EFFECTS OF LAND USE ON SPRING AND STREAMFLOW WATER QUALITY IN RIVER MALAGET SUB-CATCHMENT, KERICHO COUNTY, KENYA

MERCY KIRUI (B.A. GEOGRAPHY - M.U.)
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DECLARATION

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

Signature………………………… **Date………………………………**

Mercy Kirui

I56/27340/2014

SUPERVISORS' APPROVAL

This thesis has been submitted for examination with our approval as University supervisors.

Signature…………………………….

Date …………………………………………..

Prof. Joy Obando

Department of Geography

Kenyatta University

Signature ……………………………

Date ……………………………………...

Dr. Kennedy Obiero

Department of Geography

Kenyatta University

DEDICATION

This work is dedicated to my beloved husband Moses Chirchir and my two children, Trina Chebet and Reagan Kimutai. They are the key people who kept me motivated to go on even in the toughest times.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

ABBREVIATIONS AND ACRONYMS

APHA	American Public Health Association
BOD	Biological Oxygen Demand
Cfu/mL	Colony Forming Unit per millilitre
GIS	Geographic Information Systems
HSA	Hydrologically Sensitive Area
KNBS	Kenya National Bureau of Statistics
MCM	Million Cubic Metres
NEMA	National Environment Management Authority
NTU	Nephelometric Turbidity Unit
SID	Society for International Development
SPADNS	Sodium2-(parasulphophenylazo-)-1,8-dihydroxy-3,6-naphthalene disulphonate
UNESCO	United Nations' Educational, Scientific and Cultural Organization
UNICEF	United Nations International Children's Fund
μS/cm	Micro Siemens per centimetre
WHO	World Health Organization
WMO	World Meteorological Organization
WQI	Water Quality Index

OPERATIONAL DEFINITION OF TERMS

Agro-ecological zones: a collective term in this study used to capture all the land use categories, depending on the climatic conditions of the various zones.

Farm waste: crop residue after harvesting, farm chemical residue, animal faecal matter and eroded soil.

Human waste: household waste, human faecal matter and waste water from settlement.

Hydrologically Sensitive Areas: areas in a watershed which are more likely to generate runoff that can transport contaminants to surface water bodies.

Land use: Human activity such as settlement, agriculture (e.g. crop and animal farming) and forestry.

Spring pools: the area where spring water flowing out of the ground is collected and this may be a naturally existing shallow depression or one dug out by the users to widen the spring eye or mouth so as to facilitate fetching of water.

Unimproved water sources: untreated water sources, such as springs and streamflow.

Water sampling: collecting a portion of water from springs and streamflow for physical, microbial and or chemical analysis.

ABSTRACT

Various studies have shown that land use impacts on water quality are attributable to about 80 % of diseases in the developing world. The main objective of the study was to evaluate the effects of land use on water quality in River Malaget sub-catchment. The specific objectives were to: i) establish spring and streamflow water quality; ii) determine the water quality index of the selected sampling points and iii) evaluate the relationship between spring and streamflow water quality in River Malaget sub-catchment. Stratified and purposive sampling techniques were used to select 33 sampling points, i.e., 10 springs and 1 river point from each of the 3 agro-ecological zones. Maps of spatial distribution of the water quality parameters tested were developed. Additionally, MANOVA was used to compare the means from the three agro-ecological zones. Water samples from each sampling point were tested for 15 parameters. WQI for each sampling point and for the entire study area was determined. Parametric results revealed that all samples tested for temperature, electrical conductivity, DO, nitrites and total hardness were within the recommended levels. However, some of the samples tested for nitrates, ammonia, pH, turbidity, total dissolved and suspended solids, BOD, *E.coli*, fluorides, and phosphates were found to exceed the recommended levels. Pillai's trace in MANOVA, revealed a significant variability in the distribution of the water quality parameters in relation to land use as the means of the three agro-ecological zones were significantly different, $V = 1.535$, $F(20, 44) = 7.262$, $p < .05$. Univariate ANOVAs on each of the variables revealed significant effect on temperature, $F(2, 30) = 4.833$, $p > .05$; electrical conductivity, $F(2, 30) = 14.730$, $p > .05$; turbidity, $F(2, 30) = 3.600$, $p > .05$; and nitrates, $F(2, 30) = 5.879$, $p > .05$. WQI values ranged from 12.22 to 237.86, i.e., from excellent to very poor water quality. Most of the samples had WQI values which were less than the threshold value of 100. More than half (57.58 %) of the samples were of excellent water quality, while 24.24 % were of good water quality, 9.09 % were of poor water quality and the remaining 9.09 % of the samples were of very poor water quality. The high levels of turbidity in the sub-catchment in all the samples, which exceeded the NEMA and WHO guideline values is largely responsible for the very high WQI values. Student's independent T-test analysis showed a significant difference ($p < 0.05$) between streamflow and springs for TSS, total hardness and nitrates. In conclusion, indeed, land use has had an impact on streamflow and spring water quality in the study area, considering the spatial distribution of temperature, nitrates, electrical conductivity and turbidity. It is recommended that farming activities and waste disposal is done far from water sources, at least about 30 m away. Additionally, water should be boiled before drinking and all springs should be protected against contamination.

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Unsafe drinking water and unimproved sanitation is linked to nearly 80% of all recorded instances of diseases in developing economies (UNESCO, 2006), that is 4.6 billion diarrhoea episodes annually (WHO, 2010). Therefore, clean water will lower the risk of illnesses related to consumption of contaminated water and hence increasing life expectancy. According to UNICEF (2008), more than 1.1 billion people use unimproved water sources and almost 2 million deaths are by diarrhoea, out of 3 million people dying yearly from water-related infections. Majority of those affected are children due to the ingestion of water contaminated by faecal matter due to inadequate sanitation and hygiene.

One of the sources of water pollution is intensive agriculture where inorganic fertilizers and manures are used in order to improve crop yields. Poorly managed application of farm chemicals and improper human waste disposal, may lead to their being washed away by run-off during rains and deposited in springs, causing serious public health and environmental problems. Conceptualization of water movement through a catchment is crucial in understanding how land use impacts on water quality (McCarthy and Johnson, 2009). In as far as water quality is concerned; land use is the source of contaminants while the hydrology is the transporter, as materials are cycled among different ecosystems (Gordon *et al*., 2007).

Water scarcity and pollution are major challenges to sustainable water resources management in Africa. Apparently, water pollution due to land use in various sources has been increasing over recent decades in most countries (Mkoma and Mihayo, 2012 and Eneji *et al*., 2015). Mkoma and Mihayo (2012) recorded that only 54% of the

Tanzanian population has access to improved water supplies with 24% having adequate sanitation. Eneji *et al*., (2015) in the 2 year-study at River Benue, found that the highest levels of nutrients recorded such as phosphates, was due to run off and waste water discharge at that point of the stream. The study recorded higher concentrations of such pollutants during the dry season compared to the wet season. That was attributed to the decrease in stream discharge which consequently meant an increase in their concentration.

According to the Kenya Water Report (2005), 80% of Kenya is arid and semi - arid land and the rest experiences water scarcity due to catchment degradation resulting from land use. Water pollution is a result of catchment degradation which is related to runoff of farm chemicals and human wastes. Ontumbi *et al.*,(2015), in a study on the Influence of Agricultural Activities on the Water Quality of River Sosiani, found that there were differences in concentration of pollutants between the dry and wet seasons. These were attributed to agricultural wastes polluting the river due to leaching and surface runoff processes. Ashun (2014), in a study of groundwater in the Thiririka Sub-catchment, found that pollution to water sources under investigation was attributed to domestic and animal wastes nearest to them. Land use may impact negatively on the water quality in the surroundings and reduce its availability. Hence, it is clear that land use such as agriculture and settlement may negatively impact on water quality.

In River Malaget sub-catchment, which is within Kericho County, farm chemicals such as manure and synthetic fertilizers are used to improve farm yields due to diminishing fertility owing to continuous farming (Jaetzold *et al*., 2010). In addition, 93.7 % of households use pit latrines due to lack of water and sewerage services

(KNBS, 2010). Substances from agricultural farms and settlement are flushed by run-off into local water sources. Evaluating the effects of such land use on water quality is important, so as to check public health and environmental issues that may arise.

1.2 Problem Statement and Justification

River Malaget sub-catchment is located in Kamasian and Chilchila wards within the River Nyando catchment of the Lake Victoria Basin. Chilchila Ward has 82.9 % of households with unimproved water sources, being one of the highest numbers in Kericho County (KNBS, 2010). The disparity in access to improved sanitation amongst administrative wards in the County is over 80 % (Ngugi *et al.*, 2013). Majority of the locals are farmers and rely on spring and streamflow water sources for drinking (KNBS, 2010). Moreover, due to diminishing soil fertility owing to continuous farming, farmers use inorganic fertilizers and manure (Jaetzold *et al.*, 2010). Much of the cultivated land is on steep slopes which are largely hydrologically sensitive areas (HSA) and are at risk, as farm chemicals and settlement wastes may find their way into water sources during rainstorms, and introduce nutrients such as nitrates and phosphates into them. If application of farm chemicals is poorly managed and farm and household waste disposal is not properly done, it may lead to detrimental effects to humans.

1.3 Hypotheses

i. There is no significant variability in the distribution of water quality parameters in relation to land use.

ii. There is no significant relationship between spring water quality and streamflow water quality.

1.4 Objectives of the study

1.4.1 Main objective

The main objective of the study is to evaluate the effects of land use on water quality in River Malaget sub-catchment, Kericho County.

1.4.2 Specific objectives

i. To establish spring and streamflow water quality in River Malaget sub-catchment.
ii. To determine the spatial distribution of water quality parameters in relation to land use in River Malaget sub-catchment.
iii. To determine the water quality index of the selected water sampling points of River Malaget sub-catchment.
iv. To evaluate the relationship between spring and streamflow water quality in River Malaget sub-catchment.

1.5 Significance of Study

River Malaget Sub-catchment is not served with water and sanitation services and hence, the locals majorly rely on spring water sources. Mapping of the selected sampling points using GIS and developing a water quality index map produced easily understood results for the public and water sector stakeholders. Findings of this study provided baseline information on water quality which will assist Water Resource Management Authority officials and local authorities countrywide to manage water resources better. Information on possible impact of land use on the quality of the local water sources will be useful in the sensitization of the local farmers to improve their lives economically and health-wise. Knowledge that farm chemicals and wastes may end up in their water sources, will assist them to manage waste disposal properly and to do proper timing of chemical application and also avoiding the areas that are prone to run-off.

This study will add to existing knowledge on springs which are essentially ground water sources exposed to the surface and may be threatened by external factors like agriculture and settlement. Comparing the water quality of springs and streamflow will reveal the interaction between surface water and ground water. In addition to physico-chemical parameters that most studies (Ketata *et al*., 2011; Nikolaidis *et al*., 2007; McCarthy and Johnson, 2009; Achieng' *et al*., 2017 and Ontumbi *et al*., 2015) have dwelt on, it seeks to test for biological water quality indicators which are important in determining the sanitation level. Further, it will demonstrate the relationship between hydrology and transport of contaminants (Gordon *et al*., 2007).

1.6 Scope and Limitation of Study

This study focused strictly on the human land use impact on quality of water for only drinking purposes and it was limited to River Malaget sub-catchment. The foreseen challenge was in the variation of seasons, for instance, due to the El Nino phenomena whereby, there may be no clearly marked dry and wet season. This was anticipated to have a bearing on the results and thus in this study, seasonal variation in the concentrations of pollutants was compared using data collected in both the dry and wet seasons.

CHAPTER TWO: LITERATURE REVIEW

2.1 Land Use Impacts

According to Variable Source Area (VSA) theory, there are areas in a watershed that are more likely to generate runoff and are therefore referred to as hydrologically sensitive areas (HSAs), due to their ability to transport contaminants to surface water bodies (Frankenberger *et al*., 1999). Run off from these areas is termed as saturation-excess run off and it is a function of geology, topography, soil type, soil cover and the amount and form of precipitation. Substances such as human and animal waste, crop residues and farm chemicals from such areas can be flushed easily into a water system with only a small amount of precipitation (Lyon *et al*., 2006). Hence, the land use type and intensity would influence the location of these source areas. Thus, as illustrated by the VSA concept, if application of farm chemicals is poorly managed and waste disposal is not properly done, it may lead to detrimental effects to humans.

Land use such as agriculture and settlement are well known as major sources of nutrients and other potential pollutants to water bodies worldwide (McCarthy *et al*., 2009; Ontumbi, 2015). Ontumbi *et al*. (2015) found that agricultural activities have interfered on river water quality. Run-off and leaching from sanitation facilities in settlements have been shown to affect and lower the quality of water meant for human usage (UNICEF, 2008). Ngonzo *et al*. (2013) found that land use in the surrounding had a direct impact on the siltation of dams. Silt or sediments may introduce nutrients and faecal coliform into water.

Eneji (2015) found that the hydro-chemistry of a stream is affected by precipitation, temperature, rock weathering and human activity which impact its quality and quantity. Furthermore, he found that precipitation patterns changed between months and seasons, within the 2 years during which the study was done, which led to seasonal variation in water quality. Hence, it may be summed up that many factors may be attributed to the water quality status of any water body or source. These contributing factors are land use and socio-economic activities; precipitation and other climatic factors; soil types; topography and altitude; spring characteristics and level of protection, as well as, government policy.

2.2 Water quality indicators

In past studies, various water quality indicators were selected and determined based on the nature of study resulting in various findings. Amfo - Otu *et al*. (2011), found that all metal ions were within the WHO recommended levels, except for acidity and total hardness which was above the limits set. Suratman *et al*. (2015) found that all the 6 parameters tested, for example, dissolved oxygen and biological oxygen demand was within the set levels by Malaysia National Water Quality Standards.

There are over 100 water quality parameters in existence but only 15 were relevant in this study, and therefore were measured to reveal the impact of land use. The selected parameters are based on consideration of the potential sources of contamination amongst the land use (Ashun, 2014). These physico- chemical and biological parameters are: temperature, pH, electrical conductivity (EC), fluorides, dissolved oxygen (DO), nitrates, total dissolved solids (TDS), turbidity, total hardness (TH), Biological oxygen demand (BOD), faecal coliform and phosphates.

2.2.1 Temperature

According to WHO (2004) and NEMA (2006) water quality standards for domestic water, the recommended temperature guideline value ranges from 20^{O} to 35^{O} C for drinking water. Normally, the concentration of dissolved oxygen is affected by temperature as oxygen is more easily dissolved in cold water, while heating or boiling water expels oxygen from it. Many factors may influence spring and stream temperature causing seasonal, daily and even hourly fluctuation. Vegetation growing around springs and along streams shades and controls the impacts of temperature fluctuations.

2.2.2 Dissolved Oxygen

Generally, streams with dissolved oxygen concentrations above 8 mg/l are termed as healthy as they have cool, clear water. Those with low DO from 2 – 0.5 mg/l are described as hypoxic, while those with less than 0.5 mg/l are considered anoxic. NEMA (2006) set a guideline limit of not less than 4 mg/l, however, WHO has not set any limit for the same. Additionally, very high DO concentrations may aggravate the oxidization or rusting of metal pipes.

2.2.3 pH

Usually, pH is measured in a scale from 1 to 14 with no unit of measurement. As one goes lower on the pH scale towards 1, the acidity increases and as you go higher towards 14 on the scale the basicity increases, while scale 7 represents neutrality. In most cases, streamflow has pH levels between 6 and 9 depending on various factors. Fluxes in pH can affect the water chemistry, for instance, as pH rises, the toxicity potential of ammonia increases.

In as far as water for drinking purposes is concerned, the range of acceptable pH is 6.5 - 9.2 for WHO (2004) and USEPA (2012); while for NEMA (2006) is 6.5 - 8.5. Hence, water suitable for drinking purposes should have a pH measurement that is close to neutrality (7). Extreme values of pH can result from unintended leakage, careless dumping of waste water, and so on.

2.2.4 Turbidity

Turbidity is an indicator of the transparency of water and it is an important measure which influences consumer acceptance of water. It refers to the amount of tiny colloidal particles in water and these may provide site for pathogenic organisms' attachment and chemical adsorption. It is made up of materials in suspension which may be a mixture of organic and inorganic substances. Turbidity may lead to increase in water temperature as particles absorb sunlight and may thereby lead to a drop in dissolved oxygen (Kumar *et al*., 2010).

Highly turbid water implies reduced protection due to presence of micro-organisms and may also be oxygen- deficient (WHO, 2004). The guideline value set for turbidity by WHO (2004) and NEMA (2006) is 5 NTU.

2.2.5 Electrical Conductivity

Electrical Conductivity is a measure of the capacity of water to allow the passage of an electric current and is a good indicator of how far and deep water has flowed. It is a measure of the amount of dissolved mineral ions from aquifer geology such as phosphate, nitrate, sodium, magnesium, and so on. Sewage, road and farm runoff can raise conductivity by contributing ions such as salts, nitrates, phosphates and so on

Electrical conductivity is affected by temperature, types and concentration of ions, as well as the total hardness. Organic substances such as oil and alcohol are poor conductors of electricity, and thus register a low electrical conductivity in water. A high concentration of dissolved solids compromises the quality of water by decreasing dissolved oxygen levels. WHO (2004) recommends 2000 µS/cm as the maximum limit for electrical conductivity in drinking water.

2.2.6 Total Solids (Total Dissolved Solids and Total Suspended Solids)

Total Solids is a measure of the dissolved and suspended solids in a water body and is thus related to both conductivity and turbidity. Total Dissolved Solids (TDS) reveals the amount of dissolved ions, with high levels indicating a high concentration of dissolved ions (Kumar *et al*., 2010). It is also a good indicator of how far and deep water has flowed. Total solids is measured by placing a sample of water in a drying oven to evaporate the water, the solids left is known as total dissolved and suspended solids,. To measure dissolved solids, the sample is filtered before it is dried and weighed. The weight of the dissolved solids is subtracted from the total solids to obtain total suspended solids (TSS).

According to WHO (2004) and NEMA (2006) the maximum limit acceptable for TDS in drinking water is 1000 mg/l and 1200 mg/l respectively, while the desirable or ideal limit is 500 mg/l. Water with TDS levels above 500 mg/l may cause gastrointestinal irritation and scaling in household appliances that are meant for water use such as water pipes, water heaters and boilers.

2.2.7 Fluoride

Fluorine exists in plenty on the earth's surface in the form of fluoride compound especially in the rift valley regions due to faulting and volcanic activity (Nair *et al.,* 1984). Fluorine occurs in natural water at levels dependent on the geology of an area. High concentration levels of fluoride ion in groundwater, is attributed to fluoride minerals in the bedrock (Nair *et al*., 1984).

Fluoride has been selected in this study to reveal the effect of geology on spring water quality. Low concentrations of fluoride up to 0.2 mg/l in drinking water, protects water users from dental caries. However, fluoride can lead to mild dental fluorosis at concentrations between 0.9 and 1.2 mg/l, with higher concentrations < 4 mg/l being linked with cancer and skeletal fluorosis. The WHO (2004) and NEMA (2006) guideline value set is 1.5 mg/L which is the concentration below which no adverse effect is suffered from drinking water.

2.2.8 Total Hardness

Water hardness is a natural occurrence indicating the presence of a lot of calcium, magnesium, carbonate, hydrogen-carbonate and sulphate ions in water (Abubakar and Adekola, 2012). This is normally exhibited by soap wastage with precipitation of scum and an increased boiling point of water (Murhekar, 2011). Although hardness is caused by cations, it is often discussed in terms of bicarbonate (temporary) and non-carbonate (permanent) hardness.

Temporary hardness refers to the amount of carbonates and bicarbonates that can be removed or precipitated from solution by boiling. This type of hardness which is over 200 mg/l causes scaling in water and household appliances like water pipes and heaters. Non-carbonate or permanent hardness cannot be removed by boiling and is caused by the reaction of the hardness-causing cations with sulphate, chloride and nitrate anions. High level of total hardness may lead to various health problems such diarrhoea, gas trouble, kidney stone, among others, hence is unsuitable for domestic use. The drinking water guideline value set for hardness by WHO (2004) is 500 mg/l.

2.2.9 Nitrates

Nitrate is a macro-nutrient required by plants and is the end product of oxidation of nitrogen in the environment. It can lead to pollution of water if the excess finds its way into due to either anthropogenic activities like sewage and animal waste discharge; septic tank leakage; compost manure seepages; nitrogen fertilizer overflow from irrigation systems and industrial waste discharge. Nitrates may indicate micro-organism contamination in groundwater if the source of nitrate is animal waste or leakage from septic tanks.

NEMA (2006) and WHO (2004) recommended level in drinking water is 10 mg/l and 50 mg/l. Nitrate levels above 10 mg/L have been associated with an illness in infants under six months of age, known as methemoglobinemia or "blue-baby" syndrome. This blood disorder can be fatal as it is characterised by a drop in the oxygen-transportation capacity of blood. It may also lead to formation of nitrosamines which are cancerous if they get to the stomach or liver. In addition, there are other health problems associated with high levels of nitrates in drinking water such as respiratory infections, thyroid disorders, and certain cancers.

2.2.10 Ammonia

Ammonia is the most unstable of all nitrogen compounds and thus difficult to measure accurately. It is a good indicator of contamination from organic sources as it can be correlated with organic matter content.

High levels of ammonia especially in ionic form can be very toxic. The degree of ionization depends on the temperature, the pH, and the concentration of dissolved salts in the water. The presence of ammonia at excessive amounts beyond natural levels is key indicator of pollution from human and animal waste. Levels above 0.2 mg/l would pose challenges to disinfection by chlorination and lead to taste and odour problems, as up to 68% of the chlorine may react with the ammonia and become unavailable for disinfection. Other sources of ammonia may include the inner linings of water pipes made of cement mortar which may release significant amounts of ammonia into drinking-water and compromise chlorine disinfection (WHO, 2011).

Additionally, for other water treatment and purification processes, the presence of elevated ammonia levels in raw water may affect the working of manganese-removal filters as too much oxygen is consumed by nitrification, with the result of mouldy, earthy-tasting water. This is because the ammonium cation in raw water may be oxidized into nitrite by bacteria or catalytic action (WHO, 2011).

2.2.11 Phosphates

Phosphates test has been selected to show the effect of land use on water quality (Li *et al*., 2013; Suratman *et al.*, 2015) as it is a good indicator of pollutants from land use such as agriculture and settlement. Such pollutants include from human and animal wastes, soil erosion and farm runoff, detergents, septic systems, and sewage discharges. Phosphate is widely used as an agricultural fertilizer and as a major component of domestic detergents. The WHO (2004) and NEMA (2006) have set the guideline for phosphates at 30 mg/l.

Orthophosphate is the most stable form of phosphate, and the form used by plants, hence it is sometimes referred to as "soluble reactive phosphorus (SRP). It is produced by natural processes and as such it is found in sewage. Presence of phosphates in water is not harmful unless they are in very high levels, thus leading to digestive problems.

Phosphates cause eutrophication when algae and aquatic plants are produced in large quantities due to addition of excessive amounts of phosphorus and nitrogen. When they die, bacteria decompose them and use up oxygen.

2.2.12 BOD

Biological Oxygen Demand (BOD) is a measure of the quantity of oxygen consumed by bacteria in the decomposition of organic material. BOD is determined by incubating a sample for a number of days and comparing the dissolved oxygen level before incubation and after. This difference in the oxygen readings between the two periods is BOD and is recorded in units of mg/l. Natural unpolluted water should have less than BOD level of 5 mg/l. Highly polluted water such as that of the sewer has BOD levels ranging from 150 – 300 mg/l.

2.2.13 Faecal coliform

Faecal coliform such as *E.coli,* is a good indicator for faecal pollution compared to total coliform which only reveals excessive nutrients in water. It is valuable for detecting pollution of ground water and surface water by surface runoff (WHO, 2010). Wastes from animals and humans carried to streams are sources of disease-causing bacteria and other pathogens. Faecal coliform bacteria, which are also called thermo-tolerant coliforms are Gram negative bacteria (APHA, 1998) and can positively indicate contamination by faeces of humans or other warm-blooded animals. Faecal coliform bacteria are, therefore, considered to be a more specific indicator of the presence of faeces.

WHO (2004), NEMA (2006) and USEPA (2012) guideline for *E.coli* is NIL per 100 ml meaning that for every 100 ml of drinking water tested, no *E.coli* should be detected. In May 2000, an *E.coli* waterborne outbreak of illness occurred in the Walkerton-Ontario, Canada and led to 7 fatalities and more than 2300 casualties. This was caused by rainwater runoff containing cattle excreta finding its way into the drinking-water supply, thereby contaminating it. It is thus necessary, to prevent *E.coli* pollution by protecting water supplies from human and animal waste and by adequate treatment of water during distribution (WHO, 2011).

2.3 GIS Mapping of Water Sampling Points

GIS is a tool that has been used widely to assess water quality and manage water resources. The use of GIS has greatly eased the inventory of natural resources and understanding environmental issues, including water quality all over the world (Ketata-Mouna *et al*., 2011).

In past water quality research studies, GIS has been used in various ways for various purposes. Ashun (2014) used GIS to assess and map groundwater quality in Thiririka Sub-catchment of Kiambu County, Kenya. Jeihouni *et al*., (2014) used GIS modelling to assess groundwater quality for drinking purposes in Tabriz City. Ketata-Mouna *et al*., (2011) used GIS to assess groundwater quality in El Khairat Deep Aquifer (Enfidha, Tunisia Sahel).

