MULTIVARIATE ANALYSIS OF THE WATER QUALITY INTHE MIDDLE STRETCH OF RIVER KADUNA (MALALI – RIGASA)

BY

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A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DOCTOR OF PHILOSOPHY DEGREE IN ENVIRONMENTAL ENGINEERING

DEPARTMENT OF WATER RESOURCES AND ENVIRONMENTAL ENGINEERING,

FACULTY OF ENGINEERING,

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ZARIA

SEPTEMBER, 2018

DECLARATION

I declare that the work in this thesis entitled MULTIVARIATE ANALYSIS OF THE WATER QUALITY IN THE MIDDLE STRETCH OF RIVER KADUNA (MALALI – RIGASA) has been carried out by me in the Department of Water Resources and Environmental Engineering. The information derived from the literatures has been duly acknowledged in the text and a list of references provided. No part of this thesis has been previously presented for another degree or diploma of this or any other institution.

Francis James OGBOZIGE

Signature _____ Date _____

CERTIFICATION

The thesis entitled:

MULTIVARIATE ANALYSIS OF THE WATER QUALITY INTHE MIDDLE STRETCH OF RIVER KADUNA (MALALI – RIGASA)

By

Francis James OGBOZIGE

meets the regulations governing the award of the degree of Doctor of Philosophy [Environmental Engineering] of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This work is humbly dedicated to Supreme-being (**Jehovah**), the one who has the final say.

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ABSTRACT

The water in River Kaduna is used for; domestic purposes, fishing, recreational activities as well as irrigation of crops.However, literatures have revealed that there are lots of anthropogenic activities occurring within the middle stretch of the river that could likely deteriorate its water quality as it flows through the Kaduna city metropolis. Hence, this research was targeted at evaluating the water quality of the middle stretch of River Kaduna with respect to seasonality and land use, mapping the water quality of the catchment using Geographic Information System (GIS), determining Water Quality Index (WQI) for the sampling sites considered and finally, optimizing the number of sampling sitesand water quality parameters analyzed. These were achieved by using standard methods to analyze 13 water quality parameters from samples collected at 15 sampling sites along the middle stretch of River Kaduna on a monthly basis for a period of 12 calendar months. The water quality parameters analyzed includes temperature, turbidity, total dissolved solids (TDS), chloride ion (Cl^-), pH and electrical conductivity (EC). Others are; dissolved oxygen (DO), 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), iron (Fe) and manganese (Mn). Laboratory results were subjected to different software packages (ArcGIS 10.5,JMP 13, CorelDRAW X7 and VB.Net 2017) and it was shown that the water quality of River Kaduna was more deteriorated during the dry season. However, COD and TP were found to be the only parameters that never met the requirement set by FEPA throughout the sampling period irrespective of the sampling location and season. This is because the least measured concentrations of COD and TP were 35.34±0.1 mg/l and 0.109±0.05mg/l, respectively as against their respective permissible limits (20 mg/l and0.1 mg/l).Built-up, industrial, and agricultural land uses contributed significantly to the impairment of River Kaduna water quality while vegetation (forest coverage) mitigated the deterioration of the

water quality to a certain degree. GIS mapping was able to identify the water quality of the non-sampling points within the monitored portion of the river. In addition, the WQI (Canadian) revealed that the water quality of 11 sampling locations were marginal as their index values ranged from 48.51 to 63.62 however, the remaining 4 sampling locations had poor index values ranging from 23.41 to 30.85. These sampling sites with poor WQI values were located at the confluence points of; Kutimbi stream (between Narayi and Barnawa towns), Omo stream (at Kigo road new extension), Nigeria Breweries drainage (at Kakuri) and River Rigasa. An equation for predicting the WQI along River Kaduna was developed as; $CWQI_p = 0.0194{K_d}^2 + 0.0006K_d + 48.9697$ where: $CWQI_p$ and K_d represent predicted Canadian WQI and distance away from Kakuri along direction of flow respectively.Furthermore, the 15 sampling sites monitored fell into two major clusters viz: moderately polluted sites and highly polluted sites which correspond to sampling sites having marginal and poor WQI respectively.Analyzed laboratory results further revealed that 8 of the 13 water quality parameters examined (turbidity, TDS, Cl^-, EC, DO, COD,TN and TP) were critical parameters on a factor loading>0.75 and accounted for 75.78% of the variation in water quality of the river.Regulatory agencies were advised to check the anthropogenic activities occurring at the hot spot areas shown in the GIS maps especially at Kakuri, Tudun Wada and Rigasa communities so as to put in place appropriate mitigation measures.

ABBREVIATIONS AND SYMBOLS

APHA: American Public Health Association

BOD_5: 5-Days Biochemical Oxygen Demand

CA: Cluster Analysis

CCME: Canadian Council of Ministers of Environment

Cl^- : Chloride ion

COD: Chemical Oxygen Demand

DO: Dissolved Oxygen

DTM:Digital Terrain Model

EC: Electrical Conductivity

EPA: Environmental Protection Authority

ETM+: Enhanced Thematic Mapper Plus

FA: Factor Analysis

FCT: Federal Capital Territory (Abuja)

Fe: Iron

FEPA: Federal Environmental Protection Agency

GEMS: Global Environmental Monitoring Systems

GIS: Geographic Information System

HCA: Hierarchical Clustering Analysis

IDW: Inverse Distance Weighted

IHD: International Hydrological Decade

KEPA: Kaduna State Environmental Protection Authority

Mn: Manganese

NPDES: National Pollution Discharge Elimination System

NPS: Non-Point Source

PCs: Principal Components

PCA: Principal Component Analysis

RBDA: River Basin Development Authorit viii

SDD: Scottish Development Department

SRTM: Shuttle Radar Topography Mission

TDS: Total Dissolved Oxygen

TIN:Triangulated Irregular-terrain Network

TN: Total Nitrogen

TP: Total Phosphorous

WHO: World Health Organisation

WQI: Water Quality Index

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CHAPTER ONE

INTRODUCTION

1.1 General Background

Water quality is a critical factor that influences human health as well as the quantity and quality of grain production in semi-humid and semi-arid areas(Zhang *et al.,* 2012). Water pollution is harmful not only to fish breeding and agricultural products but also to public health in surrounding areas. Of the pollutants, heavy metals can endanger health by being incorporated into food chain. Heavy metals are not biodegradable and tend to accumulate in the sediments of water ways in association with organic and inorganic matters in the sediment (Huong and Kanayama, 2010). Studies have indicated that many rivers and streams particularly in developing countries are heavily polluted due to industrial and municipal wastewater discharges, as well as agricultural runoff (Li and Zhang, 2013; Pizarro *et al*., 2015).

Surface water bodies can be polluted from point source pollution as well as non-point source pollution. The latter of the two can be hard to locate, quantify, and regulate because non-point sources may be located within the entire watershed area (Jinliang *et al.,*2011).Runoff that travels over various land uses within a watershed is a major source of non-point source pollution. Thorough water quality monitoring and watershed land use surveys can help public agencies to locate and eliminate non-point sources of pollution to receiving water bodies. Treseder (2014) reported that excessive nutrients can lead to water eutrophication, causing a hypoxia environment, the reductions of species diversity and microbial growth, mortality of benthic communities, and stress in fishery resources. Human activities such as atmospheric pollution, effluent discharges, use of agricultural chemicals,

eroded soils and land use were identified by Niemi*et al.* (2010) as major factor determining the quality of surface and ground water. These land use changes increase the amount of impervious surface resulting in storm runoff events that negatively affect stream ecosystems and water quality. For instance, rivers in watersheds with substantial agricultural and urban land use experience increased inputs and varying compositions of organic matter and excessive concentrations of phosphorus and other nutrients from fertilizer application and watershed releases (Paul and Meyer, 2011;Sickman *et al.,* 2014 and Easton*et al.,* 2014).

The multidimensional data analysis methods are becoming very popular in environmental studies especially in water quality monitoring. The most common multivariate analysis methods used are Factor Analysis (FA), Principal Component Analysis (PCA) and Cluster Analysis (CA),which have been used to identify important components or sources that explain the variations in water quality and influence the water system (Andrade*et al.,* 2013). The application of different multivariate statistical techniques such asFA, PCA, CAand Discriminant Analysis (DA) facilitates the interpretation of complex data matrices to better understand the water quality and ecological status of studied systems (Varol *et al.,* 2012).

The enforcement of environmental quality guidelines especially for water resources in Nigeria mainly focused on point source polluters (Adebola *et al.,* 2013). More has to be done in extending monitoring and assessment of Nigeria's water resources systems to capture the vast degradation consequences of diffuse pollution. This study focused on that at sub-basin level.

1.2 Statement of Research

For proper planning and decisions on utilization of the water in middle section of River Kaduna and its tributaries, information on water quality status, factors that influence the water quality as well as critical locations within the catchment area have to be identified. Unfortunately, an in-depth work has not been done despite being part of the responsibility of the River Basin Development Authorities (RBDAs). Although, several works on water quality assessment of River Kaduna as well as it hydrology and flooding has been carried out by various researchers such asMohammed *et al.* (2015), Farouk (2015), Mohammed (2013), Alayande and Agunwamba (2010), Ekiye and Luo (2010),Yusuf*et al.* (2008) as well as Jeb and Aggarwal (2008).Nevertheless, an extensive documentation of the water quality along the river-reach such as describing the water quality with respect to land use, identifying critical parameters that causes variability of the water quality, optimizing the number of sampling sites, mapping of the water quality as well as determining the general status of the river through Water Quality Index (WQI) have not been done.

1.3 Justification

Many monitoring programs usually consist of large data of physiochemical and bacteriological properties, which are difficult to analyze and interpret because of latent inter-relationships among parameters and monitoring sites (Vujovic and Srđan, 2012; Jinliang *et al.,* 2011). Hence, applying multivariate techniques such as Factor Analysis (FA) and Principal Component Analysis (PCA)in monitoring the water quality of River Kaduna will help in extracting the parameters responsible for the main variability in the water quality (Singovszka and Balintova, 2012). This will help subsequent monitoring of River

Kaduna to lay more emphasis to these critical parameters or reducing the sampling frequency of the insignificant parameters (Shrestha and Kazama, 2015). Thus, reducing the cost to be incurred in successive monitoring of the river with minute loss of information. On the other hand, performing Cluster Analysis (CA) in monitoring the quality of River Kaduna will help in categorizing the monitoring stations into groups such as; highly polluted, moderately polluted and lowly polluted areas. This will aid relevant regulatory agencies such as the Kaduna State Environmental Protection Authority (KEPA) in enforcement of standards and pollution control activities. Understanding the effect of land use on the water quality of River Kaduna will inform the type of land use practice that threaten the water quality or mitigate deterioration of water quality. This will be very useful to the government of Kaduna state in allotting plots of land to individuals especially at the river banks. In addition, mapping the water quality of the middle stretch of River Kaduna will suggest the level of contamination at the non-sampled points while determining WQI will reveal whether the water quality at the various sampling sites are excellent, occasionally impaired, frequently impaired or always impaired (Carlos and Alejandra (2014).

1.4 Aim and Objectives

The Aim of the research is to characterize the water quality in the middle stretch of River Kaduna with respect to natural and anthropogenic factors contributing contaminants within the watershed. The specific objectives are to:

i. evaluate water quality in middle section of River Kaduna in relation to seasonality and land use pattern;

ii. map the water quality of the catchment using Geographic Information Systems (GIS);
iii. determine Water Quality Index (WQI) for the sampling locations or sites considered;
iv. identify critical water quality parameters in the catchment area using Factor Analysis (FA) and Principal Component Analysis (PCA);
v. classify similar sampling locations and identify the highly polluted locations in the study area using Clustering Analysis (CA).

1.5 Scope of the Research

i. The research only monitors the water quality of River Kaduna within Kaduna city metropolis (i.e. middle stretch of River Kaduna), starting from Malali to the new railway bridge at Rigasa (32.7km).
ii. Bacteriological parameters were not analyzed with the assumption that their presence were of high magnitudes. This is because most of the settlements along the reachdischarged their sewage directly into this river and streams (tributaries) without any form of treatment.
iii. Examined water quality parameters were limited to temperature, turbidity, total dissolved solids (TDS), pH, chloride ion (Cl^-) and electrical conductivity (EC). Others includedissolved oxygen (DO), 5-days biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), iron (Fe) and manganese (Mn).

1.6 Description of the Study Area

Kaduna city is the capital of Kaduna State in North-Western Nigeria. River Kaduna is a tributary of the River Niger with its source from Kujama Hill in Plateau State and flow for

210 km before reaching Kaduna town. It crosses the city dividing it into north and south areas. Beyond Kaduna, the river flows for about 100 km into the Shiroro Dam. It continues to flow for 100 km and finally discharges into River Niger at the northern shores of Pategi(Ekiye and Luo, 2010). The river has two storage reservoirs; Kangimi Dam in the upper region and Shiroro Dam at lower region. There are also two waterworks along the river within Kaduna metropolis (the North and South waterworks). The North waterworks, situated at Malali has a capacity of 240,000 m^3day^{-1}while the South waterworks with a capacity of 35,000$m^3day^{-1}$is at Barnawa (Yusuf*et al.,* 2008).Kaduna stateis bordered by Katsina and Kano States to the North; Bauchi State to the East; Plateau State to the South-East; FCT (Abuja). to the South; Niger State to the South-West and Zamfara state to the North-West (Figure 1.1b). The study area which is located between Latitudes10^o 28'00" – 10^o 36' 00"North and longitude 07^o 21' 00" – 07^o 35' 00" East (ArcGIS 10.5), falls strategically inside four Local Government Areas of Kaduna State. These are parts of Igabi, Chikun, Kaduna South and Kaduna North (Figure 1.1c). The localities and communities that make up the study area include Malali Gabas, Ungwa Rimi, Ungwa Maigero, Narayi, Ungwa Pama, Bayanduse, Kabala, Barnawa, Ungwa Boro and Sabon Tasha. Others include Kigo road (new extension), Tudun Wada, Kakuri, Kudende, Ungwa Mu'azu, Rigasa, Romi and Maigiginya.

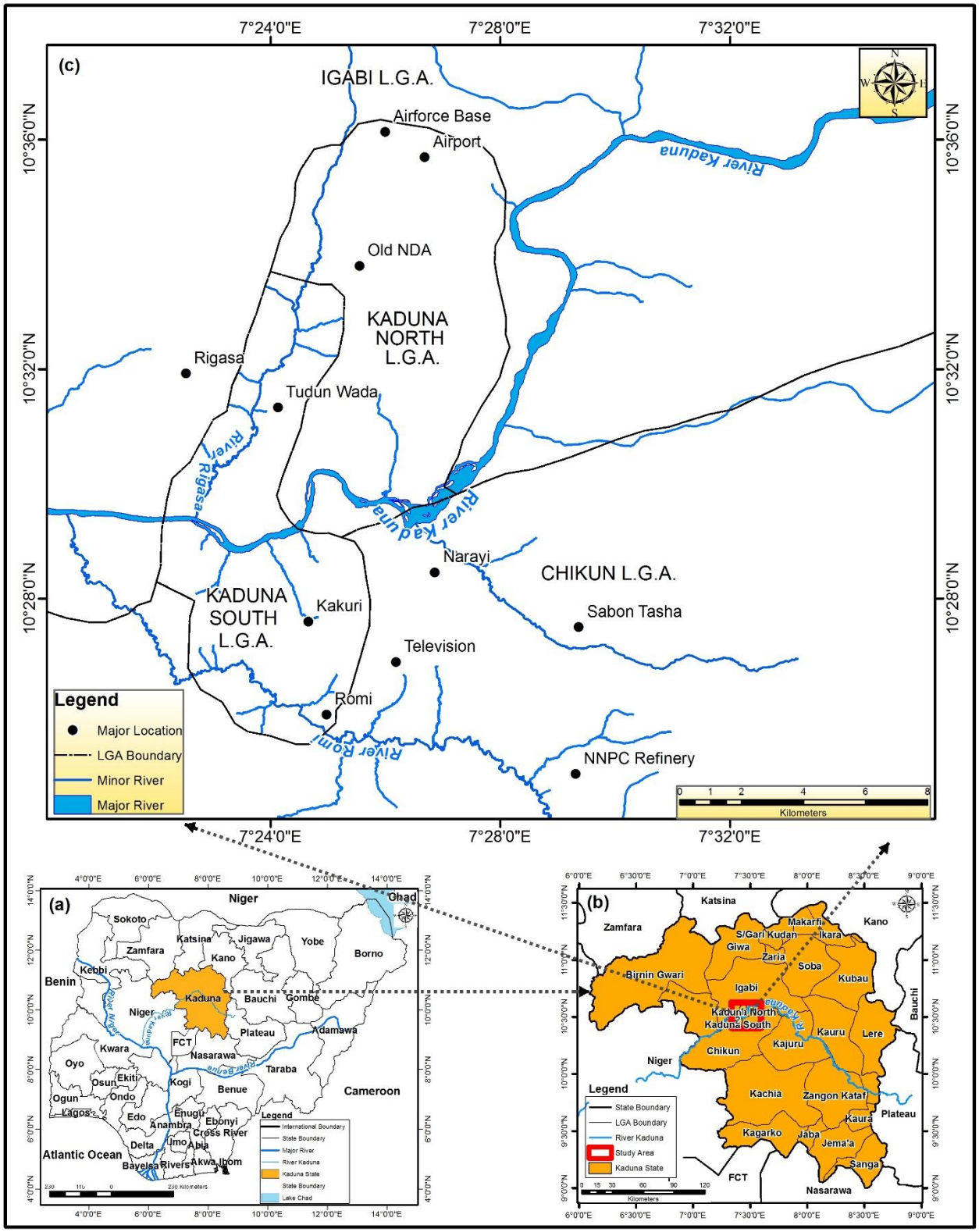


Figure 1.1: Study area maps (a); Nigeria showing Kaduna state, (b); Kaduna state showing study area, (c); Study area

Source: Modified from the Administrative Map of Nigeria, 2018

The climate of Nigeria is strongly influenced by the Equatorial Maritime and Tropical Continental air masses (Ayoade, 2015). The boundary between these two is known as the Inter-Tropical Convergence Zone (ITCZ). The Equatorial Maritime air mass is characterized by south–westerly winds which approaches the land off the Gulf of Guinea. Rainfall in River Kaduna is derived from this moisture–laden air mass with a long history of movement over the Atlantic Ocean (Saminu*et al.,* 2013). The Tropical Continental air mass is that of the dry north easterly wind known as the Harmattan. In other words, the climate of the studied area is very much affected by movement of the ITCZ. The rainy season in River Kaduna and its environ is normally in the period of May to October, when the Inter-Tropical Convergence Zone has reached the northern part of Nigeria. The dry season, usually accompanied with high evaporation rate is from November to April when the North Easterly wind cover the whole of the northern part of Nigeria (Saminu*et al.,* 2013).The mean annual rainfall can be as high as 2000 mm in wet years and as low as 500 mm in drought years, but with a long term average of 1000 mm hence, the flow rate of the river during wet and dry seasons are 2,000 $m^3s^{-1}$and 1 m^3s^{-1} respectively (Sola and Adeniran, 2015; Essoka and Umaru, 2015). Due to the perennial nature of the river, it is been used for fishing and irrigation of crops (Bolorunduro, 2016; Enabor *et al.,* 2011). The mean annual temperature is about 24.5 ^oC(Sola and Adeniran, 2015).

The bedrock geology is predominantly metamorphic rocks of the Nigerian Basement Complex consisting of biotite gneisses andolder granites. Generally, the soils and vegetation are typical red-brown to red-yellow tropical ferruginous soils and savannah grassland with scattered trees and woody shrubs. The soils in the upland areas are rich in red clay and sand but poor in organic matter. However, soils within the “fadama” areas are

richer in kaolinitic clay and organic matter, very heavy and poorly drained characteristics of vertisols (Jeb and Aggarwal, 2008).

The population of Kaduna metropolis has shown a rapid increase as follows: 10,653 in 1931; 44,540 in 1952; 149,910 in 1963; 173,000 (estimated) in 1965; 853,000 (estimated) in 1985; 1,111,282 in 1991 and 1,570,331 in 2006 (Nigeria Population Commission, 2010). This rapid increase in population resulted to rapid urbanization which consequently led to the transformation of River Kaduna floodplain into developed areas as most of the agricultural land has been converted to built-up areas.

CHAPTER TWO

LITERATURE REVIEW

2.1 Water

Water is a colourless, odourless and tasteless substance when pure, and is essential for life. Over 70% of the Earth's surface is covered by water however, almost all water on Earth is saltwater which isunsuitable for the vast majority of human needs, including consumption and agriculture(Ayoade, 2015).The distribution of the Earth's water resources is shown in Figure 2.1.

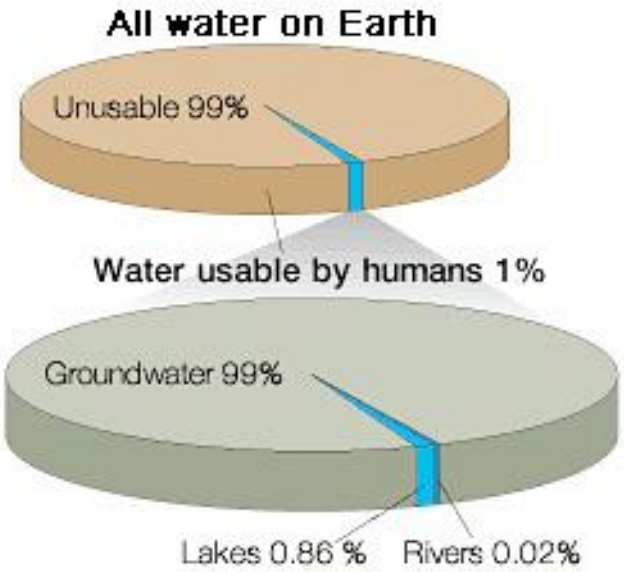


Figure 2.1: Distribution of Earth's water (Source: Ayoade, 2015)

Water molecule is made of two hydrogen atoms and one oxygen atom that arelinked together in definite structure by a chemical bond thus, having its chemical formula as; H_2O. The chemical bond between the atoms is based on the sharing of pairs of electrons (covalent bond).The overall shape of themolecule is bent, with an approximate central angle of 105°formed between the two O-H bonds (Figure 2.2) which makes the molecule asymmetrical (Aggarwal, 2013).The shared electrons are pulled slightly closer to the

oxygen atom, making the overall molecule partially charged. Hence, water molecule is polar and has its partial positive and partialnegative charges. The hydrogen atoms in a water molecule hold a partial positive charge, while oxygen atoms have a partial negative charge.

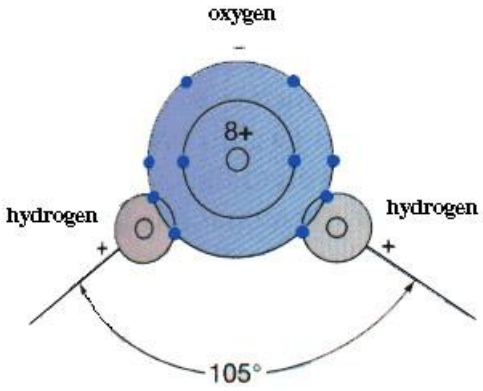


Figure 2.2:Geometry of water molecule (Source: Aggarwal, 2013)

Lious and Wang (2014) disclosed that water is also known to be the only substance that naturally occurs in all the three states of matter (solid, liquid and gas) as shown in Plate I.



Plate I: Water in different states of matter (Source:Lious and Wang, 2014)

The high boiling point of water (373 K) made it to exist predominantlyin its liquid form in the range of environments where life flourishes, although the other two phases, ice and

vapour, play an essential role in shaping the environment. Giller and Malmqvist(2012) reported that the high specific heat and heat of vaporization of waterhave important consequences for organisms at the cellular and physiological level, in particular for the efficiency of processes involving heat transfer, temperature regulation and cooling. Giller and Malmqvist(2012) also stated that viscosity is a major parameter of water that determines how fast molecules and ions can be transported and how rapidly they diffuse in aqueous solution. It thus provides a physical upper limit to the rates of many molecular level events, within which organisms must live and evolve. These include the rates of ion channel conductance, association of substrates with enzymes, binding rates, and rates of macromolecular assembly. It also sets an upper bound to the length scale over which biological processes can occur purely by diffusion. This was reaffirm by Weiner and Matthews (2013) by stating that in many cases such as enzyme–substrate reactions, evolution has pushed the components of living systems to the limits set by water's viscosity. Some of the physical properties of water are presented in Table 2.1.

Table 2.1: Selected physical properties of water

Property	**Value (constant)**
Molecular weight (g mol^{-1})	18
Density (Kg L^{-1})	0.998
Boiling point (K)	373
Molecular volume (nm^3)	0.0299
Volume of fusion (nm^3)	0.0027
Specific heat (J $K^{-1}g^{-1}$)	4.18
Heat of vapourization (KJ g^{-1})	2.3
Surface tension (mN m^{-1})	72.8
Viscosity (µPa s)	1002
Dielectric constant	78.6

Source: Nelkon and Parker, 1995

2.2 Sources of Water

The sources of water were categorized by Arora (2011) and Garg (2010) into three major groups which are; surface water, groundwater and precipitation.

2.2.1 Surface water

Surface water is water that is open to the atmosphere such as lakes, streams, rivers, seas, oceans, man-made impoundments (lakes made by damming a stream or river), etc. The following are some of the advantages and disadvantages of surface water.

Advantages

i. Surface water does not requires sophisticated equipment to find (i.e. it is easily located).
ii. It easy to abstract.
iii. Dams and reservoirs can be used for electric power.

Disadvantages

i. Surface water can easily be polluted (contaminated) with microorganisms that cause waterborne diseases and chemicals from surface runoff and upstream discharges.
ii. It is not reliable in the arid regions as most rivers and streams in the arid regions are not perennial.
iii. Reservoirs will eventually silt up.

2.2.2 Groundwater

Groundwater is water that is below the earth's crust such as wells and sprigs that are not influenced by surface water.

Advantages

i. Groundwater is not as easily contaminated as surface water.
ii. It is reliable even in times of drought.

iii. It is likely to be free of pathogenic bacteria

iv. Generally, it may be used without further treatment

Disadvantages

i. Once groundwater is contaminated, it is difficult for it to be recovered.

ii. Wells in coastal areas are vulnerable to salt water intrusion.

iii. Abstraction of groundwater mostly requires pumping thus, increasing operation cost.

2.2.3 Precipitation

Precipitation is the fall of water in various forms on the earth from the cloud. The usual forms of precipitation are rain and snow, although it may also occur in the form of sleet, glaze, hail, dew and frost (Arora, 2011). Most of the precipitation in the tropical countries is in the form of rain hence, the term precipitation and rainfall are used synonymously in tropical countries (Arora, 2011). Rain harvesting and storing rainwater in water tanks was reported by Garg(2010) of being an excellent way of backing up groundwater reserves however, it has the following advantages and disadvantages.

Advantages

Rainwater harvesting help to reduce the overall water bills, giving a chance to save the money usually spent on water utility companies.

Reduces groundwater demand.

It can also be stored in cisterns for use during times when water supply is low.

Disadvantages

i. Rainfall is hard to predict and sometimes little or no rainfall can limit the supply of rainwater.

ii. Certain roof types used in harvesting rainwater my seep chemicals.

iii. Limit to storage tank capacity.

2.3 Self Purification of Rivers

When sewage is discharged into a natural body of water, the receiving water gets polluted due to waste products present in sewage effluents. However, the conditions do not remain so forever because the natural forces of purification such as dilution, sedimentation, sunlight, oxidation and reduction go on acting upon the pollutants and bringing back the water into its original condition. This phenomenon of river naturally getting rid of pollutant in due course is called self purification (Garg, 2006). However, Weiner and Matthews (2013) reported that if the self purification is not achieved successfully either due to too much pollutant discharged into it or due to other causes, the river water itself will get polluted which in turns, may also pollute the sea where the river outfall.

2.3.1 Factors affecting self purification

The various factors affecting self purification are categorized into two major groups; physical factors (dilution-dispersion, sedimentation and sunlight) and chemical factors (oxidation and reduction). However, temperature, turbulence, hydrography, available dissolved oxygen and rate of reaction are also important factors that influences self purification.

2.3.1.1 Dilution and dispersion

When putrescible organic matter is discharge into a large volume of water contained in river or stream, it gets rapidly dispersed and diluted. The action results in diminishing the concentration of organic matter and thus, reduces the potential nuisance of sewage. The

effect of dilution and dispersion of pollutant in a flowing stream or river is given in equation (2.1) as stated in Garg (2006).

$$C = \frac{C_s Q_s + C_r Q_r}{Q_s + Q_r} \quad (2.1)$$

Where:

C = Concentration of resulting mixture of discharged sewage and water in river

C_s = Concentration of discharged sewage

Q_s = Flow rate of discharged sewage

C_r = Concentration of water in river

Q_r = Flow rate of river

2.3.1.2 Sedimentation

Settleable solids, if present in sewage effluents usually get settle down into the bed of the river, near the outfall of sewage thus, helping in the self purification process (Weiner and Matthews, 2013)

2.3.1.3 Sun light

Fair *et al.* (2014) reported that sun light has a bleaching and stabilizing effect on bacteria as well as helping certain micro-organisms to derive energy from it and converting themselves to food for other forms of life thereby absorbing carbon dioxide and releasing oxygen. This was buttressed by Mehrdadi*et al.* (2016) who reported that algae produces oxygen in the

presence of sunlight due to photosynthesis, signifying that sunlight helps in purification of stream by adding oxygen through photosynthesis.

2.3.1.4 Oxidation

According to Alam *et al.* (2015), oxidation of organic matter in sewage effluent is the most important action responsible for self purification of river and start as soon as the sewage outfalls into river water containing dissolved oxygen. Alam *et al.* (2015) further explained that the deficiency of oxygen so created is usually filled up by atmospheric oxygen and the process of oxidation will continue till the organic matters are completely oxidized.

2.3.1.5 Reduction

Reduction occurs due to hydrolysis of organic matter settled at the bottom either chemically or bacteriologically. Anaerobic bacteria help in splitting the complex organic constituents of sewage into liquids and gases thereby paving the way for their ultimate stabilization by oxidation (Omole *et al.* 2012)

2.3.1.6 Temperature

Temperature had been identified by Fair *et al.* (2014) and Garg (2006) as an influential factor on dilution and sedimentation rates as well as the rate of biological activities which are all enhanced at higher temperatures and depressed at lower temperatures. Furthermore, Fair *et al.* (2014) reported that the dissolved oxygen (DO) content of water, which is very essential for maintaining aquatic life and aerobic conditions (so as to avoid the anaerobic decomposition and subsequent nuisance) is also influenced by temperature. This is because,

at higher temperatures, the capacity to maintain DOconcentration is low; while the rate of biological and chemical activities are high, by this means, causing rapid depletion of DO.

2.3.1.7 Turbulence

Turbulence in the body of water helps in breaking the surface of streams or lakes which help in rapid re-aeration from the atmosphere. In other words, it helps in maintaining aerobic conditions in river or stream as well as keeping it clear. However, Agunwamba *et al.* (2016) reported that too much of turbulence is not desirable because it could scour bottom sediments, increase turbidity and also retards algae growth which is useful in reaeration process.

2.3.1.8 Hydrography

The hydrography of a river such as the velocity and surface expanse of the river influence self purification. High velocity cause turbulence and rapid reaeration while large surface expanse (for the same cubic contents) will also have the same effects.

2.3.1.9 Available dissolved oxygen

The higher the amount of dissolved oxygen present in water, the better and earlier the self purification will occur (Mehrdadi *et al.*,2016).

2.3.1.10 Rate of Reaction

Henry and Heinke (2005) revealed that self purification process is govern by the rate at which the DO deficiency is replenished. The greater is this rate, the quicker will be the self purification as there will be no chance of anaerobic condition.

2.3.2 Oxygen deficit of a polluted river

The oxygen deficit (also known as oxygen sag) in a polluted river at any time is defined by Garg (2006) as the difference between the actual DO content of water at that time and the saturation DO contentment at the water temperature. That is, oxygen deficit could be represented mathematically as shown in equation (2.2)

$$Oxygen\ deficit = Saturation\ DO - Actual\ DO \tag{2.2}$$

In other to maintain clean conditions in a river, the oxygen deficit must be nil, which can be found out by knowing the rates of deoxygenation and reoxygenation (Fair *et al.*, 2014). When wastewater is discharged into a river,the DO in the stream may not be at saturation level and there may be initial oxygen deficit (D_o). At this stage, the DO content of the river starts depleting and the oxygen deficit increases.This depletion of DO content is known as deoxygenation. Fair *et al.* (2014) pointed out that the rate of deoxygenation depends upon the amount of organic matter remaining (L_t) to be oxidized at any time t, as well as temperature (T) at which reaction occurs. The variation of depletion of DO content in a river with time is depicted by the deoxygenation curve in Figure 2.3. The ordinates below the deoxygenation curve indicates the oxygen remaining in the river after satisfying the biochemical oxygen demand (BOD) of oxidizable matter.

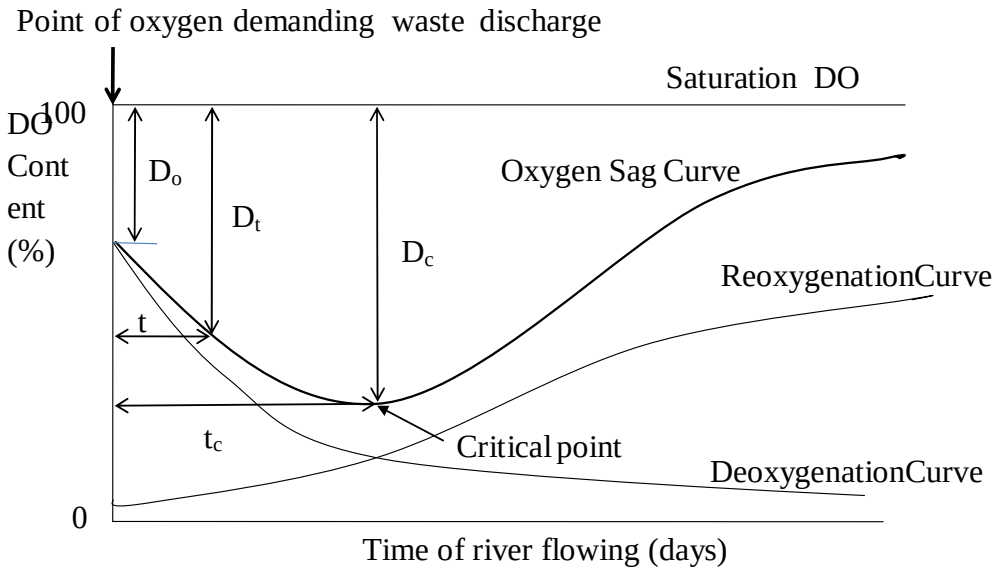


Figure 2.3: Reoxygenation, deoxygenation and oxygen sag curve (Source: Fair *et al.*,2014)

When the DO content of the stream is gradually consumed due to BOD load, atmosphere supplies oxygen continuously to the water, through the process of reoxygenatio. Fair *et al.* (2014) recognize the following as the factors governing the rate of reoxygenation.

i) Depth of water in the river (more for shallow depth)

ii) Velocity of flow in the stream (less for stagnant water)

iii) Oxygen deficit below saturation DO

iv) Temperature of water

In a flowing polluted river exposed to the atmosphere, the deoxygenation as well as reoxygenation usually occur simultaneously. If the deoxygenation is more rapid than the reoxygenation, an oxygen sag (oxygen deficit) results. Figure 2.3 also revealedthat when the deoxygenation rate exceeds the reoxygenation rate, the oxygen sag curve shows increasing deficit of oxygen. However, when both rates become equal, a maximum or critical deficit (D_c) is reached at the point of inflection of the oxygen sag curve.

2.3.3 Zones of pollution in a river

A polluted river undergoing self purification can be divided into the following four zones viz: zone of degradation, zone of active decomposition, zone of recovery and zone of cleaner water (Fair *et al.,* 2014; Garg, 2006; Henry and Heinke, 2005).

2.3.3.1 Zone of degradation

The zone of degradation, also known as zone of pollution is found below the point where sewage is discharged into a river. This zone is characterized by water becoming dark and turbid with formation of sludge deposits at the bottom. Dissolved oxygen is usually reduced to about 40% of the saturation level with an increase in carbon (IV) oxide content while reoxygenation occurs at slower rate than deoxygenation. This makes zone of degradation unfavourable to the development of aquatic life hence, algae dies out but fish life may be present, feeding on fresh organic matter (Garg, 2006).

2.3.3.2 Zone of active decomposition

This zone is marked by heavy pollution as it is characterized by water becoming greyish and darker than in the previous zone (zone of degradation). Usually, the DO concentration falls down to zero, and anaerobic conditions may set in with the evolution of gases like methane, carbon (IV) oxide as well as hydrogen sulphide bubbling to the surface, with masses of sludge forming an ugly scum layer at the surface(Fair *et al.,* 2014). However, Garg (2006) revealed that as the organic decomposition slackens due to stabilization of organic matter, the reoxygenation sets in and DO again rises to the original level (i.e. about 40%).

This zone usually encourage bacteria flora to flourish with anaerobic bacteria replacing aerobic bacteria at the upper end while the reverse is the case at the lower end of the zone. Algae and fish lives are usually absent however, maggots and Psychoda larvae are most times present (Henry and Heinke, 2005).

2.3.3.3 Zone of recovery

In this zone, the river stream tries to recover from its degraded condition to its former appearance hence, the water becomes clearer and algae reappears while fungi decreases. Also, BOD falls down and DO content rises above 40% of the saturation value thereby enabling protozoa, rotifers, crustaceans and large plants like Sponges and bryozons to also reappear(Garg, 2006).

2.3.3.4 Zone of cleaner water

In this zone, the river attains its original conditions with DO content rising up to the saturation value. The water becomes attractive in appearance, and aquatic lives prevail however, some pathogenic organisms may still survive and remain in the water thus, confirming the fact that once a river has been polluted, it will not be safe to drink it, unless it is properly treated (Weiner and Matthews (2013).

The illustration of the various zones of pollution is shown in Figure 2.4.

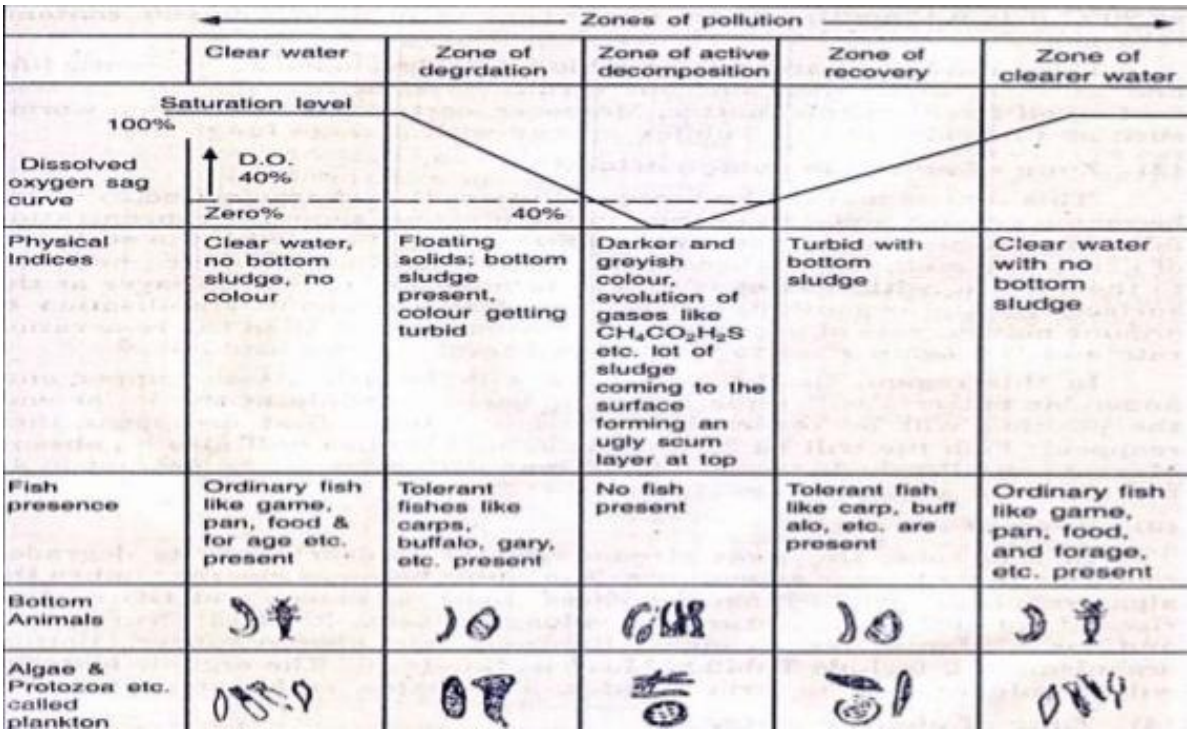


Figure 2.4: Zones of pollution along a river (Source: Garg, 2006)

2.3.4 Equations and kinetics of self purification of a river

The entire analysis of super-imposing the rates of deoxygenation and reoxygenation is demonstrated mathematically in the Streeter-Phelps model shown in equation (2.3) as reported in (Garg, 2006).

$$D_t = \frac{K_D . L}{K_R - K_D}[(10)^{-K_D . t} - (10)^{-K_R . t}] + [D_0 \times (10)^{-K_R . t}] \quad (2.3)$$

Where:

D_t = DO deficit in mg/l after t days

L = Ultimate first stage BOD of the mix at the point of waste discharge in mg/l

D_0 = Initial oxygen deficit of the mix at the mixing point in mg/l

K_D = Deoxygenation coefficient for the wastewater which can be considered as equal to the BOD rate constant. K_D varies with temperature (T) as shown in equation (2.4) as;

$$K_{D(T)} = K_{D(20)}[1.047]^{T-20} \quad (2.4)$$

The value of $K_{D(20)}$ varies between 0.1 to 0.2, generally taken as 0.1

K_R= Reoxygenation coefficient for the river.

2.4Water Quality

The assumption that water is always available has been discovered to be incomplete. Availability of water may not necessarily equate to usability or adequacy. Although, it is difficult to provide a simple definition of water quality, the quality of water is generally accepted as the state or status of physical, chemical and microbiological of water in quantitative terms (Meybeck and Helmer, 2013). The physical, chemical and microbiological characteristics of water bodies are largely determined by climatic, geomorphologic and geochemical conditions prevailing in the drainage basin and the underlying aquifer (Haag and Westrich, 2016; Richard *et al.*, 2015). Nevertheless, Ruth and Mathew (2003)reported that, a complete assessment of water quality of a water body must provide detailed information on specific indicators, variables, variation in time and space within such system, the response of the ecosystem to such variations and implications or possible issues if the trends continue.

Ever since the discussion of problems relating to artificial and natural changes in the quality of inland water bodies by the Co-coordinating Council of the International Hydrological Decade (IHD) in the late 1960s, the issues of water quality of hydrological systems have gained appropriate position (House, 2015). Despite the early agreement on the strategic importance of understanding factors driving water quality changes, the practice of water quality inventory did not gain appropriate position in the science of hydrology. This is because of the high degree of variability associated with different environment and the factor initiating water quality changes thus, hydrological surveys and water quality studies were not often adequately linked (Meybeck and Helmer, 2013).

The effort of the United Nations Education Scientific and Cultural Organization (UNESCO) and the World Health Organization (WHO) resulted in the publication of Water Quality Survey in 1978 (Deborah, 2015).

The UNEP Guide on Water Quality Management (2013) defines water quality assessment as the overall process of evaluation of the physical, chemical and biological nature of water in relation to natural quality, human effects and intended uses, particularly those which may affect human health and ecosystem.On the other hand, the collection of information at set locations and at regular intervals to provide data which can be used to define current conditions and establish trends is water quality monitoring. Water quality assessment, therefore, involves the monitoring of an array of physicochemical and biologicalparameters in a systematic and continuous manner (UNEP, 2013).

2.5Impact of Seasons on Water Quality

Pollutants entering a river system normally result from many transport pathways including storm water runoff, discharge from ditches and creeks, vadose zone leaching, groundwater seepage and atmospheric deposition. These pathways are also seasonal-dependent. Hence, Ouyang *et al.* (2010) stated that, seasonal changes in surface water quality must be considered when establishing a water quality management program.

Hun-Kyun (2013) examined the response of river water quality to rainfall changes and concluded that, rainfall events after a long term dry season accelerate water quality degradations since pollutants may be accumulated on surface areas during dry season. On the other hand, degradations of river water quality which experienced several previous heavy rainfall events are likely to be little with following rainfall events. This was buttressed by Sahana and Danbul (2015) which noticedhigh concentration of total suspended solids (TSS) and chemical oxygen demand (COD) parameters during wet season compared to dry season.Contrarily, Songyan *et al.*(2015) reported that the relationship between water quality variables and proportion of different land uses were weaker in the rainy season than that in the dry season. This relationship was achieved by using Pearson correlation analysis. In other words, Songyan *et al.*(2015) suggested that dry season has more effect on the quality or concentration of surface water than rainy season. This assertion is in line with a previous work carried out by Suratman*et al.* (2014) which studied seasonal and spatial variability of selected surface water quality parameters in Setiu wetland, Terengganu, Malaysia.The parameters measured showed lower mean values of surface salinity, temperature, dissolved oxygen (DO), pH and total suspended solids (TSS)during the wet season relative to the dry season. However, the concentration of

biochemical oxygen demand (BOD) was high during the wet season and lowestin the dry season.

2.6 Impact of Land Use Practices on Water Quality

Land use practices are believed to have important impacts on both the availability and quality of river water quality and water resources generally. These impacts can both be negative and positive (Benjamen, 2015). Agriculture, forestry, water bodies, urban settlement, mining, industries, etc are some of the land-use/land cover types that have been identified as having impacts on the hydrological regimes of a basin (Awasthi *et al.,* 2012). The report of Benjamen (2015) concluded that the impacts of land-use on surface water could include impacts on mean surface runoff, peak flow/floods, base flow, erosion, sediment discharges, and consequently water quality variations.Similarly, Buck *et al.* (2010) and Adie (2008) had earlier observed that agricultural activities were the major source of river pollution during the rainy season and domestic waste during the dry season periods. Furthermore, Calder (2011) noted that land-use impacts on water quality could include changes in sediment load and concentrations of nutrients, salts, metals and agrochemicals, the influx of pathogens and a change in the temperature regime.

Land-use activities may affect the bacteriological quality of water and create health concerns for downstream water users. The concentration of pathogenic bacteria in surface waters may increase as a result of riparian grazing activities or influx from livestock production. Agricultural activities can lead to increase of nitrogen and phosphorous in water bodies. These are derived from fertilizer application and manure from livestock production. Also, Janwa *et al.* (2014) reported that the impacts of land use varies directly

with population, management strategies for waste disposal, type of industrial activities as well as type and management of waste being generated.

Xiang *et al.* (2015) studied the Tibet Autonomous Region of China otherwise known as the "Water Tower of Asia" which comprises the seven greatest rivers in Asia. It established the impacts of non-point source pollution and the linkages between activities on land and their impacts on the hydrological systems.Xiang *et al.* (2015) concluded that the water quality in the Tibetian Rivers is related to the mining activities in the region. This is because an elevated concentration of Pb was found in Salwen River and relatively high concentration of Ni was identified in another tributary, the Yangtze River.

2.7Surface Water Pollution

Complete protection of surface water may not be possible because pollutants from the atmosphere can enter surface water through precipitation, and contaminated ground water can introduce pollutants through recharge. However, limitations on land use around surface water can reduce contamination of surface waters from the watershed itself. Surface water pollution is classified into two major categories: point source pollution and non-point source pollution.

Point source pollution, such as pipe discharges, industrial outflows, tributaries, or wastewater treatment plant outflows (Plate II) are relatively easy to define and regulate (Robert *et al.,* 2015; Palmer *et al.,* 2014). The United States EnvironmentalProtection Agency (U.S EPA) regulates point source discharges throughout the United States with the National Pollution Discharge Elimination System (NPDES) permitting program(U.S EPA, 2016a). The NPDES program, which was introduced in 1972, requires point source

dischargers to obtain permits from their state. This includes industrial and municipal dischargers, or any other facility that discharges wastewater to receiving water. The program greatly assists in the control of point source pollutants of anthropogenic origin. NPDES permits specify the allowable flow rate of a discharge and the maximum concentration of specific pollutants (U.S. EPA, 2016b).



Plate II: Point source pollution of a river (Source: Wang *et al.*, 2014)

Non-point source (NPS) pollution is typically caused by rainfall or snowmelt moving over or through the ground, picking up natural and human pollutants, and carrying those pollutants into surface waters as shown in Plate III (Anazoo and Ibe, 2015). Pollutants include but are not limited to excess fertilizers, herbicides, and insecticides from agricultural lands and residential areas; oil, grease, and toxic chemicals from urban runoff

and energy production. Others are sediment from improperly managed construction sites, crop and forest lands, and eroding stream banks; salt from irrigation practices and acid drainage from abandoned mines; and bacteria and nutrients from livestock, pet wastes, and faulty septic systems (U.S. EPA, 2016c).



Plate III: Non-point source pollution (Source: Binkley and Burhan, 2015)

Non-point source pollution is a major problem for surface waters because it is often times difficult to identify the source of the pollution. Therefore, control of non-point sources of pollution is problematic. Often times, land use surveys and groundwater or surface water quality samples are the only ways of identifying where possible non-point sources may be located (Miserendino *et al.* (2015) and Robert *et al.*, 2015).

2.8 Past Works on Multivariate Statistical Analysis

The understanding of environmental variables for better management of river basins involves data analysis for decision making. Multivariate statistical techniques have been applied to characterize and evaluate surface water quality by several researchers. It is useful in verifying temporal and spatial variations caused by natural and anthropogenic factors linked to seasonality and land use. This is because it can be used to reduce the number of samples analyzed both in space and time, without much loss of information (Adie, 2008; Adebola *et al.,* 2013 and Ayobahan*et al.,* 2014). This will assist the decision makers in identifying priorities to improve water quality that has deteriorated due to pollution from various anthropogenic activities.

Multivariate analysis includes techniques such as principal component analysis (PCA), factor analysis (FA), cluster analysis (CA) and discriminant analysis (DA). These techniques aid the understanding of complex data matrices often generated when assessing the water quality and ecological status of an ecosystem (Singh *et al.,* 2015). It also has the advantage of identification of possible factors/sources that influence water systems and offers a valuable tool for reliable management of water resources as well as rapid solution to pollution problems (Qing*et al.,* 2016).

Adie (2008) used multivariate techniques (PCA, FA, CA and DA) in analyzing the pollution characteristics in rivers of the middle Galma basin, Nigeria at 12 stations of 2 years data. The results obtained showed that principal component and factor analysis were able to isolate factors that could be used to effectively monitor the water quality of the basin. Cluster analysis clearly delineated the seasons and sampling stations. Discriminant

analysis were applied to these clusters to extracts stations that were more useful in terms of representative data as well as months that were inappropriately classified. Hence, out of the 12 stations sampled, 3 stations were identified which could provide representative results for the rivers concerned via cluster analysis.

