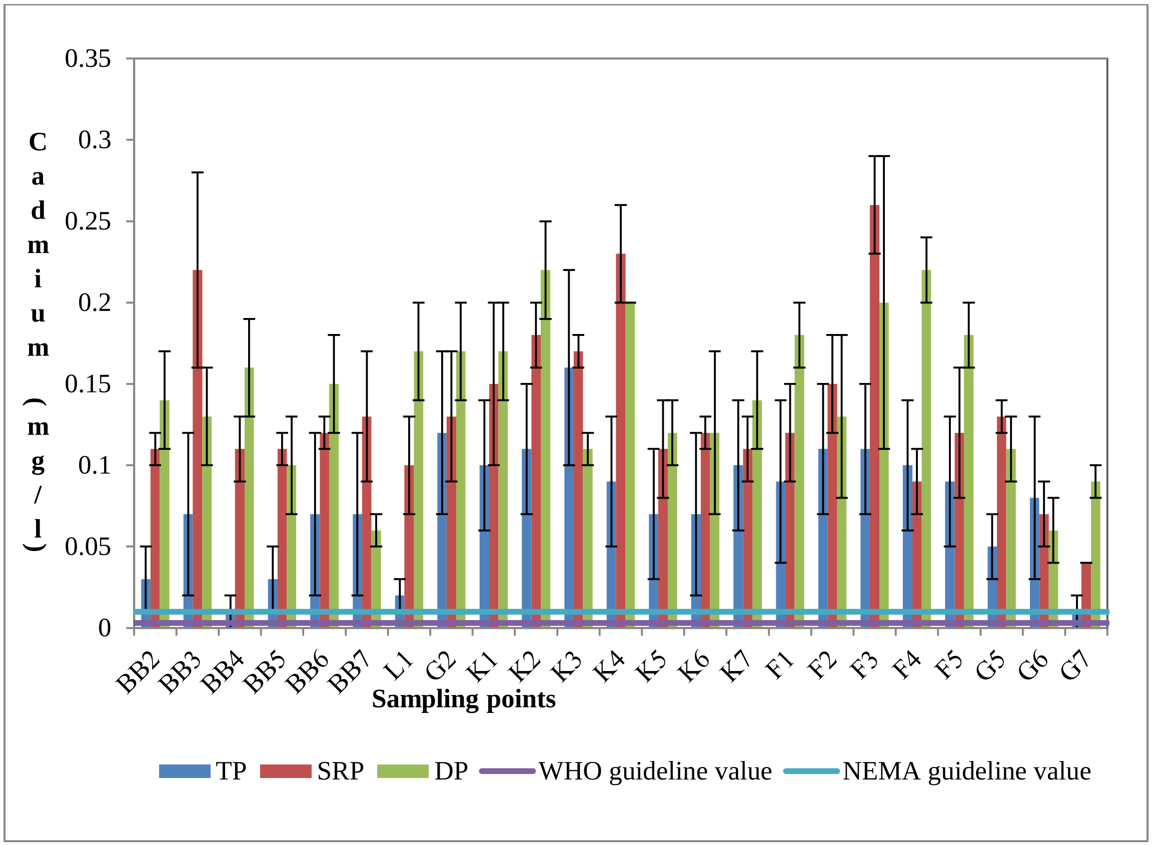

Figure 4.7: Seasonal variation in mean concentration of cadmium in ground water.

Concentration of cadmium in river water during the transition period ranged from 0.08±0.03 mg/l at sampling points; NR (River Ndarungu), MR1 (River Meroronyi sampling point 1) and Mrc (River Malewa) to 0.10±0.04 at sampling point Mrb (River Turasha) (Figure 4.8 below).

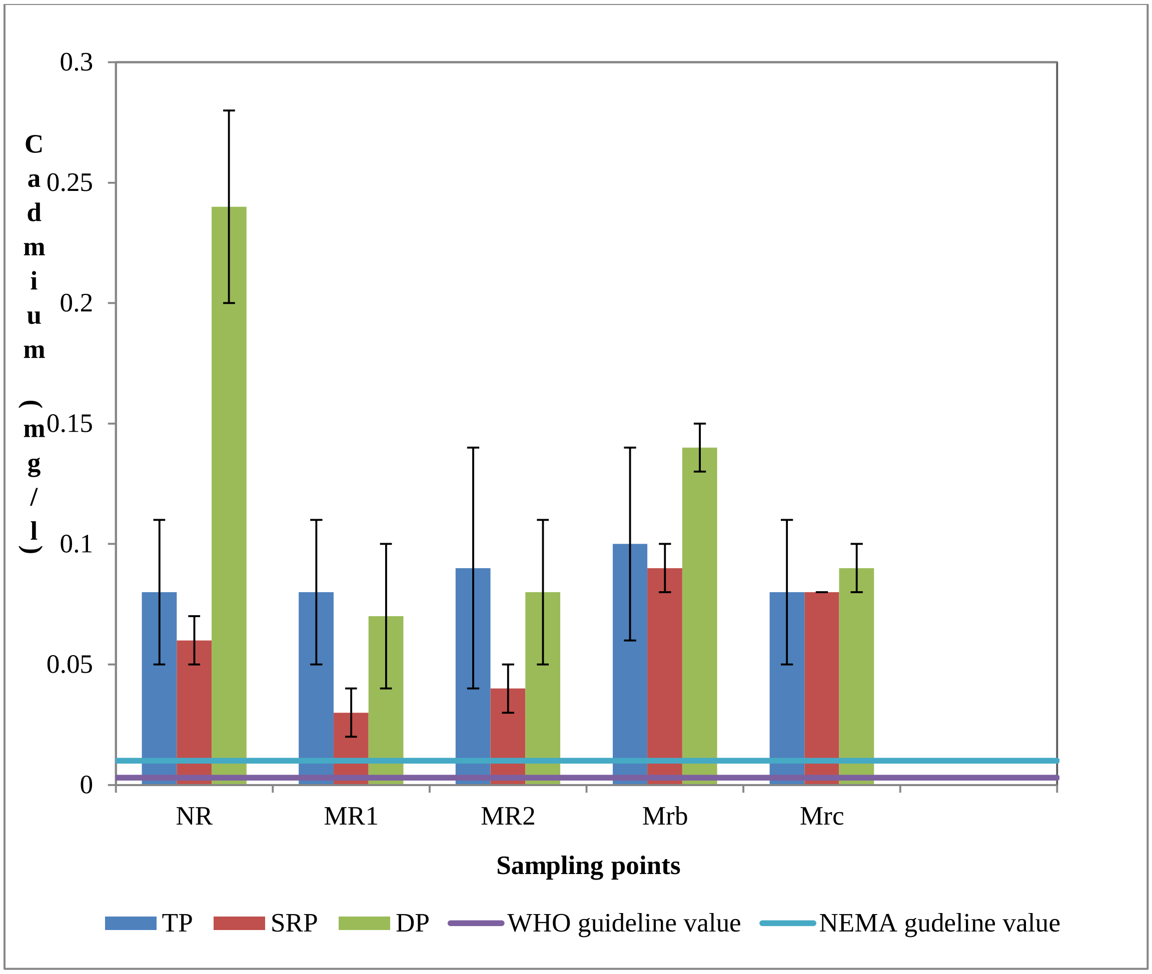

Figure 4.8: Seasonal variation in mean concentration of cadmium in river water.

Mean cadmium concentration in ground water during the short rain period were between 0.04±0.00 mg/l at sampling point G7 (Nairobi road boreholes) and 0.26±0.03 mg/l at sampling point F3 (Baharini boreholes) (Figure 4.7 above).

Concentration of cadmium in river water during the short rain period ranged between 0.03±0.01 mg/l at sampling point MR1 (Meroronyi River water intake point) and

0.09±0.01 mg/l at sampling point Mrb (Gilgil River Getco Pump Station water tap) (Figure 4.8 above).

Concentration of cadmium in ground water during the dry period varied between 0.06±0.01 mg/l at sampling point G6 and BB7 (Nairobi road and Olobanita boreholes) and 0.22±0.03 mg/l at sampling point F4 and K2 (Baharini and Kabatini boreholes) (Figure 4.7 above).

Concentration of cadmium in river water ranged from 0.07±0.03 mg/l at sampling point MR1 (River Meroronyi) to 0.24±0.04 mg/l at sampling point NR (River Ndarungu) (Figure 4.8 above). Concentration of cadmium in both river and ground water were above the WHO (2011) and NEMA (2006) guideline values for drinking water in all the sampling periods but at higher concentration compared to river water.

Kruskal-Wallis H test results show a statistically significant difference in mean concentration of cadmium values in groundwater samples between the three sampling periods at significance level of $p<0.05$ ($H(2) = 26.209$, $P = 0.000$).

Post hoc test results showed a significant mean difference in cadmium concentration between transition and short rain period ($p = 0.001$), as well as between transition period and dry period ($p = 0.000$). The null hypothesis of this study that no statistically significant difference existed in mean concentration of cadmium levels in ground water across the three sampling periods was therefore rejected. However, there was no significant difference between short rain and dry period ($p = 0.140$).

Kruskal-Wallis H test results showed that there was no statistically significant difference in mean concentration of cadmium in river water samples between the three sampling periods at significance level of $p<0.05$ (H (2) = 4.200, P = 0.122). Therefore, the null hypothesis of this study that no statistically significant difference existed in mean concentration of cadmium values in river water samples between the three sampling periods was accepted.

4.3.6 Chloride

Seasonal variation of chloride concentration in river and ground water samples was very narrow as indicated in Figures 4.9 and 4.10 below. Mean chloride concentration in groundwater samples during the transition period ranged from 14.2±0.00 mg/l at sampling point G5 (Nairobi road boreholes), K1, K2 and K4 (Kabatini boreholes) and BB2 and BB4 (Olobanita boreholes) to 28.40±0.00 mg/l at sampling point L1 (Leitmann borehole).

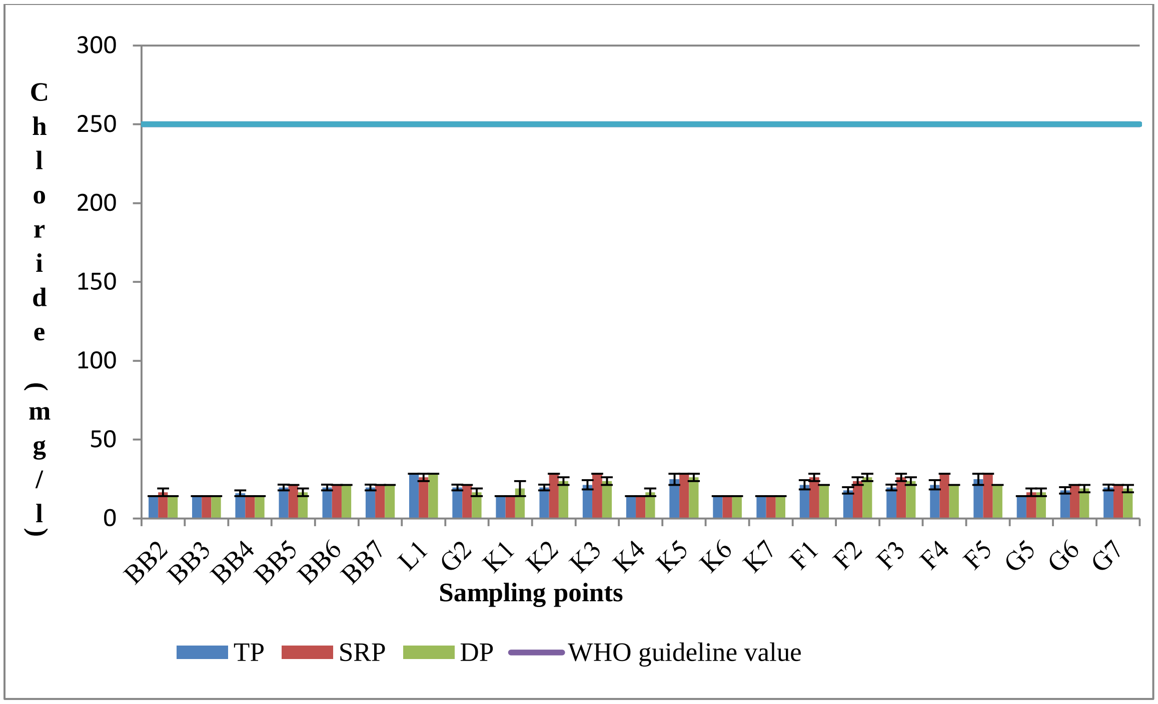

Figure 4.9: Seasonal variation in mean concentration of chloride in ground water.

concentration of chloride in river water samples during the transition period ranged from 14.2±0.00 mg/l at sampling point NR (River Ndarungu) and Mrc (River Malewa) to 15.1±0.52 mg/l at sampling point MR1 (River Meroronyi sampling point 1) (Figure 4.10 below).

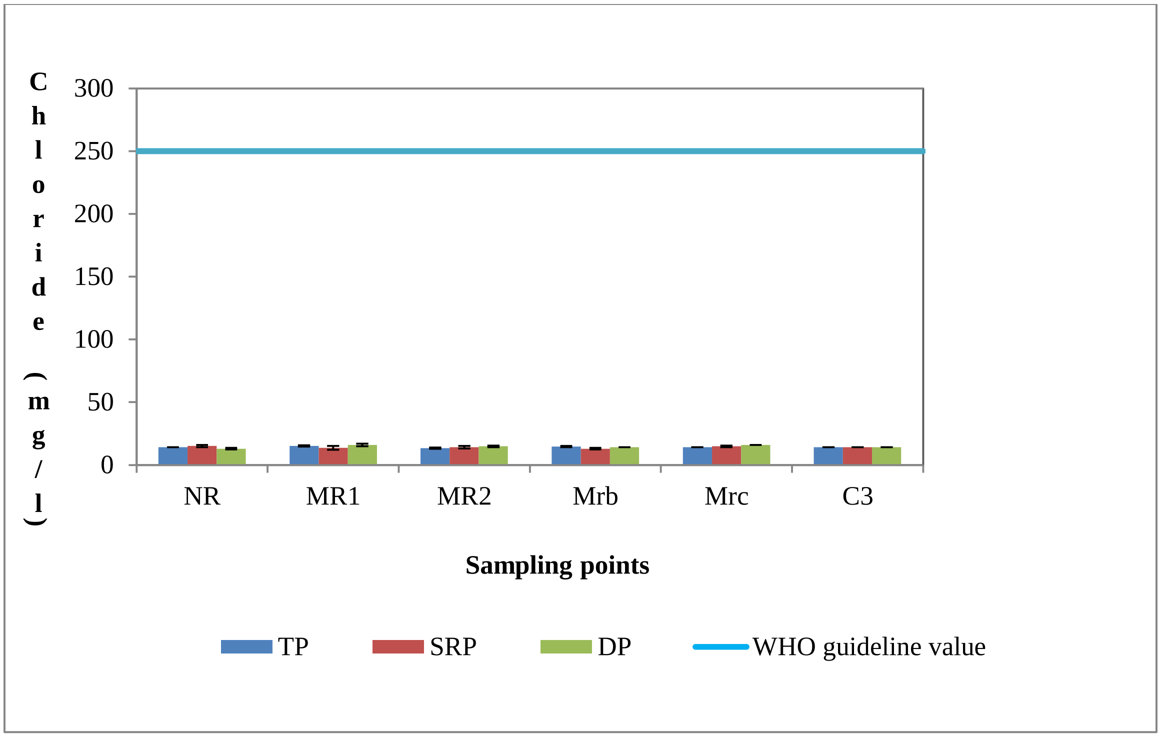

Figure 4.10: Seasonal variation in concentration of chloride in river water

Mean values of chloride concentration in groundwater samples during the short rain period ranged from 14.20±0.00 mg/l at sampling points BB2, BB3 and BB4 (Olobanita boreholes) and K1, K4, K6, K7, (Kabatini boreholes) to 28.40 mg/l±0.00 at sampling point K2, K3 and K5 (Kabatini boreholes) and F4 and F5 (Baharini boreholes) (Figure 4.9 above).

Concentration of chloride in river water samples during the short rain period ranged from 13.00±0.60 mg/l at sampling point Mrb (River Turasha) to 15.07±0.87 at sampling point NR (River Ndarugu) (Figure 4.10 above).

The values of mean concentration in chloride for all ground water samples during the dry period varied from 14.2±0.00 mg/l at sampling points; BB2, BB3 and BB4 (Olobanita boreholes), K1, K4, K6 and K7 (Kabatini boreholes), G5 (Nairobi road boreholes) to 28.40±0.00 mg/l at sampling point L1 (Leitmann borehole) (Figure 4.9 above).

Mean chloride concentration in river water samples during the dry period ranged from 13.0±0.60 mg/l at sampling point NR (River Ndarungu) and 16.0±1.04 mg/l at sampling point MR1 (River Meroronyi sampling point 1) (Figure 4.10 above).

The mean levels of chloride were relatively low and within the permissible and acceptable limits (WHO, 2011 and NEMA, 2006) for drinking water in river and ground water indicating less contamination and therefore free from excessive presence of chloride.

Kruskal-Wallis H test results showed that no statistically significant difference existed in mean concentration of chloride in ground water samples between the three sampling periods at significance level of $p<0.05$ (H (2) = 2.960, P = 0.228).

Kruskal-Wallis H test results showed that no statistically significant difference existed in mean concentration of chloride in river water samples between the three sampling periods at significance level of $p<0.05$ (H (2)= 0.927, P = 0.629). The null hypothesis of this study that no statistically significant difference existed in mean concentration of chloride values in river and ground water between the three sampling periods is therefore was accepted.

4.3.7 Seasonal variation in concentration of selenium

Selenium concentration mean values in groundwater samples during the transition period varied from 0.97±0.26 mg/l at sampling point G2 (Nakuwell borehole) and 5.58±0.36 mg/l at sampling point BB2 (Olobanita boreholes) (Figure 4.11 below).

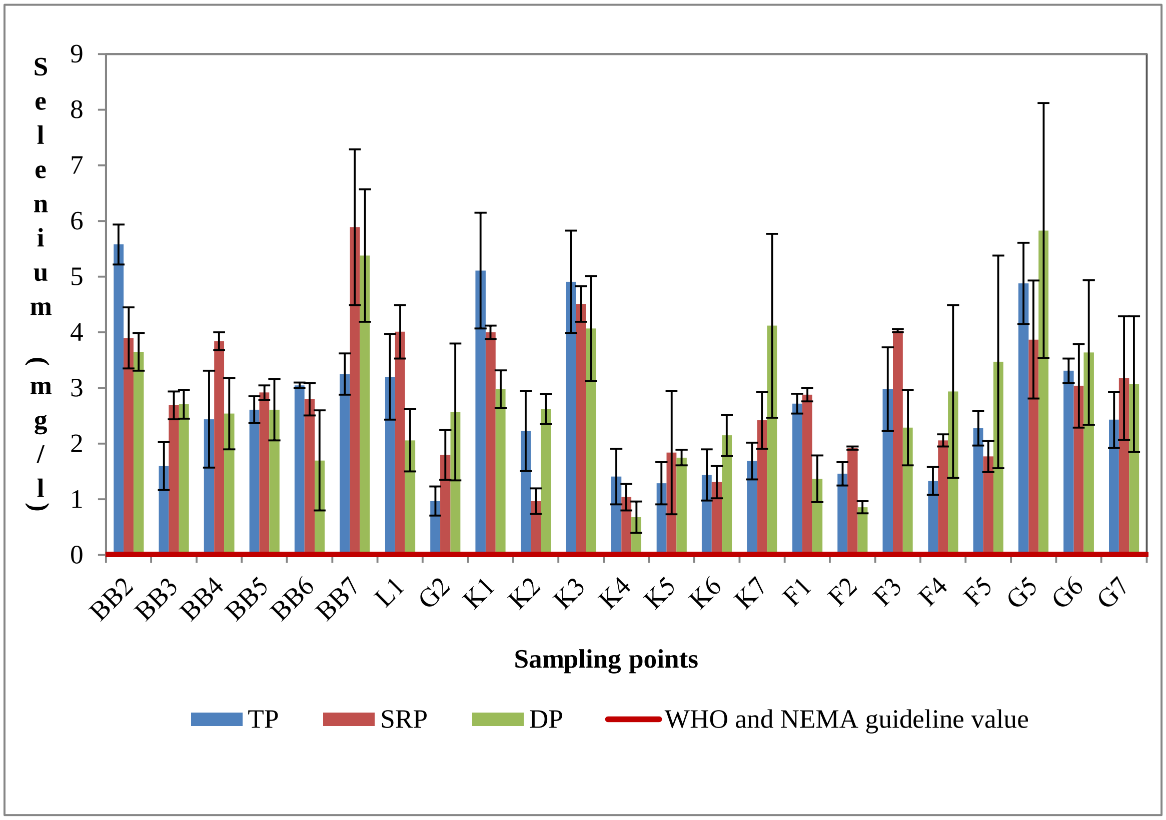

Figure 4.11: Seasonal variation in mean concentration of selenium in ground water.

In river water selenium concentration mean levels during the transition period ranged from 0.39±0.22 mg/l at sampling point MR1 (River Meroronyi) to 1.99±0.69 mg/at sampling point Mrc (Malewa River) (Figure 4.12 below).

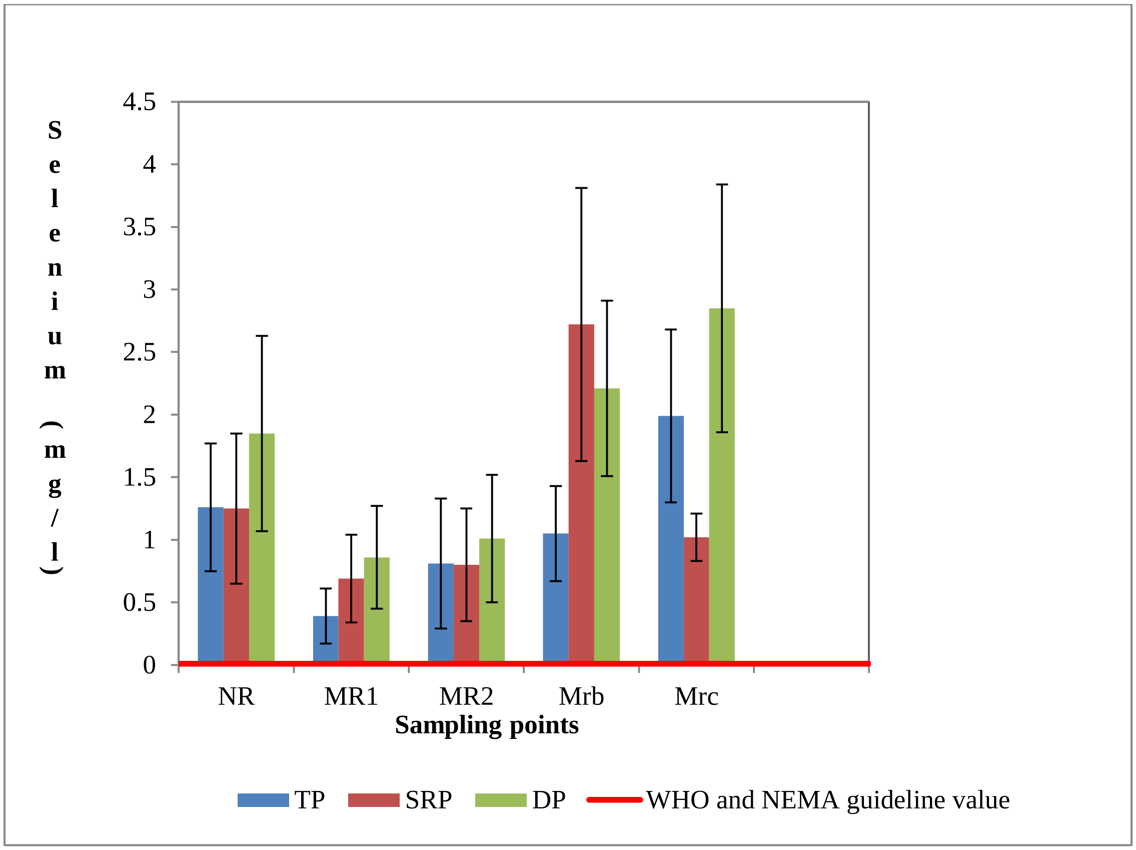

Figure 4.12: Seasonal variation in mean concentration of selenium in river water.

Mean values of selenium concentration in ground water samples during short rain period ranged from 1.04±0.50 mg/l at sampling point K4 (Kabatini borehole) to 5.89±1.40 mg/l at sampling point BB7 (Olobanita borehole) (Figure 4.11).

Mean values of selenium concentration in river water during the short rain period varied between 0.69 ± 0.35 mg/l at sampling point MR1 (River Meroronyi) and 2.72 ± 1.09 at sampling point Mrb (River Turasha).

The mean values of selenium concentration in ground water samples varied from 0.68±0.28 mg/l at sampling point K4 (Kabatini borehole) to 5.83±2.29 at sampling point G5 (Nairobi road borehole) during the dry period (Figure 4.11).

Mean values of selenium concentration in river water samples over the dry period were 0.86±0.41 mg/l at sampling point MR1 and 2.85±0.99 at sampling point Mrc (Figure 4.12).

Kruskal-Wallis H test results revealed that there was no statistically significant difference in mean concentration of selenium in ground water samples between the three sampling periods at significance level of $p<0.05$ ($H(2)= 0.038$, $p = 0.981$). For river water samples, the results revealed that there was no statistically significant difference between the mean values of selenium concentration between the three sampling periods at significance level of $p<0.05$ ($H(2) = 04.200$, $p = 0.472$). The null hypothesis of this study that no statistically significant difference existed in mean concentration of selenium values in river and groundwater samples between the three sampling periods is therefore was accepted.

4.4 Evaluation of river and ground water quality for drinking purposes

Based on the CCME-WQI model conceptual framework presented in Table 3.1, index and ranking values for overall evaluation of drinking water were calculated. Data sets representing average concentration levels of measured water quality parameters in natural river and ground water at different sampling points among the three index periods were considered. Results are as presented in Appendix V, Tables 5.1 and 5.2 and Figures 4.13 and 4.14. Guideline values for quality of drinking water set by WHO (2011) were applied in categorizing the observed water types for use as drinking water. In addition, national water quality regulations (NEMA, 2006) for drinking water were considered only as a reference for comparison of elements concentrations with WHO (2011) guideline values.

The overall cumulative influence of average concentrations of observed water quality parameters on drinking water chemical composition was calculated based on CCME-WQI conceptual framework. Results of the calculated WQI values and ranking among the sampling points between the three sampling periods indicated that river water quality was poor with an index value ranging from 20.94 to 39.69 while in ground water calculated index values ranged from 29.83 to 37.71. The results are as presented in the Figures 4.13 and 4.14.

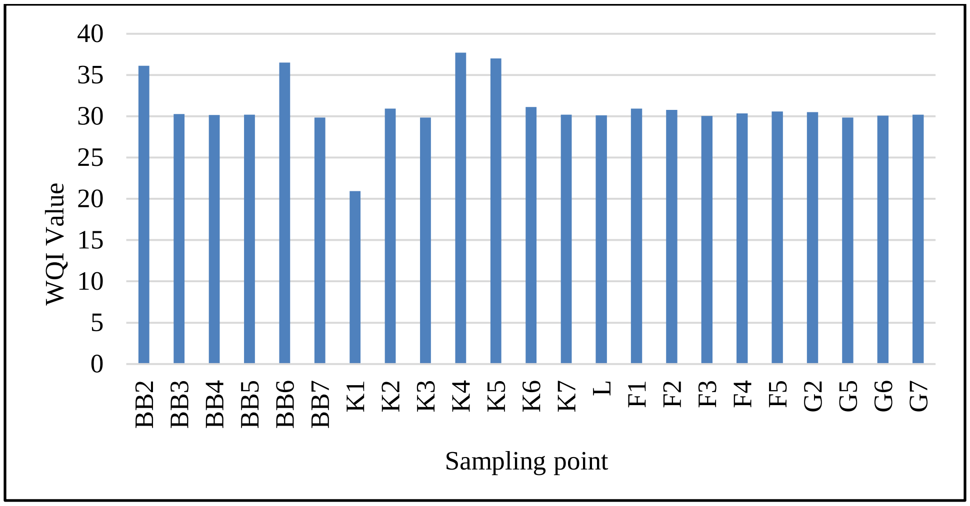

Figure 4.13: WQI values in ground water

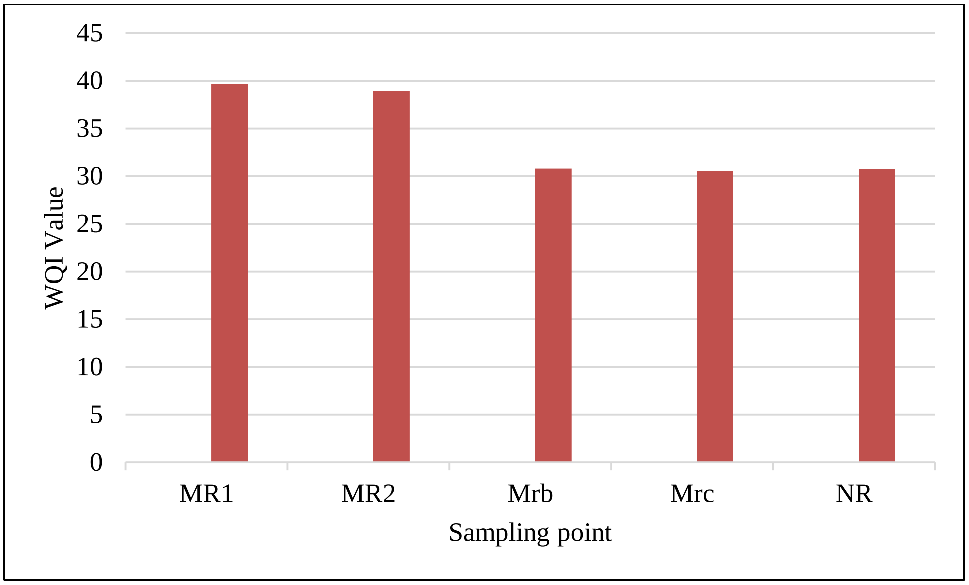

Figure 4.14: WQI values in river water

4.5 Spatial analysis of water quality parameters

Spatial distribution maps covering the study period for each observed drinking water quality parameter in river and ground water samples are presented in Figures 4.15 to 4.38. The figures show visual representation of the distribution of average water parameters concentration across the study period at different geographical locations of the sampled points. The spread was evaluated based on the distribution of the colours as depicted in the maps. Colour contrast along the path of spread represented the concentration values of measured parameters. In the maps, light colours signify locations of low values (excellent water quality <25% violation to set standards), light dark colours signify locations of average values (good water quality <50% violation to set standards) and dark colors signify locations of high values (poor water quality >50% violation to set standards). Evaluation of the colour distribution patterns in terms of water quality status was based on the parameters relative level (high, low, average) in regard to quality of drinking water in line with WHO, (2011) and NEMA, (2006) guideline values.

Spatial spread of pH levels showed that little variation existed across different sampling points over the study period (Figures 4.15, 4.16, 4.17 and 4.18). The classified data presented in legend section of Figures 4.15, 4.16, 4.17 and 4.18 showed ranges of 8.10 to 9.03 across the sampling points. With respect to drinking uses, the results showed excellent water quality in regard to pH at all sampled points for river and groundwater.