2.4 Water Quality Index (WQI)

WQI is a rating that reveals the collective influence of selected water quality parameters, on the total water quality by assigning weight to the sampling points based on the concentrations of the physico-chemical and biological constituents of the water. WQI is an important parameter, key in decision making and planning for water quality monitoring and management. The aim of a WQI is to change complex water quality data into information, in form of a single index number, which is understandable and useable by the public (Ketata-Mouna *et al*., 2011; Suratman *et al*., 2015). For instance, managers and decision makers may use it to ascertain the quality and possible uses of a sample of water from any source.

WQI provides a summary of information from several water quality parameters in the form of a single numeric value. This value can be used to compare data from multiple sites and even study trends over time on a single site. This is a measure of how the water quality parameters compare to the water quality guidelines for a specific site and assess the appropriateness of the quality of the water for a particular use such as habitat for aquatic life, irrigation, recreation, drinking water. This study focused on water quality for drinking purposes only hence the water quality standards used are based on those set for drinking.

2.5 Geology and Other Spring Characteristics

A spring is natural ground water flow from a rock or the soil onto the land surface or into a surface water body or continually replenished pools such as seeps and marshes (Galloway, 2004). Various categories of springs exist based on the hydrogeology of an area, such as limestone springs or lava-rock springs; or based on the quantity of discharge - large or small; or based on the water temperature - hot, warm, or cold; or depending on the forces propelling the spring flow - gravity or artesian flow (Kuniansky, 2011). In humid regions, it may be difficult to distinguish between these differences unless certain special features about them are seen. For example, presence of minerals in them; hence mineral springs, high temperature springs such as geysers and hot springs, and so on.

Most springs have been structurally modified so as to increase their usefulness to man. For this study, the definition will include the point at which water oozes out of the ground and the area where it is collected and this may be a naturally existing depression or one dug out by the users. Springs may be classified according to natural factors such as the amount of spring discharge; type of aquifer supplying the spring and the water temperature of the springs (Champion and Starks, 2011). The different types of springs are depression, contact, fault / fracture, karst and lava springs. Spring water quality is affected by both geology and land use because of the recharge and discharge processes, run off incidences, as well as the nature of rocks. These effects are dependent on the amount of precipitation, the nature of terraine, the ground water residence time and whether or not the springs are protected (Champion and Starks, 2011).

Topography drives the water flow downhill while geology influences the occurrence of the spring, by governing the discharge and recharge processes. Climate dictates the amount and timing of recharge to the groundwater system and the volume and variability of discharge. Spring water quality depends on the quality of water recharging the aquifer, the type of rocks that the ground water is in contact with and the groundwater residence time. Recharge points are on relatively flat areas and gently sloping land while discharge sites are on steeper hill slopes and breaks of slopes. In turn, this will have a bearing on the quality of their water. Therefore, the general notion that spring water is always pure is not necessarily true.

Human induced factors may also be considered in categorizing springs, for instance, springs may be protected or unprotected. According to Miguel *et al*., (2008), spring protection improved child health as diarrhoea among young children in households under study fell by 4.6 %, on a base diarrhoea prevalence of approximately 20 %. Therefore, it was necessary to categorize springs based on whether they are protected or unprotected, as this may have an influence on their exposure to potential sources of contaminants.

2.6 Conceptual and Theoretic Framework

Figure 2.1 illustrates the conceptual framework of the study which was adapted and modified from Kristensen (2004). The Drivers are factors such as rugged nature of terraine, absence of vegetation cover and high amount of precipitation which are the reinforcers behind the problem (Gordon *et al*, 2007). In addition, the type and intensity of land use plays a critical role in driving the problem. For instance, poor cultivation and soil management practices by farmers are related to the high run-off incidents and their effects are seen in soil erosion and spring sedimentation (Ngonzo *et al*, 2013; Ontumbi, 2015).

The effect brought by Pressures such as farm chemical pollutants and farm animal wastes are either caused by or exacerbated by the drivers. For instance, the type and intensity of land use will influence the nature of pollutant and its severity on the quality status of spring water. The quality status of spring water is determined by field measurement and laboratory analysis of samples for various selected parameters (Ashun, 2014). This would explain the impacts such as waterborne diseases, poor water quality and sedimentation of springs, as well as, streams turning turbid. As a result, various responses would be necessary, for example spring protection, reafforestation, education of farmers on proper handling of farm chemicals, improved cultivation methods and proper soil management practices (Ontumbi, 2015).

Spring protection may take various forms such as fencing off the area around the water source or encasing the vent using concrete, to avoid water flow from the ground and instead flow out through a pipe. This prevents contamination by users as they dip containers to draw water and also runoff entering and introducing pollutants (Miguel *et al*, 2008). In addition, fencing prevents animals from walking in to the sources and polluting them. Improved cultivation and soil management practices will prevent land

and soil degradation, especially in areas above the springs and river that could generate runoff laden with contaminants (Ontumbi, 2015).

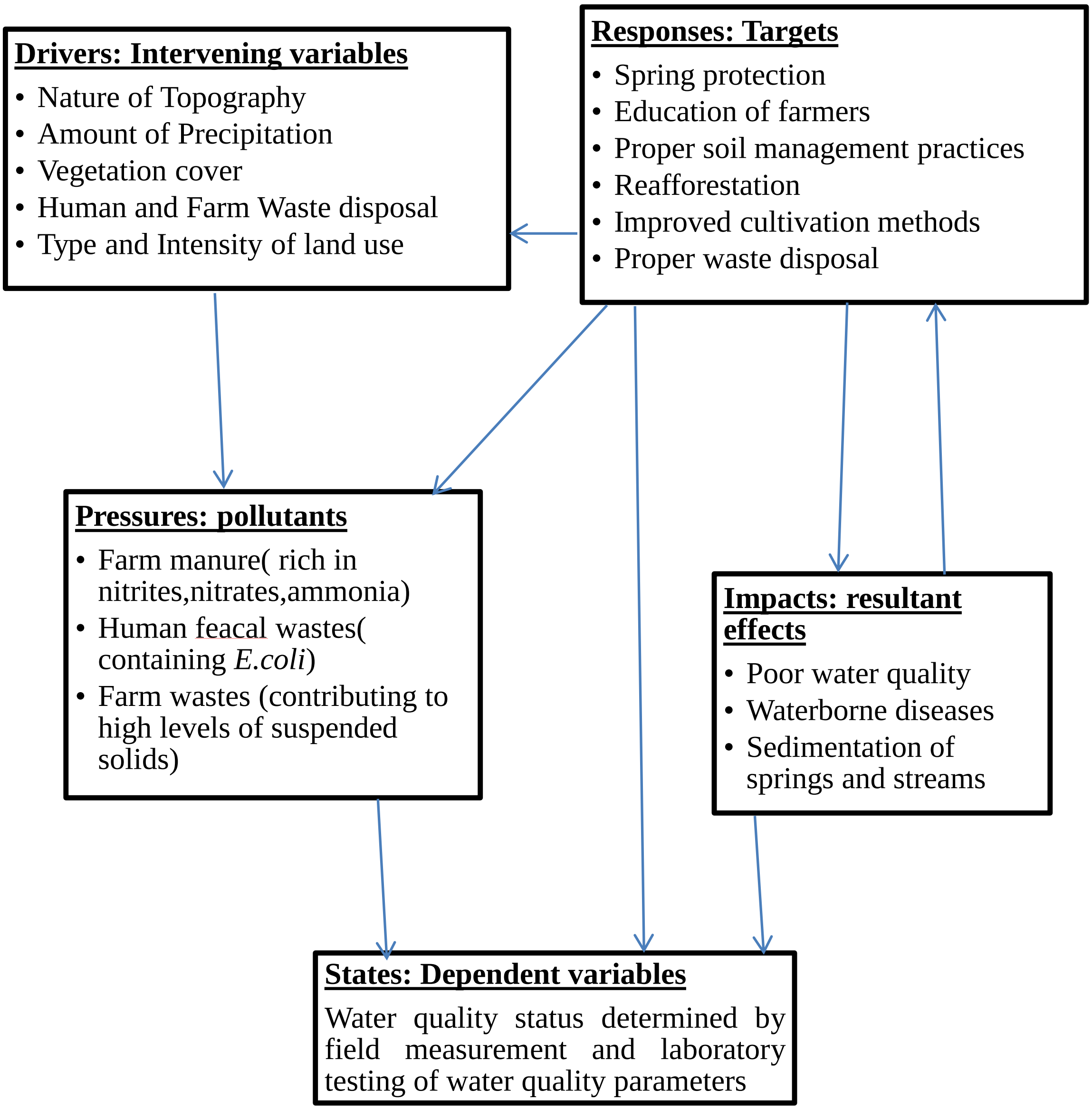


Figure 2.1: DPSIR Framework (Adopted and Modified from Kristensen, 2004)

Table 2.1: Summary of Literature reviewed and the Gaps Identified

Author(s)	Title of Research	Key Findings	Methodology	Gaps Identified
Ontumbi et al. (2015)	The influence of agricultural activities on the water quality of the River Sosiani in Uasin Gishu County.	River water quality stressed by nutrients originating from agricultural activities	Laboratory analysis of samples	BOD, Total hardness, Fluoride not tested; GIS not used and the study site was different
Ashun (2014)	Assessment and mapping of groundwater quality in the Thiririka Sub-catchment of Kiambu County, Kenya.	Human activities degrading groundwater quality as shown by high levels of Fe, Zn and Mn ions.	Inverse distance weighting by GIS	Impact of land-use on surface water quality not determined; study site was different
Jeihouni et al. (2014)	Groundwater Quality Assessment for Drinking Purposes using GIS Modelling in Tabriz City.	Optimum water quality for drinking at Centre, South and South West of the study area	Analytic Hierarchy Process	BOD, faecal coliforms, NO_3^-, PO_4^-, turbidity, EC not tested and study site was different.
Li et al. (2013)	Assessment and Correlation Analysis of Groundwater Quality in the Huanhe Unit of the Cretaceous Formation, Ordos Basin, China.	Natural factors e.g. ion exchange influence groundwater chemistry; Fluoride is human induced	Correlation analysis and laboratory analysis	Temperature, EC, DO, BOD, faecal coliforms and phosphates not tested; surface water quality not studied; study site different
Ketata-Mouna et al. (2011)	Use of GIS and WQI to Assess Groundwater Quality in El Khairat Deep Aquifer (Enfidha, Tunisia Sahel).	Majority of the water is categorized as very hard and unsuitable for drinking.	GIS and WQI	Temperature, DO, BOD, faecal coliforms and phosphates not tested; surface water quality not studied; study site different

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study Area and Location

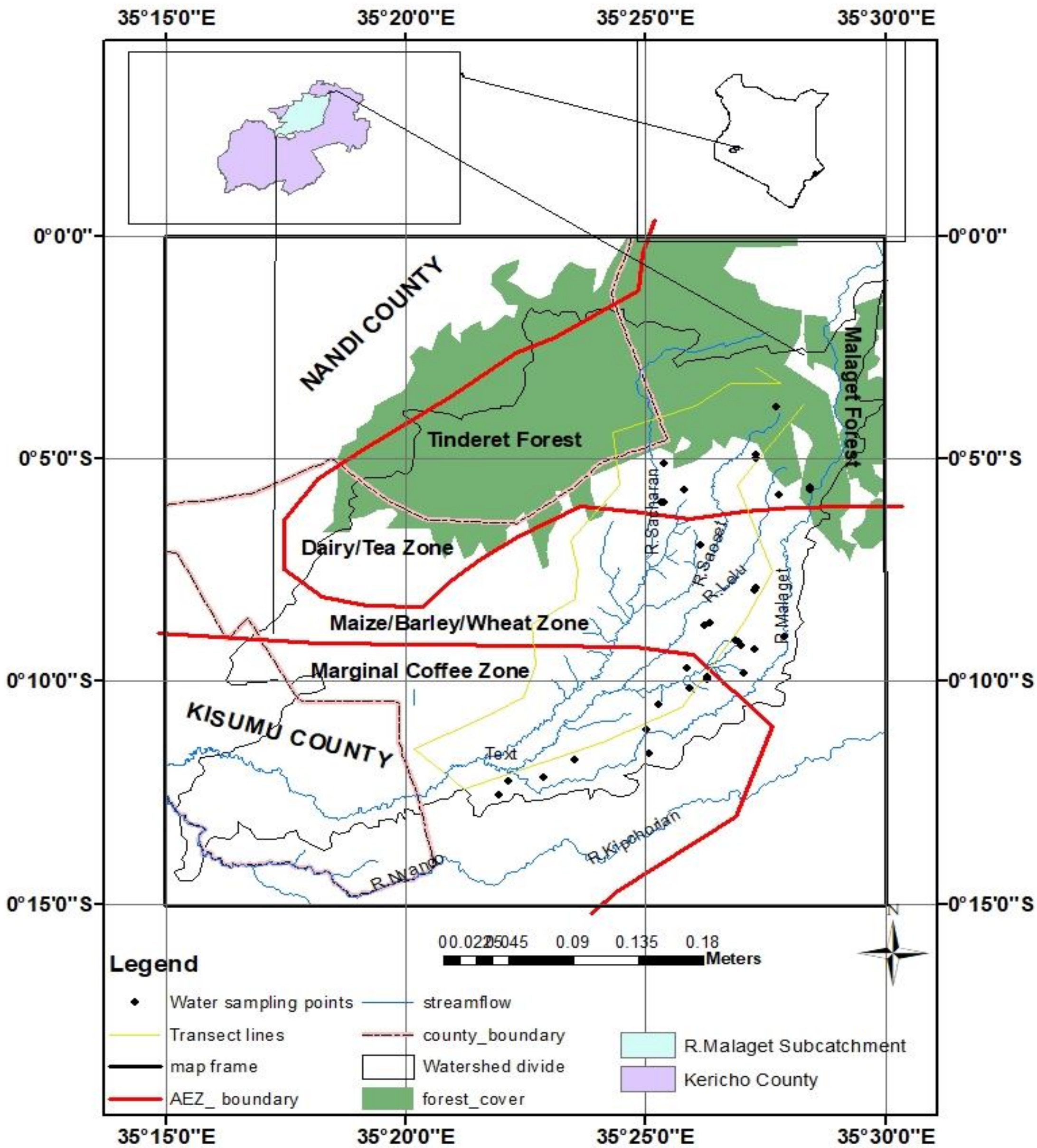


Figure 3.1: Map Showing River Malaget Sub-catchment, Kericho County- Kenya (Adopted from Survey of Kenya, 1972)

The study area is 359.14 km^2 and is located between 35°20′ E and 35°30′ E and 0°00′S and 0°20′S in Kericho County. The area borders the Tinderet Forest to the North and Londiani Hills to the East and covers Kamasian and Chilchila Wards (Binge, 1962; KNBS, 2010).

3.1.1 Climate

Climate is majorly driven by the inter-tropical convergence zone (ITCZ), modified by local relief effects. Rainfall pattern is bimodal with a long rainy season between the months of March and July, and a short rainy season between September and December. It receives an average rainfall of between 1100 and 1400 mm annually on a normal year. Mean daily temperature is between 15° and 20° C (Jaetzold *et al.*, 2010; Olang and Furst, 2010).

3.1.2 Hydrology and Water Resources

The landscape is highly rugged due to volcanic activity and faulting while altitude is around 2600 m above sea level. The drainage varies with topography and the general flow of rivers is southwest wards forming a fault-guided drainage pattern. River Lelu feeds River Sacharan which, together with River Saoset, joins River Malaget, a tributary of the River Nyando. These rivers fall in the larger Lake Victoria South Catchment Area (Binge, 1962; Jones and Lippard, 1979; Jaetzold *et al.*, 2010; Olang and Furst, 2010.

3.1.3 Geology and Hydrogeology

Geologically, intermediate and basic volcanic rocks such as phonolitic nephelinites with intercalated tuffs underlie most of the area. On plateau and upper-level upland transitions especially at the South of Tinderet are tuffs, ashes, other pyroclastic rocks and agglomerates from recent volcanoes. Rocks found around the Fort Ternan tunnel station are derived from Koru Beds specifically of the Lower Miocene Age. All these are rock formations of the Tertiary period (Binge, 1962; Jones and Lippard, 1979; Jaetzold *et al.*, 2010).

River Malaget sub- catchment is located within two major parallel fault lines with volcanic vents at Tinderet and Limutet. Groundwater occurrence here is associated with two related types of aquifers: volcanic rock types with primary porosity, and faults and fracture zones. Hence, the springs in the area are likely to be of lava and fault / fracture types. The two types of aquifers may vary considerably in thickness and are usually subject to seasonal fluctuations of groundwater level. Borehole 2 at Tinderet indicates a water-table perched on the Tinderet lavas interbedded with sediments, but there are no geophysical findings to show the depth (Binge, 1962; Olang and Furst, 2010).

3.1.4 Land Use and Socio - economic Activities

Agriculture is the predominant land use and socio-economic activity in the area where crops such as coffee, maize and beans are the leading cash earners. Other land uses include settlement and forestland while dairy farming, goat and sheep rearing are also practised. Additionally, other economic activities include trade, quarrying, and forestry (Jaetzold *et al*, 2010; Ngugi *et al.*, 2013).

3.2 Research Design

This study utilized both descriptive and experimental research designs. For the experimental study, repeated-measures design was used in that, all the water samples from all the selected sites were tested for the same water quality parameters. Prior to the actual study, a pre-survey was conducted by taking a transect walk along River Malaget, which is the main river, and around the watershed (Opio *et al*, 2011). This enabled the categorization of springs according to their seasonality and the identification of the sampling points along the River Malaget depending on the three agro-ecological zones.

Once the actual study commenced, the water sampling points were selected using stratified sampling method. A GPS was used to pick coordinates of these selected points. Thereafter, the selected indicators such as: temperature, turbidity, TDS, DO, pH and electrical conductivity were determined on site. In addition, parameters including total hardness, fluorides, nitrates, phosphates, TSS, BOD and faecal coliform were analysed in a laboratory (Ashun, 2013). Once the spring and streamflow water quality was established, maps were created using kriging method in ArcGIS™ 10.2.2, to show the spatial distribution of each of the 15 selected parameters. Secondary data was used in this study, such as an agro-ecological map, as well as, rainfall and temperature data to distinguish between the dry and wet seasons so as to guide the sampling sessions.

Water Quality Index (WQI) for each selected point was calculated based on only 6 out of the 15 selected parameters. WQI may be expressed as shown by equation 3.1.

$$WQI = \sum\left(\frac{Cx/Cx'}{n}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{Equation 3.1}$$

Where: *WQI* is the water quality index at each sampling location, *Cx* is the concentration of all measured parameters at each sampling location, Cx' is the maximum permitted level for these parameters based on set standards as shown on the table in Appendix IV and *n* is the number of measured parameters.

3.3 Variables and categories of analysis

The independent variable in the study was land use while water quality was the dependent variable, tested through the 15 relevant water quality parameters. These land use are agriculture, settlement and forestland. The extraneous variable was the amount of precipitation at the study duration. Hence, seasonal variations in the concentration of pollutants were compared using data collected during the dry and wet seasons.

3.4 Sampling of Springs and Points along the River.

Stratified sampling technique was employed, whereby the sampling sites were selected and categorized into 3 strata. This was so that the samples reflected the effects of the 3 land use categories, namely: agriculture, settlement and forestland. Further, using purposive sampling, springs and streamflow sampling points were selected based on their proximity to potential sources of contaminants. This depended on the land use which was captured under the three agro- ecological zones in the area, namely: Tea-Dairy Zone, Wheat/Maize/Barley Zone, Marginal Coffee Zone (Jaetzold *et al*., 2010). The study chose to use the agro-ecological zones in the area because it is difficult to delineate the land uses.

At least one streamflow point and ten spring sampling points were selected from each stratum, so as to meet the study objectives. Water samples were collected in 3 points along the River Malaget to ensure that the 3 agro- ecological zones are represented and also for purposes of comparing to the spring water quality from each of the 30 selected springs. In total, 33 sampling points were selected, 3 streamflow points and 30 spring points.

3.5 GIS Mapping of the Water Sampling Points

GPS coordinates of the water sampling points were taken and recorded on site using an android phone with a GPS application. These points which were recorded in degrees, minutes and decimal minutes were then transferred into an excel sheet. These data had to be converted into decimal degrees using an Excel Converter tool kit before being uploaded as X and Y data onto ArcGIS. The projection that was used is Universal Transverse Mercator (UTM), Arc 1960 - Zone 36^{o} S.

Various layers or themes were created on ArcGIS to be overlaid on the initial map of River Malaget Sub-catchment. These are the water sampling points; agro-ecological zones; forest cover; county boundary and streamflow. Water quality characteristics for each sampling point were recorded in an Excel sheet and saved in GIS-readable format before being added to Arc GIS 10.2 software. This software was used to show the spatial variation of the various water quality parameters measured in the River Malaget Sub Catchment.

3.6 Water Sampling

Water sampling for the dry season was done in December, 2016 and February, 2017 and for the wet season it was done in April, 2017 and June, 2017. Given that the study was interested in water quality variation within the wet and dry seasons, samples were collected in two different sessions per season, with a two week interval between these sampling sessions. Additionally, for each sampling session, water samples were collected on separate days with a two-day interval, at each of the three agro-ecological zones. This gave enough time for the samples to be analysed and results obtained, before embarking on the next sampling session.

Sample collection was done between 9 am and 12 noon as this gave enough time for these samples to be rushed and delivered to the laboratory in Egerton by 2 pm for the microbial analysis. The samples were drawn directly from the spring points and the 3 streamflow points along the River Malaget, after rinsing of the sample bottles with the water, to get rid of any sterilization residues. Samples for chemical analysis were stored in room temperature, while samples for microbiological tests were stored in dry ice at 4° C for not more than 48 hours to await laboratory analysis along with others.

3.7 Quality Assurance and Quality Control (QA/QC)

Hard copies of sampling plans were carried into the field to make sure that all data were collected using the same protocols and consistent to the same standard. All instruments used in this study were calibrated with standard and known concentrations. Concentrations of the analyte samples were determined from the calibration curves and average values of two replicates were taken for each determination.

Appropriate blanks consisting of de-ionized water were prepared and analysed in the same way. Usually, blank samples are used to control the quality of water samples, for instance, determining whether a water sample may be contaminated during transit or the entire sampling process. Blank samples help to detect or check the purity of reagents, containers and equipment used in sample collection, handling or transportation. They help to trace any contamination that occurs at the stage of sampling to the stage of analysis.

Sample bottles were kept in a clean environment, away from dust and dirt, and always capped and stored in clean ice boxes (coolers) both before and after the collection of the sample. Vehicle cleanliness was maintained to eliminate contamination problems. Samples were stored in a cool, dark place to minimize temperature increase in them, with majority being cooled to 4 to 10°C during transit to the laboratory. Ample amounts of ice packs were used to keep samples very cool so as to reduce biochemical activity in them. It was ensured that sample collectors kept their hands clean and refrained from eating or smoking while working with water samples. Field measurements were made using separate sub-samples, which were then discarded once the measurements were made to avoid cross-contamination.

3.8 Field Testing and Laboratory Analysis Procedures

The quality of water is considered based on various sectoral demands or uses, for instance, domestic, industrial, and agricultural, among others. This study concentrated on water quality for drinking purposes. The reliability of water resources for various uses is dependent on their physical and chemical characteristics. These were determined by testing for various parameters and comparing them with the recommended levels or standards, set by the relevant bodies charged with public safety concerns.

There are over 100 water quality parameters but for this study, only 15 were measured. The selected parameters are based on consideration of the potential sources of contamination amongst the land uses. For instance, pathogens such as *E.coli* bacteria may originate from leakage of animal and human wastes possibly from on-site sanitation facilities and thus such a potential threat of contamination may be indicated by testing for faecal coliforms parameter (Ashun, 2014).

Laboratory analysis of samples was done for tests such as TDS, Total hardness, fluorides, TSS, BOD, *E.coli*, nitrates, nitrites, ammonia and phosphates. The parameters that were measured on site are temperature, turbidity, pH, electrical conductivity and DO.

3.8.1 Determination of phosphates

There are various phosphate forms but for this study the interest was in Soluble Reactive Phosphate (SRP) which is also known as orthophosphate. The determination of phosphate concentration was done using the Ascorbic Acid method (APHA, 1998).

3.8.2 Determination of nitrates (NO_3^-) and nitrites (NO_2^-)

The determination of nitrate concentration was done using the Hydrazine Reduction Method. Nitrate was calculated by subtracting the nitrite result from the nitrite plus nitrate result (APHA, 1998).

3.8.3 Determination of Ammonia

The determination of ammonia concentration was done using the salicylate method. Test results were measured at 655 nm (APHA, 1998).

3.8.4 Determination of Electrical Conductivity

Electrical Conductivity was determined with the aid of a conductivity probe of a portable multi-parameter with automatic temperature compensation at 25 °C (APHA, 1998).

3.8.5 Determination of pH

The pH was measured with the portable pH meter probe. The pH electrode of the pH meter was first calibrated against a pH buffer 7 and 9 at a temperature of 25°C to adjust to the response of the glass electrode (APHA, 1998).

3.8.6 Determination of Total Dissolved and Suspended Solids (TSS and TDS)

The determination of total dissolved and suspended solids was done using the gravimetric method.