Similarly, Adebola *et al.* (2013) monitored the water quality of river Ogun using multivariate statistical techniques such as principal component analysis (PCA) and cluster analysis (CA) to analyze the similarities or dissimilarities among the sampling points. This was done so as to identify spatial and temporal variations in water quality and sources of contamination over time. 14 physiochemical parameters were generated from 8 sampling points. The PCA assisted to extract and recognize the factors responsible for water quality variations over the years. However, Adebola *et al.* (2013) reported that, parameter that can be significant in contributing to water quality variation in one season may less or not be significant in another. Also 3 zones were classified based on the cluster analysis results, as relatively less polluted, moderately polluted and highly pollutedzones.

Multivariate techniques such as PCA, FA and DA was used by Shrestha and Kazama (2015) in the study of water quality in the Fuji river basin with analysis of 8 years of data in such a way that critical factors responsible for variation were identified. It was observed in the study that multivariate techniques allow a reduction in the dimensionality of the large data set, delineating a few indicator parameters as responsible for large variations in water quality, interpretation of complex data sets and identification of pollution sources or factors. Shrestha and Kazama (2015) concluded that multivariate techniques are appropriate in source identification, pattern recognition and general understanding of environmental

elements. In the same way, Helena *et al.* (2016) mentioned multivariate techniques as a useful tool to identify pollutants as well as their source(s) in urban soils and groundwater.

2.9River Basin Management and Geographic Information Systems

According to Subramanya (2016), river basins are the geographic area contained within the catchment limit of a system of streams and rivers converging towards the same terminus, generally the sea or sometimes an inland water body. Due to the largeness and complexity of hydrological, geological, environmental and social data needed to be gathered in the management of natural resources at such a spatial scale, there is always a challenge of integration of large volume of data (Mtetwa *et al.,* 2013). Secondly, the cost of generating these data could also be another challenge, hence, the inability of government especially in developing countries to evolve a holistic and reliable river basin management practices. Notwithstanding, water allocation decisions have wider economic implications at the basin level. This is because the various stakeholders contributing positively or negatively as well as their water resources requirement and general impacts on the hydrologic system are better appraised at the river basin level(Rosana *et al.,* 2012).

Managing information in a holistic manner such that spatio-temporal variability is not lost as well as other crucial issues in assessing and making decisions at the river basin level is usually difficult. Nevertheless, Geographic Information Systems (GIS) is recognized and often used as a powerful tool (Mtetwa *et al.,* 2013; ESRI, 2015). This fact is buttressed by Mitasova and Neteler (2015) describing basins as spatial object with large boundaries and complex natural sequence of events in which, both traditional methods and gross simplifications may not be sufficient to manage it. However, Mitasova and Neteler (2015)

finally concluded that GIS provides capabilities to analyze and model this complex phenomenon hence, it is a support tool for researchers and resources managers.

Osborne and Wiley (2011) used GIS to assess the relationship between land use and water quality and find out that, the spatial patterns of different places impact the relationship of land use with the surface water quality. Osborne and Wiley (2011) further explained that the water is acidic and nutrients are low for the water bodies surrounded by forests whereas pH and dissolved solids are higher for water around agricultural lands in the surroundings.Also, Mtetwa *et al.* (2013)used GIS to monitor nutrient yields, pollution loads and then spatial distribution in an agro-rural catchment in South Africa. The systems enabled the delineation of impacts and patterns of pollution across the catchment.

Mapping the water quality of a river or stream is very important because it summarized the overall status of the river or stream in a pictorial form that can be easily understood. GIS techniques have been applied by various researchers including Marcelo *et al.* (2015), Oke *et al*.(2013) and Abbas(2013) to map the quality of river water. Also, in the fields of surface and ground water hydrology, several researchers have employed GIS techniques to map study areas. One of such scholar is Daffi (2013) who demonstrated the application of GIS techniques in mapping flood plain inundation. Mapping the water quality of a river cannot be done without pre-determination of the concentrations of the various considered parameters. However, it is impossible to determine the concentration of water quality parameters at every point within a river. Nevertheless, measured samples from various locations within the river can be used to make inferences about the entire river through interpolation (Shomar *et al.,* 2016; Balakrishnan *et al.,* 2014). Interpolation, been the process of estimating unknown values that fall between known values, have different

methods used in mapping study areas. The various methods are Inverse Distance Weighted Interpolation (IDW), Spline, and Kriging method. Shomar *et al.* (2016) and Marcelo *et al.* (2015) reported that IDW has an advantage over Spline and Kriging methods as it gives explicit control over the influence of distance between sampling points. This is because Inverse Distance Weighted interpolation (IDW) assumes that the nearer a sample point is to the cell whose value is to be estimated, the more closely the cell's value will resemble the sample point's value. In other words, the principle underlying IDW is the Waldo Tobler's first law in Geography which states that *"everything is related to everything else, but near things are more related than distant things".*

Daffi (2013) assessed the flood hazard levels of Dep River Basin, in North Central Nigeria, using Remote Sensing (RS) and Geographic Information Systems (GIS) techniques for effective flood plain management. Flood plains were viewed at catchment level with the objective of identifying areas that are susceptible to inundation using topographic characteristics of the watershed. Daffi (2013) recommended that low hazard areas should be used for irrigation farming and early rainy season farming while the medium and high hazard areas should be used for irrigation farming only.

Similar use of GIS in river basin related activities are well documented in the works of Li *et al.*(2014) and Jordan *et al.*(2012). On this note, Aelion and Conte (2015)specifically stated that, GIS and Remote sensing technology are gaining prominence in land resources inventory, surface and groundwater exploration and similar environmental studies.

2.10Water Quality Index

It is crucial that water quality is ascertained before use for any intended purpose. It is, however clear that each water use has different level of required quality. According to Hulyah (2014), a major objective of water quality assessment is to determine whether or not the water quality meets previously defined objectives for designated uses at national, regional, or international scales and also to investigate trends in changes. Water quality monitoring is undertaken to fulfill a variety of needs. One of such is the detection of spatial and temporal variation. The operational management of water quality requires a methodology that can provide more precise information on cycles and trends that is affordable by simple classification of an extensive list of water quality determinant concentrations (GEMS, 2007). However, Hulyah (2014) acknowledged one limitation of the traditional way of assessing water quality by comparing measured parameters with existing guidelines (or limits). Hence, Hulyah (2014) further explained that the methodology does not give an overview of spatial and temporal status of the catchment even though specific locations could be assessed. Therefore, there is need to remove the complexity arising from environmental data interpretation, and bring understandable information from data sets for policy makers as well as the general public. The use of Water Quality Index (WQI) can bridge the gap between these two extremes of water quality data acquisition and reporting methods (House, 2015). This has been identified earlier by the Scottish Development Department (SDD), where Water Quality Index was defined as…

> *"…a form of average derived by relating a group of variables to a common scale and combining them into a single number. The group should contain the most significant*

parameters of the data set, so that the index can describe the overall position and reflect change in a representative manner"(SDD,1976).

Likewise, Bordalo *et al.*(2012) described WQI as a mechanism based on numerical expression for defining the level of water quality by summarizing large amount of complex data into simplified mathematical numbers, which can be interpreted into text classes (e.g., excellent, very good, good, moderate, poor, etc.). Thus, WQI inform the regulatory agency covering a specific catchment about river water quality status in a very concise and clear manner. This way, the WQI contributes to the construction of a decision support system about a catchment (Fabio *et al.*, 2015).

Any number of water quality measurements can serve as indicators of water quality. However, there is no single measure that can describe overall water quality for any one body of water (GEMS, 2007). Therefore, a composite index that quantifies the extent to which a number of water quality measures deviate from normal, expected or 'ideal' concentrations may be more appropriate for summarizing water quality conditions across a range of inland water types and over time (GEMS, 2007).

2.10.1 Methods of determining water quality index

2.10.1.1 Oregon water quality index

Oregon Water Quality Index (OWQI) expresses water quality by integrating measurements of eight water quality variables. It provided the ambient water quality of Oregon's streams for general recreational use and its application to other geographic regions or water body types should be approached with caution (Cude, 2001). The parameters covered in this method are temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), pH,

total nitrogen, total phosphorus, total solids and fecal coliform (Dunnette, 2015). The index is free from the arbitration in weighting the parameters and employs the concept of harmonic averaging. The mathematical expression of this WQI method is given by equation (2.5) as reported in Bharti and Katyal (2015).

$$OWQI = \sqrt{\frac{n}{\sum_{i=1}^{n} \frac{1}{SI_i{}^2}}} \tag{2.5}$$

Where:

n = Number of sub-indices

SI = Sub index of ith parameter

2.10.1.2 Canadian council of ministers of environment water quality index

The Canadian Council of Ministers of Environment Water Quality Index (CCMEWQI) provides a consistent method, which was formulated by Canadian jurisdictions to convey the water quality information for both management and the public. This method can be applied by many water agencies in various countries (Khan *et al.*, 2015; Lumb *et al.*, 2013; Sargonkar and Deshpande, 2013). However, the method requires at least four variables (parameters), sampled at least four times for a minimum period of one year (CCME, 2001). In addition, CCME (2001) make known that the selection of appropriate water quality variables for a particular region is necessary for the index to yield meaningful results. Hence, choosing a small number of variables for which the objectives are not met will provide a different picture than if a large number of variables are considered, only some of which do not meet objectives. On this note, CCME (2001) stated that it is up to the professional judgement of the user (researcher) to determine which and how many variables

should be included in the CCME WQI to most adequately summarize the water quality in a particular region. The method of calculating CCMEWQI as documented in CCME (2001) is shown in equation (2.6).

$$CCMEWQI = 100 - \frac{\sqrt{\left({F_1}^2 + {F_2}^2 + {F_3}^2\right)}}{1.732} \quad (2.6)$$

Where:

F_1 = (Scope) = Number of variables whose objectives are not met

F_2 (Frequency) = Number of times by which the objectives are not met

F_3 (Amplitude) = Amount by which objectives are not met.

2.10.1.3 National sanitation foundation water quality index

The National Sanitation Foundation Water Quality Index (NSFWQI) method for comparing the water quality of various water sources is based upon nine water quality parameters such as temperature, pH, turbidity, fecal coliform, dissolved oxygen, biochemical oxygen demand, total phosphates, nitrates and total solids (Kumar and Alappat, 2016). The water quality data are recorded and transferred to a weighting curve chart, where a numerical value of Q_i is obtained. The mathematical expression for NSFWQI as reported by Kumar and Alappat (2016) is given in equation (2.7).

$$NSFWQI = \sum_{i=1}^{n} Q_i W_i \quad (2.7)$$

Where:

Q_i = Sub index for ith parameter (variable)

W_i = Weight associated with ith water quality parameter

n = Number of water quality parameter

2.10.1.4 Weighted arithmetic water quality index

The Weighted Arithmetic Water Quality Index (WAWQI) method classify water quality according to the degree of purity by using the most commonly measured water quality variables (Liou *et al.,* 2015; Shweta *et al.,* 2013). The procedure for calculating WAWQI as documented by Shweta *et al.* (2013) are given in equations (2.8), (2.9), (2.10) and (2.11).

$$WAWQI = \frac{\sum Q_i W_i}{\sum W_i} \tag{2.8}$$

Where:

Q_i = Quality of rating scale for each parameter and it is calculated as;

$$Q_i = 100\left[\frac{V_i - V_0}{S_i - V_0}\right] \tag{2.9}$$

V_i is the estimated concentration of ith parameter in the analyzed water, V_0 is the ideal value of the parameter in pure water which zero (except pH = 7 and DO = 14.6 mg/l), S_i is the recommended standard value for ith parameter.

W_i = Unit weight for each water quality parameter, calculated as;

$$W_i = \frac{K}{S_i} \tag{2.10}$$

K is a proportionality constant, calculated as;

$$K = \frac{1}{\sum\left({}^{1}/_{S_i}\right)} \tag{2.11}$$

Table 2.2 gives the water quality rating of the different WQI methods while the merits and demerits of the various WQI methods are presented in Table 2.3.

Table 2.2: Water quality rating and grading as per different WQI methods

WQI Value	Rating/Grading	
Oregon Water Quality Index (OWQI)		
900 – 100	Excellent water quality	
85 – 89	Good water quality	
80 – 84	Fair water quality	
60 – 79	Poor water quality	
0 – 59	Very poor water quality	
Canadian Council of Ministers of Environment Water Quality Index (CCMEWQI)		
95 – 100	Excellent water quality	
80 – 94	Good water quality	
60 – 79	Fair water quality	
45 – 59	Marginal water quality	
0 – 44	Poor water quality	
National Sanitation Foundation Water Quality Index (NSFWQI)		
91 – 100	Excellent water quality	
71 – 90	Good water quality	
51 – 70	Medium water quality	
26 – 50	Bad water quality	
0 – 25	Very bad water quality	
Weighted Arithmetic Water Quality Index (WAWQI)		
0 – 25	Excellent water quality	(A)
26 – 50	Good water quality	(B)
51 – 75	Poor water quality	(C)
76 – 100	Very poor water quality	(D)
Above 100	Unsuitable for drinking purpose	(E)

Source: Shweta *et al.*, 2013

Table 2.3: Merits and demerits of various WQI methods

Merits	Demerits
Oregon Water Quality Index (OWQI)	
1. Unweighted harmonic square mean formula used to combine sub-indices allows the most impacted parameter to impart the greatest influence on water quality index. 2. Formula is sensitive to changing conditions and to significant impacts on water quality. 3. Method acknowledge that different water quality parameters will pose different significance to overall water quality at different times and locations.	1. Does not consider changes in toxics concentrations, habitat or biology. 2. It is not possible to make inferences of water quality conditions outside the actual ambient network site location. 3. Cannot determine the water quality for specific uses nor can it be used to provide definitive information about water quality without considering all appropriate physical, chemical and biological data. 4. Cannot evaluate all health hazards (toxics, bacteria, metals, etc.)
Canadian Council of Ministers of Environment Water Quality Index (CCMEWQI)	
1. Adaptability to different legal requirements and different water uses. 2. Suitable tool for water quality evaluation for in a specific location. 3. Tolerance to missing data. 4. Suitable for analysis of data coming from automated sampling. 5. Clear and intelligible diagnostic for managers and the general public. 6. Statistical simplification of complex multivariate data. 7. Easy to calculate. 8. Flexibility in the selection of impute parameters and objectives.	1. F_1 not working appropriately when too few variables are considered. 2. The same importance is given to all variables. 3. No combination with other indicators or biological data. 4. Loss of information on single variables.
National Sanitation Foundation Water Quality Index (NSFWQI)	
1. Index value relate to a potential water use. 2. Facilitate communication with lay persons. 3. Evaluation between areas and identifying changes in water quality.	1. Loss of data during data handling. 2. Lack of dealing with uncertainty and subjectivity present in complex environmental issues. 3. Represent general water quality. That is, it does not represent specific use of the water.
Weighted Arithmetic Water Quality Index (WAWQI)	
1. Incorporate data from multiple water quality parameters into a mathematical equation that rates the health of water body with number. 2. Less number of parameters required in comparison to all water quality parameters for a particular use. 3. Useful for communication of overall water quality information to concern citizens and policy makers. 4. Reflect the composite influence of different parameters.	1. The index may not carry enough information about the real quality situation of the water. 2. There are many water quality parameters that are not included in the index. 3. The eclipsing or over emphasizing of a single bad parameter value.

Source: Shweta *et al.,* 2013

After extensive review of many indices of water quality from different scientists and regions, the Global Environmental Monitoring Systems (GEMS) adopted Canadian Council of Ministers of Environment (CCME) framework in the global evaluation of surface water systems (GEMS, 2007). It was noted that the index allow for measurements of the frequency and extent to which parameters exceed their respective guidelines at each monitoring station in arriving at decision on quality status which is a major advantage over the subject index frameworks. Ashok *et al.* (2015) commented that the index is flexible to accept global, regional or national guides set based on specific objectives. The index is determined on an annual basis, resulting in an overall rating for each station per year (GEM, 2007).

The Water Quality Index (WQI) of the Canadian Council of Ministers of Environment (CCME) has also been used in the context of the European Union Water Framework Directive to simulate data sets describing three different environmental conditions. These environmental conditions correspond to episodes of discharge of urban wastewater, eutrophication and risk to fish (Marta *et al.*, 2015). Simon *et al.* (2014) also used CCME WQI in comparative analysis of exposure sites to reference sites downstream of point source discharges across Canada.

2.11 Water Quality Monitoring

Water quality monitoring can be used to protect source waters by identifying pollutant levels and locations in a source water. It is a continuous process because water quality may change with season and with weather events. Water quality can be monitored by measuring physicochemical and bacteriologicalparameters of the water. However, in this research,

selected physicochemical parameters as well as two heavy metals were determined which are; temperature, turbidity, total dissolved solids (TDS), pH, chloride (Cl^-) and electrical conductivity (EC). Others include dissolved oxygen (DO),5-days biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), iron (Fe) and manganese (Mn).

2.11.1 Temperature

Temperature is a measure of the degree of hotness or coldness of a substance. The temperature of water is not used directly to evaluate the status of the water whether it is potable or wastewater. Nevertheless, temperature is one of the most important parameters in natural surface water systems as it govern to a large extent the biological species present in surface water and their rate of activities (Howard, 2015).It is also disclosed in Howard (2015) that temperature has an effect on most chemical reactions that occur in natural water systems as well as the solubility of gases in water.

The temperature of natural water systems responds to many factors, the ambient temperature (temperature of the surrounding atmosphere) being the most universal. Generally, shallow bodies of water are more affected by ambient temperatures than deeper bodies. The use of water for dissipation of waste heat in industry and the subsequent discharge of the heated water may result in temperature changes in receiving streams. Removal of forest canopies and irrigation return flows can also result in increased stream temperature.

Cooler water usually has a wider diversity of biological species. At lower temperatures, the rate of biological activities, i.e. utilization of food supplies, growth, reproduction, etc. is

slower. If the temperature is increased, biological activity increases. An increase of $10^{o}C$ is usually sufficient to double the biological activity, if essential nutrients are present (Scott, 2014). This assertion was buttressed by Raymond *et al.* (2016) which identified that, at elevated temperatures and increased metabolic rates, organisms that are efficient at food utilization and reproduction flourish, while other species decline and are perhaps eliminated altogether. Also, Raji (2015) stated that, accelerated growth of algae often occurs in warm water and can become a problem when cells cluster into algae mats because the natural secretion of oils by algae in these mats and the decay products of dead algae cells can result in taste and odour problems.

2.11.2 Turbidity

The turbidity of water is a measure of how much interference is caused to the passage of light through water. Turbidity is not detrimental to water potability unless it contains disease causing bacteria (Trevett *et al.*, 2014). However, Tebutt (1998) stated that the colloidal materials associated with turbidity provide adsorption sites for chemicals that may be harmful or cause undesirable tastes and odours and for biological organisms that may be harmful. In addition, Tebbutt(1998) stated that, disinfection of turbid waters is difficult because the colloids may partially shield organisms from the disinfectant. This statement was also affirmed by EPA (2001) that, as turbidity can be caused by sewage matter in water, there is a risk that pathogenic organisms could be shielded by the turbidity particles and hence escape the action of the disinfectant.

Most turbidity in surface waters results from the erosion of colloidal materials such as clay, silt, rock fragments and metal oxides from the soil (Helmer, 2014). However, Peavy (1998)

stated that vegetable fibers and microorganisms may also contribute to turbidity while soaps, detergents and emulsifying agents produce stable colloids that result in turbidity.

Turbidity levels in surface waters have been found to vary due to variations in precipitation and the percentage of impervious surface in a watershed. Long and Plummer (2015) found turbidity levels in a small stream to vary with changes in precipitation. Volk *et al.* (2013) found that turbidity levels in a stream could increase by as much as 300 fold during or following precipitation events.

2.11.3 Total dissolved solids

Total dissolved solids (TDS) in waterrefers to the amount of solids that cannot be evaporated when the water is heated. It composed mainly of carbonates, bicarbonates, chlorides, phosphates and nitrates of calcium, magnesium, sodium, potassium and manganese, organic matter, salt and other particles (Mahananda, 2016).Charkhabi and Sakizadeh(2011) observed that at high flows, TDS values tend to be diluted by surface runoff and for most rivers there are inverse correlation between discharge rate and TDS. Conversely, Bhatt *et al.* (2015) argued the declaration made by Charkhabi and Sakizadeh (2011) by explaining that; high flows in surface waters are more during rainy season than dry season for a given river or stream. Hence, Total Dissolved Solids in a given river or stream are more during rainy season since runofftransport large amount of sediment load from the watershed to receiving streams during the rainy season.

Several researchers such as Detenbeck *et al.* (2015),Trevett *et al.*(2014) and Elbag (2006)have stated that higher value of dissolved solids in water indicate greater amount of ions in the water. However, Bhatt *et al.* (2015) reported that some but not the entire

dissolved solids act as ions. Waters with high TDS are unpalatable and potentially unhealthy (Ouyang *et al.* 2016).

2.11.4 pH

pH represents the effective concentration (activity) of hydrogen ions (H^+) in water. However, the activities of hydrogen ions can be expressed most conveniently in logarithmic scale hence; pH is defined as the negative logarithm to base ten of the hydrogen ions concentration in a solution (Kim and Cardone, 2016). Mathematically, pH is given by equation (2.12).

$$pH = -log[H^+] (2.12)$$

Where; [H^+] is the concentration of hydrogen ions in mole per liter. Nevertheless, Lious and Wang (2014) stated that because hydrogen ions associate with water molecules to form hydronium ions (H_3O^+), pH is often expressed in terms of concentration of hydronium ions. Also, Ross and Allison (2010) documented that pure water at 22 ^oC (72 ^oF), have equal concentrations of hydronium ions (H_3O^+) and hydroxyl ions (OH^-); the concentration of each is 1.0×10^{-7} moles per liter (mol/l). Therefore, pH of pure water is given by equation (2.13).

$$-log(1.0 \times 10^{-7}) = -(-7.00) = 7.00 (2.13)$$

Since pH is defined as –log[H^+], it implies, pH decreases as [H^+] increases (which will happens if acid is added to the water). Also, pH is a base 10 log scale, hence, the pH changes by 1, for every power of 10 change in [H^+]. That is, a solution of pH 3 has an H^+ concentration 10 times that of a solution of pH 4. Mechenich and Andrew (2011) reported that pH scale ranged from 0 to 14 however, pH values less than 0 and greater than 14 have

been observed in very rare concentrated solutions. Nawal (2013) informed that pH is not static; it changes over time, it can change over the course of single day as it usually drops at night and rises during the day time. However, Schreiner (2015) noted that pH of stored water could change as the biological processes changes in the tank. A solution with a pH value less than 7 is acidic, while a solution greater than 7 is basic. Trevett *et al.* (2014) stated that most aquatic lives survive within a pH range of 7 to 8 as shown in Figure 2.5.

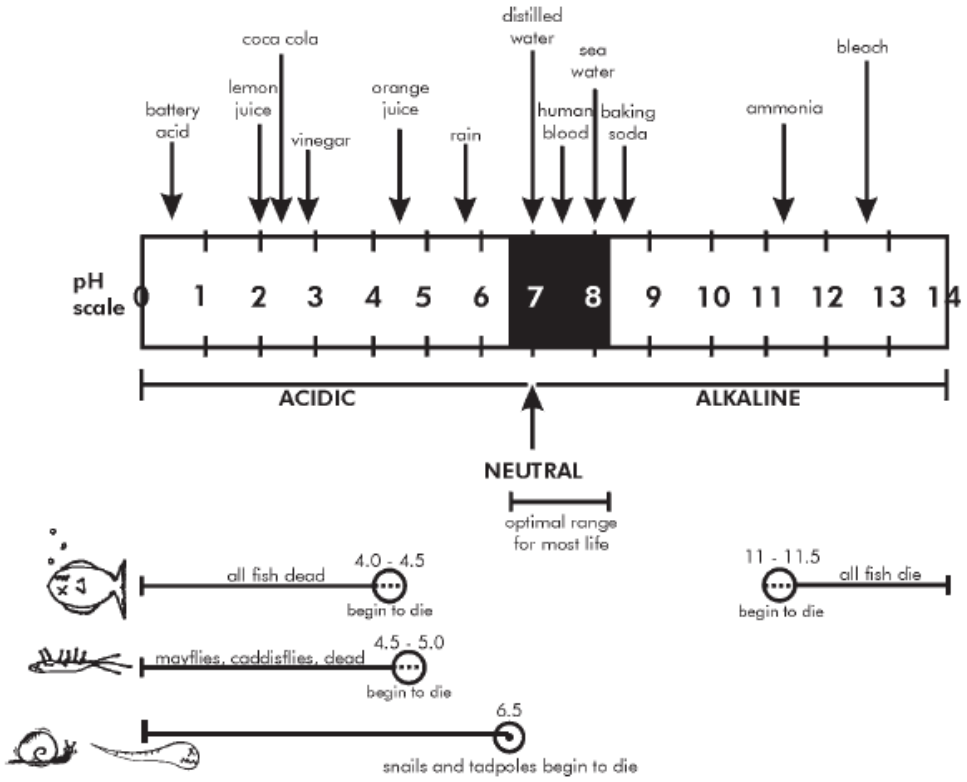


Figure 2.5: pH scale of acidity and alkalinity for aquatic lives (Source: Trevett *et al.* (2014)

A research carried out by Hem (2008) recorded the factors affecting pH to include concentration of carbon dioxide in water. Carbon dioxide (CO_2) enters a water body from a variety of sources, including the atmosphere, runoff from land, release from bacteria in water, and respiration by aquatic organisms. This dissolved CO_2 forms a weak acid. Naturally, unpolluted rain water can be as acidic as pH 5.6, because it absorbs CO_2 as it

falls through the air. Since plants take in CO_2 during the day and released it during the night, pH levels in water can change from day time to night, geology of soils and watershed; acidic and alkaline compounds can be released into water from different types of rock and soil. When calcite ($CaCO_3$) is present, carbonates (HCO_3, CO_3^{-2}) can be released, increasing the alkalinity of the water, which raises the pH. Also when sulfite minerals such as pyrite, or "fool's gold", (FeS_2) are present, water and oxygen interact with the minerals to form sulphuric acid (H_2SO_4). This can significantly drop the pH of water. Drainage water from forests and marshes is often slightly acidic, due to the presence of organic acids produced by vegetation. Other factors as also reported by Hem (2008) include air pollution and drainage from mine sites.

2.11.5 Chloride

The report of EPA (2001) informed that chlorides are widely distributed in nature as salts of sodium (NaCl), potassium (KCl) and calcium ($CaCl_2$). Natural sources of chloride in aquatic systems include naturally occurring saline lakes and groundwater discharges from saline aquifers. Nevertheless, where chloride content is known to be low, a noticeable increase in chloride concentrations may indicate pollution from sources such as septic systems, fertilizer, landfills and road salts (Michenich and Andrews, 2011). No healthbased guideline value is proposed for chloride in drinking water however, at concentrations greater than 250 mgl^{-1}, a salty taste may be observed (WHO,2015).

The report of CCME (2011) pointed out that chloride ion is naturally occurring, and therefore detection of increased levels of chloride in surface waters does not necessarily

imply an anthropogenic source (although chloride is often used as an indicator of increasing urbanization in a watershed).

2.11.6 Electrical conductivity

Electrical conductivity is the measurement of the ability of a solution to transmit electric current. This ability is dependent upon the presence of ions in solution. Raji (2015) recognized conductivity measurement as an excellent indicator of the total dissolved solids in water.This claim was also noticed by Michenich and Andrews (2011)that; for most water, dissolved solid is a product of conductivity and a factor (in the range 0.55-0.70). Michenich and Andrews (2011)Further explained that waters containing a lot of free acid, the factor may be less than 0.55 while for highly saline waters it is greater than 0.70. However, EPA (2001) reported that dissolved solids includes ionized and non-ionized matter but only the former is reflected in the conductivity. Also, Ogbozige *et al.* (2015) observed that electrical conductivity (EC) is strongly influenced by concentration of chloride ions (Cl^-) linearly.

The conductivity of surface water is affected by both natural and anthropogenic factors in the watershed.Elbag (2006) identified rocks and biological activities in surface water as some of the natural factors affecting the conductivity in surface water and explained that; conductivity of surface water can vary depending upon the type of rock or soil that the water has come in contact with. Water that has come in contact with granite bedrock tends to have a low conductivity while water that has come in contact with clay soils tends to have a high conductivity. Furthermore, a high rate of decay of organic matter by biological processes can affect the conductivity of the water. Degradation of plant matter increases the dissolved solids as well as the conductivity in the water. Hence, Elbag (2006)

concluded that seasonal change in biological activity may have an effect on the seasonal trends of conductivity levels.

Pollutants (anthropogenic factor) that entersurface water through runoff may raise or lower the conductivity of the surface water. For instance, organic compounds such as oil or alcohol lower the conductivity of water because they lack the ability to carry a charge (Jefferson, 2016). Hence, Jefferson (2016) established that areas with high percentage of impervious surfaces, such as urban areas, can yield runoff containing oils that may lower the conductivity of a receiving water body. Other human activities in a watershed that may raise the conductivity of surface waters include agricultural and residential land uses. A failing septic system near a surface water body could raise the conductivity of that surface water due to the presence of chloride, phosphate, and nitrate(Detenbeck *et al.,* 2015).

2.11.7 Dissolved oxygen

Dissolve Oxygen (DO) is a very important indicator of a water body's ability to support aquatic lives. This is because fish "breathe" by absorbing Dissolved Oxygen in water through their gills (Giller *et al.,* 2012). Dissolved Oxygen (DO) enters a water body from the atmosphere and from oxygen producing plant life living in the water. The atmosphere is made of approximately 20 percent oxygen or 200,000 ppm. However,typical oxygen levels in surface waters are below 10 ppm (Faniran *et al.,* (2016).

There are many factors that influence the amount of DO in surface water. Oxygen is transferred from the atmosphere into moving waters (streams and rivers) at a higher rate than still waters, such as lakes. This is as a result of the aeration effect caused by turbulence usually associated with moving streams and rivers (Giller *et al.,* 2012). Water

at a colder temperature also has a higher saturation level of DO than water at a warmer temperature (Ogbozige *et al.*, 2015; Howard, 2015 and Tebbutt, 1998).In addition, Howard (2015) noticed that water at a lower altitude has a higher saturation level of DO than water at a higher altitude. Furthermore, Elbag (2006) identified turbidity as one of the factor influencing the DO level of surface water and explained that; high turbidity in surface water reduce the level of DO by raising the water temperature and lowering photosynthesis due to the absorption of sunlight by suspended solids.

As earlier explain, Dissolved Oxygen have so much effect in aquatic life hence, high level of DO in surface water indicate the freshness of the water and vice versa.

2.11.8 Biochemical oxygen demand

Natural organic detritus and organic waste from wastewater treatment plants, failing septic systems, and agricultural and urban runoff, acts as a food source for water-borne bacteria. Bacteria decompose these organic materials using dissolved oxygen, thus reducing the DO present for fish. Cairncross and Faechem (2013) reported that, most of the bacteria in water are aerobic (i.e., they use oxygen to perform their metabolic activities of decomposition).The amount of oxygen consumed or needed by microorganisms in the oxidation of organic matters in contaminated water is known as Biochemical Oxygen Demand (BOD). BOD can provide information on the concentration of pollutants that may be entering surface water via point and non-point sources.Hence, Hannah and Sinton (2015) reported that high level of BOD in surface water may arise from industrial discharges, farmland runoff carrying fertilizer and animal waste as well as urban runoff and septic systems.

In BOD measurement, oxygen consumed from a sample placed in an air-tight container, and kept in a controlled environment for a preselected period of time is determined. In the standard test, a 300-ml BOD bottle is used and the sample is incubated at 20^{o} C for 5 days. However, Moe *et al.* (2013) suggested that light must be excluded from the incubator to prevent algal growth that may produce oxygen in the bottle. A BOD result with a low value generally means little pollution and/or little aerobic activities while a high BOD means the reverse (Hannah and Sinton, 2015). In BOD measurement, it is reported as milligrams of oxygen consumed per liter (mg/l) of water.

2.11.9 Chemical oxygen demand

Kumar *et al.* (2015) defined Chemical Oxygen Demand (COD) as a measure of the oxidation of reduced chemicals in water. The essence of COD test is to determine the extent of readily oxidizable organic matter, which is of two types: organic matter which can be biologically oxidized (i.e biologically active) and organic matter which cannot be oxidized biologically (i.e biologically inactive). Unlike BOD, COD does not differentiate between biologically available and inert organic matter, and it is a measure of the total quantity of oxygen required to oxidize all biologically active and inactive organic materials into carbon dioxide and water (Russell, 2015). Consequently, COD values are always higher than BOD values for given water sample. However, COD measurements can be made in few hours while BOD measurements usually take five days. Russell(2015) identified sulfides, sulfites, thiosulfates and chlorides as some the common compounds which causes COD values to be higher than BOD.

2.11.10 Total nitrogen

According to Nugent *et al.* (2013), total nitrogen is a measure of all forms of nitrogen (organic and inorganic) which is the sum of Kjeldahl nitrogen (organically-bound nitrogen and ammonia) and oxidized nitrogen. The forms of nitrogen found in surface water are nitrate (NO_3^-), nitrite (NO_2^-), and ammonia (NH_3^+).Nitrite can be formed by the oxidation of ammonia or the reduction of nitrate. Generally nitrate is found in much higher concentrations than nitriteand ammonia in water since nitrate is most stable (Bhatt *et al.*, 2015).

Nitrogen containing compounds act as nutrients in streams and rivers and are essential for the growth of algae and other plants. Hence, excessive concentration of nitrogen containing compounds in surface water can over stimulate aquatic plants and algae growth (algal bloom) thus causing eutrophication of water bodies. Eutrophication has deleterious impacts on other aquatic lives. This is because, small part of the algal blooms are consumed by zooplanktons and other aquatic organisms like fishes while the remaining larger portion stay and decay in the water thus, depleting dissolved oxygen (Pelham and Rasmussen, 2015). Usually toxic gases like hydrogen sulphide is generated andalso, an unpleasant greenish slimy layer is formed on the surface of the water body. This results in the suffocation and eventually death of aquatic organisms (Plate IV) thereby making water body emit bad odor (Barnes *et al.*, 2016). The anaerobic conditions (lack of oxygen) generate toxins in the algae, which can kill certain organisms like birds and animals (Pelham and Rasmussen, 2015). This will limit the use of such water body as a source ofmunicipal water supply or any other activity like recreational use.Nitrogen is also a concern in drinking water because high concentrations of nitrate in drinking water can

result in a temporary blood disorder in infants known asmethemoglobinemia, commonly called "blue baby syndrome." In severe, untreated cases, brain damage and eventually death can result from suffocation due to lack of oxygen (Nugent *et al.*, 2013).In order to protect the health of infants, the World Health Organization (WHO) adopted drinking water standards and set the recommended limit for nitrate-nitrogen at 10 mg/l (WHO, 2016).

Nugent *et al.*(2013) reported that the major routes of entry of nitrogen into bodies of water are runoff from fertilized agricultural field, municipal and industrial wastewater discharges, septic tanks and animal wastes.



Plate IV: Effect of eutrophication (Source:Nyenje *et al.*, 2016)

2.11.11 Total phosphorus

Phosphorus occurs widely in plants, micro-organisms, animal wastes, etc. It is usually used as constituents of agricultural fertilizer and detergents; particularly those for domestic use (Lemunyon and Gilbert, 2015).Phosphorus is generally considered to be the limiting nutrient for plant growth in freshwater with small quantities occurring naturally mainly from geological sources.Therefore, a minute amount of phosphorus entering a water body can trigger a significant algal bloom (although nitrogen and carbon are also required for algal growth) with it associated effects (Hergert*et al.*, 2013).Dormaar and Chang (2016) reported that Total Phosphorus (TP) is the most complete determination of the element phosphorus irrespective of the compounds in which it is actually present in the water. Hence, it has been the practice in lake investigations to determine total phosphorus as one of the most meaningful parameters in the assessment of eutrophication. However,Daniel *et al.* (2016) stated that not all the phosphorus measured under test conditions may be effectively available in the environment to promote algal growth. Orthophosphate is the most readily used form. The advantage of determining TP is that,the result is a total one thus, subject to less ambiguity of interpretation than other phosphorus parameters (Dormaar and Chang, 2016).

Only small proportion of the phosphorus (P) applied on croplands (through fertilizer) is removed in the form of harvested crops. Some of these harvested crops are fed to livestock and a proportion of the excrete from the livestock is usually reapplied as manure to croplands, returning some of the harvested phosphorus to the soil. This excess phosphorus may either remain in the soil or be exported to surface waters by surface runoff or leaching thus, making the receiving water body to contain phosphorus (Heathwaite, 2014).

Sewage treatment plants also provide most of the available phosphorus to surface water bodies. According to Tiessen and Moir (2015),a normal adult excretes 1.3 - 1.5 g of phosphorus per day. Additional phosphorus originates from the use of industrial products, such as toothpaste, detergents, pharmaceuticals, and food-treating compounds. Primary treatment removes only 10% of the phosphorus in the waste stream; secondary treatment removes only 30%. The remainder is discharged to the water body (Menzel, 2016). Hence, tertiary treatment in wastewater treatment plant is required to remove additional phosphorus from the water. The amount of additional phosphorus that can be removed varies with the success of the treatment technologies used. Available technologies include biological removal and chemical precipitation (Davis and Reddy, 2016). Phosphorus can also get into surface waters through runoff and leaching of the content of weathering of phosphate-rich rocks (Heathwaite, 2014).

2.11.12 Iron

Iron (Fe) exists naturally in rivers, lakes, and underground water. It may also be released to water from natural deposits in certain rocks, discharges from iron ores refining industries, and corrosion of iron containing metals in water (Davison, 2016).Iron can be present in water in two forms; the soluble ferrous iron or the insoluble ferric iron. Water containing ferrous iron is clear and colourless, and when exposed to air the water turns cloudy causing a reddish brown precipitate of ferric iron to appear (Stumm and Morgan, 2014).

Sandmann (2013) identified iron as an essential nutrient for good health asit is a major component of hemoglobin, which is used to transport oxygen and carbon dioxide in the blood. Sandmann (2013) further explained that iron deficiency can enhance lead absorption and toxicity hence, anyone with increased blood lead levels should be tested for iron deficiency. In fact, the problems associated with iron in water are primarily aesthetic, as

thesoluble (reduced) ferrous (Fe^{2+}) iron is oxidized in air to the insoluble ferric (Fe^{3+}) form, resulting in colour or turbidity (in severe cases, precipitate formation). For instance, laundry becomes stained if washed in water with excessive iron, and vegetables likewise become discoloured on cooking which may even impart taste. Also when water rich in iron are used to make tea (in which tannins are present) there may be a reaction giving rise to off-colours which may in severe cases resemble that of ink (Stumm and Morgan, 2014). Conversely, Imai*et al.* (2016) reported that the ingestion of large quantities of iron can damage blood vessels, cause bloody vomitus or stool, and damage the liver and kidneys, which may even cause death. Also, iron bacteria flourish best under dark conditions and in water containing dissolved iron and carbon dioxide. The bacteria can clog pipes and screens, and can leave brownish stains on laundry, reddish-brown particles on fixtures, and can cause an unpleasant taste and odor in water (Nagai and Adeyemi, 2015).

2.11.13 Manganese

Manganese (Mn) occurs naturally in many surface water and groundwater sources and in soils and rocks that may erode into these waters. However, human activities are also responsible for much of the manganese contamination in water in some areas. These includedischarges from industrial facilities and leachate or runoff from landfills and soils containing disposed manganese containing wastes such as dry cell batteries (Davison, 2016; Bakkaus *et al.*, 2012).

The report of Yokel*et al.* (2014), divulged that manganese is essential for normal development and body function across the life span of all mammals. This is because manganese contributes to maintain healthy nerves and immune system as well as regulating blood sugar and avoiding blood clothing defects. Itsdeficiency in human body is very rare because of its widespread presence in the human diets. However, when it does occur, Mn

deficiency has been related with skeletal abnormalities, alterations of reproductive function, difficulties in wound healing, and impaired growth (Sandmann, 2013). Nevertheless, consuming water containing very high concentration of Mn has been linked with toxicity to the nervous system especially the elderly, producing "Parkinson like syndrome". This includes weakness, muscle pain, slow speech, monotonous tone of voice, "mask-like" facial expression, and slow clumsy movement of the limbs which are usually irreversible (Crossgrove and Zheng, 2015).Conversely, Khan (2011)reported that water with high levels of manganese will be rejected by the consumer long before any danger threshold is reached. This is because the general remark for manganese is aesthetic (sever staining problem).The guidelines for the considered physicochemical parameters are given in Table 2.4.

Table 2.4:Permissible limits for determined physicochemical parameters

Parameter	**Unit**	**FEPA Standard**	**Health Impact (Excess)**
Temperature	^{o}C	≤ 40	NDHI
Turbidity	NTU	≤5.0	DHI
Total Dissolved Solids	mg/l	≤500	Organoleptic implications
pH	pH units	6.5-8.5	Organoleptic consequences
Chloride (Cl^-)	mg/l	≤250	No impacts (only palatability)
Electrical Conductivity (EC)	(µS/cm)	≤750	NDHI
DO	mg/l	≥ 5.0	Slightorganoleptic effects
BOD_5	mg/l	≤2.0	NDHI
COD	mg/l	≤20	NDHI
Total Nitrogen	mg/l	≤1.0	Organoleptic consequences
Total Phosphorus	mg/l	≤0.1	NDHI
Iron (Fe)	mg/l	≤0.3	Damage of blood vessels
Manganese (Mn)	mg/l	≤0.2	"Parkinson like syndrome"

Source: FEPA (2015)
NDHI = No direct health implications, but an important indicator of overall water quality.
DHI = Direct health implications depending on the precise composition of the turbidity causing materials.
^{o}C = Degree Celsius, NTU = Naphelometric Turbidity Unit, mg/l = milligram per liter, µS/cm = micro Mohs per centimeter.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

3.2.10 Apparatus and software used

i. Portable DO meter (DO STARTER300D, ±1%) made by OHAUS Corporation, USA.

ii. Pocket-sized pH meter (pHep®, ±0.1) made by HANNA LTD, England.

iii. Pocket-sized dissolved solids and conductivity meter with temperature compensation (TDS & EC hold, ±2%) made by Griffin Company, USA.

iv. HACH 2100N Turbidimeter made by HANNA, LTD, England

v. Phosphorous meter (Colorimeter 257) made by Sherwood, USA.

vi. Kjeldahl auto distillation machine (Kjeltec 8200™) made by FOSS, Sweden.

vii. Atomic Absorption Spectrometer (280FS AA) made by Agilent Technology, USA.

viii. Weighing balance (FA/JA series) made by HANNA LTD, England.

ix. Magnetic stirrer (GA064-331) made by Gallenkamp Group of Companies, Canada.

x. Refluxing machine

xi. Incubator

xii. Glassware (BOD bottles, conical flasks, measuring cylinders and burets) made by Kimax Company, England.

xiii. A handheld Global Position System navigator (Etrex 20x) made by Garmin, USA.

xiv. ArcGIS 10.5

xv. JMP version 13

xvi. Visual Basic.Net (VB.Net) version 2017

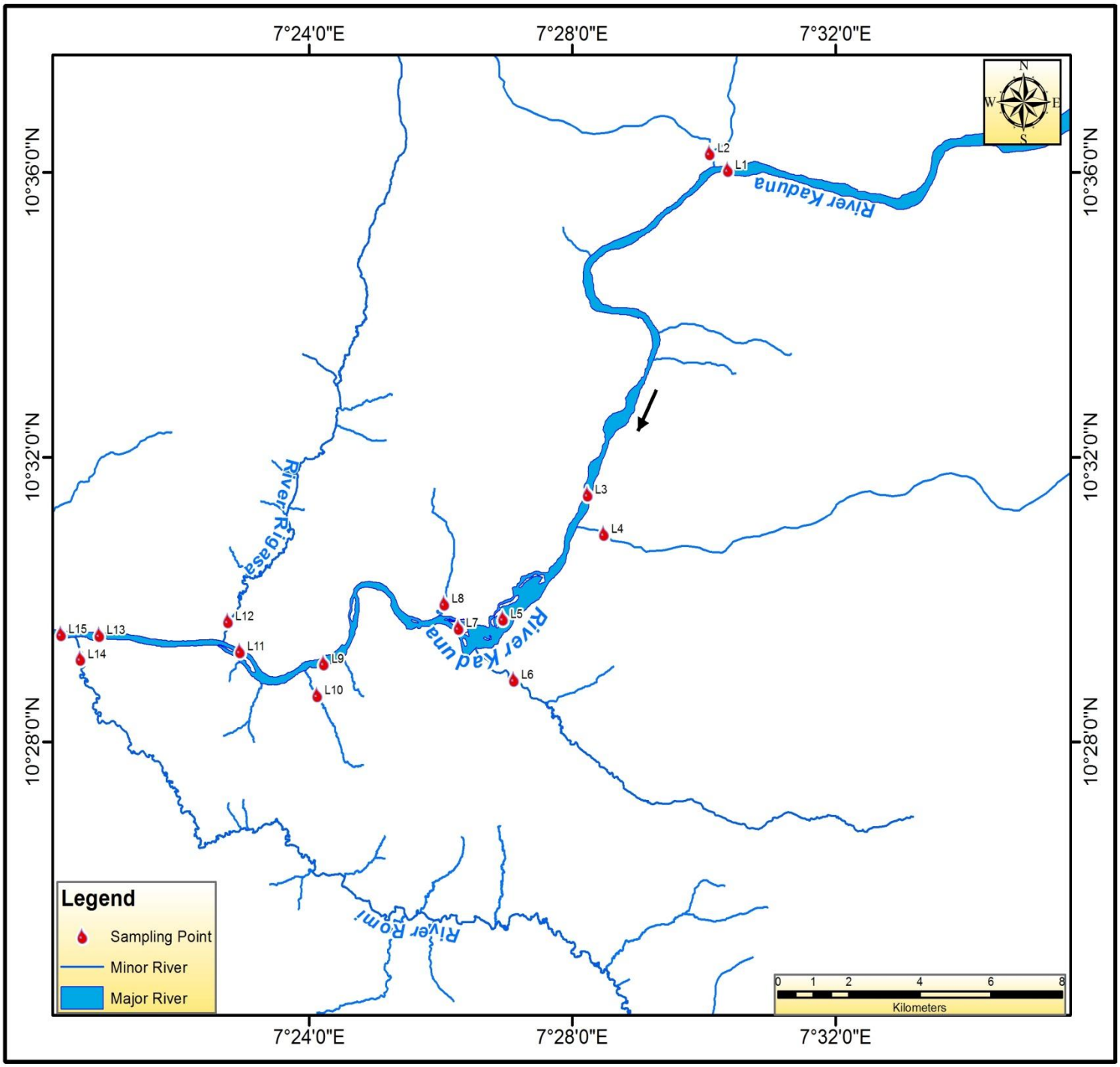
xvii. CorelDRAW X7

xviii. Swimming jacket (work-vest)

3.3 Methods

3.3.1 Sampling locations

The map of the study area was obtained as described in section 1.6 and thereafter, the sampling locations were selected from the map. There are 8 sampling locations along River Kaduna and 7 (at about 30 m away from the confluence points) along the major tributaries, making a total of 15 sampling sites. These stations correspond to flow routes and inflow from discharge point (Figure 3.1). The justification for selecting these locations as sampling points was based on past literatures.


7°24'0"E
7°28'0"E
7°32'0"E
10°36'0"N
10°32'0"N
10°28'0"N
N
S
E
W
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
L11
L12
L13
L14
L15
River Kaduna
River Kaduna
River Rigasa
River Romi
Legend
Sampling Point
Minor River
Major River
0 1 2 4 6 8
Kilometers

A preliminary visit (feasibility studies) to the selected locations was made with the guide of the studied area map. In addition, arrangement for canoes (most especially from fishermen) at different settlements along River Kaduna were made for the purpose of gaining access to the center of the river for each sampling point during sampling days. A standby motorcyclist was also arranged for the purpose of conveying the researcher together with sample bottles and equipment to the river banks during sampling days.

At each sampling point, a Global Position System (GPS) was used in recording the geographical location of such point (Plate V). Table 3.1 gives the description of the sampling sites.



Table 3.1: Description of sampling locations

Location Code	Location Name	Geographical Coordinate	Description
L1	*Malali	10°36'3.09"N 7°30'21.91"E	The location is along River Kaduna, at the river side of Malali Gabas in Igabi LGA (Plate VI). The water is used for fishing (all seasons), domestic and irrigation of farms during dry season. It contains numerous rocks and plots of farms on both sides of the river banks.
L2	+Kwarau	10°36'16.96"N 7°30'5.43"E	The location is along Kwarau stream (a tributary of River Kaduna) at about 30 m away from the confluence point (Plate VII). The stream drains effluents from Malalin Gabas Community (Igabi LGA). It is used for fishing during rainy season and irrigation of farms during dry season. It is 367.33 m downstream of L1.
L3	*NNPC	10°31'29.23"N 7°28'14.04"E	The location is 12, 279.33 m downstream of L2 and 50 m upstream of NNPC water intake stationalong River Kaduna in Chikun LGA (Plate VIII).It is between Ungwa Rimi and Ungwa Maigero communities. The water is used for fishing and bathing (all seasons) and also drinking and irrigation (dry season).
L4	+Kuyi	10°30'56.02"N 7°28'28.84"E	The location is along Kuyi stream (a tributary of River Kaduna) at Narayi community in Chikun LGA (Plate IX). The stream drains effluents from Ungwa Pama, Bayanduse and Narayi communities. The water is used for domestic, fishing and irrigation of gardens. It contains numerous rocks and at a distance of 965.23 m downstream of L3.
L5	*Barnawa	10°29'44.46"N 7°26'56.86"E	The location is along River Kaduna, between Police College in Kabala (Kaduna North LGA) and Barnawa GRA (Kaduna South LGA). It is adjacent the Christian & Muslim cemetery at Barnawa GRA (Plate X). The water is used for fishing (all seasons) and irrigation (dry season). It is 3,163.23 m downstream of L4.
L6	+Kutimbi	10°28'53.12"N 7°27'6.71"E	The location is along Kutimbi stream (a tributary of River Kaduna), between Narayi in Chikun LGA and Barnawa in Kaduna South LGA (Plate XI). It is 6799.56 m downstream of L5 and conveys effluents from Ungwa Boro, Ungwa Pama, Sabon Tasha, Narayi and Barnawa communities. It is only used for irrigation.
L7	*Living Faith	10°29'36.82"N 7°26'16.25"E	The location is 709.76 m downstream of L6 along River Kaduna.It is between Living faith Church, Barnawa (Kaduna Headquarters) in Kaduna South LGA and Ahmadu Bello stadium, Kigo road (new extension) in Kaduna North LGA (Plate XII). The water is used for fishing (all seasons),bathing, washing and irrigation (dry season).
L8	+Kigo	10°29'57.44"N 7°26'3.32"E	The location is along Omo stream, 30 m away from the confluence point to River Kaduna at Kigo road (new extention) in Kaduna North LGA. It is 616.56 m downstream from L7, conveys effluents from Kaduna main town, Kabala-costain and Kigo road new extention (Plate XIII). The water is only used for irrigation of farms (dry season).