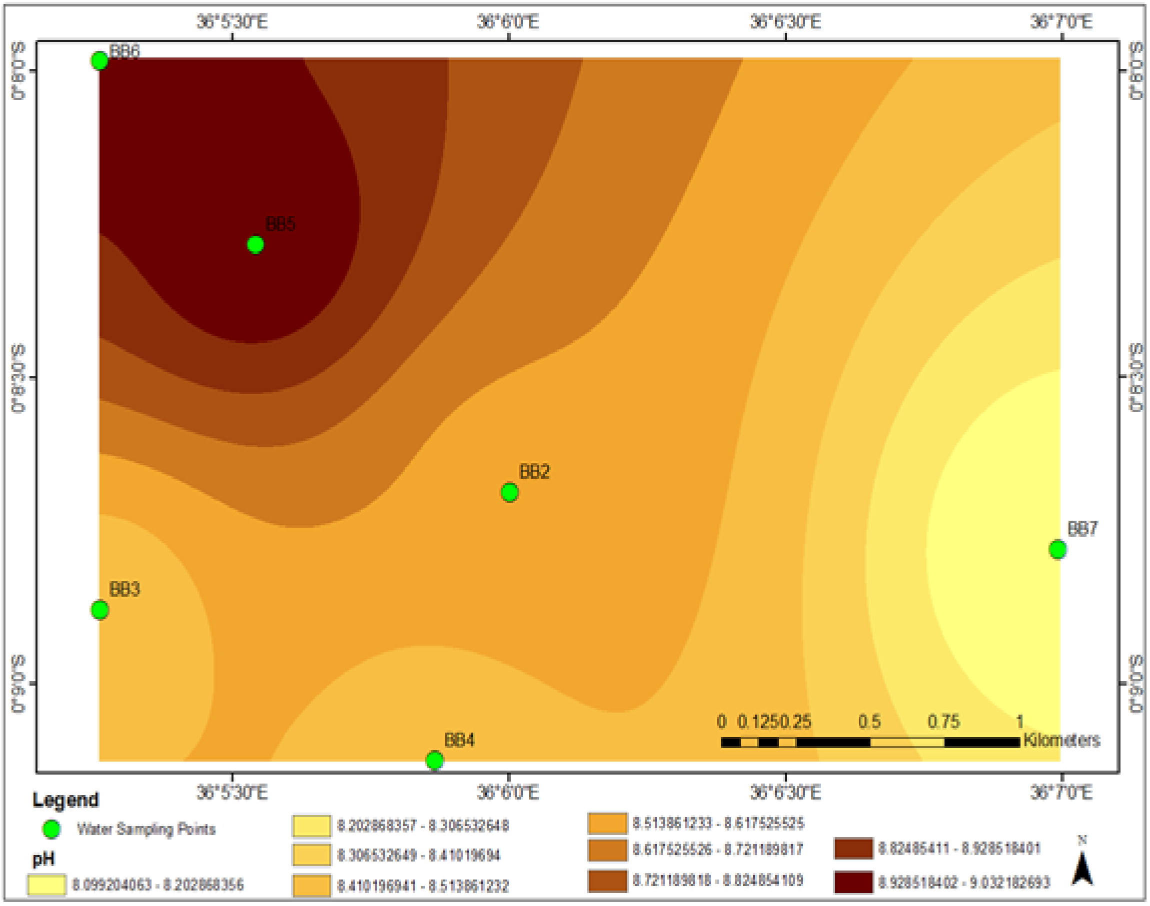

Figure 4.15: pH spatial distribution patterns at sampling points BB2 to BB7.

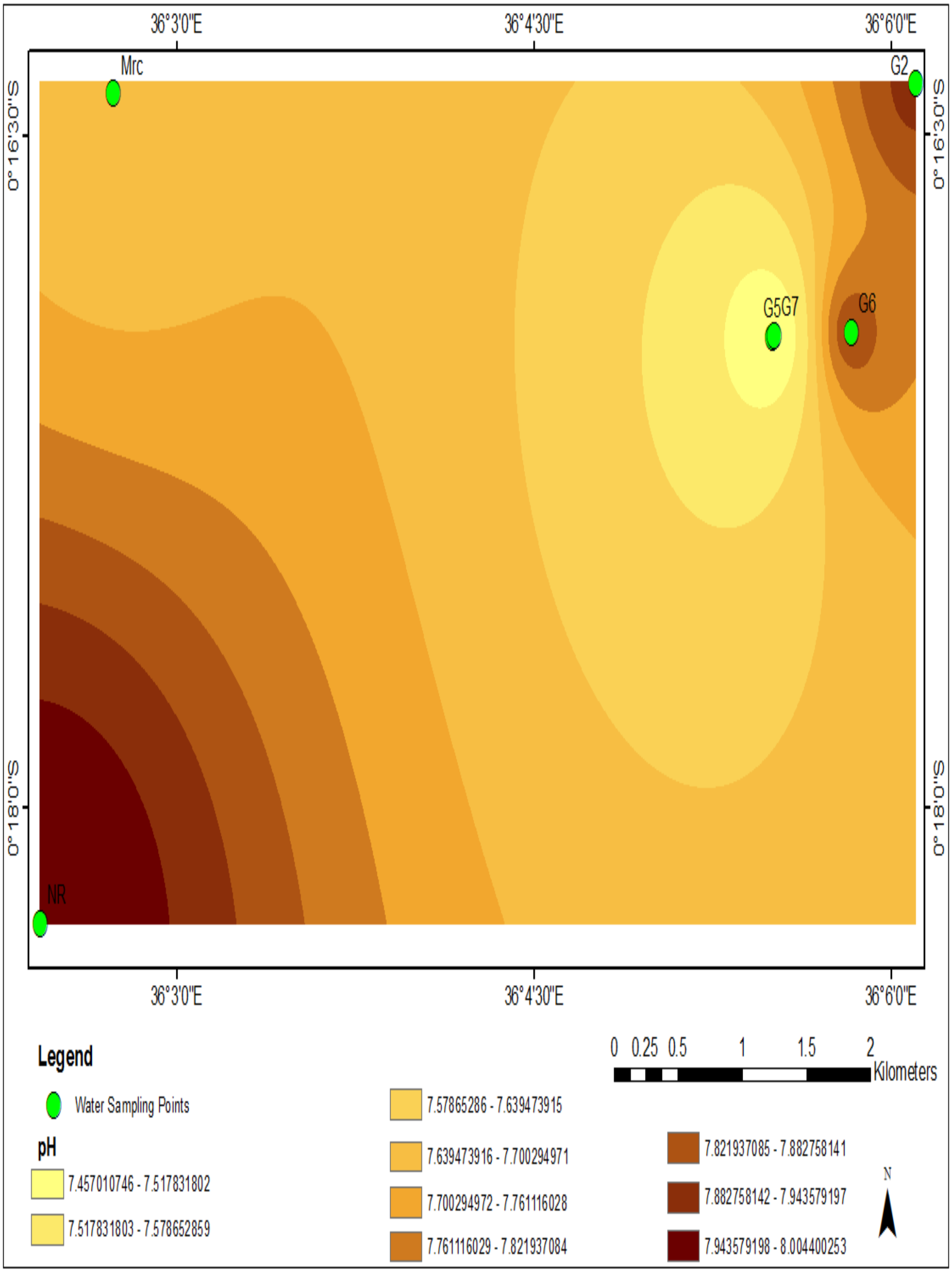

Figure 4.16: pH spatial distribution patterns at sampling points NR, Mrc, G2, G5, G6, G7

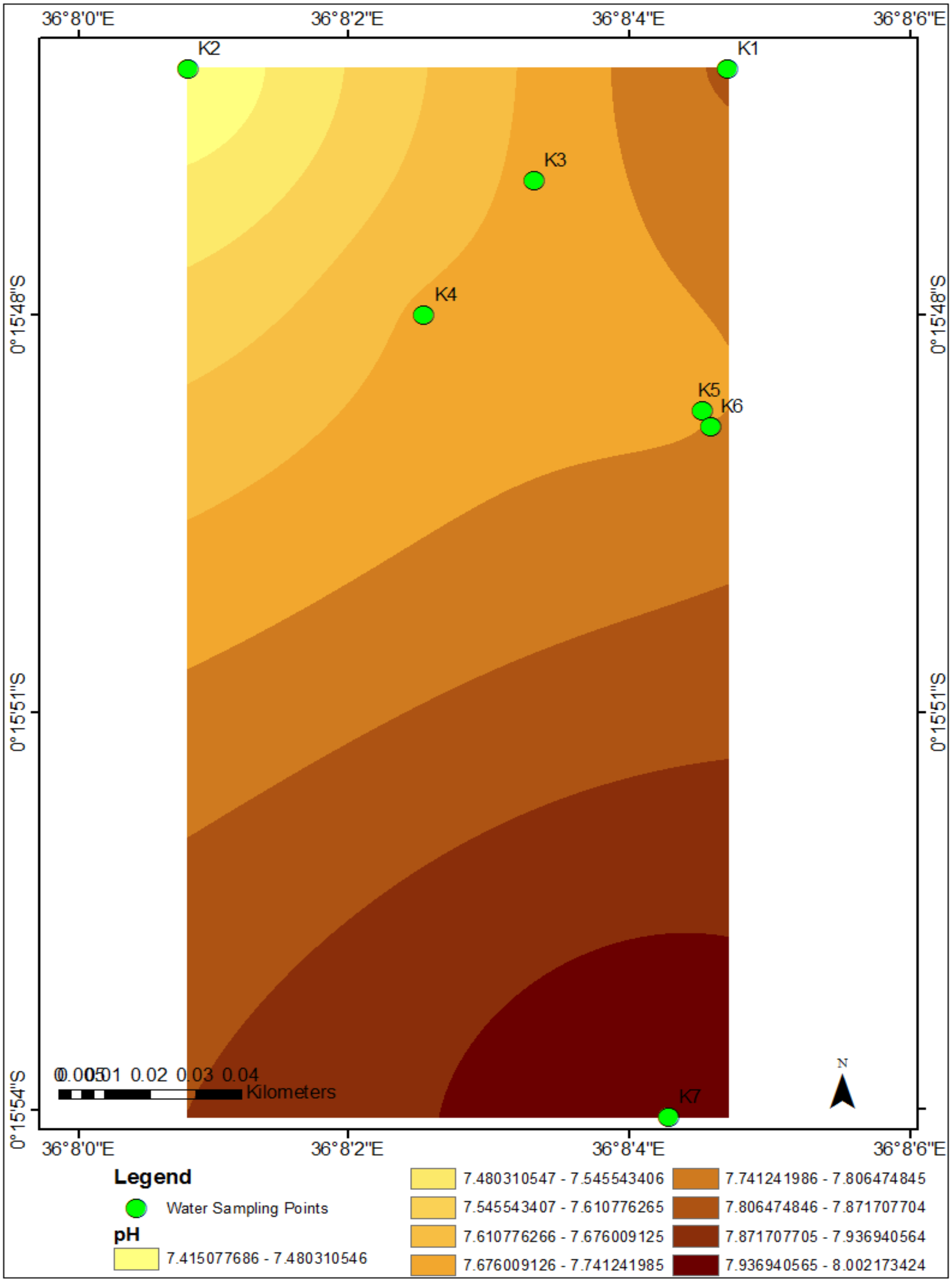

Figure 4.17: pH Spatial distribution patterns at sampling points K1, K2, K3, K4, K5, K6 and K7.

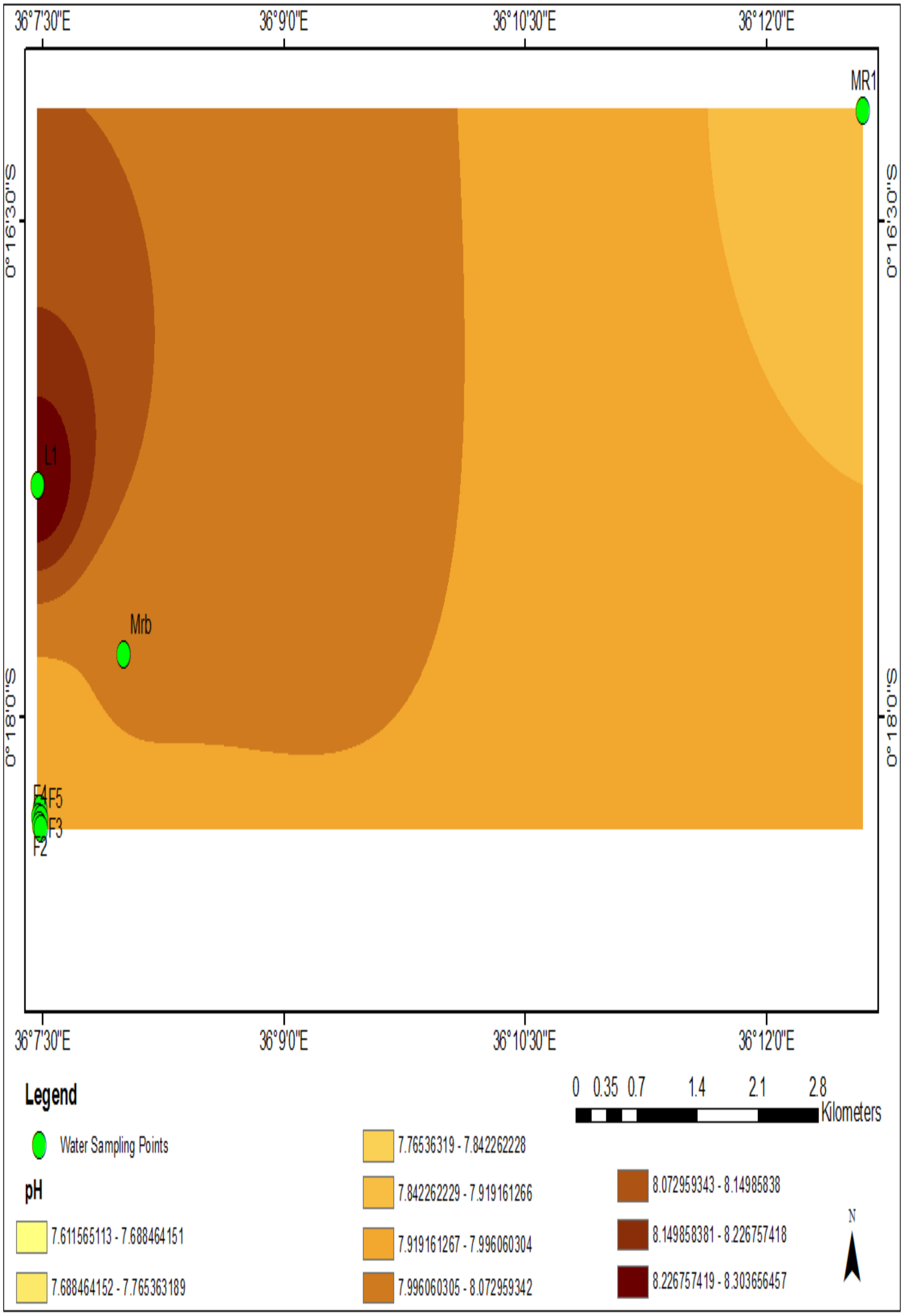

Figure 4.18: pH spatial distribution patterns at sampling points L, F1, F2, F3, F4, F5, Mrb and MR1

The spatial distribution maps of fluoride levels representing ground water showed a wide variation in regard to well field location compared to river water (Figures 4.19, 4.20, 4.21 and 4.22). In ground water, fluoride levels were above the maximum permissible limits (WHO, 2011) at all sampling points hence unsuitable for drinking purposes. For river water, the level of fluoride varied such that some samples had elevated levels while others had less concentration in reference to the maximum permissible limits (WHO, 2011) for drinking water.

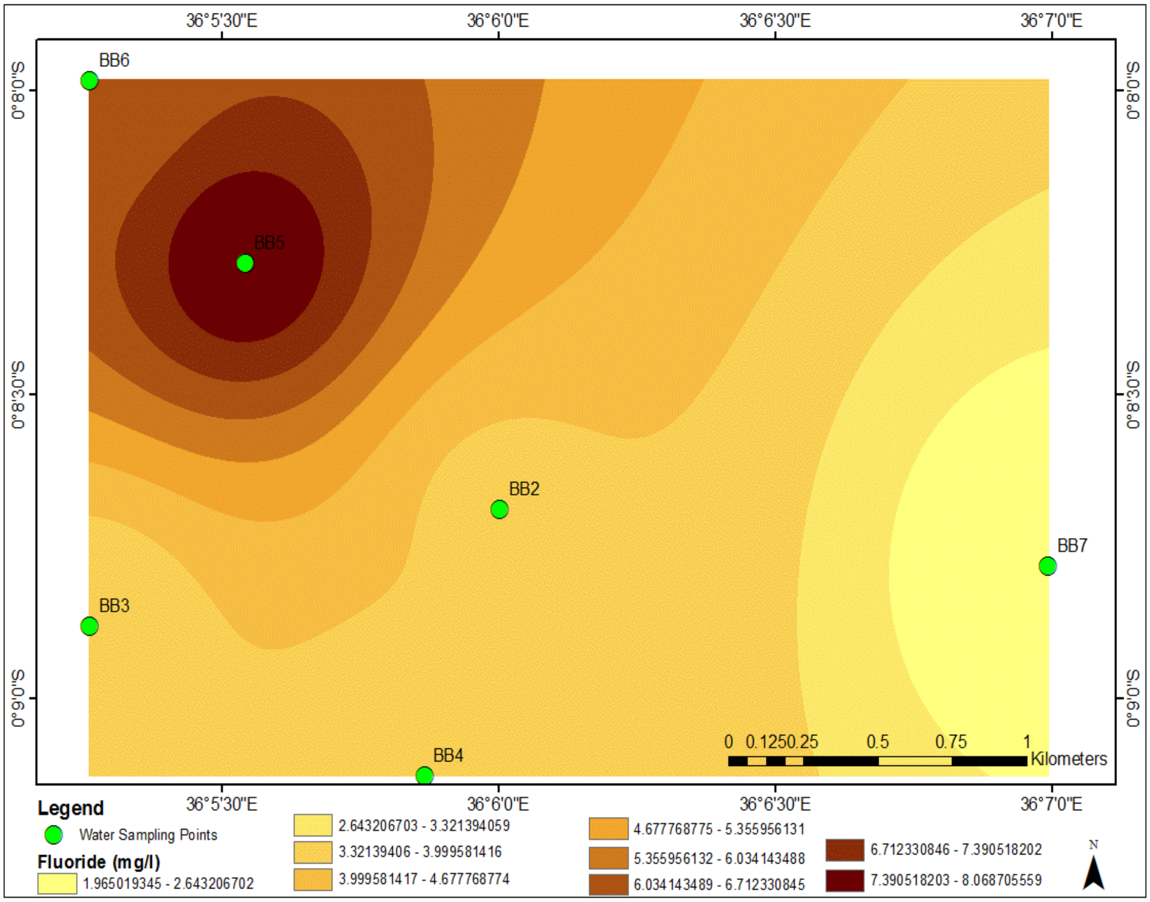

Figure 4.19: Spatial distribution of fluoride at sampling points BB2 to BB7

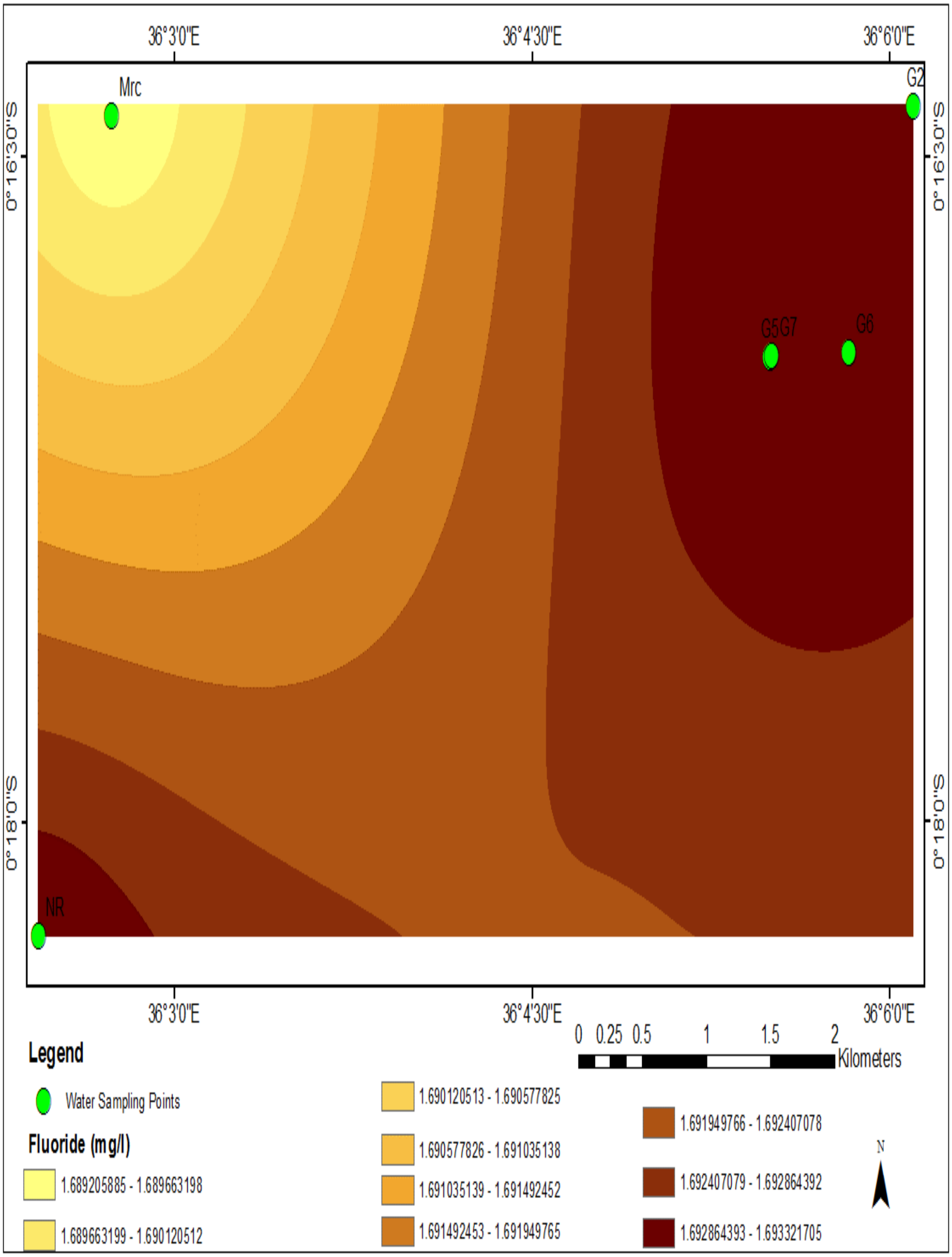

Figure 4.20: Spatial distribution of fluoride at sampling points NR, Mrc, G2, G5, G6 and G7

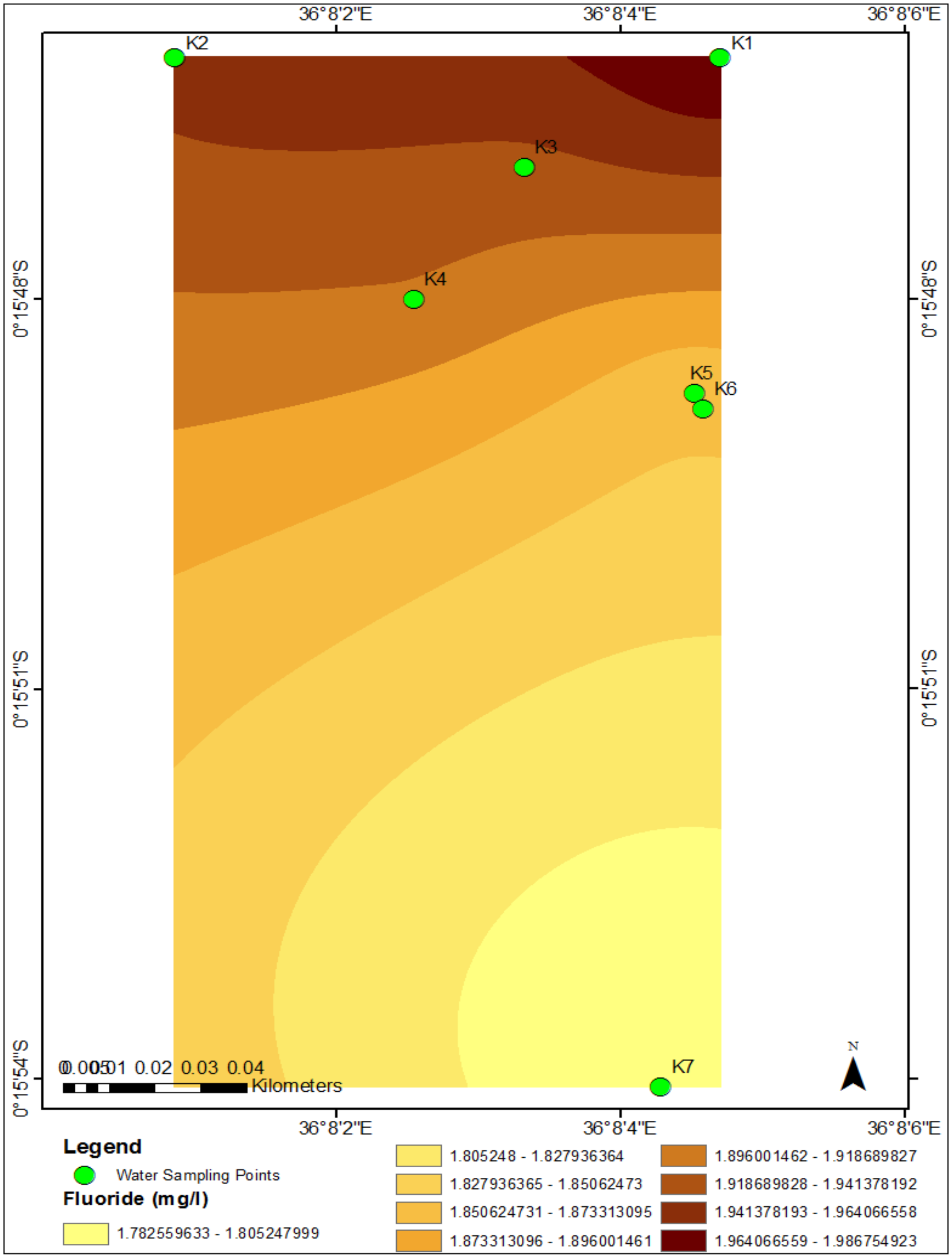

Figure 4.21: Spatial distribution of fluoride at sampling points K1, K2, K3, K4, K5, K6 and K7

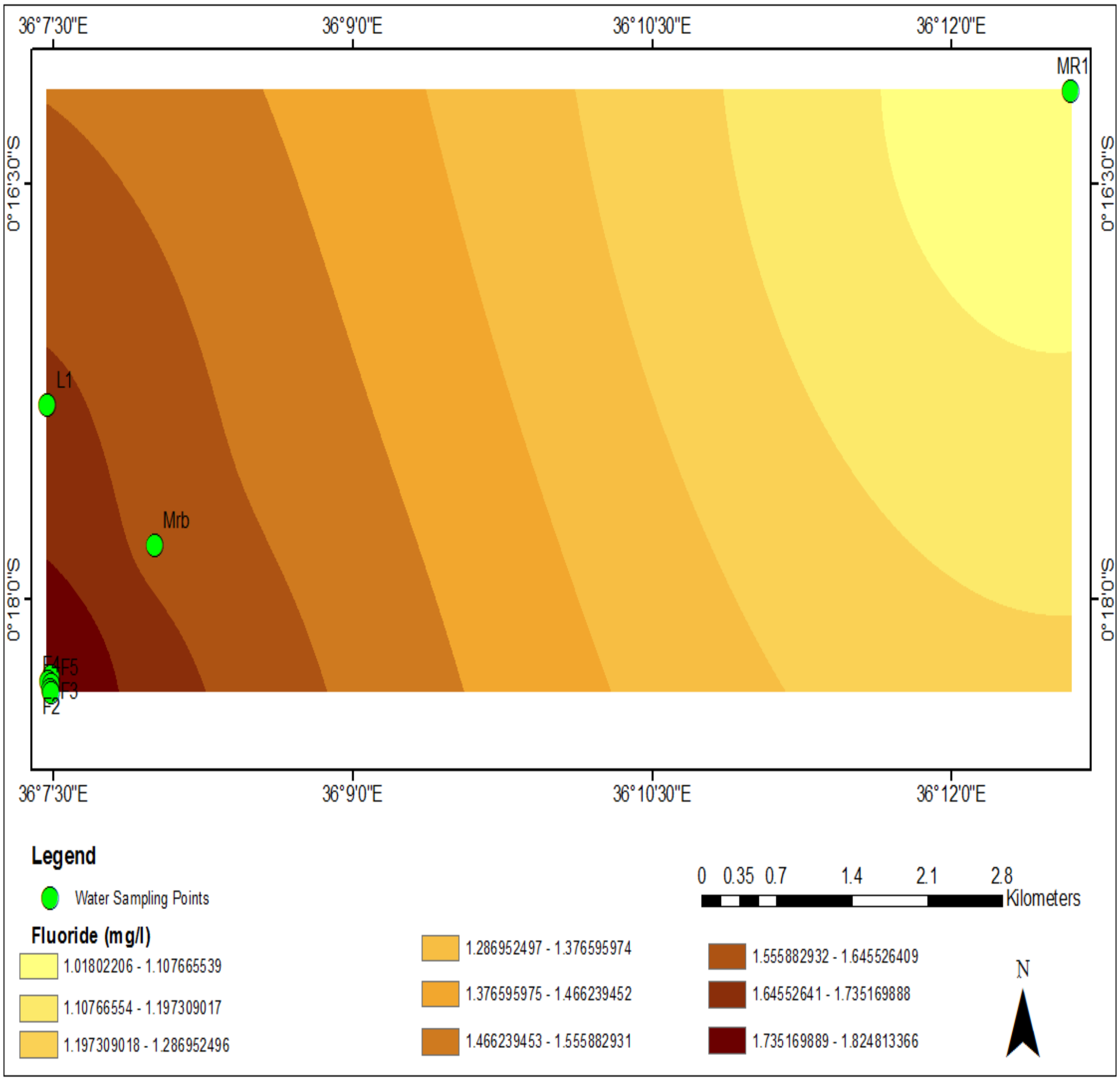

Figure 4.22: Spatial distribution of fluoride at sampling points F1, F2, F3, F4, F5, Mrb and MR1

In both river and ground water, conductivity concentration in reference to the classified data presented in as legend data Figures 4.23, 4.24, 4.25 and 4.26ranged from 146.84 µS/cm to 866.27 µS/cm as depicted in. Its spread across different sampling sites indicated differences in concentration in both river and ground water among the three sampling periods. The mean concentration values met the suitability for drinking water as evaluated to the maximum permissible limits (WHO, 2011) in both river and ground water. Elevated levels were noted in Olobanita boreholes that are represented by sampled points BB2, BB3, BB4, BB5, BB6 and BB7 (Figure 4.23).