TSS value was calculated using the equation 3.2.

$$TSS\ (mg/L)\ =\ \frac{(W2-W1)\times 1000}{(Volume\ of\ sample)ml} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{Equation 3.2}$$

Where: *W2* = weight of filter + remnant solids from filtration (mg)

W1 = weight of filter paper before use (mg)

The TDS value was calculated using the equation 3.3.

$$TDS\ (mg/L)\ =\ \frac{(A-B)\times 1000}{(Volume\ of\ sample)ml} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{Equation 3.3}$$

Where: A = weight of dried residue + dish (mg)

B = weight of dish (mg)

3.8.7 Determination of Turbidity

Nephelometric Method was used to determine Turbidity in Nephelometric Turbidity Unit (NTU) as a unit of measurement. It was measured *in situ* using the Turbidimeter (i.e. AL 250T –IR model). Firstly, the instrument was calibrated using standard solutions of 2 NTU and 8 NTU. (APHA, 1998).

3.8.8 Determination of BOD

The BOD test was carried out using the 5-day BOD method by determining the dissolved oxygen in the water sample at the beginning of the test period, incubating the water sample at 20 °C, and determining the dissolved oxygen at the end of 5 days. The difference in dissolved oxygen between the initial measurement and the fifth day measurement represents the biochemical oxygen demand (APHA, 1998).

3.8.9 Determination of *E.coli*

The recommended test for the enumeration of *E.coli* is membrane filtration using Chromocult media and incubation at 44° C for 18 - 22 hours to produce blue / purple coloured colonies (APHA, 1998).

3.8.10 Determination of DO and Temperature

The temperature and Dissolved oxygen (DO) of each sample was determined at the site of collection using a Jenway DO Meter with automatic temperature compensation at 25 ^{O}C. Water was collected in a becker and the DO probe was turned on and dipped into it. Once the readings were stable, the measurements were recorded in mg/L for DO and ^{O}C for temperature (APHA, 1998).

3.8.11 Determination of Fluorides

Fluoride in water was determined by SPADNS Spectrophotometric Method with the absorbance being measured at 570 nm. Calibration curves using absorbance values for known standards were prepared and fluoride values for the samples were then read. The values of the standard solutions in the recording table were used to plot a calibration curve of fluoride versus absorbance. The fluoride content of all samples was read from the standard curve and the F- concentration was then calculated.

3.9 Determination of Water Quality Index (WQI)

Water Quality Index (WQI) was calculated based on the weighted arithmetic water quality index. Only 6 parameters were used to compute the WQI to ascertain the quality of drinking water for the water sources in River Malaget Sub-catchment. The equation is in the following form:

$$WQI_A = \sum_{i=1}^{n} w_i q_i / \sum_{i=1}^{n} w_i \quad \text{...} \textit{equation 3.4}$$

Firstly, each of the parameters was assigned a weight *(wi*) according to its relative importance in the overall water quality for drinking purposes as shown in Table 3.1. The maximum weight of 5 was assigned to nitrates and phosphates; a weight of 4 was assigned to turbidity and TSS was given a weight of 3. Lastly, a weight of 2 was assigned to Electrical conductivity, while nitrite was assigned a weight of 1.

Table 3.1: Standards and Unit Weights for Water Quality Parameters

Parameter	WHO Guideline (Si)	Parametric weight (wi)	Relative Weight(WI)	WQI (Sum of SI)
EC	2000	2	0.1	51.285
turbidity	5	4	0.2	2010.72
TSS	30	3	0.15	0.3605
nitrates	50	5	0.25	315.5675
nitrites	3	1	0.05	-0.041666667
phosphates	30	5	0.25	0.3475
Total	-	20	1	2378.238833

Source: Lateef, (2011) and WHO, (2004)

Secondly, the relative weight (*WI)* was computed using a weighted arithmetic index method given in *equation 3.4.* For instance, Turbidity was assigned a weight of 4. This can be calculated as follows using *equation 3.5.*

$$WI = \frac{wi}{\sum_{i=0}^{n} wi} \quad \text{...} \textit{ equation 3.5}$$

Where, *Wi* is the relative weight, *wi* is the weight of each parameter and *n* is the number of parameters.

Thirdly, a quality rating scale (qi) for every parameter was determined by dividing its concentration per sample by its respective standard value according to WHO guideline and the result multiplied by 100 (Gebrehiwot *et al.*, 2011).

$qi = 100(Ci \div Si)$ ……………………………………………………*equation 3.6*

Where, qi is the quality rating, Ci is the concentration of each parameter in each water sample, and Si is the WHO drinking water standard for each parameter.

For instance, the quality rating of Turbidity ($qTurb$) can be calculated from *equation 3.7.* If the observed value of Turbidity is 4.45 N.T.U. and the WHO guideline value is given as 5N.T.U., the equation can be worked out as follows:

$qTurb = 100 * [(Ci/Si)]$.. *equation 3.7*

$qTurb = 100*(4.45/5)$

Before computing the WQI, the SI is first determined for each parameter by multiplying the relative weight (WI) by the quality rating scale (qi). This is then used to determine the WQI as indicated by *equation 3.8* (Reza and Singh, 2010).

$SI = WI \times qi$..*equation 3.8*

$WQI = \Sigma SIi$…………………………….................................. …….*equation 3.9*

Where, SIi is the sub index of ith parameter; qi is the rating based on concentration of ith parameter and the total number of parameters used for the determination of the WQI.

Usually, the computed WQI values are grouped into five categories namely; excellent, good, poor, very poor and unfit water for drinking purposes (Lateef, 2011 and Ketata, *et al*., 2011). The WQI values obtained can be interpreted according to table 3.2 which shows the WQI range and the corresponding category of water.

Table 3.2: Interpretation of the WQI Values

WQI Range	Type / category of water
<50	excellent
50-100	good
100-200	poor
200-300	Very poor
>300	Unfit for drinking

Source: Ketata, *et.al*, 2011.

3.10 Spatial Distribution of Water Quality Parameters

According to Burrough and McDonnell (1998), kriging is one of the many interpolation techniques which are based on the assumption that points nearer to each other are more correlated and similar compared to those that are far apart. It utilises complex statistical methods that put into consideration the uniqueness of a dataset. It is more informative and gives more reliable compared to other interpolation methods because it examines particular sample points to get a value for spatial autocorrelation that is only utilised for estimating within that specific point, rather than assigning a universal distance power value. In addition, kriging allows for interpolated cells to go beyond the limits of the sample range. Specifically, ordinary kriging method was used which is accessed within Arc Toolbox under Spatial Analyst - Interpolation tools.

3.11 Statistical analysis

Data from laboratory analysis was entered in an Excel sheet and transferred to SPSS Version 20 for statistical analyses. Descriptive statistics such as mean, standard deviation, maximum and minimum values were generated, as well as display of data in line graphs and histograms. The physico-chemical and microbial characteristics of spring and streamflow water in River Malaget Sub Catchment was presented in relation to NEMA and WHO standards for drinking water quality.

Principal component analysis (PCA) and factor analysis using varimax rotation was used to reduce the 15 water quality parameters measured to only 9 that indicate nutrient and micro-organic pollution. These 9 parameters were then subjected to further analysis using Multivariate Analysis of Variance (MANOVA). This was used to compare the means of the water quality parametric data for the 3 agro-ecological zones in the study area to see whether there was variability in the distribution of these water quality parameters in relation to the land use. The means of data from the two water sources, that is springs and streamflow, were compared using the independent T-test to see whether there was a relationship between them. Both of these were computed at 95 % confidence level where if the results were significant then the null hypotheses were rejected.

3.12 Ethical consideration

A permit from NACOSTI (National Commission for Science Technology and Innovation) was obtained and the local community was informed about the study through the local chief. This allowed the study to run smoothly without interference from the local authority. In addition, the permit was useful in procuring certain chemical reagents and laboratory solutions required for the study. For instance, it is a requirement by KRA (Kenya Revenue Authority) to the suppliers/sellers of ethanol to only sell to those buyers who have obtained the necessary authorization documentation to justify the purchase of the item.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Water Quality Results and Spatial Distribution of Parameters

Results of the physico-chemical and microbial analysis of water samples from the 30 springs and 3 points along the main river at River Malaget Sub catchment is presented. These include phosphates, nitrates, temperature, pH, electrical conductivity, turbidity among others obtained from field testing and laboratory analysis of the samples. Statistical presentation of these results is provided in the form of comparative bar graphs, based on the parameters tested within the dry and wet seasons in the study area.

4.1.1 Phosphates

The observed values of phosphates in the River Malaget Sub-catchment ranged from 0.004 mg/l to 0.037 mg/l in the dry season and from 0.002 mg/l to 0.037 mg/l in the wet season. There is very minimal variation in the concentration of phosphates within the two seasons. The overall mean value for phosphates in the sub-catchment was 0.013 mg/l. The phosphate values for both the springs and streamflow were within the limits of < 30 mg/l for drinking water as recommended by both NEMA (2006) and WHO (2004) .

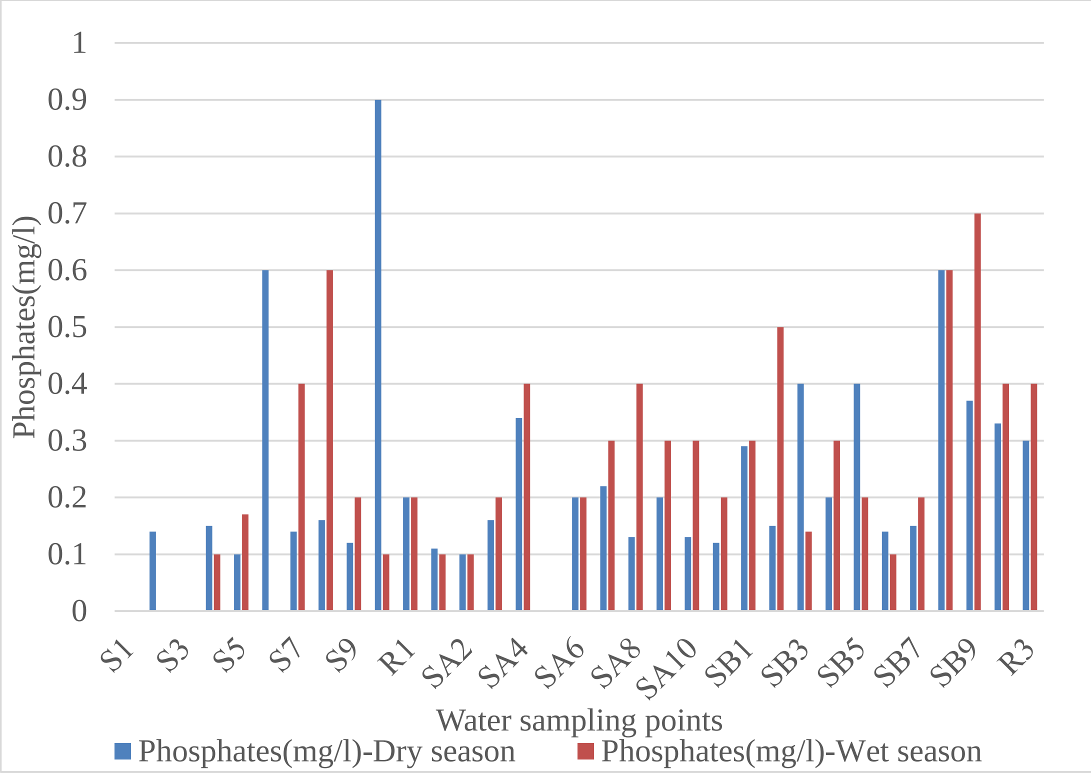


Figure 4.1: Mean of Phosphates in the Agro-ecological zones

Figure 4.2 is the thematic map for phosphates which shows the spatial distribution of the parameter in the River Malaget Sub-catchment. It was observed from the map that the highest concentration of phosphates was in the Marginal Coffee Zone at lower catchment, with the lowest concentration being in the Maize/ Barley / Wheat Zone at the mid-catchment and Dairy / Tea Zone at the upper catchment.

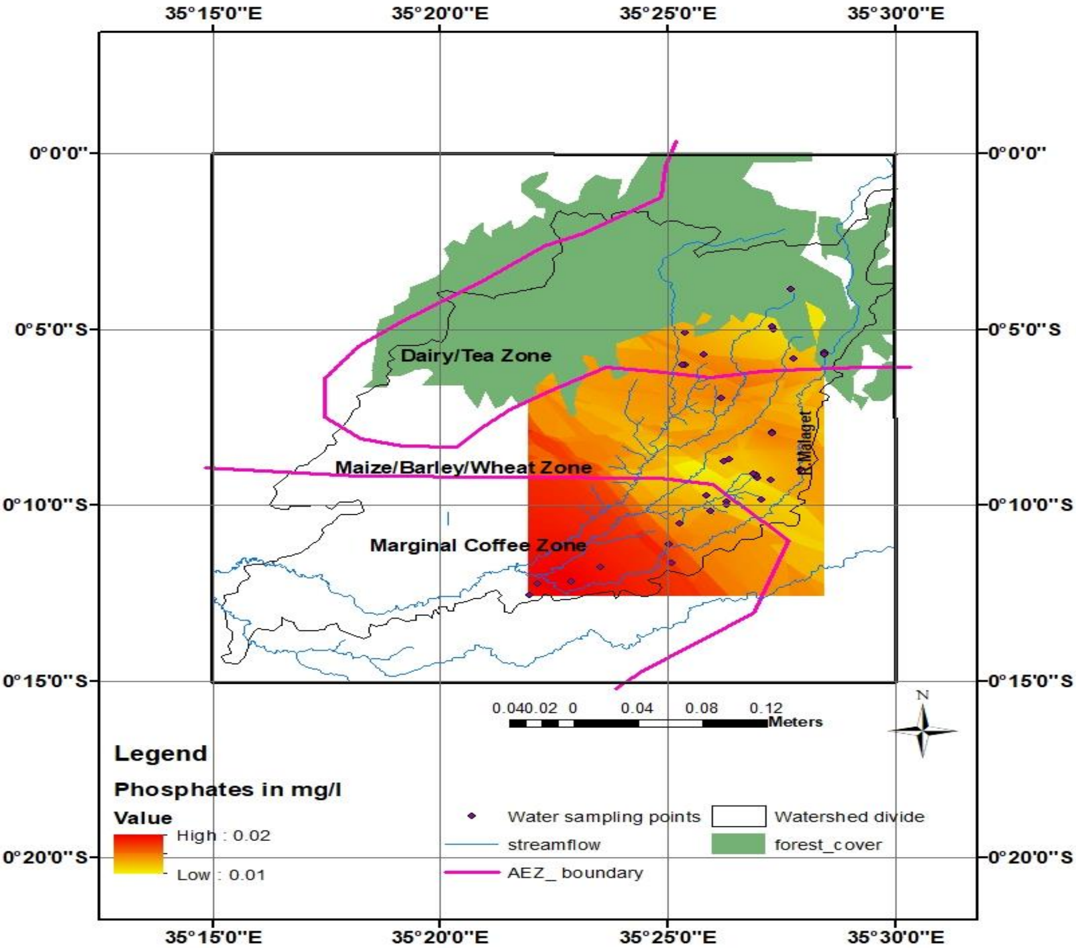


Figure 4.2: Spatial Distribution of Phosphate in River Malaget Sub-catchment

4.1.2 Nitrates

The observed values of nitrates in the River Malaget Sub Catchment ranged from 5.48 mg/l to 32.53 mg/l**.** There is very slight variation in the concentration of nitrates from the dry season to the wet season. The overall mean value for nitrates in the sub-catchment was 19.13 mg/l. The nitrate values for both the springs and streamflow were within the limits of < 10 mg/l and < 50 mg/l for drinking water as recommended by both NEMA (2006) and WHO (2004) respectively.

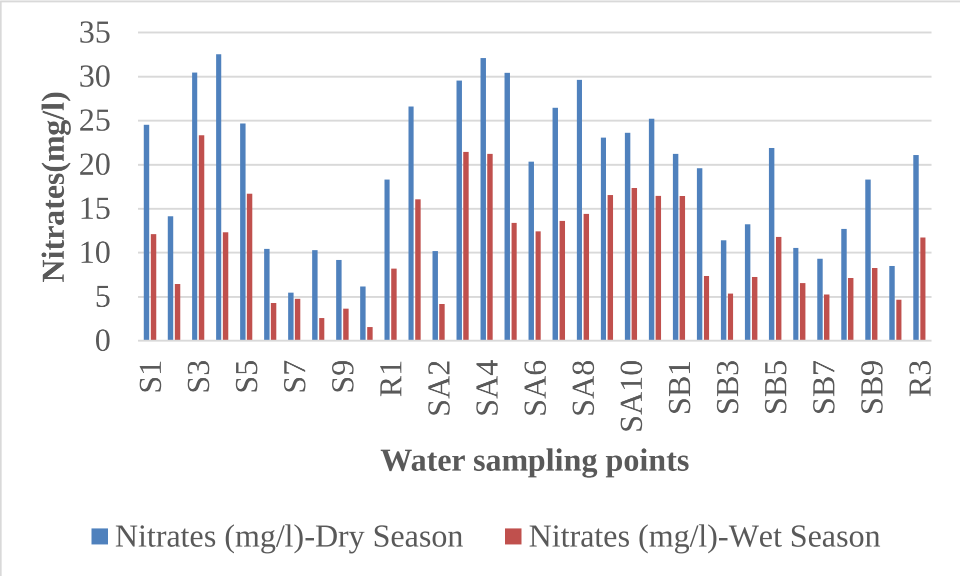


Figure 4.3: Mean of nitrates in the Agro-ecological zones

Nitrates should be determined in drinking water as excess amounts of it may lead to an illness known as methemoglobinemia. Nitrate is considered to be an indication of pollution originating from anthropogenic activity. The highest concentrations of nitrates in River Malaget sub-catchment were found in the Dairy-Tea zone which is the upper catchment or LH1, and the Wheat/Maize/Barley zone which is the mid-catchment or LH3. This could be attributed to the fact that animal waste is used as manure and could find its way into the open water sources such as streamflow and streams, thereby polluting them.

Figure 4.4 is the thematic map for nitrates which shows the spatial distribution of the parameter in the River Malaget Sub-catchment. It can be observed from the map that the concentration of nitrates is highest around the mid-catchment in the Maize/ Barley / Wheat Zone with the average concentration being at the lower catchment in the Marginal Coffee Zone compared to the lowest concentrations in the upper catchment at the Dairy / Tea Zone.

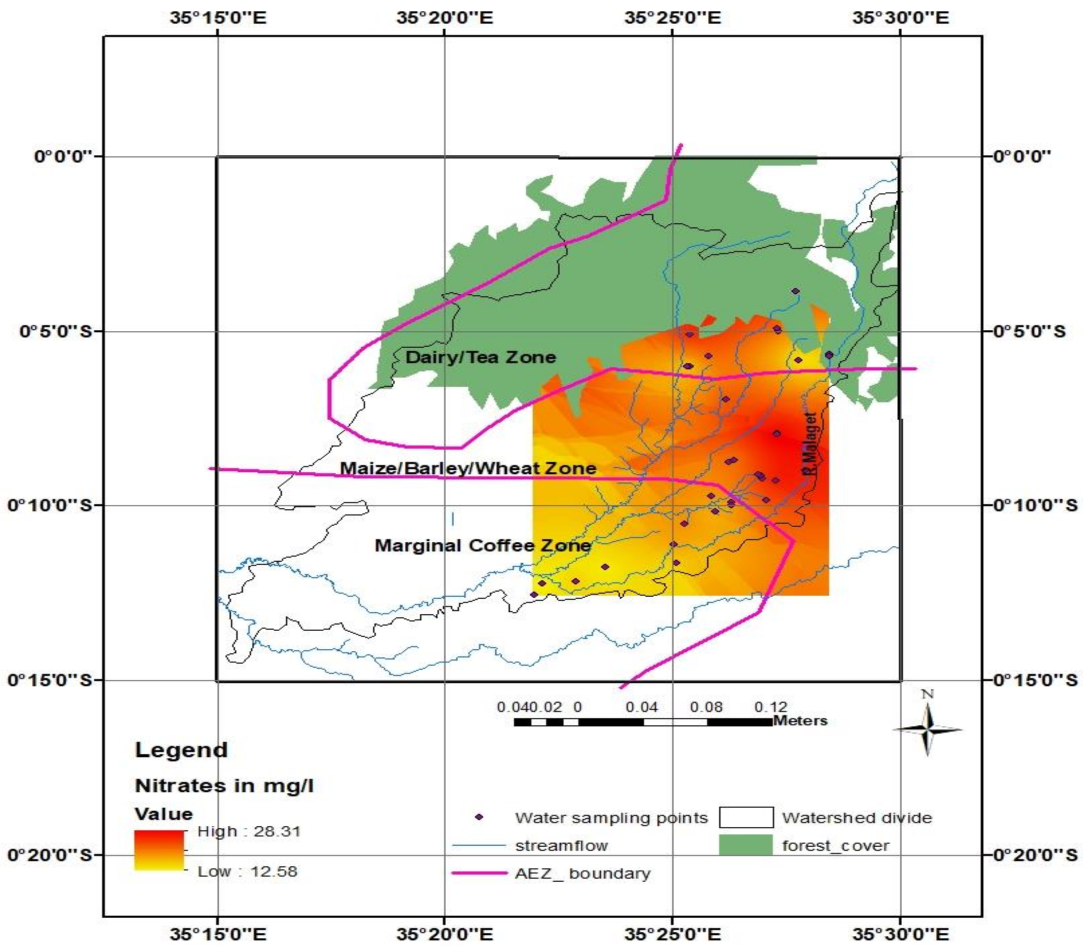


Figure 4.4: Spatial Distribution of Nitrates in River Malaget Sub-Catchment

4.1.3 Nitrites

The observed values of nitrites in the River Malaget Sub Catchment ranged from 0 mg/l to 0.013 mg/l in the wet season and from 0.0004 mg/l to 0.013 mg/l in the dry season. The overall mean value for nitrites in the sub-catchment was 0.007 mg/l. The nitrite values for both the springs and streamflow were within the limits of <3 mg/l for drinking water as recommended by both NEMA (2006) and WHO (2004).

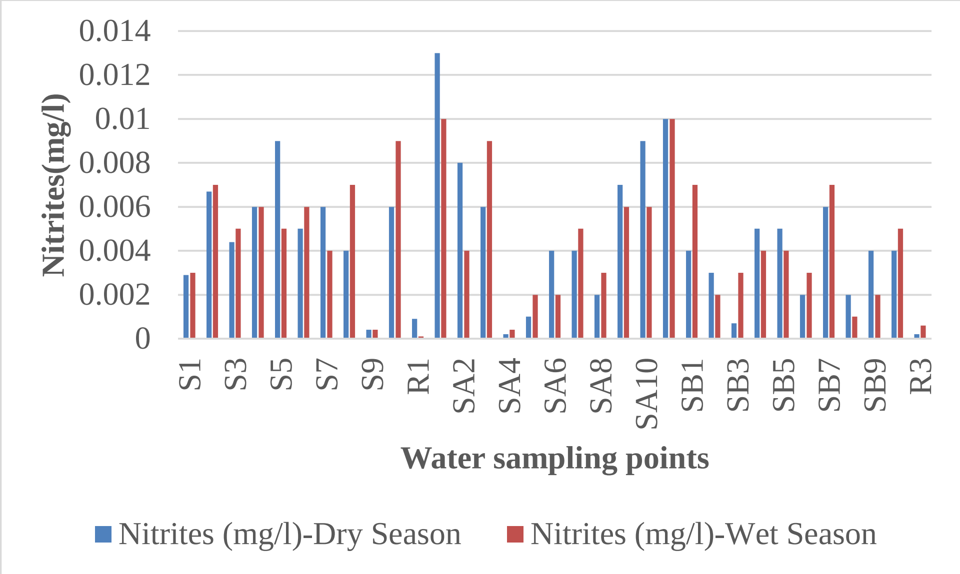


Figure 4.5: Mean nitrites of the Agro-ecological zones

Figure 4.6 is the thematic map for nitrites which shows the spatial distribution of the parameter in the River Malaget Sub-catchment. It can be observed from the map that the concentration of nitrites is highest around the mid-catchment in the Maize / Barley / Wheat Zone and lower catchment in the Marginal Coffee Zone compared to the lowest concentrations in the Dairy / Tea Zone at the upper catchment.