LGA = Local Government Area,
GRA = Government Residential Area,
* = Sampling locations along River Kaduna,
+ = Sampling locations along tributaries, 30 m away from confluence point.

Table 3.1 (Continued)

Location code	Location Name	Geographical Coordinate	Description
L9	*Down Quarters	10°29'6.80"N 7°24'13.53"E	It is along River Kaduna at 5, 099.67 m downstream of L8and 50 m upstream of Coca-Cola water intake station (Plate XIV). It is between Tudun Wada and Kakuri (Down Quarters river side) in Kaduna South LGA. Thewater is used majorly for fishing (all seasons) and irrigation of farms (dry season).
L10	+Breweries	10°28'40.07"N 7°24'7.42"E	The location is along the Nigerian Breweries drainage, 30 m away from the confluence point to River Kaduna at Kakuri (Kaduna South LGA). It drains effluents from Nigerian Breweries LTD, United Nigeria Textile LTD, Arewa Textile LTD, Kaduna Textile LTD and domestic waste (Plate XV). It is at a distance of 586.03 m from L9 (downstream).
L11	*Ungwa Mu'azu	10°29'17.15"N 7°22'56.89"E	The location is along River Kaduna, between Kudende and Ungwa Mu'azu (new extension) communities in Kaduna South LGA (Plate XVI). It is 554.45 m upstream of the confluence point of River Rigasa and 2,708.67 m downstream of L10. Unlike other locations, this location is free from rocks. The water is only used for fishing and irrigation.
L12	+Rigassa	10°29'42.63"N 7°22'45.92"E	It is along River Rigasa (a major tributary of River Kaduna) at 30 m away from the confluence point in Ungwa Mu'azu (new extention), Kaduna South LGA (Plate XVII). It is 554.45 m downstream of L11, drain effluents from Rigasa, Bakinruwa, Nariya, Kabala and Ungwa Mu'azu communities. It is used for fishing (rainy season) and irrigation.
L13	*Maigigiya	10°29'30.84"N 7°20'48.66"E	The location is along River Kaduna, 714.83 m upstream of the confluence point of River Romi and 3447.65 30 m downstream of L12. It is between Maigiginya in Rigasa (Igabi LGA) and Kudende (Chikun LGA). It contain numerous plots of farms on both sides of the riverbanks (Plate XVIII). It is used for fishing (all seasons) and irrigation.
L14	+Romi	10°29'10.65"N 7°20'31.50"E	The location is 714.83 m downstream of L13 at the confluence point of River Romi and River Kaduna (Plate XIX). The river conveys effluents from NNPC refinery, paper factories, automobile industries and domestic waste. It is used for fishing (rainy season) and irrigation of farms (dry season).
L15	*Railway Bridge	10°29'31.67"N 7°20'13.77"E	The location is along River Kaduna, 381.53 m downstream of L14 and 50 m upstream of the new railway bridge known as Kaduna River Super Major Bridge(Plate XX) that links Maigiginya in Rigasa (Igabi LGA) and Kudende (Chikun LGA). There are numerous plots of farms on both sides of the riverbanks. The water is used for fishing and irrigation.

LGA = Local Government Area, * = Sampling locations along River Kaduna,
+ = Sampling locations along tributaries, 30 m away from confluence point.


















3.2.2 Sampling frequency and method

The samplings were conducted monthly for a period one yearbetween June 2016 and May 2017.Frequency and duration of the sampling techniques were based on literatures such as; Adebayo (2014), Udiba *et al.* (2014),Esengul *et al*.(2014), Vujovic *et al.* (2012) and Carlos *et al.* (2007).

The grab sampling technique was employed in each sampling location. This was done by dipping high density polyethylene (HDPE) plastic bottles below the water surface at the center of the stream and ensuring that the mouth of the bottle faces the water current. Prior to sampling, the sample bottles were disinfected with methylated spirit and then thoroughly rinsed with the sample water before sample collection as stated in literature (APHA, 2012). Samples were taken from the most upstream site first and continued up to the most downstream site. Sampling in this manner assumes that before sampling downstream location, the water quality already sampled upstream must have flowed to that point. Preservation of sample during transportation from sampling sites to laboratory was achieved by means of a cooler containing ice (Plate XXI).



Plate XXI: Transit preservation of samples

3.2.3 Laboratory analytical techniques

Samples were allowed to attain room temperature before analysis the selected parameters. Nevertheless, parameters such as Dissolved Oxygen (DO), pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS) and Temperature were determinedin-situ (on site) as shown in Plates XXII, XXIII and XXIV. The summary of the standard laboratory methods employed in analyzing the selected parameters in the water samples are shown in Table 3.2 while the details are given afterward







Table 3.2: Summary of laboratory techniques used

Parameter	Method/Equipment	Reference
Temperature	Thermometric (Thermistor)	U.S EPA, 2001
Turbidity	Naphelometric (Turbidimeter)	U.S EPA, 2001
TDS	Electrometric (TDS meter)	U.S EPA, 2001
pH	Electrometric (pH meter)	U.S EPA, 2001
Chloride (Cl^-)	Titrimetric (Mohr's method: Silver nitrate as titrant)	U.S EPA, 2001
EC	Electrometric (EC meter)	U.S EPA, 2001
DO	Electrometric (DO meter)	U.S EPA, 2001
BOD_5	Incubation technique with DO determination by DO meter	U.S EPA, 2001
COD	Reflux distillation, followed by titrimetric	U.S EPA, 2001
Total Nitrogen	Digestion, followed by distillation and titrimetric	U.S EPA, 2001
Total Phosphorous	Digestion, followed by colorimetric	U.S EPA, 2001
Iron (Fe)	Spectrometric (AAS)	U.S EPA, 2001
Manganese (Mn)	Spectrometric (AAS)	U.S EPA, 2001

AAS = Atomic Absorption Spectrometer, DO = Dissolved Oxygen, EC = Electrical Conductivity EPA = Environmental Protection Authority, TDS = Total Dissolved Solids.

3.2.3.1 Temperature

Measurement of temperature was achieved with the aid of a Pocket-sized dissolved solids and conductivity meter (TDS & EC meter hold) made by Griffin Company, USA. The device has an inbuilt thermometer which automatically records the temperature (in both degree Celsius and degree Fahrenheit) of the sample when determining TDS or EC.

The device was switched "ON" after removing the electrode protective cap and then dipped into a beaker containing the water sample up to a level where the sensing electrode fully submerged in the sample. Thereafter, the temperature of the sample was displayed at the bottom of the LCD. The displayed temperature reading was allowed to stabilize and the value observed was recorded as the temperature of the sample.

3.2.3.2 Turbidity

This was determined with the use of HACH 2100N Turbidimeter made by HANNA, LTD, England (Plate XXV). The device was standardized with respect to the standard cell in the device at 0.14 NTU (Naphelometric Turbidity Unit) and after which, the sample was well shaken and poured into another cell. A tissue paper was used in cleaning the walls of the cell in order to remove any finger print and it was thereafter replaced with the standard cell. The reading was recorded directly from the LCD in NTU.



3.2.3.3 Total dissolved solids

This parameter (TDS) was measured on site with the use of TDS & EC meter hold (pocket-sized). The procedure involve switching the device "ON" after removal of the electrode protective cap, followed by dipping it into a beaker containing the water sample. The device then displayed EC and temperature value on its LCD. However, the concentration of Total Dissolved Solids (TDS) was obtained by pressing the "SHIFT" button on the device. The displayed TDS reading in ppm (parts per million) on the LCD was allowed to stabilized before recording.

3.2.3.4 pH

The pH of the water sample was examined by means of a pocket sized pH meter (pHep®) made by HANNA LTD, England. The protective cap of the sensing electrode was removed and the device was turned "ON". Thereafter, it was immersed in the water sample contained in a beaker up to the maximum immersion level as directed by the manufacturer. The device was then gently stirred in the sample until the reading on the LCD steadied and the value was recorded.

3.2.3.5 Chloride

The method employed here involved titration. The sample was well agitated, followed by measuring 100 ml into a conical flask. 1 ml of standard potassium chromate (an indicator) was added and the solution was titrated with standard silver nitrate solution to a reddish-brown colour as end point (Plates XXVI and XXVII). Concentration of chloride in milligram per liter of the sample was obtained by applying the formula in equation (3.1), APHA (2012).

$$Chloride\ concentration\ (mg/l) = \frac{A \times N}{Z} \times 35450 (3.1)$$

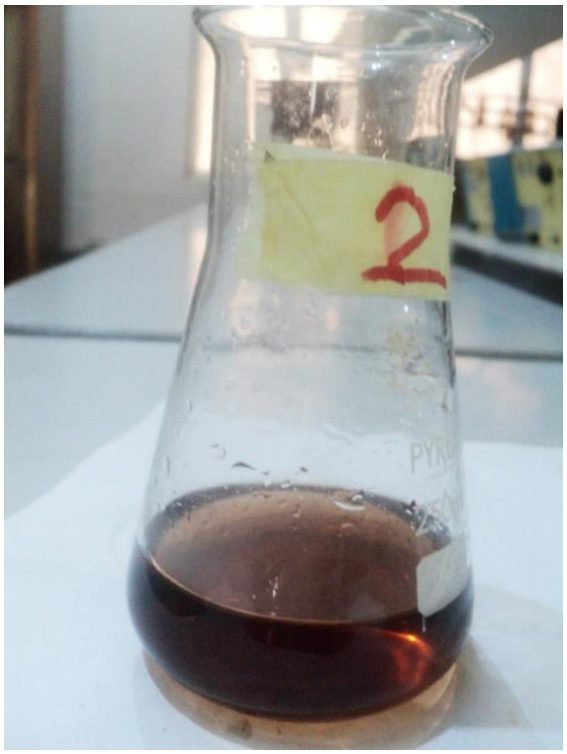
Where:

A = Volume of titrant used in titrating to end point (ml)

N = Normality of silver nitrate solution = 0.0141

Z = Volume of sample used for analysis = 100 ml





3.2.3.6 Electrical conductivity

Electrical Conductivity (EC) was also measured with a pocket-sized TDS & EC meter hold made by HANNA LTD, England. The procedure is also similar to that of Temperature and TDS determination (earlier explained in sub-sections 3.2.3.1 and 3.2.3.3). That is, the sensing electrode of the device was dipped in the water sample after switching "ON" the device. Nevertheless, after allowing the displayed EC value in µS/cm (micro Mohs per centimeter) on the LCD to stabilized, the button labeled "HOLD" was pressed before recording the displayed EC value

3.2.3.7 Dissolved oxygen

Determination of Dissolved Oxygen (DO) was done through a portable DO meter (DO STATER300D) made by OHAUS Corporation, USA. The electrode clip was connected to

the meter and the protective cap of the sensor in the probe was removed. This was followed by immersing the probe in the sample with care not to allow the probe touch the floor of the beaker containing the sample. The device was switched "ON" by pressing the "Exit/Power" key and then set in automatic (Auto) end point mode by pressing and holding the key labeled "Read" for 3 seconds. After successfully setting the device in automatic end point mode, the button "Read" was pressed once to start the measurement and then, the measurement icon appears on the LCD and blinks. When the signal stabilized, the sample reading freezes and the measurement icon blinks 3 times and disappeared. Finally, the Auto end point icon ($\sqrt{Auto}$) blink 3 times and freeze on the display screen (LCD), thereafter, the sample reading was recorded in mg/l.

32.3.8Biochemical oxygen demand

The 5-days Biochemical Oxygen Demand (BOD_5) was determined in the lab by initial measurement of the Dissolved Oxygen content of the water sample through a portable DO meter (DO STATER300D) as shown in Plate XXVIII. Thereafter, the sample was gently filled in a BOD bottle (300 ml), stoppered and then incubated for 5 days at 20 ^{o}C (Plate XXIX). After the 5 days elapsed, the BOD bottle containing the sample was removed from the incubator and the DO content was again measured and recorded (Plate XXX). Quantity of Biochemical Oxygen Demand after 5 days (BOD_5) in mg/l was computed using equation (3.2) as stated in APHA (2012).

$$BOD_5(mg/l) = DO_i - DO_f \quad (3.2)$$

Where:

DO_i = Initial DO content of water sample before incubation

DO_f = Final DO content of water sample after 5 days incubation







3.2.3.9 Chemical oxygen demand

Determination of Chemical Oxygen Demand (COD) was accomplished by thorough shaking of the sample and measuring 20 ml into a reflux bottle already containing 0.4g of mercuric sulphate. Thereafter, 10 ml of potassium dichromate and 20 ml of concentrated sulphuric acid (H_2SO_4) containing silver sulphate (Ag_2SO_4) were added into it. The same reagents were also added into another reflux bottle containing 20 ml of distilled water which served as blank.

The bottle containing the sample and reagents and that of the blank were refluxed for one hour through a reflux machine (Plate XXXI) and then, allowed to cool at room temperature. Thereafter, 50 ml of distilled water and 3 drops of ferron indicator were added to both reflux bottles (i.e sample and blank) each, and were titrated against ferrous ammonia sulphate to reddish-brown.

Concentration of Chemical Oxygen Demand (COD) in milligram per liter of sample was calculated through equation (3.3), APHA (2012).

$$COD\ (mg/l) \quad = \frac{(A-B)C \times 8000}{D} (3.3)$$

Where:

A = Volume of titrant used intitrating blank to end point (ml)

B = Volume of titrant used in titrating sample to end point (ml)

C = 0.25 (constant)

D = Volume of sample used = 20 ml



3.2.3.10 Total nitrogen

Total nitrogen (TN) was determined by measuring 10 ml of the sample into a Kjeldahl digestion tube after thorough agitation of the sample. Thereafter, 10 ml of concentrated sulphuric acid and 3 g of mixed catalyst (comprising of sodium sulphate, copper sulphate and selenium) were added into the digestion tube. Another 3 g of mixed catalyst and 10 ml of concentrated sulphuric acid were also introduced into an empty Kjeldahl digestion tube which served as a blank. The digestion tubes (sample and blank) were then digested in Kjeldahl digestion block (Plate XXXII) for $3\frac{1}{2}$ hour (Eno *et al.*, 2013). Afterward, each of the digest (sample and blank) were transferred into 100 ml volumetric flask and diluted to mark (100 ml) with distilled water. This was followed by introducing 10 ml of the aliquot or diluted digest (each for sample and blank) into a Kjeldahl distillation chamber. Thereafter, 10 ml of 10N sodium hydroxide solution was added into the aliquot (diluted digest) contained in the distillation chamber. Finally, 10 ml of 2% boric acid together with 3 drops of mixed indicator (comprising bromocrisol blue and methyl red) were transferred

into a conical flask and then placed under the distillate collection point of a Kjeldahl auto distillation machine (Plate XXXIII) until 40 ml of the distillate were collected.



After distillation, the distillate of the sample and that of the blank were titrated against 0.1N hydrochloric acid (HCl) to pink colour as end point.

Total nitrogen (TN) concentration in milligram per liter of sample was calculated by using the formula expressed in equation (3.4), Eno *et al.* (2013).

$$TN\ (mg/l) = \left[\frac{0.014 \times NA \times VD(T-B) \times 100}{VA\ \times VS}\right] \quad (3.4)$$

Where:

TN = Total Nitrogen

NA = Normality of acid (0.1)

VD = Volume of digest = 100 ml

T = Volume of titrant used in titrating sample to end point

B = Volume of titrant used in titrating blank to end point

VA = Volume of aliquot = 10 ml

VS = Volume of sample used = 10 ml

3.2.3.11 Total phosphorous

Determination of total phosphorus was achieved by initial digestion of the sample by adding 10 ml of nitric acid into 50 ml of the sample, then heating the sample solution on a digestion block until 25 ml remains. After cooling to room temperature, the digest was transferred into a 50 ml volumetric flask and then diluted to mark (50 ml) with distil water. 10 ml of the aliquot (diluted digest) was transferred into a 25 ml volumetric flask and 5 ml of colour developing reagent (combination of ammonium molybdate, amonium metavanadate and nitric acid) was added into the sample. Thereafter, the sample was again diluted to mark (25 ml) with distil water and then left for 30 minute for colour development.

A colorimeter (Plate XXXIV) was zeroed via distilled water, which was followed by reading the colour absorbance of the sample after thorough cleaning of the surfaces of the cuvette with tissue paper.



Concentration of total phosphorus (TP) in milligram per liter of sample was calculated through the formula shown in equation (3.5), Eno *et al.* (2013).

$$TP\ (mg/l) = \frac{W \times VD \times G \times R}{VA} \tag{3.5}$$

Where:

TP = Total Phosphorous

W = Volume of distilled water used in diluting aliquot = 25 ml

VD = Volume of digest = 50 ml

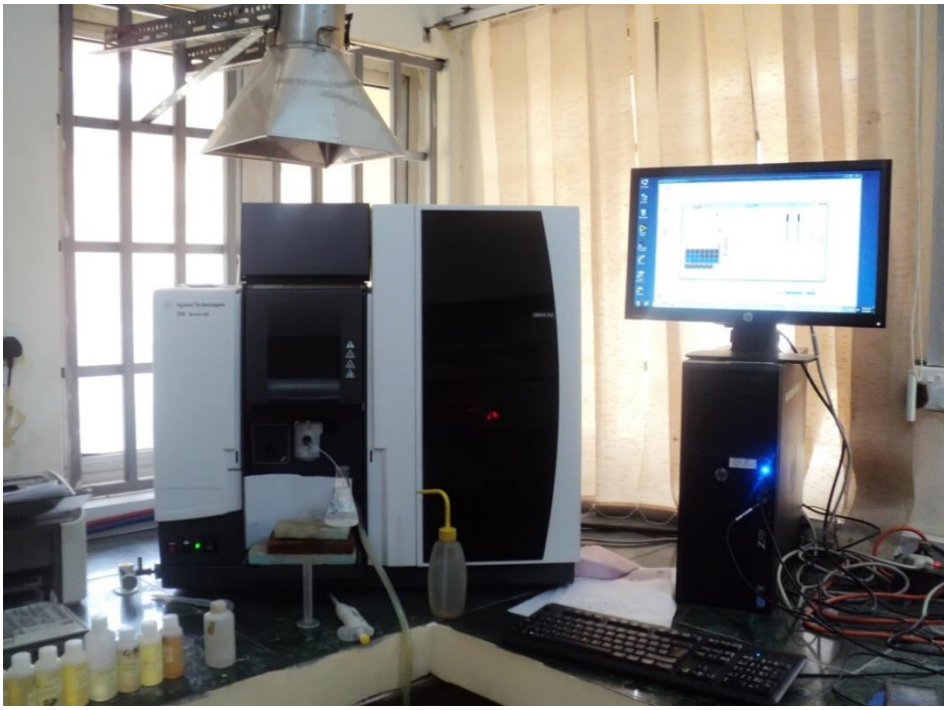
G = Constant known as Gradient (90.91)

R = Sample's reading on colorimeter

VA = Volume of aliquot = 10 ml

3.2.3.12 Iron

Concentration of iron (Fe) was examined with the use of Atomic Absorption Spectrometer (280FS AA) made by Agilent Technologies, USA (Plate XXXV). The sample was initially digested by measuring 50 ml into a beaker and adding 10 ml of hydrochloric acid (HCl) into the beaker. The beaker was heated in a water digestion block until it remains half (25 ml). Thereafter, the beaker was removed from the heating source and the sample was allowed to cool to room temperature, which was followed by topping it to 50 ml with 25 ml of distilled water.After digestion, 2 ml of lanthanum oxide (2%) was added into the sample before analyzing the said parameter in the AAS. It should be noted that the essence of the digestion was to break any bond into solution that might have caused interference while the addition of lanthanum oxide was to prevent any interference if it occur at all (Russell, 2015).



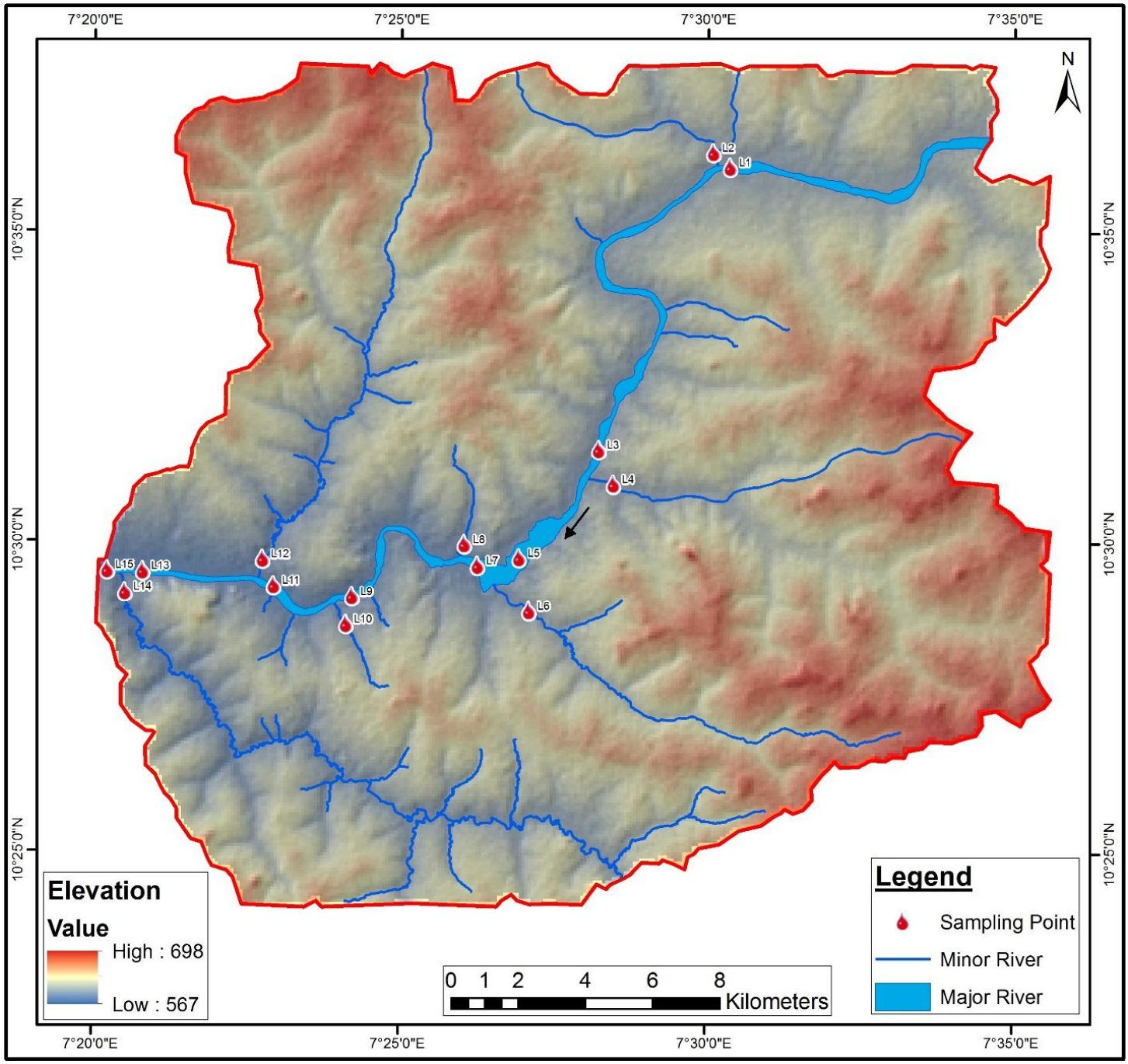
3.2.3.13 Manganese

The procedure or method involved in determining the concentration of Manganese in the water samples was the same with that of Iron as explained in the preceding section (3.2.3.12).

3.2.4 Watershed map

Watershedmapwas generated with the aim ofidentifying areas of land that drains rain water into the River Kaduna. This was done using Shuttle Radar Topography Mission(SRTM) data obtained from Global Land Cover Facility (online portal).

In order to provide an undulating view of the terrain morphology, a Digital Terrain Model (DTM) was generated. In addition, a Triangulated Irregular-terrain Network (TIN) and a hill shed map types of model werealso generated. All these analyses were carried out through the use ofsurface analysis tools in ArcGIS 10.5. The developed watershed map of the study area is shown in Figure 3.2.

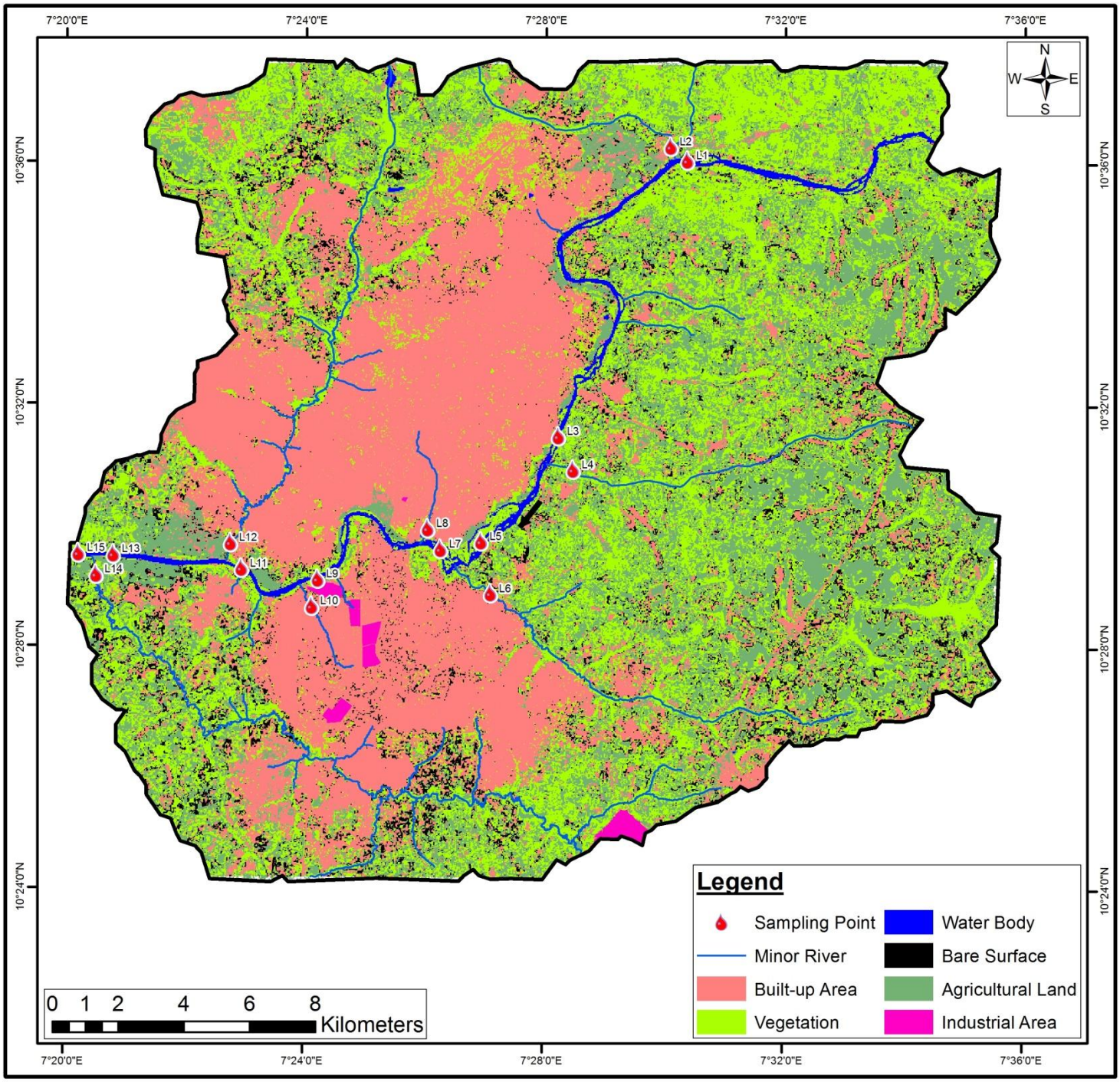

7°20'0"E
7°25'0"E
7°30'0"E
7°35'0"E
10°35'0"N
10°30'0"N
10°25'0"N
N
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
L11
L12
L13
L14
L15
Elevation
Value
High : 698
Low : 567
0 1 2 4 6 8
Kilometers
Legend
Sampling Point
Minor River
Major River

3.2.5Land use land cover map

Landsat Enhanced Thematic Mapper Plus (ETM+) imagery of 23rd August, 2016 with 30m resolution was sourced fromGlobal Land Cover Facility (online portal). This wasused to generate the land use landcover map of the study area (Figure 3.3) using maximum likelihood classification method based on its high accuracy. The image was classified into different land use themes as could be seen in Table 3.3.

Table 3.3 Land use land cover classification scheme

Land Use-Land Cover Type	**Description**
Agricultural land	All cultivated lands
Vegetation	All vegetated lands that are not yet cultivated such as grassland, shrubs, forest and other natural vegetation.
Built-up Area	Areas used for both urban and rural residential land uses
Industrial Area	Areas used for industrial purposes
Water Body	All water surfaces such as rivers, streams and ponds
Bare surface	Rocky land and land without vegetation


7°20'0"E
7°24'0"E
7°28'0"E
7°32'0"E
7°36'0"E
10°36'0"N
10°32'0"N
10°28'0"N
10°24'0"N
N
W
E
S
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
L11
L12
L13
L14
L15
0 1 2 4 6 8
Kilometers
Legend
Sampling Point
Minor River
Built-up Area
Vegetation
Water Body
Bare Surface
Agricultural Land
Industrial Area

The whole watershed is 571.04 km^2 of which; built-up area is 197.97 km^2 (34.67%), vegetation is 178.46 km^2 (31.25%), agricultural area is 151.69 km^2(26.56%), bare surface is 33.80 km^2 (5.92%), water body is 6.57 km^2 (1.15%) and industrial area is 2.25 km^2 (0.45%). However, the sub-basin distribution of the various land use land cover is shown in Table 3.4.

Table 3.4: Land use distribution at sub-basin scale

Sampling Location	Built-up area (%)	Vegetation (%)	Water body (%)	Bare surface (%)	Agricultural area (%)	Industrial area (%)
L1	8.11	38.04	1.48	3.85	48.52	0.00
L2	12.12	56.34	0.79	3.03	27.72	0.00
L3	48.93	22.58	1.16	7.85	19.36	0.12
L4	24.05	32.93	0.54	14.22	28.26	0.00
L5	26.74	33.58	0.46	10.41	28.81	0.00
L6	37.61	28.65	1.10	8.08	24.56	0.00
L7	52.13	24.20	1.29	1.61	20.77	0.00
L8	68.04	14.73	3.98	0.61	12.64	0.00
L9	50.13	24.83	0.19	1.50	21.32	2.03
L10	61.37	16.50	1.50	3.03	14.19	3.41
L11	40.89	25.49	1.40	10.35	21.87	0.00
L12	50.76	23.50	0.65	4.91	20.18	0.00
L13	10.69	44.74	0.55	5.23	38.79	0.00
L14	24.11	32.82	1.82	11.82	28.24	0.00
L15	4.37	49.82	0.34	2.30	43.17	1.19

3.2.6 Statistical analysis

In order to understand the effect of land use and seasonality on the water quality of the catchment area, the seasons were categorized as Dry and Rainy with the months distributed as follows:

Dry season – November, December, January, February, March and April

Rainy season – May, June, July, August, September and October.

The seasonal (dry and rainy) mean value for each of the examined parameters were computed and afterward, the students' t-test analysis ($p < 0.01$) was carried out to determine the level of difference between data obtained during dry season and rainy season. The t-test analysis was also carried out to understand the level of difference between observed data and maximum/minimum allowable limits set by the Federal Environmental Protection Agency (FEPA).

Spearman's rank correlation coefficients between the water quality parameters and the different land use at each spatial scale in the dry and rainy seasons were calculated (Yin *et al.*, 2014). The effects of the different land use (i.e built-up, vegetation, water body, bare surface, agriculture and industrial) on the water quality were explained based on the values of the correlation coefficients determined. Negative correlation coefficients signify inverse proportional relationship between land use and water quality parameter while positive correlation coefficients connotes direct proportional relationship. Since correlation coefficient (ρ) lies between –1.0 and +1.0 i.e $-1 \leq \rho \leq 1$, the strength of the correlation or relationship were explained as follows:

$\rho = -1$ (Perfect negative correlation)

$-1 < \rho \leq -0.5$ (Strong negative correlation)

$-0.5 < \rho < 0$ (Weak negative correlation)

$\rho = 0$ (No correlation)

$0 < \rho < 0.5$ (Weak positive correlation)

$0.5 \leq \rho < 1$ (Strong positive correlation)

$\rho = 1$ (Perfect positive correlation) (Gupta, 2011)

The statistical computations were executed using JMP version 13 (software) and Microsoft Excel spreadsheet.

3.2.7 Mapping of water quality

Inverse Distance Weighted Interpolation (IDW) method of the spatial analyst extension (ESRI, 2015) in the ArcGIS 10.5 was used in mapping the water quality parameters within the catchment area. Like other methods, IDW uses linear combination of weights at known points to estimate unknown location values (ESRI, 2015). That is, values at unknown locations$\hat{Z}(S_0)$ were determined by the weighting value $\lambda_i(S_0)$and values at known locations $Z(S_i)$ expressed mathematically as shown in equation (3.6), ESRI (2015).

$$\hat{Z}(S_0) = \sum_{i=1}^{n} \lambda_i(S_0).Z(S_i) \tag{3.6}$$

However, the weights $\lambda_i(S_0)$ were estimated through inverse distance from all points to the new points by applying equation (3.7), ESRI (2015)

$$\lambda_i(S_0) = \frac{\frac{1}{\beta d\,(S_0,S_1)}}{\sum_{i=0}^{n} \frac{1}{\beta d\,(S_0,S_1)}} \; ; \; \beta > 1 \tag{3.7}$$

Where:

$\boldsymbol{\lambda_i} =$ Weight for neighbor *i* (the sum of weights must be unity to ensure an unbiased interpolator),

$\boldsymbol{d(S_0, S_1)} =$ Distance from the new point to a known sample point,

$\boldsymbol{\beta}$ =Coefficient used to adjust the weights,

$\boldsymbol{n}$ =Total number of points in the neighbourhood analysis.

All the measured points (water quality data) were used in the calculation of each interpolation cell (water quality grid). A feature dataset (river network) was used for the mask. Only cells that falls within the specified shape of the feature data (river network) received the values of the first input raster (water quality grid) on the output raster (water quality result). The output raster is the extraction of the cells of the water quality grid (input raster) that correspond to the routes defined by the mask. These illustrations for IDW method of mapping in ArcGIS 10.5 are shown in Figures 3.4 and 3.5.

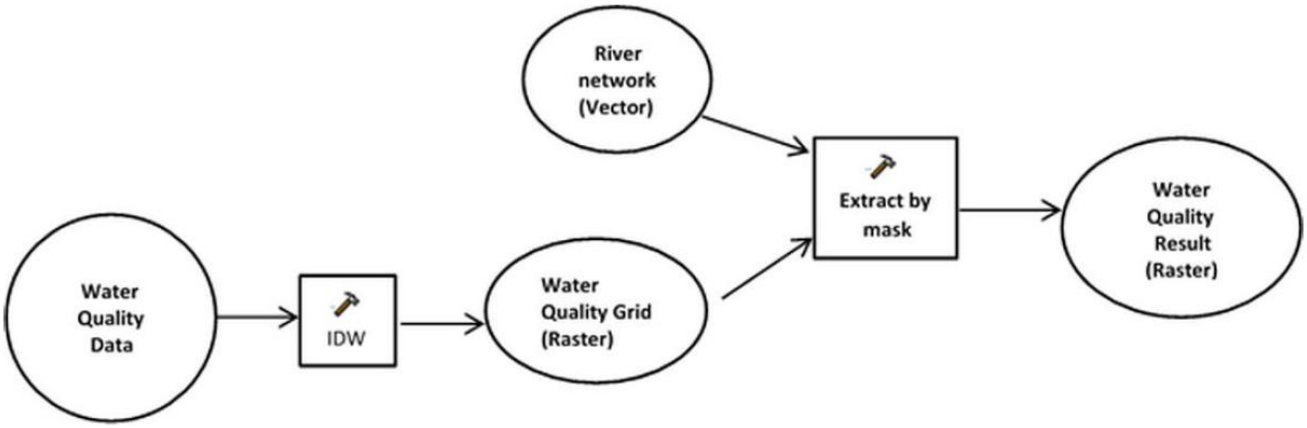


Figure 3.4: Flow chart of IDW mapping procedure in ArcGIS 10.5

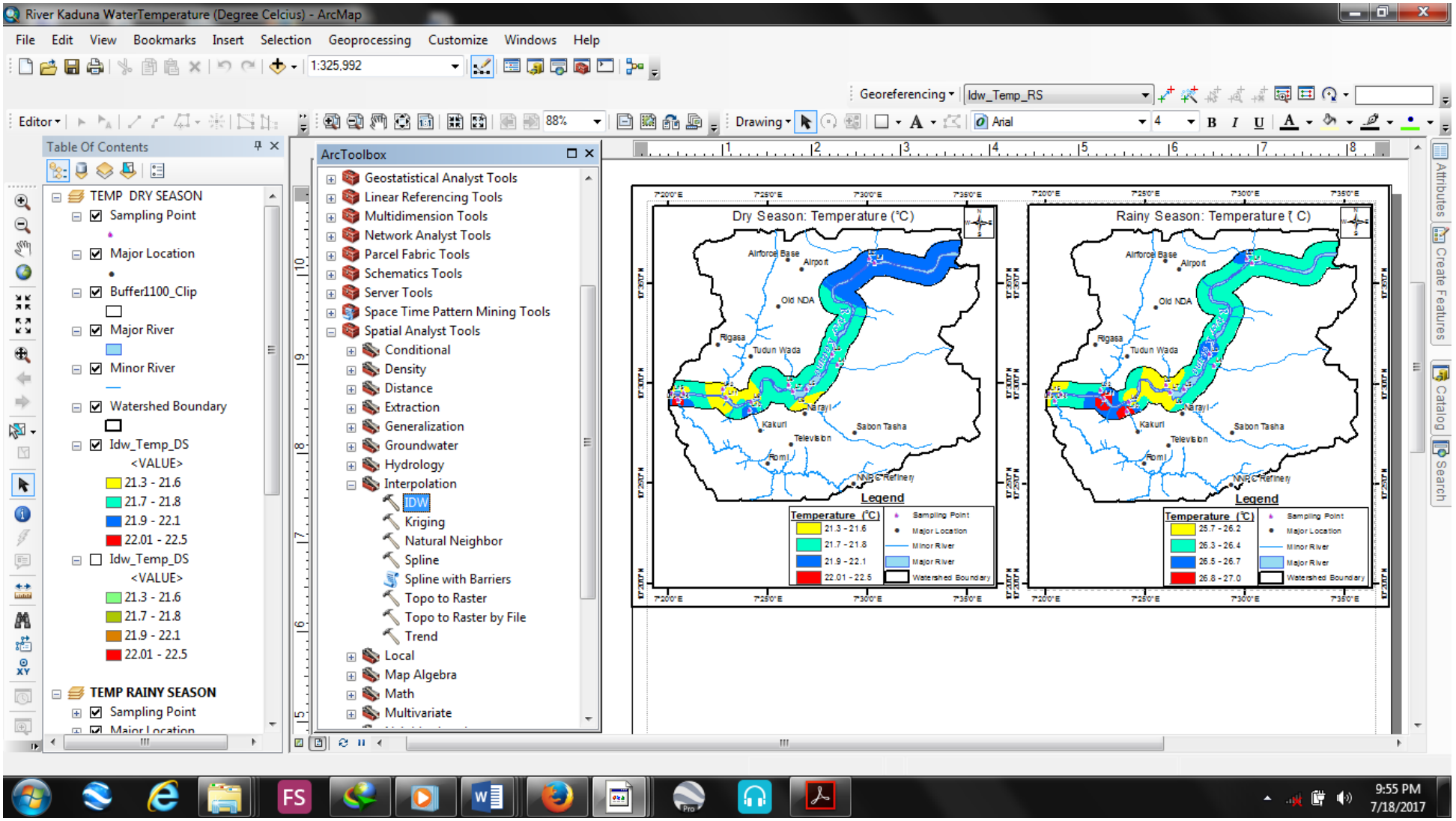


Figure 3.5: Screen-shot of IDW mapping procedure in ArcGIS 10.5

Seasonal classifications were based on Dry season (November, December, January, February, March and April) and Rainy season (May, June, July, August, September and October) with the map legend according to the data range for the season.

3.2.8 Water quality index

Water Quality Index (WQI) was determined based on the Canadian Council of Ministers of Environment (CCME), which has been adopted by the Global Environmental Monitoring Systems (GEMS, 2007). The index was based on a combination of three factors which were determined using equations (3.8) to (3.13), CCEM (2001).

i. **Scope, F_1** - the number of variables whose objectives were not met.

$$F_1 = \frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables} \times 100 \tag{3.8}$$

ii. **Frequency, F_2, -** the frequency with which the objectives were not met.

$$F_2 = \frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests} \times 100 \tag{3.9}$$

iii. **Amplitude, F_3, -** the amount by which the objectives were not met. F_3 was calculated in three steps:

a. The number of times by which an individual concentration was greater than (or less than, when the objective is a minimum) the objective, termed as "excursion" and expressed as follows. When the test value must not exceed the objective:

$$excursion_i = \frac{Failed\ Test\ Value_i}{Objective_j} - 1 \tag{3.10a}$$

For cases in which the test value must not fall below the objective:

$$excursion_i = \frac{Objective_j}{Failed\ Test\ value_i} - 1 \quad (3.10b)$$

b. The collective amount by which individual tests were out of compliance was calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). This variable, referred to as the normalized sum of excursions(nse), was calculated as:

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{number\ of\ tests} (3.11)$$

c. F_3 was thereafter calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a range between 0 and 100.

$$F_3 = \frac{nse}{0.01nse + 0.01} (3.12)$$

The Canadian Council of Ministers of Environment Water Quality Index (CCMEWQI) was then determined by substituting the values of F_1, F_2 and F_3 into equation (3.13). That is;

$$WQI = 100 - \frac{\sqrt{\left({F_1}^2 + {F_2}^2 + {F_3}^2\right)}}{1.732} (3.13)$$

Equation (3.13) was employed in all the sampling locations and their respective results were computed. Thereafter, the results obtained were ranked into five categories as

recommended by the Canadian Council of Ministers of Environment (CCME, 2001). These five categories for the assessment and protection of aquatic environment are as follows;

Excellent: (CCME WQI Value 95-100) – Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels.

Good: (CCME WQI Value 80-94) – Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.

Fair: (CCME WQI Value 65-79) – Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.

Marginal: (CCME WQI Value 45-64) – Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.

Poor: (CCME WQI Value 0-44) – Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

In order to be able to predict the WQI at any given point along the middle stretch of River Kaduna (Malali – Rigasa), the WQI values determined at the sampling locations along River Kaduna were plotted against distance along the direction of flow (Ayobahan *et al.*, 2014). A regression line with the associated equation were fitted into the curve obtained using Microsoft Excel 2010. The point with the lowest WQI (turning point) along the river was determined by solving the first derivative of the regression equation when equated to zero. Thereafter, the curve and regression line earlier fitted were transformed to have the determined turning point as referenced point. A flowchart for the equation was drawn using

CorelDraw X7 and also, a computer programming language was written for the equation through Visual Basic.Net (VB.Net) version 2017.

3.2.9 Multivariate analysis

Principal Component Analysis (PCA) and Factor Analysis (FA) were applied on the data in order to reduce the water quality parameters so as to identify the critical water quality indicators that are responsible for the changes in the water quality across the catchment area. This provides information on the most meaningful parameters which comes as principal components (PCs) thus, describing the whole data set, rendering data reduction with minimum loss of original information (Adie, 2008 and Adebola *et al.,* 2013). The mathematical expression employed for the determination of principal component (PC) is shown in equation (3.14), Liu *et al.* (2016)

$$Z_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + a_{i3}x_{3j} + \cdots + a_{im}x_{mj} \quad (3.14)$$

Where:

Z = Component score,

a = Component loading,

x = Measured value of a variable (water quality concentration),

i = Component number,

j = Sample number,

m = Total number of variables.

An eigenvalue gives a measure of the significance of the factor, and factors with the highest eigenvalues are the most significant. Eigenvalues of 1.0 or greater are considered significant (Shrestha and Kazama, 2015). Classification of principal components is thus strong, moderate and weak, corresponding to absolute loading values of >0.75, 0.75 – 0.50 and 0.50 – 0.30, respectively (Liu *et al.*, 2016). PCs were defined according to the criterion that only factors that account for variance greater than 1 (eigenvalue one criterion) was included. The rationale for this is that any component should account for more variance than any single variable in the standardized test score space (Li and Zhang, 2013). Hence, PCA was applied using varimax rotation with Kaiser Normalization. By extracting the eigenvalues from the correlation matrix, the number of significant factors and the percentage of variance explained by each of them were calculated.

For the sake of optimum sampling strategy that can lessen the number of sampling stations and the affiliated recurring costs in the future, Cluster Analysis (CA) was executed to determine the similarity between sampling stations. The CA was performed by developing an agglomerative hierarchical clustering using a combination of the Ward's linkage method and squared Euclidean distances as a measure of similarity. The similarity between two objects, i and j known as Euclidean distance was computed through equation (3.15) as stated in Liu *et al.* (2016).

$$d(i,j) = \sqrt{\sum_{k=1}^{m} \left(Z_{ik} - Z_{jk}\right)^2} \quad (3.15)$$

Where:

$d(i,j)$ =Euclidean distance,

Z_{ik} = Value for variable *k* for object *i*,

Z_{jk} = Value for variable *k* for object *j*,

m = Number of variables.

The levels of similarity at which observations merged were used to construct a dendrogram which aids the identification of highly polluted locations. All multivariate analyses were executed with the aid of JMP version 13 (software).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 General

The effects of seasonal variability (dry season and rainy season) on the water quality indicators are shown on multiple bar charts. The charts clearly showed the concentrations of each of the water quality parameter considered in all the sampling stations during each season via colour legends allotted to each season.This helps in determining the very season (dry season or rainy season) that improve or deteriorate the quality of each of the consigned parameters. On the other hand, the impacts of the various land use and land cover on the water quality were explained through the size of Spearman's correlation coefficients which are presented in tables. The tables were prepared such that the impacts of the various land use and land cover on a given water quality parameter could be identified in each season.

The relationship between the water quality indicators and downstream locations along River Kaduna were analyzed using line graphs. Regression analysis relating the observed data with sampling distance were also computed for each water quality parameter along the river course during the two sampling seasons (dry season and rainy season). The relationship best fitted a polynomial function with the degree ranging from 1 to 6. Higher degree of polynomial suggests high level of fluctuations along the river profile which implies heterogeneity of pollutants distribution across the river course. The coefficients of determination (R^2) in most of the polynomial functions were very high thus, indicating high reliability of the functions.

The water quality indicators that were monitored and assessed in this study were mapped using GIS. The variation of the water quality parameters presented in the maps makes better understanding of the changes than ordinary line graphs and also helps to appreciate more the variations across the river (River Kaduna). This is because the GIS mapping revealed the spatial relationship of levels of pollutant to specific area with the aid of colours without a need for difficult spatial imagination. Hence, the maps enabled the identification of critical reaches of environmental concern since it delineated various hot spots in each of the quality parameters where surge in pollutant levels are identified for further query. This will help environmental standard enforcement agents, planners and policy makers to facilitate quick attention to such places of elevated level of pollutants and hence, identification or arrest of polluters.

Identification of water quality parameters that mostly influenced the variability in quality of the studied river is presented ina scree plot. The scree plot clearly revealed the principal components (PCs) that have eigenvalues greater than unity (1.0)which signify that high factor loading of such PCs highly influenced the variation of the river quality. On the other hand,reduction of sampling stations for the sake of future sampling are presented in dendrogram and constellation plots. The dendrogram categorized the sampling locations into two clusters based on their similarities while the constellation plot went further to sub classify the two major classifications obtained from the dendrogram.

4.2 Trend Analysis of Water Quality Indicators

4.2.1Temperature

The minimum water temperature during the sampling period ($19\pm0.02^{o}C$) was recorded in the month of March, corresponding to sampling locations L3 (NNPC), L6 (Kutimbi), L8

(Kigo), L13 (Maigiginya) and L15 (Railway Bridge). On the other hand, the maximum water temperature (29±0.02^{o}C) was noted in the month of July at sampling location L10 (Breweries). Figure 4.1 make known that the water temperature values recorded during the rainy season were higher than those of the dry season in all the sampling locations. This could be attributed to the fact that, atmospheric humidity is lower during dry season (especially harmattan period) than rainy season (Garg, 2010). This might have caused more water molecules on the surface of River Kaduna or sampling locations to have evaporated during the dry season than rainy season (Garg, 2010; Arora, 2011). This higher evaporation rate of the dry season resulted to the lower water temperature observed (cooling effect of evaporation) during dry season (Nelkon and Parker, 1995).

The water temperature values observed in the catchment area (River Kaduna) in each season (dry season and rainy season) did not show large variations irrespective of the sampling location (Figure 4.1). This is because dry season values ranged between 21.5 – 22±0.02^{o}C while rainy season ranged between 25.7 – 27±0.02^{o}C which is in accordance with an earlier work conducted by Yusuf *et al.* (2008). Nevertheless, a significant difference (at $p < 0.01$) existed between temperature values recorded in both seasons. This implies that river water temperature is climatologically influenced. This assertion is in line with EPA (2001).