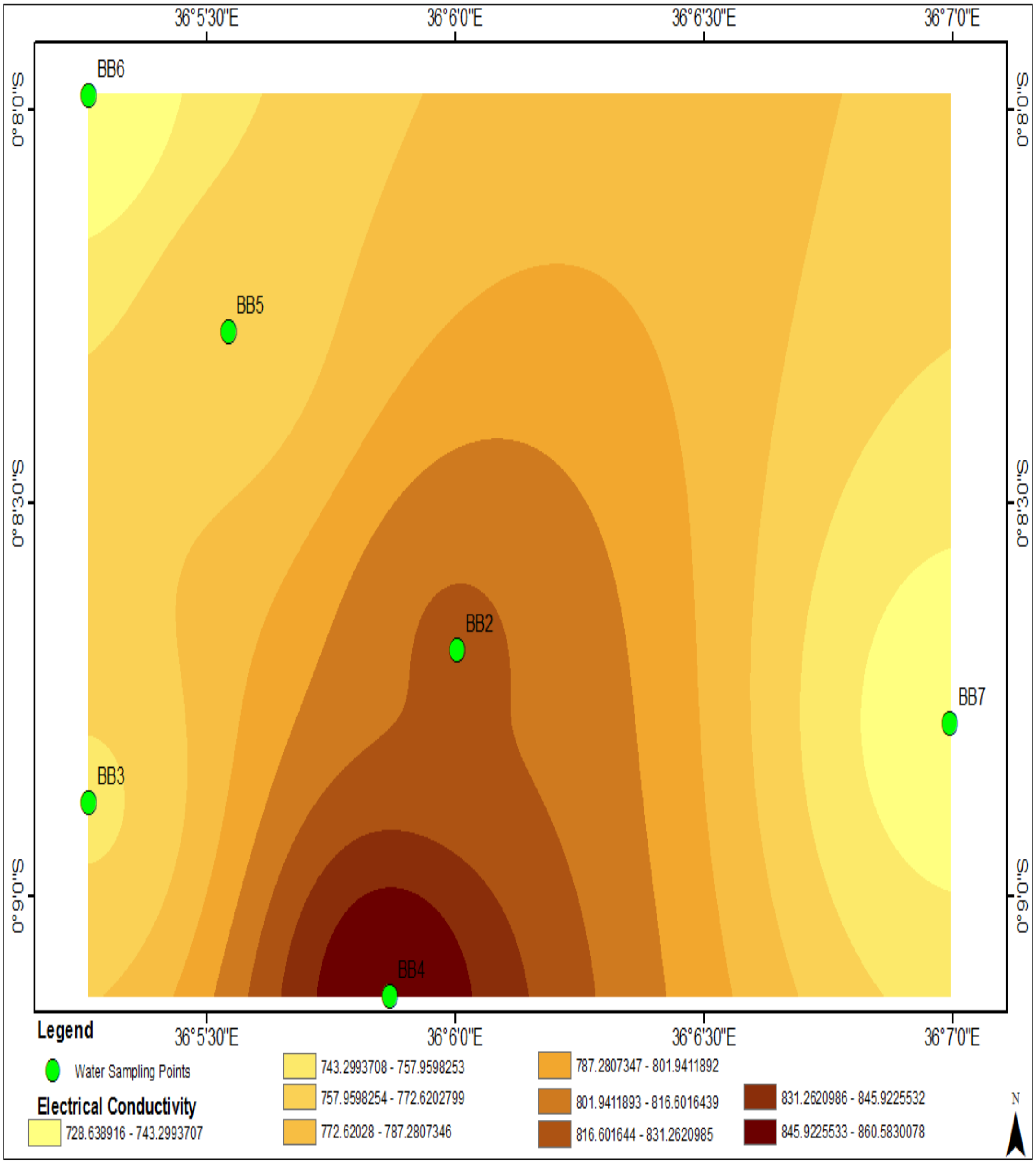

Figure 4.23: Spatial distribution of electrical conductivity at sampling points BB2 to BB7.

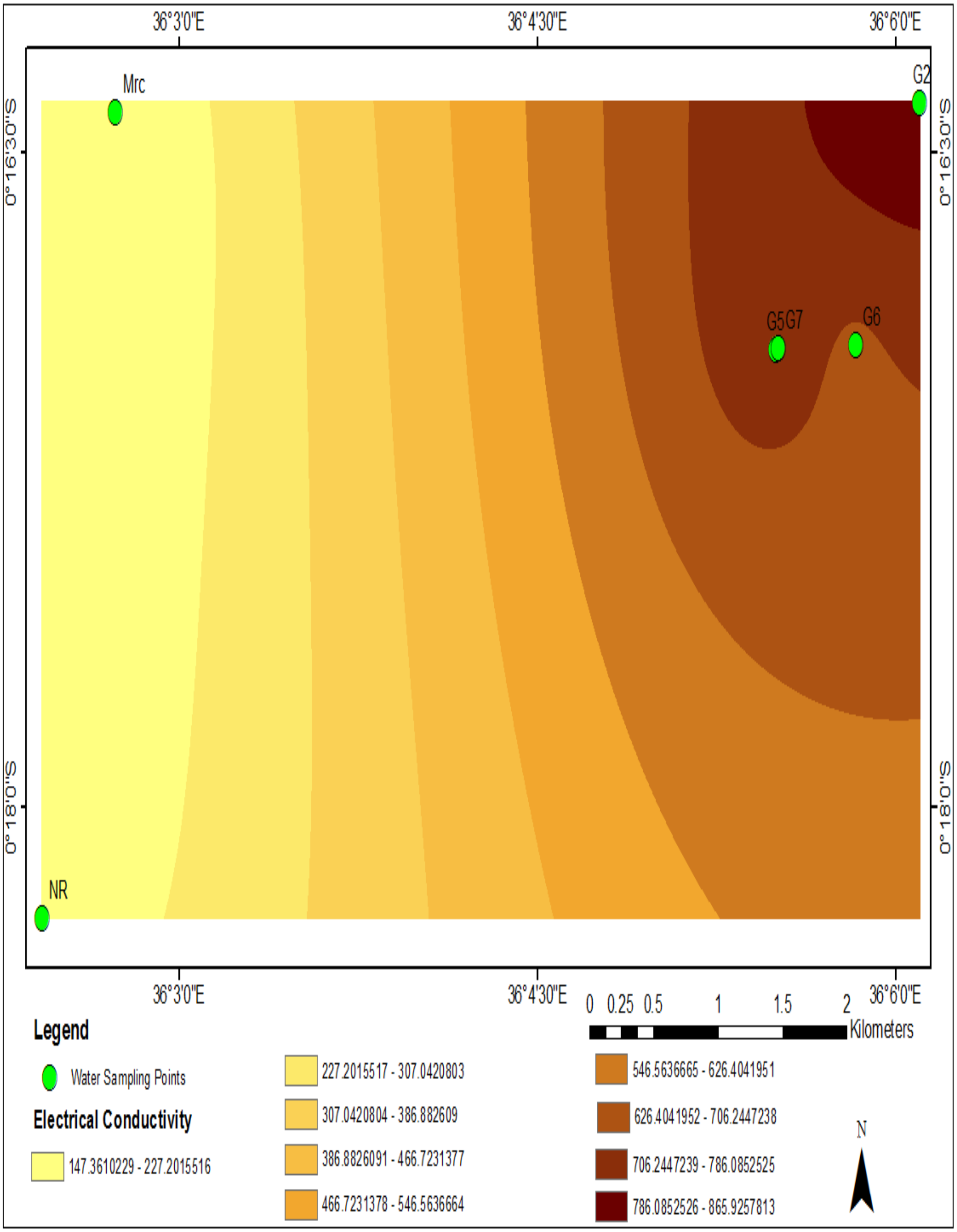

Figure 4.24: Spatial distribution of electrical conductivity at sampling points NR, Mrc, G2, G5, G6 and G7.

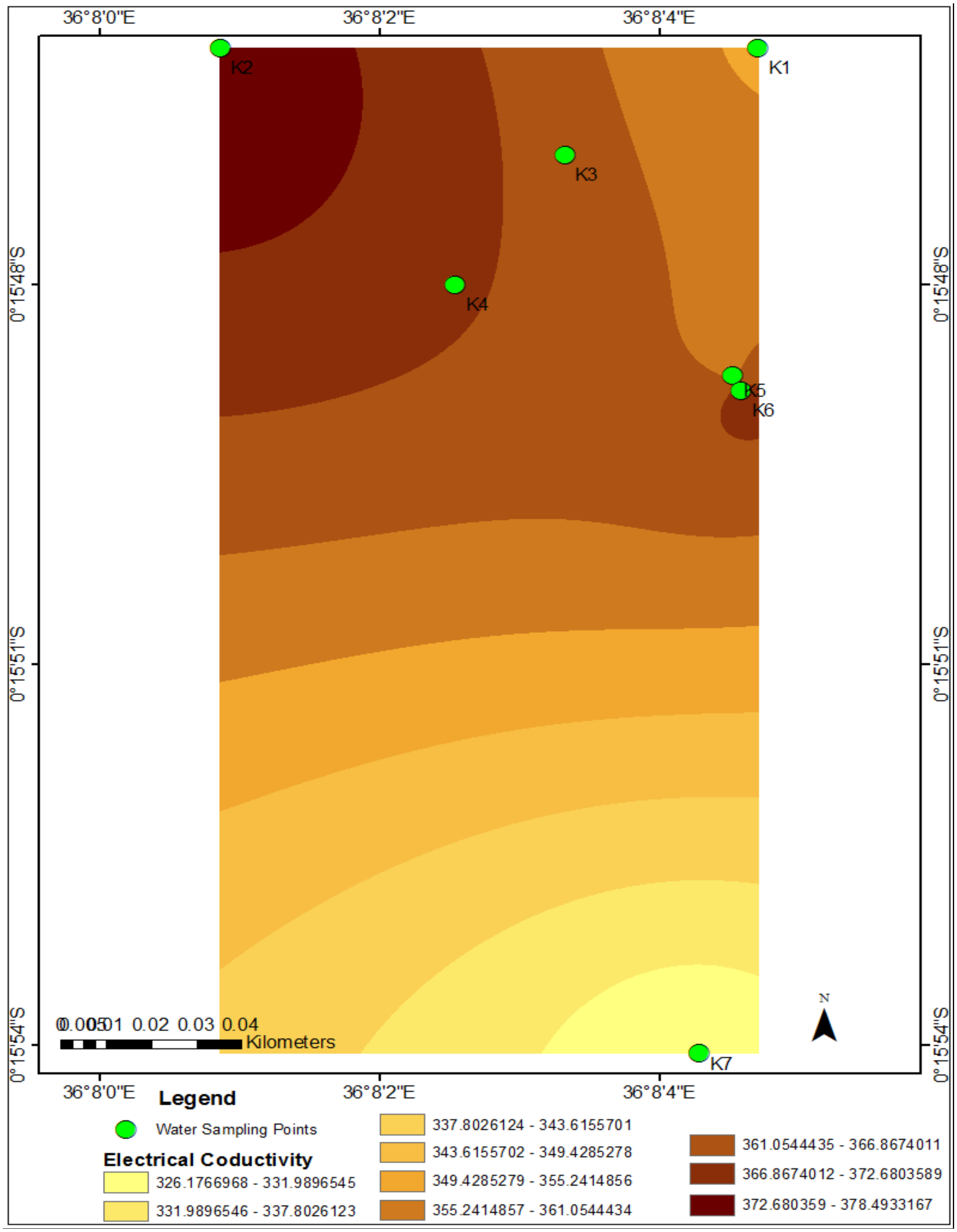

Figure 4.25: Spatial distribution of electrical conductivity at sampling points K1, K2, K3, K4, K5, K6 and K7.

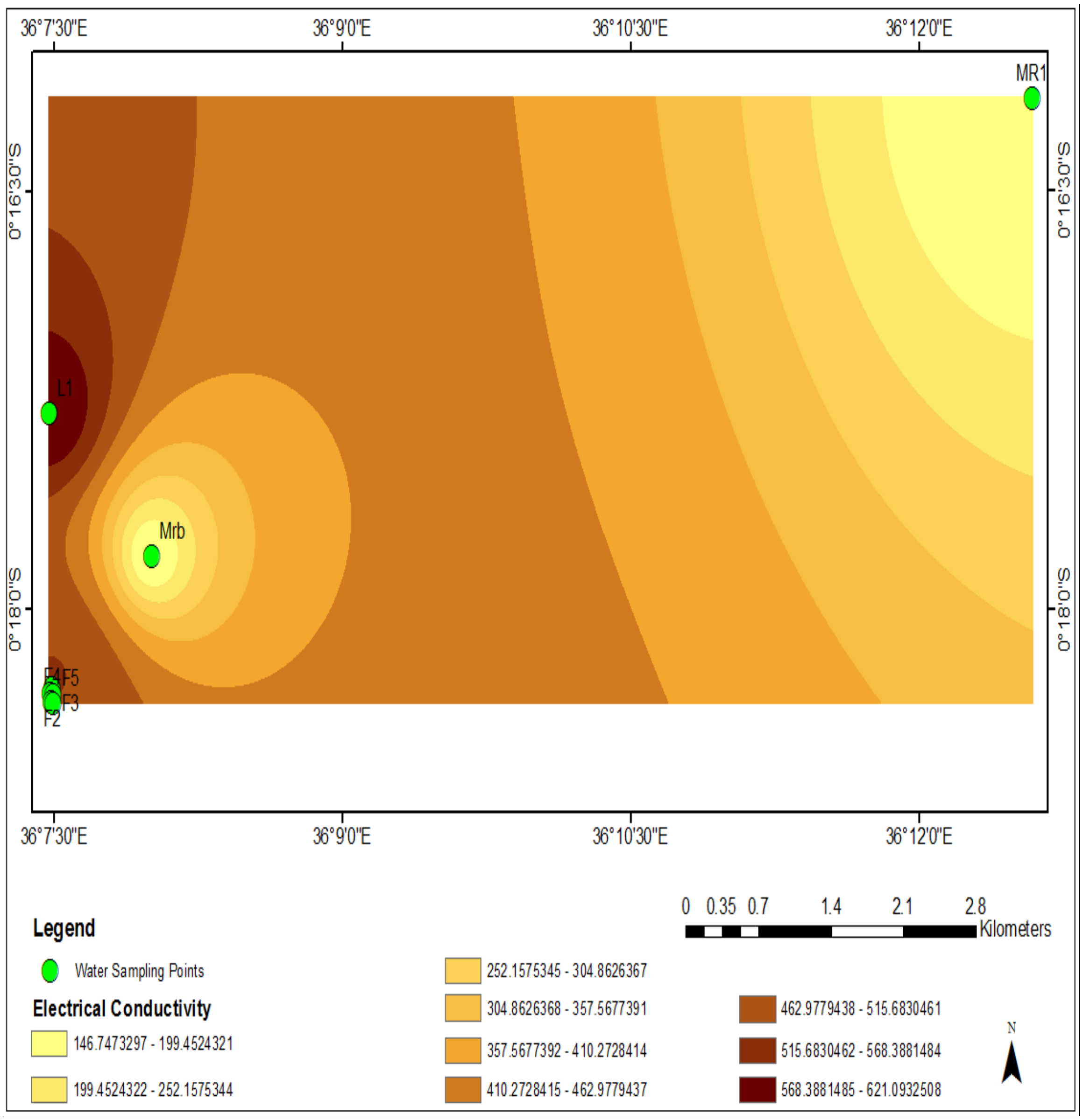

Figure 4.26: Spatial distribution of electrical conductivity at sampling points F1, F2, F3, F4, F5, Mrb and MR1

Spatial distribution maps (Figures 4.27, 4.28, 4.29 and 4.30) of cadmium average concentration in both river and ground water showed little variation between different sampling points across the three sampling periods. The spatial extent of water quality was noted to vary with respect to sampling point and type of water source. The classified data presented in legend of Figures 4.27, 4.28, 4.29 and 4.30 showed ranges of 0.046 mg/l to 0.419 mg/l among the sampling points with respect to groundwater but in river water the range was from 0.046 mg/l to 0.124 mg/l. Results showed that cadmium levels in both river and ground water were above the permissible guideline values (WHO, 2011) at all sampled points over the sampling period.

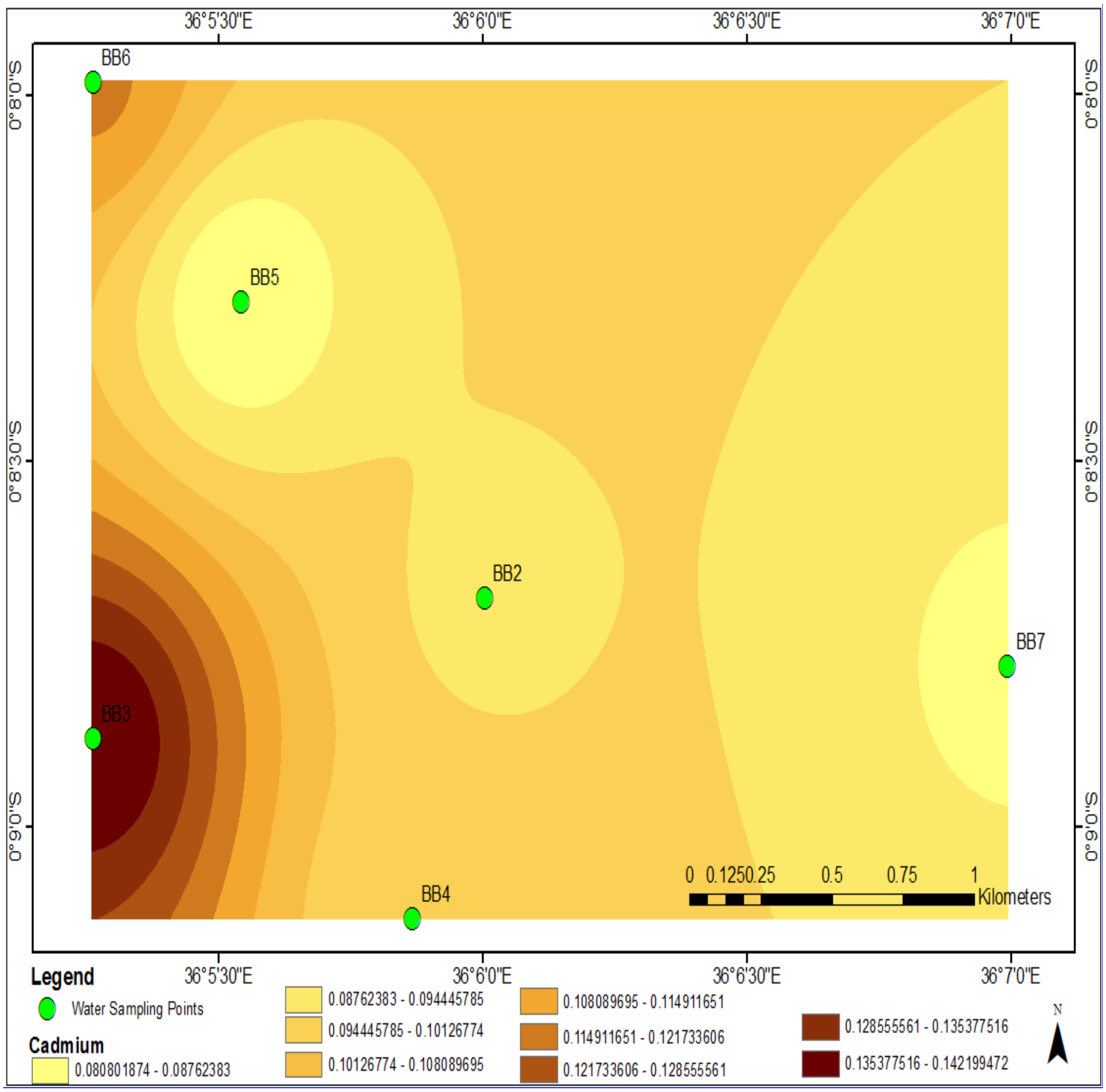

Figure 4.27: Spatial distribution of cadmium at sampling points BB2 to BB7.

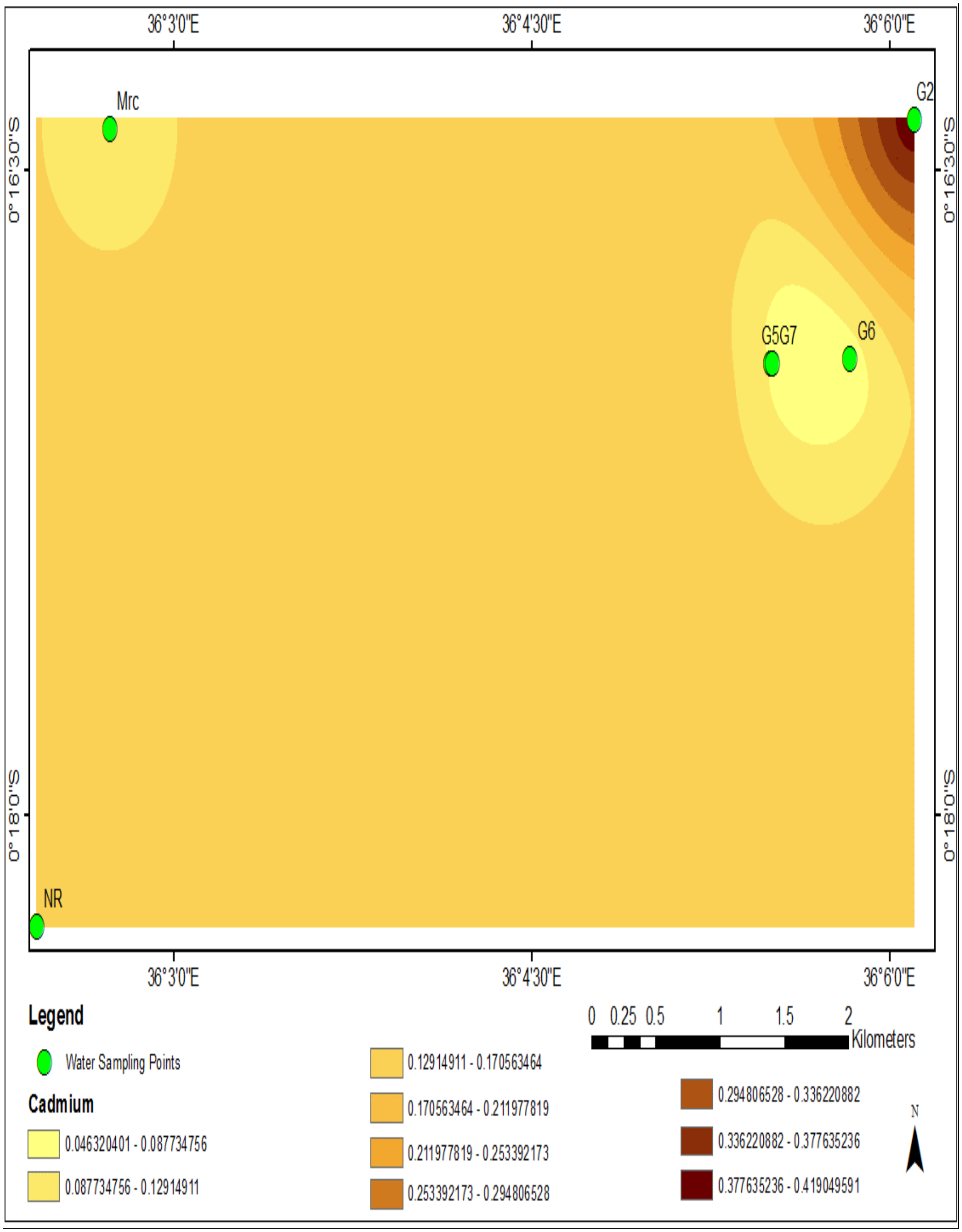

Figure 4.28: Spatial distribution of cadmium at sampling points NR, Mrc, G2, G5, G6 and G7.

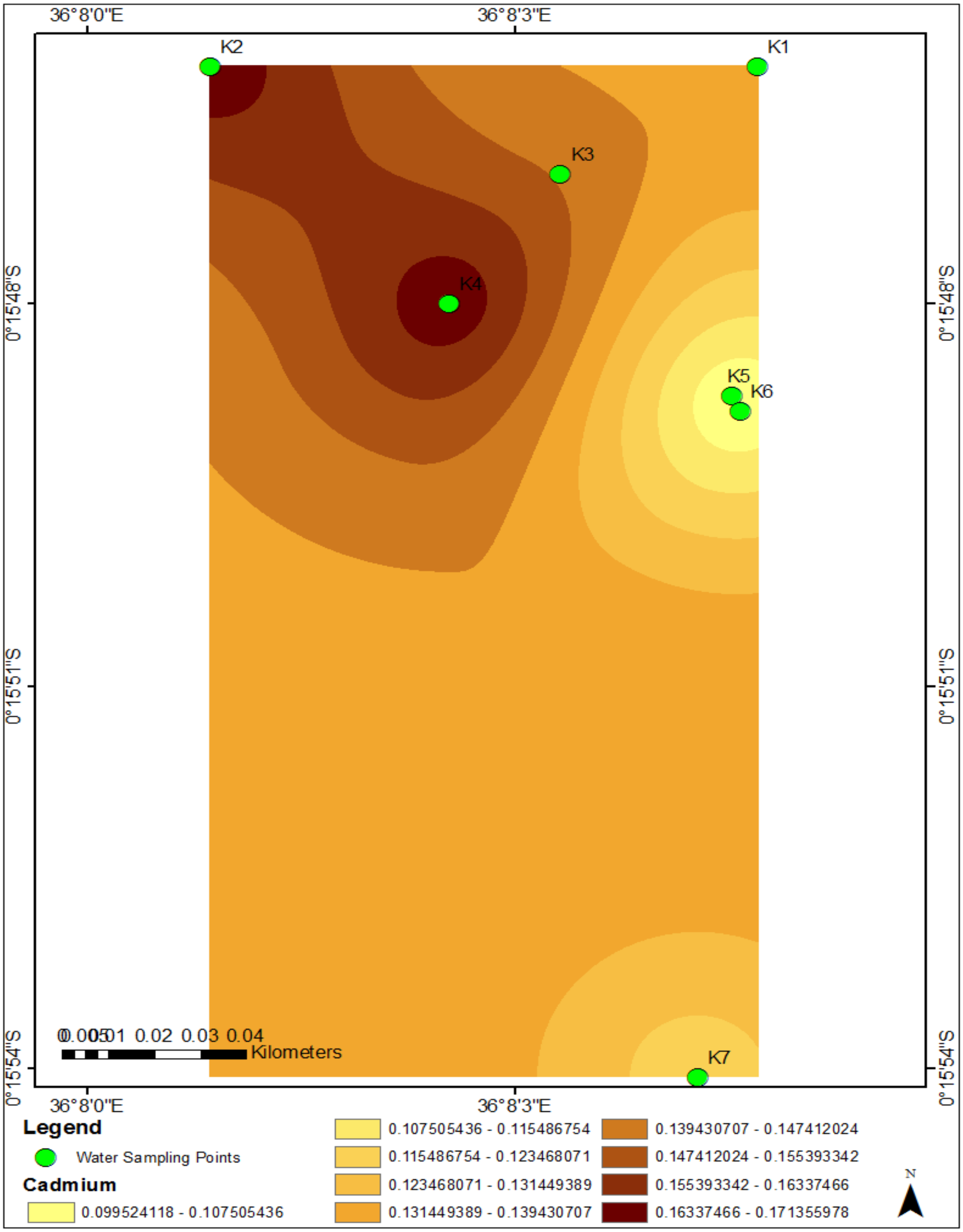

Figure 4.29: Spatial distribution of cadmium at sampling points K1, K2, K3, K4, K5, K6 and K7.

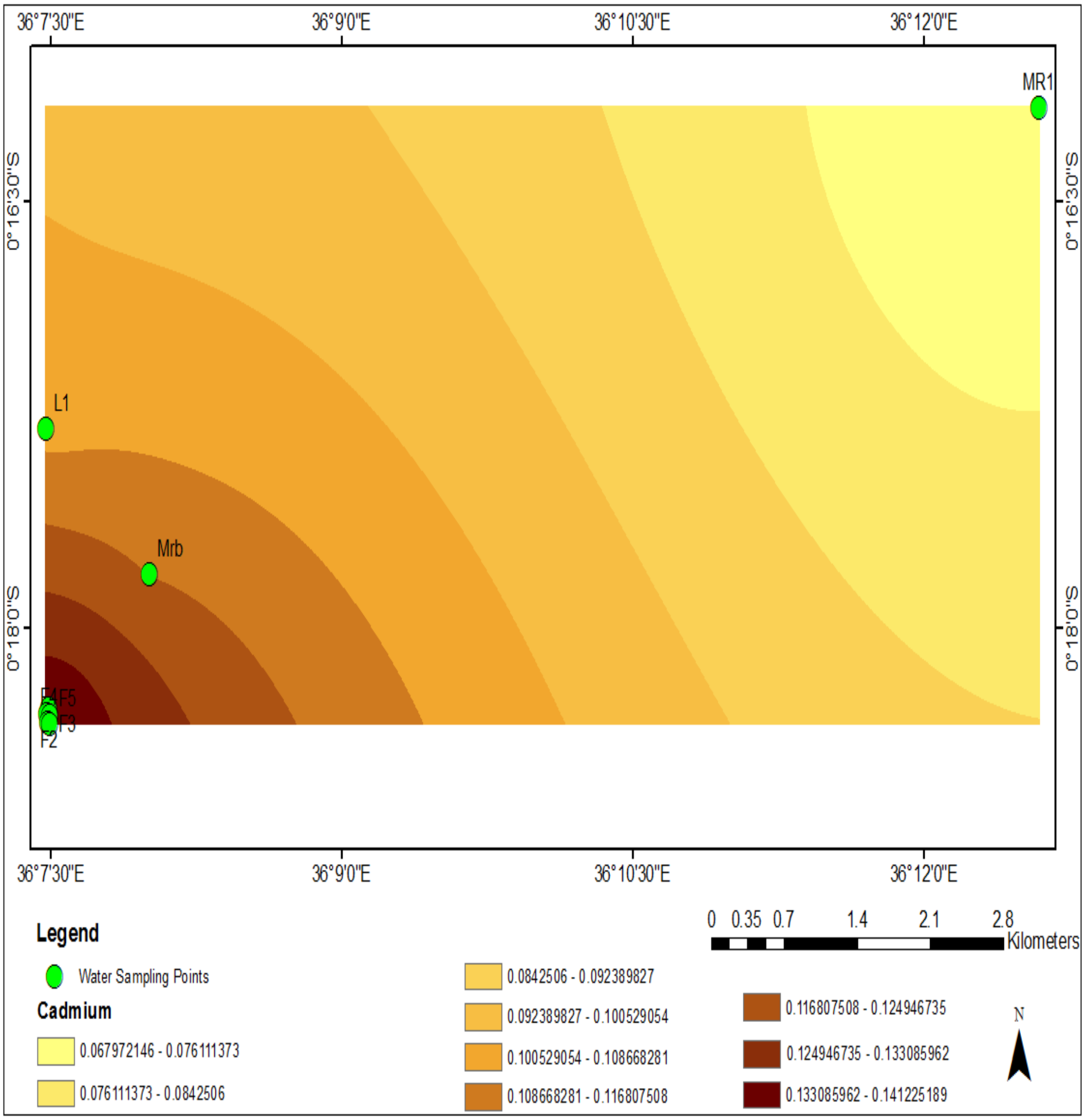

Figure 4.30: Spatial distribution of cadmium at sampling points F1, F2, F3, F4, F5, Mrb and MR1

Chloride level classified data presented in legend in Figures 4.31, 4.32, 4.33 and 4.34 showed ranges of 13.96 mg/l to 27.56 mg/l across the sampling periods. The spatial extent of chloride varied narrowly with respect to sampling points (Figures 4.31, 4.32, 4.33 and 4.34) over the study period. Chloride levels were within the permissible limits (WHO, 2011 and NEMA, 2006) at all sampling points hence safe for drinking purposes.