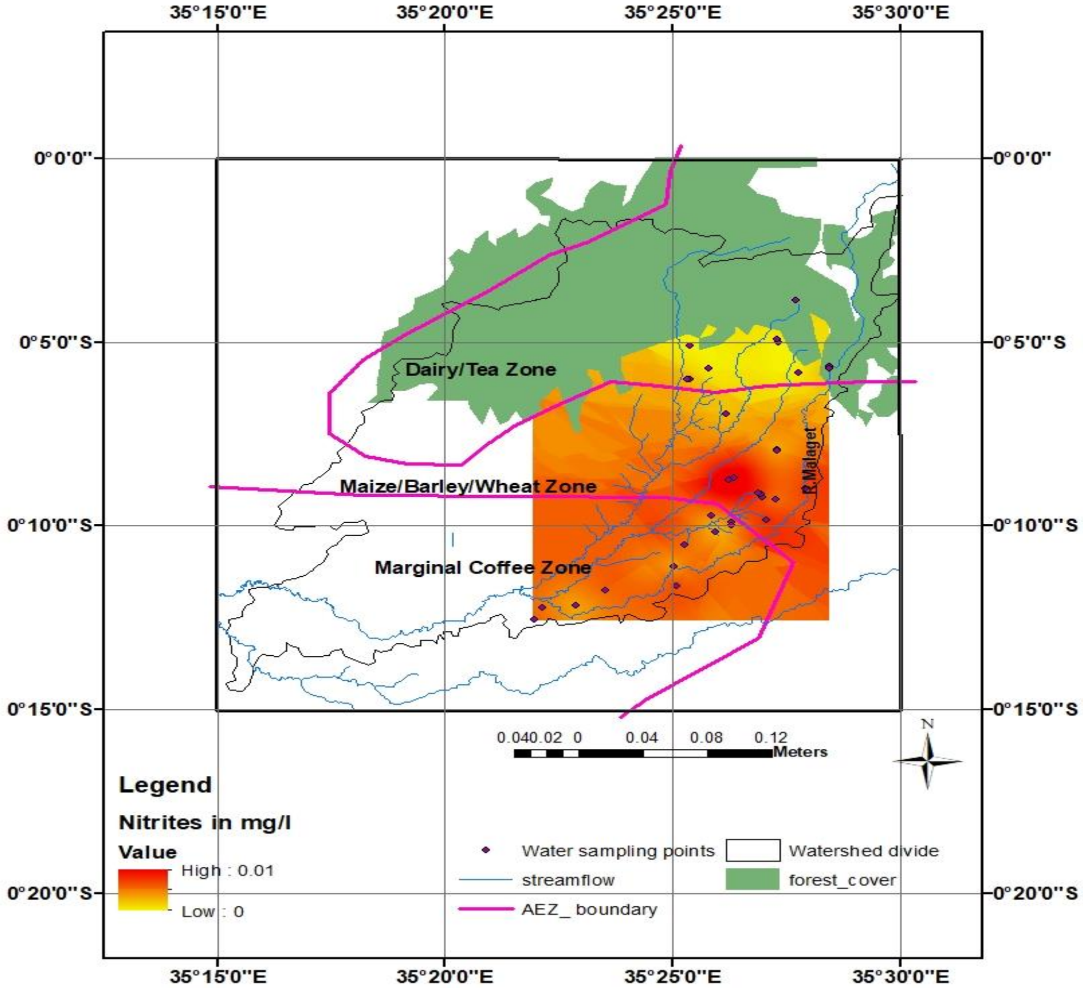


Figure 4.6: Spatial Distribution of Nitrites in River Malaget Sub-Catchment

4.1.4 Ammonia

The observed values of ammonia in the River Malaget Sub Catchment ranged from -0 mg/l to 0.09 mg/l in both the dry season and from 0.001 mg/l to 0.09 mg/l in the wet season. This indicates a very negligible difference in ammonia concentrations between the two seasons. The overall mean value for ammonia in the sub-catchment was 0.014 mg/l.

No guideline value has been set for ammonia by WHO as it is not directly important for health in the expected concentrations in drinking water, which is usually below 0.2 mg/l of ammonia. However, NEMA has set a limit of 0.05 mg/l, of which all samples were found to be within.

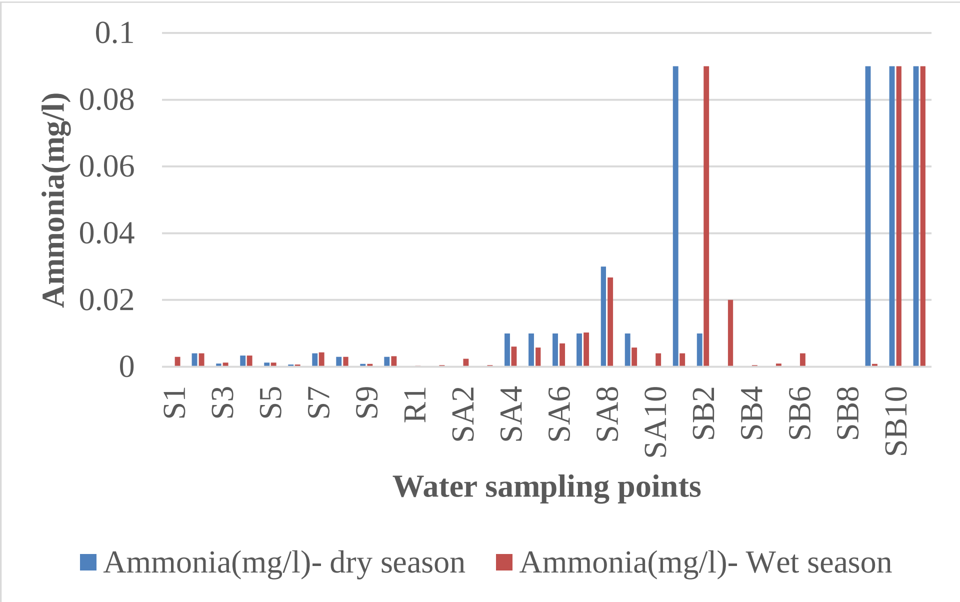


Figure 4.7: Mean ammonia of the Agro-ecological zones

Figure 4.8 is the thematic map for ammonia which shows the spatial distribution of the parameter in the River Malaget Sub-catchment. It can be observed from the map that the concentration of ammonia is highest around the lower catchment in the Marginal Coffee Zone with the lowest concentrations being in the Maize / Barley / Wheat Zone at the mid-catchment and in the Dairy / Tea Zone at the upper catchment.

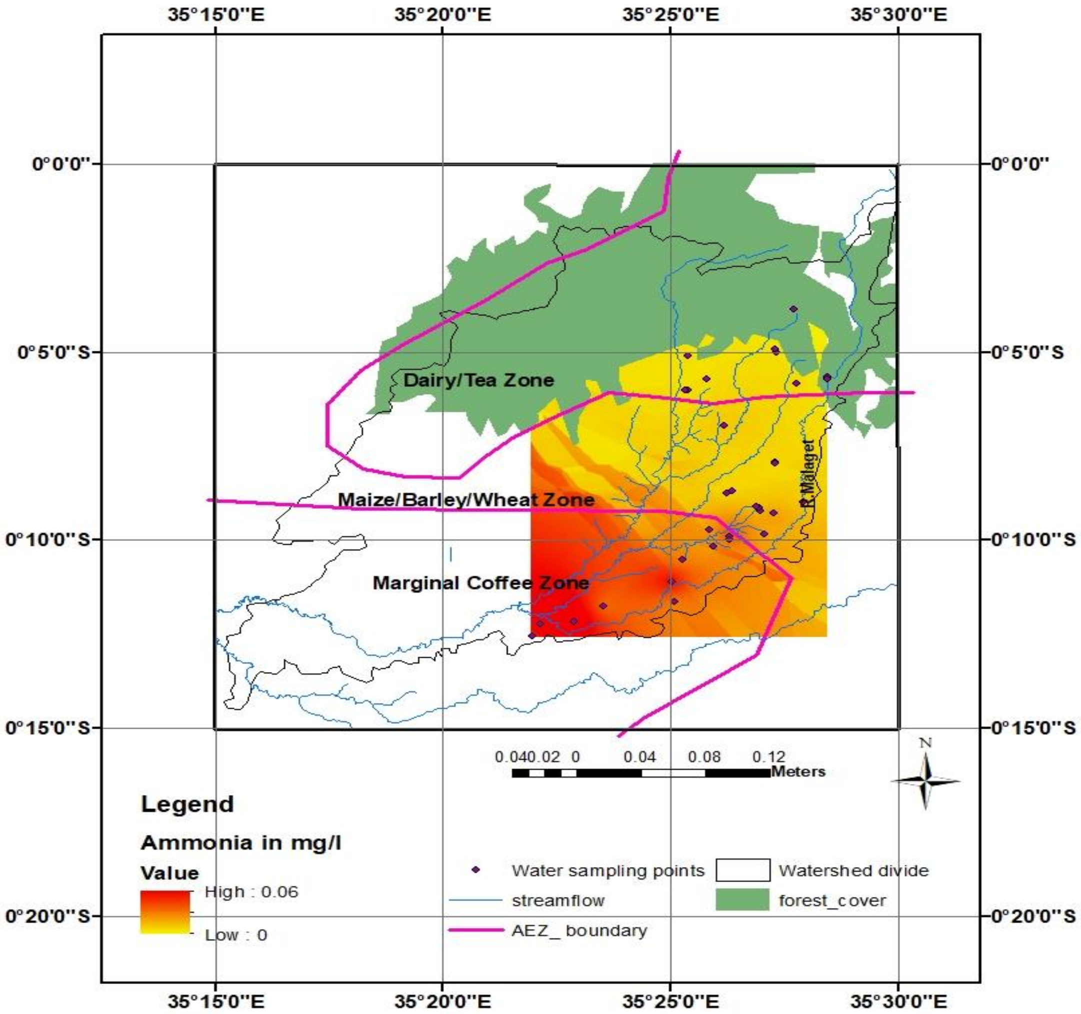


Figure 4.8: Spatial Distribution Ammonia in River Malaget Sub Catchment

4.1.5 Electrical Conductivity

The observed values of electrical conductivity in the River Malaget Sub Catchment ranged from 93 μS/cm to 654 μS/cm in the dry season and from 21 μS/cm to 631 μS/cm in the wet season. This indicates a very small difference in the electrical conductivity concentration between the two seasons.

The values for both the springs and streamflow were within the limits of < 1200 µS/cm and < 2000 µS/cm for drinking water as recommended by both NEMA (2006) and WHO (2004) respectively. Electrical conductivity of water is influenced by the presence of various inorganic dissolved solids such as chlorides, nitrates, nitrites, sulphates, phosphates and metals like Al, Fe, Ca, Na and Mg. It is a function of temperature, types and concentration of ions and total hardness.

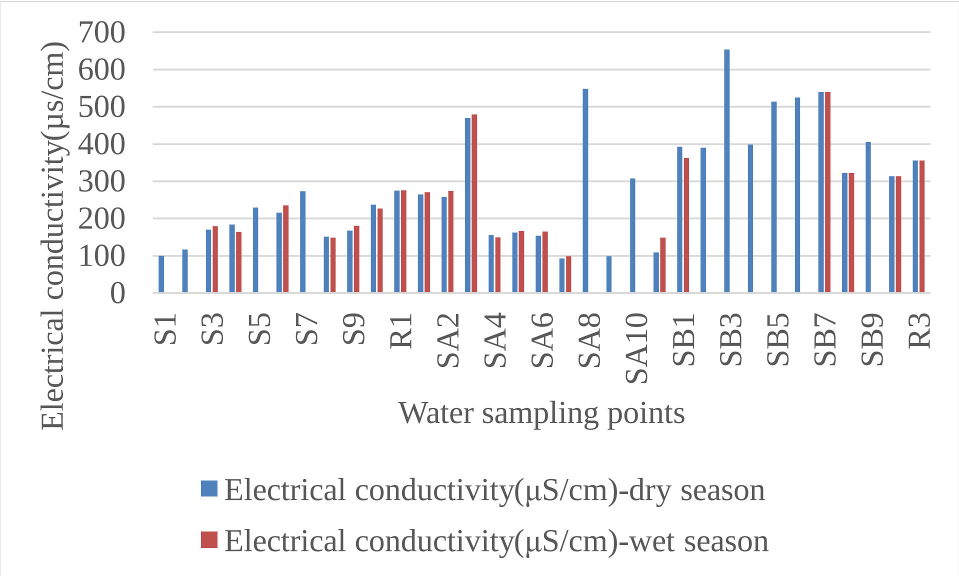


Figure 4.9: Mean electrical conductivity of the Agro-ecological zones

Figure 4.10 is the thematic map for electrical conductivity which shows the spatial distribution of the parameter in the River Malaget Sub-catchment. It was observed from the map that the concentration of electrical conductivity is highest around the mid-catchment in the Maize / Barley / Wheat Zone and lower catchment in the Marginal Coffee Zone compared to the lowest concentrations in the Dairy / Tea Zone at the upper catchment.

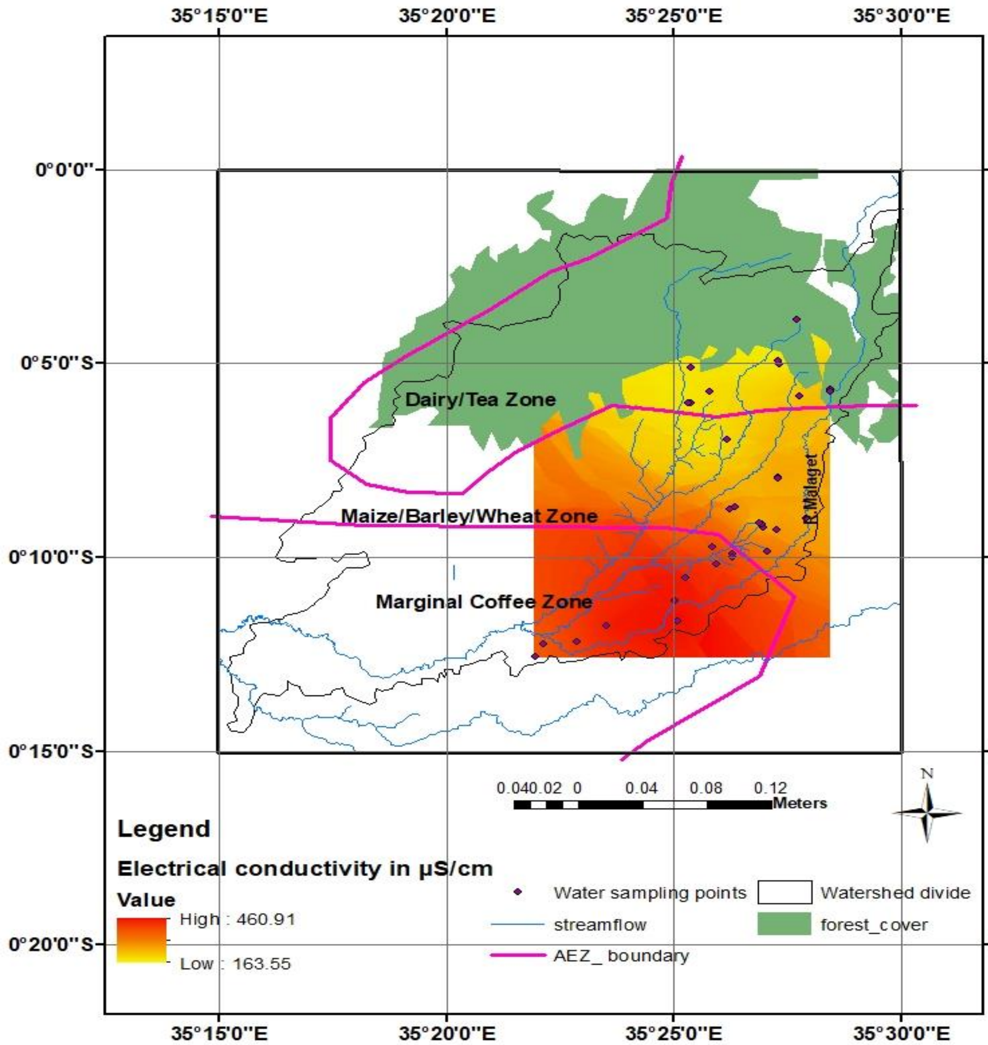


Figure 4.10: Spatial Distribution of Electrical Conductivity in River Malaget Sub- Catchment

4.1.6 Total Suspended Solids (TSS)

The observed values of TSS in the River Malaget Sub-catchment ranged from 0 mg/l to 3.40 mg/l in both the dry season and from 16.24 mg/l to 80.2 mg/l in the wet season. It appears from the results that generally TSS levels are higher in the wet season compared to the dry season. The possible explanation to this is run off incidences during the wet season, which introduce pollution in the form of suspended solids. The

TSS values in the dry season, for all the water sampling points were within the limits of < 30 mg/l for drinking water as recommended by both NEMA (2006) and WHO (2004). However, during the wet season, about a third of these sampling points had TSS levels that exceeded the recommended levels.

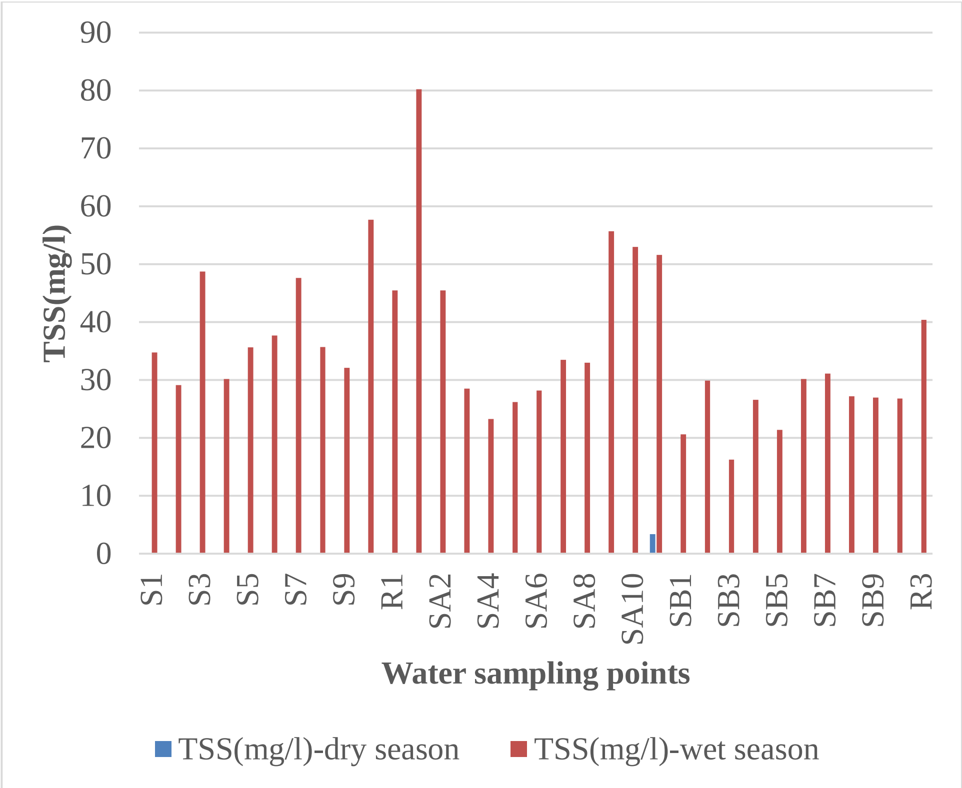


Figure 4.11: Mean TSS values for the 3 Agro-ecological zones

Figure 4.12 is the thematic map for TSS which shows the spatial distribution of the parameter in the River Malaget Sub-catchment. It can be observed from the map that the concentration of TSS is highest around the mid-catchment in the Maize / Barley / Wheat Zone, with the average concentration being at the upper catchment in the Dairy / Tea Zone compared to the lowest concentrations at the lower catchment in the Marginal Coffee Zone.

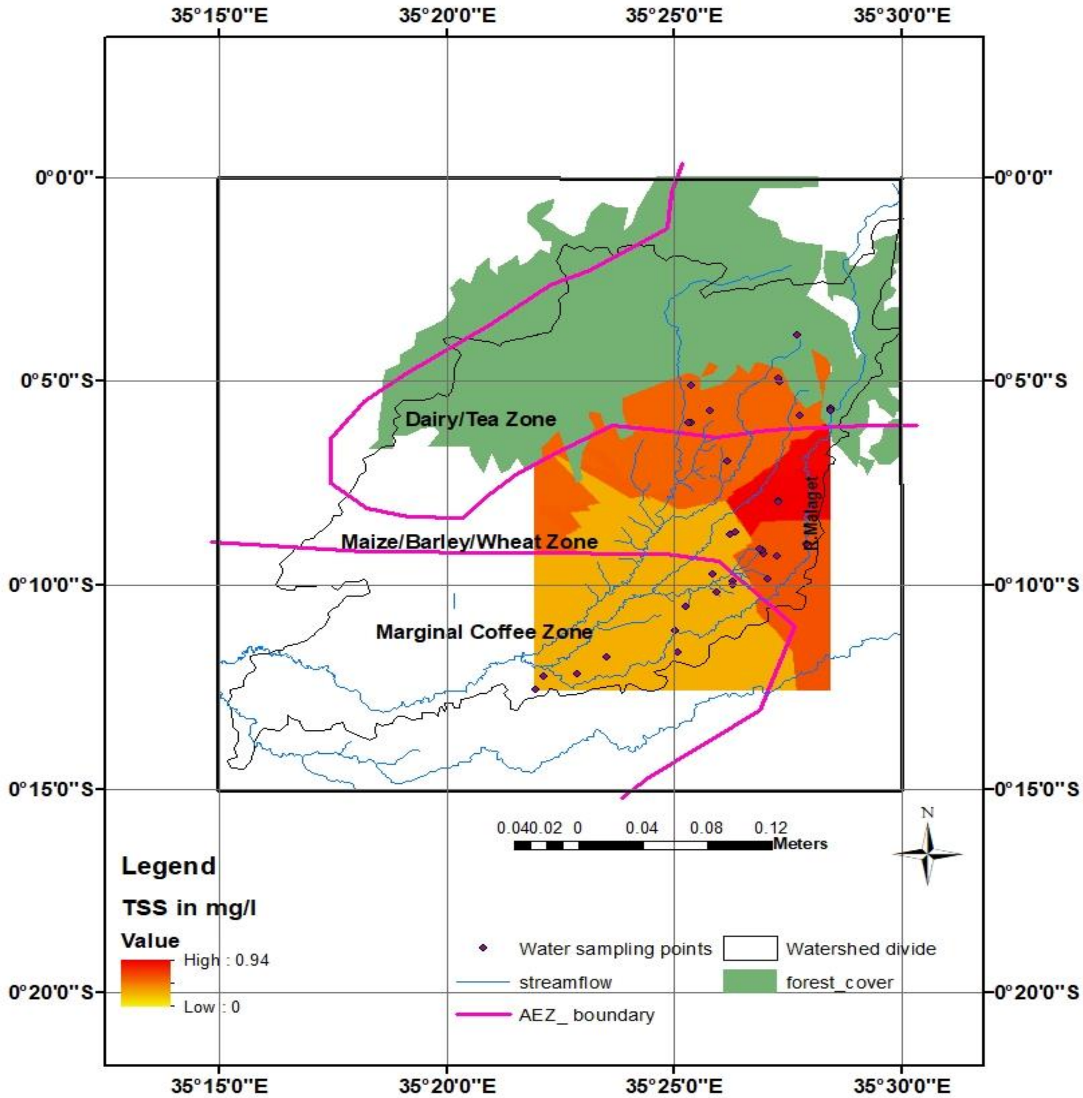


Figure 4.12: Spatial Distribution of TSS in River Malaget Sub Catchment

4.1.7 Total Dissolved Solids (TDS)

The observed values of TDS in the River Malaget Sub-catchment ranged from 2.02 mg/l to 88.60 mg/l in the dry season and from 6.02 mg/l to 92.03 mg/l in the wet season. This indicates a very slight variation in the concentration of TDS between the two seasons. The TDS values for both the springs and streamflow were within the limits of < 1200 mg/l and < 1000 mg/l for drinking water as recommended by both NEMA (2006) and WHO (2004).

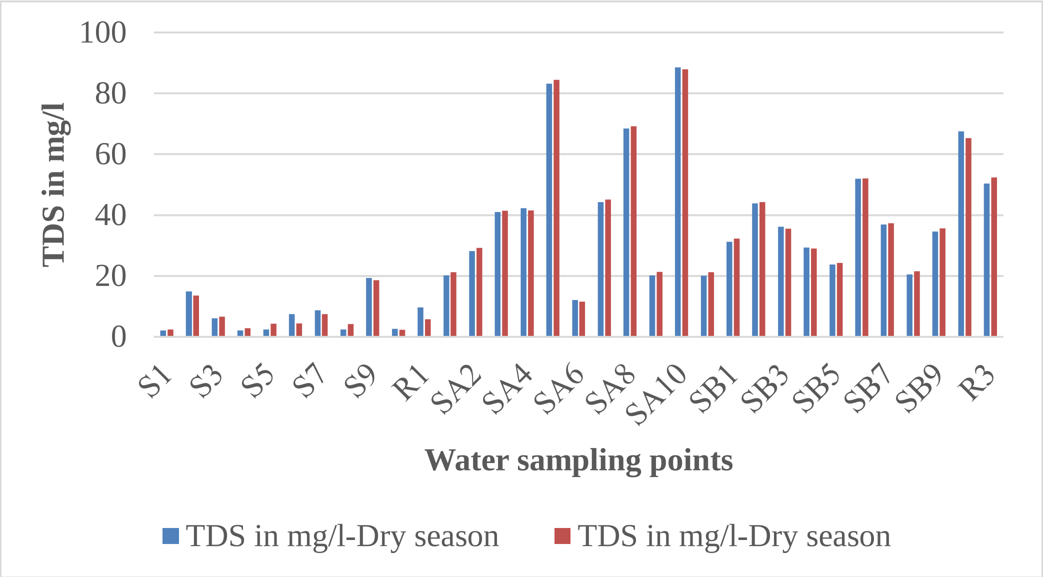


Figure 4.13: Mean TDS values for the Agro-ecological zones

Figure 4.14 is the thematic map for TDS which shows the spatial distribution of the parameter in the River Malaget Sub-catchment. It can be observed from the map that, the concentration of TDS is highest around the mid-catchment in the Maize / Barley / Wheat Zone and lower catchment in the Marginal Coffee Zone with the lowest concentration being at the upper catchment in the Dairy / Tea Zone.