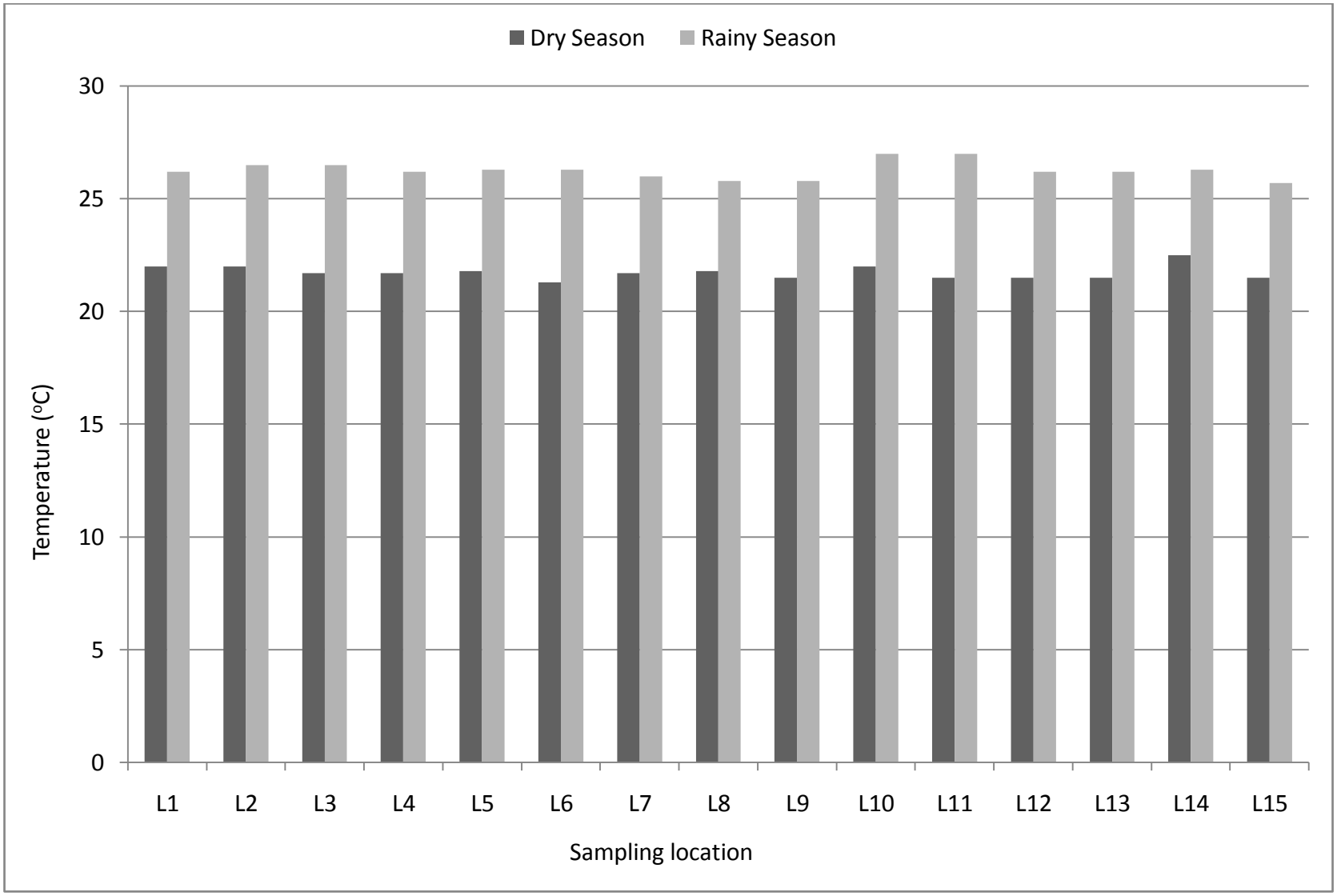


Figure 4.1: Seasonal variation of temperature across sampling locations

The information displayed in Table 4.1 indicates that the correlation coefficients between water temperature and the various land use land cover were approximately zero. This simply suggest that the water temperature in the catchment area is not influenced by the various land use land cover types considered as at the period this research was conducted.

Table 4.1: Spearman's correlation coefficients between water temperature and land use land cover types

Land use land cover	Dry Season	Rainy Season
Built-up	0.0304*	0.0143*
Vegetation		
Water body	−0.0411*	−0.0275*
Bare surface		0.0183*
Agricultural land	0.0096**	
Industrial land	0.0196**	

Only significance levels (*<0.05 and **<0.01) are shown.

The line graph shown in Figure 4.2 indicates that the river temperature during both seasons decrease as the water flow downstream which could also be confirmed in the GIS map (Figure 4.3). This drop in temperature could be attributed to the aeration of the flowing water due to the turbulence created by numerous rocks in the river. The degrees of the regression equations shown in Figure 4.2 suggest that the River temperature fluctuated more during the rainy season. This might be due to the characteristics of the different runoff that flow from various points into the river (Seto *et al.,* 2016).

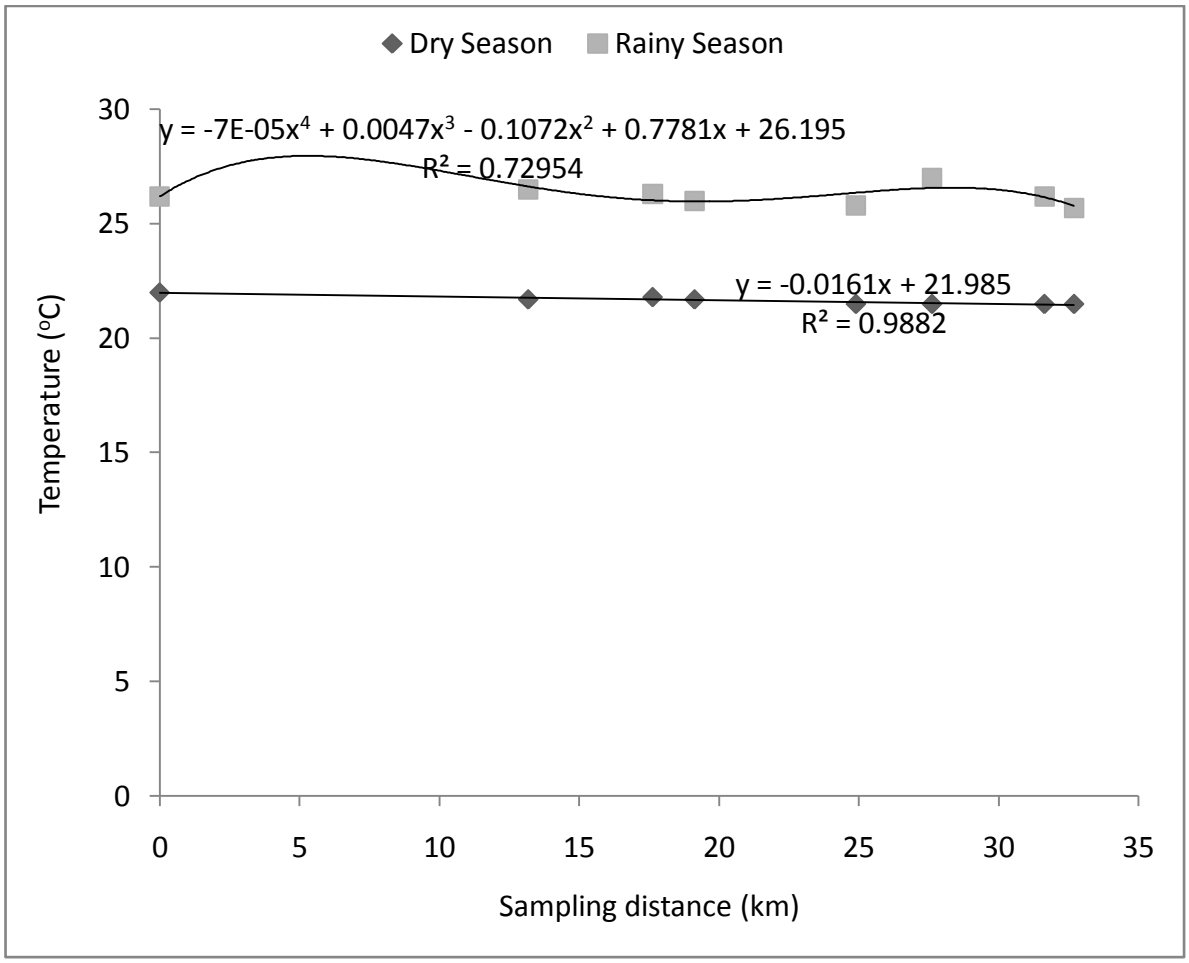


Figure 4.2: Relationship between temperature and downstream location in River Kaduna

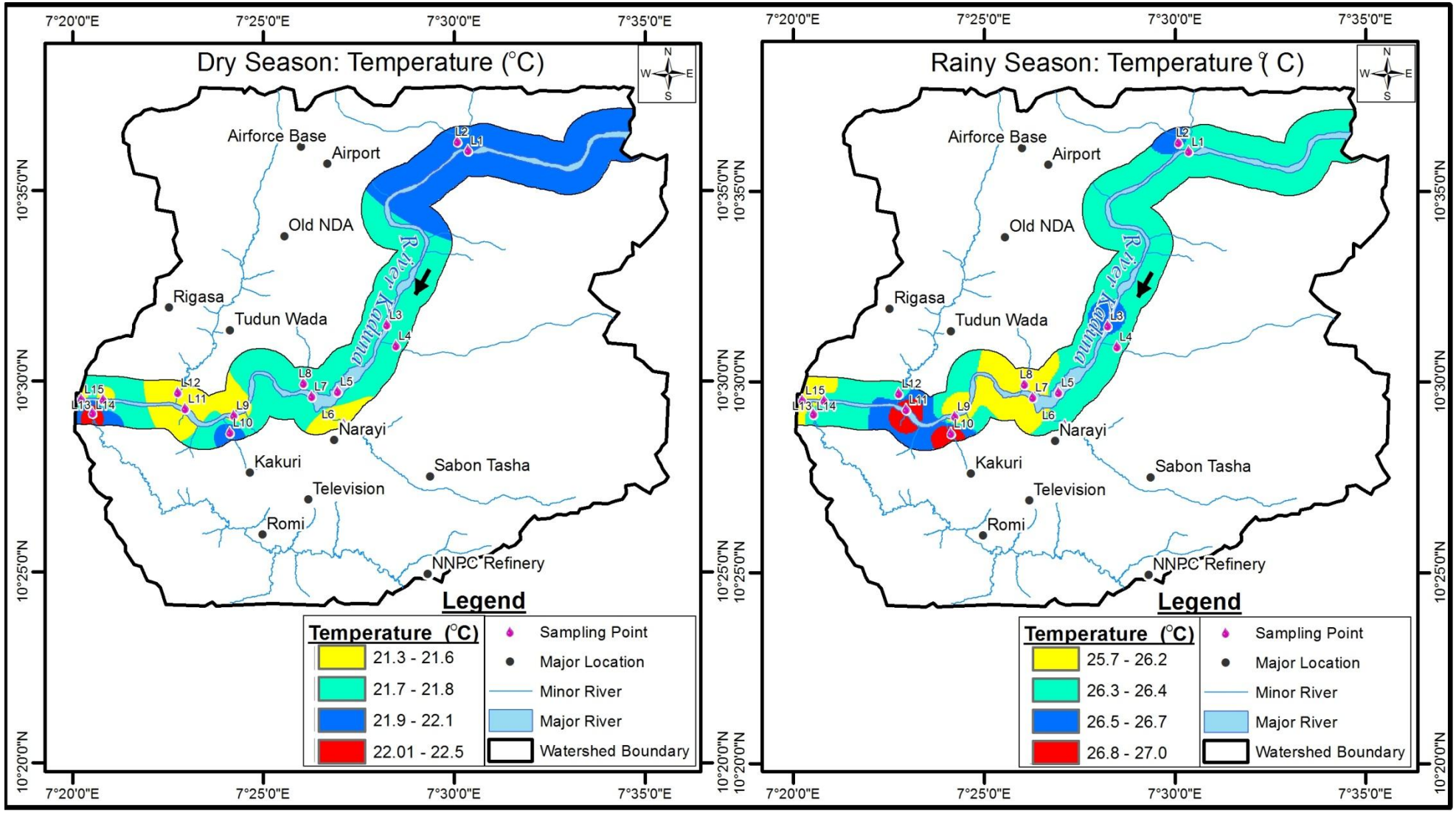


Figure 4.3: Map showing water temperature along River Kaduna

4.2.2Turbidity

The highest (221.251±0.05NTU) and least (0.583±0.05NTU) values of turbidity were recorded at sampling location L8 (Kigo) in the months of July and April respectively.In all the sampling locations, the turbidity values recorded in the months of May – October were higher than the permissible limit (5.000 NTU). Also, locations L1 (Malali), L13 (Maigiginya) and L15 (Railway Bridge) recorded turbidity values above the permissible limit all through the research period. However, sampling locations L2 – L12 and L14 recorded turbidity values within the permissible limit in certain months.

Figure 4.4 showed that in all the sampling locations, the turbidity values recorded during the rainy season were excessively higher than those observed during the dry season. This might be as a result of runoff which is a product of rainfall. Runoff carries clay particles, silt and sand washings, organic and biological sludge, etc., from agricultural fields as well as from drainages and unpaved urban land in which the soil is easily washed. This runoff with its associated debris finally flows into the river thereby causing the river water to be highly turbid during rainy season. Conversely, the presence of turbidity (although small) during dry season despite the absence of runoff might be caused by in-stream activities. During dry season, river depths are usually shallow due to less water in the rivers hence, in-stream activities such as watering of animals by nomads as well as rowing of canoes by fishermen might have stirred up bottom sediments which consequently made the water turbid. The extremely higher turbidity values recorded during the rainy season compared to dry season is in agreement with the works of Ogedengbe and Oke (2015) and Jaji *et al.*(2013).

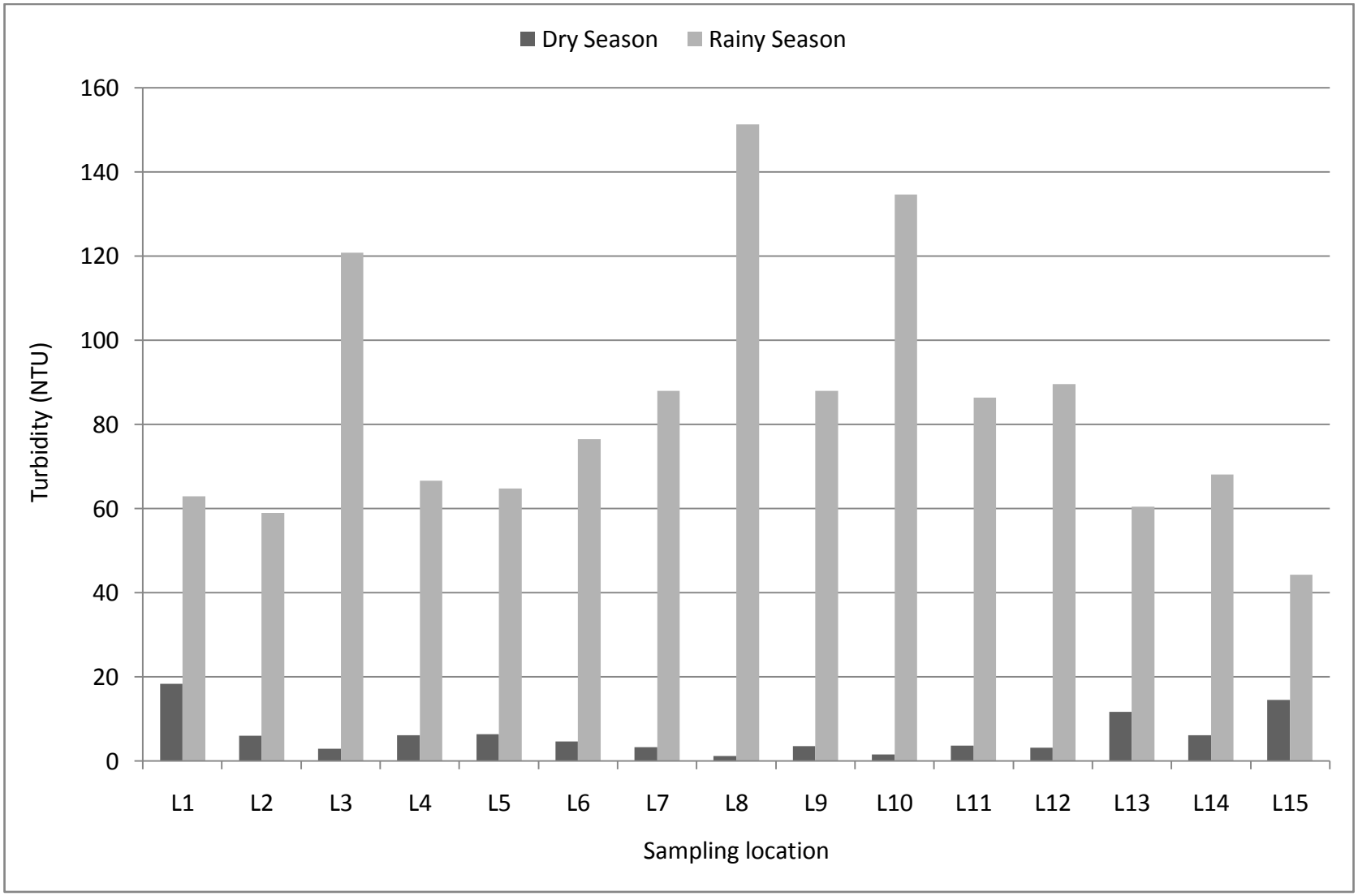


Figure 4.4: Seasonal variation of turbidity across sampling locations

There is no significant difference (at $p < 0.01$) between the turbidity values recorded during dry season and the permissible limit set by the Federal Environmental Protection Agency (FEPA) which is 5NTU. On the contrary,the turbidity values recorded during the rainy season were significantly higher than the FEPA permissible limit,suggesting that the turbidity of the river is influenced by the sampling season (i.e dry or rainy season). The high turbidity recorded during the rainy season can meaningfully reduce the aesthetic quality of the river with a negative impact on recreation and tourism. It can also increase the cost of water treatment for drinking and food processing as well as harming fishes and other aquatic lives by reducing food supplies, degrading spawning beds and affecting gill functions (Ursula *et al.*,2016).

The correlation coefficients shown in Table 4.2 point out built-up, vegetation, agricultural and industrial lands as the major land use and land cover impelling the turbidity of River Kaduna. Built-up and agricultural land uses had strong positive correlations with turbidity in both seasons while vegetation land cover had a negative correlation during dry season and positive correlation during rainy season. However, industrial land use showed a very weak positive correlation.

Table 4.2: Spearman's correlation coefficients between turbidity and land use land cover types

Land use land cover	Dry Season	Rainy Season
Built-up	0.5026*	0.6130*
Vegetation	−0.5490*	0.2426**
Water body	0.0116**	
Bare surface		0.0103*
Agricultural land	0.5091*	0.7035*
Industrial land	0.1227**	0.0281*

Only significance levels (*<0.05 and **<0.01) are shown

The positive correlation between turbidity and built-up land use during the dry season might be as a result of the domestic use of the river water for bathing and washing of cloths at the riverside. This is because water scarcity during dry season due to absence of rainfall and dried hand dug wells pushed many persons to limit the use of water obtained from boreholes for cooking and drinking only. Hence, bathing and laundryactivities are done at the river side by most people who live close to the riverthus, rendering the water turbid. Also during dry season, despite the absence of surface runoff from built-up areas to rivers, domestic effluents still find their ways into the surrounding rivers through drainages, which also contribute to turbidity. On the other hand during the rainy season, surface runoff emanating from built-up areas carries sludge, oil, grease, sand, etc into the receiving streams and rivers which give rise to turbidity.

The positive correlation between turbidity and agricultural land use during dry season might have been caused by the return flow of excess irrigation water into the streams and river. This is because during dry season, a lot of farming activities are carried on the banks of the river, which are irrigated daily with water from the river, mostly through water pumping machines. The excess or overflow water from this practice flows back into the river together with soil particles, grasses, ashes and other turbidity contributing materials. However, during the rainy season, turbidity from agricultural land use might have been caused by runoff from the agricultural fields. According to Suresh (2013), soil particles in agricultural fields are easily detached and transported by runoff since the soil has been mechanically manipulated (ploughed and harrowed).In other word, runoff from agricultural fields carried a lot of debris into the receiving water bodies which makes the water highly turbid.

The negative correlation between turbidity and vegetation during the dry season might be caused by the absence of runoff during dry season. Also people who live in vegetation land cover which is more of forests and bushes were not much since only few Fulani herdsmen with their families reside in such areas (Dada *et al.,* 2011). Hence, human activities that could have caused turbidity such as domestic effluents from drainages and laundry at the river sides during dry season were minimal. However, during rainy season, the positive correlation between vegetation land cover and turbidity could be linked to the effect of runoff. Nevertheless, the tendency for runoff to detach and transport soil particles in vegetation land cover is not much as the soil particles are not loose since it has not been ploughed and harrowed (Suresh, 2013). Furthermore, plants roots and grasses obstruct the free flow of runoff from vegetation lands thus, retaining some of the transported turbid causing particles from entering receiving water bodies (Suresh, 2013; Arora, 2011). In addition, Garg (2010) reported that tree canopies (leaves) and branches intercept rainfall before reaching ground surface thus, reducing the energy for detaching soil particles. Hence, even though there is runoff during rainy season, the quality of the runoff from vegetation lands in terms of turbidity was not as much as those from built-up and agricultural lands. This could be the reason why there was weak positive correlation between turbidity and vegetation land during rainy season as could be seen in Table 4.4.

The positive correlation between industrial land use and turbidity might be as a result of the strong colour of effluents discharged by textile industries which contain a lot of dyes. However, the weakness of the correlation could be connected to the small percentage of industrial land use in the overall watershed (0.45%).

Figure 4.5 revealed that during the rainy season, the turbidity level at a distance of 13.18 km downstream of the sampling commencement point was excessively high. This denotes an urgent attention of environmental standards enforcement agents to find out the cause in other to safeguard the river. The locations with extremely high turbidity level in each of the seasons could be identified in Figure 4.6.

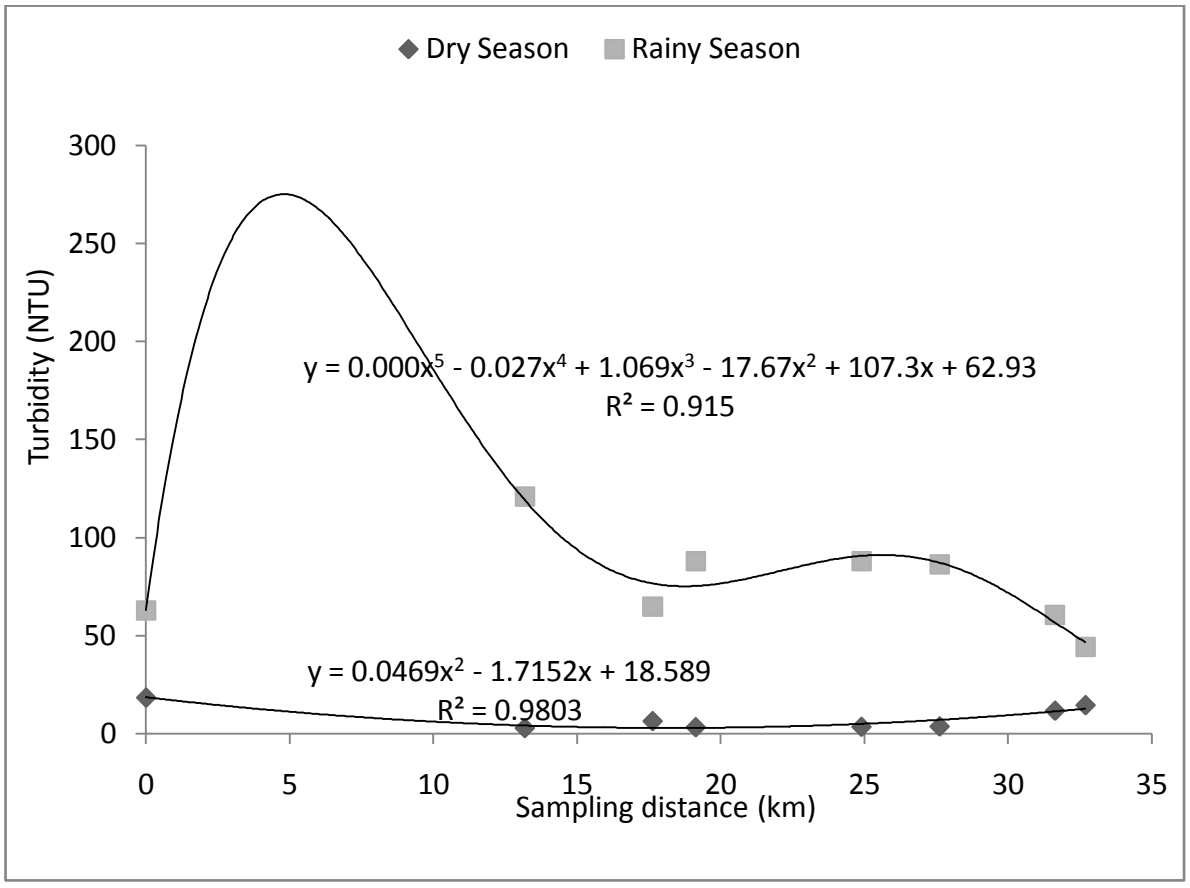


Figure 4.5: Relationship between turbidity and downstream location in River Kaduna

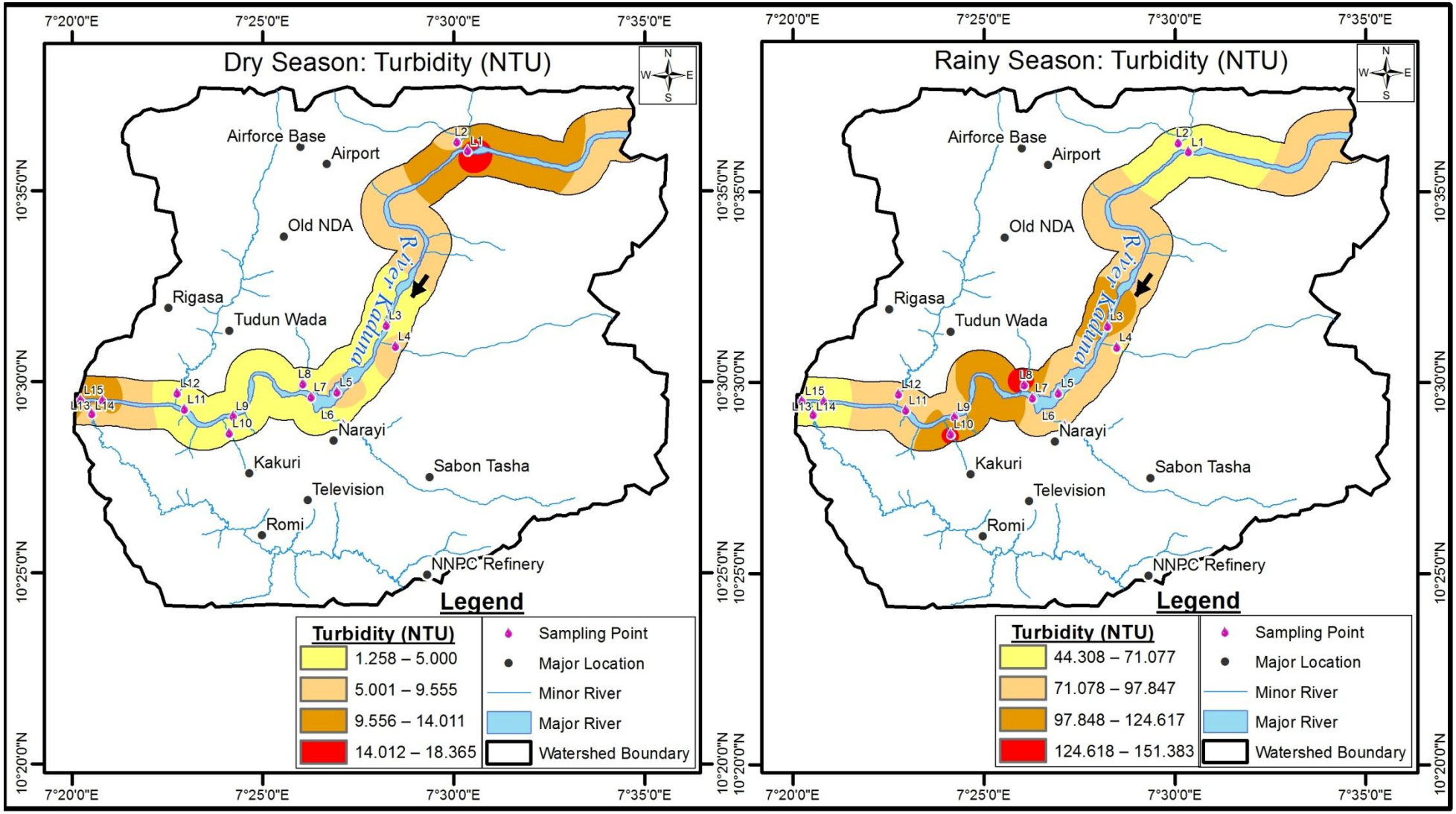


Figure 4.6: Map showing turbidity along River Kaduna

4.2.3Total dissolved solids

Total Dissolved Solids (TDS) in the studied area ranged from 59±0.02mg/l at locations L3 (NNPC) and L5 (Barnawa) in the month of October to 609±0.02mg/l at Location L10 (Breweries) during the month of February. The concentrations of TDS in all the sampling locations were within the FEPA permissible limit (500 mg/l) all through the research period apart from locations L6 (Kutimbi), L8 (Kigo), L10 (Breweries) and L12 (Rigassa). These locations recorded TDS content higher than the permissible limit in certain months especially during the dry season.

The information displayed in Figure 4.7 connotes that the variation pattern of TDS in all the sampling locations were similar during each season with the exception of Locations L6, L8, L10 and L12. These locations correspond to sampling stations at the confluence points of tributaries draining to River Kaduna within the densely populated areas. Though surface runoff which is a product of precipitation (mostly during rainy season) is a major source of TDS in a draining river however, Figure 4.7 revealed that TDS concentrations in all the sampling locations were a bit higher during the dry season. This could be related to the effect of higher evaporation rate during dry season caused by solar heating and low humidity (Garg, 2010). This is because TDS are solutes in solvent (water) hence, as the evaporation rate of the solvent (water) increases during dry season, the concentration of the solutes (TDS) in the surface water increase correspondingly. The higher concentration of TDS observed during dry season is in agreement with previous researches carried by Kayode and Napoleon (2015), Kunwar *et al.* (2015),Emmanuel *et al.* (2016) and Adie (2008). Nevertheless, Chilundo *et al.* (2014) as well as Bindu and Michael (2013) reported lower TDS during dry season.

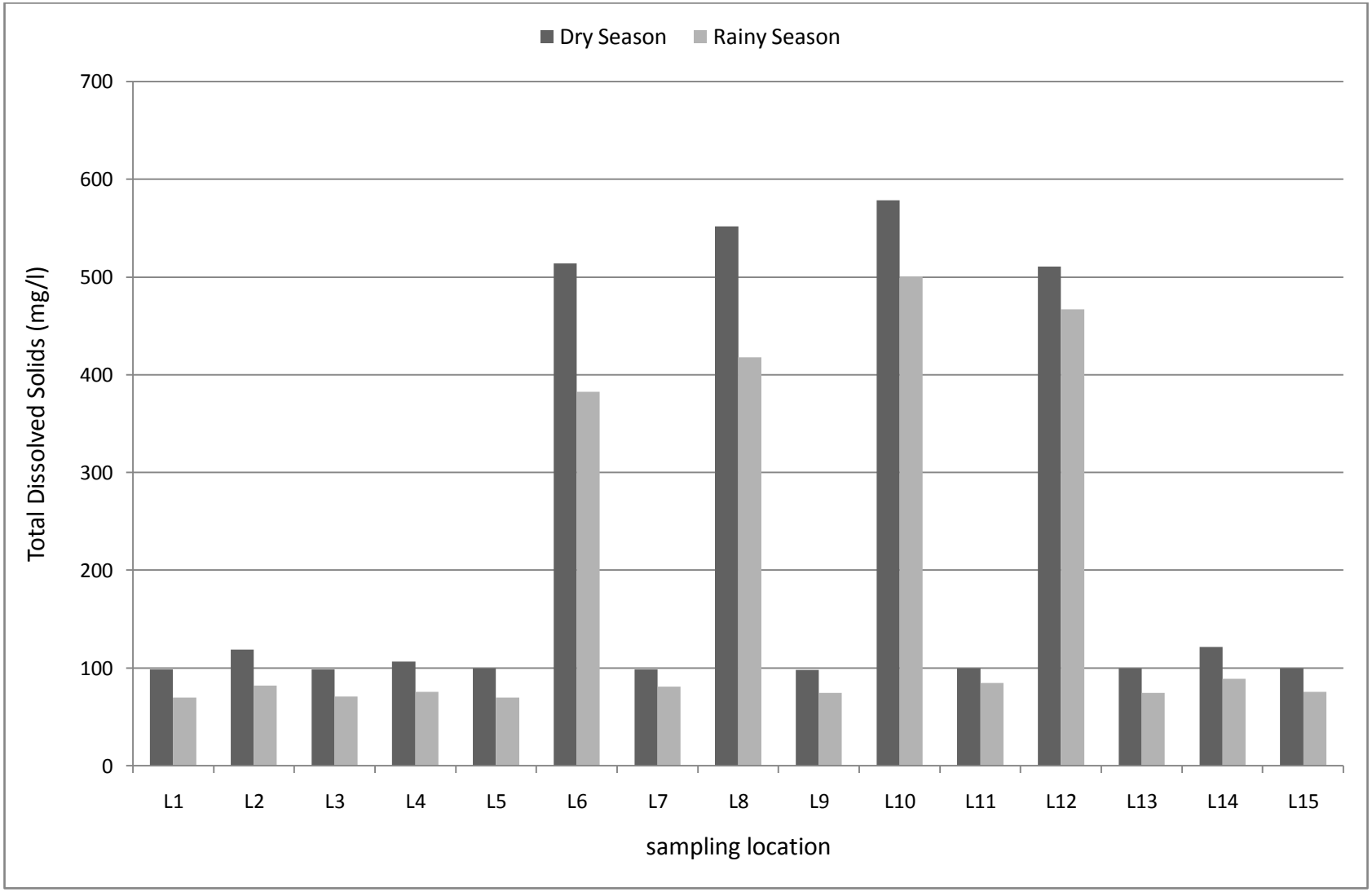


Figure 4.7: Seasonal variation of total dissolved solids across sampling locations

The fact that surface waters naturally contain some dissolved solids irrespective of the season due to the dissolution and weathering of rocks and soils (EPA, 2001) could be a source of TDS in the river. It should be noted that irrespective of the sampling season, there was no significant difference (at $p < 0.01$) between the observed TDS and the guide value set by FEPA (500 mg/l). This implies that the river is safe in terms of TDS. However, the TDS concentrations recorded during the dry season were significantly different (at $p < 0.01$) from those recorded during the rainy season. This suggests that the TDS concentration of a river could be influenced by the season of sampling.

The land use and land cover that had realistic effect on the TDS content of the studied area (River Kaduna) were built-up, vegetation, water body, agriculture and industrial lands (Table 4.3). Just like in the case of Turbidity (Table 4.2), built-up and agricultural lands varies directly with TDS content in both seasons while vegetation land had direct and inverse relationship with TDS during dry and rainy seasons respectively. However, water body and industrial land were positively correlated with TDS during dry season but without a significant correlation (at $p < 0.01$ or $p < 0.05$) during the rainy season.

Table 4.3: Spearman's correlation coefficients between TDS and land use land cover types

Land use land cover	Dry Season	Rainy Season
Built-up	0.5446*	0.6828*
Vegetation	−0.2125**	0.3004*
Water body	0.1068**	
Bare surface		
Agricultural land	0.4637*	0.5063*
Industrial land	0.0973*	

Only significance levels (*<0.05 and **<0.01) are shown, TDS = Total Dissolved Solids

The positive correlation coefficients shown during the rainy season could be attributed to runoff. That is, the larger the area occupied by these land use and land cover, the more

TDSin the runoff been drained into the receiving river. However, during the dry season, the positive correlation between built-up and TDS might be caused by municipal effluent discharges containing dissolved solids such as kitchen and laundry effluents. The negative correlation between vegetal land and TDS during dry season signifies the reduction (improvement) of TDS with increase in vegetation land cover within the drainage basin during dry season. The positive correlation between agricultural land and TDS could be associated with runoff (rainy season) and return flow of excess irrigation water (dry season) which carried several solid particles into the river. Water-body also showed positive correlation with TDS during dry season signifying that during dry season, TDS in the river deteriorated with increase in surface area occupied by water. This is because during dry season, there is high abstraction of water from the river to meet water needs as well as high evaporation rate of water molecule from the river surface due to solar heating and low humidity. This result to a decrease in the depth of the river. Shallow depth and large surface area of water increase evaporation rate of surface water (Garg, 2010) thus increasing TDS content. Dissolved solids contained in industrial effluents can contribute to TDS in receiving streams and rivers (Wright*et al.,* 2016). The use of common salt (NaCl) and glauber salt in industrial processes (especially textile industries) directly increase TDS level in the effluent (Sengupta, 2007). This might be the reason for the positive correlation noted between industrial land and TDS.

It couldbe inferred from Figure 4.8 thateven though the TDS concentrations of River Kaduna during both seasons were less than the maximum permissible limit (500 mg/l), its concentration during each season increased downstream. Figure 4.8 also showed that the fluxes in concentrations of total dissolved solids in River Kaduna were higher during rainy

season compared to dry season. The fluxes or fluctuations of TDS along River Kaduna with respect to the sampling locations could be seen in Figure 4.9.

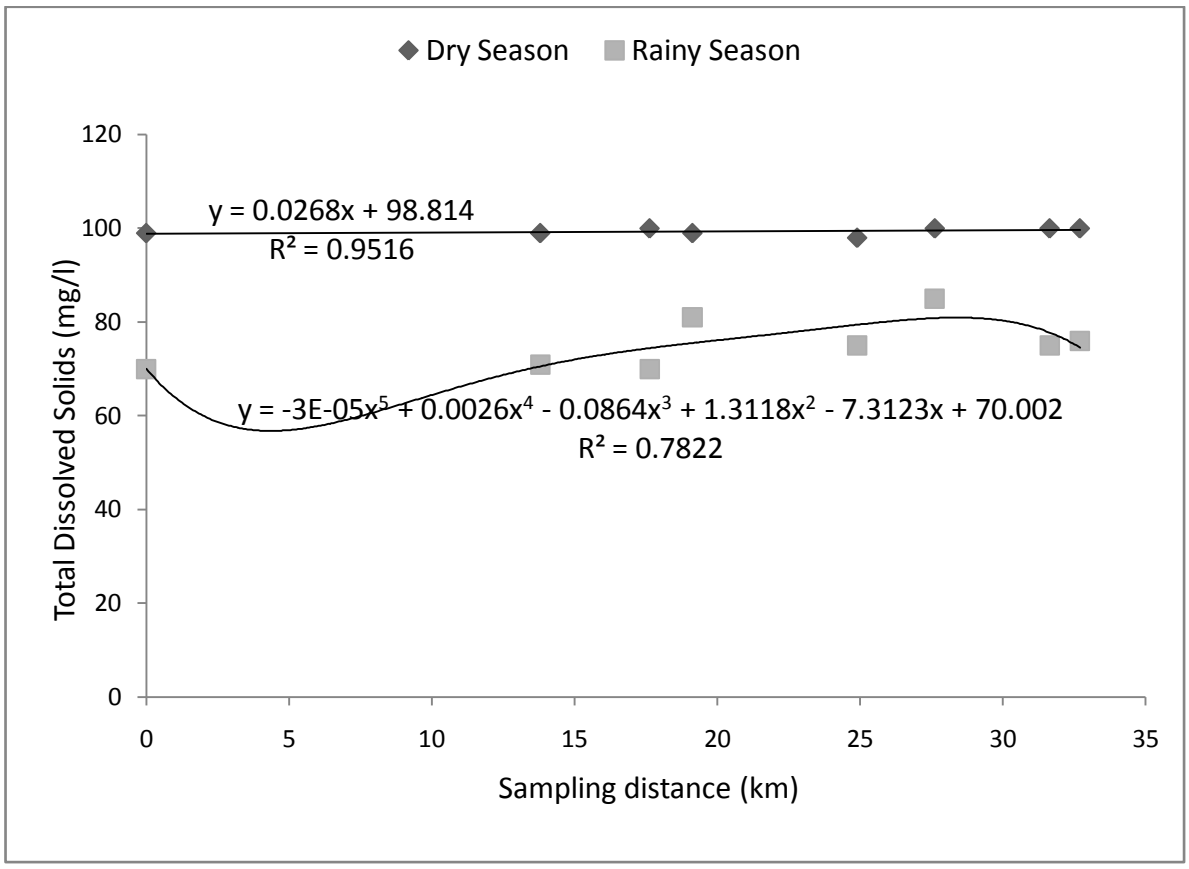


Figure 4.8: Relationship between TDS and downstream location in River Kaduna

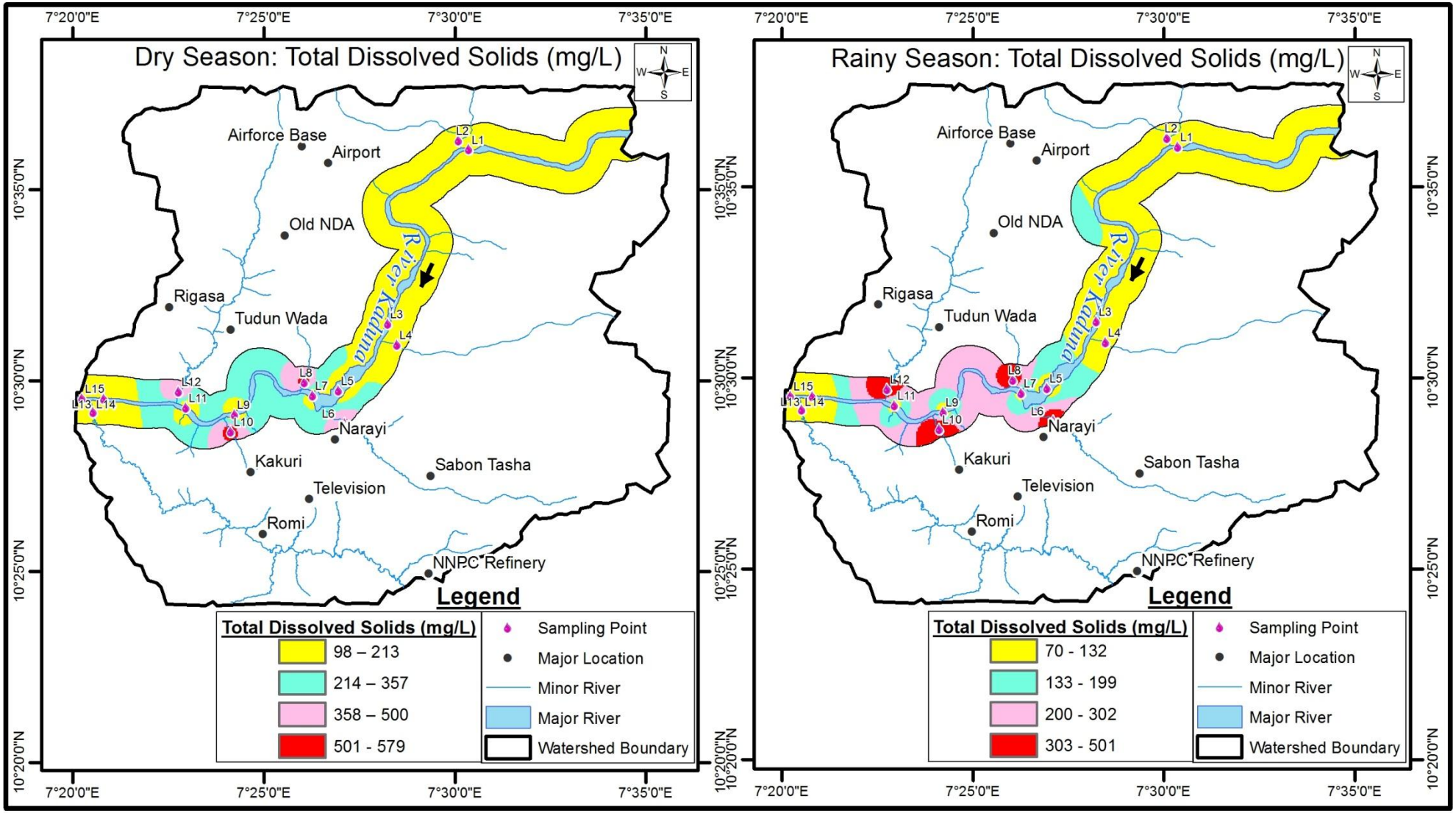


Figure 4.9: Map showing total dissolved solids along River Kaduna

4.2.4 pH

The least pH value which was 6.2±0.1 was recorded during the month of August at sampling locations L6 (Kutimbi) and L8 (Kigo) while the peak value (9.3±0.1) was noted in the month of March at location L10 (Breweries). Between the months of May and September, sampling locations L6 (Kutimbi) and L8 (Kigo) recorded pH values less than 6.5. This was also noted in sampling location L12 (Rigasa) but during the months of May and July – October. Similarly, location L10 (Breweries) had pH values higher than 8.5 all through the sampling period. On the contrary, the pH values of all other sampling locations (i.e. apart from L6, L8, L10 and L12) were found to fall within the FEPA permissible limits (6.5 – 8.5) throughout the sampling period.Figure 4.10 showed that despite the fact that pH values during rainy season were lower than dry season, the variation in pH between the seasons were not much in all the sampling sites. The slight drop in pH values recorded during rainy season in all the sampling sites could be as a result of precipitation. This is because atmospheric pollutants, particularly oxides of sulphur and nitrogen triggered by anthropogenic activities such as burning of fossil fuels (coal, oil and gas), can cause precipitation to become acidic when converted to sulphuric and nitric acids (Sawyer *et al.*,2015). Hence, the rainfall (acid rain) might have caused the drop in pH of the river during the rainy season. This observation of lower pH in a riverduring rainy season compared to dry season had earlier been noted by Adebayo (2014),Wogbere*et al.*(2013) and Yusuf *et al.* (2008). Though, the variations in pH between the seasons in all the sampling locations were not much as could be seen in Figure 4.10, yet, a significant difference (at $p < 0.01$) was observed between the values obtained during dry season and rainy season. This denotes that the pH of the river was swayed by the sampling season.

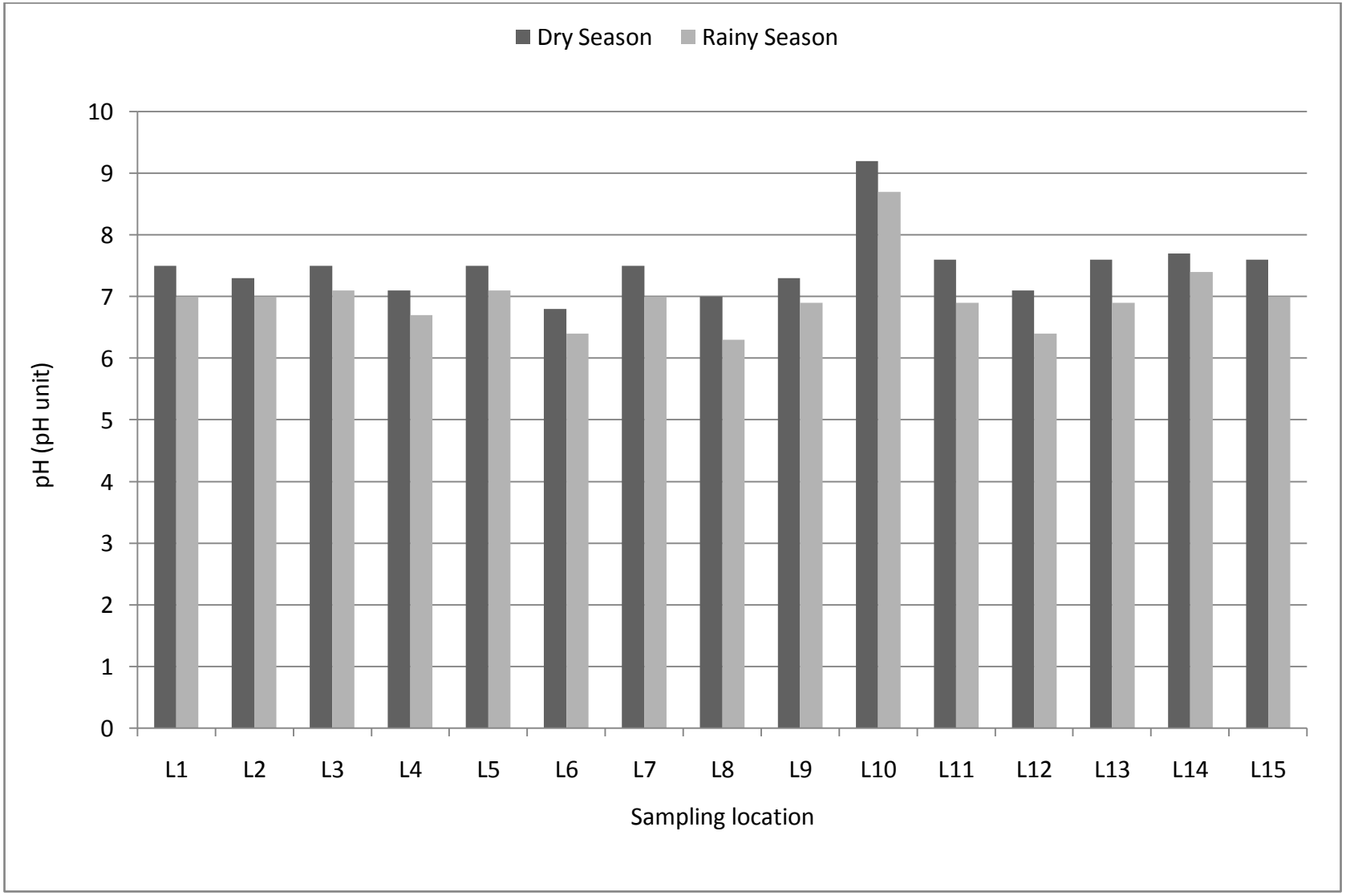


Figure 4.10: Seasonal variation of pH across sampling locations

The effects on pH by the different land use and land cover within the watershed are shown in Table 4.4. Built-up and agricultural lands were negatively correlated with pH in both seasons while vegetation land cover had negative correlation only during the rainy season. This implies that as the proportion of these lands uses increase within the watershed, the pH of the draining river reduces thus causing the water to be acidic. On the contrary, positive correlations were noted between industrial land use and pH during both seasons. This suggests that the larger the percentage of industrial land within the watershed, the higher the pH or alkalinity of the river. Notwithstanding, Table 4.4 indicates that all the correlation coefficients (negative or positive) between pH and the various land uses were very weak irrespective of the seasons as at the period this research was conducted.

Table 4.4: Spearman's correlation coefficients between pH and land use land cover types

Land use land cover	Dry Season	Rainy Season
Built-up	−0.2196*	−0.2839*
Vegetation		−0.1482*
Water body	0.0035*	
Bare surface		
Agricultural land	−0.1732*	−0.2268*
Industrial land	0.3286**	0.1693**

Only significance levels (*<0.05 and **<0.01) are shown

Hornung *et al.* (2012) reported that built-up areas are occupied by humans hence, the discharge of untreated sewage containing acidifying pollutant such as nitrogen compounds (ammonia, nitrite and nitrate) from human excreta are usually much. In other words, the release of these acidifying effluents into the river through point and non-point sources might be the reason behind the lowering of pH (acidic) with increase in built-up land that reflected as negative correlation.