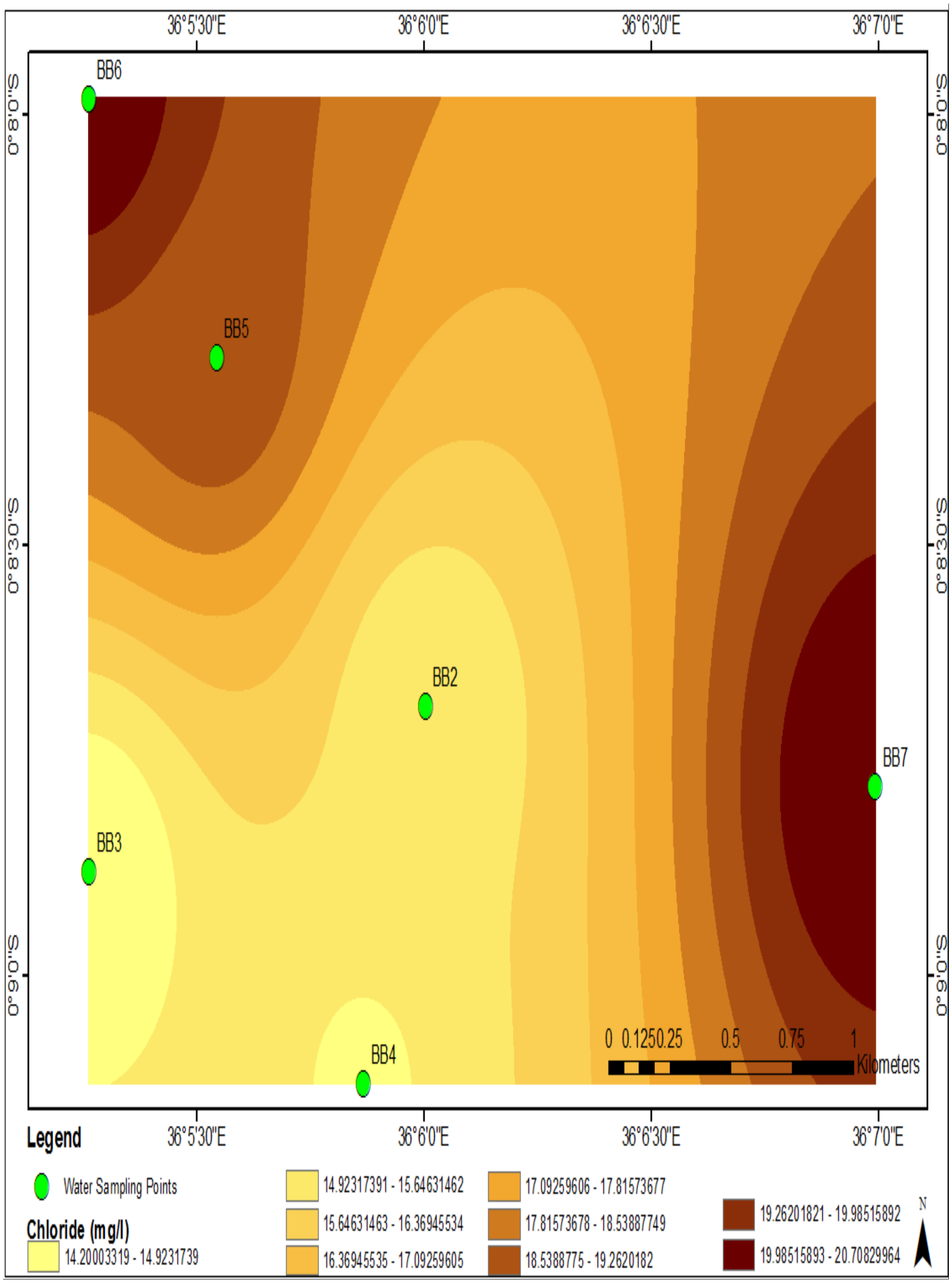

Figure 4.31: Spatial distribution of chloride at sampling points BB2 to BB7.

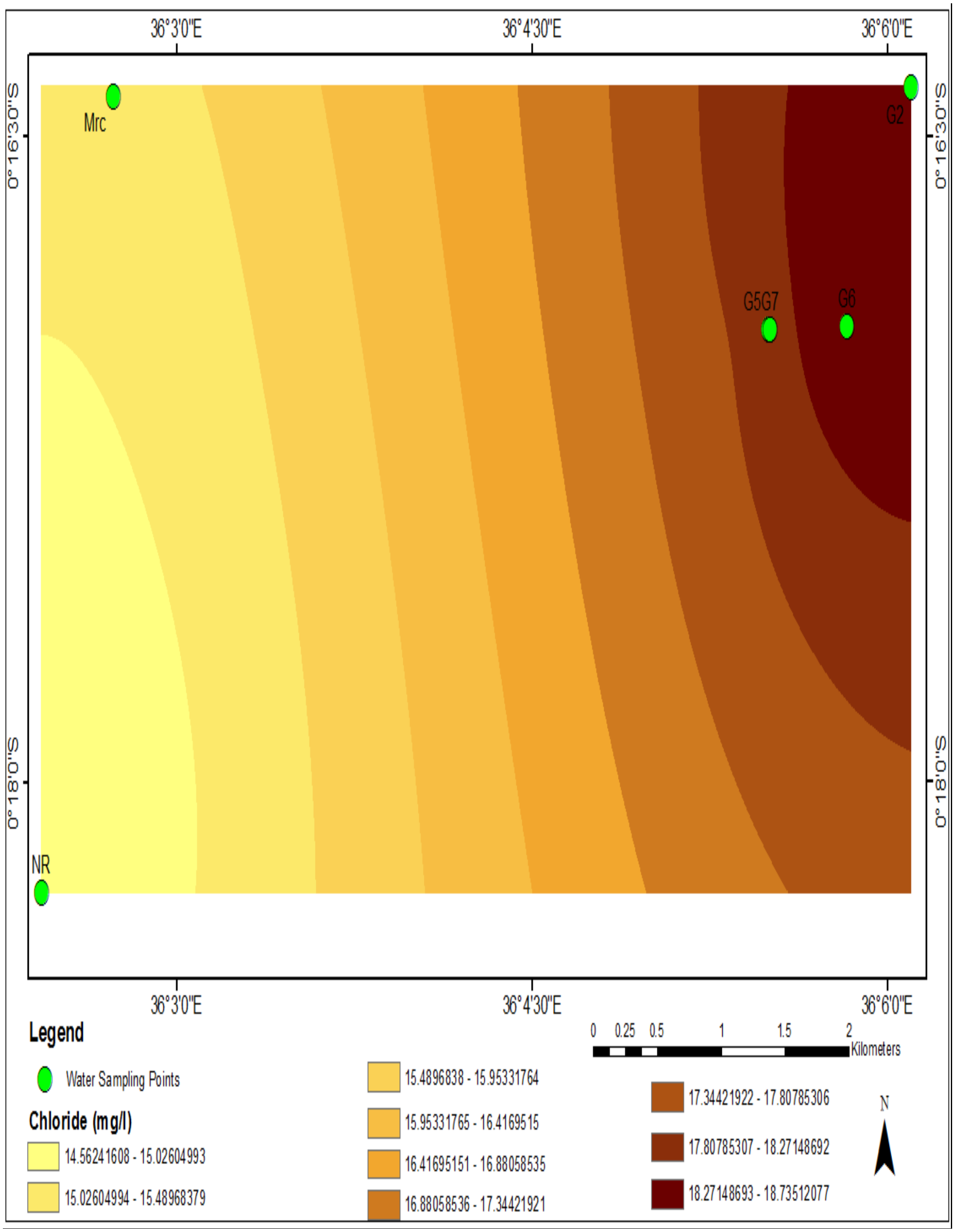

Figure 4.32: Spatial distribution of chloride at sampling points NR, Mrc, G2, G5, G6 and G7.

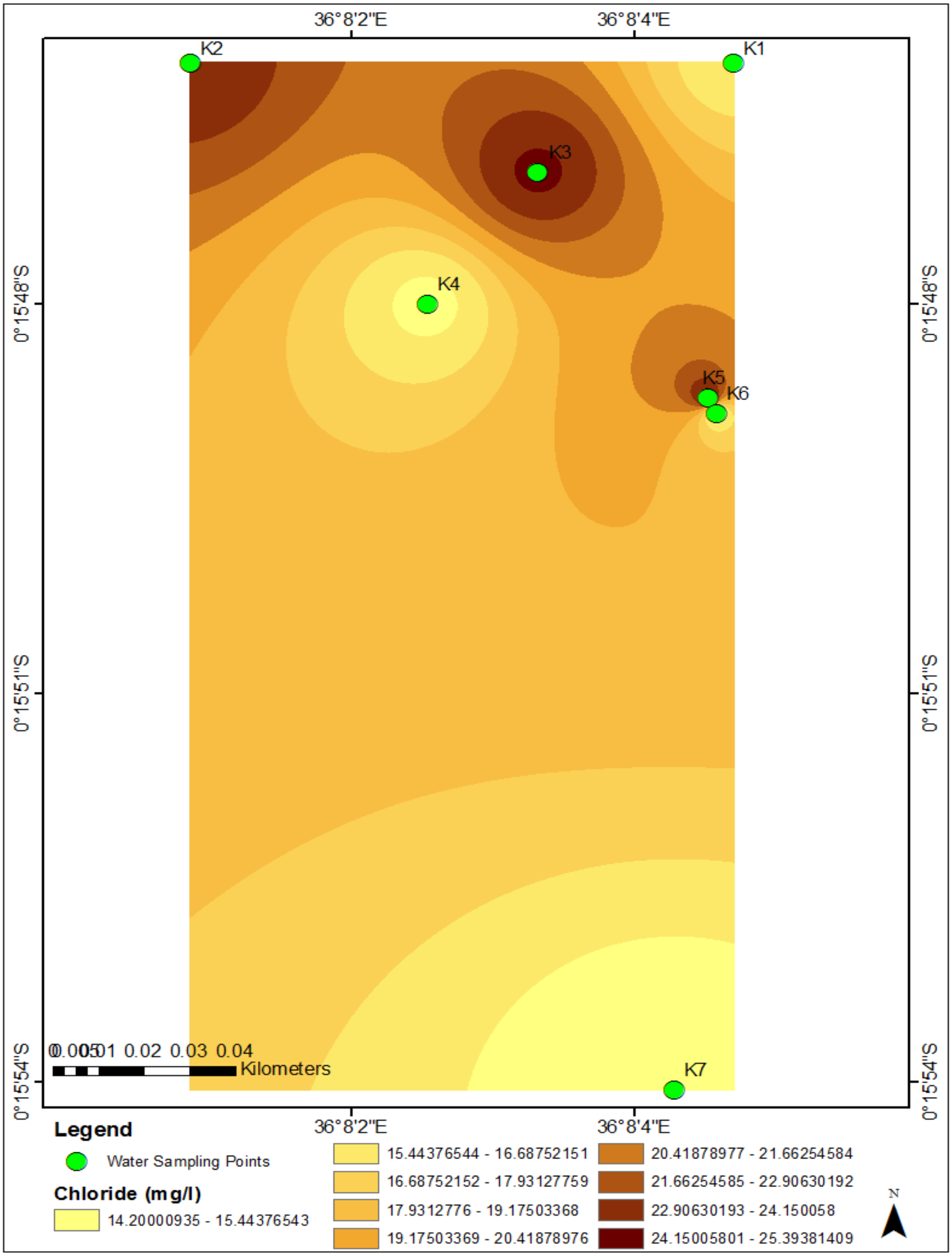

Figure 4.33: Spatial distribution of chloride at sampling points K1, K2, K3, K4, K5, K6 and K7.

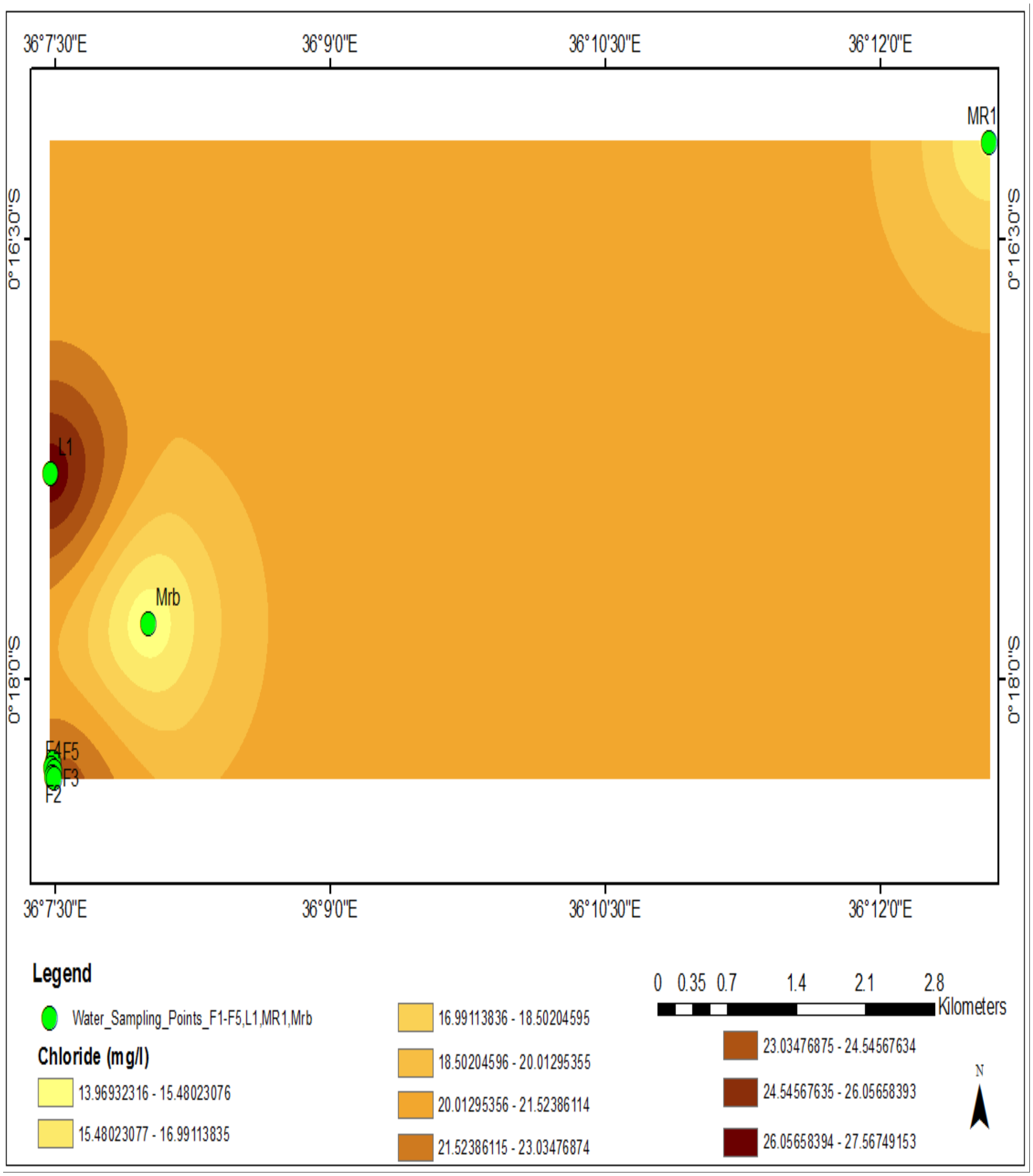

Figure 4.34: Spatial distribution of chloride at sampling points F1, F2, F3, F4, F5, Mrb and MR1

Selenium concentration in regard to the classified data presented as legend in Figures 4.31, 4.32, 4.33 and 4.34 for river and groundwater ranged from 0.64 mg/l to 4.80 mg/l as depicted by the spread with different colors. The spatial extent was noted to vary with respect to sampling point and type of water source. It was observed that the levels were above the permissible limits (WHO, 2011) in both river and ground water hence unsafe for drinking. The levels were more elevated in groundwater than in river water where variation existed from one sampling point to another.

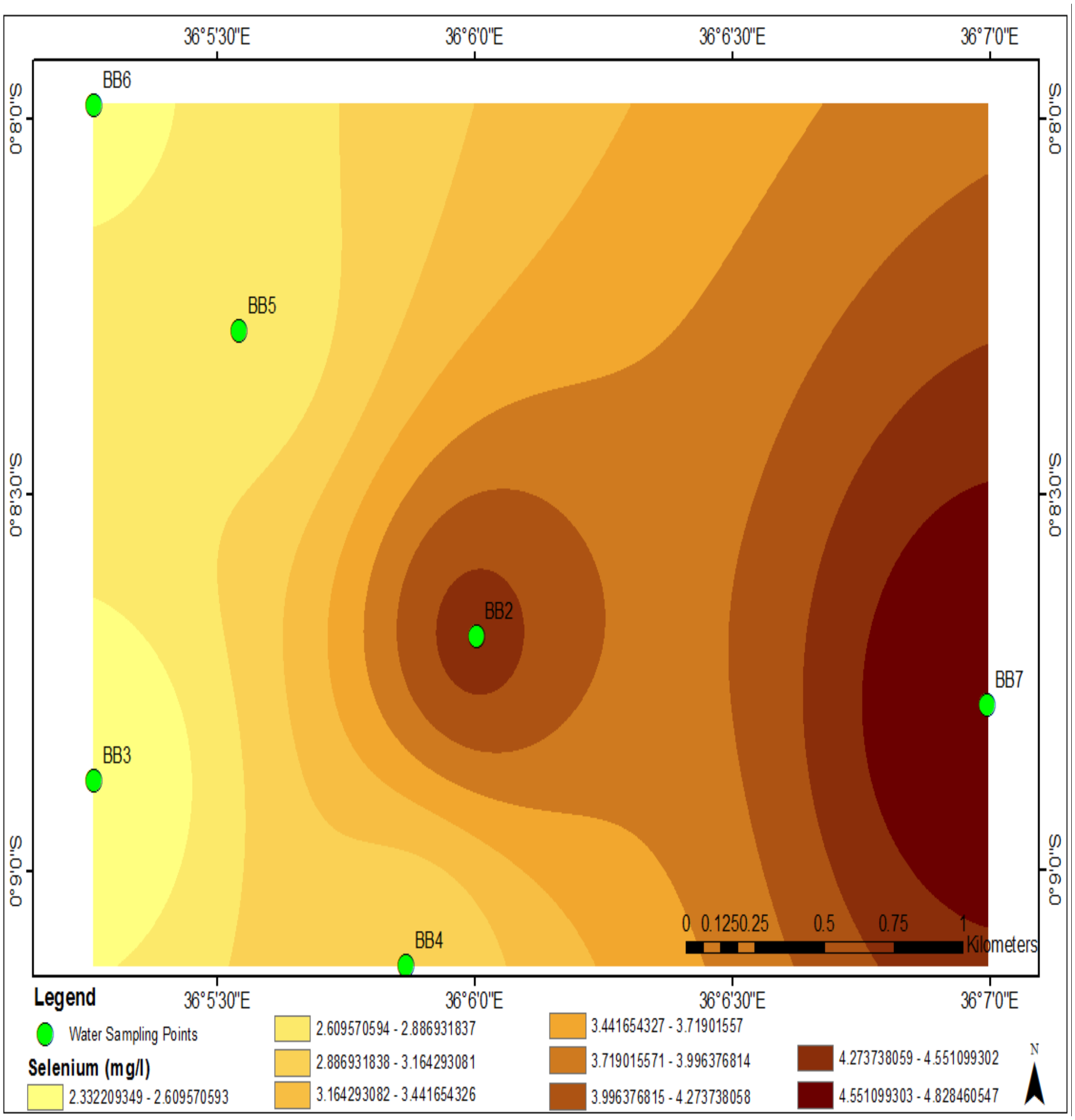

Figure 4.35: Spatial distribution of selenium at sampling points BB2 to BB7

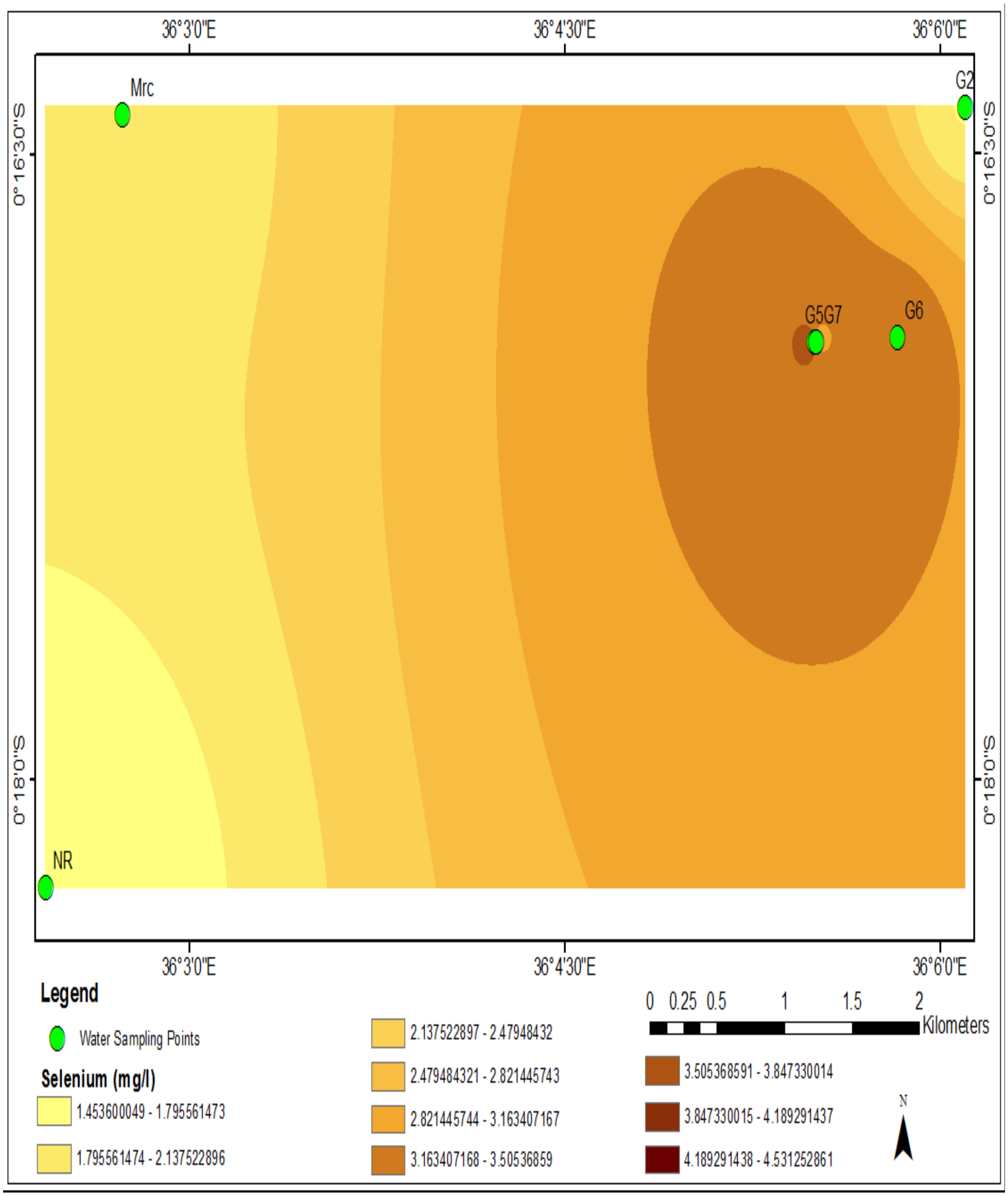

Figure 4.36: Spatial distribution of chloride at sampling points NR, Mrc, G2, G5, G6 and G7

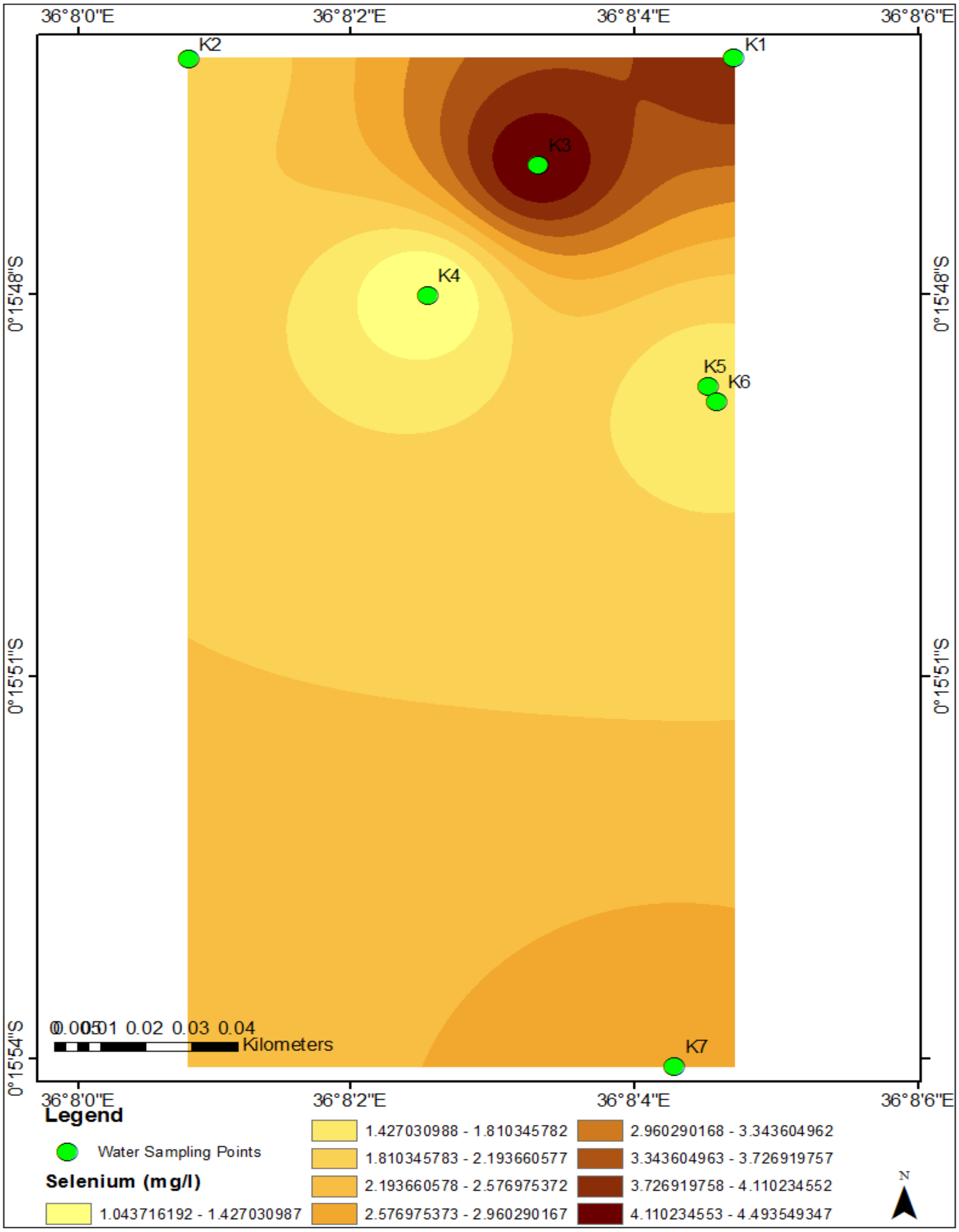

Figure 4.37: Spatial distribution map of selenium at sampling points K1, K2, K3, K4, K5, K6 and K7

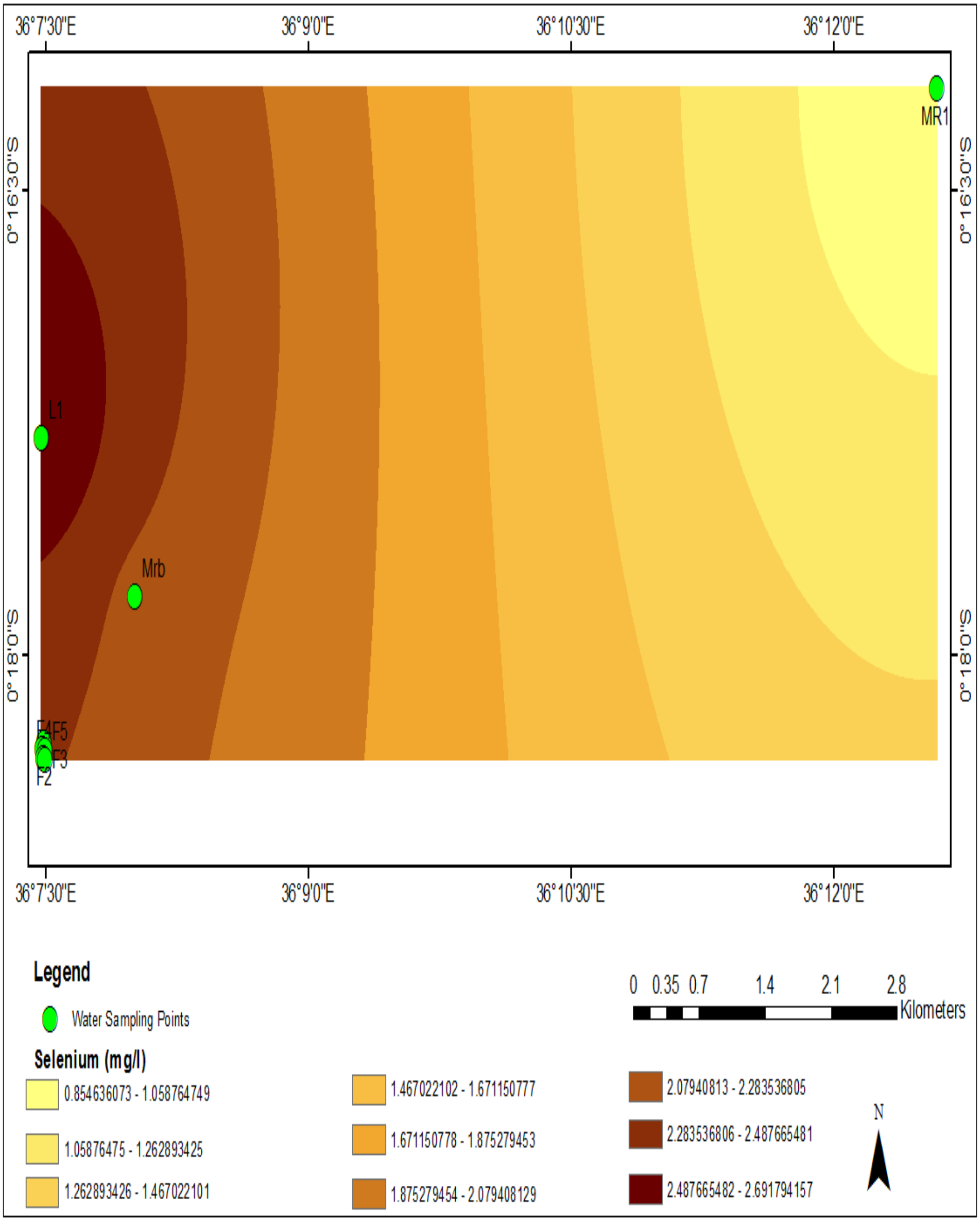

Figure 4.38: Spatial distribution of selenium at sampling points F1, F2, F3, F4, F5, Mrb and MR1

4.6 Aquifer geology and quality characteristics

Aquifer map showing the location of sampled boreholes (Figure 4.39 below) and their underlying surface geological formations was developed. Underlying surface geological formations depicted in Figure 4.39 were found to comprise welded vitrous tuffs, ignibrites, gravel tuffs, diatomaceous silts, superficial deposits, volcanic soils and phonolites and trachytes.