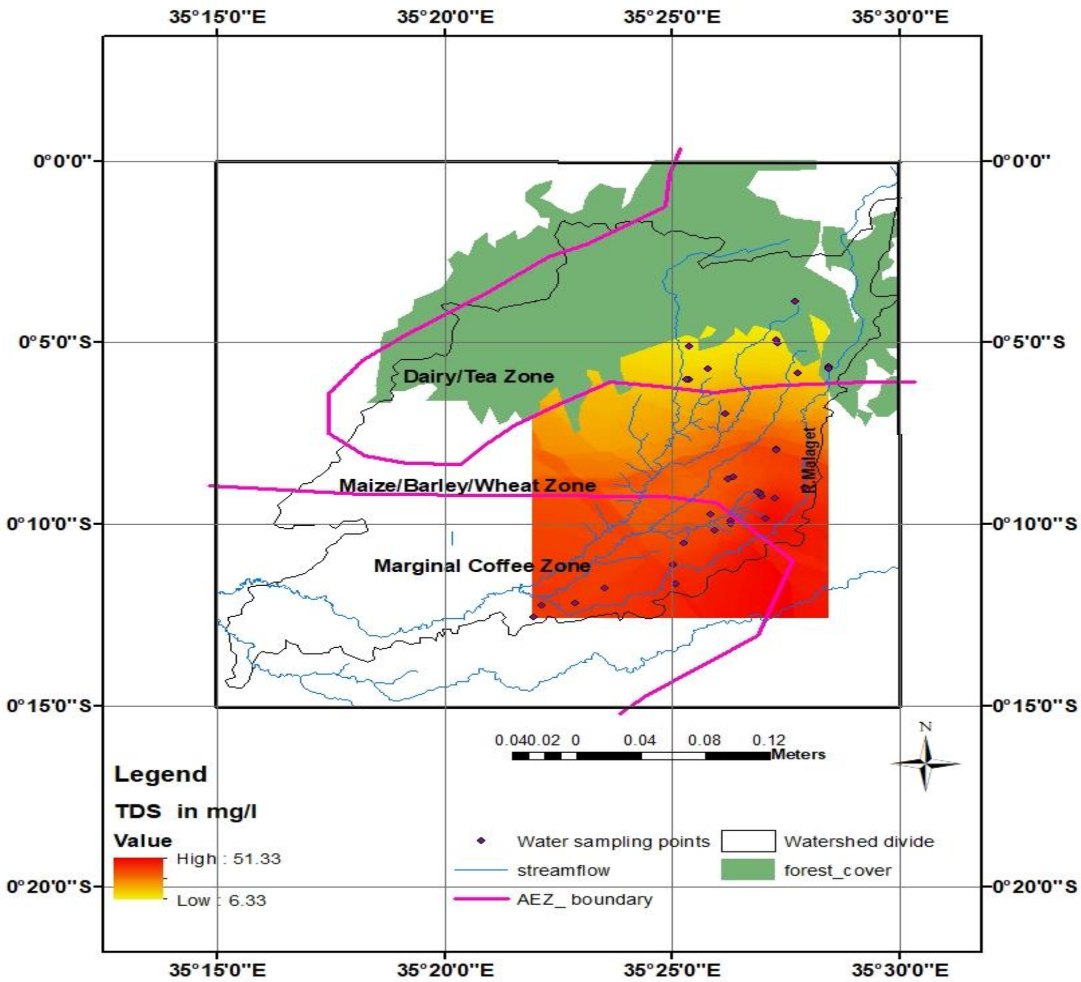


Figure 4.14: Spatial Distribution of TDS in River Malaget Sub-Catchment

4.1.8 Turbidity

The observed values of turbidity in the River Malaget Sub Catchment ranged from 0.82 NTU to 55.70 NTU in the dry season and from 24.01 N.T.U to 56.2 N.T.U in the wet season. There is generally higher turbidity levels in the wet season compared to the dry season, which can be attributed to increased pollution due to run-off. The overall mean value for turbidity in the sub-catchment was 15.23 NTU. The turbidity values for both the springs and streamflow were within the limits of < 5 NTU for drinking water as recommended by both NEMA (2006) and WHO (2004).

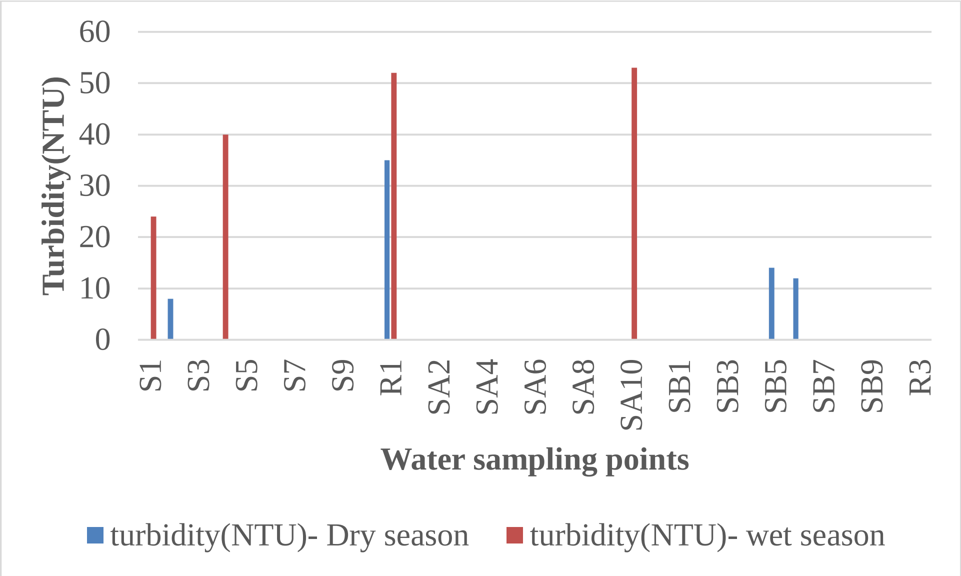


Figure 4.15: Mean turbidity values for the Agro-ecological zones

Figure 4.16 is the thematic map of turbidity which shows the spatial distribution of the parameter in the River Malaget Sub-catchment. It can be observed from the map that the concentration of turbidity is highest around the mid-catchment in the Maize / Barley / Wheat Zone while the average is within the lower catchment in the Marginal Coffee Zone and the lowest concentration being at the upper catchment in the Dairy / Tea Zone.

The highest levels of turbidity are in sampling points within the mid-catchment where vegetation cover is minimal compared to the upper catchment which is largely forested. These result in more runoff incidences which lead to contamination of open water sources by debris, hence, high turbidity levels. Generally, only 5 out of the 33 sampling sites had turbidity concentrations within the acceptable limits by WHO (2004) and NEMA (2006).

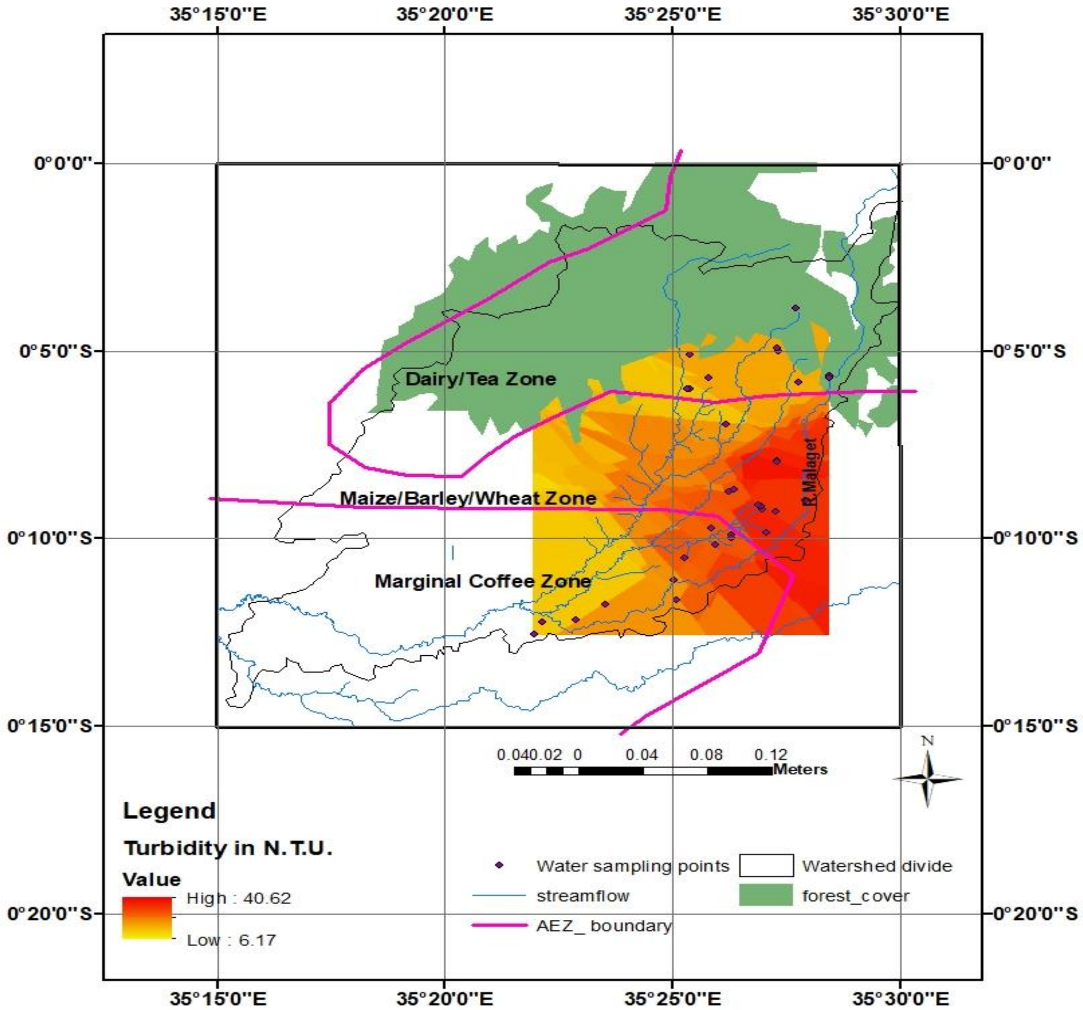


Figure 4.16: Spatial distribution map of Turbidity in River Malaget Sub Catchment

4.1.9 *E.coli*

The observed values of E.coli in the River Malaget Sub-catchment ranged from 0 CFU / 100 ml to 51 CFU / 100 ml in the dry season and 0 CFU / 100 ml to 82 CFU / 100 ml in the wet season. There is a very slight difference in *E.coli* pollution between the two seasons.

The *E.coli* values for most of the sampling points were within the limits of 0 CFU / 100 ml of water as recommended by both NEMA (2006) and WHO (2004) for drinking water. This means that *E.coli* should not be present in any sample of drinking water measured per 100 ml. This is except for 9 sampling points in the dry season and 14 sampling points in the wet season, all of which are spring sources. Run off incidences in the wet season could be responsible for the increase in sampling points polluted by *E.coli*. During a rainstorm human and animal waste may be carried and end up in the spring pools thereby introducing *E.coli* pollution in them.

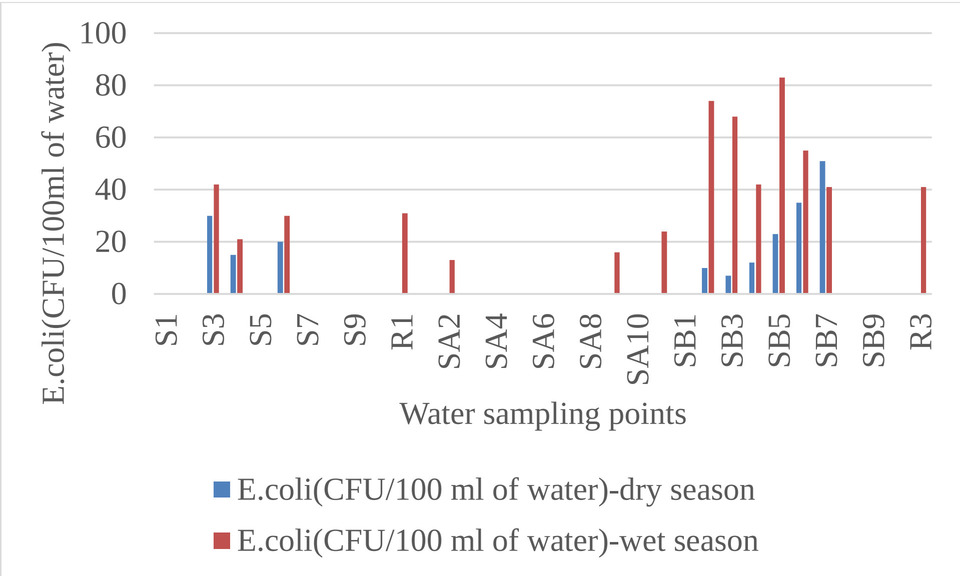


Figure 4.17: Mean *E.coli* values for the Agro-ecological zones

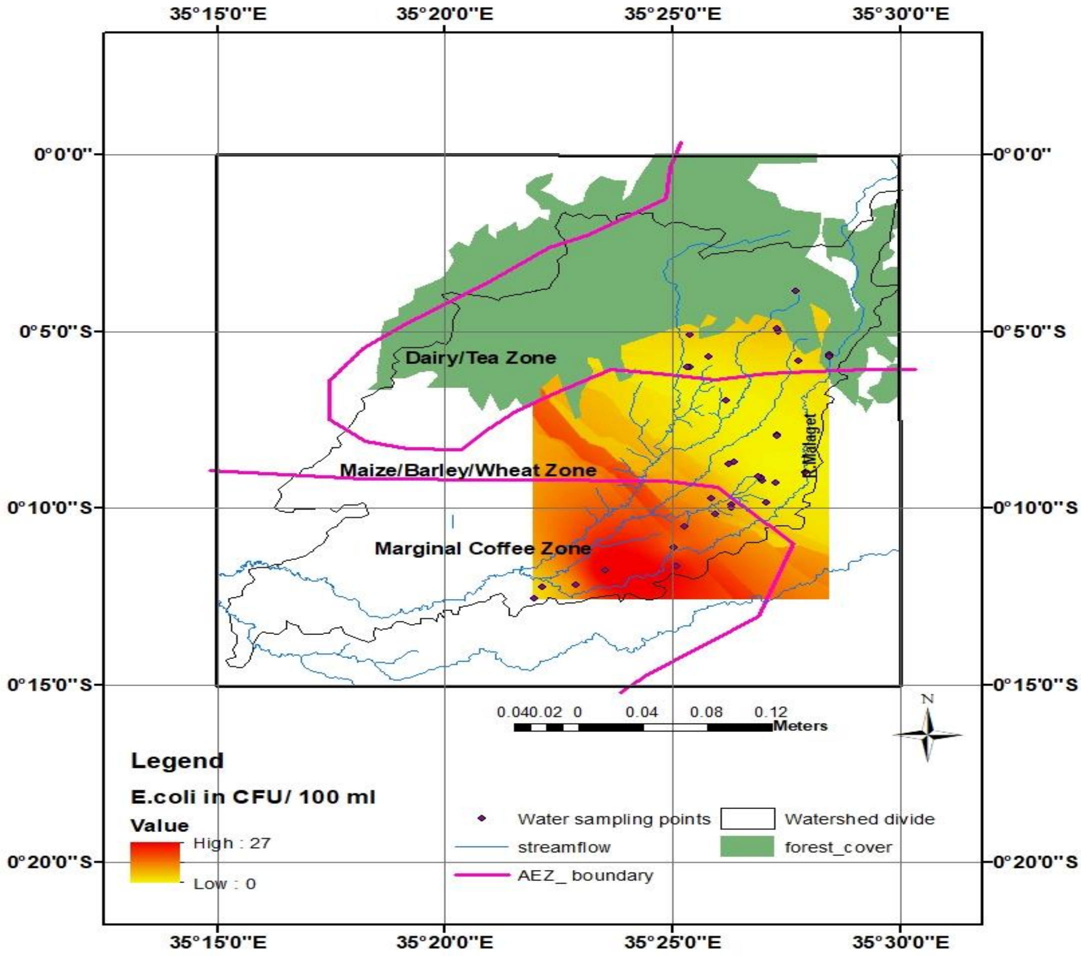


Figure 4.18: Spatial Distribution of *E.coli* in River Malaget Sub-catchment

Figure 4.18 is the thematic map for *E.coli* which shows the spatial distribution of the parameter in the River Malaget Sub-catchment. It can be observed from the map that the concentration of *E.coli* is highest around the mid-catchment in the Maize / Barley / Wheat Zone with the average concentration being at the lower catchment in the Marginal Coffee Zone and the lowest concentration being at the upper catchment in the Dairy / Tea Zone.

4.1.10 BOD

The observed values of BOD in the River Malaget Sub Catchment ranged from 0 mg/l to 5.13 mg/l in the dry season and from 0 mg/l to 4.36 mg/l in the wet season. The variation in the concentration of BOD between the two seasons is very minimal.

The BOD values for both the springs and streamflow were within the limits of 3 mg/l for drinking water as recommended by WHO (2004). BOD is an indicator of oxygen depletion in drinking water, as it is a measure of the amount of oxygen required by micro-organisms such as bacteria to breakdown organic matter in water. Thus, a high BOD is indicative of high levels of organic matter usually originating from waste water discharges. BOD of safe drinking water should be zero, which means that there is no organic matter content and thus no oxygen is required.

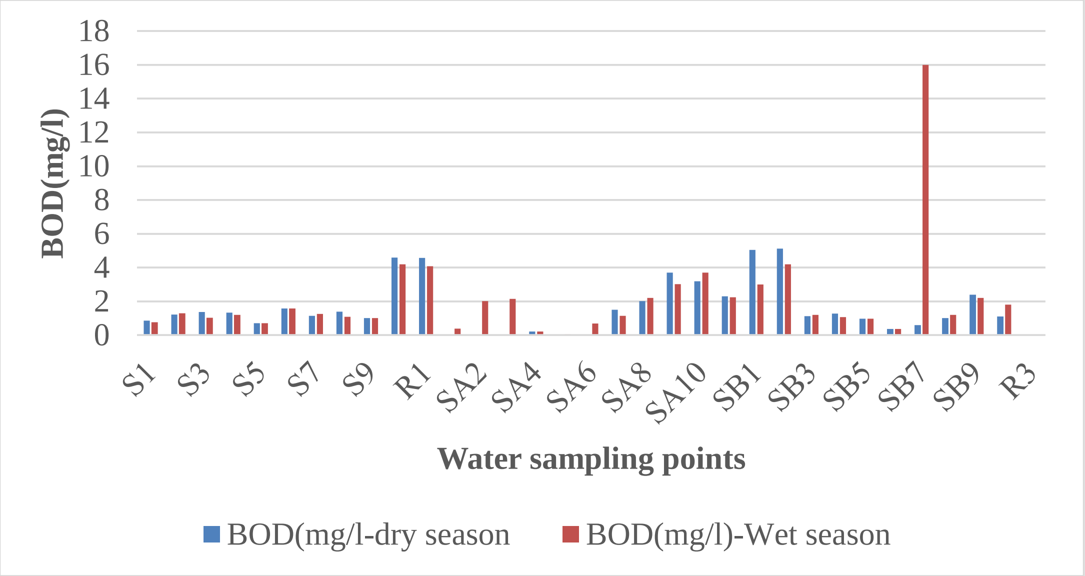


Figure 4.19: Mean BOD of the 3 Agro-ecological zones, Wet Season

Figure 4.20 is the thematic map for BOD which shows the spatial distribution of the parameter in the River Malaget Sub-catchment. It was observed from the map that the concentration of BOD is highest around the upper catchment in the Dairy / Tea Zone and lower catchment in the Marginal Coffee Zone with the average and the lowest concentrations being at the mid catchment in the Maize / Barley / Wheat Zone.

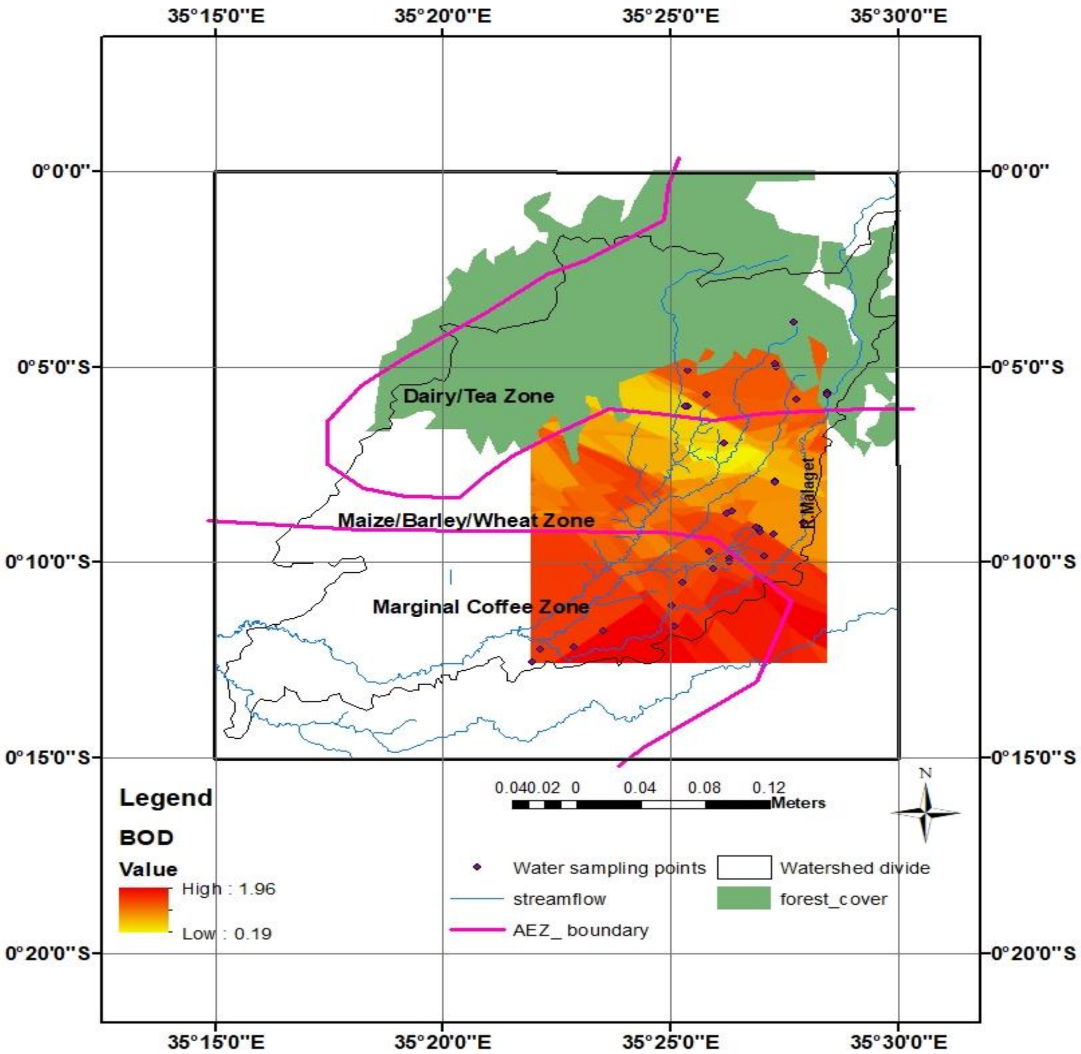


Figure 4.20: Spatial Distribution of BOD in River Malaget Sub-catchment

4.1.11 DO

The observed values of DO in the River Malaget Sub Catchment ranged from 2.49 mg/l to 8.43 mg/l. The overall mean value for DO in the sub-catchment was 5.14 mg/l. There is no guideline value set for DO by either NEMA (2006) or WHO (2004). DO is an indicator of oxygen dissolved in drinking water which is largely a function of the water temperature.

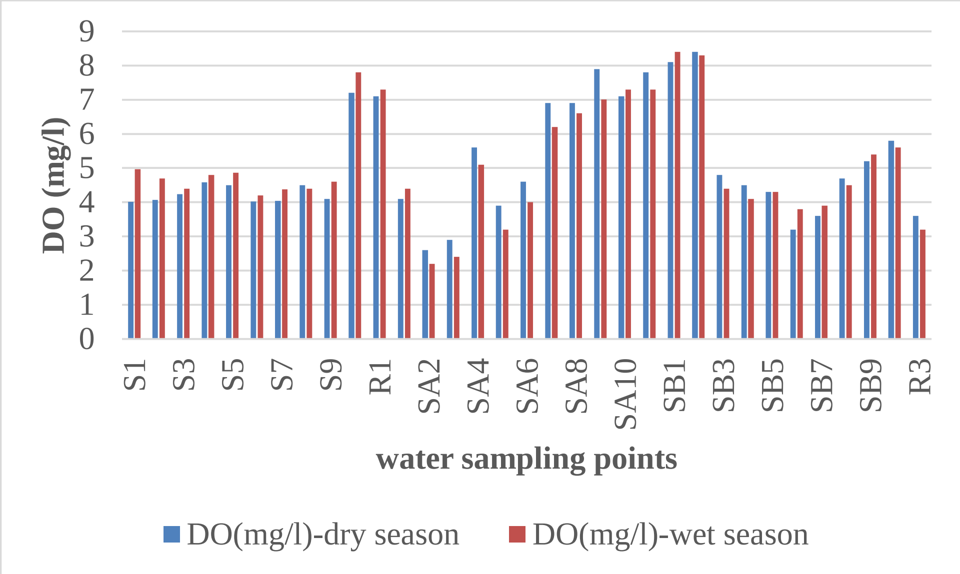


Figure 4.21: Mean DO of the Agro-ecological zones

Figure 4.22 is the thematic map for DO which shows the spatial distribution of the parameter in the River Malaget Sub-catchment. It can be observed from the map that the concentration of DO is highest around the mid-catchment in the Maize / Barley / Wheat Zone with the average concentration being at the lower catchment in the Marginal Coffee Zone and the lowest concentration being at the upper catchment in the Dairy / Tea Zone.