Acidification of vegetation or forest runoff could be caused by many factors. Forest canopies intercept or captured more atmospheric pollutants (e.g. sulphur dioxide and nitrogen dioxide) than shorter types of vegetation (Nisbet and Evans, 2014). This increased capture, the so-called scavenging effect, arises due to the turbulent air mixing above and within the forest canopy and it is a function of the stand structures (Reynolds *et al.*, 2016). The effect therefore becomes more important as trees grow and the height of the stand increases. The pollutants deposited in this way include nitric acid vapour (HNO_3), hydrochloric acid vapour (HCl) and ammonia NH_3 (Nisbet and Evans, 2014; Reynolds *et al.*, 2016). These various forms of acidic pollutants captured by forest canopies might have acidified the rainfall within the vegetal land cover which finally drains into river through runoff. In addition, forest soils are characterized by having acid surface litter, fermentation and humus layers, due to the enrichment of the soil with organic matters such as fallen leaves and dead woods (Hughes *et al.*, 2015). Hence, the drop in pH with increase in vegetation (forest) might as well be initiated by the release of organic acids from these layers via precipitation that drains into the river.

The excessive application of organic and inorganic fertilizers in the agricultural lands might be the reason for the negative correlation between agricultural land use and pH. This is because fertilizers in the form of urea or ammonia nitrate are potentially acidifying due to nitrification of ammonia and leaching of nitrate (Jenkins *et al.*, 2012). Furthermore, planting of nitrogen-fixing species such as cowpea, groundnut and soya beans at the river banks can promote nitrate leaching from soils to river (Wright*et al.*, 2016).This leachate might have contributed to the river water acidification. In addition, cultivation disturbs and mixes the soil, potentially improving soil aeration and warming the soil. This can enhance

the oxidation of soil organic matters and the release of organic acid and stored sulphate (Nisbet and Evans, 2014). The washout of these chemicals into the river by irrigation water and runoff might have also contributed to the acidic pH of the surface waters within the agricultural land.

The positive correlation between pH and industrial land suggest that the industries within the drainage basin discharge more of alkaline effluents. This could be linked to the effluents been discharged by the numerous textile companies in the hot spot industrial zone (Kakuri). This is because the pH of textile effluents are generally high because of the use of many alkaline substances in textile processing (Ashraful and Arun, 2013; Yusuf *et al.*, 2008).Nevertheless, Figure 4.11 indicates that the pH within River Kaduna is within the allowable limit of river protection (6.5-8.5) which is in line with the assertion of Mohammed (2013). This implies that the impacts of natural and anthropogenic activities have not significantly altered the acidity and alkalinity status of the water body. However, areas (towns) of relative higher or lower pH in comparison across the river are shown in Figure 4.12.

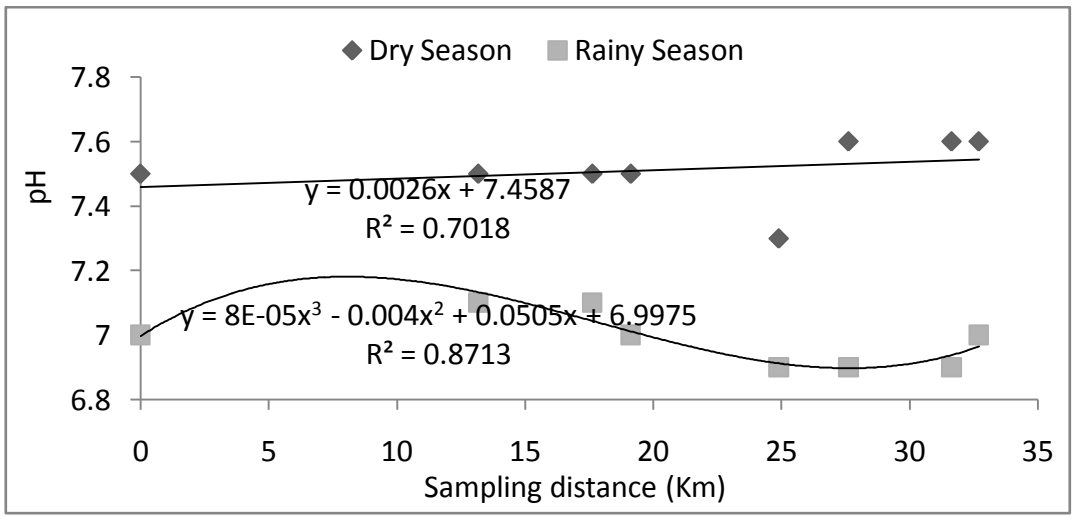


Figure 4.11: Relationship between pH and downstream location in River Kaduna

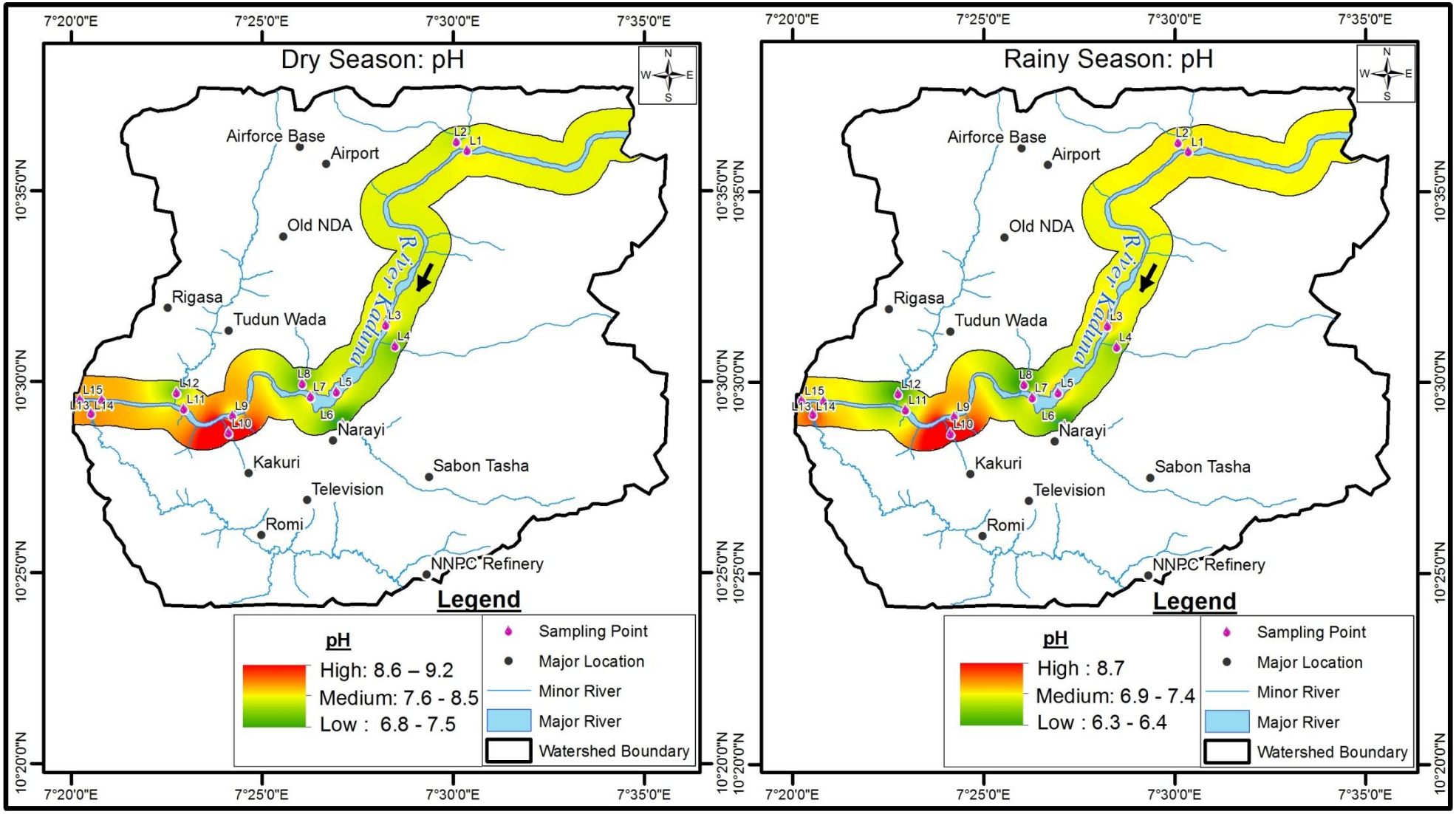


Figure 4.12: Map showing pH along River Kaduna

4.2.5Chloride

The concentrations of chloride ion (Cl^-) ranged from 0.63±0.1 mg/l to 313.28±0.1 mg/l, matching sampling locations L3 (NNPC) and L10 (Breweries) during the months of October and February respectively. Chloride ion concentrations during both seasons in most of the sampling sites were relatively low compared to the maximum permissible limit (250 mg/l). Out of the fifteen (15) sampling stations, only four (4) locations recorded chloride concentrations higher than 250 mg/l in certain months during the period of sampling. These locations were L6, (Kutimbi), L8 (Kigo), L10 (Breweries) and L12 (Rigassa) as could be seen in Table 4.9. Hence, there was no significant difference (at $p < 0.01$) between the Cl^- of the river and the permissible limit for protecting river water quality (250 mg/l) which implies that the river is safe in terms chloride ion.

The effect of season on chloride ion concentration was demonstrated through Figure 4.13. The chloride concentrations in all the sampling sites were lower during the rainy season than the dry season. This could be connected to the dilution caused by precipitation during rainy season. Moshood (2016) and Richard *et al.* (2015) also recorded lower concentration of chloride during rainy season compared to dry season in surface water.

Table 4.5 revealedthat all the land use and land cover showed positive correlations with chloride ion (Cl^-). This implies that the larger the expansion of these land uses and land covers, the higher the concentration of chloride ion (Cl^-) in the draining river or stream.

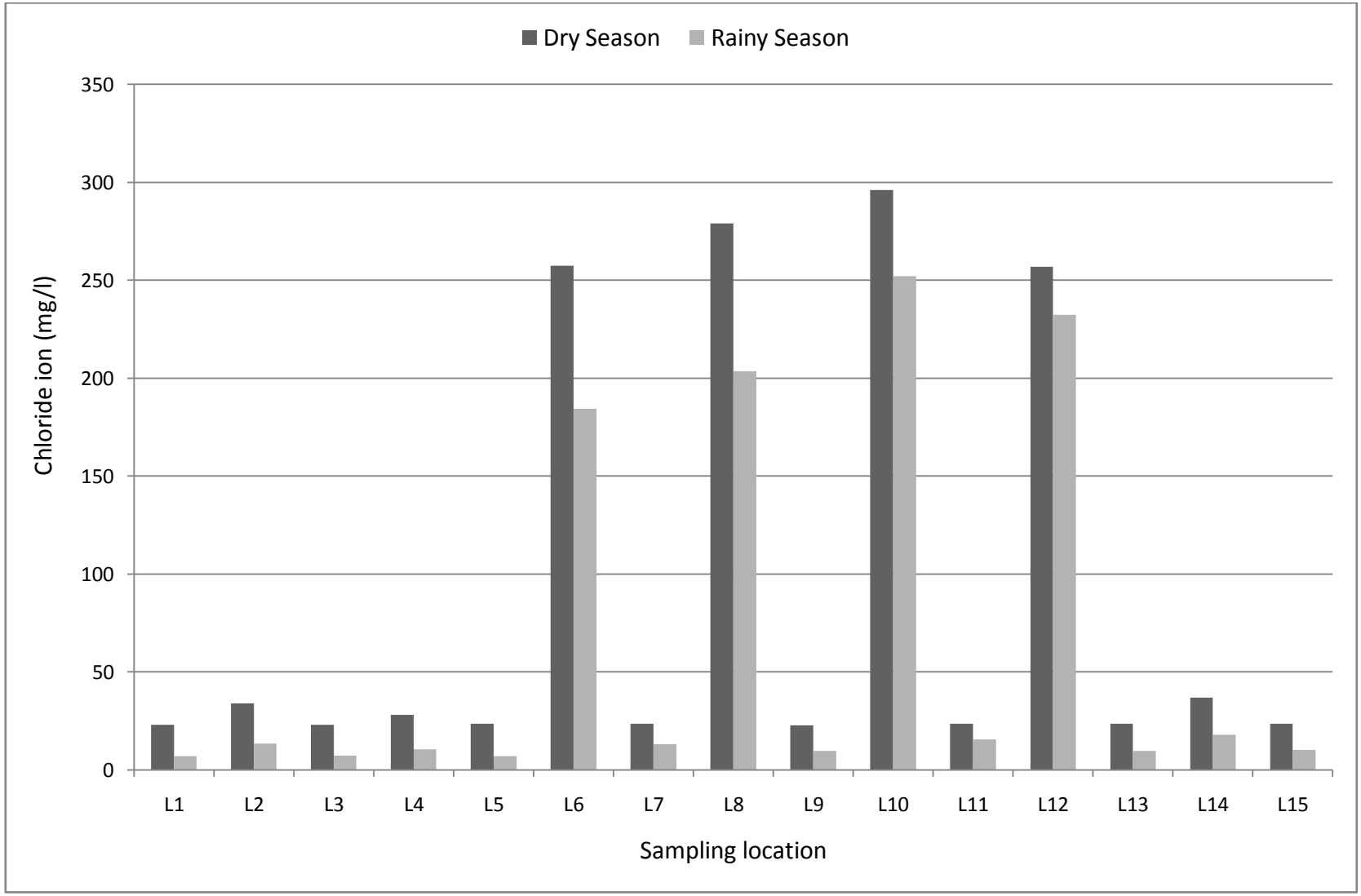


Figure 4.13: Seasonal variation of chloride ion across sampling locations

Table 4.5: Spearman's correlation coefficients between Cl^- and land use land cover types

Land use land cover	Dry Season	Rainy Season
Built-up	0.4381**	0.3601**
Vegetation		0.0501*
Water body	0.1157*	0.0883*
Bare surface		
Agricultural land	0.2969**	0.2507*
Industrial land	0.1694**	0.1288*

Only significance levels (*<0.05 and **<0.01) are shown

The presence of chloride ions in built-up watershed might be caused by point and non-point discharges of domestic and municipal effluents. This is because chloride ion occurs naturally in foodstuffs atlevels normally less than 0.36 mg/g with an average intake of 100mg/day when salt-free diet is consumed (Apte *et al.,* 2011). However, the addition of salt during processing, cooking, or eating can markedly increase the chloride level in food, resulting in an average dietary intake of 6 g/day, which may rise to 12 g/day in some cases. Hence, human excreta generated per person per day contain about 6g of chloride (George *et al.,* 2004). In other words, effluent discharges from kitchen, leachate from failed septic tanks as well as the practice of defecating at the riverside by humans and livestock might be the reason for the increase in $Cl^-$with respect to the proportion of built-up area (positive correlation). In addition, landfills leachate could be another source of chloride ion in built-up watershed since food scrap, pet waste and condemned batteries are usually found in landfills.

The positive correlation (though weak) between vegetation land cover and chloride ion during rainy season was because, vegetation covers (grassland, shrubs, forest) were commonly used by herdsmen for grazing livestock (Dada *et al.,* 2011). Hence, runoff from

vegetation watershed carries excretes of herdsmen and grazing livestock into draining streams thus imparting chloride.

Rock-water interactions such as mineral dissolution and desorption usually increase the concentration of chloride ions (Walton *et al.,* 2016). Therefore, the rise in chloride ionswith increase in water body surface (positive correlation) could be attributed to the presence of numerous rocks in River Kaduna which might have leached out chloride ions in the course of weathering and getting in contact with the flowing water.

Irrigation and rising of groundwater tables has been reported asone of the main cause of Cl^- in agricultural watersheds, especially in the arid and semi-arid regions of the world where crop production consumes large quantities of water (Miguel *et al.,* 2015). This is because crops absorb only a fraction of the salt in irrigation water, thus making soil water to be more saline or salty which usually leached out through interflow and end up in the river(Lerotholi *et al.,*2013). Also, the practice of excessive use of inorganic fertilizers to improve soil fertility by farmers might be another reason for the presence of Cl^- in the agricultural watershed (Walton *et al.,* 2016).

Chloride ions in industrial watershed could be attributed to untreated effluent discharges from industries manufacturing pesticides, fertilizers, animal feed, detergents, pulp mills as well as a large number of small scale processing units in textile industries. In majority of these industries, the main source of chlorides in the effluent is the use of Lime ($Ca(OH)_2$) or Sodium Hydroxide (NaOH) for the neutralization of acidic effluents (Apte *et al.,* 2011). At different instances, Hydrochloric acid (HCl), or Sodium Hydroxide (NaOH) can be a

major part of the industrial processes, where they are used for the initial de-coating of oil film on the raw material thus contributing to the chlorides in wastewater (Apte *et al.*, 2011).

Figure 4.14 showed that the fluctuations of chloride ion across the sampling locations in River Kaduna were highly pronounced during the rainy season compared to dry season. The chloride content suddenly rises at 19.13 km and 27.62 km downstream away from the sampling commencement point. These two points respectively correspond to sampling locations L7 (Living Faith) and L11 (Ungwa Mu'azu), which are watersheds mostly comprising built-up and agricultural land use. Even though River Kaduna is environmentally satisfactory in terms of Cl^- as earlier mentioned, the GIS map for Cl^- (Figure 4.15) indicates that the river was more concentrated in Cl^- at the central part.

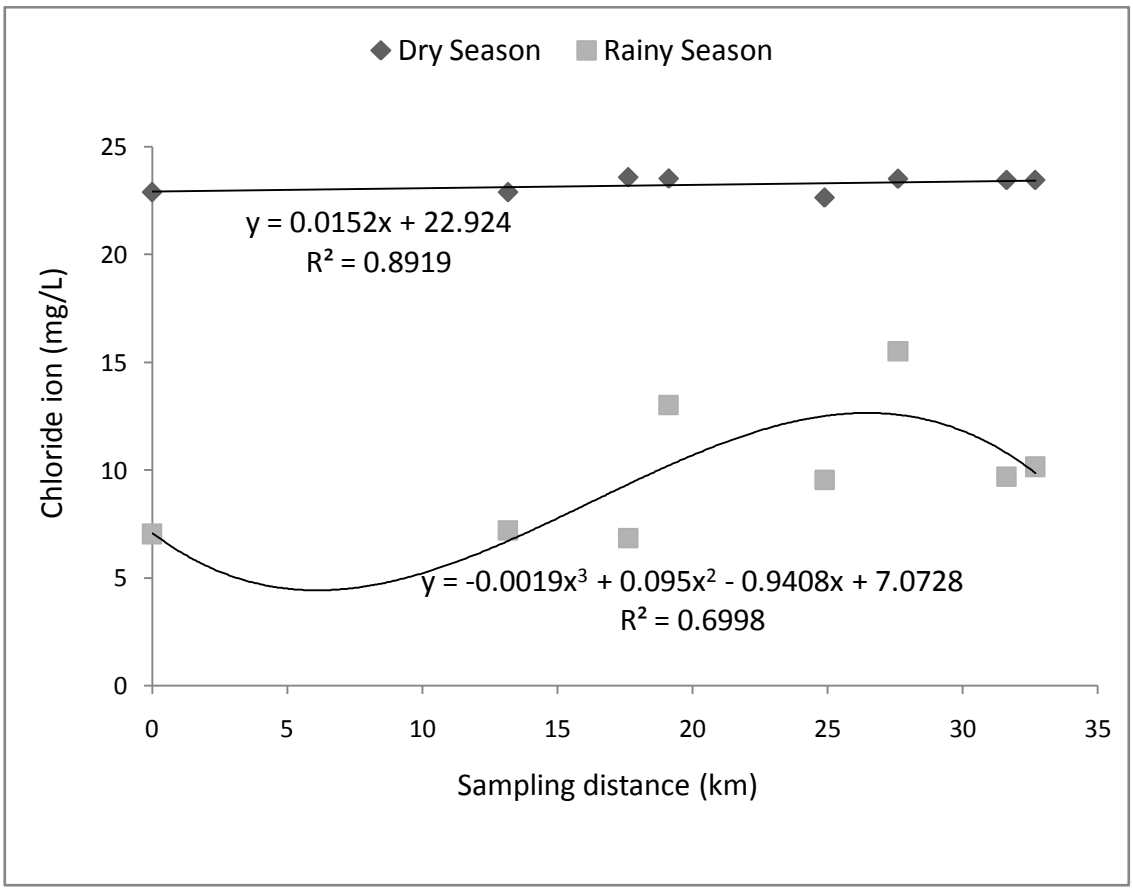


Figure 4.14: Relationship between chloride ion and downstream location in River Kaduna

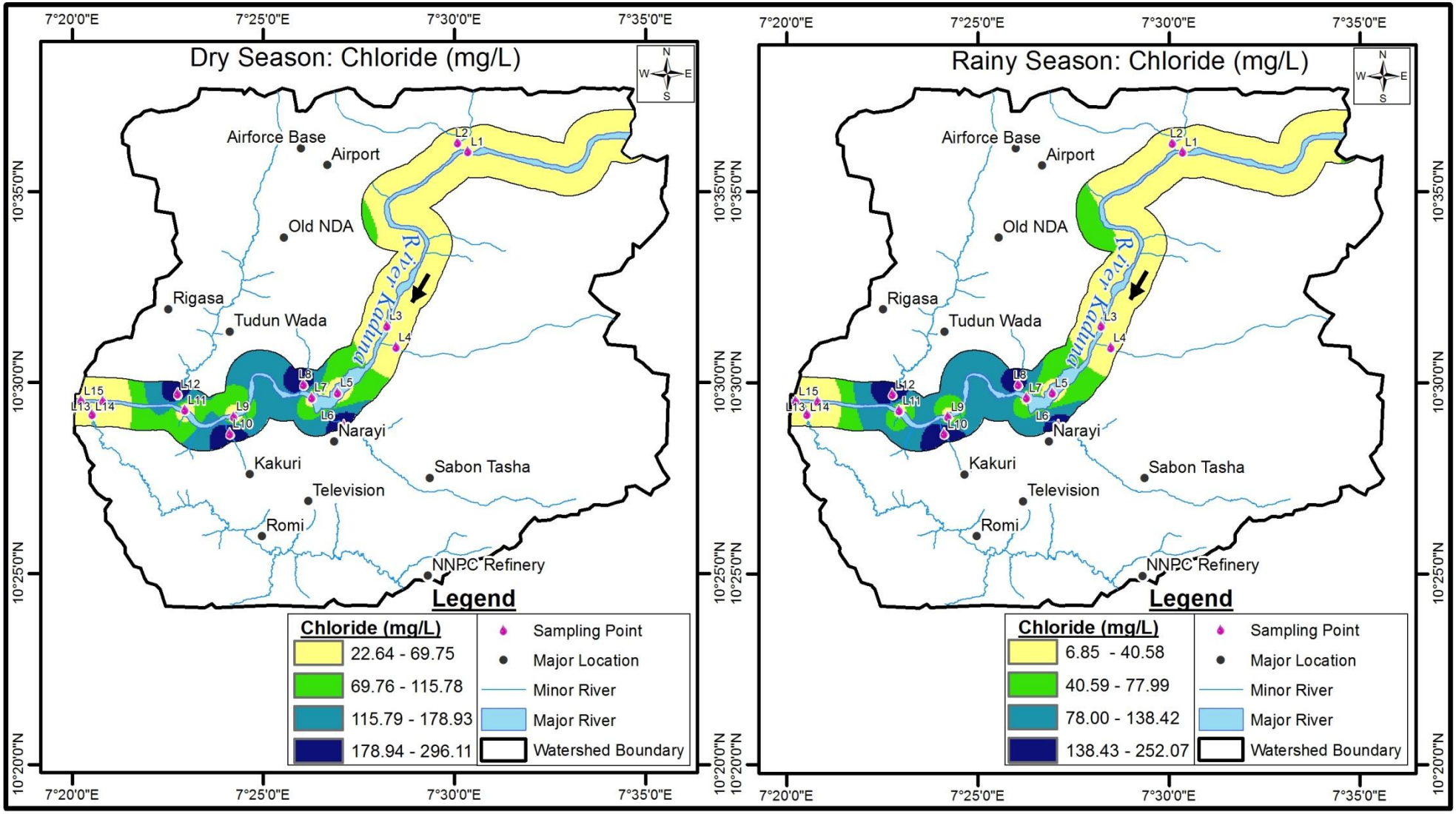


Figure 4.15: Map showing chloride ion along River Kaduna

4.2.6Electrical conductivity

The electrical conductivity (EC) values of the sampling sites ranged from 88±0.02 µS/cmto 915±0.02µS/cm. These minimum and maximum values were recorded at sapling stations L3 (NNPC) and L10 (Breweries) during the months of October and February respectively. The EC values in all the sampling sites were within the FEPA permissible limit (750µS/cm) apart from locations L6 (Kutimbi), L8 (Kigo), L10 (Breweries) and L12 (Rigasa). Locations L6, L8 and L12 recorded EC values higher than 750µS/cm in between the months of December and May while location L10 was between November and June. Student's t-test revealed that though there was a significant difference (at $p < 0.01$) between the dry and rainy season EC, both seasons recorded EC significantly lower than the maximum permissible limit(750µS/cm).The seasonal variation of electrical conductivity across the sampling locations (Figure 4.16) is similar to that of Chloride (Figure 4.13) as well as total dissolved solids (Figure 4.7). This could be probably because electrical conductivity is a linear function of total dissolved solids and chloride ion (Ogbozige *et al.*, 2015; Ghaly *et al.*, 2014; Siyanbola*et.al.*, 2011; Peavy, 1998). It is obvious in Figure 4.16 that the recorded EC values were lower during the rainy season. This is because water conductivity is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions or sodium, magnesium, calcium, iron, and aluminum cations (EPA, 2001; Karia and Christian, 2013). Hence, the dilution of the concentration of these dissolved solids by precipitation which occurred during the rainy season might be the reason for the lower EC values recorded the during rainy season. This finding is in line with that of Mohamed *et al.* (2015) butagainst study.

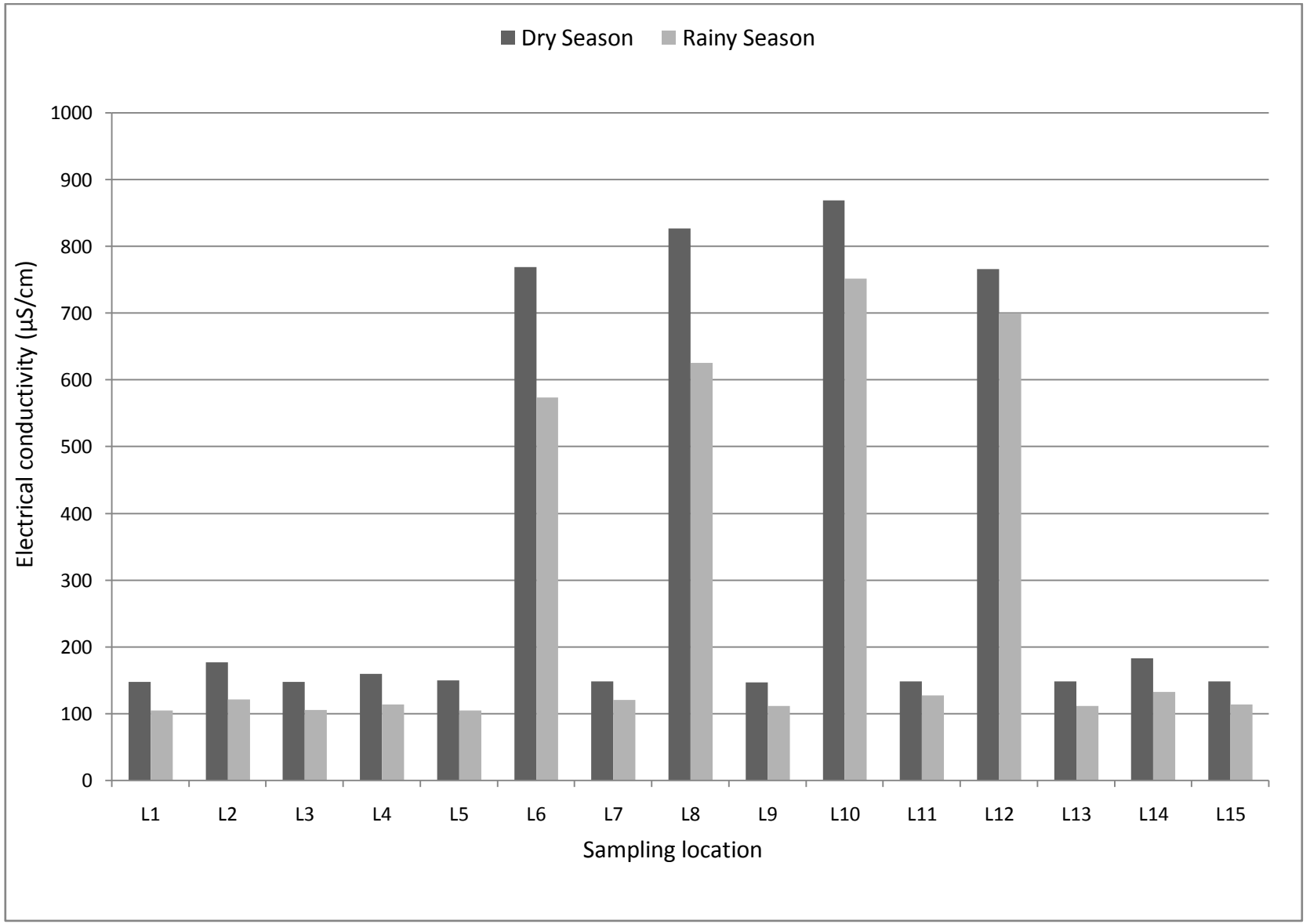


Figure 4.16: Seasonal variation of electrical conductivity across sampling locations

The impacts of land use and land cover on the electrical conductivity as shown in Table 4.6 informed that the various land uses had positive correlated with EC during both season with the exception of vegetation cover during dry season.

Table 4.6: Spearman's correlation coefficients between EC and land use land cover types

Land use land cover	Dry Season	Rainy Season
Built-up	0.4914*	0.4215*
Vegetation	−0.1246**	0.1902*
Water body	0.1113*	
Bare surface		
Agricultural land	0.3803**	0.2678*
Industrial land	0.1334**	0.1062*

Only significance levels (*<0.05 and **<0.01) are shown, EC = Electrical Conductivity

Electrical conductivity in built-up watershed might be initiated by discharges of both point and non-point sources of domestic and municipal effluents. The presence of dissolved solids such as sodium chloride (common salt) and mono sodium glutamate (magi) in kitchen effluents could have imparted EC since these substances contain sodium ions (Na^+) (Ruth and Mathew, 2003). Runoff from lawns and gardens containing agrochemicals like fertilizer as well as leachate from failed septic tanks and landfills could also be other sources of EC in built-up watershed since they contain ions like potassium (K^+), nitrate (NO_3^{2-}), phosphate (PO_4^{3-}) and chloride(Cl^-) (Afua *et al.,* 2015). Furthermore, the presence of sodium carbonate (Na_2CO_3) and sodium sulphate (Na_2SO_4) in detergents (Ruth and Mathew, 2003) could contribute EC in surface water that receives laundry effluents since these compounds contains sodium ion (Na^+).

Some of the sources of EC in surface water such as kitchen effluents, fertilizers, leachates from failed septic tanks and landfills as earlier mention are not usually found within shrubs and forested areas (vegetation cover). Also, EC has been identified to be a function of

dissolved solids and one of the means by which dissolve solids gets into surface water is through surface runoff (EPA, 2001; Peavy, 1998). However, surface runoff is not experienced during dry season due to the absence of precipitation. Hence, the negative correlation (inverse relationship) between vegetation cover and EC during dry season might be as a result of the low or absence of domestic and municipal effluent loading as well as the nonexistence of runoff during dry season. Conversely, vegetation covers (grasslands, shrubs and forests) usually served as grazing areas for livestock thus, causing vegetal covers to contain livestock excretes. The transportation of this livestock excretes together with other dissolved solids within the vegetal cover by runoff to the nearby waterways could be the reason for the positive correlation between vegetation cover and EC during the rainy season.

The rise in conductivity with respect to water body surface during dry season suggests that the numerous rocks in River Kaduna might have released ions such as chloride into the water as a result of weathering (EPA, 2001).

Fertilizer application (NPK) in farmlands within the study area was very common. Runoff during the rainy season as well as return of excess irrigation water during the dry season might have carried nitrate ion (NO_3^{2-}), phosphate ion (PO_4^{3-}) and potassium ions (K^+) in the fertilizers to the draining water body which consequently increase the EC content. This effect was well noticed asthere were numerous plots of farmlands at closed range to the waterways (farms along the riverbanks). In other words, the rise in EC content of the river with respect to increase in agricultural land (positive correlation) was as a result of the excessive use of inorganic fertilizers by farmers.

The reason behind the positive correlation between EC and industrial land use could be due to the use of various salts by textile industries especially during the dyeing process (Sengupta, 2007). This might have increased the chloride ions in the effluent which consequently raise the EC of the draining river.

The fluctuations pattern of electrical conductivity during both seasons in Figure 4.17 is similar to that of total dissolve solids (Figure 4.8). Also, a critical observation of the GIS map for EC (Figure 4.18) showed that the diffusion trend is similar to that of chloride ion shown in Figure 4.15. This confirm that the electrical conductivity was influenced by the concentration of both total dissolved solids and chloride ion which have earlier been noted byOgbozige *et al.* (2015),Ghaly *et al.* (2014),Siyanbola*et al.* (2011) and Peavy (1998).

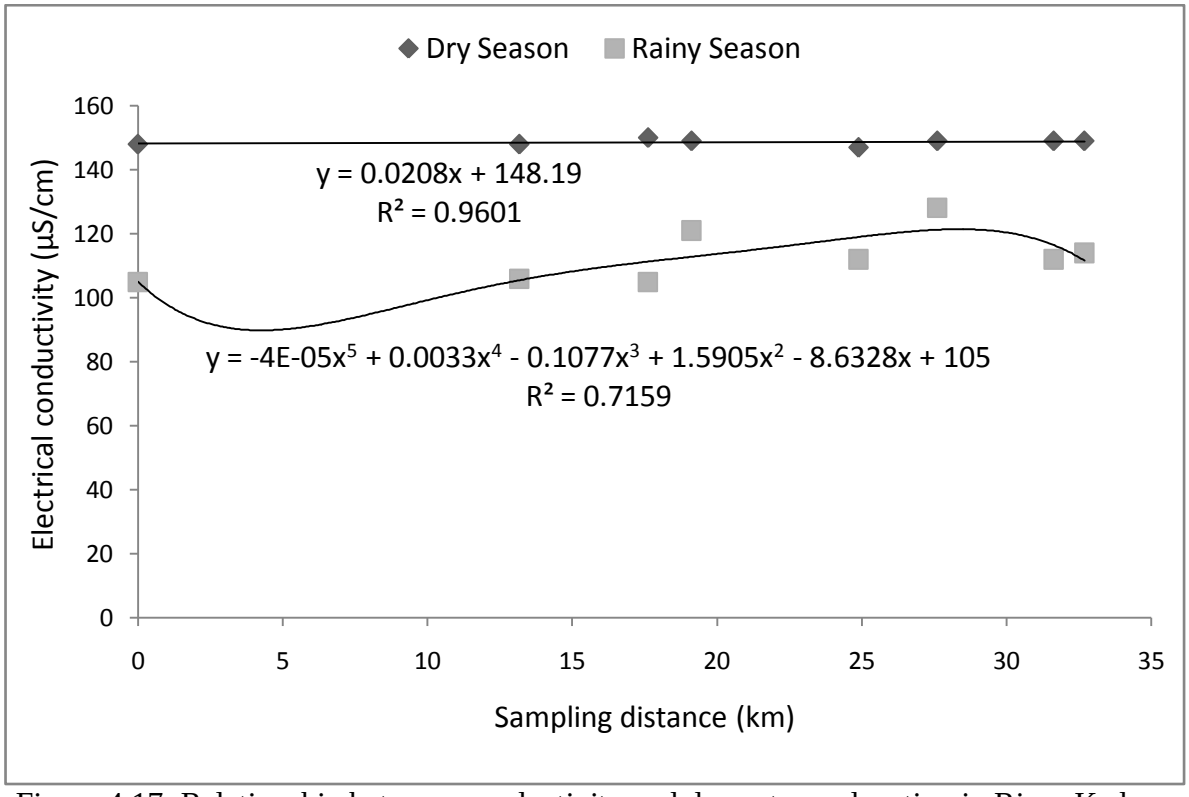


Figure 4.17: Relationship between conductivity and downstream location in River Kaduna

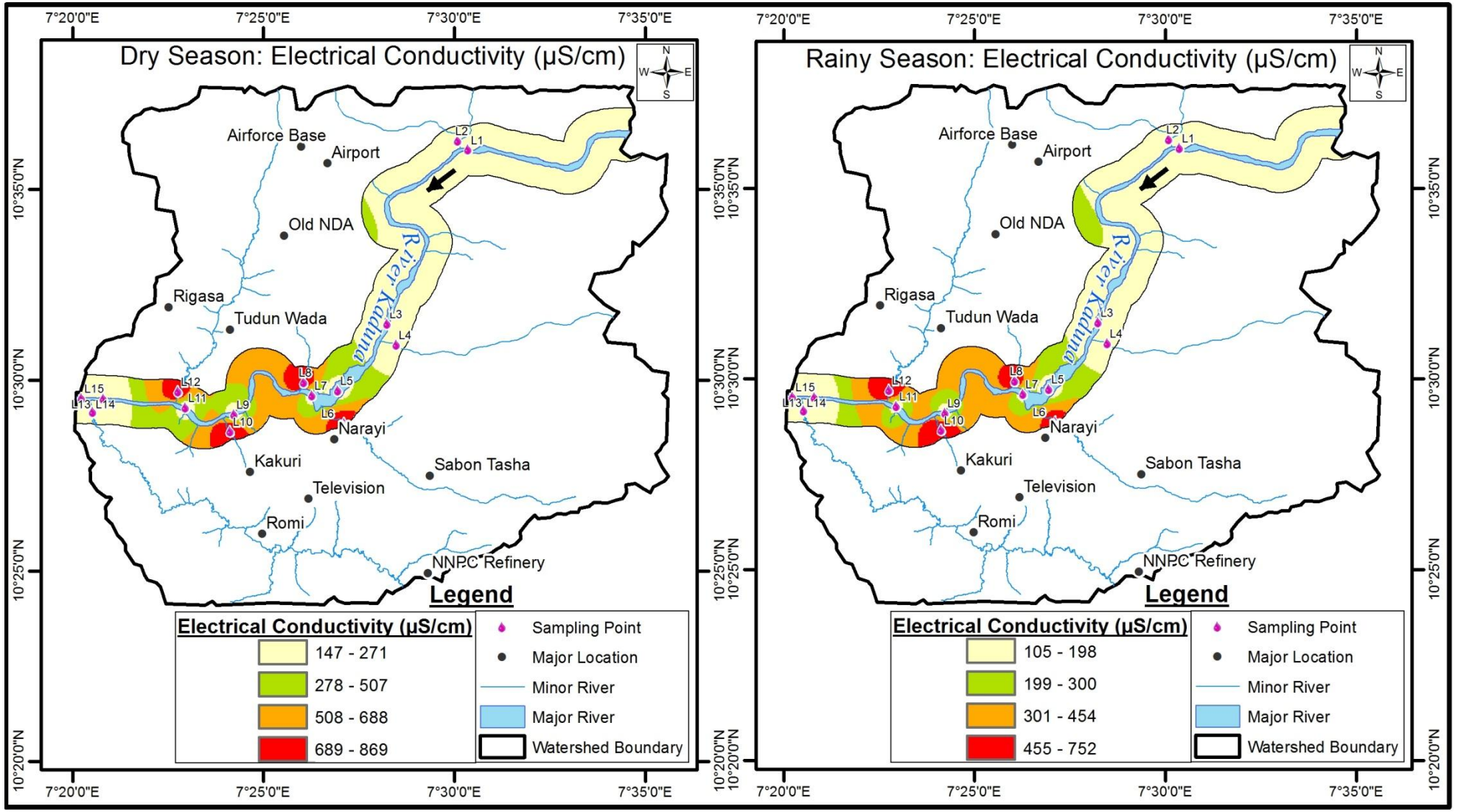


Figure 4.18: Map showing electrical conductivity along River Kaduna

4.2.7Dissolved oxygen

The minimum Dissolved Oxygen (DO) content (2.18±0.01 mg/l) was recorded during the month of April at sampling location L8 (Kigo) while the peak value (8.22±0.01 mg/l) was noted at location L1 (Malali) during August. Sampling locations L6 (Kutimbi), L8 (Kigo), L10 (Breweries) and L12 (Rigasa) were poorly oxygenated throughout the sampling period (DO < 5.00 mg/l). Salinity is an important factor in determining the amount of oxygen that a body of water can hold. This is because as the amount of dissolved salt in water increases, the amount of oxygen the water can hold decreases and vice versa (Esengul*et al.*, 2014). Hence, the low content of DO at locations L6, L8, L10 and L12 could be attributed to the high chloride ions recorded in these locations (Figure 4.13). Unlike locations L6, L8, L10 and L12, sampling location L1 (Malali) recorded DO content higher than the minimum permissible limit all through the 12 months of sampling. However, in the remaining sampling locations, both permissible and none permissible DO content were observed.

The influence of season on the availability of oxygen was distinct as could be seen in Figure 4.19. The DO contents were higher during the rainy season in all the sampling locations. This is because during the rainy season, the water current which was very high was obstructed with the presence of numerous rocks in the river. This obstruction produced turbulence which created aeration or oxygenation of the flowing water unlike the case of water stagnation during the dry season. This was buttressed by the student's t-test which showedthe rainy season and dry season DO contents to be respectively significantly higher and lower than the minimum permissible limit set by FEPA (5 mg/l) at 99% confidence level. This implies that the river is not safe in terms of DO content during dry season.

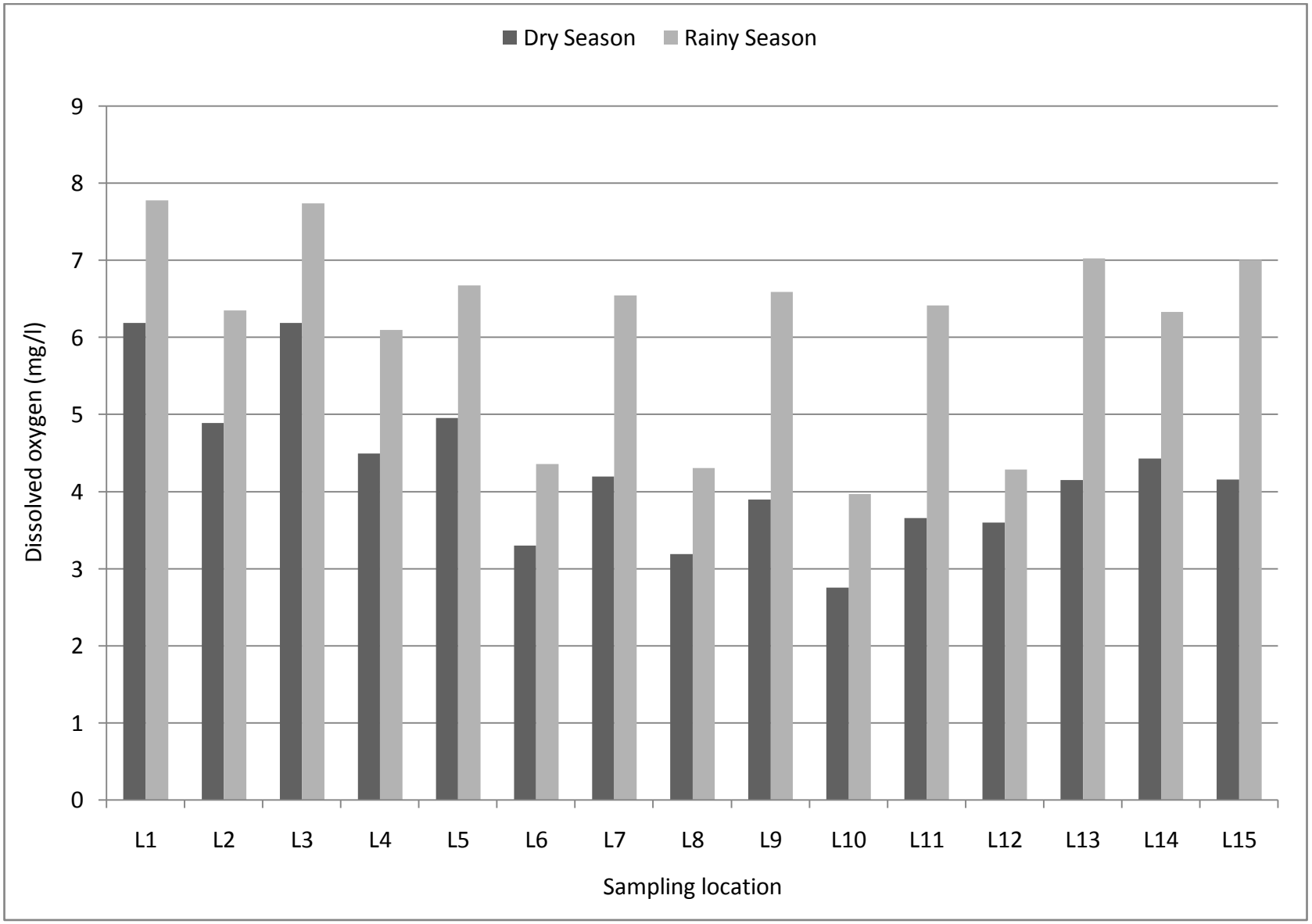


Figure 4.19: Seasonal variation of dissolved oxygen across sampling locations

The lower concentration of DO observed during the dry season compared to the rainy season reaffirm the reports of Udiba *et al.* (2014),Adebayo (2014) and Yusuf *et al.*(2008) but negate that of Kolo (2015).

The level of impacts on the oxygen content of the river by the various land use practices is shown in Table 4.7. Built-up, agricultural and industrial watersheds were negatively correlated with dissolved oxygen during both seasons. Nevertheless, vegetation watershed had a positive correlation with DO in dry seasons and negative correlation in rainy season.

Table 4.7: Spearman's correlation coefficients between DO and land use land cover types

Land use land cover	Dry Season	Rainy Season
Built-up	−0.5982**	−0.5679*
Vegetation	0.2644**	−0.1821*
Water body	0.0125*	
Bare surface		
Agricultural land	−0.3815*	−0.4714*
Industrial land	−0.3107*	−0.2696*

Only significance levels (*<0.05 and **<0.01) are shown, DO = Dissolved Oxygen

Built-up (urban) areas are usually populated with humans and one of the associated effects is the tendency of polluting surface and ground water. This is because effluent discharges (point and non-point sources) from septic tanks, abattoirs, hospitals, laundries, kitchens, institutions and landfill leachates are mostly observed in built-up areas (Iyanu, 2011). Hence, the assertion of Iyanu (2011) suggests that surface waters within a built-up drainage basin will contain more organic pollutant as built-up area expands (urbanization). However, organic pollutants in surface water usually deplete it DO content since bacteria consume or utilized the available oxygen to oxidize these organics. This might be the reason for the strong negative correlation between built-up drainage basin and dissolved oxygen content.

Unlike urban or built-up areas, people hardly reside with their families in forested areas (vegetation covers) due to the fear of the presence of wild animals (Etusoaga and Randy, 2015). Though few Fulani herdsmen with their livestock and families reside temporarily in the forested areas nevertheless, the activities of these people (Herdsmen) are more of grazing and watering of livestock. Hence, the absence of storm runoff during the dry season as well as lack of municipal effluent dischargesenables forested watershed not to contribute much organic matters into the draining river. This might be the reason for the positive correlation between vegetation cover and DO during the dry season. On the contrary, during the rainy season, forest runoff carries excretes of; herdsmen, farmers, animals (livestock and wildlife) as well as decayed woods and leaves into the River Kaduna which reduced it DO content. In other words, during the rainy season, larger vegetal covers (grasslands, shrubs, forests) had the tendency of eroding more organic pollutant to surface waters than smaller vegetal areas. This explains the reason for the negative correlation between vegetation cover and dissolved oxygen during the rainy season.

The negative correlation between agricultural land and dissolved oxygen could be attributed to several factors. The excessive use of compost manure and animal dungs by farmers in enriching the soil might have increase the organic contamination of the draining river following the washing of these organics by runoff or return irrigation water (Afua *et al.,* 2015). Also, the practice of farmers spraying pesticides including herbicides and insecticides on weeds and insects might have added substantial quantities of decaying weeds and insects (organics) to the river when eroded by runoff or return irrigation water (Hrenandez *et al.,* 2013). In addition the rotting residues of plant left behind on the field after harvest could have also increased the organic load of the river via runoff and

returnirrigation water. The negative correlation between industrial watershed and dissolved oxygen suggest that the industrial effluents contain biodegradable organics. Biodegradable organics such as alcohol, starch, aldehydes and esters are usually associated with industrial effluents (Jamaluddin and Nizamuddin, 2012; Peavy, 1998). The continuous utilization of the available oxygen in the effluents by bacteria in other to oxidized or stabilized these organics resulted to the depletion in DO which is reflected as negative correlation.

The curves in Figure 4.20 indicate that both seasons (rainy and dry) recorded similar variations pattern in the concentrations of DO as the water flow downstream along River Kaduna. The DO content of the water in both seasons deteriorated (reduced) in between the starting point (Malali)and a point at 27.62 km downstream (Kakuri) and thereafter, improved (increased) downstream.Low level of DO in a water body reduces the potential of the water to be used for fishery and aquaculture (Bolorunduro, 2016). The areas and towns with low DO level are shown in Figure 4.21 hence, attention should be given to these areas by enforcement agents for the sake of safe guiding the river quality in terms of DO.