The surface geological units were matched with borehole geo-logs of Olobanita, Kabatini and Baharini (next to Lake Nakuru on the north-eastern side) and drillers' logs of aquifers around Nakuru Town. Olbanita, Kabatini and Baharini borehole geo-logs at a depth of 50 m below the surface of the earth to more than 200 m showed that composition of aquifer materials were made of sediments and tuffs, volcano-clastic sediments, weathered/fissured trachytes, phonolitic rocks, pumice and tuffaceous ash materials, lacustrine sediments and clay materials. Around Nakuru town, Nairobi, Leitmann and Nakuwell boreholes had aquifer formations of tuffaceous ash materials, fractured and weathered trachytes between depths of 72 m to 270 m below the earth's surface. Quality levels of all examined water parameters varied across the boreholes for the whole sampling period. Fluoride, selenium and cadmium had elevated levels compared to WHO, (2011) and NEMA, (2006) guideline values for drinking water quality.

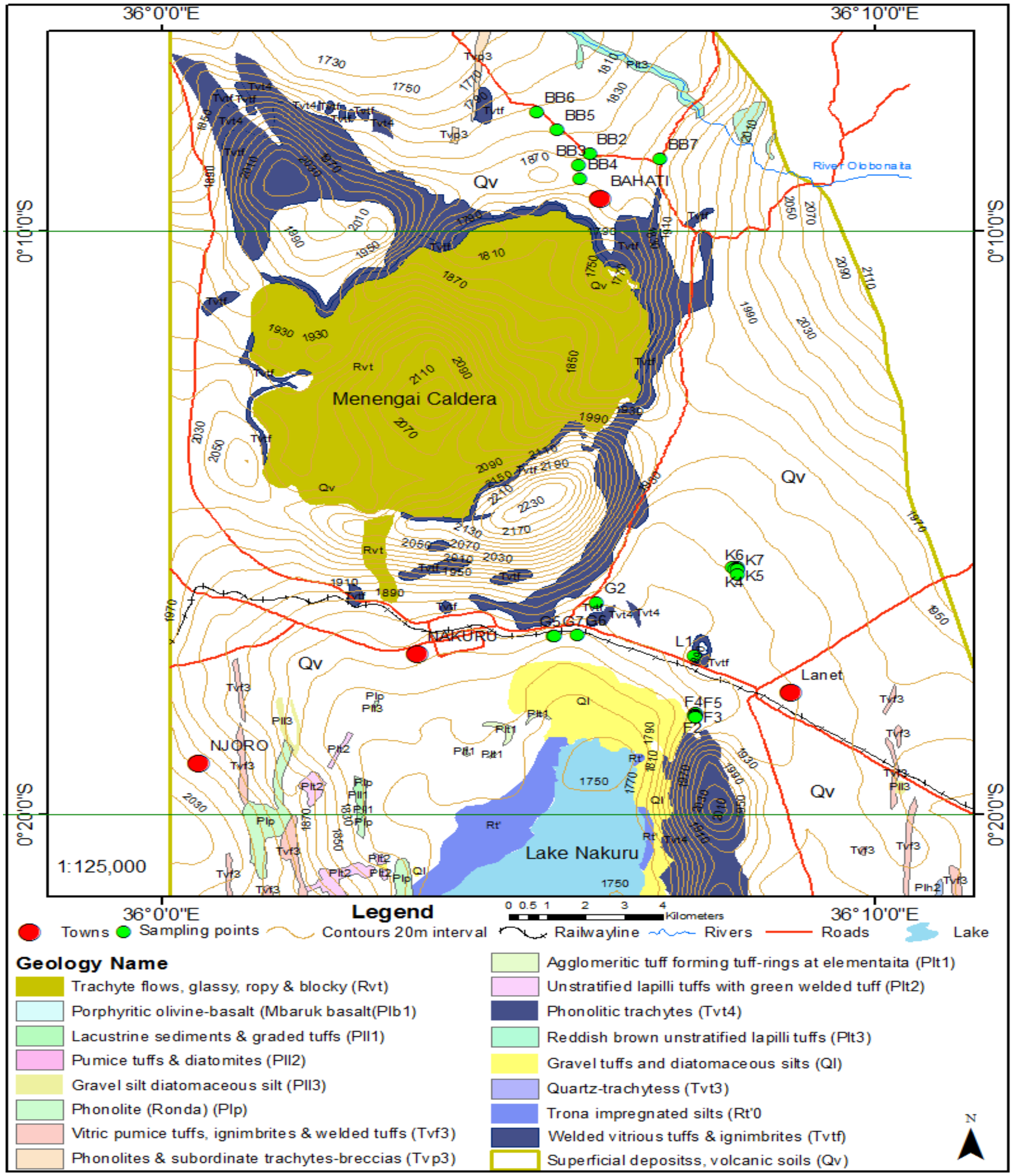

Figure 4.39: Nakuru geological map depicting locations of sampled boreholes

4.7 The influence of rainfall on quality characteristics of river and ground water

4.7.1 Rainfall data and hydrological periods/seasons

Mean monthly rainfall data of the area of study (June 2014 to March 2015) are presented in Appendix IV, Table 4.1. The study period covered three hydrological periods; transition period (June 2014 to September 2014), short rain season (October 2014 to December 2014) and dry season (January 2015 to March 2015).

4.7.2 Trend analysis of rainfall data

Results of graphical rainfall trend analysis of total mean monthly precipitation for 38 year period representing the months sampled (June, July, August, September, October, November, December, January, February and March) and total mean monthly precipitation of the study area (Nakuru) covering the whole period of study (June 2014 to March 2015) are presented in Appendix IV, Table 4.2.

The results showed existence of changing trends in average monthly rainfall patterns for the 38 year period as well as mean monthly rainfall data covering the sampling period (June 2014 to March, 2015). For all the months, significant decreasing and increasing patterns were observed but sharp decreasing differences in monthly rainfall received were recorded in January, February and March (Figure 4.40 below).

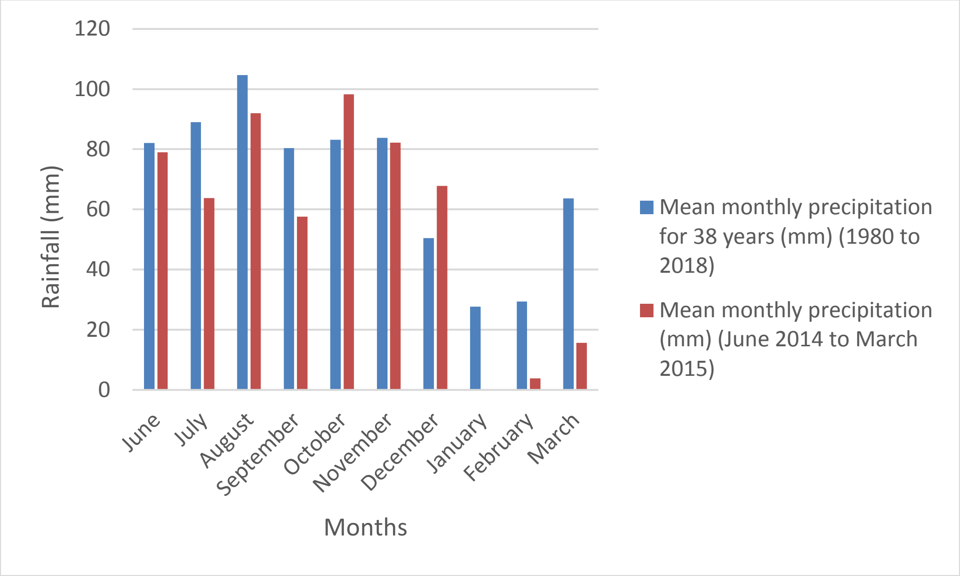

Figure 4.40: Graphical rainfall trend analysis for the study area

4.8 Correlation analysis

Statistical relationship between rainfall trends and variation in concentration of measured water parameters are shown by use of a correlation coefficient (r). Correlation coefficient (r) results (June 2014 to March 2015) are presented in Appendix IV, Tables 4.3 and 4.4. The relationship was described in terms of increasing or decreasing order, weak or strong.

Correlation analysis results (Appendix IV, Table 4.3) indicated a weak positive and negative relationship between rainfall and concentration in measured ground water quality parameters over the study period (June 2014 to March 2015). The values of correlation coefficient (r) ranged from -0.87 to 0.56.

Results of correlation analysis in measured parameters in river water (Appendix IV, Table 4.4) showed a strong positive relationship between rainfall and chloride levels at sampling point NR (River Ndarugu) over the study period. Relationship between rainfall and levels of other parameters (pH, cadmium, selenium, electrical conductivity and fluoride) in river water indicated a weak positive and negative relationship. The values of correlation coefficient (r) ranged from -0.85 to 0.70.

CHAPTER FIVE

DISCUSSION

5.1 Introduction

This chapter presents discussion of results of the study on chemical composition in reference to river and ground waters, suitability for drinking purposes, borehole water chemistry and underlying geology, seasonal variation, spatial changes and spatial distribution patterns of measured water quality variables in Nakuru Municipality. The parameters were measured at different hydrological periods to evaluate seasonal changes and at different spatial sampling points to evaluate spatial changes.

5.2 Chemical characteristics of natural and treated drinking water from river and ground sources

Physical characteristics, chemical composition and biological parameters are usually used in characterization of water quality (Lobina and Mercy, 2015; Azrina *et al,*. 2011; Appelo and Postma, 2005; Chapman, 1996). Evaluation of water chemical composition differentiates between potable and undrinkable water, reflects the problem in the water quality and determines its suitability for other uses (Azrina *et al.,* 2011).

Chemical concentration characteristics of treated and natural water samples were evaluated based on analytical water quality data where average value of each water variable was considered for all sampling points and among the three sampling periods. The results presented in Appendices 11 and 111, Tables 4.1 and 4.2 showed significant variations in examined natural and treated water samples from river and ground water according to chemical characteristics of observed variables. From these tables, it is clear that the quality of water considerably varied between the three sampling periods. Range of average levels of all the water quality parameters were generally characterized by small to average to large variations across the three sampling periods (Tables 4.1 and 4.2). The results also showed that both river and ground water were naturally contaminated in regard to selenium, fluoride and cadmium where ground water was considerably ionized. Except for pH, electrical conductivity and chloride, levels of selenium, fluoride and cadmium in ground water for treated and natural water were elevated compared to recommended standards by WHO (2011) for drinking water indicating unsuitability for drinking.

For river water, elevated levels were noted mainly in selenium and cadmium in regard to set standards while fluoride levels remained within required level but frequently exceeded the requirements. Chloride, electrical conductivity and pH concentration levels remained below the required limits over the study period. The differences at different sampling points and sampling periods in both river and ground water quality were attributed to local environmental factors, geographical locations and geological characteristics related to the sampling points. The same findings agree with observations by Abdul *et al.* (2015), Anwar *et al.* (2011) and Ayanew (2008) in related studies. Other causes were attributed to various natural processes for example rock-water interaction, hydrological cycles, soil erosion, weathering of crustal materials and atmospheric deposition as confirmed in other studies on water quality evaluation by Mir and Gani (2019).

5.3 Seasonal and spatial variations of natural river and ground water quality

For effective water environmental management, assessment and analysis of spatiotemporal characteristics of quality water are important for making informed evidence based on resolutions for water resources management (Zhang *et al.,* 2009). Mohammad *et al.* (2012) confirm that statistical analysis can be a useful method of measuring seasonal variations of ground water samples.

Descriptive analysis results of water quality data sets, WHO (2011) and NEMA (2006) guideline values for drinking water were taken into consideration to evaluate river and ground water quality at spatial and seasonal scales. To confirm existence of seasonal variations (transition, short rain and dry periods) in mean concentration values of the examined water quality variables, Kruskal-Wallis H test was employed where the results were reported at 0.05 level of significance.

5.3.1 pH

pH is classed as one of the most important operational water quality parameters and according to Mohammed (2013), its determination is significant because of its influence on other physicochemical parameters and availability of metal ion in water and waste water.

Spatially, narrow variations of pH levels were noted in river and ground water samples across different sampling points and sampling periods where the mean levels ranged from

6.89 to 9.65±0.10 (Appendices II and III, Figures 4.1 and 4.2). Error bars indicate low to average variation of the data around the sample mean values.

Seasonally, the results show significant differences in mean values of pH in river water ($P = 0.050$) and ground water ($P = 0.001$). In both river and ground water samples, pH levels were high during the short rain period, followed by the dry and transition periods.

Mean levels of pH confirmed river and ground water of the area to be of neutral to slightly alkaline type but the range for most of the samples was between 6.5 and 8.5 that is associated with natural waters and also designated for quality of drinking and domestic purposes (Chapman, 1996). The levels were also within the desirable limits set by WHO, 2011 and NEMA, 2006 for drinking water except at Olobanita boreholes and Leitmann borehole.

Variation of pH conditions in river and ground water from different sampling points of the study area and periodical changes were linked to the areas geological formations, temporal climatic and hydrological variations, geographical variations and land use with input from anthropogenic factors. Petalas *et al.* (2006), Dallas and Day, (2004) concur with the same observations from related studies on the effect of geological factors on pH in ground water. The authors also attested that pH of a given water body can reflect its water inputs, chemical characteristics of the surrounding land and is also affected by the type of minerals and soils the water contacts as it moves through the land. The results are also consistent with findings by Kanda (2010), Oketch (2012) and Ngotho (2014) in Lake Nakuru Basin who reported a pH variation from 6.33 to 9.23 in boreholes. The results are also comparable with observations by Mwamati *et al.* (2017) and Kitaka (1991). Similar trends have been reported in Rift Valley areas with alkaline volcanic rocks that also characterize the area of study (Wetang'ula and Wamalwa, 2015; Mutonga, 2014; Wamalwa and Mutia, 2014; Oketch, 2012; Olago *et al.*, 2009; Petalas *et al.*, 2006; Wamalwa Tenalem Ayenew, 2005; Devies, 1996).

5.3.2 Electrical conductivity

The concentration of dissolved salts is usually related to conductivity but changes in its concentration over time may indicate changing water quality (Odiyo *et al.,* 2012; APHA, 1992).

Spatially, the results show that ground water exhibited low to high levels of electrical conductivity that ranges from 242.50±16.65 µS/cm to 938±19.48 µS/cm (Appendix II and III; Figure 4.3) among all sampled boreholes for the three sampling periods. Narrow to marginal to wide variations in electrical conductivity was noted especially in groundwater compared to river water. The error bars show characteristic of low variability of the data around the sample mean values (Figures 4.3 and 4.4). Seasonally, the results showed significant variation in mean values of electrical conductivity in river water ($P = 0.008$) but not ground water ($P = 0.130$). Electrical conductivity in groundwater samples was high during the transition period compared to other sampling periods though narrowly. However, the levels remained within guideline values for drinking water (WHO, 2011) and above the highest desirable limit of 500 µS/cm (WHO, 1998). The findings indicated that ground water within the study area contained considerable amounts of ions which were responsible for such conductivities. Dallas and Day (2004) concur that in regard to water studies, electrical conductivity of a solution is a function of the number of charged particles (ions).

Spatially, the Olobanita boreholes had the highest electrical conductivity levels. Per well field, the mean levels observed had small variations between the boreholes but variations around the mean according to standard error values were variable. The differences from one well field to another in electrical conductivity were attributed to the underlying geology, climatic factors and geochemical processes. High conductivity levels in Olobanita boreholes was also related to hydrothermal discharges, well depth and high temperatures as observed by Kanda (2010) and Oketch (2012) in related studies in the larger Lake Nakuru Basin. Borehole depths sampled in Olobanita well fields ranged from 150 m to 180 m while temperatures ranged between 32^{o}C to 42^{o}C. An increase in temperature causes an increase in conductivity such that for every 1°C increase, there is an increase of 2-4% in conductivity level (Lenntech, 2014). Conductivity levels for Baharini boreholes located next to the shores of Lake Nakuru were attributed to seepage from the lake and some springs (Clarke *et al.*, 1990; SAPS II, 2002; Kanda, 2010). Kabatini boreholes had the lowest values of conductivity.

Spatial and seasonal variations of electrical conductivity levels at different sampling points were also attributed to aquifer depth, weathering of bedrock minerals, dissolution and ion exchange process. Other factors are variation of bed rock type in each water basin, differences in residence time along the flow paths, variation of rainfall distribution, geomorphological processes, geographic variations and climatic factors (temperatures and evaporation rates). The results are consistent with findings by Kanda (2010) and Oketch, (2012) in related studies in the larger Lake Nakuru Basin. The results are also comparable to other related studies by Oketch, 2012, Kanda, (2010), Ocheri and Idoko, (2012), APHA, (2005), Appelo and Postma, (2005), Tenalem, (2005) and Mavura *et al.*, (2003).

For river water samples, mean values of electrical conductivity ranged from 107.33± 9.56 μS/cm to 246.67±29.01 μS/cm among all sampling points for the three sampling periods (Figure 4.4). Lower values of electrical conductivity was noted in transition and short rain periods, this was attributed to dilution effect to the river by rainfall falling directly and atmospheric deposition (Grochowska and Tandyrak, 2009). Higher concentrations over the dry period were attributed to stream recharge from ground water at base flow conditions, concentration of solutes by higher temperatures and high rates of evaporation. Previous studies by Naslund and Snell (2005), Oketch (2012) and Ngotho (2014) reported similar trends.

Spatial distribution among the sampling stations was also noted. For example, sampling stations that represented upper parts of River Meroronyi (MR1). Low electrical conductivity levels were observed compared to sampling station NR that represented lower stream point of River Ndarungu whose environment was characterized by various anthropogenic interferences at upstream and downstream areas (Appendix III). The high values were attributed to discharge of pollutants from industries, liquid waste and erosion during the rainy season. Similar distribution patterns were also found by Vaishali and Punita, (2013), Oketch, (2012) and Kanda (2010) on related studies.

5.3.3 Fluoride

The variation of fluoride levels in drinking water from various sources is due to many factors even within the same area. The nature of water chemistry, availability of fluoride minerals and the contact time between the source mineral and water affects the release of fluoride ions to groundwater (Jha *et al.,* 2011; Kumar, 2010).

No significant seasonal differences existed in mean values of fluoride in ground water ($P = 0.293$). Narrow to marginal to wide variations in fluoride concentration was also noted across the sampling periods and sampling points. The results show that ground water exhibited high values of fluoride ranging between 1.40±0.64 mg/l and 11.60±1.63 mg/l among all sampled boreholes for the three sampling periods. Low to larger variation from the sample mean values as indicated by the error bars mainly in dry and short rain periods was noted (Figure 4.5). Concentrations above the set standards for quality of drinking water (WHO, 2011; NEMA 2006) were noted in most of the sampled boreholes. The mean values of fluoride in ground water samples were high during the dry period compared to other sampling periods.

The seasonal variations in the concentrations were associated with hydrological factors for example, high temperatures, high rates of evaporation and low precipitation that characterized the dry period of the study area. The variations were also attributed to local geological factors for example, the extent of ground water interaction and volcanic rocks, possible presence of volcanic sediments in underground water reservoirs, type of local soil and its mineral content. The results are comparable with observations of previous studies in Lake Nakuru basin **(**Oketch, 2012; Kanda, 2010; CDN, 2009; 2005; Gikunju, 2002) and in other areas in the Rift Valley (Tenalem, 2005; Naslund and Snell, 2005; Davies, 1996) where they agree that among the most significant factors that control the concentration of fluoride in a given area are climate and availability of accessory minerals in the rock minerals assemblage through which the ground water circulates. Naslund and Snell (2005) reported that the abundance of fluoride in ground water in the rift valley can be attributed to the weathering of alkaline volcanic rocks rich in fluorides.

Spatially, variation in fluoride levels was noted across all sampled boreholes. The results show that the trends of fluoride concentration in borehole water vary a lot where the magnitude is more gradual in Olobanita well fields than it is in other well fields (Appendix II; Figure 4.5). High levels of fluoride in Olobanita well fields as reported by Wamalwa and Mutia (2014) was strongly associated with the geothermal anomaly that is prominent in the basin interior area. They concur that the well fields associated with geothermal anomalies contribute to interaction with deeper geothermal-related waters, well depth, high temperatures, long ground water residence time, weathering and leaching of alkaline volcanic rocks rich in fluorides content as compared to other well fields. The results also agree with previous findings from other studies in the larger Lake Nakuru Watershed where hydrothermal discharges with abnormally high concentrations of fluoride and other total dissolved salts are reported to influence groundwater quality (Benson and Isaac, 2017; Kanda, 2010).

Spatial variability of fluoride ions was also observed in other well fields (Kabatini, Baharini and Nairobi) and privately owned boreholes (Leitmann and Nakuwell). The high levels of fluoride and variations in ground water samples across the sampling points could be as a result of slow ground water movement and well depth, climatic and hydrological factors. Other factors are long residence time of ground water, low rate of ground water recharge, geochemistry of water, geogenic sources, weathering, circulation of water in rocks, soils and alkaline rocks that prevail in the area. The results are in conformity with findings of Ngotho (2014), Mutonga (2014), Oketch (2012), Jha *et al.*, (2011) found in Keller, (1979), Olago *et al.* (2009), Guo *et al.* (2007), Chae *et al.* (2006) Naslund and Snell)2005), Appelo and Postma, (2005), Brunt *et al.* (2004) Gikunju (2002), Davies, (1996) on related studies around the Rift Valley region.

For river water, the range in fluoride levels was from 0.49±0.11 mg/l to 2.95±0.88 mg/l among all sampled points across the three sampling periods. Standard error of the mean show low to larger spread of the data around the mean values (Figure 4.6). There were no seasonal variations in mean values of fluoride in river water (0.105). Narrow to marginal variations in fluoride concentration was noted across the sampling periods and sampling points where the mean values were below the standards for drinking water (WHO, 2011; NEMA, 2006). Lower concentration was noted in short rain period, followed by the dry period and finally the transition period and this was attributed to dilution effect to the river by direct rainfall falling and atmospheric deposition (Grochowska and Tandyrak, 2009). Higher concentrations over the transition period was attributed to stream recharge from ground water at base flow conditions, concentration of solutes by higher temperatures and high rates of evaporation. Previous studies at the study area by Naslund and Snell (2005), Oketch (2012) and Ngotho (2014) reported similar trends.

Other sources of fluoride to rivers were attributed to various anthropogenic interferences like discharge of pollutants from industries and agricultural areas, liquid waste fueled by erosion during the rainy season at upstream and downstream areas. Natural sources were also factored in. The variations in fluoride concentrations in river water generally are consistent with seasonal variations in fluoride concentrations that have been found in other rivers. Similar distribution patterns were also found by Kanda (2010), Oketch (2012) and Vaishali and Punita (2013) on related studies. Generally, the low fluoride concentration in short rain and transition period can be attributed to the dilution effects caused by rainfall runoff (Frencken *et al.,* 1992; Gikunju, 2002).

5.3.4 Cadmium

Sources of cadmium in aquatic systems include processes of weathering, erosion of soils and bed rock, atmospheric deposition of direct discharges from industrial operations, leakage from landfills, contaminated sites, dispersive use of sludge and fertilizers in agriculture (WHO, 1992).

Spatially, the results show that concentration of cadmium in ground water exhibited mean values varying between 0.01±0.01mg/l and 0.26±0.03 mg/l among all the sampled boreholes for the three sampling periods. Narrow to marginal to wide variations were noted across the sampling periods and sampling points where the error bars indicated larger variability of the data around the mean in both river and ground water (Figures 4.7 and 4.8).

Seasonally, significant differences in mean values of cadmium in ground water existed (P = 0.000). The mean values in ground water samples were high during the short rain period, followed by the dry period and transition period. The levels were above the set permissible limits for drinking water (WHO, 2011; NEMA, 2006) at all sampling points across the three sampling periods.

In river water samples, no significant differences were noted in mean values of cadmium (P = 0.122) between the three sampling periods. However the levels were above the set permissible limits for drinking water (WHO, 2011; NEMA, 2006) at all sampling points across the three sampling periods.

Increased concentration in cadmium was noted in river water during the dry period. The sources were attributed to pollutant emissions, increase in the rate of element accumulation due to the higher temperature and high evaporation, anthropogenic inputs as enrichment factor in respect to crustal composition, rainfall water quality and erosion of natural deposits. Similar observations were reported by Kanda (2010), Wetang'ula and Wamalwa (2015) on related studies on seasonal variations in metal concentrations in Lake Nakuru Basin. Gratz *et al.* (2009) reported that in river water, highest metal concentrations were usually observed with low precipitation amounts because most of the trace elements are removed during the onset of precipitation and additional precipitation added dilutes the concentration throughout the remainder of the event.

On related studies on spatiotemporal variability of heavy metals contamination in recent sediments from Barigui River Basin, South Brazil, similar observations were reported (Machado *et al.,* 2017). According to SAPS II (2002) and Wetang'ula and Wamalwa (2015), Nakuru and Menengai's water resources depend mostly on rainwater for surface and subsurface recharge hence rain water quality becomes an important factor in water quality as it can affect geochemical processes of an area.

Elevated cadmium levels in ground water was attributed to the areas underlying geology as confirmed in related studies on borehole water quality evaluation for drinking purposes at Menengai geothermal project site, Nakuru, Kenya which is characterized volcanic geology (Wamalwa and Mutia, 2014).

5.3.5 Chloride

Chloride is an important parameter in assessment of water quality. Depending on geochemical conditions in any given region it is usually found in natural water at varying concentrations but elevated levels in concentration indicates higher degree of organic pollution (Huchhe and Bandela, 2016).

Spatially, the results show narrow variations of chloride in river and ground water that ranged from 13.00±0.60 to 28.40±0.00 among all sampled sites for the three sampling periods. In reference to the error bars, low variability around the sample mean values was noted across the three sampling periods and different sampling points (Appendices II and III; Figures 4.9 and 4.10). No major significant differences in mean values of chloride between the three sampling periods in river water (P = 0.629) and ground water (P = 0.293) was noted. Chloride mean levels of river and ground water were relatively low in accordance to guide line values for drinking water (WHO, 2011 and NEMA, 2006) indicating less contamination.

In respect to the study area, low mean values of chloride levels in river and ground water were attributed to low naturally occurring chloride salts in the natural rocks, low runoff rates from agricultural, industrial and domestic wastes to the surface water bodies. In ground water, low levels of chloride were attributed to low contributions from geological formations of the area. Similar studies by Wamalwa and Mutia (2014) around Menengai area and by Sosi *et al.*, (2019) in Olobanita basin in Nakuru gave similar trends in chloride concentration of the area’s water resources. On related studies from other areas (Mariappan *et al.,* 2000; Biswajeet and Saied, 2011; Hasalam, 1991) report same observation.

5.3.6 Selenium

Naturally, the concentration of selenium in river and ground water usually ranges between 0.06 μg/l and 400 μg/l. However, the levels may approach 6000 μg/l in groundwater in some areas (WHO, 2011). Concentrations of selenium in soils have also varied to a wide extent (from 5 to 1 200 000 µg/kg) being higher in soils of more recent volcanic origin (UK E GVM, 2002).

Spatially, narrow to marginal to wide variations in selenium concentration was noted across the sampling periods and sampling points for both river and ground water. The results show that concentration of selenium in ground water was high ranging from 0.68±0.28 mg/l to 5.89±1.40 mg/l among all the sampled boreholes. In river water, selenium concentration varied from 0.39±0.22 mg/l to 2.85±0.99 mg/l across different sampling points among the three sampling periods. The error bars indicate a large spread of the data around the sample mean (Appendices II and III; Figures 4.11 and 4.12) across the three sampling periods and at different sampling points in both river and ground water.

The results show that seasonal variation did exist in mean values of selenium concentration between the sampling periods in river water (P = 0.472) and ground water (P = 0.981). The mean levels were above the set permissible limits for drinking water (WHO, 2011; NEMA 2006). The findings indicated that river and ground water of the study area contained considerable amounts of selenium ions hence not suitable for drinking without proper treatment.

The observations concur with findings on assessment of trace elements in rainfall around Menengai area, Nakuru, Kenya (Wetang'ula and Wamalwa, 2015). They reported presence of selenium and cadmium ions among other trace elements in precipitation concentrations and confirmed presence of same elements along the path of travel of the rain water.

The study area is characterized by volcanic rocks and soils, sedimentary rocks, and porous light, and poorly structured soils (Olago *et al.*, 2009; Kanda, 2010). UK E GVM (2002) and USEPA (1992) reported higher concentrations of selenium in water and soils to be related to the type of rock whether volcanic, sedimentary or carbonate.

The findings were also related to other findings by Stillings *et al.* (2017) where they agree that selenium is usually found concentrated naturally in soils that overlie bedrock with high selenium concentration. In addition, amounts and forms of selenium found in various depositional environments can be attributed to function of mineral solubility, redox potential and pH. If pH is relatively high, selenium bearing minerals become unstable and dissolution occurs. It is stable in air, water and most acids, but reactive to alkalis. It is also highly soluble in well aerated soils.

5.4 Evaluation of river and ground water quality status for drinking purposes

The CCME-WQI model framework (2001), WHO (2011) standards and the combined influence of examined six variables were used to calculate index values for water quality at each sampling point representing natural river and ground water types. The calculated index values of CCME-WQI ranked quality of river water as poor in regard to drinking. Based on the 5 sampled points representing natural potable water, the average index value was calculated as 34.14 (Appendix V, Table 5.2). Ground water was also ranked as poor where the average value of the calculated index was 31.05 for the 23 sampled points representing natural potable water (Appendix V, Table 5.1). Index values for both river and ground water among the three sampling periods across different sampling points ranged from 20.94 to 30.94 (Appendix V, Tables 5.1 and 5.2, Figures 4.13 and 4.14), respectively. The levels of pH, electrical conductivity and chloride varied across the index periods but remained below the objectives in reference to WHO (2011) standards for drinking water. Quality problems mainly in ground water were attributed to high levels of selenium, cadmium and fluoride which exceeded permissible limits for drinking water (WHO, 2011 and NEMA, 2006) almost at all the sampling points across the three sampling periods. For river water, all examined parameters exhibited lower concentration compared to groundwater but selenium and cadmium exceeded WHO (2011) standards for quality of drinking water. Qualities of examined water quality parameters in both river and groundwater were mainly attributed to the geological factors that characterize the study area (Olago, 2018; Kanda, 2010; Olago *et al.,* 2009).

The CCME-WQI as applied in this study successfully rated the status of drinking water quality in river and ground water. Overall, the results of the calculated WQI values indicated that river and ground water of the examined sites and water quality parameters were not potable. In related studies, Igor *et al.* (2015), Muralitharan and Palanivel (2018) also reported that WQI is an important parameter that can be used to describe the quality of water and its trends based on given objectives. Sureja *et al.* (2018), Wang et *al.* (2017) and Lai (2011) also concur that indices are important tools that can be used in communication of water quality information to respective stakeholders (public, policy makers and managers).