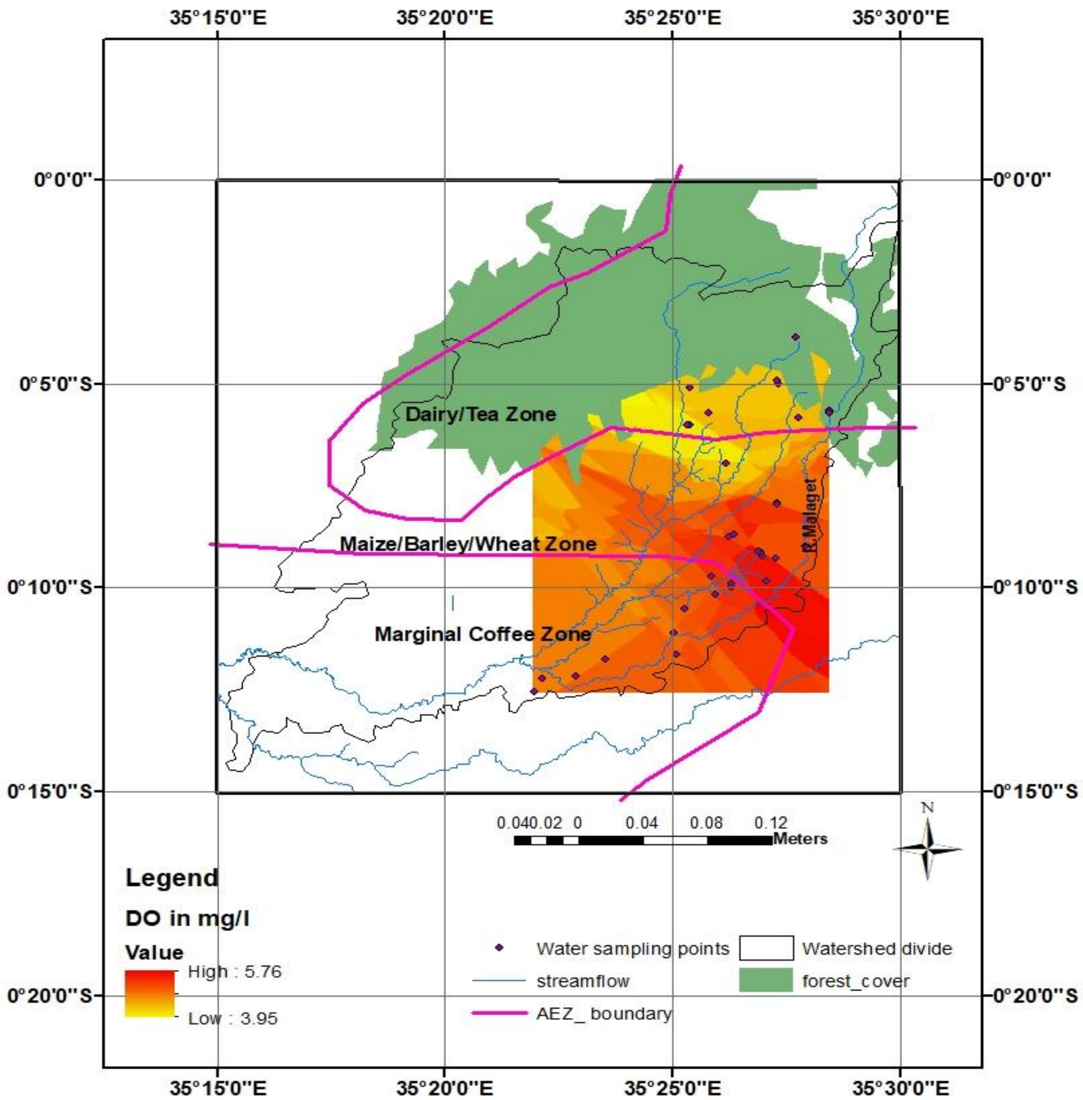


Figure 4.22: Spatial Distribution of DO in River Malaget Sub-Catchment

4.1.12 Temperature

The observed values for water temperature in the River Malaget Sub Catchment ranged from 16.50 ^{o}C to 24.20 ^{o}C in the dry season and from 15 ^{o}C to 23.1 ^{o}C in the wet season. The overall mean temperature in the sub-catchment was 18.98 ^{o}C. Most of the sampling points recorded temperatures below 20 ^{o}C except for a few which were within the limits of 20 - 35 ^{o}C for drinking water as recommended by both NEMA (2006) and WHO (2004). The possible explanation for temperatures below the lower limit of 20 ºC is that these sampling points are springs. Usually springs are sheltered from direct sunshine by the vegetation growing around or nearby, hence the cool temperatures.

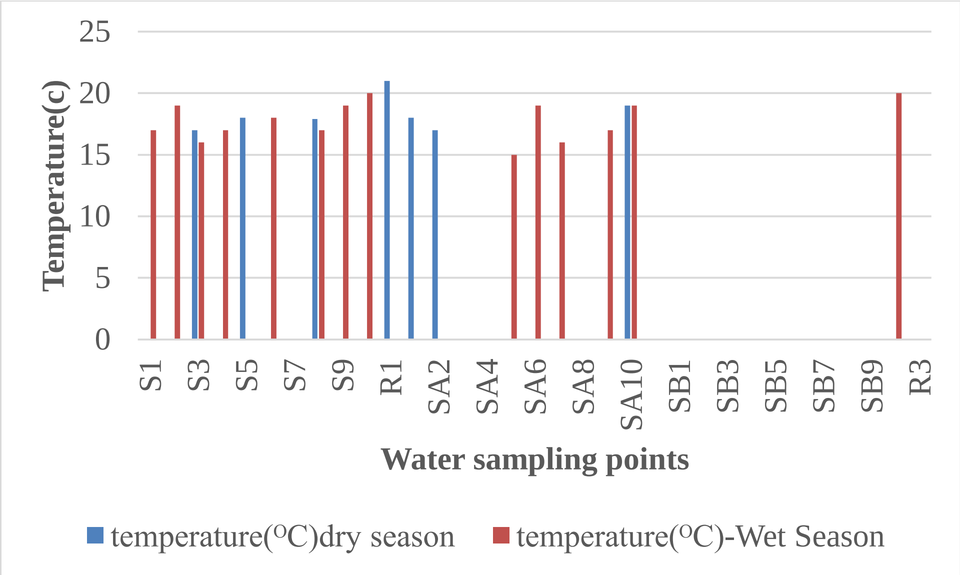


Figure 4.23: Mean temperature of the Agro-ecological zones

It is necessary that the temperature of drinking water is determined, as it is a crucial physical characteristic to the chemical properties of water. Temperature affects the chemical and biological reactions in water as it influences the dissolution of oxygen and the decomposition of organic matter. The higher the temperature the lower the DO levels in water, the higher the toxicity of ammonia, the more the micro-organism activity and the higher the acidity of water (WHO, 2011).

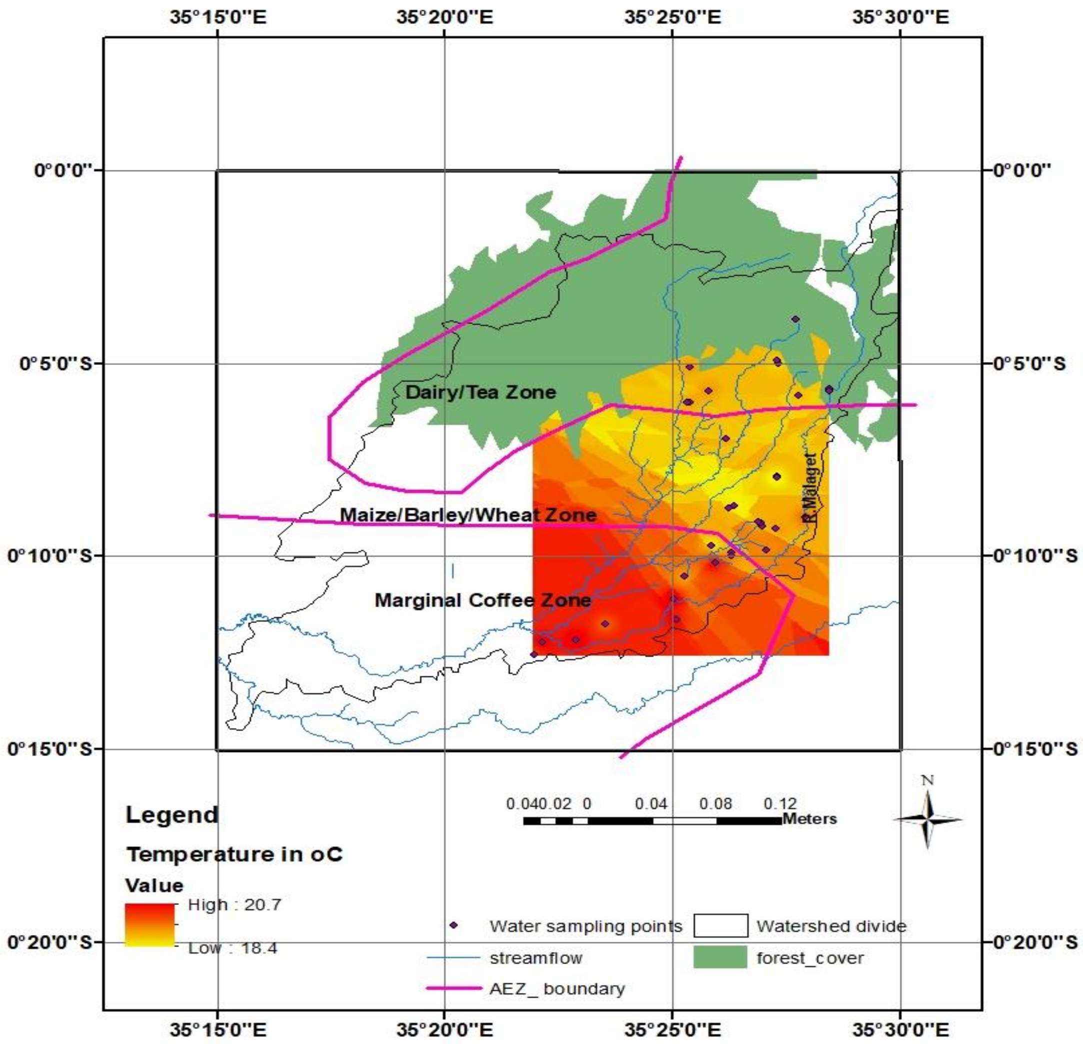


Figure 4.24: Spatial Distribution of Temperature in River Malaget Sub-Catchment

Figure 4.24 is the thematic map for temperature which shows the spatial distribution of temperature in the River Malaget Sub-catchment. It was observed from the map that the concentration of temperature is highest around the lower catchment in the Marginal Coffee Zone with lowest concentration being at the upper catchment in the Dairy / Tea Zone and mid-catchment in the Maize / Barley / Wheat Zone.

4.1.13 pH

The observed values for pH in the River Malaget Sub Catchment ranged from 6.79 to 8.64 in the dry season and from 7.23 to 8.89 in the wet season. This indicates a very slight variation in pH levels between the two seasons.

The pH values for both the springs and streamflow were within the limits of 6.5 - 9.2 and 6.5 - 8.5 for drinking water as recommended by both NEMA (2006) and WHO (2004) respectively in both seasons. Generally, pH levels have no direct or immediate effect on consumers.

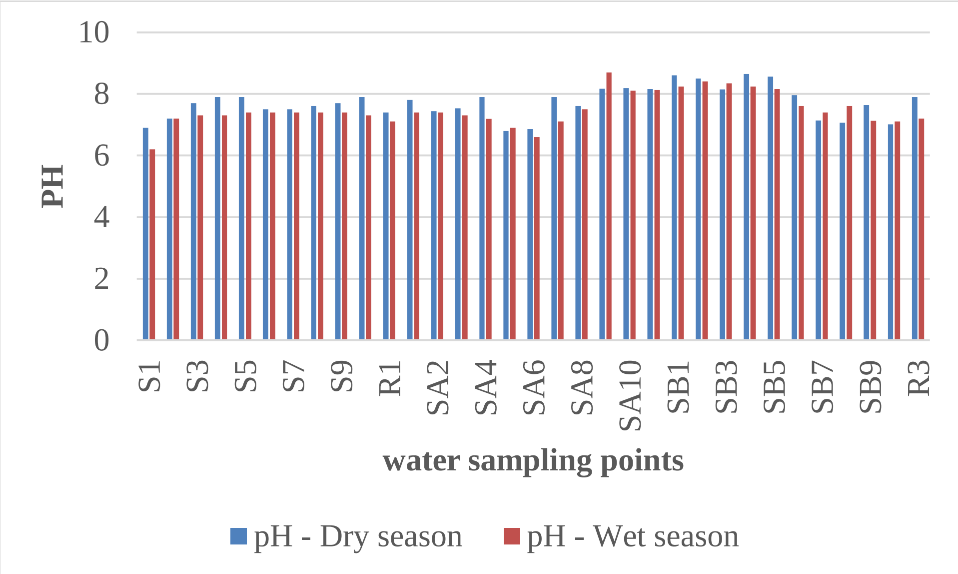


Figure 4.25: Mean pH of the Agro-ecological zones

Figure 4.26 is the thematic map for pH which shows the spatial distribution of the parameter in the River Malaget Sub-catchment. It was observed from the map that the concentration of pH is highest around the mid-catchment in the Maize / Barley / Wheat Zone and lower catchment in the Marginal Coffee Zone with the lowest concentration being at the upper catchment in the Dairy Tea Zone.

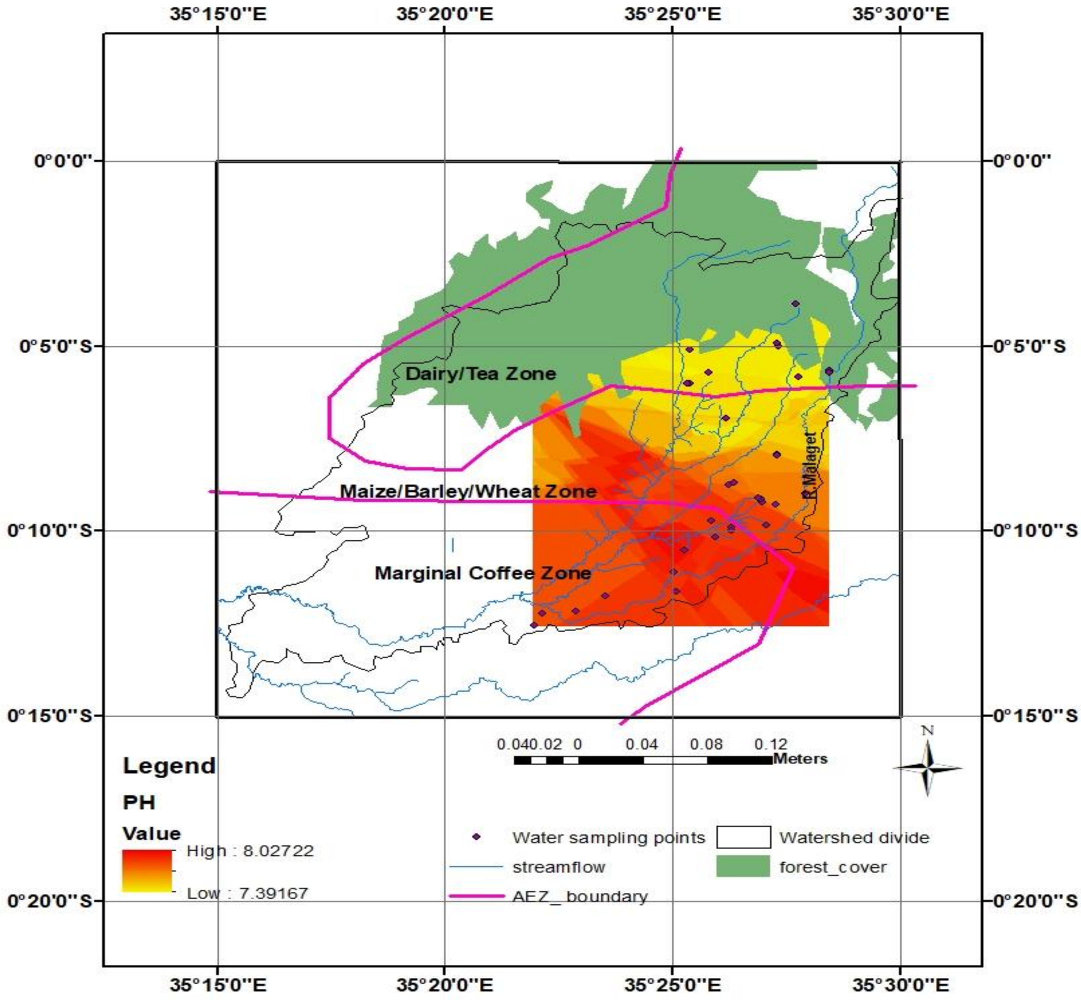


Figure 4.26: Spatial Distribution of pH in River Malaget Sub-Catchment

4.1.14 Fluorides

The observed values for fluorides in the River Malaget Sub Catchment ranged from 0.05 mg/l and 1.76 mg/l in the dry season and from 0.1 mg/l to 1.71 mg/l in the wet season. The fluoride values for both the springs and streamflow were within the limits of 1.5 mg/l for drinking water as recommended by both NEMA (2006) and WHO

(2004) respectively with the exception of a few. These are four spring sites in the dry season and 5 spring sites in the wet season.

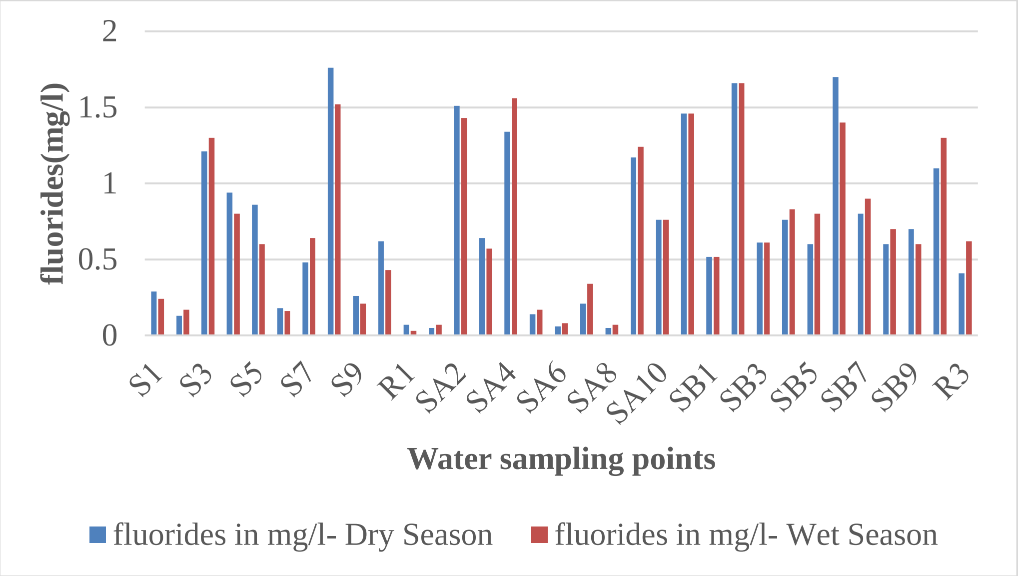


Figure 4.27: Mean fluorides of the Agro–ecological zones

Excessive concentration of fluoride above 1.5 mg/l is associated with dental fluorosis or the browning of the teeth enamel. This study area, being in the Rift valley region which is known to have high fluoride levels in its geology, is expected to have some of its springs containing high levels of the same ions. This is because springs originate from underground and therefore the spring water interacts with the geology before being discharged. There is also not much seasonal variation in the levels of fluorides because these ions originate from the underground and therefore the surface processes may not have much effect on its concentration.

Figure 4.28 is the thematic map for fluorides which shows the spatial distribution of the parameter in the River Malaget Sub-catchment. It was observed from the map that the concentration of fluorides is highest around the mid-catchment in the Maize /

Barley / Wheat Zone and lower catchment in the Marginal Coffee Zone with the lowest concentration being at the upper catchment in the Dairy / Tea Zone.

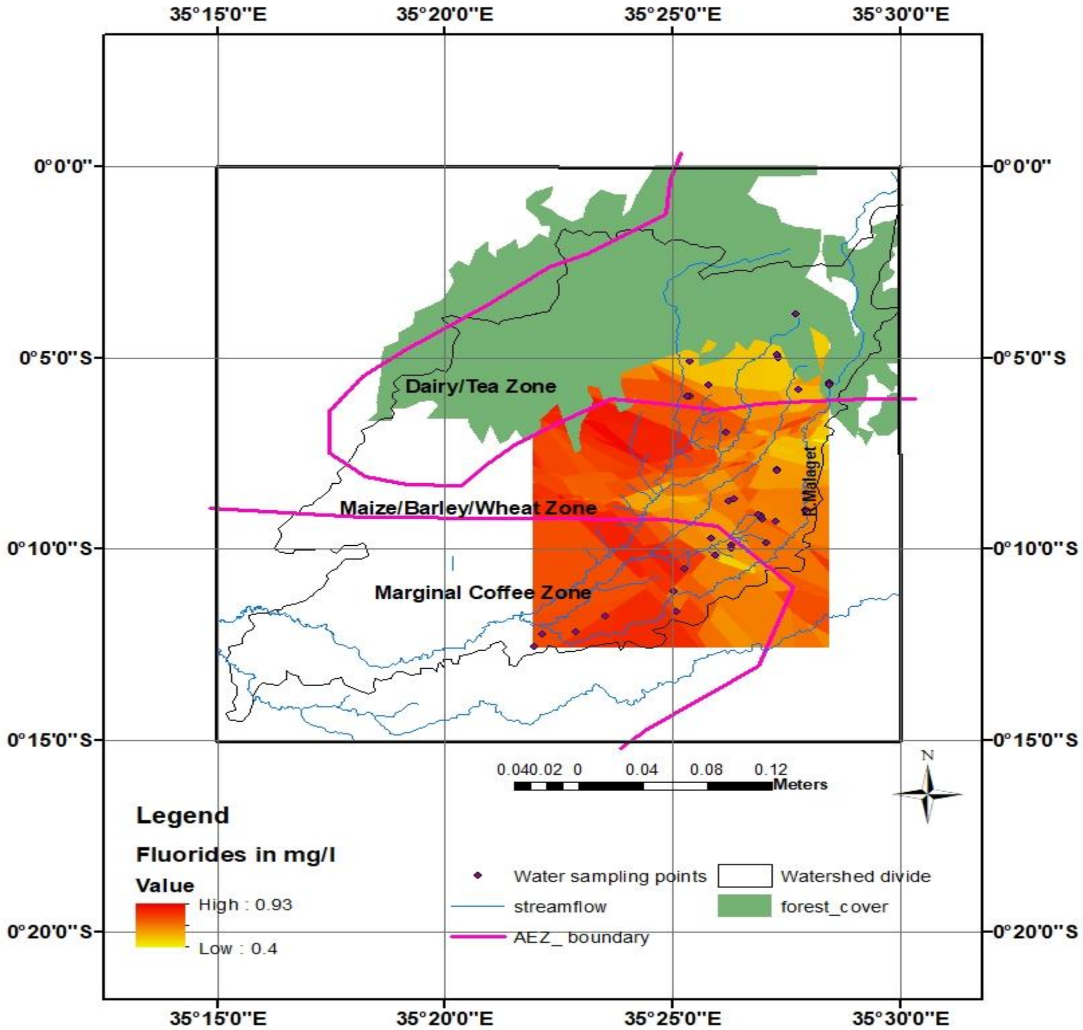


Figure 4.28: Spatial Distribution of Fluorides in the River Malaget Sub-catchment

4.1.15 Total Hardness (TH)

The observed values for Total Hardness in the River Malaget Sub Catchment ranged from 12 mg/l to 354.07 mg/l in the dry season and 13.4 mg/l to 325.4 mg/l in the wet season. The overall mean value for Total hardness in the sub-catchment was 118.39

mg/l. The Total hardness values for both the springs and streamflow were within the limits of < 500 mg/l for drinking water as recommended by both NEMA (2006) and WHO (2004) respectively.