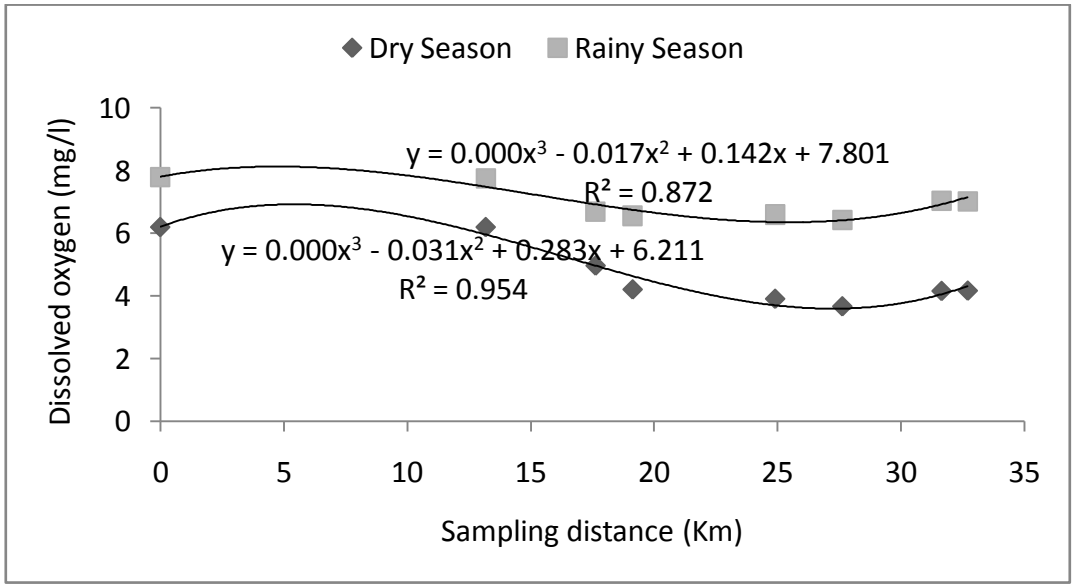


Figure 4.20: Relationship between dissolved oxygen and downstream location in River Kaduna

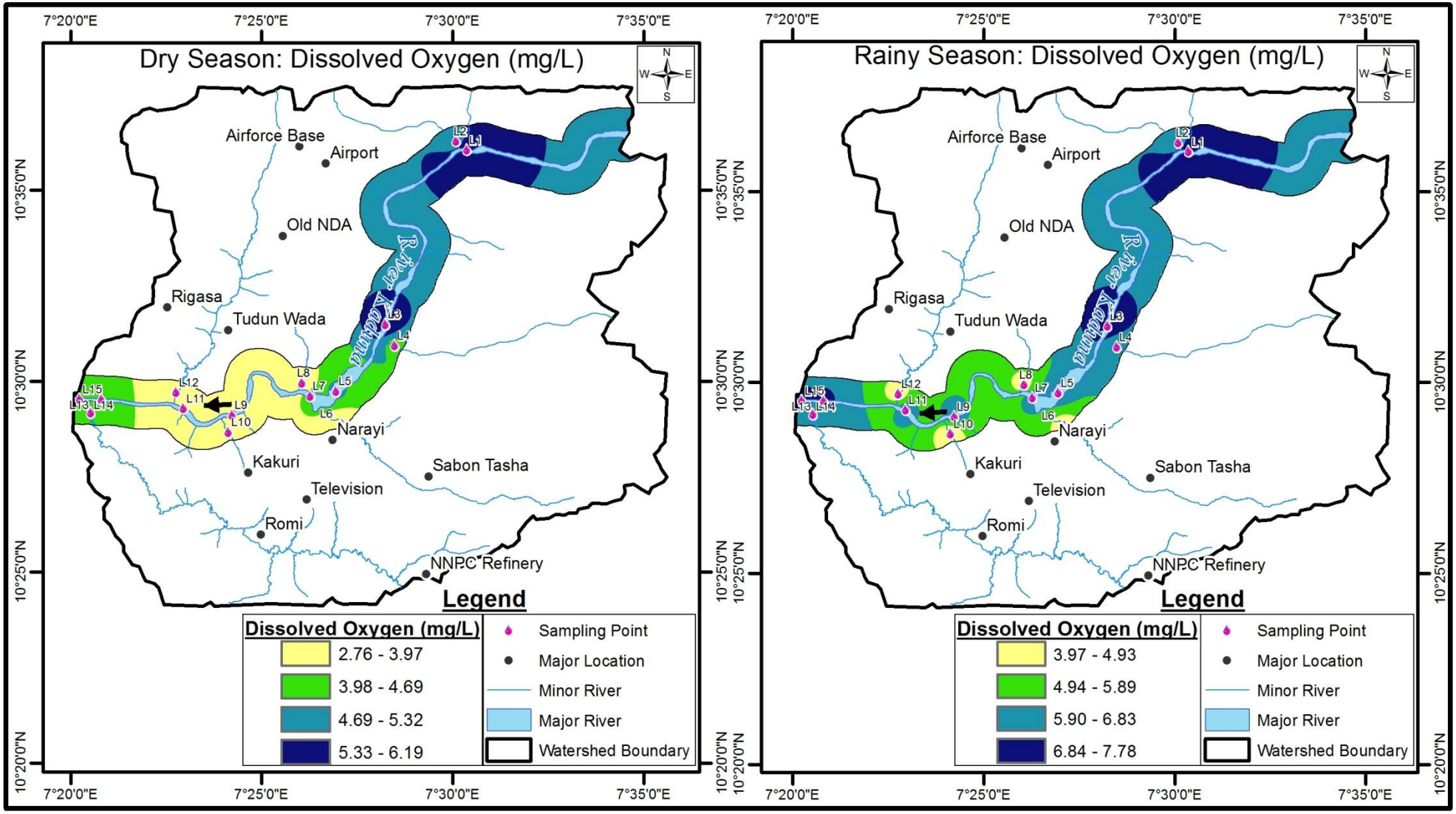


Figure 4.21: Map showing dissolved oxygen along River Kaduna

4.2.85-Day biochemical oxygen demand

The concentration of the 5-Day Biochemical Oxygen Demand (BOD_5) during the research period ranged from 0.16±0.01 mg/l to 2.93±0.01 mg/l. These concentrations were respectively recorded in the months of May and April at sampling locations L15 (Railway Bridge) and L9 (Down Quarters). The BOD_5content in sampling locations L1 (Malali), L2 (Kwarau), L3 (NNPC), L4 (Kuyi), L5 (Barnawa), L13 (Maigiginya), L14 (Romi) and L15 (Railway Bridge) were within the permissible limit set by FEPA ($\leq$ 2.0 mg/l) throughout the sampling period. However, this was not the case in the other sampling locations.Though, the BOD_5content recorded during the dry season in some of the sapling sites were above the maximum permissible limit (2.0 mg/l) however, the overall dry season BOD_5content were not significantly (at $p < 0.01$) above the maximum permissible limit. On the other hand, the overall BOD_5 concentration noted during the rainy season were significantly below the maximum permissible limit at 99% confidence level (i.e. at $p < 0.01$).

Unlike Dissolved Oxygen (DO), the concentrations of BOD_5 in all the sampling locations were lower during the rainy season compared to dry season as could be seen in Figure 4.22. This is because during the rainy season, the river contains higher DO content as earlier explained in section 4.8. This synergy noted between the BOD_5 and DO was also observed in similar researches carried out by Cansu *et al.*(2016), Moshood (2016), Anazoo and Ibe (2015), Adebayo (2014) and Adie (2008). In other words, as the DO content of a given water sample increases, its BOD_5 reduces and vice-versa.

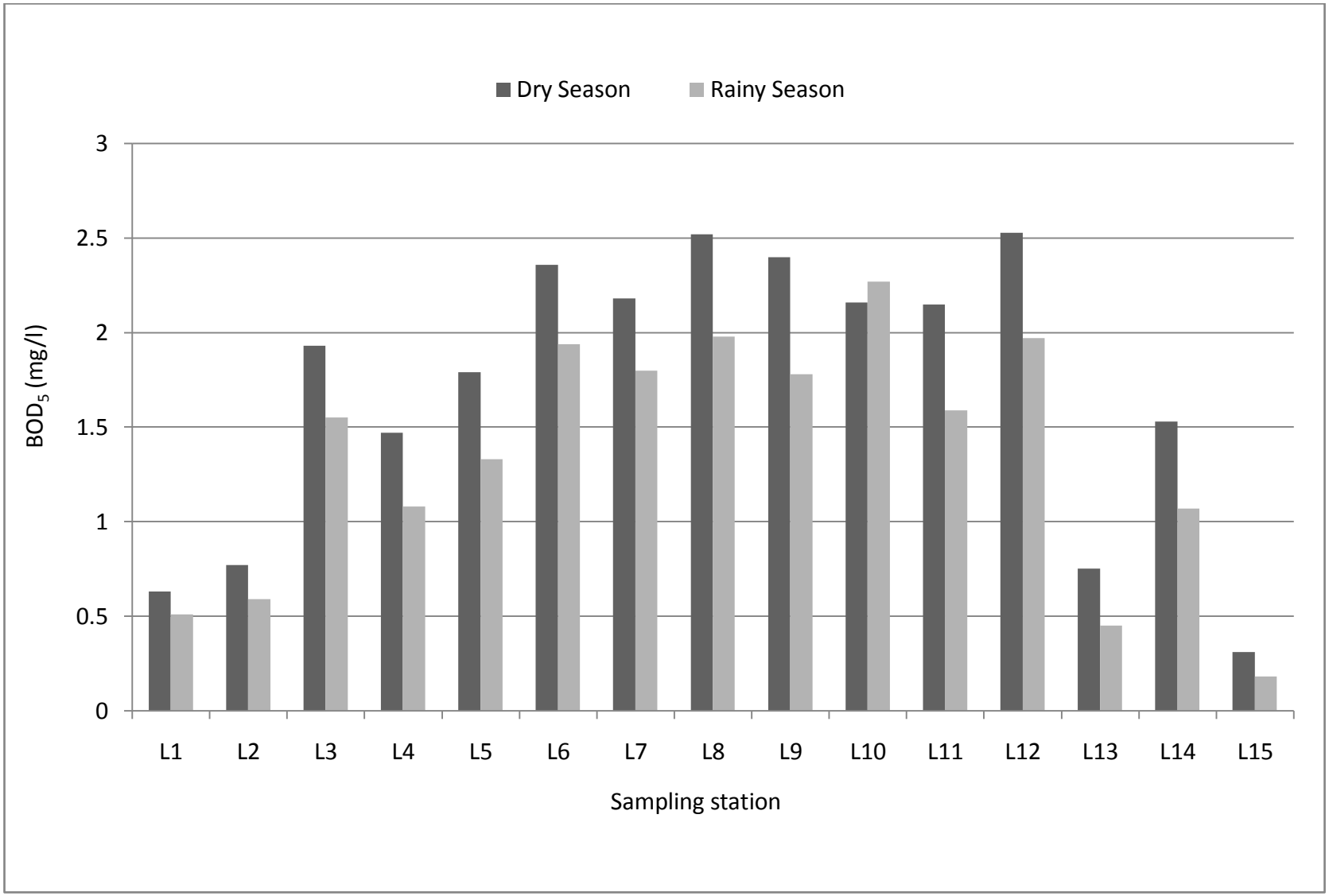


Figure 4.22: Seasonal variation of 5-day Biochemical Oxygen Demand (BOD_5) across sampling locations

The effect of the various land use activities on the 5-day Biochemical Oxygen Demand of the water are shown in Table 4.8. Built-up, Agricultural and Industrial land uses were positively correlated with BOD_5 during both seasons while vegetation cover respectively had a negative and positive correlation with BOD_5 during dry and rainy season. However, the correlation between bare surfaces and BOD_5 is insignificant (approximately zero) in both seasons.

Table 4.8: Spearman's correlation coefficients between BOD_5 and land use land cover types

Land use land cover	Dry Season	Rainy Season
Built-up	0.5397**	0.5016**
Vegetation	−0.3102**	0.1170*
Water body		
Bare surface	−0.0211*	0.0137*
Agricultural land	0.2773**	0.2948**
Industrial land	0.2681**	0.2014**

Only significance levels (*<0.05 and **<0.01) are shown, BOD_5= 5-Day BiochemicalOxygen Demand

Effluents from households, institutions, hospitals and abattoirs are usually found in built-up (urban) areas. The discharge of these effluents from both point and non-point sources might have caused the observed strong positive correlation between BOD_5 andbuilt-up land use during both seasons.

The reduction in BOD_5 of the water with increase in vegetation cover (negative correlation) during dry season was due to the absence of surface runoff during the dry season. In addition, vegetation covers which are usually forested lands lack municipal effluents that could be discharged via drainages or pipes to receiving water body. On the other hand, the positive correlation (though weak) noted during the rainy season could be accredited to transportation of fallen and decayed leaves as well as animal excretes by surface runoff.

The increase in BOD_5 of the water with increase in the proportion of agricultural land use within the watershed (positive correlation) could be linked to the practice of using organic manures to enrich the soil by farmers. Runoff caused by precipitation during the rainy season as well as return flow of excess irrigation water during the dry season carried these organic matters to the draining river thus, reducing the DO content of the river and increasing its BOD_5.

The direct variation (positive correlation) between BOD_5 and industrial land use could be associated to the kind of effluents discharged by the industries. Majority of the industries within the watershed are textile industries (located at Kakuri). Organic pollutants, which originate from organic compounds of dye stuffs, acids, sizing materials, enzymes, tallow etc. are usuallyfound in textile effluents, reflecting a high BOD of the effluents (Sengupta, 2007).

The fluctuationpatterns of BOD_5 along River Kaduna during the rainy and dry seasons were similar (Figure 4.23). Nevertheless, the highest BOD_5 during the dry season was recorded at 24.90 km downstream of the sampling starting point while the rainy season highest value was recorded at 19.13 km downstream. Beyond these points, the BOD_5 during both seasons improved (reduced) as the water flow downstream till the last sampling location which is 32.70 km away from the starting point. As earlier noted, the BOD_5 of the catchment area deviated from the permissible limit during the dry season even though the concentrations were not significantly higher than the maximum permissible limit. Notwithstanding, there is need for the relevant environmental regulatory bodies such as KEPA to check the possible polluters of the river especially in areas and towns identified to be highly polluted through Figure 4.24.

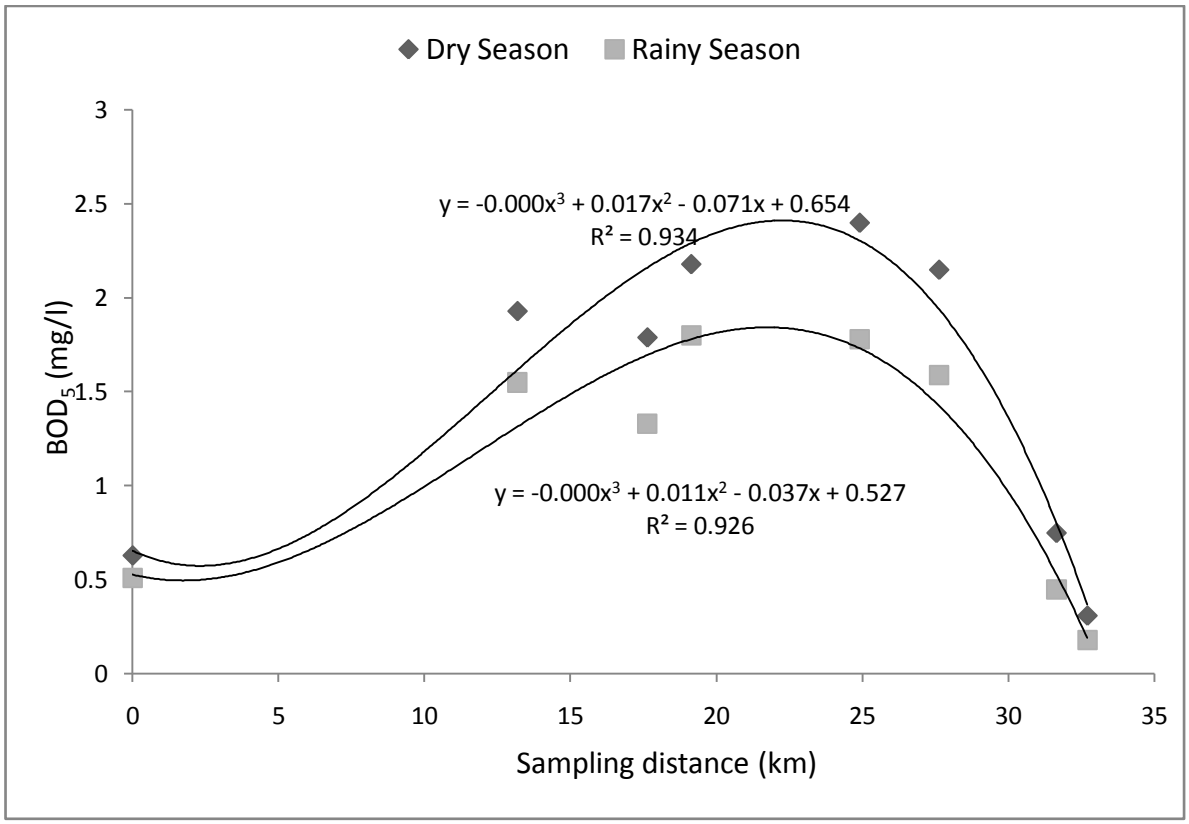


Figure 4.23: Relationship between BOD_5 and downstream location in River Kaduna

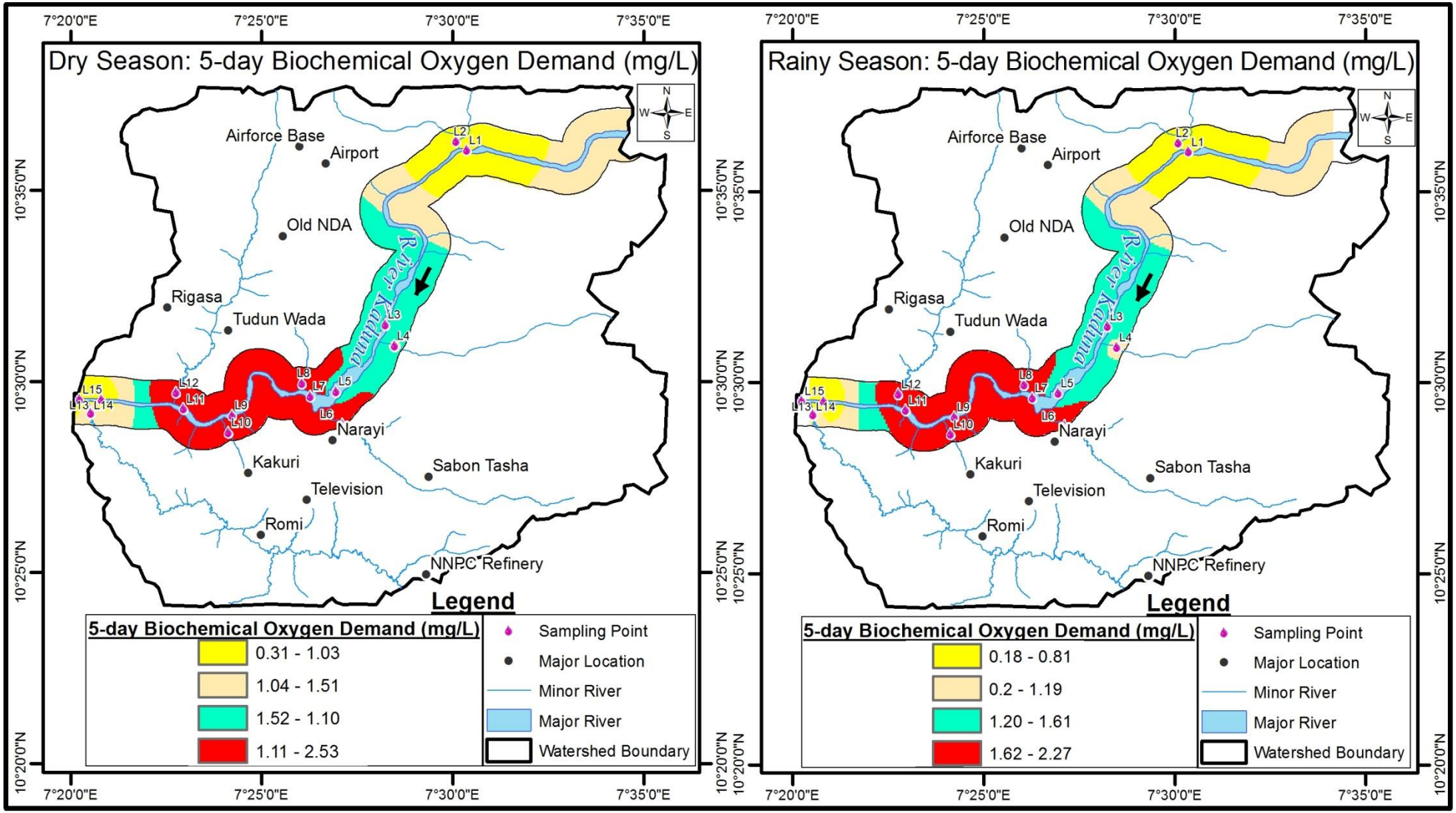


Figure 4.24: Map showing 5-day Biochemical Oxygen Demand along River Kaduna

4.2.9Chemical oxygen demand

The values of the Chemical Oxygen Demand (COD) recorded in all the sampling sites werehigher than the minimum permissible limit (20 mg/l) as the least value noted was 33.37±0.1 mg/l. This value was observed during the month of July at sampling location L15 (Railway Bridge).In contrast, the highest COD value (77.59±0.1 mg/l) was recorded during the month of April at sampling location L8 (Kigo).

Chemical Oxygen Demandis a measure of the total quantity of oxygen required to oxidize all biologically active and inactive organic materials into carbon dioxide and water (Russell, 2015). The quantity of oxygen needed to oxidize the biologically active organic matters corresponds to the BOD. Hence, the excessively higher concentrations of COD compared to BOD in all the sampling location indicates that the river contains more of biologically inactive organic matters than biodegradable organic matters. This suggests that certain organic substances in the water may be toxic to the microorganisms involved in the BOD test. Also, the presence of inorganic substances in which the chemical oxidant (dichromate) reacted with, could have caused the excessively higher COD values compared to BOD (George *et al.,* 2004).

The seasonal variation of COD shown in Figure 4.25 disclosed that higher COD values were recorded during the dry season and also, the trend in the variation pattern is similar to that of BOD_5(Figure 4.22). This could be traceable to the factors responsible for BOD_5 earlier mentioned.

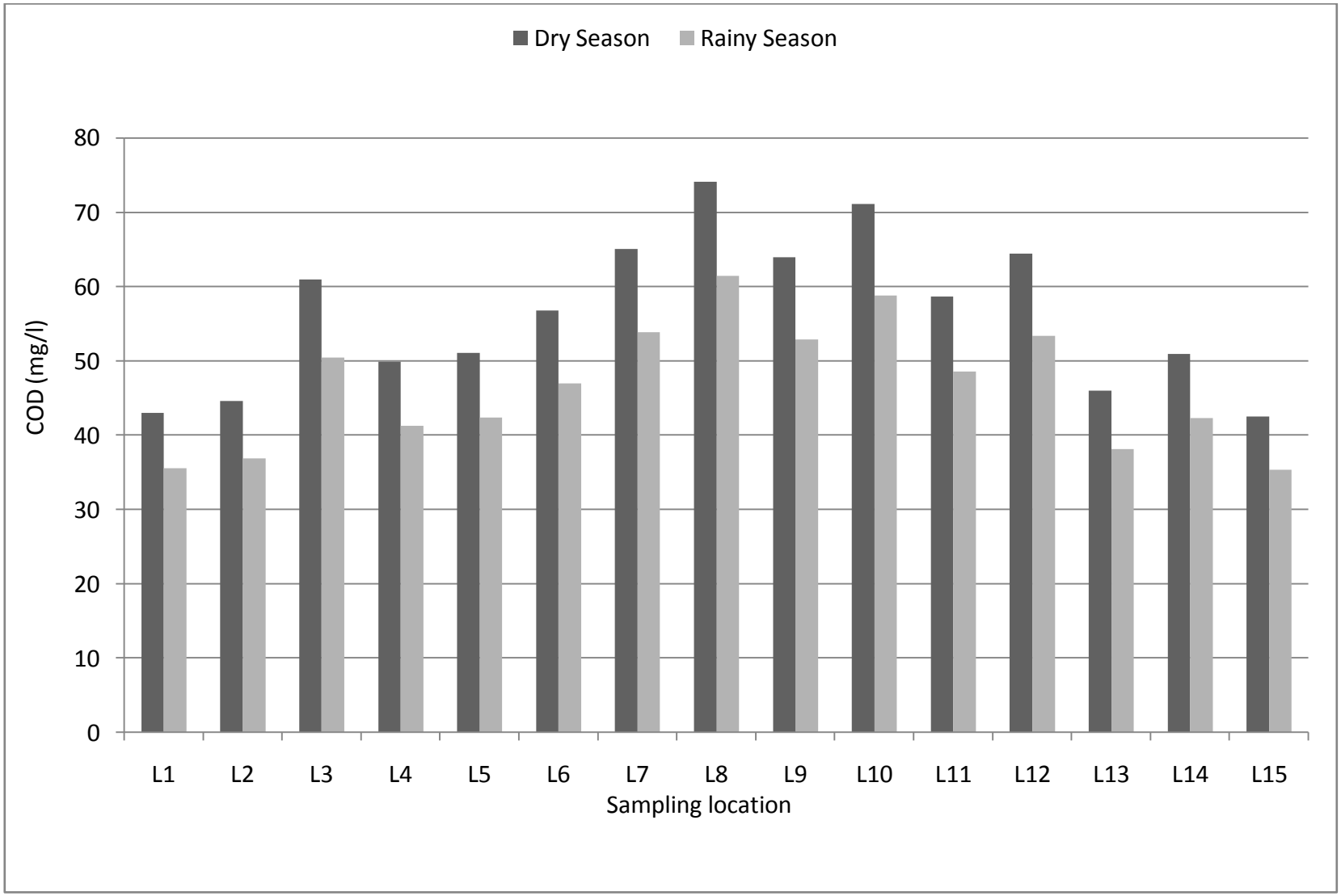


Figure 4.25: Seasonal variation of Chemical Oxygen Demand (COD) across sampling locations

The record of higher COD during the dry season compared to the rainy season agreed with the reports of Moshood (2016), Anazoo and Ibe (2015), Adebayo (2014), Adie (2008) and Yusuf *et al.* (2008). On the contrary, Shrestha and Kazama (2015) as well as Chaosheng (2013) recorded lower COD during dry season.Nevertheless, the BOD/COD ratio of all the sampling sites during both seasons were below 0.3 which signifies that River Kaduna contains some toxic components which may not be easily treated by biological means (George *et al.,* 2004). The COD level is significantly higher ($p < 0.01$) than the maximum allowable limit irrespective of the season and sampling location.The high COD during the dry season could be attributed to low dilution of organic load due to the absence of precipitation while increased movement of organic materials into the river course with increasing runoff accounts for the high COD level during the rainy season. The correlations between COD and the various land use land cover are shown in Table 4.9.

Table 4.9: Spearman's correlation coefficients between COD and land use land cover types

Land use land cover	Dry Season	Rainy Season
Built-up	0.3722**	0.3091**
Vegetation	−0.2805**	0.2037**
Water body		
Bare surface		0.0169*
Agricultural land	0.3523**	0.4112**
Industrial land	0.2732**	0.2885**

Only significance levels (*<0.05 and **<0.01) are shown, COD= Chemical Oxygen Demand

Most residents living close to the river within the built-up areas usually do their laundry activities at the riverbanks. Certain detergent compounds like alkyl benzene sulfonate (ABS) did not biodegrade as a result of it benzene ring (Ruth and Mathew, 2003). The use of detergents containing such compounds together with domestic and municipal effluentsmight have contributed to the positive correlation observed between COD and built-up (urban) areas during both seasons.

The negative correlation between COD and vegetation during the dry season could be allied to the same factors responsible for BOD as earlier explained. Conversely, the positive correlation noted during the rainy season in vegetation covers might be caused by runoff carrying both non-biodegradable and biodegradable substances. The non-biodegradables in vegetation cover include constituents of woody plants such as tannic and lignin acids, cellulose, and phenol while the biodegradablescould be fallen and decayed leaves as well as animal excrete (George *et al.,* 2004; Peavy, 1998).

Pesticides including insecticides and herbicides, have found wide-spread use in agriculture (Hernandez *et al.,* 2013). Organic insecticides are usually chlorinated hydrocarbons (i.e aldrin, dieldrin, endrin and lindane) while herbicides are usually chlorophenoxys (e.g. 2,4-dichlorophenoxyactic acid and 2,4,5-trichlorophenoxypropionic acid) which are not biodegradable (Aggarwal, 2013; Philip, 2010). Hence, poor application practices of these chemicals (pesticides) and subsequent wash-off by runoff and return irrigation water together with biodegradables (organic manures) might be the reason for the positive correlation between COD and agricultural watershed during both seasons.

Sengupta (2007) reported that textile effluents are often contaminated with non-biodegradable organics termed as refractory materials of which, the presence results in high COD value of the effluents. In other words, the positive correlation between COD and industrial land use suggests that the industrial effluents contain refractory materials such as detergents.

Figure 4.26 suggests that during both seasons, the COD of the studied river fluctuated so much with its peak values at a distance of 19.13 km downstream of the starting point.

However, beyond this point, the COD for both seasons improved (reduced) as the water flow downstream till the last sampling location which is 32.7 km away from the starting point. As previously stated, the COD level of the studied area (River Kaduna) was found significantly higher than the maximum tolerable limit irrespective of the season and sampling location. Therefore, control measures should be taking by relevant authorities with more emphases at Kakuri and Tudun Wada areas or towns which showed higher level of COD relative to the other areas and towns as could be seen in Figure 4.27.

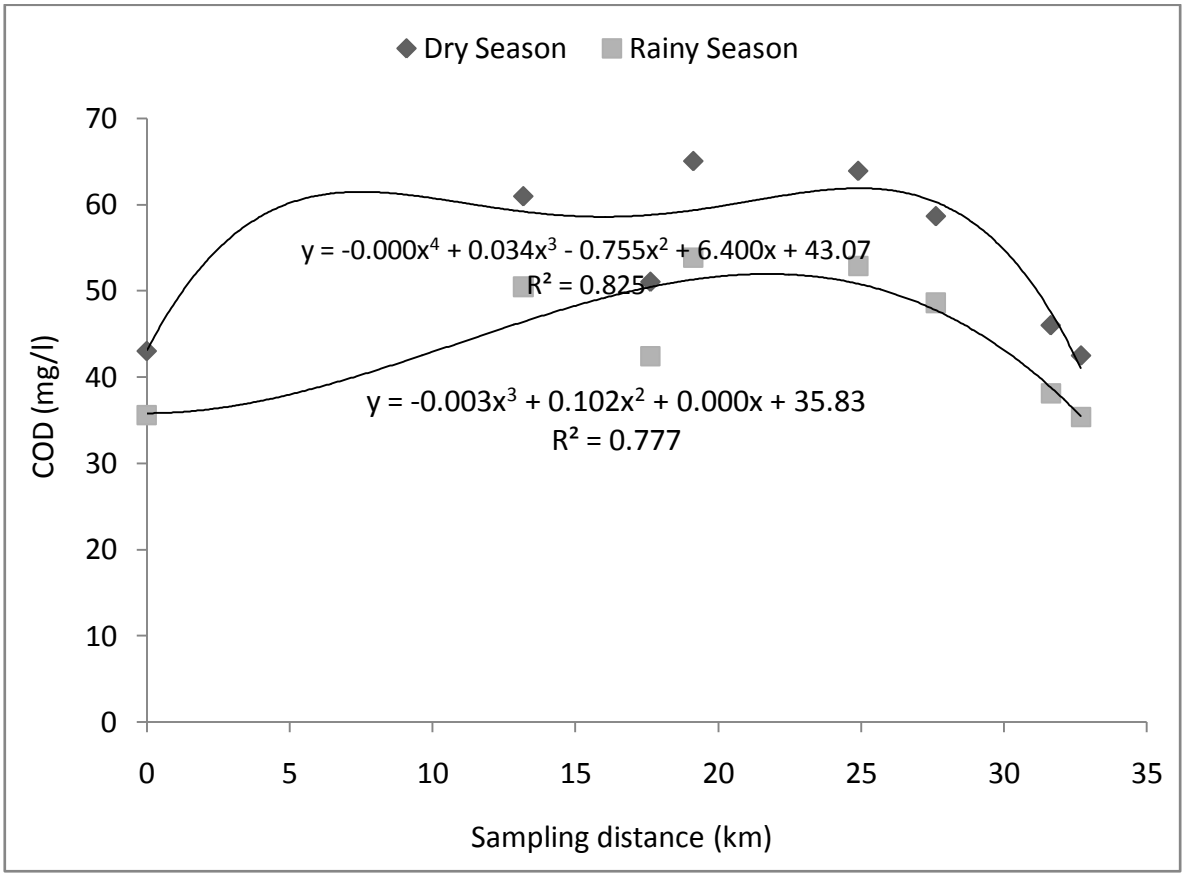


Figure 4.26: Relationship between COD and downstream location in River Kaduna

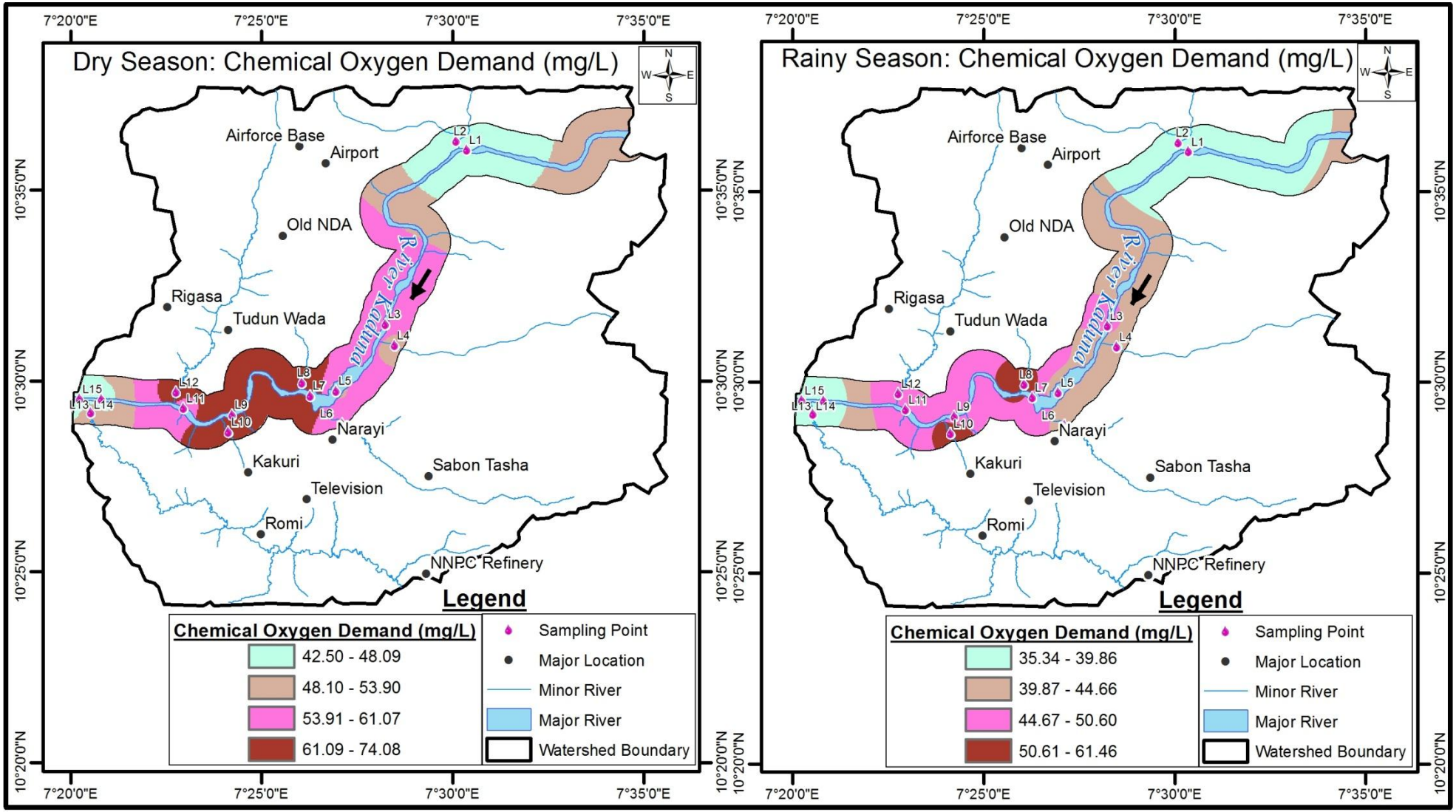


Figure 4.27: Map showing Chemical Oxygen Demand along River Kaduna

4.2.10Total nitrogen

The minimum (0.59±0.01 mg/l) and maximum (2.18±0.01 mg/l) concentrations of total nitrogen (TN) were recorded during the months of August and April at sampling locations L6 (Kutimbi) and L1 (Malali) respectively. All the sampling sites recorded TN concentrations lower and higher than the permissible limit (1.0 mg/l) however, the peak values of TN in all the sampling sites occurred during the month of April.

Figure 4.28 showed that TN concentrations were lower during the rainy season in all the sampling locations. This could be caused by the effect of precipitation on pollutant dilution experienced during the rainy season. In addition, during rainy season, not all the precipitation (rainfall) on a watershed flows as surface runoff into streams and rivers. Part of the rainfall known as sub-surface runoff or interflow leached into the soil and moves laterally without joining the water table, to the streams or rivers. However, another proportion of the rainfall known as base flow infiltrate deep into the soil and meet the water table before flowing into streams and rivers. The movement of water in this type of runoff (base flow) is very slow before joining the streams or rivers hence, base flow is also known as delayed runoff (Subramanya, 2016; Suresh, 2013;Arora, 2011). Nitrate (NO_3^-) in percolated water is usually caused by the oxidation of nitrogen compounds by soil bacteria and it moves freely with groundwater flow (Sall and Vanclooster, 2016; Lindgren *et al.*, 2014). Hence, the higher values of TN during the dry season could also be caused by deep infiltrated waters(base flow) that were contaminated with nitrogen compounds which leached into the studied river during the dry season. This observation of higherconcentration of TN during dry seasoncompared to rainy season had earlier been noted by Moshood*et al.* (2016),Biao *et al.* (2014),Mohammed (2013) and Adie (2008).

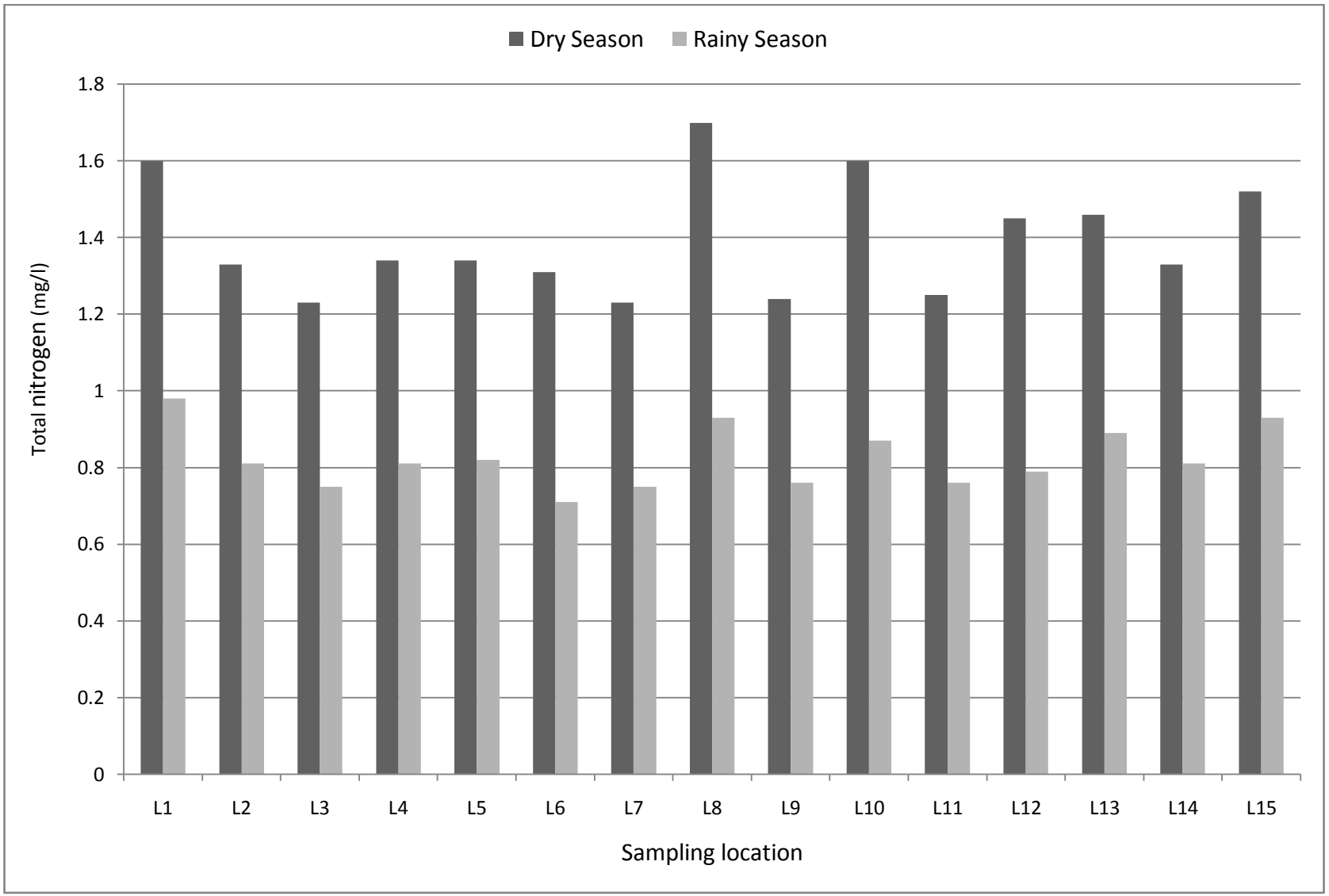


Figure 4.28: Seasonal variation of total nitrogen across sampling locations

Statistically, the total nitrogen concentrations of the basin were significantlybelow ($p < 0.01$) the maximum permissible limit (1.0 mg/l) during the rainy season irrespective of the sampling location. On the contrary, total nitrogen concentrations observed during the dry season were significantly higher than the maximum permissible limit regardless of the sampling point. This further confirms that the nitrogen content of the river was seriously influenced by metrologicalseason.

The effects of the various land uses on the total nitrogen content of the studied river are reflected in Table 4.10. Apart from bare surface land use which showed a negative correlation during the dry season, other land uses and land cover had a direct relationship (positive correlation) with total nitrogen during both seasons. However, the positive correlation between total nitrogen and vegetation during dry season was very weak, approximately zero (0.0146).

Table 4.10: Spearman's correlation coefficients between TN and land use land cover types

Land use land cover	Dry Season	Rainy Season
Built-up	0.5944**	0.6513**
Vegetation	0.0146*	0.2811**
Water body	0.1041*	
Bare surface	−0.1635*	
Agricultural land	0.7287**	0.6901**
Industrial land	0.2619**	0.2023**

Only significance levels (*<0.05 and **<0.01) are shown, TN = Total Nitrogen

Built-up areas are usually more populated with humans than the other land use and land cover considered in this work. Nitrogen compounds such as ammonia (NH_3), nitrite (NO_2^-) and nitrate (NO_3^-) were identified to be constituents of human and animal excretes by Nyenje *et al.* (2016) and Biao *et al.* (2014).The discharge of untreated sewage (point and non-point sources) such as excretes from humans, animals, poultry as well as leachates

from poorly functioning septic systems into River Kaduna might have contributed to the positive correlation between TN and Built-up watershed. Also, nitrogen is a constituent of protein as reported by Yang *et al.* (2014) hence, the discharge of untreated abattoir effluents which is common in the built-up areas could also increase the TN content of the receiving stream or river. In addition, activities such as swimming, bathing and fish cleaning which is mostly common in built-up areas can contribute nitrogen to streams through body contact (Yang *et al.*, 2014).

The herdsmen mostly grazed their animals in the vegetation cover (grassland, shrubs and forests) hence, animal excretes were much in grazing areas. Runoff from these grazing areas transportedammonia, nitrite and nitrate from the livestock dung to nearby waterways. This explains the reason for increase in TN with vegetation cover (positive correlation) during rainy season. Furthermore, death plants or animals (usually found in vegetation cover) are broken down to simpler forms by bacterial decomposition (Oskarson *et al.*, 2016). Proteins for instance are converted to amino acids and further reduced to ammonia (NH_3). Oskarson *et al.* (2016) further explain that if oxygen is present, the ammonia is oxidized to nitrite (NO_2^-) and then to nitrate (NO_3^-). Hence, the transportation of these forms of nitrogen (NH_3, NO_2^-, NO_3^-) by runoff into the nearby waterways could also be a reason for the positive correlation observed between TN and vegetation watershed. In addition, interflow of nitrogen contaminated water into the nearby water ways as a result of the processes explained above could cause the positive correlation noticed.

The rise in the concentration of nitrogen in line with water surface might be triggered by algal bloom. This is because blue-green algae (the primary component of algal blooms), have the tendency of introducing nitrogen to surface water by biologically converting

gaseous or atmospheric nitrogen to usable forms (Nyenje *et al.,* 2016). Beside, nitrogen occurs naturally at low concentrations in surface waters as a result of decaying plants and other organic matters (EPA, 2001).

The negative correlation between nitrogen and bare surface during the dry season could be linked to the absence of surface runoff. Also, bare surface land is characterized as rocky land and land without plants (ETM+ in ArcGIS 10.5). This implies that there was no possibility of infiltrated water containing decayed organic materials such as dead plants and animals which would have interflowed into the nearby waterway (River Kaduna).

The increase in nitrogen content of the river alongside agricultural watershed (positive correlation) could be connected to the overuse of inorganic and organic fertilizer by famers to enrich the soil. Inorganic fertilizers such as NPK and organic manures like animal droppings are usually transported by runoff and return irrigation water to the nearby streams (Afua *et al.,* 2015; Binkley and Burnham, 2015). In addition, infiltrated water from the agricultural fields carried these materials down the soil as interflow and leached into nearby streams after meeting an impervious stratum (Afua*et al.,* 2015; Suresh, 2013). Furthermore, the nitrogen-fixing legumes within the watershed produced nitrate that leaked out of the root system into the soil and thereafter, infiltrated and interflowed into the nearby shallow water table been River Kaduna (Ezeonu *et al.,* 2014).

The direct variation between nitrogen and industrial land use (positive correlation) suggests that the industrial effluents discharged into River Kaduna contain nitrogen compounds. Figure 4.29 represent the fluctuations of total nitrogenalong the direction of flow in River Kaduna and it clearly revealed that nitrogen concentration were highest at the first and last

sampling points during both seasons. However, the areas and towns that drain into these sampling locations could be identified in Figure 4.30.

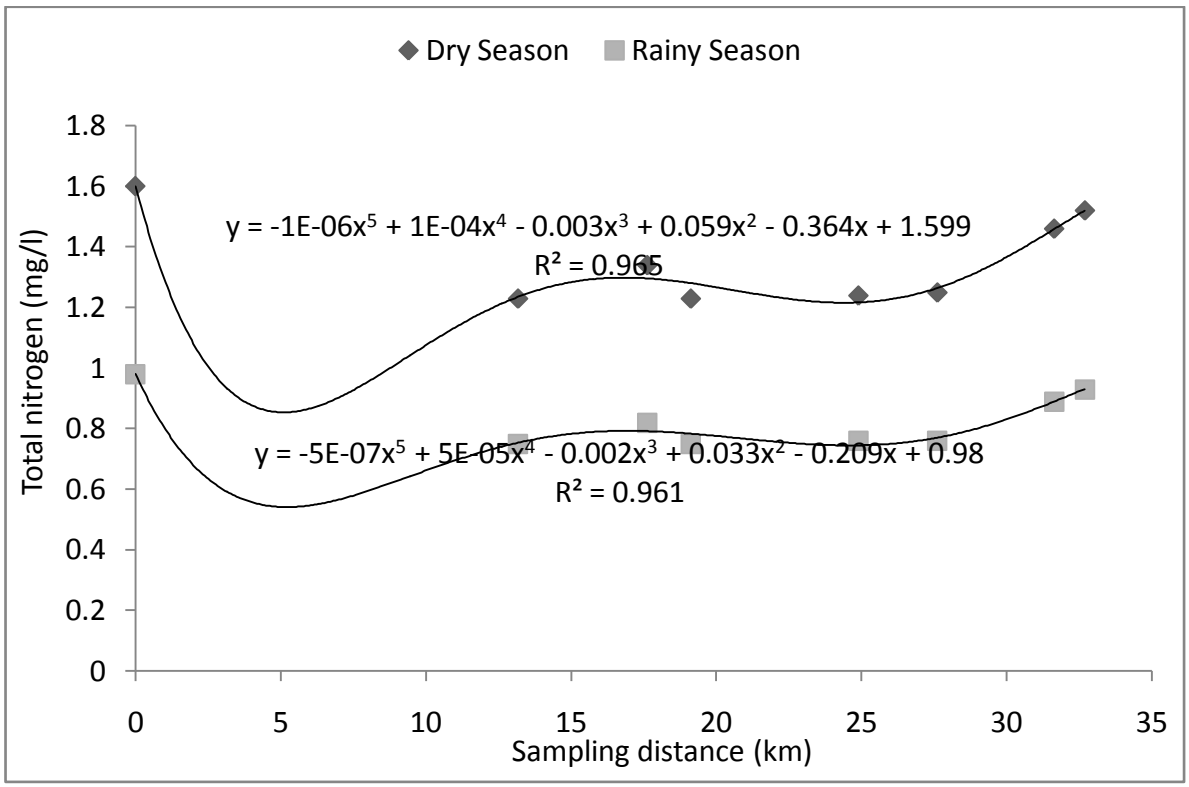


Figure 4.29: Relationship between total nitrogen and downstream location in River Kaduna

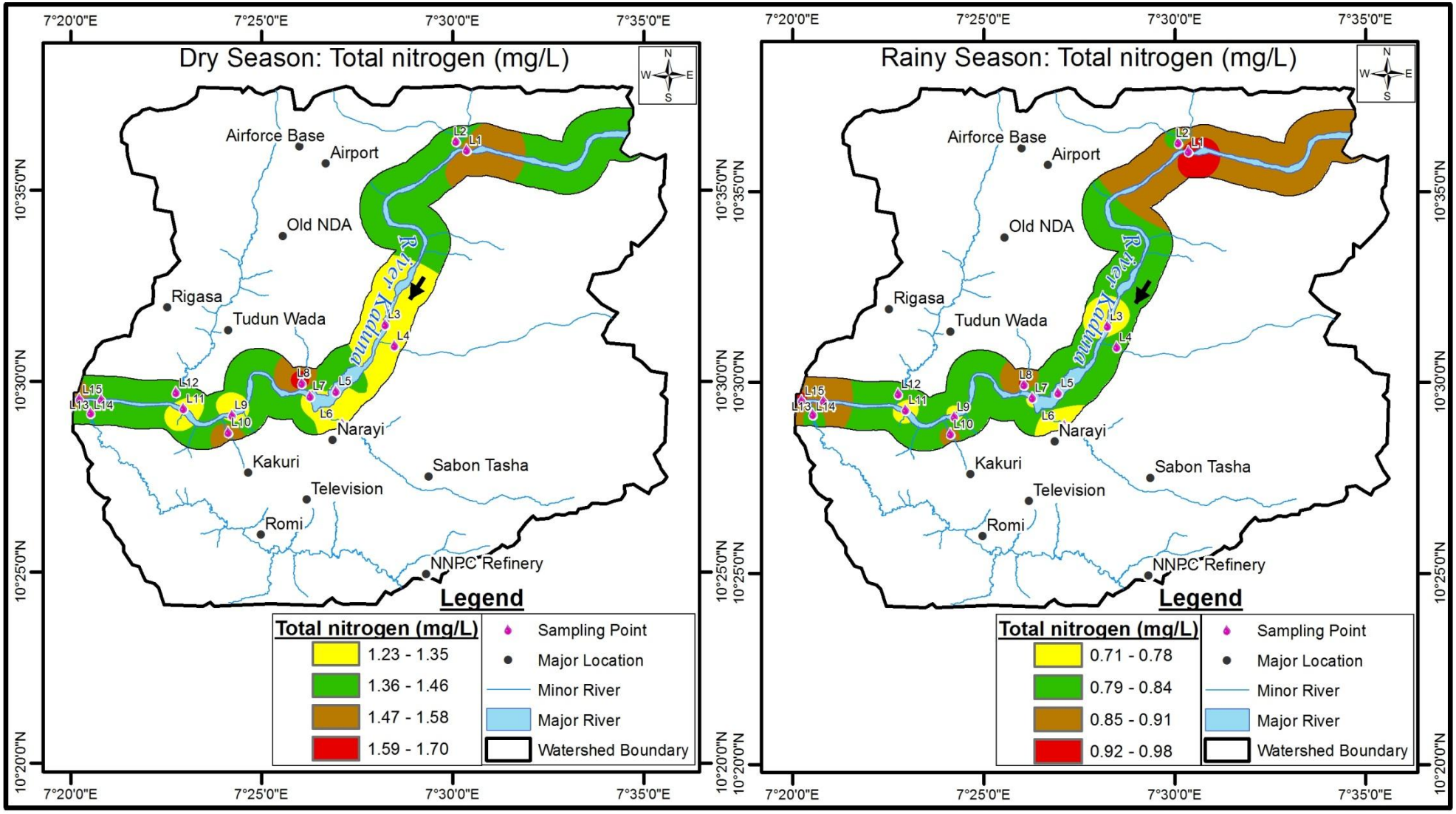


Figure 4.30: Map showing total nitrogen along River Kaduna

4.2.11Total phosphorous

The concentration of Total Phosphorus (TP) all through the research period ranged from 0.092±0.05mg/l to 0.318±0.05mg/l. The minimum concentration being 0.092±0.05mg/l was noted at sampling location L6 (Kutimbi) during the month of July. On the other hand, the maximum concentration (0.318±0.05mg/l) was recorded at sampling location L1 (Malali) during the month of April.