5.5 Spatial distribution patterns of water quality parameters

Surface and ground water maps in regard to water quality are important in evaluation of water to ascertain its suitability against various uses (Huchhe and Bandela, (2016). Analysis results of the maps confirm existence of spatial patterns for all water parameters across different sampling sites over the sampling period for both river and ground water as presented in Figures 4.15 to 4.38. The spread of examined water quality parameters over all the sampled sites indicated that some variables (selenium, cadmium and fluoride) exhibited a problem in quality when evaluated to guideline values for drinking water. Other parameters such as chloride, electrical conductivity and pH, however did not present any problems at all the sampling points over the entire study period.

Between the sampling points, spatial patterns of some parameters (pH, electrical conductivity and chloride) were similar across many of the sampling points and all remained within the permissible limits for drinking water although electrical conductivity varied significantly from one sampling point to another. Average to wide variation was noted in fluoride, cadmium and selenium where their levels exceeded the set limits for drinking water (WHO, 2011; NEMA, 2006) in most of the sampling points in ground water compared to river water. Their spatial variability exhibited similar patterns especially for sampling points representing ground water.

The quality characteristics of the observed water parameters were attributed to the areas' geological factors, climate and hydrological changes with input from anthropogenic influences. The spatial patterns could be explained by topography, soil factors and local geology with input from anthropogenic processes. The findings support prior observations in Kenya and other countries on studies concerning evaluation and analysis of spatiotemporal variability in quality of water from various sources intended for different uses (Venkataraman and Manikumari, 2019; Hongxing *et al.,* 2019; Avery and smith, 2018; Mwamati *et al.,* 2017; Al- Mutairi *et al.,* 2017; Rejith *et al,* 2009).

5.6 Aquifer geology and water quality characteristics

Many factors affect the quality of water resources but Alper and Orhan (2017), Pazand *et al.* (2011), Kanda (2010) and Davies (1996) agree that geology of a watershed is the main parameter that determines the natural chemistry of water resources of a region.

Variation in composition of ground water existed across the examined boreholes. But concentration of three parameters (selenium, cadmium and fluoride) across the sampled boreholes over the sampling period were elevated compared to WHO (2011) and NEMA (2006) standards for quality of drinking water. Spatially, the variation was mainly attributed to hydrogeological settings of the area and lithological units of sampled boreholes. In related studies, Huchhe and Bandela, (2016), Oyem *et al.* (2014), Pazand *et al.* (2011) and Appelo and Postma (1993) confirm geological formations and lithological influences of any given aquifer as being an important factor in water quality characteristics. Other factors include temporal changes, origin of the water recharge, periodical variations in climate, geomorphology and chemical weathering as confirmed by Alper and Orhan (2017), Garizi *et al.* (2011) and Venkatesharaju *et al.* (2010) from other regions.

Based on sampled boreholes and quality characteristics of examined water parameters, potential sampling sites of potable and non-potable water were identified in the map (Figure 4.39). Based on WHO (2011) permissible limits for potable water, Olobanita, Kabatini, Baharini, Nairobi, Nakuwell and Leitmann boreholes were classified as unsuitable sources of drinking water. With appropriate chemical treatment to remove excess levels of selenium, cadmium and fluoride, all the examined boreholes were coded as suitable sources of drinking water in the absence of better alternate sources.

Correlation results of borehole lithological logs of Olobanita, Kabatini and Baharini (Olago, 2018, Sosi, 2010; 2019) and drillers' log of other sampled boreholes confirm aquifer geological formations composed of at least sediments and tuffs, volcano-clastic sediments, weathered/fissured trachytes, phonolitic rocks, pumice and tuffaceous ash materials, lacustrine sediments and clay materials. The findings concur with findings by Kanda (2010) who reported that aquifer settings within Lake Nakuru Basin are for the most part multilithological, comprising trachytes, basalts, phonolites, tuffs and volcano-sediments in his studies on relating aquifer stratigraphy and lithology to ground water geochemistry. Another study by McCall (2007) confirmed phonolites, basalts and phonolitic trachytes to be the oldest volcanic rocks exposed on the valley floor in the Nakuru area.

5.7 Relationship between rainfall and quality of measured water parameters

5.7.1 Introduction

The processes of infiltration and percolation of rain water into the ground are the major pathways in which rainfall affects quality of surface and ground water. For surface water, influence is mainly through surface runoff. Correlation techniques are mainly used to determine the correlation of two variables (Bahar and Reza, 2010).

5.7.2 Rainfall trend analysis

Trend analysis of rainfall data can establish existence of trends in rainfall patterns received in a given area either in increasing or decreasing order over a period of time (Donald *et al.*, 2011; Helsel, 1992; Hirsch *et al.*, 1991). Trend analysis results of the long-term (38 year period), the mean monthly rainfall and mean monthly rainfall data representing the study period (June 2014 to March 2015) (Figure 4.40) show existence of rainfall trends in the study area. Peak levels of rainfall were recorded in August and November, 2014 and lowest amount in January and February, 2015.

5.7.3 Correlation analysis

Hydrological variables frequently exhibit variability in time that can mislead the interpretation of water concentration data. Therefore, continuous analysis of concentration, discharge and rainfall data is essential for comprehensive and reliable evaluation of water quality (Tajmunnaher and Chowdhury, 2017; Helsel and Hirsch, 2002). Parameters from the same source usually have high correlations (Edet *et al.*, 2011).

The results of calculated correlation coefficient (r) values confirmed that the degree of rainfall influence on chemical quality of river and groundwater was insignificant (Appendix IV (Tables 4.3 and 4.4). From the results, values of correlation coefficient (r) indicate a range of weak negative and positive correlation between rainfall variability and levels of pH, cadmium, fluoride, selenium, chloride and electrical conductivity over the sampling period (June 2014 to March 2015). Generally the findings were attributed to geological variations, climatic factors, hydrologic factors, rate of rainwater infiltration, aquifer type and depth.

The findings are in agreement with those reported by Mwamati *et al.* (2017), Tavassoli and Khaksar (2002) that in deep aquifers of volcanic formations, ground water is not influenced by rainfall. The results are also in agreement with observations by Tole (1996) where he reported that direct rainfall contributes to a very small part of the ground water flowing within the rift, which may become geothermal water on encountering a heat source as a result of high rates of evaporation on the rift floor.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

From this study, it was concluded that;

1. Little variation existed in chemical quality of water parameters in treated and natural drinking water. River and ground water had elevated concentrations of selenium, cadmium and fluoride compared to recommended guideline values set by WHO and NEMA.
2. The dominance and variability of ions in both river and ground water of the area had almost similar trend at seasonal scales across the three sampling periods.
3. Seasonal variation was exhibited by all parameters where higher concentration was mainly in dry period as compared to transition period and short rain period. Some of the water quality parameters showed significant seasonal variations in their mean concentration in both river and ground water samples but others did not. For ground water, Kruskal-Wallis H test results showed a statistically significant difference between the means of pH (P = 0.001) and cadmium (P = 0.000) but no significant difference in electrical conductivity (P = 0.130), selenium (P = 0.981), fluoride (P = 0.293) and chloride (P = 0.228). Post hoc results showed that significant mean difference in pH existed between the TP and DP (P = 0.000) and TP and SRP (P = 0.006) while for cadmium, significant mean difference existed between TP and SRP (P = 0.001) and TP and DP (P = 0.000).
4. For natural river water samples, Kruskal-Wallis H test results showed existence of significant differences between the means of pH (P = 0.050) and electrical

conductivity (P = 0.008) while chloride (P = 0.629), cadmium (P = 0.122), fluoride (P = 0.105) and selenium (P = 0.472) did not. Post hoc results showed significant mean difference in electrical conductivity existed between TP and DP (P = 0.004) and SRP and DP (P = 0.016) while for pH significant mean difference existed between TP and DP (P = 0.034) and SRP and DP (P = 0.34).

8. Based on the results of WQI values, index values for both river and ground water ranged from 20.94 to 39.69 and their ranks for drinking were recorded as poor indicating that the quality of the areas drinking water was poor. Based on the combined influence on the overall water quality parameters, selenium, cadmium and fluoride were taken as important parameters in rating of the water quality as their concentrations exceeded the objective (permissible limits for drinking water as per WHO, 2011).
9. All examined water quality parameters had a spatially variable pattern.
10. Hydrogeological and geological settings of the area combined with interactive climatic, hydrological and anthropogenic factors have significant influence on water quality characteristics of the examined boreholes.
11. Correlation results indicated a weak positive and negative relationship between rainfall variability and variation in concentration in measured parameters hence temporal variation in ground water quality was not controlled by the dilution of rainwater. In both river and ground water, numerical values of correlation coefficient (r) ranged from -0.88 to 0.56 except chloride in river water (0.70).
12. GIS, WQI and statistical methods applied in this study could together be considered as efficient tools in water quality evaluation of drinking purposes. In

addition, they can provide effective tools and useful information with regard to management of drinking water resources of the study area.

13. The performance of the methods applied in this study can also guide the innovation of other modern methods to overcome the limitations linked to the conventional methods for effective water quality management.

6.2 Recommendations

The following recommendations were forwarded in view of the findings of this present study.

1. Since river and ground waters of the area of study were of poor quality and therefore not suitable for drinking purposes, there is need for proper treatment before use.
2. To establish the overall mineral content in drinking water together with spatiotemporal dimensions of various water variables based on underlying geology, there is need for long term studies.
3. For overall surface and groundwater quality evaluation, there is need to assess other potential water contaminations such as chemicals, microbial and radiological materials for a longer period of time.
4. In a move towards provision of clean drinking water for sustainable uses and public welfare, adoption of alternative sources, improvement of water supply structures and water treatment are possible solutions to improve the quality of drinking water in the area.
5. Study the impact of hydrogeological settings on quality of ground water in the study area.

6.3 Way forward

Based on the outcome of this study, the way forward can be to;

1. Identify relevant natural chemical contaminants with reference to available water sources for drinking and their impacts on human health for effective water quality monitoring.
2. Create a robust water quality data based on long-years detailed study to confirm the results of this study and identify uncertainties associated with few years' data.
3. Determine the relationship between ground water quality variability and aquifer systems.
4. Analyze the correlations between the examined water quality parameters.

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LIST OF APPENDICES

APPENDIX I: DESCRIPTION OF SAMPLING POINTS

NO	Identification ID	Description of Water sampling points	Geographical Location and altitude	water sample type/category/stakeholder	Location of sampling points
1.	NR	River Ndarungu - River water	S 00^o 18.257' E 036^o 02.433' Elevation 1822m	Natural river water - public	River (near mouth)
2.	MR1	River Meroronyi	S 00^o 16.165' E 036^o 12.599' Elevation 2141	Natural river water - public	Upstream of River Meroronyi NAWASSCO water intake point (at source)
3.	MR2	Rive Meroronyi	S 00^o 16.043' E 036^o 05.14' Elevation 1923m	Natural river water - NAWASSCO	River Meroronyi NAWASSCO water outlet point
4.	Mrb	River Turasha	S 00^o 17.807' E 036^o 08.011' Elevation 1886 m	Natural river water- public	Customer water use point
5.	Mrc	River Malewa	S 00^o 16.404' E 036^o 03.444' Elevation 1904 m	Natural river water - NAWASSCO	River Malewa NAWASSCO treatment plant intake point
6.	C3	River Meroronyi filtered water – river water	S 00.27781^o E 036.0833^o Elevation 1917m	treated river water – NAWASSCO	NAWASSCO water use point (tap), at water treatment plant
7.	BB2	Olobanita borehole No.2 – borehole water	S 00^o 08.687' E 036^o 06.009' Elevation 1852m	Natural borehole water - NAWASSCO	Borehole pump outlet
8.	BB3	Olobanita borehole No.3 – borehole water	S 00^o 08.880' E 036^o 05.851' Elevation 1862m	Natural borehole water- NAWASSCO	Borehole pump outlet
9.	BB4	Olobanita borehole No.4	S 00^o 09.126'	Natural borehole water - NAWASSCO	Borehole pump outlet

			E 036^{o} 05.873’ Elevation 1867m		
10.	BB5	Olobanita borehole No.5	S 00^{o}08.282’ E 036^{o} 05.549’ Elevation 1835m	Natural Borehole water - NAWASSCO	Borehole pump outlet
11.	BB6	Olobanita borehole No.6	S 00^{o} 07.982’ E 036^{o} 05.268’ Elevation 1815m	Natural borehole water - NAWASSCO	Borehole pump outlet
12.	BB7	Olobanita borehole No.7	S 00^{o} 08.780’ E 036^{o} 07.00’ Elevation 1876m	Natural borehole water - NAWASSCO	Borehole pump outlet
13.	BB8	Olobanita well field mixed borehole water (2, 3, 4, 5,6 and 7)	S 00^{o} 08.847’ E 036^{o}07.011’ Elevation 1874	Natural water - NAWASSCO	Inlet to collection tank of borehole water from borehole 1,2,3,4,5,6 and 7
14.	BB9	Olobanita well field mixed borehole water treatment booster pump station	S 00^{o} 08.551’ E 036^{o} 06.996’ Elevation 1881	Mixed Olobanita boreholes chlorinated water - NAWASSCO	At pump station
15.	BB10	Bahati water storage reservoir	S 00^{o}09.998’ E 036^{o}08.253’ Elevation 2015m	Mixed Olobanita boreholes chlorinated water - NAWASSCO	At the storage tank water us point (tap)
16.	K1	Kabatini borehole No.1	S 00^{o} 15.769’ E 036^{o} 08.083’ Elevation 1904m	Natural borehole water – NAWASSCO	Borehole pump outlet
17.	K2	Kabatini borehole No.2	S 00^{o} 15.773’ E036^{o} 08.019’ Elevation 1902m	Natural borehole water – NAWASSCO	Borehole pump outlet
18	K3	Kabatini borehole No.3	S 00^{o} 15.783’ E 036^{o} 08.060’ Elevation 1904m	Natural borehole water – NAWASSCO	Borehole pump outlet
19.	K4	Kabatini	S 00^{o} 15.800’	Natural borehole water -	Borehole pump

		borehole No.4	E 036^{o} 08.047’ Elevation 1907m	NAWASSCO	outlet
20.	K5	Kabatini borehole No.5	S 00^{o} 15.812’ E036^{o} 08.080’ Elevation 1901m	Natural borehole water – NAWASSCO	Borehole pump outlet
21.	K6	Kabatini borehole No.6	S 00^{o} 15.814’ E 036^{o} 08.081’ Elevation 1902m	Natural borehole water - NAWASSCO	Borehole pump outlet
22.	K7	Kabatini borehole No.7	S 00^{o} 15.901’ E 036^{o} 08.076’ Elevation 1901m	Natural borehole water - NAWASSCO	Borehole pump outlet
23.	F1	Baharini borehole No. 1	S 00^{o} 18.278’ E 036^{o} 07.493’ Elevation 1828m	Natural borehole water - NAWASSCO	Borehole pump outlet
24.	F2	Baharini borehole No. 2	S 00^{o} 18.299’ E 036^{o} 07.481’ Elevation 1828m	Natural borehole water - NAWASSCO	Borehole pump outlet
25.	F3	Baharini borehole No. 3	S 00^{o} 18.307’ E 036^{o} 07.496’ Elevation 1830m	Natural borehole water - NAWASSCO	Borehole pump outlet
26.	F4	Baharini borehole No. 4	S 00^{o} 18.328’ E 036^{o} 07.487’ Elevation 1829m	Natural borehole water - NAWASSCO	Borehole pump outlet
27.	F5	Baharini borehole No. 5	S 00^{o} 18.335’ E 036^{o} 07.498’ Elevation 1829m	Natural borehole water - NAWASSCO	Borehole pump outlet
28.	G1	Kayowas water kiosk (managed by NAWASSCO)	S 00^{o} 17.695’ E 036^{o} 02.738’ Elevation 1840 m	Treated water – NAWASSCO	At water use point
29.	G2	Nakuwell borehole (private)	S 00^{o} 16.385’ E 036^{o} 06.105’ Elevation 1894	Natural water– Private	At water use point

			m		
30.	G4	Nakuru town market water tap use point (Tap, managed by NAWASSCO	S 00^{o} 17.087’ E 036^{o} 04.524’ Elevation 1851 m	Treated water- NAWASSCO	At water use point
31.	G5	Nairobi road borehole No.4	S 00^{o} 16.950’ E 036^{o} 05.503’ Elevation 1855 m	Natural water - NAWASSCO	Borehole pump outlet
32.	G6	Nairobi borehole No.5	S 00^{o} 16.94’ E 036^{o} 05.836’ Elevation 1856 m	Natural water - NAWASSCO	Borehole pump outlet
33.	G7	Nairobi road borehole No. 6	S 00^{o} 16.948’ E 036^{o} 05.512’ Elevation 1856 m	Natural water - NAWASSCO	Borehole pump outlet
34.	L1	Leitmann borehole (private)	S 00^{o} 17.296’ E 036^{o} 07.476’ Elevation 1877 m	Natural water – Private	At water use point
35.	C2	Olobanita mixed borehole chlorinated water at milimani NAWASSCO water treatment plant	S 00.27811^{o} E 036.08553^{o} Elevation 1920m	Chlorinated water – NAWASSCO	At water pipe bulk transfer outlet point (tap)
36.	C4	Mixed Baharini and Nairobi road borehole water reservoir	S00^{o} 16.961’ E 036^{o} 05.419’ Elevation 1853m	Chlorinated water - NAWASSCO	At water reservoir storage point (tank)
37.	C5	Kabatini boreholes mixed water inlet to Milimani NAWASSCO treatment plant)	S 00^{o}16.27811, N 036^{o} 05.08553, Elevation	Chlorinated water - NAWASSCO	At water pipe bulk transfer outlet point (tap)

			1920 m		
38.	C6	Milimani water booster pump to consumers in Nakuru Town	S 00^o 16.882’ E 036^o 05.145’ Elevation 1919m	Chlorinated and blended water – NAWASSCO	At water booster pump distribution point

Source: Author’s field work (June 2014 to March 2015)

APPENDIX II: SPATIAL AND SEASONAL DESCRIPTIVE STATISTICS FOR ANALYTICAL RESULTS OF MEASURED PARAMETERS IN GROUNDWATER SAMPLES (JUNE 2014 TO MARCH 2015)

Table 2.1: Natural potable water

Station ID	Parameter/ Units	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	EMCR Water quality regulations (2006) MAX
BB2	pH	Transition period	7.57	8.27	7.9850	0.16686	0.33372	5.5 - 9.5	6.5 - 8.5
		Short rain	8.85	9.49	9.1900	0.18583	0.32187		
		Dry period	8.10	9.10	8.5667	0.29059	0.50332		
	Ec µS/cm at 25°C	Transition period	766.00	922.00	863.000	34.30743	68.61487	2500 µS/cm	-
		Short rains	720.00	890.00	784.3333	53.24889	92.22979		
		Dry period	595.00	920.00	808.3333	106.70572	184.81973		
	Selenium mg/l	Transition period	5.04	6.64	5.5825	0.35899	0.71798	0.01 mg/l	0.01 mg/l
		Short rains	3.29	5.01	3.9033	0.55442	0.96028		
		Dry period	2.99	4.12	3.6533	0.34070	0.59011		
	Cadmium mg/l	Transition period	0.00	0.07	0.0275	0.01702	0.03403	0.003 mg/l	0.01 mg/l
		Short rains	0.10	0.12	0.1067	0.00667	0.01155		
		Dry period	0.08	0.20	0.1433	0.03480	0.06028		
	Fluoride mg/l	Transition period	2.30	2.61	2.4425	0.07353	0.14705	1.5 mg/l	1.5 mg/l
		Short rains	2.10	3.11	2.5200	0.30370	0.52602		
		Dry period	5.23	7.00	6.2767	0.53592	0.92824		
	Chloride mg/l	Transition period	14.20	14.20	14.2000	0.00000	0.00000	250 mg/l	250 mg/l
		Short rains	14.20	21.30	16.5667	2.36667	4.09919		
		Dry period	14.20	14.20	14.2000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

Table 2.2: Natural potable water

Station ID	Parameter / unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA (2006) MAX
BB3	pH	Transition period	7.73	8.21	8.0675	0.11302	0.22603	5.5 - 9.5	6.5 - 8.5
		Short rains	8.67	9.36	9.0100	0.19925	0.34511		
		Dry period	6.08	9.48	8.2700	1.09701	1.90008		
	Ec µS/cm at 25^{o}C	Transition Period	474.00	697.00	583.0000	56.88732	113.77643	2500 µS/cm	-
		Short rains	842.00	940.00	905.333	31.71400	54.93026		
		Dry period	475.00	939.00	779.3333	152.22826	263.66709		
	Selenium mg/l	Transition period	1.10	2.87	1.6000	0.42597	0.85194	0.01 mg/l	0.01 mg/l
		Short rains	2.20	3.02	2.6900	0.24987	0.43278		
		Dry Period	2.23	3.13	2.7067	0.26117	0.45236		
	Cadmium mg/l	Transition period	0.00	0.21	0.0700	0.04950	0.09899	0.003 mg/l	0.01 mg/l
		Short rains	0.10	0.29	0.2233	0.06173	0.10693		
		Dry period	0.10	0.20	0.1333	0.03333	0.05774		
	Fluoride mg/l	Transition period	2.32	2.55	2.4100	0.05115	0.10231	1.5 mg/1	1.5 mg/l
		Short rains	1.89	2.40	2.1467	0.14723	0.25502		
		Dry period	5.00	6.00	5.6667	0.33333	0.57735		
	Chloride mg/l	Transition period	14.20	14.20	14.2000	0.00000	0.00000	250 mg/l	250 mg/l
		Short rains	14.20	14.20	14.2000	0.00000	0.00000		
		Dry period	14.20	14.20	14.2000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

Table 2.3: Natural potable water

Station ID	Parameter	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA (2006) MAX
BB4	pH	Transition Period	7.08	8.25	7.8850	0.27455	0.54909	5.5 - 9.5	6.5 - 8.5
		Short rains	8.45	9.43	8.9200	0.28361	0.49122		
		Dry period	6.99	9.59	8.5600	0.79764	1.38156		
	Ec µS/cm at 25^{o}C	Transition Period	897.00	991.00	938.7500	19.47809	38.95617	2500 µS/cm	
		Short rains	805.00	920.00	881.3333	38.16776	66.10850		
		Dry period	435.00	930.00	761.6667	163.35884	282.94581		
	Selenium mg/l	Transition Period	0.89	4.02	2.4375	0.86552	1.73104	0.01 mg/l	0.01 mg/l
		Short rains	3.60	4.14	3.8400	0.15875	0.27495		
		Dry period	1.33	3.49	2.5433	0.63763	1.10442		
	Cadmium mg/l	Transition period	0.00	0.04	0.0100	0.01000	0.02000	0.003 mg/l	0.01 mg/l
		Short rains	0.09	0.15	0.1133	0.01856	0.03215		
		Dry period	0.10	0.20	0.1633	0.03180	0.05508		
	Fluoride mg/l	Transition period	2.27	2.50	2.4300	0.05401	0.10801	1.5 mg/l	1.5 mg/l
		Short Rains	1.98	2.95	2.3100	0.32005	0.55435		
		Dry period	5.00	6.00	5.5667	0.29627	0.51316		
	Chloride mg/l	Transition period	14.20	21.30	15.9750	1.77500	3.55000	250 mg/l	250 mg/l
		Short Rains	14.20	14.20	14.2000	0.00000	0.00000		
		Dry period	14.20	14.20	14.2000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

Table 2.4: Natural potable water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA (2006) MAX
BB5	pH	Transition Period	6.66	9.26	8.3200	0.57283	1.14566	5.5 – 9.5	6.5 - 8.5
		Short rains	9.45	9.76	9.6500	0.10017	0.17349		
		Dry period	7.10	10.53	9.1267	1.03805	1.79795		
	Ec µS/cm at 25^{o}C	Transition Period	825.00	861.00	849.2500	8.39022	16.78044	2500 µS/cm	-
		Short rains	690.00	823.00	773.0000	41.78915	72.38094		
		Dry period	416.00	814.00	675.0000	129.61610	224.50167		
	Selenium mg/l	Transition Period	1.99	3.15	2.6050	0.24264	0.48528	0.01 mg/l	0.01 mg/l
		Short rains	2.67	3.13	2.9167	0.13383	0.23180		
		Dry period	1.50	3.17	2.6067	0.55336	0.95845		
	Cadmium mg/l	Transition period	0.00	0.09	0.0325	0.02136	0.04272	0.003 mg/l	0.01 mg/l
		Short rains	0.10	0.14	0.1133	0.01333	0.02309		
		Dry period	0.04	0.15	0.0967	0.03180	0.05508		
	Fluoride mg/l	Transition period	2.65	8.90	4.3500	1.51905	3.03810	1.5 mg/1	1.5 mg/l
		Short Rains	3.27	14.50	8.2567	3.30215	5.71950		
		Dry period	8.50	14.00	11.6000	1.62583	2.81603		
	Chloride mg/l	Transition period	14.20	21.30	19.5250	1.77500	3.55000	250 mg/l	250 mg/l
		Short rains	21.30	21.30	21.3000	0.00000	0.00000		
		Dry period	14.20	21.30	16.5667	2.36667	4.09919		

Source: Author, (June 2014 to March 2015)

Table 2.5: Natural potable water

Station ID	Parameter / unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO STD (2011) MAX	NEMA (2006) MAX
BB6	pH	Transition Period	8.10	8.51	8.2750	0.10396	0.20793	6.5 - 8.5	6.5 - 8.5
		Short rains	9.43	9.98	9.6367	0.17285	0.29939		
		Dry period	7.42	10.12	9.1467	0.86567	1.49938		
	Ec µS/cm at $25^{o}C$	Transition Period	721.00	776.00	758.2500	12.55903	25.11805	2500 µS/cm	-
		Short rains	734.00	780.00	763.3333	14.71205	25.48202		
		Dry period	394.00	833.00	664.3333	136.54344	236.50018		
	Selenium mg/l	Transition Period	2.92	3.13	3.0500	0.04637	0.09274	0.01 mg/l	0.01 mg/l
		Short rains	2.33	3.32	2.8033	0.28661	0.49642		
		Dry period	0.064	3.49	1.7033	0.89871	1.55661		
	Cadmium mg/l	Transition period	0.00	0.20	0.0725	0.04750	0.09500	0.003 mg/l	0.01 mg/l
		Short rains	0.10	0.15	0.1233	0.01453	0.02517		
		Dry period	0.10	0.21	0.1533	0.03180	0.05508		
	Fluoride mg/l	Transition period	2.75	9.30	4.5075	1.60038	3.20075	1.5 mg/1	1.5 mg/l
		Short Rains	3.15	11.50	6.6933	2.49183	4.31597		
		Dry period	5.50	10.00	7.3333	1.36423	2.36291		
	Chloride mg/l	Transition period	14.20	21.30	19.5250	1.77500	3.55000	250 mg/l	250 mg/l
		Short rains	21.30	21.30	21.3000	0.00000	0.00000		
		Dry period	21.30	21.30	21.3000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

Table 2.6: Natural potable water

Station ID	Parameter / unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA (2006) MAX
BB7	pH	Transition Period	7.26	8.10	7.6175	0.18630	0.37259	6.5 - 8.5	6.5 - 8.5
		Short rains	7.64	9.49	8.4100	0.55609	0.96317		
		Dry period	5.97	9.88	8.2700	1.18027	2.04428		
	Ec µS/cm at 25^{o}C	Transition Period	760.00	810.00	787.7500	10.57020	21.14040	400 µS/cm	300 µS/cm
		Short rains	687.00	817.00	763.000	39.10669	67.73478		
		Dry period	454.00	762.00	656.0000	101.04125	175.00857		
	Selenium mg/l	Transition Period	2.54	4.30	3.2450	0.37400	0.74800	0.01 mg/l	0.01 mg/l
		Short rains	3.35	8.20	5.8900	1.40479	2.43317		
		Dry period	3.00	6.75	5.3800	1.19453	2.06899		
	Cadmium mg/l	Transition period	0.00	0.20	0.0725	0.04750	0.09500	0.003 mg/l	0.01 mg/l
		Short rains	0.08	0.20	0.1267	0.03712	0.06429		
		Dry period	0.04	0.08	0.0600	0.01155	0.02000		
	Fluoride mg/l	Transition period	2.24	2.82	2.5750	0.12453	0.24906	1.5 mg/1	1.5 mg/l
		Short Rains	1.10	2.56	1.8200	0.42158	0.73021		
		Dry period	0.50	3.00	1.5000	0.76376	1.32288		
	Chloride mg/l	Transition period	14.20	21.30	19.5250	1.77500	3.55000	200 mg/l	200 mg/l
		Short rains	21.30	21.30	21.3000	0.00000	0.00000		
		Dry period	21.30	21.30	21.3000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

Table 2.7: Potable treated water

Station ID	Parameter / unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA (2006) MAX
BB8	pH	Transition Period	7.31	8.12	7.9075	0.19922	0.39844	6.5 - 8.5	6.5 - 8.5
		Short rains	8.77	9.23	8.9967	0.13283	0.23007		
		Dry period	5.93	9.10	8.0300	1.05006	1.81876		
	Ec µS/cm at 25^{o}C	Transition Period	480.00	902.00	785.0000	101.87738	203.75475	1500 µS/cm	-
		Short rains	817.00	874.00	852.0000	17.69181	30.64311		
		Dry period	403.00	881.00	699.3333	149.42371	258.80945		
	Selenium mg/l	Transition Period	0.00	3.65	2.4625	0.83126	1.66252	0.01 mg/l	0.01 mg/l
		Short rains	1.20	5.30	3.4933	1.20832	2.09288		
		Dry period	1.31	2.01	1.5433	0.23333	0.40415		
	Cadmium mg/l	Transition period	0.00	0.07	0.0275	0.01702	0.03403	0.003 mg/l	0.01 mg/l
		Short rains	0.04	0.08	0.0600	0.01155	0.02000		
		Dry period	0.10	0.20	0.1500	0.02887	0.05000		
	Fluoride mg/l	Transition period	2.50	2.72	2.6150	0.04941	0.09883	1.5 mg/1	1.5 mg/l
		Short Rains	2.50	3.12	2.7067	0.20667	0.35796		
		Dry period	2.50	9.50	5.1667	2.18581	3.78594		
	Chloride mg/l	Transition period	14.2	14.2	14.2000	0.00000	0.00000	200 mg/l	200 mg/l
		Short rains	14.2	14.2	14.2000	0.00000	0.00000		
		Dry period	14.2	14.2	14.2000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

Table 2.8: Potable treated water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA (2006) MAX
BB9	pH	Transition Period	8.15	8.63	8.3625	0.11161	0.22322	6.5 - 8.5	6.5 - 8.5
		Short rains	9.06	9.83	9.4633	0.22303	0.38631		
		Dry period	6.00	10.14	8.5833	1.30070	2.25287		
	Ec µS/cm at $25^{o}C$	Transition Period	804.00	980.00	867.2500	38.99866	77.99733	1500 µS/cm	-
		Short rains	810.00	872.00	850.6667	20.34153	35.23256		
		Dry period	420.00	865.00	695.3333	138.90084	240.58332		
	Selenium mg/l	Transition Period	1.88	2.10	2.0200	0.05083	0.10165	0.01 mg/l	0.01 mg/l
		Short rains	1.67	2.85	2.1867	0.34844	0.60352		
		Dry period	0.59	2.33	1.3467	0.51492	0.89187		
	Cadmium mg/l	Transition period	0.00	0.20	0.0675	0.04715	0.09430	0.003 mg/l	0.01 mg/l
		Short rains	0.12	0.15	0.1300	0.01000	0.01732		
		Dry period	0.10	0.13	0.1100	0.01000	0.01732		
	Fluoride mg/l	Transition period	2.35	3.09	2.8250	0.16525	0.33050	1.5 mg/1	1.5 mg/l
		Short Rains	2.98	5.50	4.3267	0.73261	1.26891		
		Dry period	3.00	6.00	4.5000	0.86603	1.50000		
	Chloride mg/l	Transition period	14.2	14.2	14.2000	0.00000	0.00000	250 mg/l	250 mg/l
		Short rains	14.2	14.2	14.2000	0.00000	0.00000		
		Dry period	14.2	14.2	14.2000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