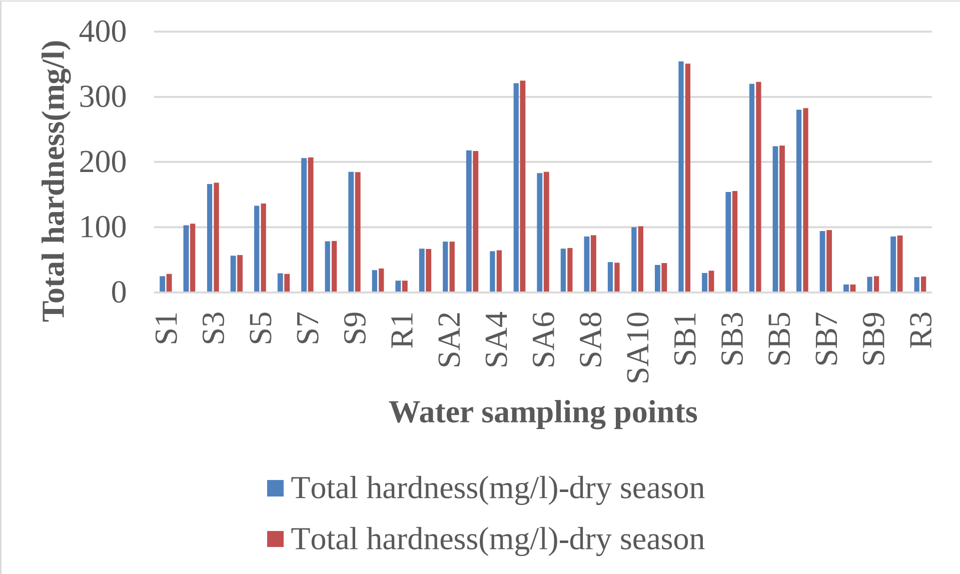


Figure 4.29: Mean Total Hardness values for the 3 Agro-ecological zones

Figure 4.30 is the thematic map for total hardness which shows the spatial distribution of the parameter in the River Malaget Sub-catchment. It was observed from the map that the concentration of total hardness is highest around the mid-catchment in the Maize / Barley / Wheat Zone and lower catchment in the Marginal Coffee Zone with the lowest concentration being at the upper catchment in the Dairy / Tea Zone.

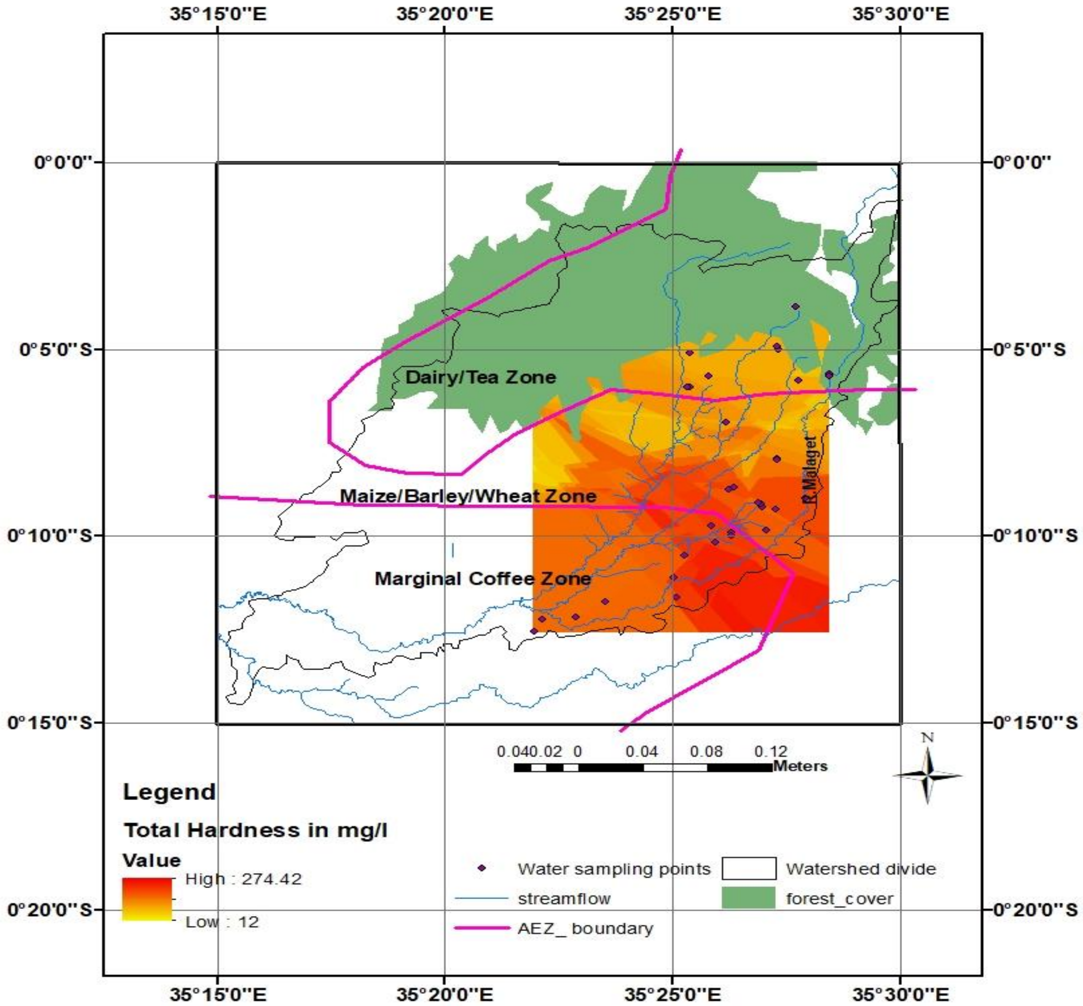


Figure 4.30: Spatial Distribution of Total Hardness in the River Malaget Sub-catchment

4.2 Testing Hypothesis 1 for the Mean Differences of the Agro-ecological Zones

Principal component analysis (PCA) and factor analysis using varimax rotation was used to reduce the 15 water quality parameters measured to only 9 that indicate nutrient and micro-organic pollution. These 9 parameters were then subjected to further analysis using Multivariate Analysis of Variance (MANOVA).

Factor analysis was conducted and principal component analysis (PCA) was used as the extraction method. The Kaiser–Meyer–Olkin measure verified the sampling adequacy for the analysis, KMO = .447 and all KMO values for individual items were <.5, which is the acceptable limit. Bartlett's test of sphericity χ^2 (66) = 171.425, $p < .001$, indicated that correlations between items were sufficiently large for PCA.

An initial analysis was run to obtain eigenvalues for each component in the data. Five components had eigenvalues over Kaiser's criterion of 1 and in combination explained 77.46% of the variance. Given the convergence of the scree plot and Kaiser's criterion on five components, this is the number of components that were retained in the final analysis.

Table 4.1: Rotated Component Matrix

Parameters	Component				
	1	2	3	4	5
BOD in mg/L	.925				
DO in mg/L	.925				
pH	.678		.537		
turbidity in N.T.U	.658			.534	
ammonia		.896			
phosphates in mg/L		.862			
conductivity in µS/cm			.830		
E.coli in C.F.U./100 mL			.706		
nitrites				.773	
TSS in mg/L				.699	
nitrates in mg/L					.892
temperature in ^{o}C		.542			-.680

Table 4.2 shows the factor loadings after orthogonal (varimax) rotation. The items that cluster on the same components suggest that factor 1 represents measures of oxygen levels (BOD, DO); factor 2 represents measures of pollution from nutrients (ammonia,

phosphates), that are sensitive to temperature levels ; factor 3 represents measures of pollutants that are sensitive to pH levels (electrical conductivity and E.coli) ; factor 4 represents measures of pollutants in suspension which are sensitive to turbidity levels (TSS and nitrites) and factor 5 represents pollutants from nutrients which are sensitive to temperature levels (nitrate).

MANOVA was used to compare the means of the three agro-ecological zones, i.e., Tea-Dairy Zone, Wheat/Maize/Barley Zone, and Marginal Coffee Zone. Using Pillai's Trace, there was significant variability in the distribution of water quality parameters in relation to land use as the means of the three agro-ecological zones were significantly different, $V = 0.75$, $F(9, 23) = 7.70$, $p < .05$. This is illustrated by Table 4.2, as the values are highlighted in yellow. Pillai's Trace is the most robust of the four multivariate tests when the group sizes are equal and when comparing the means of several dependent variables per group. In addition, it is also the safest test and the most robust to violations of MANOVA assumptions.

Table 4.2: Summary of MANOVA Tests

Test	Value	F	Hypothesis df	Error df	Sig.
Pillai's Trace	.751	7.696	9.000	23.000	.000
Wilks' Lambda	.249	7.696	9.000	23.000	.000
Hottelling's Trace	3.012	7.696	9.000	23.000	.000
Roy's Largest Root	3.012	7.696	9.000	23.000	.000

The univariate ANOVAs on each of the dependent variables revealed significant effect on electrical conductivity, $F(1, 31) = 329402.91$, $p > .05$; phosphates, $F(1, 31) = 0.001$, $p > .05$; and ammonia, $F(1, 31) = 0.006$, $p > .05$. Table 4.3 shows the results for the univariate ANOVA tests that followed-up the main MANOVA analysis.

Table 4.3: Test of Between Subjects Effects

Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Conductivity in µS/cm	329402.91	1	329402.91	24.174	.000
DO in mg/L	.208	1	.208	.086	.771
TSS in mg/L	.359	1	.359	.553	.463
E.coli in C.F.U./100 mL	242.227	1	242.227	1.604	.215
BOD in mg/L	.016	1	.016	.005	.946
nitrates in mg/L	15.376	1	15.376	.217	.645
phosphates in mg/L	.001	1	.001	4.968	.033
Nitrites in mg/L	8.542E-005	1	8.542E-005	3.704	.063
Ammonia in mg/L	.006	1	.006	8.865	.006

The MANOVA was also followed up with discriminant function analysis, which revealed two discriminant functions. The first explained 79.5% of the variance, canonical R^2 = .52, whereas the second explained only 20.5%, canonical R^2 = .22. In combination these discriminant functions significantly differentiated the treatment groups, λ=0.378, χ^2 (4) =28.673, p = <.05, and even removing the first function indicated that the second function still significantly differentiate the treatment groups, λ=0.784, χ^2 (1) =7.187, p <.05.

The correlations between outcomes and the discriminant functions revealed that electrical conductivity loaded very highly onto the first function (r =.942) and lowly on the second function and (r =.336); turbidity loaded more highly on the first function (r = -.091) than the second function (r = -.027); nitrates loaded very highly onto the second function (r =.924) and lowly on the first function and (r = -.382); and temperature loaded very highly onto the second function (r = -.237) and lowly on the first function (r =.050). The discriminant function plot showed that the second function discriminated the Tea-Dairy Zone from the Wheat/Maize/Barley Zone, and the first function differentiated the Marginal Coffee Zone from the two zones, that is, Tea-Dairy Zone from the Wheat/Maize/Barley Zone.

4.3 Water Quality Index Results

The computed WQI values were grouped into five categories namely; excellent, good, poor, very poor and unfit water for drinking purposes (Lateef, 2011 and Ketata-Mouna, *et al.*, 2011). WQI range of < 50 is categorised as excellent water; 50-100 is good water; 100-200 is poor water; 200-300 is very poor water while > 300 categorised as unfit water for drinking purposes.

The results obtained for WQI values for the various sampling points ranged from 12.22 at sampling point SB7, to 237.86 at sampling point SA9 as shown on Table 4.2. Most of the samples had WQI values which were less than the threshold value of 100. More than half (57.58 %) of the samples were of excellent water quality, while 24.24 % were of good water quality, 9.09 % were of poor water quality and the remaining 9.09 % of the samples were of very poor water quality.

Table 4.4: Water Quality Index Results of River Malaget Sub-catchment

Water sampling points	SI=(WI*qi)	Status of water quality
S1	31.88	Excellent
S2	44.124	Excellent
S3	50.98	Good
S4	57.99	Good

S5	44.04	Excellent
S6	37.07	Excellent
S7	34.58	Excellent
S8	36.98	Excellent
S9	36.68	Excellent
S10	36.14	Excellent
R1	152.55	Poor
SA1	17.95	Excellent
SA2	68.38	Good
SA3	51.13	Good
SA4	32.18	Excellent
SA5	40.83	Excellent
SA6	43.03	Excellent
SA7	147.71	Poor
SA8	151.09	Poor
SA9	234.86	Very poor
SA10	225.39	Very poor
R2	221.28	Very poor
SB1	95.027	Good
SB2	91.37	Good
SB3	33.92	Excellent
SB4	33.51	Excellent
SB5	20.49	Excellent
SB6	90.73	Good
SB7	12.22	Excellent
SB8	38.05	Excellent
SB9	39.10	Excellent
SB10	33.04	Excellent
R3	93.94	Good
totals	2378.23	

Figure 4.31 is the water quality index map developed for the River Malaget Sub-catchment, which shows the spatial distribution of water quality parameters and their status in the area. It was observed from the map that, generally sampling points within the upper catchment which is the Dairy / Tea Zone had excellent water quality compared to the other zones that had scores above 50.

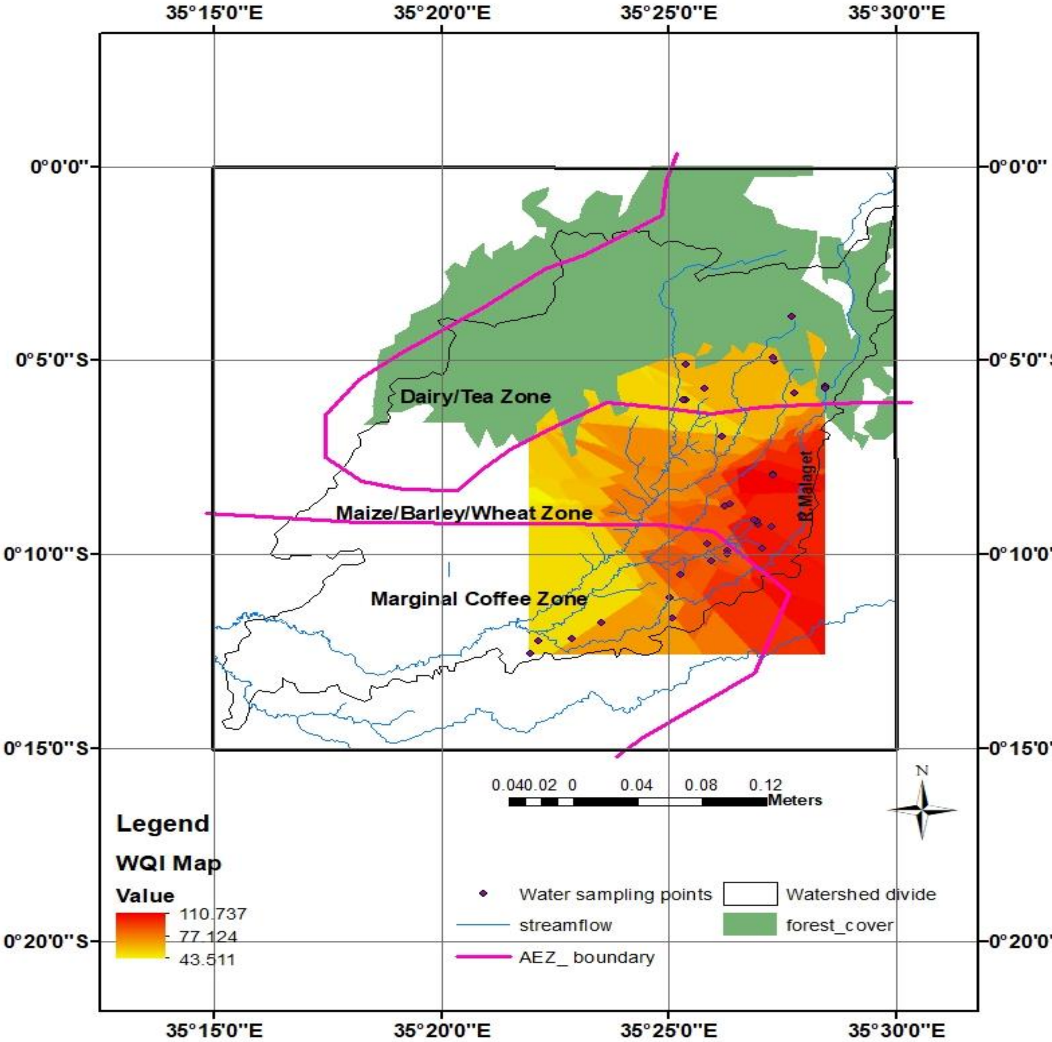


Figure 4.31: WQI Map of River Malaget Sub-catchment

4.4 Testing Hypothesis 2 to Compare Spring and Streamflow Water Quality

Independent t-test was used to compare the means of the two water sources, that is, springs and streamflow. T-test analysis was performed to compare the variation in the means of the water quality parameters from the two water sources, that is, spring and streamflow. Data was checked for normality and equality of variance using histograms and Levene's tests respectively.

The student's independent t-test analysis performed at 95% confidence interval showed that there was a significant difference (P < 0.05) between the sampled streamflow points and springs for TSS and nitrates. The average TSS for spring water sources was lower (*M* = -.09, *SE* = .10) compared to that of streamflow sources (*M* = 1.14, *SE* = 1.13). This difference was significant *t* (31) = -1.08, *p* <.05; however, it did represent a medium-sized effect *r* = 0.19. The average nitrates for spring water sources was lower (*M* = 18.88, *SE* = 1.58) compared to that of streamflow sources (*M* = 21.55, *SE* = 2.00). This difference was significant *t* (31) = -1.04, *p* <.05; however, it did represent a medium-sized effect *r* = 0.18. Table 4.5 shows the summary of the T-Test results.

Table 4.5: T-Test Analysis Results

Parameters tested	F	Sig.	t	df	Sig. (2-tailed)
temperature in °C	.001	.975	-3.741	31	.001
conductivity	.623	.436	.503	31	.619
pH	.110	.743	-.043	31	.966
turbidity in N.T.U	.018	.893	-2.702	31	.011
DO in mg/L	1.363	.252	-.924	31	.363
TSS in mg/L	17.388	.000	-2.785	31	.009
BOD in mg/L	.198	.660	-.867	31	.392
E.coli in C.F.U./100 mL	3.601	.067	.898	31	.376
nitrates in mg/L	5.299	.028	-.523	31	.605
phosphates in mg/L	.219	.643	-.352	31	.727
nitrites	.468	.499	-.261	31	.796
Ammonia	3.085	.089	-1.036	31	.308

The average temperature for spring water sources was lower (*M* = 18.65, *SE* = .29) compared to that of streamflow sources (*M* = 22.30, *SE* = .97). This difference was not significant *t* (31) = -3.74, *p* >.05; however, it did represent a medium-sized effect *r* = 0. 56. The average electrical conductivity for spring water sources was higher (*M* = 293.92, *SE* = 28.85) compared to that of streamflow sources (*M* = 246.70, *SE* = 72.67). This difference was not significant *t* (31) = .503, *p* >.05; however, it did represent a medium-sized effect *r* = 0.09.

The average pH for spring water sources was lower (*M* = 7.60, *SE* = .10) compared to that of streamflow sources (*M* = 7.62, *SE* = .27). This difference was not significant *t* (31) = - .043, *p* >.05; however, it did represent a medium-sized effect *r* = 1.64.

The average turbidity for spring water sources was lower (*M* = 13.17, *SE* = 2.51) compared to that of streamflow sources (*M* = 35.83, *SE* = 9.01). This difference was not significant *t* (31) = -2.7, *p* >.05; however, it did represent a medium-sized effect *r* = 0.44. The average DO for spring water sources was lower (*M* = 5.06, *SE* = .27) compared to that of streamflow sources (*M* = 5.92, *SE* = 1.33). This difference was not significant *t* (31) = -.924, *p* >.05; however, it did represent a medium-sized effect *r* = 0.16.

The average BOD for spring water sources was lower (*M* = 1.29, *SE* = .33) compared to that of streamflow sources (*M* = 2.26, *SE* = 1.35). This difference was not significant *t* (31) = -.867, *p* >.05; however, it did represent a medium-sized effect *r* = 0.15. The average *E.coli* for spring water sources was higher (*M* = 6.77, *SE* = 2.35) compared to that of streamflow sources (*M* = .00, *SE* = .00). This difference was not significant *t* (31) =.898, *p* >.05; however, it did represent a medium-sized effect *r* = 0.16.
The average phosphates for spring water sources was lower (*M* = .010, *SE* = .002) compared to that of streamflow sources (*M* = .015, *SE* = .008). This difference was not significant *t* (31) = -.352, *p* >.05; however, it did represent a medium-sized effect *r* =

0.06. The average nitrites for spring water sources was higher (*M* = -.0008, *SE* = .0009) compared to that of streamflow sources (*M* = .0000, *SE* = .0026). This difference was not significant *t* (31) = -.261, *p* >.05; however, it did represent a medium-sized effect *r* = 0.05. The average ammonia for spring water sources was higher (*M* = 013, *SE* = .005) compared to that of streamflow sources (*M* = .031, *SE* = .029). This difference was not significant *t* (31) = -1.04, *p* >.05; however, it did represent a medium-sized effect *r* = 0.18.

Most of the springs sampled were found to be unprotected. In fact out of the 30 springs sampled, only 2 were found to be adequately protected using concrete walls with an outlet through a pipe from which drawing of water is done by the users. In fact, going by the results, it is clear that protection of springs by concrete is effective in controlling pollution. All the water quality indicators tested for the two protected springs were found to be within the acceptable limits by WHO (2004) and NEMA (2006).

This is supported by the findings by Miguel *et al*., (2008), that spring protection improved child health as diarrhoea among young children in households under study fell by 4.6 %, on a base diarrhoea prevalence of approximately 20 %. Construction of concrete walls to encase the spring pools from contamination by run-off or careless methods of water collection should be encouraged, based on results from such protected sources.


Plates 4.1: Photographs of the two protected springs in River Malaget Sub-catchment. Both are fully sealed from all forms of external contaminants. The one on the left is Tinga monastery Spring while the one on the right is Tingatela Community Spring (Source: field data).


Plates 4.2: Photographs of the two semi-protected springs are fenced off with either a stone wall or wood plugs to keep away large animals (Source: field data)

The location of springs generally exposes them to the risk of pollution, because they are on the path of runoff which may introduce dirt into them. This is more so where these springs have been modified to increase their usefulness, thereby resulting in spring pools as is the case with those sampled in this study. Hence, such water sources become receiving pools or bowls that collect runoff, in addition to the spring water already oozing into them from the ground water system.

Plate 4.3: Photographs showing the position of springs along the slope which exposes them to contamination by run-off (Source: field data).

CHAPTER FIVE: SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of Findings

5.1.1 Spring and Streamflow Water Quality

Parametric results revealed that all samples tested for temperature, electrical conductivity, DO, nitrites and total hardness were within the recommended levels. However, some of the samples tested for nitrates, ammonia, pH, turbidity, total dissolved and suspended solids, BOD, *E.coli*, fluorides, and phosphates were found to exceed the recommended levels.

5.1.2 Mean Differences of the Agro-ecological Zones

The first hypothesis - there is no significant variability in the distribution of water quality parameters in relation to land use - was tested using MANOVA. The means of each parameter was compared amongst the three agro-ecological zones. The univariate ANOVAs on each of the dependent variables revealed significant effect on temperature, $F (2, 30) = 4.833$, $p > .05$; electrical conductivity, $F (2, 30) = 14.730$, $p > .05$; turbidity, $F (2, 30) = 3.600$, $p > .05$; and nitrates, $F (2, 30) = 5.879$, $p > .05$. Hence, it can be concluded that indeed land use has an impact on the water quality of the study area, considering the spatial distribution of temperature, nitrates, electrical conductivity and turbidity.

5.1.3 Spatial Distribution of Water Quality Parameters

Each water quality indicator was measured and mapped to illustrate the spatial distribution of each in relation to the land use. Various observations were made from the spatial distribution maps of the individual water quality parameters tested. Firstly, it was observed that the highest concentration of phosphates was in the lower catchment, with the lowest concentration being at the mid-catchment and upper catchment. It was also observed from that the concentration of nitrates is highest around the mid-catchment with the average concentration being at the lower catchment compared to the lowest concentrations in the upper catchment zone. Additionally, it was observed that the concentration of nitrites is highest around the mid-catchment and lower catchment compared to the lowest concentrations in the upper catchment zone.

Further, it was observed that the concentration of ammonia is highest around the lower catchment with the lowest concentrations being in the mid-catchment and the upper catchment zones. It was also observed from the map that the concentration of electrical conductivity is highest around the mid-catchment and lower catchment compared to the lowest concentrations in the upper catchment zone. Additionally, it was observed that the concentration of TSS is highest around the mid-catchment, with the average concentration being in the upper catchment compared to the lowest concentrations in the lower catchment zone. It was also observed that the concentration of TDS is highest around the mid-catchment and lower catchment with the lowest concentration being in the upper catchment.