Just as in the case of total nitrogen, the concentrations of TP in all the sampling locations were lower during the rainy season as could be seen in Figure 4.31. This could be caused by the same factors responsible for total nitrogen earlier explained in section 4.10. Observation of lower concentrations of total phosphorous in surface water during rainy season compared to dry season were also documented by Nyenje *et al.* (2016), Biao *et al.* (2014) and Adebola *et al.* (2013).However, statistical result revealed that the phosphorous level of River Kaduna is significantly higher ($p < 0.01$) than the maximum allowable limit (0.1mg/l) set by FEPA irrespective of the season and sampling location.

The impacts of the various land uses on the total phosphorus content of the studied river are shown in Table 4.11. Apart from water body and bare surface, all other land uses and land covers had positive correlation with the concentration of TP. This signifies that the presence of TP in the river is contributed by these various land uses and land covers. However, the degree or level of impacts of these land uses in contributing to the presence of TP in the river is reflected in the size of the correlation coefficients.

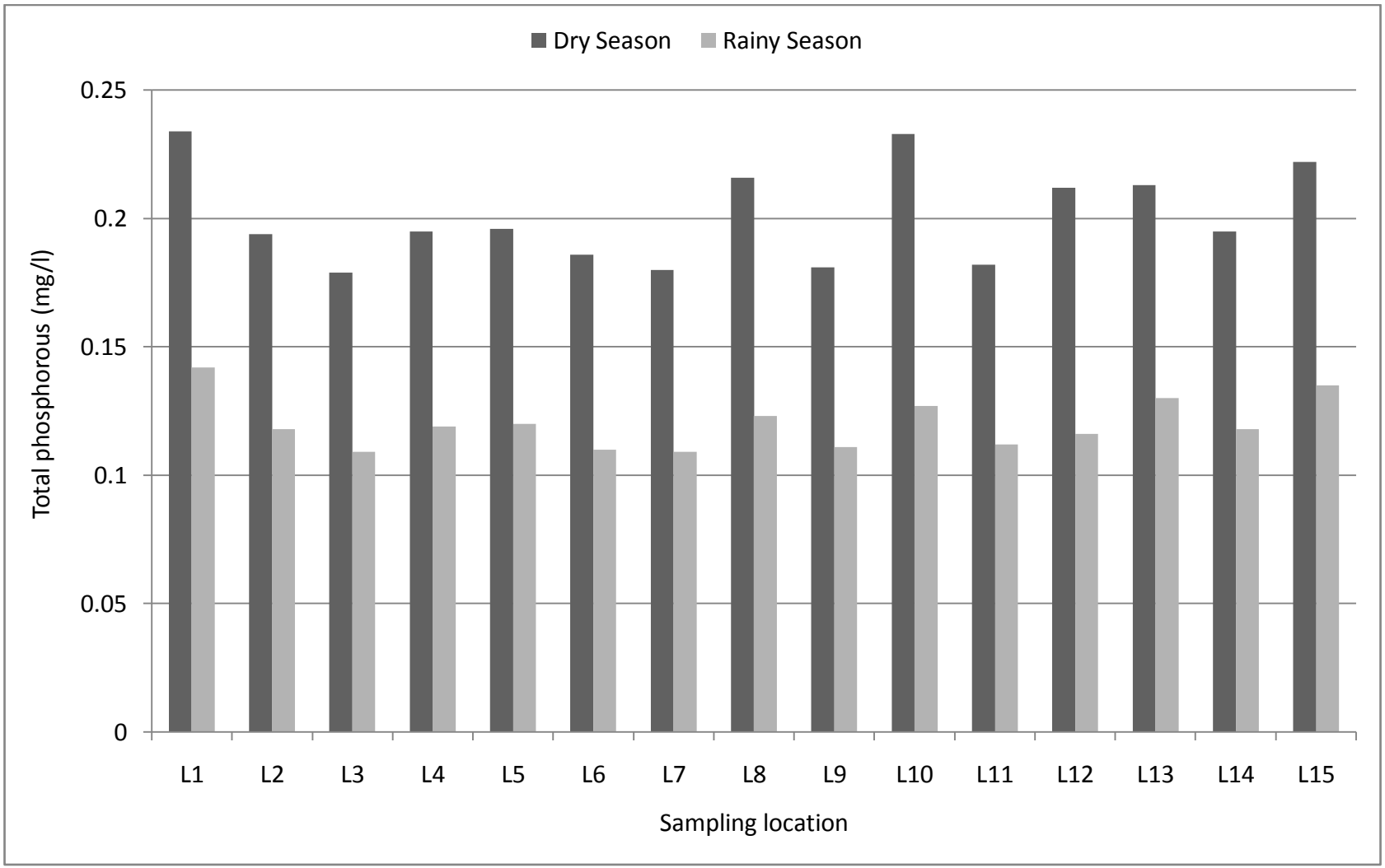


Figure 4.31: Seasonal variation of total phosphorous across sampling locations

Table 4.11: Spearman's correlation coefficients between TP and land use land cover types

Land use land cover	Dry Season	Rainy Season
Built-up	0.2672**	0.2885**
Vegetation	0.0113*	0.1414*
Water body		
Bare surface		
Agricultural land	0.4339**	0.4910**
Industrial land	0.1860*	0.1205*

Only significance levels (*<0.05 and **<0.01) are shown, TP = Total Phosphorous

The presence of phosphorous in built-up watershed could be attributed to the fact that municipal wastewaters are major sources of phosphorus in surface water. This is because condensed phosphates are used extensively as builders in detergents while organic phosphates are constituents of body waste and food residue (Peavy, 1998). Also, failed septic tanks in built-up areas could leach out phosphate into the nearby waterways (Marco *et al.*, 2015).

Phosphate being a constituent of animal waste (Harley and Lawson, 2016) might have been incorporated into the soil in grazing areas which are mostly vegetal cover and then conveyed by runoff and irrigation water as well as interflow into receiving waterways (River Kaduna). This could be the reason for the presence of phosphorus in vegetation watershed.

Phosphate is also a major component of both organic and inorganic fertilizers which are usually used by farmers in improving or supplementing the natural fertility of the soil (Afua *et al.*, 2015). In other words, the presence of phosphorous in the agricultural watersheds could be attributed to the extensive use of inorganic fertilizers (mostly NPK) and organic fertilizers (especially cow dung) by farmers in improving the soil fertility.

The presence of phosphorous in industrial watershed could be linked to the practice of industries using phosphate compounds in boiler-water conditioning (Peavy, 1998).Actually, the presence of phosphorus in water do not represent a direct threat to humans and other organisms nevertheless, they do represent a serious indirect threat to surface water quality. This is because phosphorus is the limiting nutrient in surface waters hence, when the concentration is increased, rapid growth of aquatic plants such as algae usually result with severe consequences (EPA, 2001). This information suggests that the anthropogenic activities within the watershed that could trigger the increase of phosphorus should be thoroughly checked in order to avoid eutrophication of the river. One of the ways forward for this problem is by banning the practice of farming along the river banks.

Just likenitrogen, Figure 4.32 also indicates that phosphorus concentrations of the river were higher at the beginning and ending parts of the stretch considered during both seasons. The areas or towns that drain into these parts of the river could be identified in Figure 4.33.

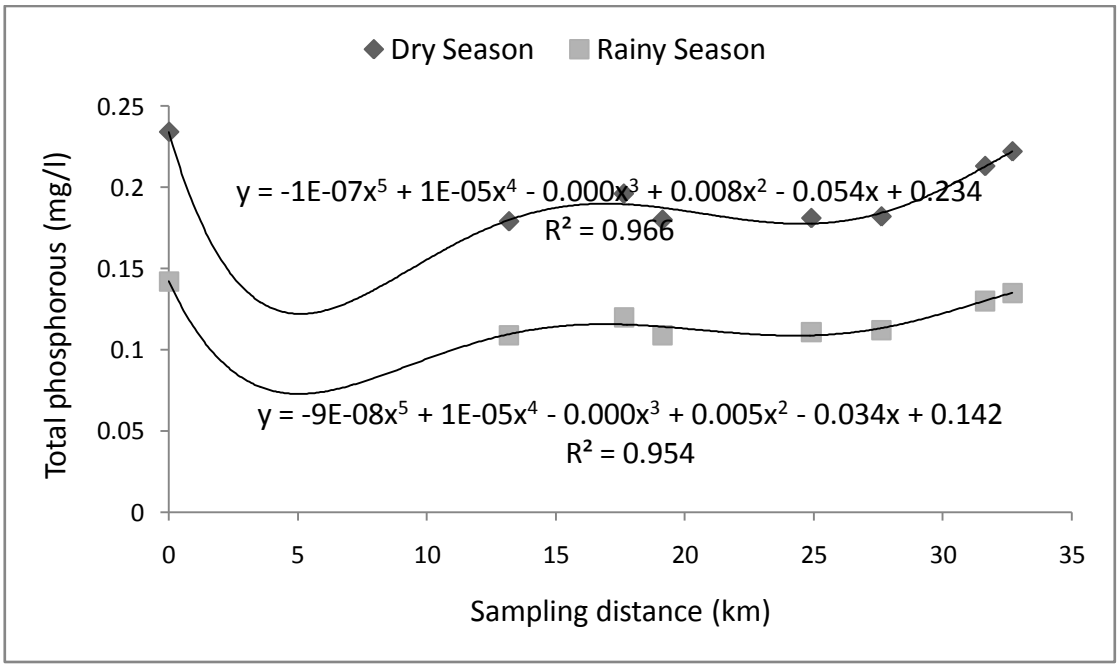


Figure 4.32: Relationship between total phosphorus and downstream location in River Kaduna

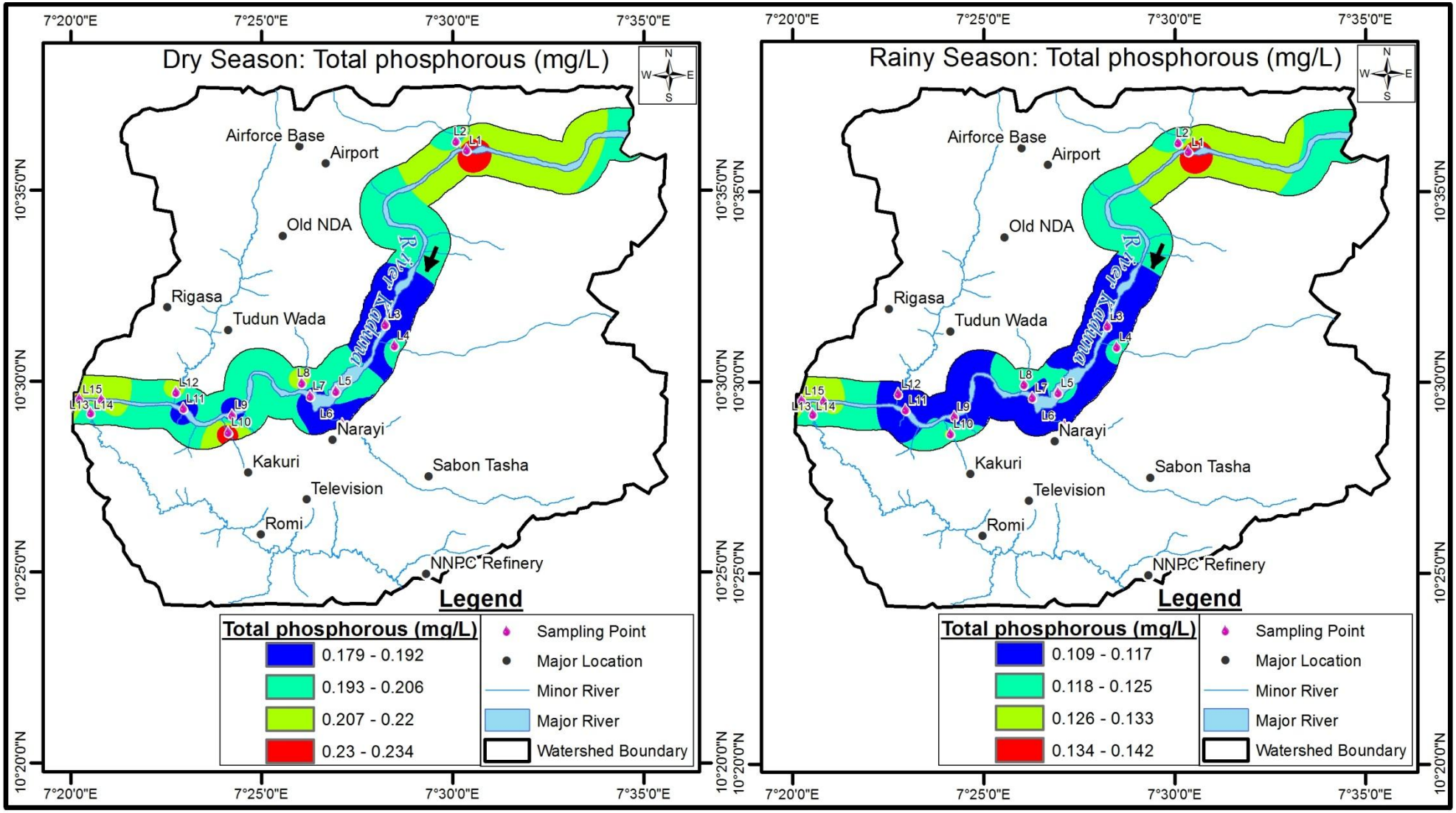


Figure 4.33: Map showing total phosphorus along River Kaduna

4.2.12Iron

The concentration of iron (Fe) during the sampling period ranged from 0.159±0.001 mg/l to 0.799±0.001 mg/l, corresponding to sampling locations L15 (Railway Bridge) and L8 (Kigo) in that order. These minimum and maximum values of Fe concentration were recorded during the months of July and March respectively.

There was an indication of lower concentration of Fe during the rainy season in all the sampling locations (Figure 4.34). This could be attributed to the dilution effect of precipitation experienced during the rainy season. Also, the high aeration caused by high stream flow rate and runoff as confirmed by higher DO during the rainy season reduced the Fe complexes in the river (Deborah, 2015). In addition, re-suspension from polluted sediments could also contribute to the surge in the dry season iron concentration (Kari-Matti, 2017). Statistically, there is a significant difference ($p < 0.01$) between the concentrations of Fe obtained during the rainy season and dry season, confirming that the sampling season has effect on the concentration of Fe in all the sampling locations. Also, the difference between the recorded values of Fe in all the sampling locations and the maximum permissible limit (0.3 mg/l) is only significant ($p < 0.01$) during the dry season.This buttress the reports of Sanja *et al.*(2014), Zaynab *et al.* (2016) as well as Jonathan and Mothiba(2016).

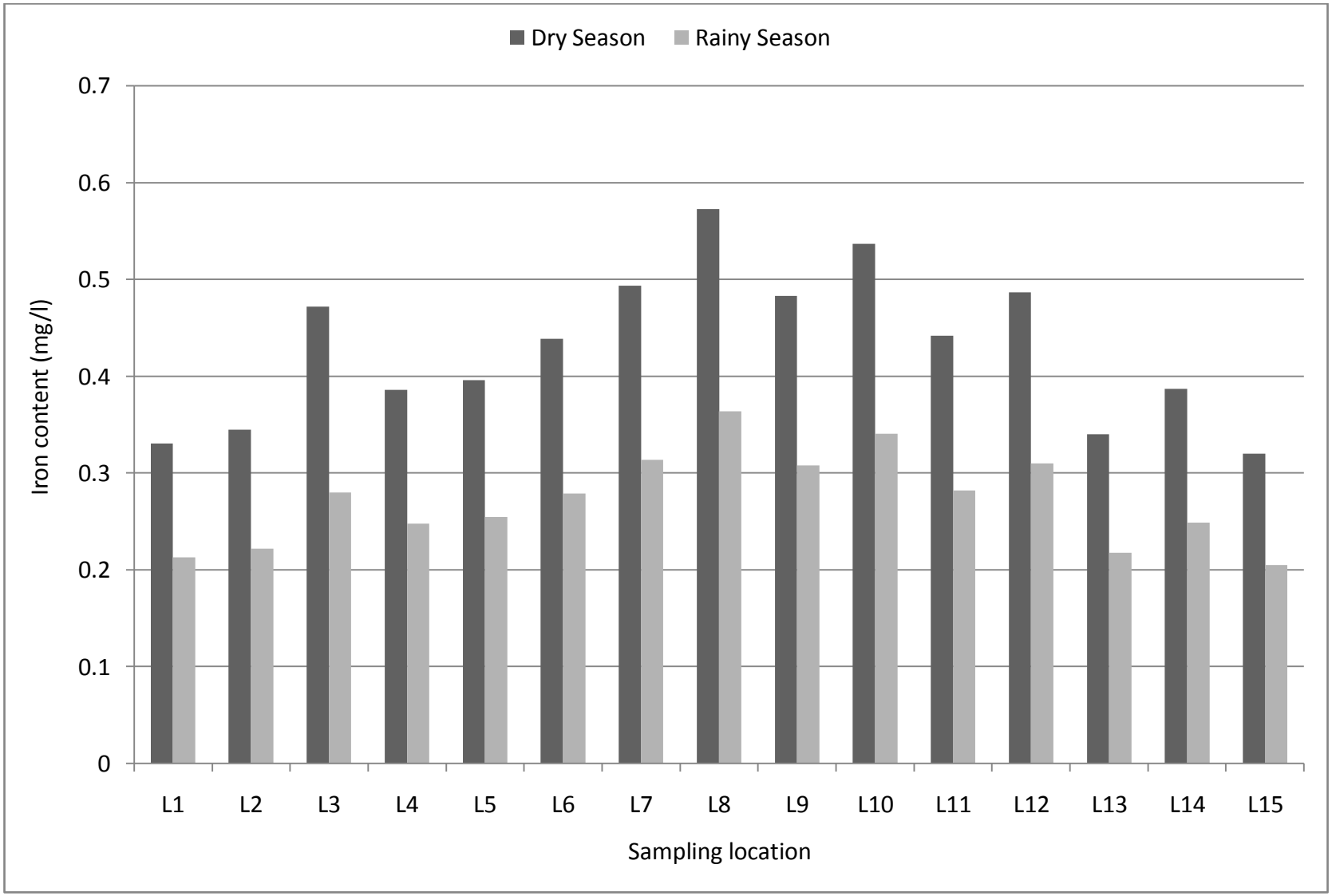


Figure 4.34: Seasonal variation of iron content across sampling locations

The land use land cover effects on Fe concentrations are reflected in Table 4.12. Apart from vegetation cover and bare surface which showed no correlation with Fe (at < 0.05 significance level), all other land use and land cover had a weak positive correlation with Fe. Iron is present in significant amounts in soils and rocks, principally in insoluble forms however, many complex reactions which occur naturally in ground formations can give rise to more soluble forms of iron which will therefore be present in water passing through such formations (Lisla and Michael, 2016). Hence, the presence of numerous rocks in River Kaduna could be a source of Fe in the water. Also, interflow of infiltrated groundwater, effluent discharges from industries and residential dwellings especially through corroded iron conduit could also be some of the sources of Fe in the river.

Table 4.12: Spearman's correlation coefficients between Fe and land use land cover types

Land use land cover	Dry Season	Rainy Season
Built-up	0.2118**	0.2052**
Vegetation		
Water body	0.1005*	0.0633*
Bare surface		
Agricultural land	0.0830*	0.0447*
Industrial land	0.1141*	0.0821*

Only significance levels (*<0.05 and **<0.01) are shown, Fe = Iron

Figure 4.35 showed that there was high level of fluctuations of iron (Fe) concentrations along River Kaduna during both seasons. Though, higher concentrations of Fe were recorded during the dry season nevertheless, the trends in the fluctuation or variation pattern for both seasons were the same. It could also be inferred from Figure 4.35 that the highest concentrations of Fe for both seasons occurred at a distance of 19.13km downstream of the first sampling location and afterward, the concentrations of Fe drops.

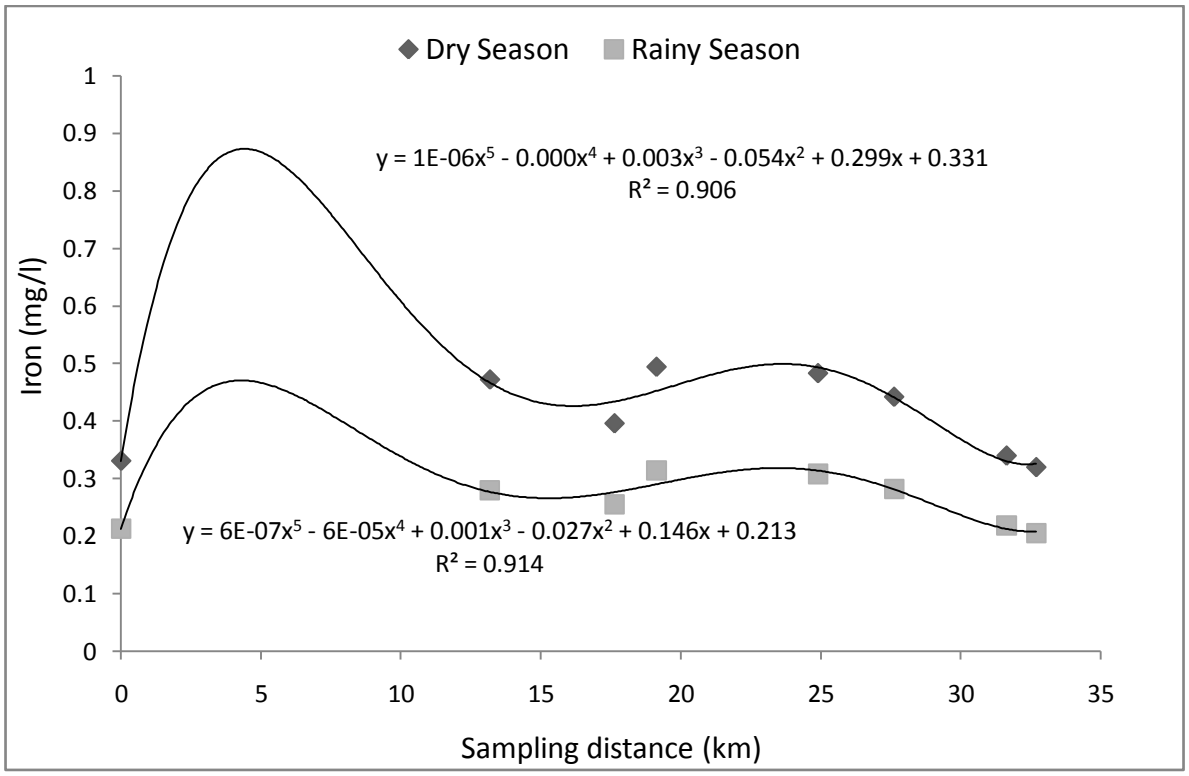


Figure 4.35: Relationship between iron content and downstream locations in River Kaduna

The areas and towns having Fe concentrations higher than the maximum permissible limit (0.3 mg/l) could be identified in the mapshown in Figure 4.36. The map clearly showed that the concentration of Fe in the river were higher at the Kakuri and Tudun Wada areas/towns during both seasons. These localities correspond to industrial and densely built-up areas within the watershed.

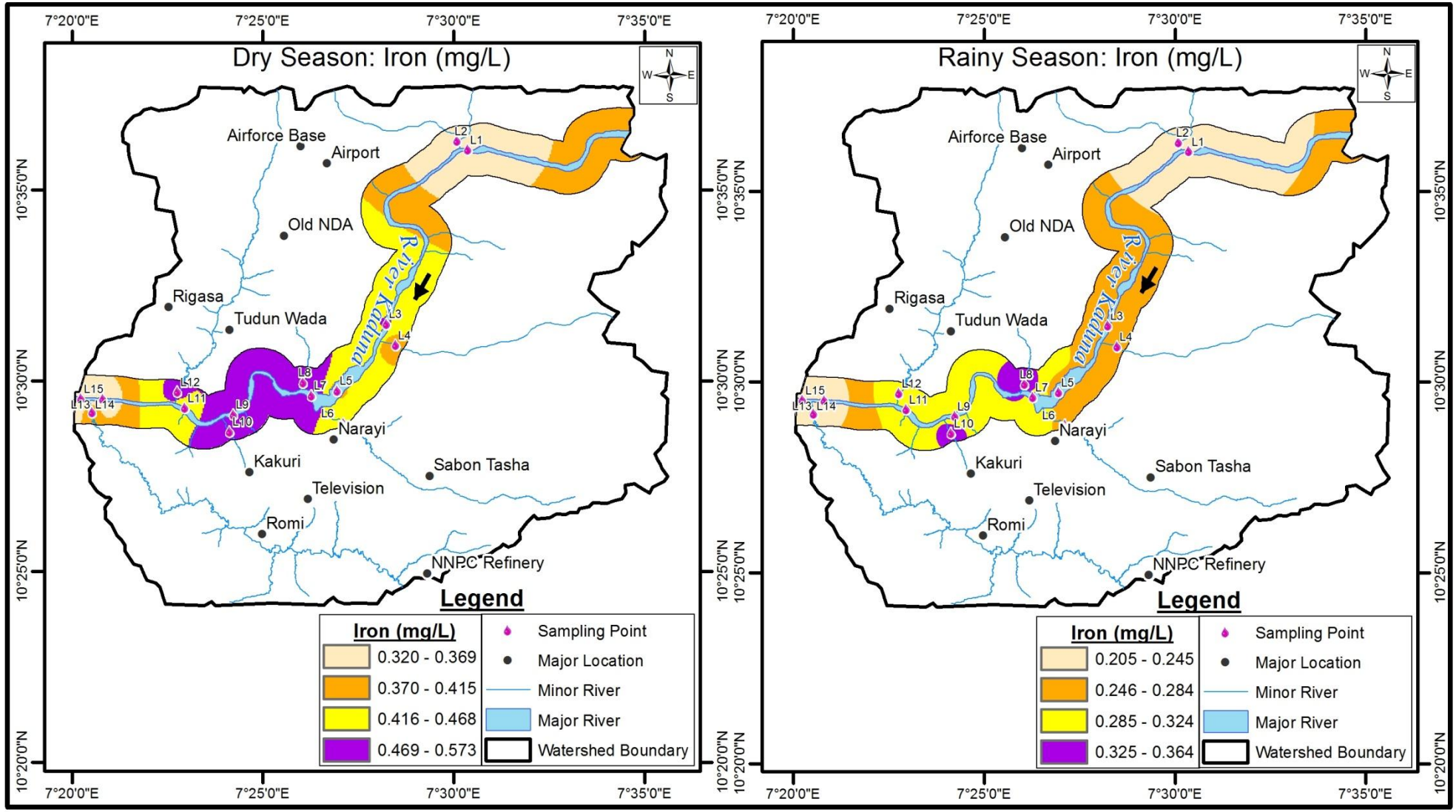


Figure 4.36: Map showing iron content along River Kaduna

4.2.13Manganese

Among all the sampling locations, only location L2 (Kwarau) recorded manganese (Mn) concentrations that fell within the permissible limit (0.2 mg/l) all through the sampling period. The maximum concentration of Mn (5.88±0.001 mg/l) was noted at sampling location L10 (Breweries) during the month of March while the presence of Mn were not detected at location L2 (Kwarau) during the months of June, July and August. These two locations respectively correspond to bult-up/industrial and agricultural areas.

In line with the other heavy metal (Fe), the concentrations of Mn in all the sampling locations were lower during the rainy season compared to the dry season as could be seen in Figure 4.37. This could also be attributed to the same factors responsible for Fe earlier explained (mostly dilution effect of precipitation during rainy season). The observation of Mn across the sampling sites was found to be significantly higher ($p < 0.01$) than the guide value (0.2 mg/l)only during the dry season. This suggests that the population or local communities that use the river during the dry season are at risk of bioaccumulation.Similar observation of higher concentrations of Mn above the guide value during dry season had been recorded in River Kaduna by Mohammed (2013) and Yusuf *et al.*(2008) while Ayobahan *et al.*(2014), Udiba *et al.* (2014) and Oke *et al.* (2013) recorded a similar trend in other Nigerian rivers.The diffused nature of Mn in the river is further confirmed to be related to the land use-land cover as could be seen in Table 4.13. The natural presence of manganese in rocks (EPA, 2001) could be a source of manganese in the river since River Kaduna contains numerous rocks.

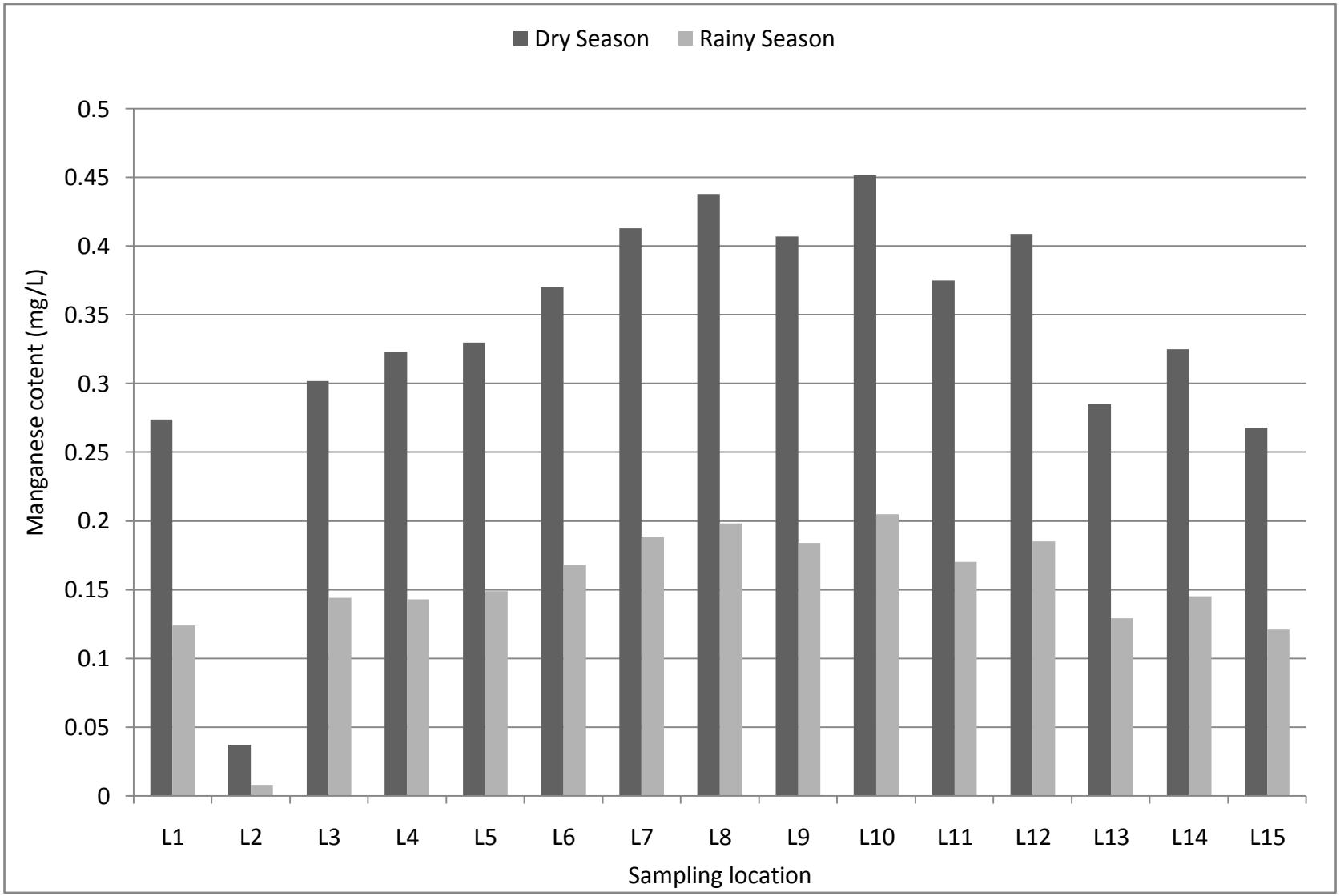


Figure 4.37: Seasonal variation of manganese content across sampling locations

Table 4.13: Spearman's correlation coefficients between Mn and land use land cover types

Land use land cover	Dry Season	Rainy Season
Built-up	0.1794*	0.1241*
Vegetation		
Water body		
Bare surface		
Agricultural land	0.0758*	
Industrial land	0.1095*	0.0668*

Only significance levels (*<0.05 and **<0.01) are shown, Fe = Iron

Municipal wastewater discharges, sewage sludge, leachate from landfills as well as combustion of fossil fuels could have contributed to the presence of Mn in built-up watershed (Lisla and Michael, 2016).The application of herbicides by farmers during the dry season could be a source of Mn in the agricultural watershed after been eroded into the river alongside with return irrigation water. On the other hand, the presence of Mn in the industrial watershed could be connected to water discharges from industrial facilities including waste emanating from welding operations (Sanja *et al.,* 2014).The relationship between Mn concentration and downstream location along River Kaduna could be seen in Figure 4.38 while the GIS map of Mn concentration for the river is shown in Figure 4.39.

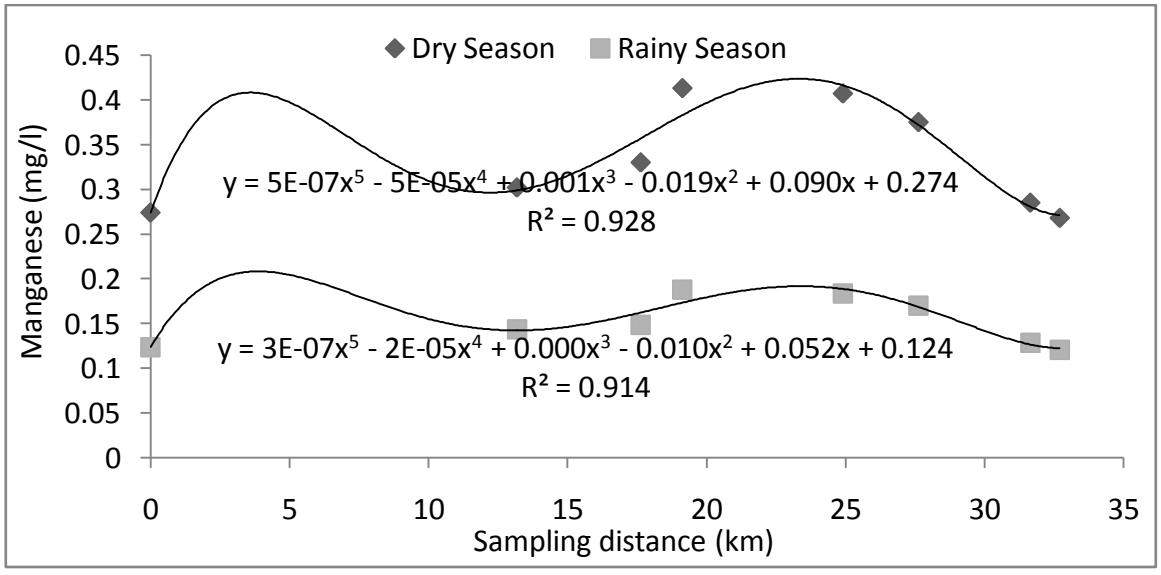


Figure 4.38:Relationship between manganeseand downstream locations in River Kaduna

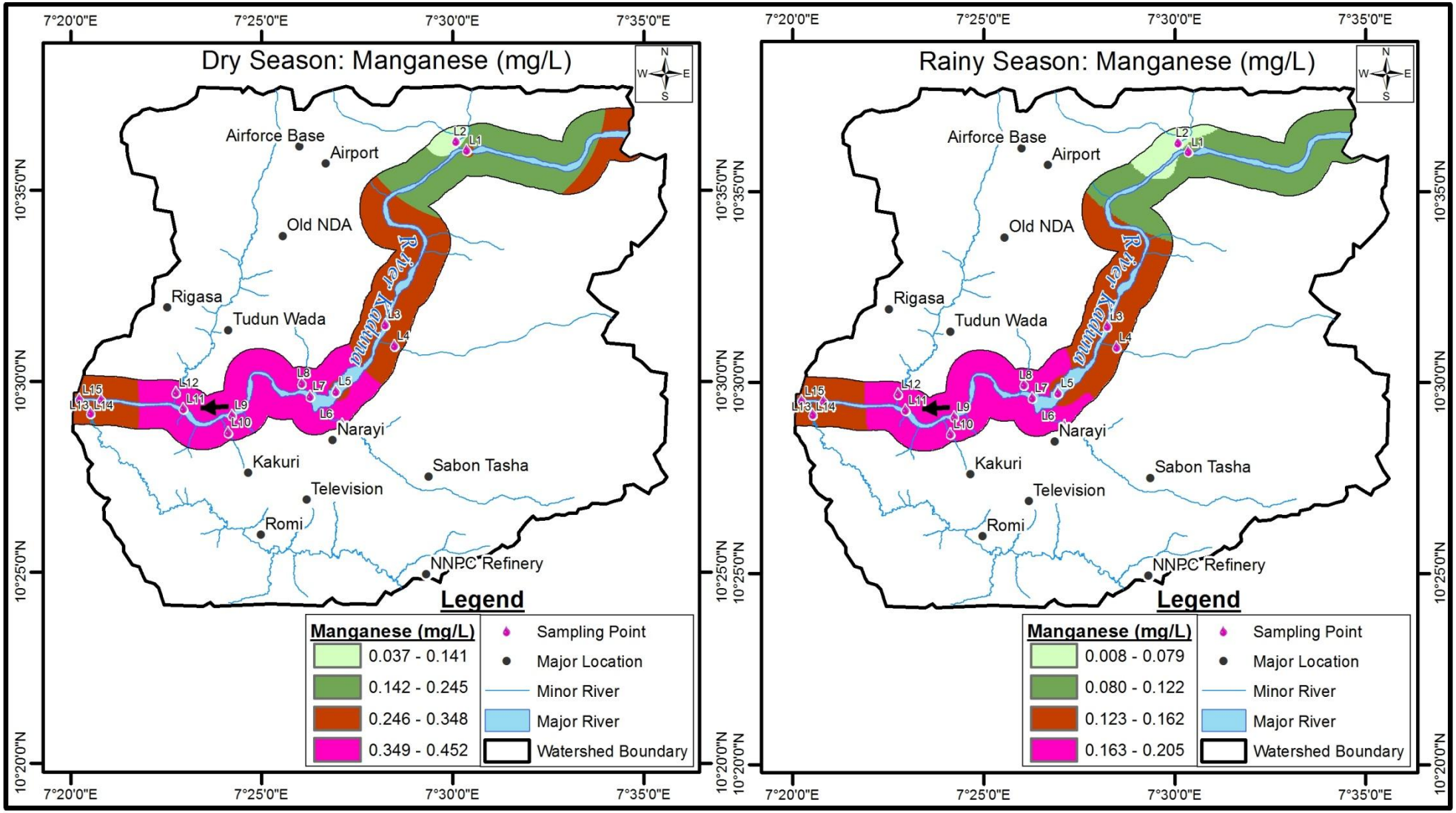


Figure 4.39: Map showing manganese content along River Kaduna

4.3 Determination of Water Quality Index

For the sake of simplicity in computing the Water Quality Index (WQI), only the laboratory results of the first sampling site (L1, Malali) is presented in Table 4.14. The results of the remaining sampling stations are shown in Appendix A. Hence, the procedure for determining the Canadian Water Quality Index (WQI) was only demonstrated for sampling location L1 (Malali) which is applicable to the remaining sampling locations.

Table 4.14: Water quality index computation table for Location L1 (Malali)

	Temp °C	Turb (NTU)	TDS (mg/l)	pH	Cl^- (mg/l)	EC (µS/cm)	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	TN (mg/l)	TP (mg/l)	Fe (mg/l)	Mn (mg/l)
June	27	**78.399**	81	7.2	26.39	157	7.80	0.43	**35.08**	0.96	**0.140**	0.181	0.064
July	26	**92.021**	76	6.8	27.13	159	8.18	0.48	**33.79**	0.88	**0.128**	0.165	0.106
August	27	**74.262**	65	6.8	22.27	146	8.22	0.50	**34.32**	0.85	**0.124**	0.208	0.121
September	27	**41.369**	60	6.9	23.76	150	8.10	0.59	**36.04**	0.83	**0.121**	0.236	0.143
October	25	**29.362**	61	7.2	18.15	135	7.96	0.61	**37.99**	0.90	**0.131**	0.239	0.168
November	22	**26.838**	93	7.4	12.15	119	7.48	0.65	**40.12**	**1.11**	**0.162**	0.241	0.192
December	21	**22.836**	105	7.4	13.28	122	7.25	0.66	**41.46**	**1.24**	**0.181**	0.248	**0.246**
January	23	**21.423**	106	7.5	10.28	114	6.11	0.67	**43.26**	**1.39**	**0.203**	0.294	**0.285**
February	22	**18.195**	97	7.6	3.91	97	5.87	0.66	**43.84**	**1.77**	**0.258**	**0.399**	**0.310**
March	21	**12.183**	100	7.3	0.92	89	5.25	0.63	**44.39**	**1.93**	**0.282**	**0.463**	**0.364**
April	23	**8.714**	90	7.5	1.67	91	5.18	0.52	**45.07**	**2.18**	**0.318**	**0.343**	**0.249**
May	25	**62.054**	79	7.2	19.64	139	6.39	0.42	**36.21**	**1.43**	**0.209**	0.249	0.139
Objective	≤ 40	≤ 5.0	≤ 500	6.5-8.5	≤ 250	≤ 750	≥ 5.0	≤ 2.0	≤ 20	≤ 1.0	≤ 0.1	≤ 0.3	≤ 0.2

1) Temp = Temperature, Turb = Turbidity, TDS = Total Dissolved Solids, Cl^- = Chloride, DO = Dissolved Oxygen, BOD_5 = 5-days Biochemical Oxygen Demand, COD = Chemical Oxygen Demand, TN = Total Nitrogen, TP = Total Phosphorous, Fe = Iron, Mn = Manganese, ≤ = less than or equal to, ≥ = greater than or equal to.
2) Bold values do not meet the objective.

The number of variables (parameters) not meeting the objectives is 6 (i.e Turb, COD, TN, TP, Fe and Mn) while the total number of variables is 13. Therefore,

$$\text{Scope, } F_1 = \left[\frac{6}{13}\right] \times 100 = 46.15$$

The number of tests not meeting the objectives is 51 while the total number of tests is 156. Hence,

$$\text{Frequency, } F_2 = \left[\frac{51}{156}\right] \times 100 = 32.69$$

$$excusion_1 = \left[\frac{78.399}{5}\right] - 1 = 14.68,$$

$$excusion_2 = \left[\frac{92.021}{5}\right] - 1 = 17.40,$$

$$excusion_3 = \left[\frac{74.262}{5}\right] - 1 = 13.85, \qquad etc.$$

Normalized sum of excursions, $nse = \frac{\sum_{i=1}^{n} excursion_i}{number\ of\ tests} = \frac{114.995}{156} = 0.7371$

Amplitude, $F_3 = \frac{nse}{0.01nse + 0.01} = \left[\frac{0.7371}{0.01(0.7371) + 0.01}\right] = \frac{0.7371}{0.017371} = 42.43$

$$WQI = 100 - \frac{\sqrt{\left({F_1}^2 + {F_2}^2 + {F_3}^2\right)}}{1.732} = 100 - \frac{\sqrt{(46.15^2 + 32.69^2 + 42.43^2)}}{1.732} = 59.18$$

As earlier stated, the WQI for the remaining sampling locations were calculated in a similar way and their values are given in Table 4.15.

Table 4.15: Summary of Canadian WQI of Sampling locations

Location Code	Location Name	WQI	Interpretation
L1	*Malali	59.18	Marginal; frequently impaired (45 – 64)
L2	+Kwarau	63.62	Marginal; frequently impaired (45 – 64)
L3	*NNPC	56.26	Marginal; frequently impaired (45 – 64)
L4	+Kuyi	59.07	Marginal; frequently impaired (45 – 64)
L5	*Barnawa	56.13	Marginal; frequently impaired (45 – 64)
L6	+Kutimbi	30.85	Poor; always impaired (0 – 44)
L7	*Living Faith	49.78	Marginal; frequently impaired (45 – 64)
L8	+Kigo	25.88	Poor; always impaired (0 – 44)
L9	*Down Quarters	48.51	Marginal; frequently impaired (45 – 64)
L10	+Breweries	23.41	Poor; always impaired (0 – 44)
L11	*Ungwa Mu'azu	50.15	Marginal; frequently impaired (45 – 64)
L12	+Rigasa	29.50	Poor; always impaired (0 – 44)
L13	*Maigiginya	56.04	Marginal; frequently impaired (45 – 64)
L14	+Romi	55.83	Marginal; frequently impaired (45 – 64)
L15	*Railway Bridge	57.28	Marginal; frequently impaired (45 – 64)

WQI = Water Quality Index, * = Sampling locations along River Kaduna, + = Sampling locations along tributaries, 30 m away from confluence point,

The WQI values of all the sampling locations shown in Table 4.28 were used in mapping the entire sampled portion of the river via Inverse Distance Weighted (IDW) interpolation method as could be seen in Figure 4.40.

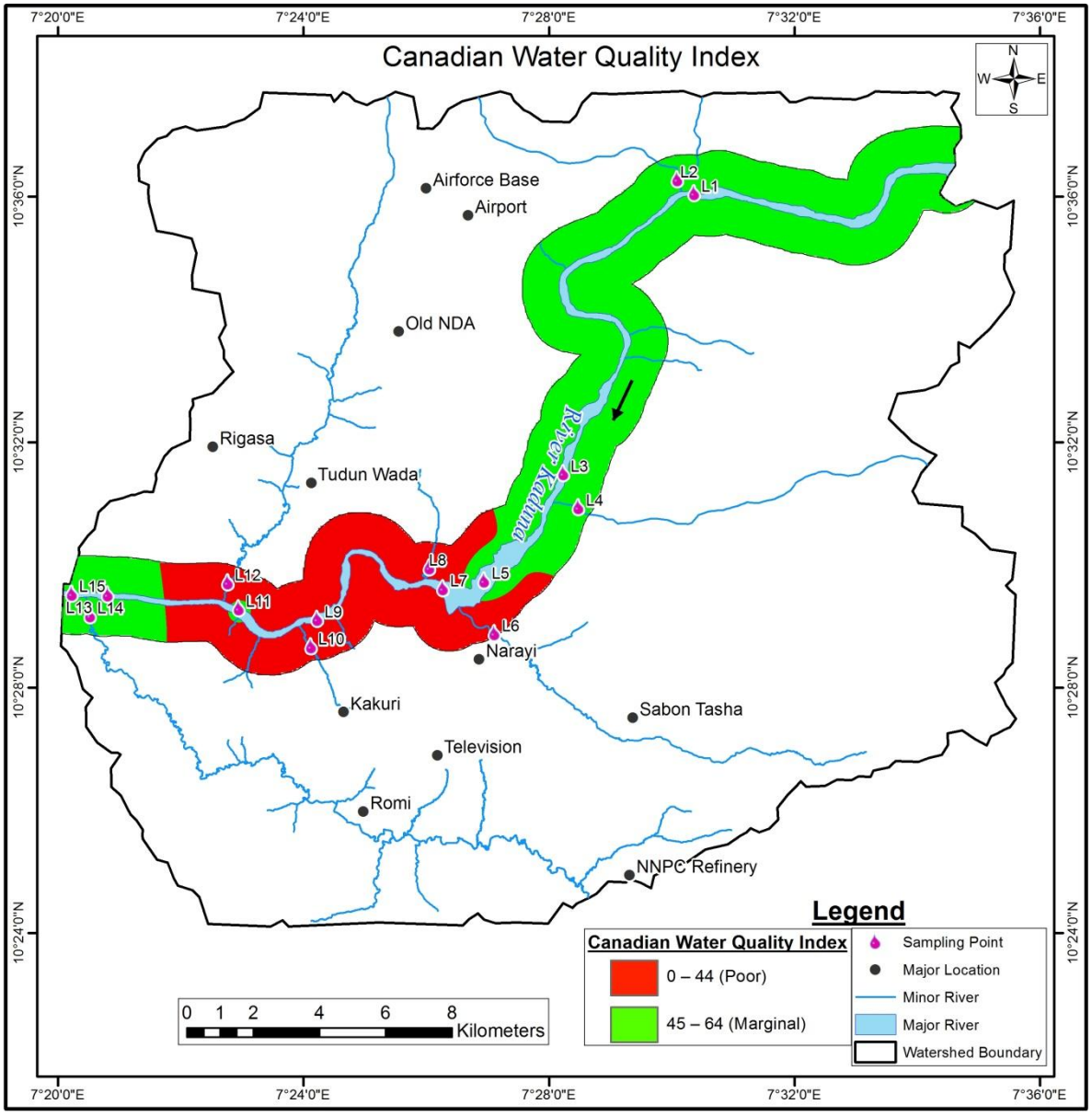


Figure 4.40: Canadian WQI map of River Kaduna

Table 4.15disclosed that among the 15 sampling locations, only locations L6 (Kutimbi), L8 (Kigo), L10 (Breweries) and L12 (Rigasa) recorded poor WQI. This could be attributed to the anthropogenic activities within the areas and towns draining to these locations however,

Figure 4.40 revealed that the communities draining to these sampling locations are Kakuri, Narayi, Sabon Tasha, Tudun Wada and Rigasa. These settlements are majorly industrialized and built-up areas within the watershed. The WQI map (Figure 4.40) also indicates that the water quality of the river upstream of Narayi community was marginal based on the Canadian WQI. Nevertheless, the quality of the river became poor in between Narayi and Rigasa communities and thereafter, the water quality started improving downstream at a point in between River Rigasa and River Romi.