Table 2.9: Potable treated water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA (2006) MAX
BB10	pH	Transition Period	8.02	8.34	8.1800	0.07303	0.14606	6.5 - 8.5	6.5 - 8.5
		Short rains	9.26	9.73	9.4300	0.15044	0.26058		
		Dry period	7.18	9.97	8.9100	0.87230	1.51086		
	Ec µS/cm at 25^{o}C	Transition Period	403.00	697.00	536.0000	63.27980	126.55960	1500 µS/cm	-
		Short rains	368.00	740.00	584.3333	111.58903	193.27787		
		Dry period	212.00	687.00	437.3333	137.65940	238.43308		
	Selenium mg/l	Transition Period	0.08	4.21	2.2600	0.91800	1.83599	0.01 mg/l	0.01 mg/l
		Short rains	2.98	4.94	3.6400	0.65003	1.12588		
		Dry period	1.49	3.49	2.3233	0.60093	1.04083		
	Cadmium mg/l	Transition period	0.00	0.21	0.0700	0.04950	0.09899	0.003 mg/l	0.01 mg/l
		Short rains	0.10	0.10	0.1000	0.00000	0.00000		
		Dry period	0.10	0.30	0.2200	0.06110	0.10583		
	Fluoride mg/l	Transition period	2.31	2.97	2.7075	0.15739	0.31479	1.5 mg/1	1.5 mg/l
		Short Rains	1.70	8.00	4.2433	1.91717	3.32064		
		Dry period	3.50	5.00	4.3000	0.43589	0.75498		
	Chloride mg/l	Transition period	14.20	21.30	15.9750	1.77500	3.55000	250 mg/l	250 mg/l
		Short rains	14.20	14.20	14.2000	0.00000	0.00000		
		Dry period	14.20	21.30	16.5667	2.36667	4.09919		

Source: Author, (June 2014 to March 2015)

Table 2.10: Natural potable water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. deviation	WHO GV (2011) MAX	NEMA (2006) MAX
K1	pH	Transition Period	7.50	7.80	7.6775	0.06356	0.12712	5.5 - 9.5	6.5 - 8.5
		Short rains	7.50	8.68	8.2533	0.37777	0.65432		
		Dry period	6.05	8.92	7.9033	0.92812	1.60756		
	Ec µS/cm at 25^{o}C	Transition Period	240.00	390.00	297.5000	32.50000	65.00000	2500 µS/cm	-
		Short rains	360.00	411.00	380.3333	15.60271	27.02468		
		Dry period	208.00	527.00	380.3333	92.97730	161.04140		
	Selenium mg/l	Transition Period	1.99	6.40	5.1050	1.04231	2.08462	0.01 mg/l	0.01 mg/l
		Short rains	3.78	4.21	3.9967	0.12414	0.21502		
		Dry period	2.33	3.49	2.9833	0.34280	0.59375		
	Cadmium mg/l	Transition period	0.00	0.21	0.1000	0.04301	0.08602	0.003 mg/l	0.01 mg/l
		Short rains	0.04	0.20	0.1467	0.05333	0.09238		
		Dry period	0.10	0.20	0.1667	0.03333	0.05774		
	Fluoride mg/l	Transition period	1.85	2.60	2.2850	0.18187	0.36373	1.5 mg/1	1.5 mg/l
		Short Rains	0.40	4.00	2.3467	1.04953	1.81784		
		Dry period	1.49	2.50	1.8600	0.32130	0.55651		
	Chloride mg/l	Transition period	14.20	14.20	14.2000	0.00000	0.00000	250 mg/l	250 mg/l
		Short rains	14.20	14.20	14.2000	0.00000	0.00000		
		Dry period	14.20	28.40	18.9333	4.73333	8.19837		

Source: Author, (June 2014 to March 2015)

Table 2.11: Natural potable water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA (2006) MAX
K2	pH	Transition Period	6.90	7.50	7.1350	0.13124	0.26249	5.5 - 9.5	6.5 - 8.5
		Short rains	7.10	8.00	7.5333	0.26034	0.45092		
		Dry period	6.08	7.45	6.8933	0.41579	0.72016		
	Ec µS/cm at 25^{o}C	Transition Period	245.00	284.00	262.5000	8.35165	16.70329	2500 µS/cm	-
		Short rains	365.00	570.00	438.3333	65.97558	114.27306		
		Dry period	278.00	568.00	438.6667	85.16911	147.51723		
	Selenium mg/l	Transition Period	0.09	3.08	2.2275	0.71563	1.43126	0.01 mg/l	0.01 mg/l
		Short rains	0.50	1.20	0.9667	0.23333	0.40415		
		Dry period	2.20	3.12	2.6200	0.26858	0.46519		
	Cadmium mg/l	Transition period	0.00	0.20	0.1075	0.04347	0.08694	0.003 mg/l	0.01 mg/l
		Short rains	0.15	0.20	0.1833	0.01667	0.02887		
		Dry period	0.19	0.28	0.2233	0.02848	0.04933		
	Fluoride mg/l	Transition period	1.99	2.81	2.2975	0.18714	0.37429	1.5 mg/1	1.5 mg/l
		Short Rains	1.00	2.86	1.6533	0.60402	1.04620		
		Dry period	1.84	2.25	2.0267	0.11977	0.20744		
	Chloride mg/l	Transition period	14.20	21.30	19.5250	1.77500	3.55000	250 mg/l	250 mg/l
		Short rains	28.40	28.40	28.4000	0.00000	0.00000		
		Dry period	21.30	28.40	23.6667	2.36667	4.09919		

Source: Author, (June 2014 to March 2015)

Table 2.12: Natural potable water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA (2006) MAX
K3	pH	Transition Period	7.20	8.17	7.7050	0.21857	0.43715	5.5 - 9.5	6.5 - 8.5
		Short rains	7.00	8.00	7.5000	0.28868	0.50000		
		Dry period	7.14	8.50	7.8800	0.39716	0.68790		
	Ec µS/cm at 25^{o}C	Transition Period	267.00	341.00	309.2500	16.81455	33.62910	1500 µS/cm	-
		Short rains	350.00	421.00	380.3333	21.13712	36.61056		
		Dry period	297.00	502.00	403.0000	5.28181	102.67911		
	Selenium mg/l	Transition Period	2.23	6.35	4.9075	0.91804	1.83609	0.01 mg/l	0.01 mg/l
		Short rains	3.98	5.09	4.5067	0.32168	0.55717		
		Dry period	2.20	5.15	4.0667	0.93734	1.62352		
	Cadmium mg/l	Transition period	0.00	0.30	0.1625	0.06250	0.12500	0.003 mg/l	0.01 mg/l
		Short rains	0.15	0.18	0.1700	0.01000	0.01732		
		Dry period	0.10	0.12	0.1067	0.00667	0.01155		
	Fluoride mg/l	Transition period	1.50	2.72	2.1775	0.27271	0.54543	1.5 mg/1	1.5 mg/l
		Short Rains	0.70	2.67	1.4233	0.62600	1.08427		
		Dry period	1.76	2.34	2.0667	0.16826	0.29143		
	Chloride mg/l	Transition period	14.20	28.40	21.3000	2.89856	5.79713	250 mg/l	250 mg/l
		Short rains	28.40	28.40	28.4000	0.00000	0.00000		
		Dry period	21.30	28.40	23.6667	2.36667	4.09919		

Source: Author, (June 2014 to March 2015)

Table 2.13

Station ID	Parameter / unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO STD (1998; 2006)	NEMA (2006) MAX
K4	pH	Transition Period	6.85	7.74	7.3575	0.18808	0.37615	6.5 - 8.5	6.5 - 8.5
		Short rains	6.90	8.54	7.9533	0.52780	0.91418		
		Dry period	6.25	8.96	8.0167	0.88401	1.53115		
	Ec µS/cm at 25^{o}C	Transition Period	276.00	295.00	284.5000	4.085175	8.10350	1500 µS/cm	500 µS/cm
		Short rains	400.00	444.00	421.0000	12.71919	22.03028		
		Dry period	216.00	562.00	399.0000	100.38094	173.86489		
	Selenium mg/l	Transition Period	0.33	2.71	1.4075	0.49723	0.99446	0.01 mg/l	0.01 mg/l
		Short rains	0.69	1.49	1.0433	0.23561	0.40808		
		Dry period	0.25	1.20	0.6800	0.27791	0.48135		
	Cadmium mg/l	Transition period	0.00	0.20	0.0875	0.04191	0.08382	0.003 mg/l	0.01 mg/l
		Short rains	0.19	0.29	0.2267	0.03180	0.05508		
		Dry period	0.19	0.20	0.1967	0.00333	0.00577		
	Fluoride mg/l	Transition period	1.49	2.32	2.0275	0.19111	0.38222	1.5 mg/1	1.5 mg/l
		Short Rains	1.50	2.26	1.9200	0.22301	0.38626		
		Dry period	1.65	2.19	1.9133	0.15603	0.27025		
	Chloride mg/l	Transition period	14.20	14.20	14.2000	0.00000	0.00000	250 mg/l	200 mg/l
		Short rains	14.20	14.20	14.2000	0.00000	0.00000		
		Dry period	14.20	21.30	16.5667	2.36667	4.09919		

Source: Author, (June 2014 to March 2015)

Table 2.14

Station ID	Parameter	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO STD (1998; 2006)	NEMA (2006) MAX
K5	pH	Transition Period	6.85	7.50	7.1875	0.18071	0.36142	6.5 - 8.5	6.5 - 8.5
		Short rains	7.10	7.90	7.5000	0.23094	0.40000		
		Dry period	6.25	8.50	7.5333	0.66854	1.15794		
	Ec µS/cm at 25°C	Transition Period	245.00	270.00	260.2500	6.06046	12.12092	1500 µS/cm	500 µS/cm
		Short rains	382.00	402.00	394.0000	6.11010	10.58301		
		Dry period	249.00	555.00	394.0000	88.69611	153.62617		
	Selenium mg/l	Transition Period	0.23	2.00	1.2875	0.37513	0.75026	0.01 mg/l	0.01 mg/l
		Short rains	1.69	2.05	1.8400	1.10817	0.18735		
		Dry period	1.49	1.98	1.7467	0.14193	0.24583		
	Cadmium mg/l	Transition period	0.00	0.20	0.0700	0.04435	0.08869	0.003 mg/l	0.01 mg/l
		Short rains	0.08	0.18	0.1133	0.03333	0.05774		
		Dry period	0.10	0.15	0.1167	0.01667	0.02887		
	Fluoride mg/l	Transition period	1.21	2.12	1.6350	0.23876	0.47753	1.5 mg/1	1.5 mg/l
		Short Rains	1.44	1.68	1.5567	0.06936	0.12014		
		Dry period	1.20	2.02	1.7333	0.26692	0.46231		
	Chloride mg/l	Transition period	14.20	28.40	24.8500	3.55000	7.10000	250 mg/l	200 mg/l
		Short rains	28.40	28.40	28.4000	0.00000	0.00000		
		Dry period	21.30	28.40	26.0333	2.36667	4.09919		

Source: Author, (June 2014 to March 2015)

Table 2.15

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO STD (1998; 2006)	NEMA (2006) MAX
K6	pH	Transition Period	7.10	7.97	7.5025	0.17900	0.35799	6.5 - 8.5	6.5 - 8.5
		Short rains	7.20	8.75	8.1333	0.47463	0.82209		
		Dry period	6.90	8.97	8.2533	0.67706	1.17270		
	Ec µS/cm at 25^{o}C	Transition Period	294.00	428.00	371.7500	28.21458	56.42916	1500 µS/cm	500 µS/cm
		Short rains	358.00	424.00	391.6667	20.73912	35.92121		
		Dry period	205.00	520.00	379.6667	92.53888	160.28204		
	Selenium mg/l	Transition Period	0.09	2.00	1.4400	0.45609	0.91218	0.01 mg/l	0.01 mg/l
		Short rains	0.74	1.68	1.3100	0.28919	0.50090		
		Dry period	1.49	2.76	2.1500	0.36747	0.63647		
	Cadmium mg/l	Transition period	0.00	0.20	0.0650	0.04717	0.09434	0.003mg/l	0.01 mg/l
		Short rains	0.10	0.13	0.1167	0.00882	0.01528		
		Dry period	0.04	0.21	0.1167	0.04978	0.08622		
	Fluoride mg/l	Transition period	1.34	2.35	1.9400	0.23562	0.47124	1.5 mg/1	1.5 mg/l
		Short Rains	1.52	2.00	1.8333	0.15677	0.27154		
		Dry period	1.89	2.22	2.0733	0.09701	0.16803		
	Chloride mg/l	Transition period	14.20	14.20	14.2000	0.00000	0.00000	250 mg/l	200 mg/l
		Short rains	14.20	14.20	14.2000	0.00000	0.00000		
		Dry period	14.20	14.20	14.2000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

Table 2.16

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO STD (2006)	NEMA (2006) MAX
K7	pH	Transition Period	6.67	8.02	7.4350	0.31023	0.62046	6.5 - 8.5	6.5 - 8.5
		Short rains	6.90	8.77	8.0400	0.57744	1.00015		
		Dry period	8.10	9.50	8.8800	0.41199	0.71358		
	Ec µS/cm at 25^oC	Transition Period	215.00	290.00	242.5000	16.64582	33.29164	1500 µS/cm	500 µS/cm
		Short rains	338.00	380.00	363.0000	12.76715	22.11334		
		Dry period	219.00	495.00	368.3333	80.47636	139.38914		
	Selenium mg/l	Transition Period	0.99	2.45	1.6875	0.33016	0.66032	0.01 mg/l	0.01 mg/l
		Short rains	1.43	3.13	2.4167	0.50942	0.88235		
		Dry period	1.09	6.75	4.1200	1.64610	2.85112		
	Cadmium mg/l	Transition period	0.00	0.20	0.0975	0.04090	0.08180	0.003 mg/l	0.01 mg/l
		Short rains	0.09	0.15	0.1133	0.01856	0.03215		
		Dry period	0.10	0.20	0.1400	0.03055	0.05292		
	Fluoride mg/l	Transition period	1.57	2.02	1.7675	0.11383	0.22765	1.5 mg/1	1.5 mg/l
		Short Rains	1.38	1.85	1.6367	0.13740	0.23798		
		Dry period	1.45	2.02	1.6700	0.17692	0.30643		
	Chloride mg/l	Transition period	14.20	14.20	14.2000	0.00000	0.00000	250 mg/l	200 mg/l
		Short rains	14.20	14.20	14.2000	0.00000	0.00000		
		Dry period	14.20	14.20	14.2000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

Table 2.17

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO STD (1998; 2006)	NEMA (2006) MAX
L1	pH	Transition Period	7.10	10.54	8.1625	0.79854	1.59709	6.5 – 8.5	6.5 - 8.5
		Short rains	8.00	9.50	8.8633	0.44760	0.77526		
		Dry period	7.26	8.92	7.8933	0.51799	0.89718		
	Ec µS/cm at 25^{o}C	Transition Period	435.00	676.00	515.2500	55.21077	110.42154	1500 µS/cm	500 µS/cm
		Short rains	695.00	718.00	707.6667	6.74125	11.67619		
		Dry period	368.00	848.00	646.0000	143.68020	248.86141		
	Selenium mg/l	Transition Period	1.49	4.89	3.2000	0.76880	1.53760	0.01 mg/l	0.01 mg/l
		Short rains	3.20	4.85	4.0133	0.47646	0.82525		
		Dry period	0.95	2.76	2.0567	0.56007	0.97007		
	Cadmium mg/l	Transition period	0.00	0.04	0.0200	0.01155	0.02309	0.003 mg/l	0.01 mg/l
		Short rains	0.04	0.15	0.0967	0.03180	0.05508		
		Dry period	0.10	0.20	0.1667	0.03333	0.05774		
	Fluoride mg/l	Transition period	1.99	3.00	2.4200	0.21676	0.43351	1.5 mg/1	1.5 mg/l
		Short Rains	0.23	3.51	1.3467	1.08186	1.87383		
		Dry period	0.30	2.50	1.4000	0.63509	1.10000		
	Chloride mg/l	Transition period	28.40	28.40	28.4000	0.00000	0.00000	250 mg/l	200 mg/l
		Short rains	21.30	28.40	26.0333	2.36667	4.09919		
		Dry period	28.40	28.40	28.4000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

Table 2.18

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Standard deviation	WHO STD (2006)	NEMA (2006) MAX
F1	pH	Transition Period	7.35	7.98	7.6075	0.14625	0.29250	6.5 - 8.5	6.5 - 8.5
		Short rains	7.90	8.89	8.3733	0.28661	0.49642		
		Dry period	7.21	9.10	8.4200	0.60655	1.05057		
	Ec µS/cm at 25^{o}C	Transition Period	401.00	641.00	506.0000	56.57738	113.15476	1500 µS/cm	500 µS/cm
		Short rains	589.00	605.00	595.6667	4.80740	8.32666		
		Dry period	307.00	623.00	504.3333	99.34004	172.06200		
	Selenium mg/l	Transition Period	2.33	3.12	2.7225	0.18459	0.36918	0.01 mg/l	0.01 mg/l
		Short rains	2.65	3.05	2.8833	0.12019	0.20817		
		Dry period	0.95	2.20	1.3667	0.41667	0.72169		
	Cadmium mg/l	Transition period	0.00	0.21	0.0850	0.05172	0.10344	0.003 mg/l	0.01 mg/l
		Short rains	0.08	0.19	0.1233	0.03383	0.05859		
		Dry period	0.15	0.20	0.1833	0.01667	0.02887		
	Fluoride mg/l	Transition period	1.55	2.56	1.8900	0.23370	0.46740	1.5 mg/1	1.5 mg/l
		Short Rains	1.35	2.25	1.7667	0.26194	0.45369		
		Dry period	1.75	1.89	1.8267	0.04096	0.07095		
	Chloride mg/l	Transition period	14.20	28.40	21.3000	2.89856	5.79713	250 mg/l	200 mg/l
		Short rains	21.30	28.40	26.0333	2.36667	4.09919		
		Dry period	21.30	21.30	21.3000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

Table 2.19: Natural potable water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA (2006) MAX
F2	pH	Transition Period	6.90	7.81	7.3275	0.19085	0.38170	5.5 - 8.5	6.5 - 8.5
		Short rains	7.10	7.52	7.2400	0.14000	0.24249		
		Dry period	7.50	9.29	8.1367	0.57771	1.00062		
	Ec µS/cm at 25^{o}C	Transition Period	415.00	623.00	505.0000	50.08659	100.17318	1500 µS/cm	500 µS/cm
		Short rains	583.00	597.00	588.3333	4.37163	7.57188		
		Dry period	306.00	667.00	523.6667	110.64106	191.63594		
	Selenium mg/l	Transition Period	1.09	1.95	1.4625	0.21100	0.42201	0.01 mg/l	0.01 mg/l
		Short rains	1.85	1.95	1.9167	0.03333	0.05774		
		Dry period	0.64	0.99	0.8600	0.11060	0.19157		
	Cadmium mg/l	Transition period	0.00	0.20	0.1050	0.04406	0.08813	0.003 mg/l	0.01 mg/l
		Short rains	0.09	0.20	0.1467	0.03180	0.05508		
		Dry period	0.04	0.21	0.1333	0.04978	0.08622		
	Fluoride mg/l	Transition period	1.43	2.35	1.8850	0.21574	0.43147	1.5 mg/1	1.5 mg/l
		Short Rains	1.45	1.88	1.6067	0.13115	0.23756		
		Dry period	1.65	1.78	1.7333	0.04177	0.07234		
	Chloride mg/l	Transition period	14.20	21.30	17.7500	2.04959	4.09919	250 mg/l	200 mg/l
		Short rains	21.30	28.40	23.6667	2.36667	4.09919		
		Dry period	21. 30	28.40	26.0333	2.36667	4.09919		

Source: Author, (June 2014 to March 2015)

Table 2.20: Natural potable water

Station ID	Parameter	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviaton	WHO GV (2011) MAX	NEMA (2006) MAX
F3	pH	Transition Period	7.10	7.85	7.4825	0.15402	0.30804	5.5 - 9.5	6.5 - 8.5
		Short rains	7.21	8.73	8.1300	0.46705	0.80895		
		Dry period	7.29	9.06	8.1833	0.51102	0.88512		
	Ec µS/cm at 25^{o}C	Transition Period	324.00	632.00	438.2500	67.93180	135.86360	2500 µS/cm	-
		Short rains	635.00	647.00	642.6667	3.84419	6.65833		
		Dry period	308.00	663.00	535.0000	113.80832	197.12179		
	Selenium mg/l	Transition Period	0.95	4.21	2.9775	0.74734	1.49469	0.01 mg/l	0.01 mg/l
		Short rains	3.99	4.10	4.0333	0.03383	0.05859		
		Dry period	0.95	3.17	2.2933	0.68201	1.18128		
	Cadmium mg/l	Transition period	0.00	0.20	0.1050	0.04173	0.08347	0.003 mg/l	0.01 mg/l
		Short rains	0.20	0.29	0.2600	0.03000	0.05196		
		Dry period	0.04	0.35	0.1967	0.08950	0.15503		
	Fluoride mg/l	Transition period	1.47	2.25	1.9350	0.17900	0.35800	1.5 mg/1	1.5 mg/l
		Short Rains	0.80	2.23	1.5200	0.41284	0.71505		
		Dry period	1.90	7.00	4.1167	1.50951	2.61454		
	Chloride mg/l	Transition period	14.20	21.30	19.5250	1.77500	3.55000	250 mg/l	250 mg/l
		Short rains	21.30	28.40	26.0333	2.36667	4.09919		
		Dry period	21.30	28.40	23.6667	2.36667	4.09919		

Source: Author, (June 2014 to March 2015)

Table 2.21: Natural potable water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011)	NEMA (2006) MAX
F4	pH	Transition Period	6.90	7.75	7.2600	0.19626	0.39251	6.5 - 8.5	6.5 - 8.5
		Short rains	7.95	8.82	8.3900	0.25120	0.43509		
		Dry period	7.45	9.15	8.0600	0.54629	0.94620		
	Ec µS/cm at 25^{o}C	Transition Period	321.00	432.00	366.2500	24.66906	49.33812	1500 µS/cm	500 µS/cm
		Short rains	598.00	613.00	604.0000	4.58258	7.93725		
		Dry period	299.00	687.00	534.0000	119.27419	206.58896		
	Selenium mg/l	Transition Period	0.59	1.74	1.3300	0.25334	0.50669	0.01 mg/l	0.01 mg/l
		Short rains	1.85	2.23	2.0600	0.11150	0.19313		
		Dry period	1.12	6.03	2.9433	1.55178	2.68776		
	Cadmium mg/l	Transition period	0.00	0.21	0.1000	0.04301	0.08602	0.003 mg/l	0.01 mg/l
		Short rains	0.04	0.12	0.0867	0.02404	0.04163		
		Dry period	0.20	0.25	0.2167	0.01667	0.02887		
	Fluoride mg/l	Transition period	1.69	2.52	2.1100	0.20237	0.40653	1.5 mg/1	1.5 mg/l
		Short Rains	1.54	2.31	1.9467	0.22333	0.38682		
		Dry period	0.90	1.89	1.4467	0.29042	0.50302		
	Chloride mg/l	Transition period	14.20	28.40	21.3000	2.89856	5.79713	250 mg/l	200 mg/l
		Short rains	28.40	28.40	28.4000	0.00000	0.00000		
		Dry period	21.30	21.30	21.3000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

Table 2.22: Natural potable water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA (2006) MAX
F5	pH	Transition Period	6.90	8.12	7.4725	0.28494	0.56988	5.5 - 9.5	6.5 - 8.5
		Short rains	8.89	8.95	8.9200	0.01732	0.03000		
		Dry period	7.25	9.35	8.0833	0.64377	1.11505		
	Ec µS/cm at 25°C	Transition Period	308.00	453.00	381.5000	29.76155	59.52310	2500 µS/cm	-
		Short rains	300.00	584.00	397.6667	93.2028	161.43213		
		Dry period	318.00	645.00	530.0000	106.12728	183.81784		
	Selenium mg/l	Transition Period	1.88	3.21	2.2825	0.31103	0.62206	0.01 mg/l	0.01 mg/l
		Short rains	1.49	2.33	1.7700	0.28000	0.48497		
		Dry period	1.50	7.48	3.6733	1.90971	3.30771		
	Cadmium/ mg/l	Transition period	0.00	0.18	0.0925	0.03683	0.07365	0.003 mg/l	0.01 mg/l
		Short rains	0.04	0.18	0.1233	0.04256	0.07371		
		Dry period	0.15	0.20	0.1833	0.01667	0.02887		
	Fluoride mg/l	Transition period	1.50	1.79	1.6450	0.05923	0.11846	1.5 mg/1	1.5 mg/l
		Short Rains	0.85	1.76	1.1700	0.29535	0.51157		
		Dry period	1.40	1.77	1.6267	0.11465	0.19858		
	Chloride mg/l	Transition period	14.20	28.40	24.8500	3.55000	7.10000	250 mg/l	250 mg/l
		Short rains	28.40	28.40	28.4000	0.00000	0.00000		
		Dry period	21.30	21.30	21.3000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

Table 2.23: Treated potable water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO STD (2011)	NEMA (2006) MAX
G1	pH	Transition Period	7.30	7.98	7.5300	0.15610	0.31220	6.5 - 8.5	6.5 - 8.5
		Short rains	7.38	9.41	8.5300	0.60136	1.04159		
		Dry period	7.25	9.42	8.0500	0.68825	1.19202		
	Ec µS/cm at 25°C	Transition Period	245.00	390.00	312.5000	30.17311	60.34622	1500 µS/cm	-
		Short rains	213.00	448.00	353.6667	71.68527	124.16253		
		Dry period	258.00	486.00	387.0000	67.50556	116.92305		
	Selenium mg/l	Transition Period	2.13	2.76	2.3100	0.15072	0.30144	0.01 mg/l	0.01 mg/l
		Short rains	2.33	5.70	3.5267	1.08852	1.88537		
		Dry period	0.64	3.49	2.2600	0.84552	1.46448		
	Cadmium mg/l	Transition period	0.00	0.20	0.0975	0.04328	0.08655	0.003 mg/l	0.01mg/l
		Short rains	0.06	0.10	0.0867	0.01333	0.02309		
		Dry period	0.10	0.20	0.1633	0.03180	0.05508		
	Fluoride mg/l	Transition period	2.18	3.40	2.5750	0.27852	0.55705	1.5 mg/1	1.5 mg/l
		Short Rains	1.77	3.20	2.4567	0.41378	0.71668		
		Dry period	2.70	5.50	3.7000	0.90185	1.56205		
	Chloride mg/l	Transition period	14.20	14.20	14.2000	0.00000	0.00000	250 mg/l	250 mg/l
		Short rains	14.20	14.20	14.2000	0.00000	0.00000		
		Dry period	14.20	14.20	14.2000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

Table 2.24: Potable natural water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA (2006)
G2	pH	Transition Period	6.88	7.78	7.4725	0.15610	0.41161	5.5 - 9.5	6.5 - 8.5
		Short rains	7.50	7.95	7.6900	0.13454	0.23302		
		Dry period	7.43	9.12	8.5367	0.55360	0.95887		
	Ec µS/cm at 25°C	Transition Period	867.00	912.00	888.5000	10.72769	21.45538	2500 µS/cm	-
		Short rains	848.00	875.00	859.0000	8.18535	14.17745		
		Dry period	570.00	994.00	851.3333	140.67141	243.65002		
	Selenium mg/l	Transition Period	0.55	1.68	0.9650	0.25653	0.51306	0.01 mg/l	0.01 mg/l
		Short rains	0.95	2.46	1.8000	0.44613	0.77272		
		Dry period	0.10	3.85	2.5667	1.23367	2.13678		
	Cadmium mg/l	Transition period	0.00	0.25	0.1200	0.05307	0.10614	0.003 mg/l	0.01 mg/l
		Short rains	0.08	0.20	0.1333	0.03528	0.06110		
		Dry period	0.10	0.20	0.1667	0.03333	0.05774		
	Fluoride mg/l	Transition period	2.11	3.28	2.5150	0.26085	0.52170	1.5 mg/1	1.5 mg/l
		Short Rains	2.01	2.85	2.3900	0.24576	0.42568		
		Dry period	4.56	5.95	5.3033	0.40416	0.70002		
	Chloride mg/l	Transition period	14.20	21.30	19.5250	1.77500	3.55000	250 mg/l	250 mg/l
		Short rains	21.30	21.30	21.3000	0.00000	0.00000		
		Dry period	14.20	21.30	16.5667	2.36667	4.09919		

Source: Author, (June 2014 to March 2015)

Table 2.25: Treated potable water

Station ID	Parameter /unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011)	NEMA (2006)
G4	pH	Transition Period	7.53	9.01	8.0550	0.32671	0.65343	6.5 - 8.5	6.5 - 8.5
		Short rains	7.51	8.52	7.8967	0.31466	0.54501		
		Dry period	7.90	8.16	8.0533	0.07860	0.13614		
	Ec µS/cm at 25^oC	Transition Period	318.00	375.00	339.0000	13.58308	27.16616	1500 µS/cm	-
		Short rains	370.00	428.00	394.3333	17.38134	30.10537		
		Dry period	299.00	445.00	363.0000	43.09679	74.64583		
	Selenium mg/l	Transition Period	1.68	6.55	3.7000	1.02477	2.04954	0.01 mg/l	0.01 mg/l
		Short rains	3.35	5.32	4.2333	0.57771	1.00062		
		Dry period	1.50	2.15	1.9300	0.21502	0.37242		
	Cadmium mg/l	Transition period	0.00	0.04	0.0100	0.01000	0.02000	0.003 mg/l	0.01 mg/l
		Short rains	0.10	0.10	0.1000	0.00000	0.00000		
		Dry period	0.10	0.15	0.1333	0.01667	0.02887		
	Fluoride mg/l	Transition period	2.21	3.15	2.7600	0.20547	0.41093	1.5 mg/1	1.5 mg/l
		Short Rains	1.80	2.65	2.2533	0.24700	0.42782		
		Dry period	4.80	5.74	5.3633	0.28696	0.49702		
	Chloride mg/l	Transition period	14.20	14.20	14.2000	0.00000	0.00000	250 mg/l	250 mg/l
		Short rains	14.20	14.20	14.2000	0.00000	0.00000		
		Dry period	14.20	14.20	14.2000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