Furthermore, it was observed from the map that the concentration of BOD is highest around the upper catchment and lower catchment with the average and the lowest concentrations being in the mid-catchment. It was also observed that the concentration of DO is highest around the mid-catchment with the average concentration being in the lower catchment and the lowest concentration being in the upper catchment. Moreover, it was observed that the concentration of temperature is highest around the lower catchment with lowest concentration being in the upper catchment and mid-catchment. It was also observed that the concentration of pH is highest around the mid-catchment and lower catchment with the lowest concentration being in the upper catchment. In addition, it was observed that the concentration of fluorides is highest around the mid-catchment and lower catchment with the lowest concentration being in the upper catchment. Lastly, it was observed from the map that the concentration of total hardness is highest around the mid-catchment and lower catchment with the lowest concentration being in the upper catchment.

5.1.4 Water Quality Index of Each Selected Sampling Point

The results obtained for WQI values for the various sampling points ranged from 12.22 at sampling point SB7, to 237.86 at sampling point SA9 as shown on Table 4.2. Most of the samples had WQI values which were less than the threshold value of 100, which meant that generally the water quality was either excellent or good. More than half (57.58 %) of the samples were of excellent water quality, while 24.24 % were of good water quality, 9.09 % were of poor water quality and the remaining 9.09 % of the samples were of very poor water quality. The high levels of turbidity in the sub-catchment in all the samples, which exceeded the NEMA (2006) and WHO (2004) guideline values is largely responsible for the very high WQI values.

5.1.5 Difference between Spring and Streamflow Water Quality

The fourth objective of this study was to evaluate the relationship between spring and streamflow water quality in River Malaget sub-catchment. This was done using the T-test analysis to test the null hypothesis: there is no significant difference between the spring water quality and streamflow water quality. The student’s independent T-test analysis performed at 95% confidence interval showed that there was a significant difference ($p < 0.05$) between the sampled streamflow points and springs for TSS, total hardness and nitrates. The average concentration was higher for ammonia, E.coli, electrical conductivity and nitrites; and lower for temperature, phosphates, pH, TSS, BOD, DO, turbidity and nitrates, in spring water sources compared to that of streamflow sources. However, the observed values for TSS, nitrates and total hardness were within the recommended levels by both NEMA (2006) and WHO (2004) respectively.

Further, correlation analysis for all the parameters tested was performed using the Pearson's technique. In summary, it was found that the strongest and most significant correlations (that is with $r > .3$ and significance level of $p < .001$) are between DO and BOD, $r = .909$; turbidity and DO, $r = .609$; ammonia and phosphates, $r = .686$; turbidity and BOD, $r = .463$; turbidity and TSS, $r = .392$; pH and turbidity, $r = .410$; pH and DO, $r = .468$; and pH and BOD, $r = .475$. In addition, some correlations were found to be strong ($r > .3$ and significant at $p < .005$. These were: temperature and nitrates, $r = -.382$; temperature and ammonia, $r = .440$, temperature and phosphates, $r = .363$; Electrical conductivity and E.coli, $r = .401$; Electrical conductivity and TDS, $r = .382$ and lastly, TSS and total hardness, r = -.344.

5.2 Conclusions

Generally, it can be concluded that the lowest concentration of all the parameters tested was found in the upper catchment. Largely, the average and the highest concentrations were within the mid-catchment and the lower catchment. Moreover, the concentration of nutrients such as phosphates, nitrates, nitrites and ammonia was highest in the lower catchment and mid catchment where agriculture is practised. These are the Maize/Wheat/Barley zone and the Marginal Coffee zone where manure from animal wastes is added to the soil to improve its fertility. These findings correspond to various studies (Ketata *et al*., 2011; McCarthy and Johnson, 2009; Achieng' *et al*., 2017; Ontumbi *et al*., 2015; Okumu and Otim, 2015 and Ashun, 2014) done in agricultural regions worldwide.

The third specific objective was to determine the WQI of the selected sampling points. WQI values calculated placed the quality of the water from the different sites within varying categories. Hence it can be concluded from the WQI results that, most sites in the agro-ecological zones 1 and 3 were of excellent and good water quality, while most of those in zone 2 were of poor and very poor water quality and therefore unsuitable for drinking purposes.

The fourth objective of this study was to evaluate the relationship between spring and streamflow water quality in River Malaget sub-catchment. This was done using the T-test analysis to test the null hypothesis: there is no significant difference between the spring water quality and streamflow water quality. The average concentration was higher for ammonia, E.coli, electrical conductivity and nitrites; and lower for temperature, phosphates, pH, TSS, BOD, DO, turbidity and nitrates, in spring water sources compared to that of streamflow sources. Hence, it can be concluded that there is a relationship between the sampled streamflow points and springs**,** considering TSS, total hardness and nitrates.

Further, it can be concluded from the correlation results that ammonia and phosphate contamination sources are anthropogenic, most likely coming from manure added to soil to improve fertility. These end up being washed into the water sources by run-off during a rain storm, hence, a human-induced impact on the water quality of the area. The significant correlation between temperature and the three nutrients tested, that is phosphates, nitrates and ammonia also seems to suggest the same. In addition, the significant correlation between TSS and turbidity helps to further strengthen this conclusion. Finally, the significant positive correlation between electrical conductivity and TDS, and the significant negative correlation between TSS and total hardness seems to suggest that some of the effect on the water quality of River Malaget Sub-catchment is from the geological makeup and not just from land uses.

5.3 Recommendations

The study recommends the following based on the conclusions drawn from the findings:

a. The community should protect all springs using concrete or by fencing off to minimize their contamination by run-off or by users as they draw water from them and by large animals such as livestock.
b. The local users should treat water before drinking by either boiling or adding treatment chemicals and filtering.

5.4 Areas of Further Study

Further research is required in the following areas in the River Malaget Sub-catchment:

a. The effect of on-site sanitation facilities such as pit latrines on spring and streamflow quality.
b. Possibility of contamination of groundwater by leaching of wastes from land use especially, animal waste, herbicides and pesticides.

REFERENCES

Achieng', A.O., Raburu, P.O., Kipkorir, E. C., Ngodhe, S. O., Obiero, K.O. and Ani-Sabwa, J. (2017). Assessment of Water Quality using Multivariate Techniques in River Sosiani, Kenya. Springer International Publishing, Switzerland.

APHA (1998), Standard Methods for the Examination of Water and Wastewater (20th Edition), American Public Health Association, American Water Works Association and Water Environment Federation, L. Clesceri, A. Greenburg and A. Eaton (Eds.), Washington.

American Public Health Association and American Water Works Association (2005). Standard methods for the examination of water and wastewater, 21st Edition. Washington, DC, American Public Health Association, American Water Works Association and Water Environment Federation, pp. 7 – 15.

Amfo-Otu, R., Omari, S. and Boakye-Dede, E., (2012). Assessment of Physico-chemical Quality of Groundwater Sources in Ga East Municipality of Ghana, *International Journal of Environment and Pollution*, 2 (3), pp. 19 – 24.

Ashun, E., (2014). Assessment and Mapping of Groundwater Quality in the Thiririka Sub Catchment Kiambu County, Kenya. A Master's Thesis of Kenyatta University.

Binge, F.W., (1962). Geology of the Kericho Area. Ministry of Commerce, Industry and Communications, Geological Survey of Kenya. Report No.50.

Burrough, P.A., and McDonnell, R.A. (1998) Creating Continuous Surfaces from Point Data. In: Burrough, P.A., Goodchild, M.F., McDonnell, R.A., Switzer, P., Worboys, M. (Eds.), Principles of Geographic Information Systems. Oxford University Press, Oxford, UK.

Champion, K. M. and Starks, R., (2011). Hydrology and Water Quality of Select Springs in the Southwest Florida Water Management District, Water Quality Monitoring Program – Southwest Florida Water Management District, 2001,Revised in 2011.

Eneji, I.S., Akaahan, T. J. A and Leke, L. (2015). Seasonal Variation in Hydro Chemistry of River Benue at Makurdi, Benue State Nigeria. *International Journal of Environment and Pollution Research,*Vol.3 (3), pp.67-78, European Centre for Research Training and Development UK. Available online at www.eajournals.org

Frankenberger, J. R., Brooks, E. S., Walter, M. T., Walter, M. F., and Steenhuis, T. S.,(1999). A GIS-based variable source area model, *Hydrological Processes*, 13, 804–822.

Gebrehiwot, A.B., Tadesse, N. and Jigar, E. (2011). Application of Water Quality Index to Assess Suitability of Groundwater Quality for Drinking Purposes in Hantebet Watershed, Tigray, Northern Ethiopia. *ISABB Journal of Food and Agricultural Science*, 1 (1), pp. 22 – 30.

Gordon, L.J., Garry, D. P. and Elena, M. B.,(2007). Agricultural Modifications of Hydrological Flows Create Ecological Surprises, *Trends in Ecology and Evolution*.

Jaetzold, R., Schmidt, H., Hornetz, B. and Shisanya, C, (2010). Farm Management Handbook of Kenya – Natural Conditions and Farm Management Information, Second Edition Part B, Central Kenya subpart B1a, South Rift Valley Province – Vol. II), Ministry of Agriculture and German Agency for Technical Cooperation.

Jeihouni, M., Toomanian, A., Shahabi, M., Alavipanah, S. K., (2014). Groundwater Quality Assessment For Drinking Purposes Using GIS Modelling (Case Study: City Of Tabriz), *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XL-2/W3.

Jones, W. B. and Lippard, S. J., (1979). New Age Determinations and the Geology of the Kenya Rift-Kavirondo Rift junction, W Kenya. J. geol. Soc. London, Vol. 136, pp. 693-704.

Ketata-Mouna, R., Gueddari, M. and Bouhlila, R., (2011). Use of Geographical Information System and Water Quality Index to Assess Groundwater Quality in El Khairat Deep Aquifer (Enfidha, Tunisian Sahel), *Iranica Journal of Energy and Environment*, 2 (2), pp. 133–144.

KNBS, (2010). The 2009 Population and Housing Census - Population and Household Distribution by Socio Economic Characteristics, Vol. 2.

Kristensen, P., (2004). The DPSIR Framework -National Environmental Research Institute, Department of Policy Analysis - European Topic Centre on Water, European Environment Agency, Denmark.

Kumar, A., Bisht, B.S., Joshi, V.D., Singh, A.K. and Talwar, A., (2010). Physical, Chemical and Bacteriological Study of Water from Rivers of Uttarakhand. *Journal of Human Ecology*, 32(3): 169-173.

Kuniansky, E.L., 2011, U.S. Geological Survey Karst Interest Group Proceedings, Fayetteville, Arkansas, April 26-29, 2011, U.S. Geological Survey Scientific Investigations Report 2011-5031, 212p. Available online at: http://water.usgs.gov/ogw/karst/

Li, P., Jianhua W., and Qian H., (2012). Assessment and Correlation Analysis of Groundwater Quality in the Huanhe Unit of the Cretaceous Formation, Ordos Basin, China , *International Journal of Environmental Engineering Research*, Volume 2, Issue 2.

Lyon, S.W., Seibert, J., A., Lembo, J., Walter, M. T. and Steenhuis, T. S., (2006). Geo-statistical investigation into the temporal evolution of spatial structure in a shallow water table. *Hydrology and Earth System Sciences*.

McCarthy, K.A., and Johnson, H.M.(2009). Effect of agricultural practices on hydrology and water chemistry in a small irrigated catchment, Yakima River basin, Washington, U.S. Geological Survey Scientific Investigations Report 2009–5030, 22 p.

Miguel, E., Kremer M., Leino J., and Zwane A.P., (2008). Spring Cleaning: Rural Water Impacts, Valuation, and Institutions.

Mkoma, S.L. and Mihayo I.Z., (2012). Chemical Water Quality of Bottled Drinking Water Brands Marketed in Mwanza City, Tanzania. *Research Journal of Chemical Sciences*.

Murhekar, G. H. (2011).Determination of Physico-Chemical parameters of Surface Water Samples in and around Akot City. Available online at: www.ijrce.org. *International Journal of Research in Chemistry and Environment. Vol. 1 Issue 2 Oct. 2011(183-187)* ISSN 2248-9649

Nair, K.R., Manji, F. and Gitonga, J. N., (1984) The Occurrence and Distribution of Fluoride in Groundwaters of Kenya. *Challenges in African Hydrology and Water Resources* (Proceedings of the Harare Symposium, July 1984). 1AHS publication no. 144.

National Environment Management Authority, (2006). Environmental Management and Co-Ordination (Water Quality) Regulations, Nairobi, Kenya

Ngonzo, C., Obando, J. A., and Shisanya, C., (2013). Climate Change, Excess Land–Uses and Farmers' Water Demand: An Induction from Smallholder Farms of Muooni Dam Site, Kenya. *JAAS Journal.* Vol. 1(2), pp. 24–36.

Ngugi, E., Kipruto, S., Samoei, P., Kamula, G.M., Katindi ,S.N., Lakin, J., Zaidi ,A.N., and Wanyama, L.,(2013). Exploring Kenya's Inequality- Pulling Apart or Pulling Together, Kericho County, Published by KNBS and SID.

Nikolaidis, C., Mandalos, P. and Vantarakis, A., (2007). Impact of intensive agricultural practices on drinking water quality in the EVROS Region (NE GREECE) by GIS analysis, Springer Science and Business Media, Greece.

Nkemdirim, V.U., Alozie, G.C. and Felix Ike (2016). Spatial Analysis of the Quality of Groundwater Supply: Evidence from Abia State. *American Journal of Water Resources,* vol. 4, no. 4: 83-90. doi: 10.12691/ajwr-4-4-2.

Okumu, J.O. and Otim, J., (2015). The Quality of Drinking Water used by the Communities in Some Regions of Uganda. International Journal of Biological and Chemical Sciences.

Olang, L. O. and Furst J., (2011). Effects of Land Cover Change on Flood Peak Discharges and Runoff Volumes: Model Estimates for the Nyando River Basin, Kenya. *Hydrol. Process.*

Ontumbi, G.M., Obando, J.A., Ondieki, C.M., (2015).The Influence of Agricultural Activities on the Water Quality of the River Sosiani in Uasin Gishu County, Kenya. *International Journal of Research in Agricultural Sciences,* Volume 2.

Ontumbi, G.M., (2015).The Influence of Land use Activities on the Water Quality of the River Sosiani in Uasin Gishu County, Kenya. Unpublished Masters Thesis of Kenyatta University.

Opio, A., Lukale, J.K., Masaba, I.S., and Oryema, C.,(2011). Socio–economic benefits and pollution levels of water resources, Pece Wetland, Gulu Municipality,Uganda. *African Journal of Environmental Science and Technology*,vol. 5(7), pp. 535-544.Available online at http://www.academicjournals.org/AJEST ISSN 1996-0786 ©2011 Academic Journals

Suratman, S., Mohd, S.M.I., Hee, Y.Y., Bedurus, E.A. and Latif, M.T., (2015). A Preliminary Study of Water Quality Index in Terengganu River Basin, Malaysia, *Sains Malaysiana*.

UNICEF, (2008). UNICEF Handbook on Water Quality, http://www.unicef.org/wes. Accessed on 20th February, 2016.

Water Report, (2005). Kenya National Water Development Report Prepared for the 2nd UN World Water Development Summit themed *'Water: A shared responsibility'*.
.
WHO, (2004). Guidelines for Drinking Water Quality", Vol. 1 Recommendations, 3rd Edition, WHO, Geneva.

WHO, (2006a). *Health and the MDGs: background.* http://www.who.int/mdg/background/en/index.html. Accessed May 21, 2010

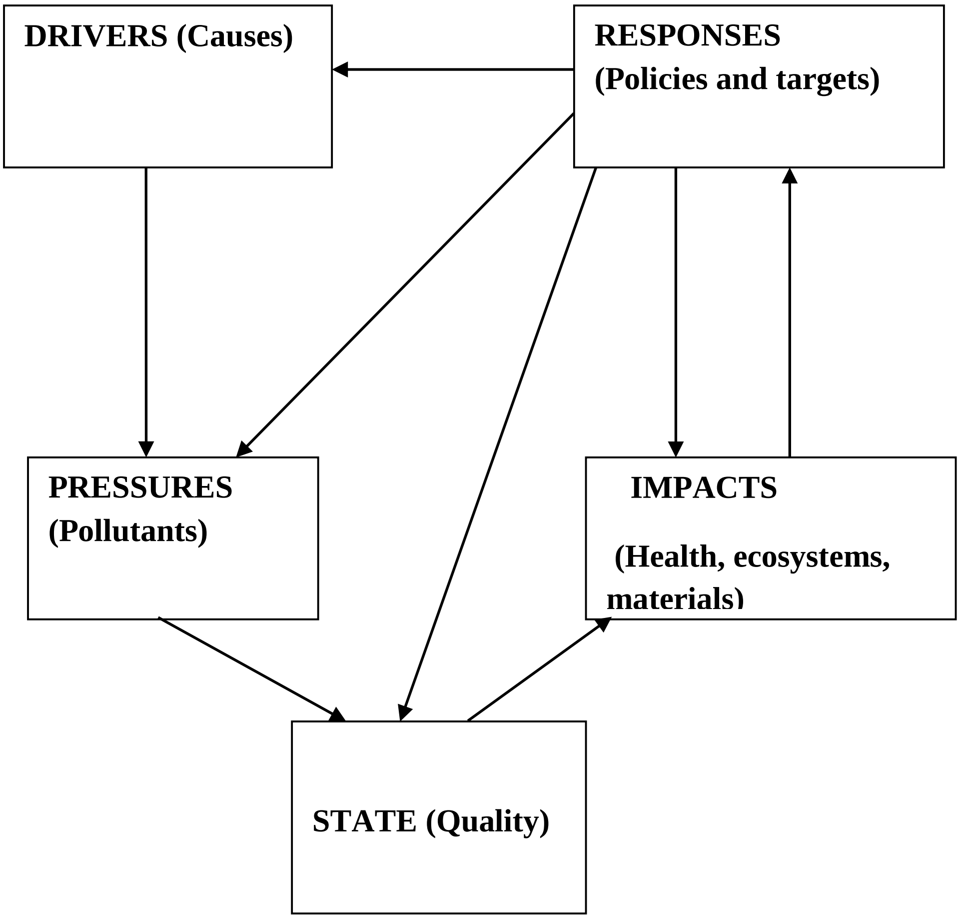
WHO, (2006b). *Typhoid and Paratyphoid enteric fevers.* http://www.who.int/water sanitation health/disease/typhoid. Accessed August, 2012.

WHO, (2010). Water For Health-Who Guidelines For Drinking-Water Quality. Available at http://www.who.int/water_sanitation_health/publications/guideline_policy_procedure/en/ Accessed on 27th February, 2016.

WHO, (2011). Guidelines for Drinking Water Quality, 4th Edition, WHO, Geneva.

APPENDICES

APPENDIX I: Conceptual Framework (DPSIR)



APPENDIX II: WHO and NEMA Drinking Water Guidelines

(Source: WHO, 2011 and NEMA, 2006).

Parameter	Unit	WHO Guideline	NEMA Guideline	Type of Analysis	Methodology / Instrument
pH	pH scale	6.5 – 9.2	6.5 - 8.5	On site	Universal meter
Conductivity	uS/cm	<2000	<1200	On site	Universal meter
turbidity	N.T.U	<5	<5	On site	Turbidimeter
temperature	°C	20 - 35	20 - 35	On site	Universal meter
Dissolved oxygen	Mg/l	<4	_	On site	Universal meter
TSS	Mg/l	<30	<30	lab	Gravimetric method
TDS	Mg/l	<1000	< 1000	lab	Gravimetric method
Total hardness	Mg/l	<500	<500	lab	EDTA titration
nitrate	Mg/l	<50	<10	lab	Hydrazine reduction
ammonia	Mg/l	_	< 0.5	lab	Salicylate method
nitrite	Mg/l	< 3	< 3	lab	Hydrazine reduction
phosphate	Mg/l	< 30	< 30	lab	Ascorbic acid
E.coli	cfu/100ml	NIL	NIL	lab	Membrane Filtration
BOD	Mg/l	_	_	lab	BOD 5 Method
Fluorides	Mg/l	< 1.5	< 1.5	lab	SPADNS Spectrophotometry

APPENDIX III: Summary of Field and Laboratory Calibration Procedures

Procedure	Quality Control Measures
General	• No field measurements will be conducted from a sample designated for chemical analysis or bio-assay. • Protocol instructions for how to collect a sample for each parameter of interest will be followed to avoid contamination of the samples before testing at the field or reaching the laboratory.
in situ or on-site measurements	• At least one standard in each instrument range to be used will be run to calibrate the equipment prior to use and readings will be read directly from instrument display once its stable (APHA, 1998) • The manufacturer's operating instructions will be adhered to as each instrument's calibration procedure and buffer solution varies with the type of model (Federman *et al*., 2006) and the temperature of the buffer or sample will be noted first so that the meter can compensate for this effect (APHA, 1998). • To maintain calibration between sampling sites, the pH meter will be left on and kept in pH 7 or deionized water between uses. For this study, a two point calibration will be adopted hence the instructions in the manual for that will be followed, that is, pH 4 and pH 7 buffers are used for water that is less than pH 7, and pH 10 and pH 7 buffers are used for water that has a pH greater than 7 (Federman et al., 2006).
Storage and transportation	• Samples will be cooled to 4°C, to minimize microbiological decomposition of solids. Storage will not exceed 1 week especially when using frost free refrigerators as it may cause excessive media dehydration. • A glass or metal thermometer graduated to 0.5° C will be used to monitor the temperature of the incubators and refrigerators. Chilled samples will be warmed to 20 ± 3° C before any laboratory analysis (APHA, 1998).
Laboratory measurements	• In all lab analyses sample cells or tubes of clear, colourless glass or plastic will be used. • Cells will be kept clean, both inside and out by washing thoroughly with laboratory cleaning agents. This will be followed by multiple rinses with distilled or deionized water; and cells will be allowed to air-dry. • Before conducting any lab analyses, at least one standard will be prepared to check the reliability of the instruments used such as UV spectrophotometer. In addition, blank samples will also be used to check the validity of the instrument readings. • Microbial analysis will be conducted within 48 hours from the time of sample collection to minimize sample alteration.

APPENDIX IV: Research Permit

THIS IS TO CERTIFY THAT:
MS. MERCY - KIRUI
of KENYATTA UNIVERSITY, 67679-200
NAIROBI,has been permitted to conduct
research in Kericho County

on the topic: EFFECTS OF LANDUSE ON SPRINGS AND STREAMFLOW WATER QUALITY IN RIVER MALAGET SUB-CATCHMENT,KERICHO COUNTY, KENYA

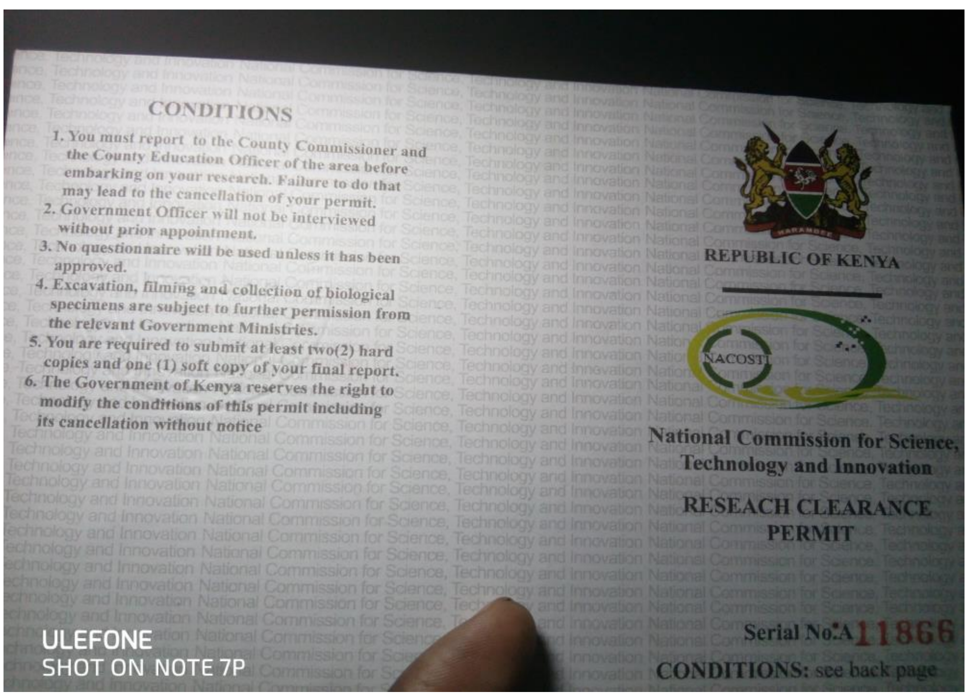
for the period ending:
26th August,2017

Applicant's Signature

Permit No : NACOSTI/P/16/90158/12453
Date Of Issue : 29th August,2016
Fee Recieved :Ksh 1000

Director General
National Commission for Science, Technology & Innovation

ULEFONE
SHOT ON NOTE 7P



CONDITIONS

1. You must report to the County Commissioner and the County Education Officer of the area before embarking on your research. Failure to do that may lead to the cancellation of your permit.
2. Government Officer will not be interviewed without prior appointment.
3. No questionnaire will be used unless it has been approved.
4. Excavation, filming and collection of biological specimens are subject to further permission from the relevant Government Ministries.
5. You are required to submit at least two(2) hard copies and one (1) soft copy of your final report.
6. The Government of Kenya reserves the right to modify the conditions of this permit including its cancellation without notice

REPUBLIC OF KENYA

NACOSTI

National Commission for Science, Technology and Innovation

RESEACH CLEARANCE PERMIT

Serial No.A 11866

CONDITIONS: see back page

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