Table 2.26: Natural potable water

Station ID	Parameter	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011)	NEMA (2006)
G5	pH	Transition Period	6.68	7.72	7.2575	0.21650	0.43300	5.5 - 9.5	6.5 - 8.5
		Short rains	6.90	8.64	7.5633	0.54315	0.94076		
		Dry period	7.40	7.76	7.5267	0.11681	0.20232		
	Ec µS/cm at 25°C	Transition Period	443.00	563.00	498.0000	28.50439	57.00877	2500 µS/cm	-
		Short rains	890.00	932.00	910.6667	12.12894	21.00794		
		Dry period	854.00	930.00	899.6667	23.24029	40.25336		
	Selenium mg/l	Transition Period	3.50	6.75	4.8800	0.73370	1.46740	0.01 mg/l	0.01 mg/l
		Short rains	1.85	5.45	3.8667	1.06158	1.83870		
		Dry period	1.45	9.20	5.8333	2.29426	3.97377		
	Cadmium mg/l	Transition period	0.00	0.10	0.0450	0.02062	0.04123	0.003 mg/l	0.01 mg/l
		Short rains	0.10	0.15	0.1267	0.01453	0.02517		
		Dry period	0.08	0.15	0.1100	0.02082	0.03606		
	Fluoride mg/l	Transition period	2.30	2.59	2.4275	0.07040	0.14080	1.5 mg/1	1.5 mg/l
		Short Rains	2.30	3.95	3.3500	0.52678	0.91241		
		Dry period	5.11	5.45	5.3367	0.11333	0.19630		
	Chloride mg/l	Transition period	14.20	14.20	14.2000	0.00000	0.00000	250 mg/l	250 mg/l
		Short rains	14.20	21.30	16.5667	2.36667	4.09919		
		Dry period	14.20	21.30	16.5667	2.36667	4.09919		

Source: Author, (June 2014 to March 2015)

Table 2.27: Natural potable water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA (2006)
G6	pH	Transition Period	7.50	7.95	7.7500	0.09407	0.18815	5.5 - 9.5	6.5 - 8.5
		Short rains	6.43	7.54	7.1567	0.36352	0.62963		
		Dry period	6.71	9.65	8.6700	0.98000	1.69741		
	Ec µS/cm at 25°C	Transition Period	488.00	630.00	546.0000	33.53605	67.07210	2500 µS/cm	-
		Short rains	770.00	870.00	808.3333	31.13590	53.92897		
		Dry period	545.00	834.00	712.6667	86.58393	149.96777		
	Selenium mg/l	Transition Period	2.98	3.95	3.3100	0.21752	0.43505	0.01 mg/l	0.01 mg/l
		Short rains	1.68	4.25	3.0433	0.74602	1.29214		
		Dry period	1.58	6.03	3.6367	1.29559	2.24402		
	Cadmium mg/l	Transition period	0.00	0.21	0.0750	0.04664	0.09327	0.003 mg/l	0.01 mg/l
		Short rains	0.04	0.10	0.0667	0.01764	0.03055		
		Dry period	0.04	0.10	0.0600	0.02000	0.03464		
	Fluoride mg/l	Transition period	2.18	3.20	2.7125	0.21383	0.42766	1.5 mg/1	1.5 mg/l
		Short Rains	2.20	3.95	2.8233	0.56440	0.97757		
		Dry period	2.94	4.10	3.5133	0.33493	0.58011		
	Chloride mg/l	Transition period	14.20	21.30	17.7500	2.04959	4.09919	250 mg/l	250 mg/l
		Short rains	21.30	21.30	21.3000	0.00000	0.00000		
		Dry period	14.20	21.30	18.9333	2.36667	4.09919		

Source: Author, (June 2014 to March 2015)

Table 2.28: Natural potable water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA (2006)
G7	pH	Transition Period	6.81	7.95	7.4675	0.26871	0.53742	6.5 - 8.5	6.5 - 8.5
		Short rains	7.30	7.65	7.4833	0.10138	0.17559		
		Dry period	7.35	7.80	7.6067	0.13371	0.23159		
	Ec µS/cm at 25^{o}C	Transition Period	445.00	795.00	552.0000	81.72005	163.44010	1500 µS/cm	500 µS/cm
		Short rains	845.00	978.00	907.3333	38.61922	66.89046		
		Dry period	470.00	920.00	768.3333	149.17365	258.37634		
	Selenium mg/l	Transition Period	1.12	3.49	2.4275	0.49638	0.99275	0.01 mg/l	0.01 mg/l
		Short rains	0.99	4.56	3.1767	1.10608	1.91579		
		Dry period	0.64	4.56	3.0667	1.22406	2.12013		
	Cadmium mg/l	Transition period	0.00	0.02	0.0050	0.00500	0.01000	0.003 mg/l	0.01mg/l
		Short rains	0.04	0.04	0.0400	0.00000	0.00000		
		Dry period	0.08	0.10	0.0933	0.00667	0.01155		
	Fluoride mg/l	Transition period	1.75	2.95	2.3425	0.25636	0.51273	1.5 mg/1	1.5 mg/l
		Short Rains	1.50	4.01	2.9100	0.74097	1.28339		
		Dry period	2.78	4.80	4.1200	0.67002	1.16052		
	Chloride mg/l	Transition period	14.20	21.30	19.5250	1.77500	3.55000	250 mg/l	200 mg/l
		Short rains	21.30	21.30	21.3000	0.00000	0.00000		
		Dry period	14.20	21.30	18.9333	2.36667	4.09919		

Source: Author, (June 2014 to March 2015)

Table 2.29: Treated potable water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA (2006)
C2	pH	Transition Period	7.61	8.57	7.9850	0.20658	0.41316	6.5 - 8.5	6.5 - 8.5
		Short rains	9.11	9.83	9.4933	0.20915	0.36226		
		Dry period	6.17	10.05	8.2600	1.13006	1.95732		
	Ec µS/cm at 25^{o}C	Transition Period	645.00	715.00	680.5000	19.08970	38.17940	1500 µS/cm	-
		Short rains	645.00	666.00	653.6667	6.33333	10.96966		
		Dry period	376.00	677.00	559.3333	92.88763	160.88609		
	Selenium mg/l	Transition Period	0.64	4.86	2.5275	0.99627	1.99254	0.01 mg/l	0.01 mg/l
		Short rains	2.99	3.49	3.1600	0.16503	0.28583		
		Dry period	2.33	2.40	2.3767	0.02333	0.04041		
	Cadmium mg/l	Transition period	0.00	0.04	0.0125	0.00946	0.01893	0.003 mg/l	0.01 mg/l
		Short rains	0.04	0.10	0.0600	0.02000	0.03464		
		Dry period	0.04	0.10	0.0767	0.01856	0.03215		
	Fluoride mg/l	Transition period	2.61	10.60	4.9775	1.90088	3.80176	1.5 mg/1	1.5 mg/l
		Short Rains	4.51	6.98	5.5967	0.72829	1.26144		
		Dry period	5.20	9.50	6.8000	1.35769	2.35160		
	Chloride mg/l	Transition period	14.20	14.20	14.2000	0.00000	0.00000	250 mg/l	250 mg/l
		Short rains	14.20	14.20	14.2000	0.00000	0.00000		
		Dry period	14.20	21.30	16.5667	2.36667	4.09919		

Source: Author, (June 2014 to March 2015)

Table 2.30: Treated potable water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011)	NEMA (2006) MAX
C4	pH	Transition Period	7.06	7.85	7.3775	0.18621	0.37241	6.5 - 8.5	6.5 - 8.5
		Short rains	7.10	8.45	7.5833	0.43429	0.75222		
		Dry period	7.50	8.30	7.8333	0.24037	0.41633		
	Ec µS/cm at 25°C	Transition Period	308.00	456.00	402.2500	32.40981	64.81962	1500 µS/cm	-
		Short rains	560.00	695.00	641.6667	41.46618	71.82154		
		Dry period	443.00	715.00	609.3333	84.17508	145.79552		
	Selenium mg/l	Transition Period	1.10	2.75	2.0250	0.3596	0.71937	0.01 mg/l	0.01 mg/l
		Short rains	1.49	2.35	1.9467	0.24969	0.43247		
		Dry period	0.95	2.13	1.6900	0.37220	0.64467		
	Cadmium mg/l	Transition period	0.00	0.20	0.0950	0.04113	0.08226	0.003 mg/l	0.01mg/l
		Short rains	0.02	0.20	0.1067	0.05207	0.09018		
		Dry period	0.12	0.19	0.1633	0.02186	0.03786		
	Fluoride mg/l	Transition period	0.99	2.14	1.7700	0.26780	0.53560	1.5 mg/1	1.5 mg/l
		Short Rains	1.45	2.01	1.7367	0.16180	0.28024		
		Dry period	1.99	2.11	2.0333	0.03844	0.06658		
	Chloride mg/l	Transition period	14.20	14.20	14.2000	0.00000	0.00000	250 mg/l	250 mg/l
		Short rains	14.20	14.20	14.2000	0.00000	0.00000		
		Dry period	14.20	14.20	14.2000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

Table 2.31

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) max	NEMA (2006)
C5	Ph	Transition Period	6.66	7.50	7.1250	0.18835	0.37670	6.5 - 8.5	6.5 - 8.5
		Short rains	6.65	7.21	7.0200	0.18502	0.32047		
		Dry period	6.21	7.50	7.0700	0.43000	0.74478		
	Ec µS/cm at 25^{o}C	Transition Period	270.00	396.00	327.5000	29.02154	58.04309	2500 µS/cm	-
		Short rains	299.00	490.00	406.3333	56.39247	97.67463		
		Dry period	285.00	432.00	366.0000	43.09292	74.63913		
	Selenium mg/l	Transition Period	0.85	3.02	2.1175	0.53327	1.06653	0.01 mg/l	0.01 mg/l
		Short rains	0.67	2.46	1.4167	0.53760	0.93115		
		Dry period	0.18	0.50	0.3400	0.09238	0.16000		
	Cadmium mg/l	Transition period	0.00	0.20	0.0875	0.04191	0.08382	0.003 mg/l	0.01 mg/l
		Short rains	0.02	0.32	0.1733	0.08667	0.15011		
		Dry period	0.20	0.30	0.2633	0.03180	0.05508		
	Fluoride mg/l	Transition period	1.40	2.26	1.8350	0.20106	0.40212	1.5 mg/1	1.5 mg/l
		Short Rains	0.70	2.04	1.2167	0.41611	0.72072		
		Dry period	0.10	2.02	1.2333	0.58073	1.00585		
	Chloride mg/l	Transition period	14.20	14.20	14.2000	0.00000	0.00000	250 mg/l	250 mg/l
		Short rains	14.20	14.20	14.2000	0.00000	0.00000		
		Dry period	14.20	14.20	14.2000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

Table 2.32: Potable treated water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV(2011) MAX	NEMA (2006)
C6	Ph	Transition Period	6.80	7.47	7.2125	0.15201	0.30401	6.5 - 8.5	6.5 - 8.5
		Short rains	6.50	7.35	7.0533	0.27691	0.47962		
		Dry period	6.09	8.30	7.2867	0.64452	1.11635		
	Ec µS/cm at $25^{o}C$	Transition Period	121.00	443.00	219.0000	75.25512	150.51024	1500 µS/cm	-
		Short rains	335.00	399.00	358.0000	20.55075	35.59494		
		Dry period	297.00	446.00	384.6667	44.98271	77.91234		
	Selenium mg/l	Transition Period	0.09	1.85	1.2325	0.39502	0.79004	0.01 mg/l	0.01 mg/l
		Short rains	0.11	1.90	0.9967	0.51680	0.89512		
		Dry period	0.07	0.15	0.1033	0.02404	0.04163		
	Cadmium mg/l	Transition period	0.00	0.19	0.0950	0.03884	0.07767	0.003 mg/l	0.01 mg/l
		Short rains	0.06	0.10	0.0767	0.01202	0.02082		
		Dry period	0.08	0.10	0.0933	0.00667	0.01155		
	Fluoride mg/l	Transition period	0.11	1.20	0.4425	0.25490	0.50980	1.5 mg/1	1.5 mg/l
		Short Rains	0.30	1.50	0.7000	0.40000	0.69282		
		Dry period	0.60	1.12	0.8400	0.15144	0.26230		
	Chloride mg/l	Transition period	14.20	14.20	14.2000	0.00000	0.00000	250 mg/l	250 mg/l
		Short rains	14.20	14.20	14.2000	0.00000	0.00000		
		Dry period	14.20	14.20	14.2000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

APPENDIX III: SPATIAL AND SEASONAL DESCRIPTIVE STATISTICS FOR ANALYTICAL RESULTS OF MEASURED PARAMETERS IN RIVER WATER SAMPLES (JUNE 2014 TO MARCH 2015)

Table 3.1: Natural potable water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA(2006)
NR	pH	Transition Period	7.07	8.23	7.6000	0.23885	0.47770	5.5 - 9.5	6.5 - 8.5
		Short rains	7.94	8.96	8.3600	0.30790	0.53329		
		Dry period	6.44	9.21	8.0533	0.83159	1.44036		
	Ec µS/cm at 25^{o}C	Transition Period	121.25	180.50	144.3750	14.08845	28.17690	2500 µS/cm	-
		Short rains	146.25	160.75	152.5833	4.28499	7.42181		
		Dry period	188.75	280.50	246.6667	29.09479	50.39366		
	Selenium mg/l	Transition Period	0.28	2.29	1.2575	0.51219	1.02438	0.01 mg/l	0.01 mg/l
		Short rains	0.06	2.02	1.2500	0.60352	1.04532		
		Dry period	0.36	2.96	1.8533	0.77506	1.34244		
	Cadmium mg/l	Transition period	0.02	0.15	0.0825	0.02926	0.05852	0.003 mg/l	0.01 mg/l
		Short rains	0.05	0.08	0.0633	0.00882	0.01528		
		Dry period	0.20	0.31	0.2367	0.03667	0.06351		
	Fluoride mg/l	Transition period	0.51	3.79	2.4700	0.76238	1.52475	1.5 mg/1	1.5 mg/l
		Short Rains	0.66	1.30	1.0733	0.20699	0.35852		
		Dry period	1.36	1.89	1.5367	0.17667	0.30600		
	Chloride mg/l	Transition period	14.20	14.20	14.2000	0.00000	0.00000	250 mg/l	250 mg/l
		Short rains	14.20	16.80	15.0667	0.86667	1.50111		
		Dry period	12.40	14.20	13.0000	0.60000	1.03923		

Source: Author, (June 2014 to March 2015)

Table 3.2: Natural potable water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA (2006) MAX
MR1	pH	Transition Period	6.83	8.50	7.6025	0.34752	0.69505	5.5 - 9.5	6.5 - 8.5
		Short rains	7.49	8.21	7.8600	0.20809	0.36042		
		Dry period	6.52	9.50	8.2067	0.88245	1.52844		
	Ec µS/cm at 25^{o}C	Transition Period	105.50	147.00	126.1875	9.47110	18.94221	2500 µS/cm	500 -
		Short rains	137.50	160.50	152.8333	7.66667	13.27906		
		Dry period	127.75	203.50	163.2500	21.99574	38.09774		
	Selenium mg/l	Transition Period	0.01	0.87	0.3925	0.22175	0.44350	0.01 mg/l	0.01 mg/l
		Short rains	0.02	1.19	0.6867	0.34748	0.60186		
		Dry period	0.04	1.31	0.8567	0.40916	0.70868		
	Cadmium mg/l	Transition period	0.02	0.16	0.0825	0.03065	0.06131	0.003 mg/l	0.01 mg/l
		Short rains	0.02	0.04	0.0300	0.0057	0.01000		
		Dry period	0.03	0.12	0.0667	0.02728	0.04726		
	Fluoride mg/l	Transition period	0.21	1.71	0.9725	0.36250	0.72500	1.5 mg/1	1.5 mg/l
		Short Rains	0.27	0.63	0.4867	0.11020	0.19088		
		Dry period	0.90	1.27	1.0900	0.10693	0.18520		
	Chloride mg/l	Transition period	14.20	16.00	15.1000	0.51962	1.03923	250 mg/l	250 mg/l
		Short rains	10.70	16.00	13.6333	1.55599	2.69506		
		Dry period	14.20	17.80	16.0000	1.03923	1.80000		

Source: Author, (June 2014 to March 2015)

Table 3.3: Natural potable water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA (2006)
MR2	pH	Transition Period	6.74	8.13	7.5300	0.29060	0.58121	6.5 - 8.5	6.5 - 8.5
		Short rains	7.50	8.29	7.8433	0.23383	0.40501		
		Dry period	6.33	9.37	8.0867	0.90892	1.57430		
	Ec µS/cm at 25°C	Transition Period	104.25	145.00	126.7500	9.46099	18.92199	2500 µS/cm	-
		Short rains	123.00	144.75	135.1667	6.41017	11.10274		
		Dry period	140.75	184.50	156.0833	14.22317	24.63526		
	Selenium mg/l	Transition Period	0.03	2.31	0.8100	0.52149	1.04298	0.01 mg/l	0.01 mg/l
		Short rains	0.01	1.56	0.7967	0.44760	0.77526		
		Dry period	0.01	1.71	1.0100	0.51316	0.88882		
	Cadmium mg/l	Transition period	0.01	0.22	0.0850	0.04628	0.09256	0.003 mg/l	0.01 mg/l
		Short rains	0.03	0.05	0.0400	0.00577	0.01000		
		Dry period	0.03	0.12	0.0767	0.02603	0.04509		
	Fluoride mg/l	Transition period	0.25	2.02	1.1825	0.38949	0.77899	1.5 mg/1	1.5 mg/l
		Short Rains	0.61	1.16	0.9267	0.16415	0.28431		
		Dry period	1.04	1.43	1.2433	0.11289	0.19553		
	Chloride mg/l	Transition period	12.40	14.20	13.3000	0.51962	1.03923	250 mg/l	250 mg/l
		Short rains	12.40	16.00	14.2000	1.03923	1.80000		
		Dry period	14.20	16.00	14.8000	0.60000	1.03923		

Source: Author, (June 2014 to March 2015)

Table 3.4: Natural potable water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA (2006)
Mrb	pH	Transition Period	6.91	8.12	7.5000	0.24782	0.49565	5.5 - 9.5	6.5 - 8.5
		Short rains	7.67	8.59	8.2333	0.28498	0.49359		
		Dry period	7.86	9.26	8.3267	0.46667	0.80829		
	Ec µS/cm at 25^{o}C	Transition Period	127.50	157.25	139.7950	6.71019	13.42037	2500 µS/cm	-
		Short rains	122.25	144.75	130.8333	7.02130	12.16124		
		Dry period	143.25	210.25	169.5833	20.62630	35.72581		
	Selenium mg/l	Transition Period	0.22	1.95	1.0525	0.37560	0.75119	0.01 mg/l	0.01 mg/l
		Short rains	0.54	3.94	2.7167	1.09112	1.88988		
		Dry period	0.92	3.31	2.2067	0.69600	1.20550		
	Cadmium mg/l	Transition period	0.01	0.17	0.1025	0.04029	0.08057	0.003 mg/l	0.01 mg/l
		Short rains	0.06	0.10	0.0867	0.01333	0.02309		
		Dry period	0.12	0.17	0.1433	0.01453	0.02517		
	Fluoride mg/l	Transition period	0.89	4.58	2.9475	0.88341	1.76681	1.5 mg/1	1.5 mg/l
		Short Rains	0.69	0.84	0.7600	0.04359	0.07550		
		Dry period	0.40	0.63	0.5300	0.06807	0.11790		
	Chloride mg/l	Transition period	14.20	16.00	14.6500	0.45000	0.90000	250 mg/l	250 mg/l
		Short rains	12.40	14.20	13.0000	0.60000	1.03923		
		Dry period	14.20	14.20	14.2000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

Table 3.5: Natural potable water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA (2006)
Mrc	pH	Transition Period	7.00	8.18	7.6675	0.24871	0.49742	5.5 - 9.5	6.5 - 8.5
		Short rains	7.66	8.21	7.8467	0.18169	0.31470		
		Dry period	6.61	9.18	7.4667	0.85667	1.48379		
	Ec µS/cm at 25^{o}C	Transition Period	93.75	136.25	113.3750	8.74077	17.48154	1500 µS/cm	500 µS/cm
		Short rains	90.00	123.00	107.3333	9.56266	16.56301		
		Dry period	152.25	278.00	221.1667	36.80023	63.73987		
	Selenium mg/l	Transition Period	0.27	3.33	1.9850	0.68859	1.37718	0.01 mg/l	0.01 mg/l
		Short rains	0.74	1.38	1.0200	0.18903	0.32741		
		Dry period	0.98	4.37	2.8500	0.99413	1.72189		
	Cadmium mg/l	Transition period	0.02	0.14	0.0750	0.02500	0.05000	0.003 mg/l	0.01mg/l
		Short rains	0.08	0.09	0.0833	0.00333	0.00577		
		Dry period	0.08	0.11	0.0933	0.00882	0.01528		
	Fluoride mg/l	Transition period	0.85	4.08	2.4175	0.66654	1.33308	1.5 mg/1	1.5 mg/l
		Short Rains	1.17	1.63	1.3567	0.13968	0.24194		
		Dry period	1.03	1.59	1.2933	0.16251	0.24148		
	Chloride mg/l	Transition period	14.20	14.20	14.2000	0.00000	0.00000	250 mg/l	250 mg/l
		Short rains	14.20	16.00	14.8000	0.60000	1.03923		
		Dry period	16.00	16.00	16.0000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

Table 3.6: Treated potable water

Station ID	Parameter/ unit	Hydrological period	Minimum	Maximum	Mean	Std. Error of the mean	Std. Deviation	WHO GV (2011) MAX	NEMA (2006)
C3	pH	Transition Period	6.93	7.49	7.2225	0.14941	0.29882	6.5 - 8.5	6.5 - 8.5
		Short rains	6.84	8.04	7.6333	0.39671	0.68712		
		Dry period	6.94	8.95	7.6100	0.67000	1.16047		
	Ec μS/cm at 25^{o}C	Transition Period	91.25	105.00	97.2500	3.47761	6.95521	1500 μS/cm	-
		Short rains	111.00	138.25	122.2500	8.21711	14.23245		
		Dry period	144.50	175.75	156.3333	9.78555	16.94907		
	Selenium mg/l	Transition Period	0.01	0.03	0.0200	0.00577	0.01155	0.01 mg/l	0.01 mg/l
		Short rains	0.01	1.19	0.6967	0.35409	0.61330		
		Dry period	0.08	0.48	0.2433	0.12115	0.20984		
	Cadmium mg/l	Transition period	0.00	0.06	0.0375	0.01436	0.02872	0.003 mg/l	0.01 mg/l
		Short rains	0.02	0.06	0.0367	0.01202	0.02082		
		Dry period	0.08	0.13	0.0967	0.01667	0.02887		
	Fluoride mg/l	Transition period	0.13	2.35	1.1625	0.47664	0.95329	1.5 mg/1	1.5 mg/l
		Short Rains	0.44	0.81	0.5767	0.11724	0.20306		
		Dry period	0.38	0.63	0.5433	0.08172	0.14154		
	Chloride mg/l	Transition period	14.20	14.20	14.2000	0.00000	0.00000	250 mg/l	250 mg/l
		Short rains	14.20	14.20	14.2000	0.00000	0.00000		
		Dry period	14.20	14.20	14.2000	0.00000	0.00000		

Source: Author, (June 2014 to March 2015)

APPENDIX IV

Table 4.1: Mean monthly rainfall data of the study area (JUNE 2014 TO MARCH 2015) and hydrological periods of the study area

Month	Rainfall (mm)	Sampling hydrological period
June	79	Transitional period
July	63.8	
August	92	
September	57.6	
October	98.2	Short rain period
November	82.2	
December	67.8	
January	0	Dry period
February	3.8	
March	15.6	

Source: Nakuru Meteorological Station; Rainfall Station Number 9036261; WMO No.63714.

Table 4.2: Mean monthly rainfall data

Month	Mean monthly precipitation for 38 years (mm) (1980 to 2018)	Mean monthly precipitation (mm) (June 2014 to March 2015	Sampling hydrological period
June	82.1	79	Transitional period
July	89.0	63.8	
August	104.6	92	
September	80.4	57.6	
October	83.1	98.2	Short rain period
November	83.8	82.2	
December	50.4	67.8	
January	27.7	0	Dry period
February	29.4	3.8	
March	63.7	15.6	

Source: Nakuru Meteorological Station; Rainfall Station Number 9036261; WMO No.63714.

Table 4.3: Correlation analysis (Rainfall variability and water quality trend analysis of groundwater sources)

Sampling site of boreholes	Ph	Cadmium (mg/l)	Fluoride (mg/l)	Electrical conductivity (µS/cm)	Chloride (mg/l)	Selenium (mg/l)
Olbanita boreholes	0.04634	-0.24458	-0.60773	0.14514	0.21701	0.26787
Kabatini boreholes	_ 0.25955	-0.22503	0.05108	-0.33936	-0.13933	0.06731
Leitmann borehole	0.25941	-0.73435	0.30153	-0.05791	-0.11360	0.30882
Baharini boreholes	-0.27023	-0.50043	-0.37046	-0.22326	0.11388	0.228862
Nakuwell borehole	-0.65543	-0.31385	-0.87725	-0.03701	0.55841	-0.32985
Nairobi road boreholes	-0.54992	-0.50241	-0.80087	-0.28866	-0.01820	-0.04904

Source: Author, based on data analysis (June 2014 to March 2015) in SPSS 22.0.

Table 4.4: Correlation analysis (Rainfall variability and water quality trend analysis of river water samples)

River sampling points	Ph	Cadmium (mg/l)	Electrical conductivity (µS/cm)	Fluoride (mg/l)	Chloride (mg/l)	Selenium (mg/l)
NR	0.09778	-0.84897	-0.80805	0.10534	0.69642	-0.15466
MR1	-0.0731	-0.08317	-0.50085	-0.35187	-0.54981	-0.14047
MR2	-0.06250	-0.09116	-0.71156	-0.22576	-0.25086	0.02277
Mrb	-0.22504	-0.49314	-0.74570	0.37745	0.09654	0.00364
Mrc	0.30364	-0.20906	-0.81923	0.37587	-0.80651	-0.46994

Source: Author, based on data analysis (June 2014 to March 2015) in SPSS 22.0.

APPENDIX V

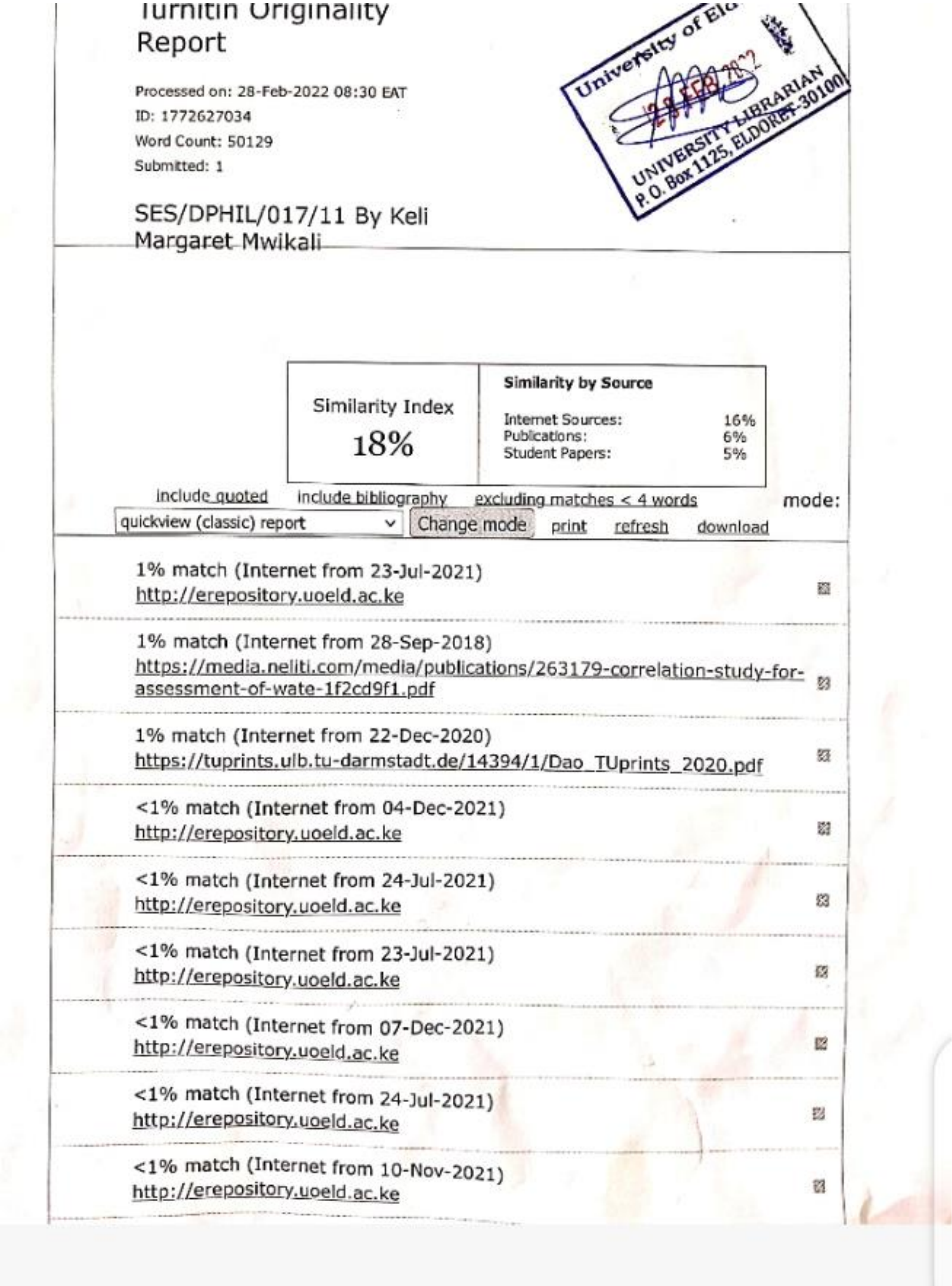
Table 5.1: Calculated WQI values in groundwater samples

Sampling point	F1	F2	F3	WQI Value	Rank	Water quality is almost always threatened or impaired, conditions usually depart from natural or desirable levels
BB2	50	50	98.73	36.1	Poor	
BB3	50	50	97.89	30.28	Poor	
BB4	50	50	98.19	30.14	Poor	
BB5	50	50	98.04	30.21	Poor	
BB6	50	50	97.98	36.49	Poor	
BB7	50	50	98.83	29.84	Poor	
K1	50	50	98.12	20.94	Poor	
K2	50	50	96.47	30.94	Poor	
K3	50	50	98.81	29.85	Poor	
K4	50	50	95.62	37.71	Poor	
K5	50	50	97.01	36.99	Poor	
K6	50	50	96.12	31.11	Poor	
K7	50	50	98.10	30.18	Poor	
L	50	50	98.26	30.1	Poor	
F1	50	50	97.85	30.92	Poor	
F2	50	50	96.82	30.78	Poor	
F3	50	50	98.31	30.04	Poor	
F4	50	50	97.72	30.36	Poor	
F5	50	50	97.25	30.58	Poor	
G2	50	50	97.39	30.51	Poor	
G5	50	50	98.85	29.83	Poor	
G6	50	50	98.34	30.07	Poor	
G7	50	50	98.01	30.20		

Table 5.2: Calculated WQI values in river water samples

Sampling point	F1	F2	F3	WQI Value	Rank	Water quality is almost always threatened or impaired, conditions usually depart from natural or desirable levels
MR1	33.33	33.33	93.22	39.69	Poor	
MR2	33.33	33.33	94.73	38.91	Poor	
Mrb	50	50	98.78	30.8	Poor	
Mrc	50	50	97.36	30.53	Poor	
Nk	50	50	98.87	30.75	Poor	

APPENDIX VI: SIMILARITY REPORT



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