The WQI values of the sampling sites along River Kaduna (i.e L1, L3, L5, L7, L9, L12 and L15), were plotted against their respective sampling distances from the first sampling site L1 (Malali) along the direction of flow as shown in Figure 4.41.

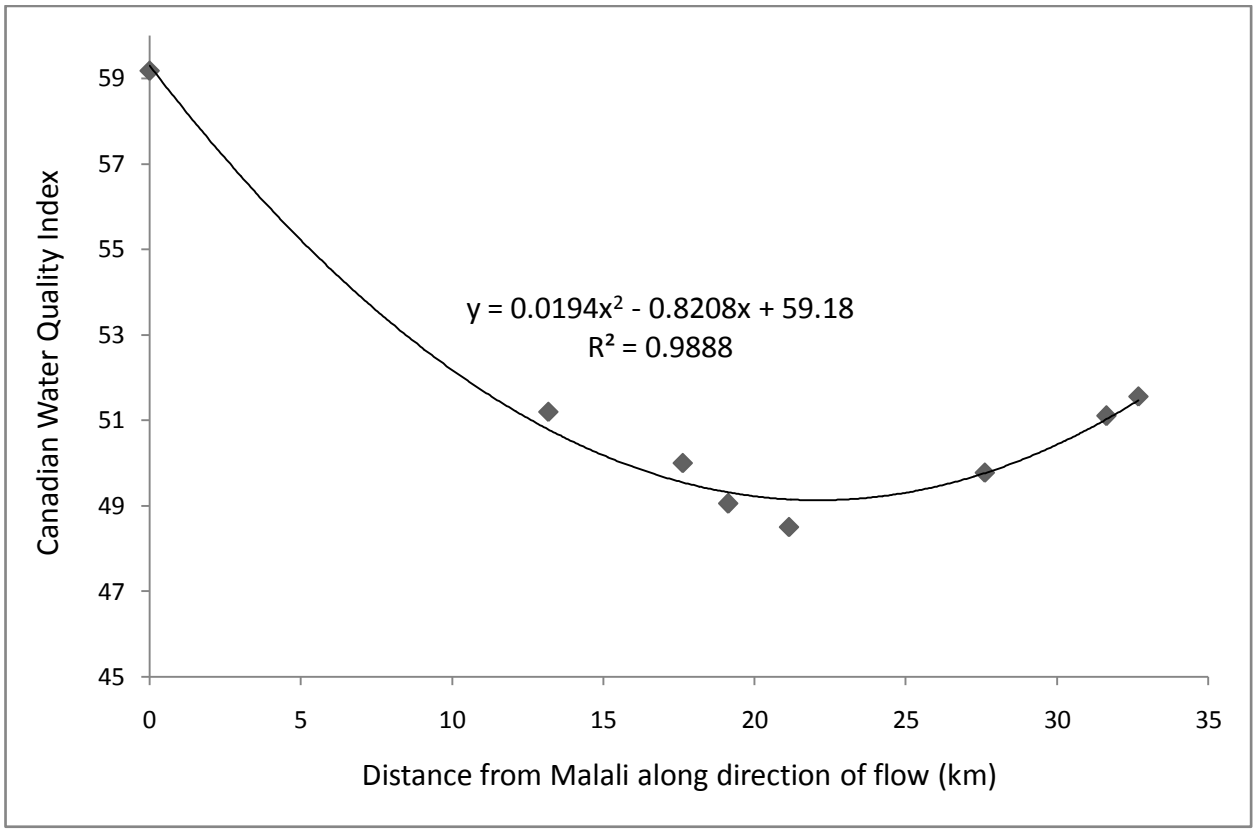


Figure 4.41: Line of best fit between WQI and sampling distance along direction of flow

The turning or minimum point of the curve in Figure 4.41 was determined by equating the first derivative of the equation of the curve to zero. That is, at turning point;

$$\frac{d(0.0194x^2 - 0.8208x + 59.18)}{dx} = 0 \quad (4.1)$$

It implies,

$$0.0388x - 0.8208 = 0 \quad (4.2)$$

Therefore, $x = \frac{0.8208}{0.0388} = 21.15$ (4.3)

Equation (4.3) revealed that the Canadian WQI of the sampling sites along River Kaduna is lowest or minimum at a distant of 21.15 km from the first sampling station (L1, Malali) along the direction of flow. This distant (21.15 km) along the direction of flow correspond

to the Kakuri area or town within the watershed (ArcGIS 10.5). The industries within the watershed are concentrated at Kakuri thus, reflecting the poorness in its water quality when compared to other areas or towns within the watershed. Kakuri town is also densely built-up which means that municipal discharges might as well contributed to the poorness in water quality of the river within this area (Kakuri). Hence, the curve in Figure 4.41 was transformed so as to have Kakuri as the referenced point (i.e Kakuri at x = 0) as shown in Figure 4.42.

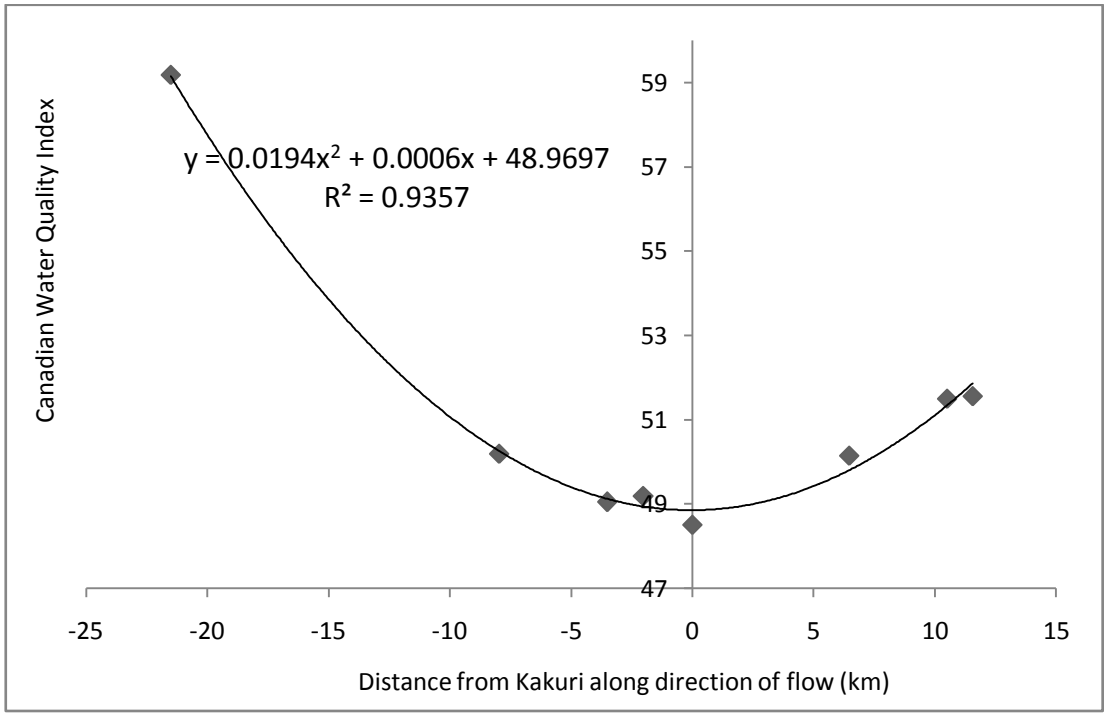


Figure 4.42: WQI of River Kaduna with respect to distance away from Kakuri

The information in Figure 4.42 suggests that there is improvement in the water quality of River Kaduna (middle stretch) when moving away from Kakuri or deterioration when moving towards Kakuri. Therefore, the predicting equation for the WQI of the middle section of River Kaduna (Malali – Rigasa) is given as follows;

$$CWQI_p = 0.0194{K_d}^2 + 0.0006K_d + 48.9697 \quad (4.4)$$

Where:

$CWQI_p$ = predicted Canadian Water Quality Index of middle stretch of River Kaduna (Malali – Rigasa),

K_d = distance away from Kakuri along direction of flow.

However, it should be noted that equation (4.4) recognized distance measured away from Kakuri against the direction of flow as negative and also, the equation is peculiar to the middle section of River Kaduna (Malali – Rigasa) only. A programming language was written for equation (4.4) and the flowchart of the program is shown in Figure 4.43.

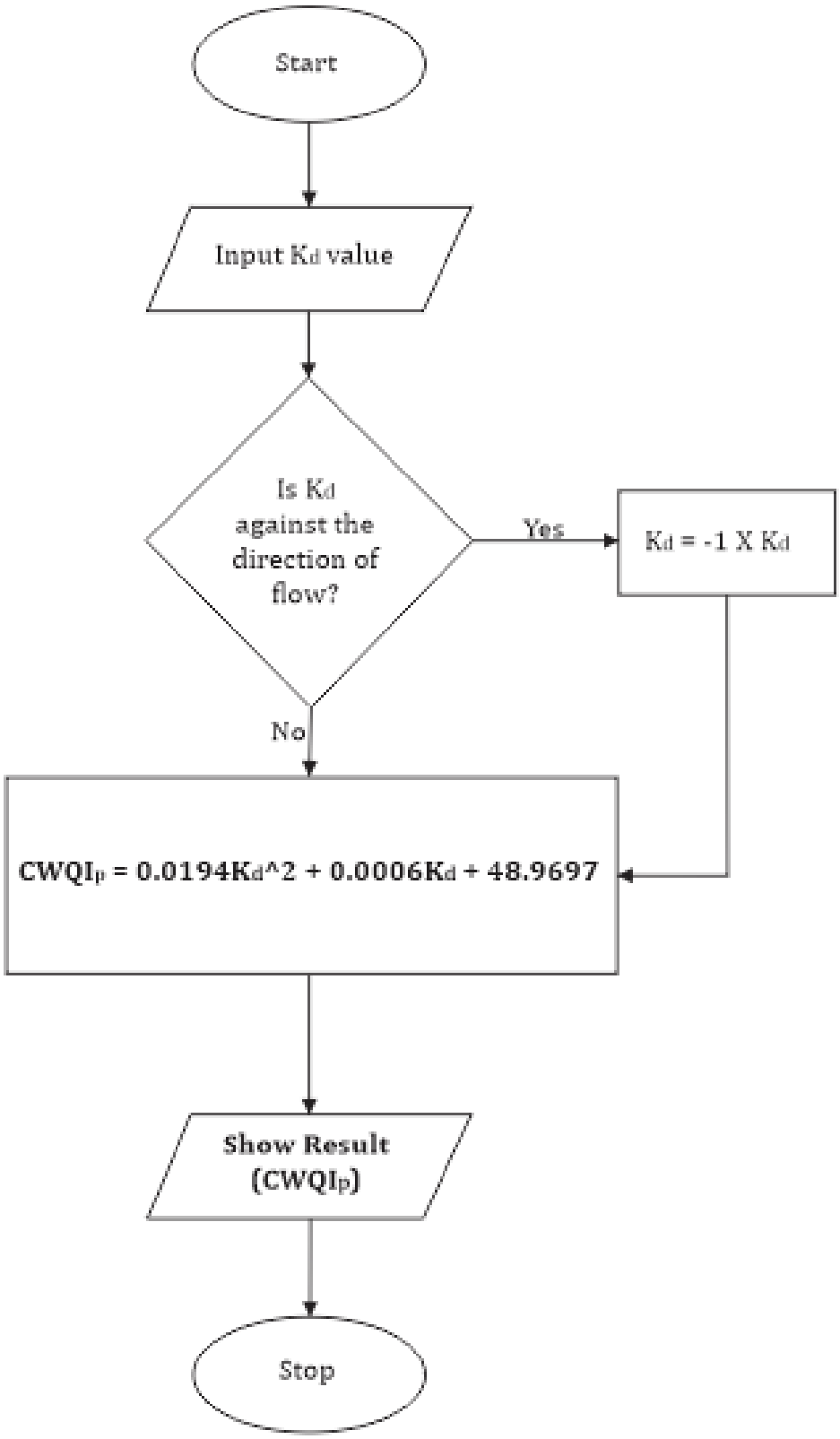


Figure 4.43: Flowchart of computer program for WQI along River Kaduna middle stretch

4.3.1 Computer program for water quality index

Program Source Code (written in Visual Basic.Net)

```
PublicClass frmMain
Dim dblKd AsDouble
PrivateSub btnReset_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles btnReset.Click
        txtKd.Text = ""
        lblCWQIp.Text = "CWQIp = "
        rdbNo.Checked = True
EndSub

PrivateSub btnCWQIp_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles btnCWQIp.Click
If txtKd.Text <>""Then
If rdbNo.Checked = TrueThen
                dblKd = CDbl(txtKd.Text)
EndIf
If rdbYes.Checked = TrueThen
                dblKd = -1 * CDbl(txtKd.Text)
EndIf
            lblCWQIp.Text = "CWQIP = "& (0.0194 * dblKd ^ 2) + (0.0006 *
dblKd) + 48.9697
Else
            MessageBox.Show("Must enter the distance measured (Kd) in
kilometers (KM)", "Null entry", MessageBoxButtons.OK,
MessageBoxIcon.Information)
            txtKd.Focus()
EndIf
EndSub

PrivateSub txtKd_KeyPress(ByVal sender AsObject, ByVal e As
System.Windows.Forms.KeyPressEventArgs) Handles txtKd.KeyPress
Dim KeyAscii AsShort = Asc(e.KeyChar)
If KeyAscii = 8 Or KeyAscii = 46 Or (KeyAscii >= 48 And KeyAscii <= 57)
Then
            e.KeyChar = Chr(KeyAscii)
Else
            KeyAscii = 0 ' Cancel the character.
            Beep() ' Sound error signal.
EndIf
If KeyAscii = 0 Then
            e.Handled = True
EndIf
EndSub
EndClass
```

4.4 Identification of critical water quality parameters

Principal Component Analysis (PCA) was carried out on the data generated from the field in order to identify the key variables (water quality parameters) that influenced the water quality changes of the river. The scree plot in Figure 4.44 showed that component number or principal components (PCs) 1 – 3 have eigenvalues greater than 1.0 (i.e. 6.045, 3.806 and 1.04 respectively in Table 4.16). The rest PCs are less than 1.0 which means that they are not significant hence; their contribution to water quality variation is therefore negligible (Adebayo, 2014; Adie, 2008). In the reports of Onojake and Abrakasa (2012), Zhaoa *et al.* (2012) and Liu *et al.* (2016), factor loading were classified as strong, moderate and weak corresponding to absolute loading values of >0.75, 0.75 – 0.50 and 0.50 – 0.30 respectively. Hence, this research considered factor loading >0.75 (strong) as being significant without considering moderate and weak factors.

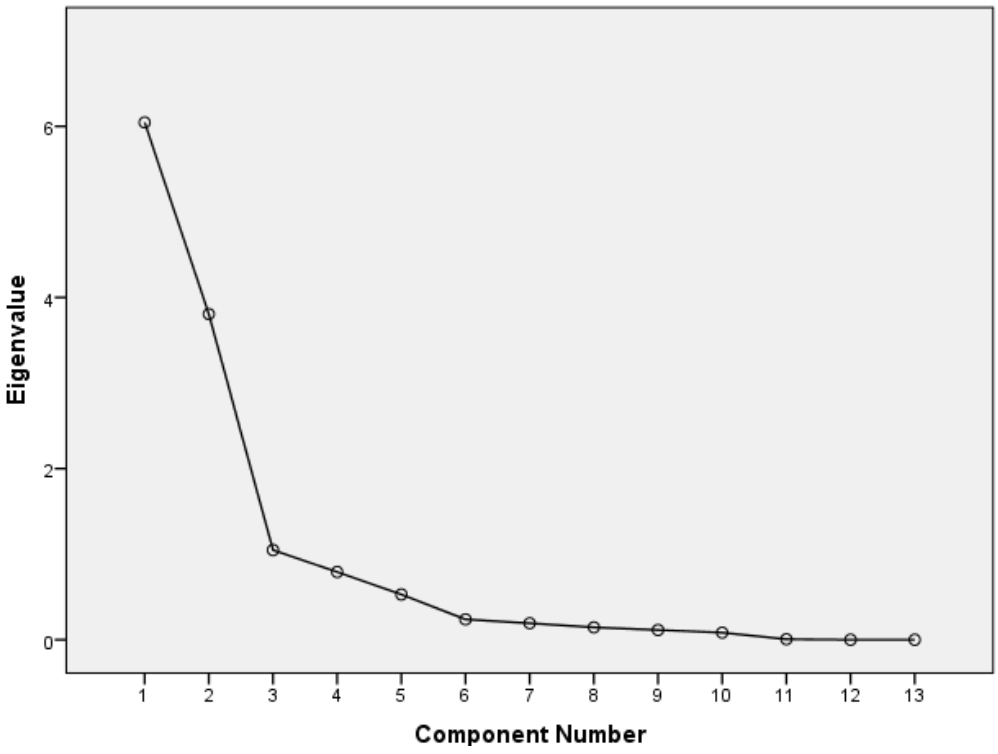


Figure 4.44: Scree plot

Table 4.16: Absolute factor loading of parameters in principal components of water quality

Parameter	PC1	PC2	PC3
Temperature	−0.722	0.483	0.096
Turbidity	**−0.757**	0.613	0.052
Total Dissolved Solids	0.374	**0.889**	0.218
pH	0.440	−0.185	0.336
Chloride (Cl^-)	0.375	**0.888**	0.219
Electrical Conductivity	0.374	**0.889**	0.219
Dissolved Oxygen	**−0.877**	−0.149	−0.175
BOD_5	0.642	0.481	−0.520
COD	**0.836**	0.292	−0.325
Total Nitrogen	**0.891**	−0.442	0.363
Total Phosphorus	**0.908**	−0.475	0.377
Iron (Fe)	0.736	−0.118	−0.185
Manganese (Mn)	0.542	−0.143	−0.256
Eigenvalue	6.045	3.806	1.048
Proportion of Variance (%)	46.501	29.276	8.064
Cumulative Proportion (%)	46.501	75.776	83.840

Extraction Method: Principal Component Analysis; Rotation Method: Varimax with Kaiser Normalization; Communalities (34 – 98%); Kaiser– Meyer–Olkin (KMO) measure of sampling adequacy = 0.812; Bartlett's Test of Sphericity (Chi-square = 6648.897; P<0.001). Bold figures indicate absolute values >0.75 of parameters with strong loading factor.

The three principal components (PC1, PC2 and PC3) shown in Table 4.29 accounted for 83.840% of the observed variations in the water quality however, the absolute factor loadings of PC3 were less than the target value (>0.75). Hence, the first two principal components (PC1 and PC2) were extracted based on a strong factor loading of >0.75 and accounted for 75.776%. PC1 represent 46.501% of variability which indicates a strong negative loading factor on turbidity and dissolved oxygen as well as a strong positive loading factor on COD, total nitrogen and total phosphorus. PC2 with 29.276% of variance designates a strong positive loading factor on total dissolved solids, chloride and electrical conductivity. The extracted critical parameters are shown in Table 4.17

Table 4.17: Extracted principal components and critical parameters

	PC1	**PC2**
	Turbidity	Total Dissolved Solids
	Dissolved Oxygen	Chloride
	COD	Electrical Conductivity
	Total Nitrogen	
	Total Phosphorus	
Eigenvalue	6.045	3.806
Proportion of Variance (%)	46.501	29.276
Cumulative Proportion (%)	46.501*	75.776

46.501* is the initial cumulative proportion of variance

It could be inferred from Table 4.17 that among the 13 water quality parameters monitored along the middle stretch of River Kaduna, 8 strongly influenced the water quality changes. These 8 critical water quality parameters were turbidity, dissolved oxygen (DO), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), total dissolve solids (TDS), chloride ion (Cl^-)and electrical conductivity (EC).

4.5Classification of Similar Sampling Locations

The various sampling locations across the basin were categorized based on the pattern and closeness of the observed physiochemical parameters via Hierarchical Clustering Analysis (HCA) technique. The 15 sampling locations were classified into two clusters with the first cluster (moderately polluted zones) containing 11 locations while the second cluster (highly polluted zones) contains 4 locations as could be seen in Figure 4.45.

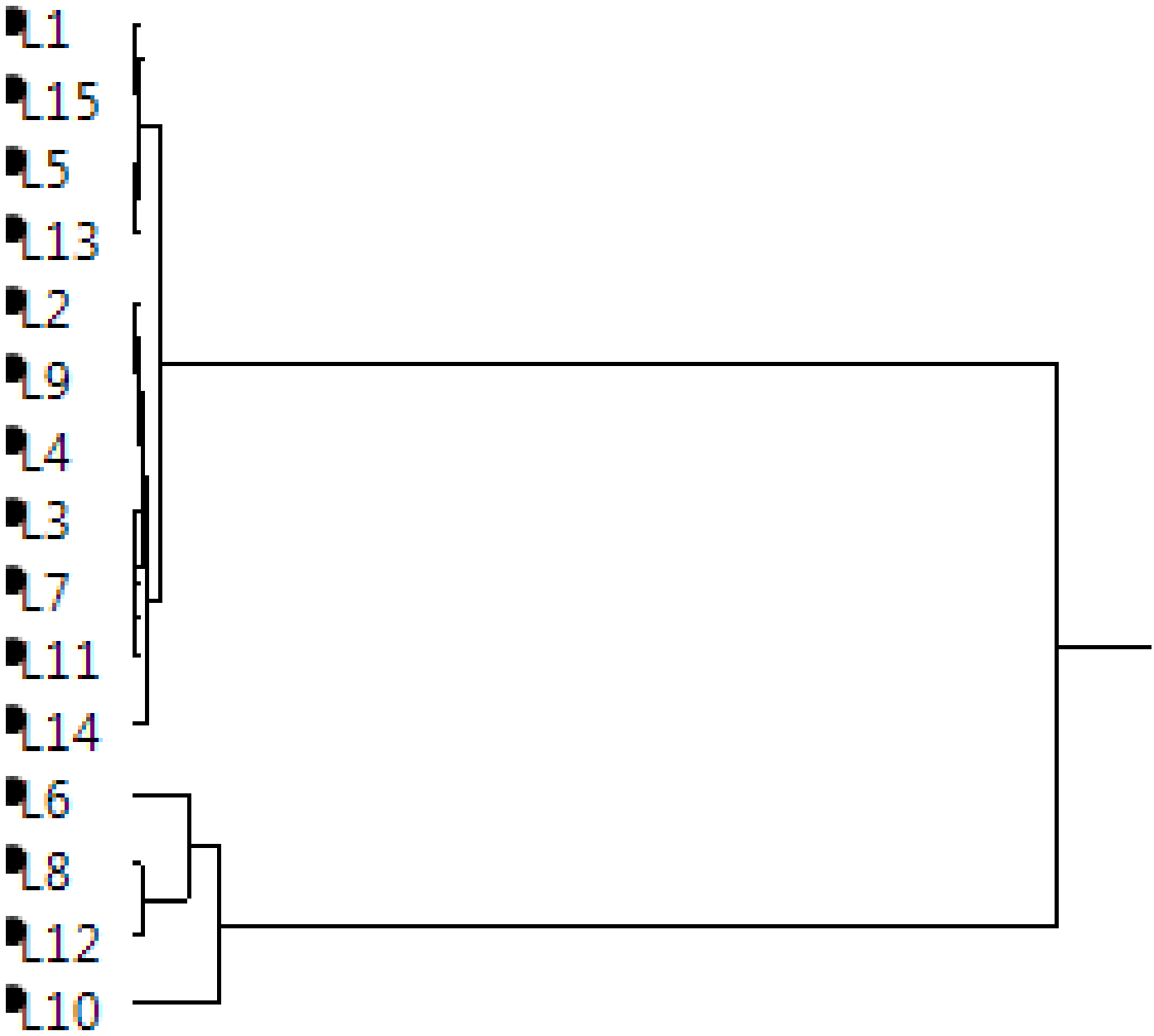


Figure 4.45: Dendrogram of cluster analysis for sampling sites

As could be seen in Figure 4.45, the sampling locations that fell in the first cluster are L1 (Malali), L2 (Kwarau), L3 (NNPC), L4 (Kuyi), L5 (Barnawa), L7 (Living Faith), L9 (Down Quarters), L11 (Ungwa Mu'azu), L13 (Maigiginya), L14 (Romi) and L15 (Railway Bridge). On the other hand, the locations that fell in the second cluster are L6 (Kutimbi), L8 (Kigo), L10 (Breweries) and L12 (Rigassa).

In this research, a total of 15 sampling sites comprising 8 sites along River Kaduna and 7 sites at 30 m away from the confluence points of tributaries draining to River Kaduna were considered. All the 8 sampling sites along River Kaduna (L1, L3, L5, L7, L9, L11, L13 and L15) together with 3 sampling sites along streams draining to River Kaduna (30 m away from confluence point) which are L2, L4 and L14 fell into cluster 1 (moderately polluted sites). However, cluster 2 (highly polluted sites) contains 4 sampling sites along streams draining to River Kaduna (30 m away from confluence point)which are; Kutimbi stream between Narayi and Barnawa communities (L6), Omo stream at Kigo road new extension (L8), Nigeria Breweries drainage at Kakuri (L10) and River Rigassa (L12). These tributaries drain effluents from the densely built-up areas within the watershed. The clusters were sub classified through a constellation plot as could be seen in Figure 4.46 with cluster 1 (moderately polluted sites) been classified into 4 sub-groups. Sampling locations L1, L15, L5 and L13 fell in the same sub-group. Also locations L2, L9 and L4 as well as locations L3, L7 and L11 are in the same sub-groups respectively while sampling location L14 is on its own sub-group. On the other hand, cluster 2 (highly polluted sites) was classified into 3 sub-groups in which, L12 and L8 fell into the same sub-group while L6 and L10 formed singled site sub-groups each.Hence, the total sub-classification of cluster 1(moderately polluted sites) and cluster 2 (highly polluted sites) sum up to 7. The significance of these sub-classifications is to optimize sampling strategy that can lessen the number of sampling stations or sites and the affiliated recurring costs in future monitoring. That is, the 15 sampling sites can be reduced to 7 by selecting any sampling site in a sub-group during subsequent monitoring.

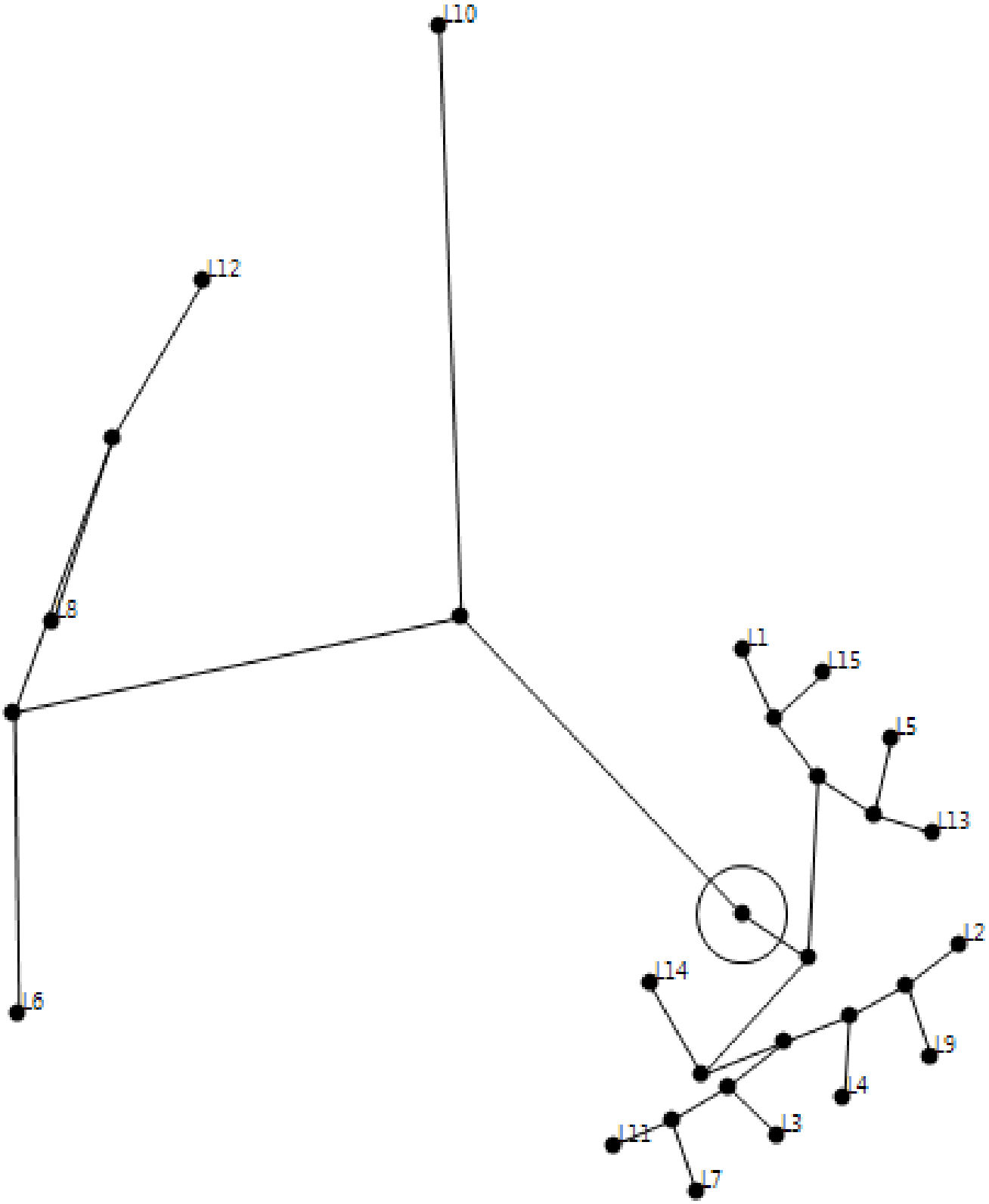


Figure 4.46: Constellation plot of sampling sites

The two clusters in the dendrogram shown in Figure 4.46 are in agreement with the developed Canadian Water Quality Indexshown in Table 4.28. That is, the sampling locations in cluster 1 (moderately polluted) are the same as those in the faircategory of the Canadian Water Quality Index (WQI value 45 – 64). Similarly, all the sampling locations in cluster 2 (highly polluted) are the same as those in the poor category of the Canadian Water Quality Index (WQI value 0 – 44).

Just as the case of sampling sites, the sampling months (June to May) were categorized into two clusters as shown in Figure 4.47.February, April, March, January, November and December (i.e November to April) fell in the first cluster while June, August, July, October, May and September (i.e May to October) fell in the second cluster. The months in the first cluster (November to April) and second cluster (May to October) correspond to dry season and rainy season respectively, which confirmed the seasonal grouping of the sampling months earlier shown in section 3.2.6.

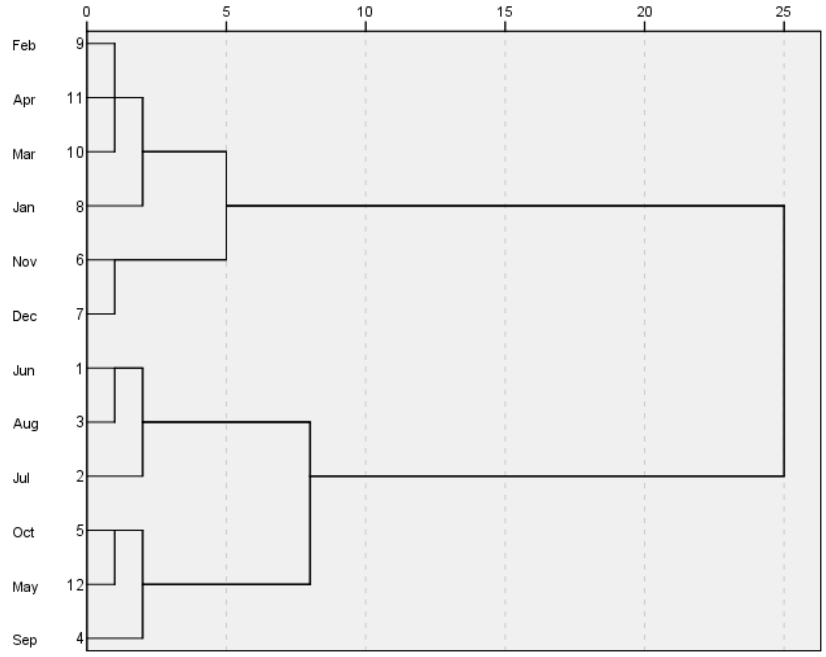


Figure 4.47:Dendrogram of cluster analysis for sampling months

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the findings in River Kaduna, the following conclusions may be drawn:

1. Rainy season improves the water quality of River Kaduna in terms of TDS, Cl^-, EC, DO, BOD, COD, nitrogen, phosphorous, and heavy metals (Fe and Mn) while dry season only improve the turbidity and pH qualities of the river. Hence, the water quality of River Kaduna is more deteriorated during the dry season. Built-up, industrial, and agriculturalland uses contributes significantly to the impairment of River Kaduna water quality. On the other hand, a significant positive correlation exist between vegetation (forest coverage) and water quality improvement, suggesting that forest cover can mitigate the deterioration of water quality to a certain degree.
2. The use of GIS in mapping the water quality of River Kaduna (middle stretch) have identified the water quality of the none sampled points along the river.
3. The Water Quality Index (WQI) of River Kaduna is mostly marginal (i.e. frequently impaired or threatened) on the Canadian scale.However, the areas with high impairment level (poor) along the river are located within Sabon Tasha, Narayi, Kakuri, Tudun Wada and Rigasa communities. All the same, the entire river may contain some toxic constituents which cannot be easily treated with biological means irrespective of the sampling site and season since the BOD/COD ratio in all sampling sites during both seasons fell below 0.3.

4. Out of the 13 water quality parameters analyzed, 8 parameters which are; turbidity, TDS, Cl^-, EC, DO, COD, total nitrogen and total phosphorous were identified as critical parameters on a factor loading greater than 0.75. This signifies that they strongly influenced the variability of the water quality however, the principal components (PCs) of these 8 parameters accounted for 75.78% of the total variation in water quality of River Kaduna (middle stretch).
5. The 15 sampling sites monitored in River Kaduna within Kaduna city metropolis fell into two major clusters viz: moderately polluted sites and highly polluted sites. The first cluster (moderately polluted sites) and second cluster (highly polluted sites) contain 11 and 4 sampling sites respectively.Nevertheless, the two clusters were further categorized into 7 sub-clusters. All sampling sites along River Kaduna together with sampling sites at the tributaries; Kwarau stream, Kuyi stream and River Romi (all at 30 m away from confluence points)are moderately polluted sites. Contrarily, sampling sites along the tributaries; Kutimbi stream, Omo stream (Kigo), Nigeria Breweries drainage and River Rigassa (all at 30 m away from confluence points)arehighly polluted sites.

5.2Recommendations

Based on the conclusions above, the following measures are therefore recommended:

1. More vegetal cover within the watershed should be encouraged as it has the ability to mitigate water quality deterioration.Henceforth, farming at the river banks should be banned as it will permit the growth of natural vegetation (grasses, shrubs, etc.) which could control the erosion of particles into the river. Organic and inorganic

fertilizers usually applied by farmers at the river banks during dry season easily drain into the river via return irrigation water, to deteriorate the river water quality. In order words, none farming at the river banks will also improve the water quality of the river during the dry season since there won't be fertilizers to drain into the river from the banks.

2. Regulatory agencies such as KEPA are advised to check the anthropogenic activities occurring at the hot spot areas shown in the GIS maps especially at Kakuri, Tudun Wada and Rigasa communities and then impose disciplinary measures against culprits.
3. Subsequent monitoring of the physicochemical qualities of River Kaduna with respect to the 13 water quality parameters monitored should put more emphasis on the 8 critical parameterswhich are turbidity, DO, COD, total nitrogen, total phosphorus, TDS, Cl^- and EC. However, other water quality parameters outside the 13 parameters monitored could as well be analyzed.
4. The sites at the following combination of locations along River Kaduna should be considered as similar sites in terms of water quality; (Malali, Barnawa, Maigingiya and Railway Bridge), (Kwarau stream, Kuyi stream and Down-Quarter), (NNPC, Living Faith and Ungwa Mu'Azu), (Omo stream and River Rigassa). Hence, for the sake of reducing the cost of subsequent monitoring, once any of the location in each of these combinations is selected as sampling site, the remaining locations within such combination may not be sampled since their water qualities are similar.
5. Further studies of this kind should consider a composite sampling at the two banks ofthe river and the center to better represent the water quality of each sampling site. In addition, the depth of sampling at each site should be considered.

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APPENDIX A: MONTHLY VARIATION OF ANALYZED PARAMETERS

Appendix A1: Monthly variation of temperature (±0.02 ^{o}C)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	FEPA Limit
June	27	26	26	27	26	28	27	26	25	28	28	26	26	25	26	≤ 40
Jul	26	26	26	25	27	26	25	27	27	29	27	27	28	26	25	≤ 40
Aug	27	28	27	26	26	27	28	25	26	27	26	27	26	28	27	≤ 40
Sep	27	26	28	27	27	25	26	27	26	26	27	26	25	26	25	≤ 40
Oct	25	24	25	26	26	25	25	26	25	26	27	25	25	25	24	≤ 40
Nov	22	22	23	22	22	23	24	22	23	22	21	22	22	24	22	≤ 40
Dec	21	22	21	22	23	22	22	22	21	23	22	23	23	23	23	≤ 40
Jan	23	21	22	22	21	21	22	23	22	23	22	22	21	23	20	≤ 40
Feb	22	22	21	21	22	21	20	21	20	21	20	21	20	21	21	≤ 40
Mar	21	22	19	20	20	19	20	19	20	20	20	20	19	20	19	≤ 40
Apr	23	23	24	23	23	22	22	24	23	23	24	21	24	24	24	≤ 40
May	25	26	27	26	26	27	25	24	26	26	27	26	27	28	27	≤ 40

Appendix A2: Monthly variation of turbidity (±0.05 NTU)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	FEPA Limit
Jun	78.399	49.359	150.893	83.361	81.003	95.416	110.073	188.258	109.712	167.500	107.554	111.495	75.891	84.856	55.270	≤ 5.000
Jul	92.021	58.018	176.495	98.072	95.127	111.871	128.159	221.251	128.492	196.424	126.126	130.509	87.894	99.946	65.061	≤ 5.000
Aug	74.262	46.199	142.359	77.818	76.018	90.258	103.856	176.613	103.782	158.866	101.178	106.309	70.858	80.700	52.077	≤ 5.000
Sep	41.369	27.786	79.907	43.280	42.579	50.348	57.650	100.436	58.174	88.930	56.826	59.061	39.301	44.615	28.877	≤ 5.000
Oct	29.362	18.454	56.246	31.340	30.117	35.735	41.542	71.810	41.230	63.460	41.026	42.063	28.653	31.930	20.788	≤ 5.000
Nov	26.838	8.741	4.254	9.054	9.400	6.869	4.939	1.833	5.223	2.308	5.465	4.642	17.116	9.072	21.199	≤ 5.000
Dec	22.836	7.453	3.673	7.777	8.030	5.859	4.206	1.560	4.443	1.961	4.640	3.955	14.633	7.746	18.077	≤ 5.000
Jan	21.423	7.012	3.430	7.337	7.657	5.542	3.947	1.460	4.148	1.847	4.412	3.747	13.805	7.327	17.146	≤ 5.000
Feb	18.195	5.955	2.914	6.159	6.350	4.622	3.311	1.232	3.523	1.553	3.671	3.131	11.586	6.141	14.350	≤ 5.000
Mar	12.183	3.938	1.902	4.073	4.254	3.091	2.211	0.878	2.307	1.024	2.439	2.087	7.749	4.107	9.598	≤ 5.000
Apr	8.714	2.843	1.387	2.935	3.030	2.194	1.564	0.583	1.670	0.737	1.746	1.481	5.454	2.911	6.849	≤ 5.000
May	62.054	38.994	119.473	66.093	63.764	75.276	87.182	149.927	86.979	132.964	85.932	88.159	60.210	67.141	43.776	≤ 5.000

Appendix A3: Monthly variation of total dissolved solids (±0.02 mg/l)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	FEPA Limit
Jun	81	88	84	83	80	401	93	460	82	525	95	498	80	94	80	≤ 500
Jul	76	85	79	80	75	387	82	408	80	504	88	476	75	89	77	≤ 500
Aug	65	80	62	73	66	345	77	388	69	474	83	454	69	85	71	≤ 500
Sep	60	76	61	70	58	333	68	351	66	470	78	422	67	79	69	≤ 500
Oct	61	75	59	65	59	329	75	392	71	485	81	451	77	84	77	≤ 500
Nov	93	121	94	100	95	389	98	466	91	505	97	468	93	114	94	≤ 500
Dec	105	127	103	113	103	542	103	561	102	562	105	529	104	127	103	≤ 500
Jan	106	123	107	116	107	576	105	598	107	604	107	532	108	132	108	≤ 500
Feb	97	115	97	106	99	550	99	569	97	609	99	524	98	124	99	≤ 500
Mar	100	116	102	108	101	518	100	587	101	600	101	508	102	121	101	≤ 500
Apr	90	110	88	99	93	507	91	529	91	593	89	504	92	116	92	≤ 500
May	79	86	78	86	82	502	91	506	82	547	87	502	81	102	81	≤ 500

Appendix A4: Monthly variation of pH (±0.1 pH unit)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	FEPA Limit
Jun	7.2	7.3	7.3	6.7	7.3	6.3	7.2	6.4	7.2	8.9	7.2	6.5	7.2	7.4	7.2	6.5 – 8.5
Jul	6.8	7.3	6.9	6.7	6.8	6.3	6.8	6.3	6.9	8.8	6.8	6.4	6.7	7.3	6.8	6.5 – 8.5
Aug	6.8	6.8	6.8	6.5	6.7	6.2	6.7	6.2	6.8	8.7	6.7	6.4	6.7	7.3	6.7	6.5 – 8.5
Sep	6.9	6.7	6.8	6.6	6.8	6.4	6.8	6.3	6.9	8.9	6.9	6.3	6.8	7.4	6.8	6.5 – 8.5
Oct	7.2	6.8	7.3	6.8	7.4	6.6	7.3	6.5	6.7	8.9	7.2	6.4	7.2	7.5	7.3	6.5 – 8.5
Nov	7.4	6.8	7.5	6.7	7.6	6.8	7.7	6.6	6.9	9.0	7.4	6.7	7.4	7.6	7.5	6.5 – 8.5
Dec	7.4	7.4	7.4	6.8	7.4	6.8	7.5	6.8	7.2	9.1	7.5	6.8	7.6	7.5	7.6	6.5 – 8.5
Jan	7.5	7.4	7.5	7.3	7.5	6.9	7.4	7.1	7.4	9.2	7.7	7.9	7.8	7.7	7.7	6.5 – 8.5
Feb	7.6	7.5	7.5	7.3	7.3	6.8	7.5	7.3	7.4	9.1	7.8	7.2	7.7	7.7	7.7	6.5 – 8.5
Mar	7.3	7.6	7.4	7.4	7.4	6.7	7.4	7.4	7.4	9.3	7.9	7.4	7.8	7.8	7.8	6.5 – 8.5
Apr	7.5	7.3	7.4	7.2	7.5	6.6	7.6	6.8	7.3	9.2	7.5	6.8	7.3	7.6	7.4	6.5 – 8.5
May	7.2	7.3	7.3	6.9	7.4	6.4	7.3	6.3	7.2	9.0	7.3	6.4	7.1	7.5	7.2	6.5 – 8.5

Appendix A5: Monthly variation of chloride ion (±0.1 mg/l)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	FEPA Limit
Jun	26.39	38.45	25.26	31.33	25.64	273.25	25.64	284.40	24.89	286.59	26.39	267.01	26.01	39.25	25.64	≤ 250
Jul	27.13	36.58	27.88	32.84	27.88	292.28	26.76	305.08	27.51	310.27	27.51	268.87	28.26	41.87	28.26	≤ 250
Aug	22.27	31.69	21.89	27.18	23.01	277.35	23.39	288.91	21.89	313.28	23.01	264.38	22.64	37.75	23.01	≤ 250
Sep	23.76	32.44	24.89	28.69	24.51	259.82	23.76	299.06	24.14	308.02	24.51	255.39	24.89	35.88	24.14	≤ 250
Oct	18.15	29.06	17.02	23.40	19.64	253.47	18.90	266.36	18.90	303.88	17.77	252.77	19.27	33.26	19.27	≤ 250
Nov	12.15	15.53	11.40	15.86	12.53	250.86	18.52	253.20	13.65	278.32	16.27	251.64	12.53	25.02	13.28	≤ 250
Dec	13.28	16.65	14.78	14.35	12.88	194.52	19.64	227.64	13.02	265.91	21.14	249.77	12.69	20.52	12.53	≤ 250
Jan	10.28	15.15	12.15	12.84	9.91	186.68	13.65	197.94	12.53	253.88	17.02	237.04	9.91	17.90	10.66	≤ 250
Feb	3.91	12.14	2.42	8.69	4.66	162.80	10.66	187.03	6.16	236.59	14.40	225.05	6.54	15.66	7.28	≤ 250
Mar	0.92	10.26	2.04	7.18	0.17	156.46	5.79	165.98	4.66	234.71	11.40	207.07	5.41	12.66	6.16	≤ 250
Apr	1.67	9.51	0.63	4.16	0.92	154.22	9.91	188.91	7.28	242.98	12.90	223.18	11.03	15.28	11.03	≤ 250
May	19.64	35.45	20.39	24.16	20.77	187.80	22.64	230.64	18.52	254.63	21.89	232.92	19.64	32.13	20.39	≤ 250

Appendix A6: Monthly variation of electrical conductivity (±0.02 µS/cm)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	FEPA Limit
Jun	122	131	126	124	120	601	136	690	123	789	143	747	120	140	120	≤ 750
Jul	114	127	119	120	113	580	139	611	120	757	132	713	113	133	115	≤ 750
Aug	97	119	93	109	99	516	123	582	103	711	125	681	104	127	106	≤ 750
Sep	89	114	92	105	87	499	115	526	99	706	117	633	101	119	103	≤ 750
Oct	91	112	88	97	89	493	102	587	106	728	121	676	116	126	116	≤ 750
Nov	139	181	141	150	142	583	113	698	136	759	145	702	139	171	141	≤ 750
Dec	157	189	154	169	155	812	155	841	153	844	157	793	156	190	155	≤ 750
Jan	159	184	161	173	161	863	158	896	160	907	160	798	162	197	162	≤ 750
Feb	146	171	145	158	148	823	149	853	145	915	148	786	147	186	148	≤ 750
Mar	150	173	153	162	152	776	150	880	151	901	152	762	153	181	151	≤ 750
Apr	135	164	132	148	139	759	137	793	137	890	134	755	138	174	138	≤ 750
May	119	128	117	128	120	752	136	758	123	822	130	752	120	152	122	≤ 750

Appendix A7: Monthly variation of dissolved oxygen (±0.01 mg/l)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	FEPA Limit
Jun	7.80	6.85	7.72	6.51	7.27	4.72	7.23	4.80	7.09	4.24	7.01	4.09	7.58	6.88	7.58	≥ 5.00
Jul	8.18	6.92	8.15	6.68	7.32	4.77	7.19	4.86	7.13	4.37	7.04	4.83	8.02	6.97	8.01	≥ 5.00
Aug	8.22	6.88	8.23	6.23	6.84	4.56	6.77	4.73	6.81	4.29	6.75	4.52	7.79	6.56	7.76	≥ 5.00
Sep	8.10	6.32	8.06	5.97	6.50	4.22	6.59	4.39	6.54	4.06	6.42	4.49	7.08	6.39	7.08	≥ 5.00
Oct	7.96	6.11	7.85	5.46	6.17	3.97	6.14	4.12	6.10	3.71	5.97	4.17	6.48	6.11	6.44	≥ 5.00
Nov	7.48	5.73	7.52	5.17	5.88	3.66	5.09	3.90	5.07	3.55	4.81	3.91	5.02	5.60	5.04	≥ 5.00
Dec	7.25	5.28	6.99	4.86	5.69	3.39	4.51	3.44	4.10	3.46	3.77	3.91	4.36	4.81	4.38	≥ 5.00
Jan	6.11	4.86	6.27	4.39	4.87	3.28	4.12	3.37	4.02	2.61	3.64	3.86	4.05	4.48	4.09	≥ 5.00
Feb	5.87	4.77	5.93	4.33	4.61	3.23	3.95	3.15	3.56	2.19	3.49	3.54	3.98	4.11	4.01	≥ 5.00
Mar	5.25	4.50	5.37	4.20	4.48	3.15	3.86	3.11	3.44	2.43	3.16	3.29	3.82	3.93	3.82	≥ 5.00
Apr	5.18	4.19	5.06	4.05	4.22	3.11	3.67	2.18	3.23	2.29	3.07	3.08	3.64	3.62	3.64	≥ 5.00
May	6.39	5.04	6.42	5.72	5.96	3.93	5.38	2.97	5.84	3.14	5.33	3.61	5.20	5.09	5.19	≥ 5.00

Appendix A8: Monthly variation of 5-days Biochemical Oxygen Demand (±0.01 mg/l)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	FEPA Limit
Jun	0.43	0.55	1.63	1.01	1.20	1.81	1.85	2.04	1.70	2.16	1.72	1.67	0.41	0.95	0.17	≤ 2.00
Jul	0.48	0.58	1.37	1.04	1.23	1.84	1.81	2.09	1.75	2.24	1.59	1.96	0.43	0.99	0.18	≤ 2.00
Aug	0.50	0.59	1.33	1.06	1.30	1.86	1.73	2.05	1.73	2.32	1.46	2.04	0.43	1.08	0.18	≤ 2.00
Sep	0.59	0.64	1.42	1.17	1.52	2.02	1.72	2.12	1.87	2.41	1.43	2.10	0.47	1.16	0.19	≤ 2.00
Oct	0.61	0.69	1.68	1.24	1.57	2.07	1.77	2.19	1.85	2.46	1.49	2.19	0.54	1.35	0.22	≤ 2.00
Nov	0.65	0.74	1.84	1.31	1.65	2.12	1.94	2.55	1.96	2.66	1.54	2.36	0.69	1.47	0.28	≤ 2.00
Dec	0.66	0.77	1.94	1.44	1.74	2.21	2.08	2.68	1.99	2.88	1.97	2.42	0.76	1.54	0.31	≤ 2.00
Jan	0.67	0.83	1.98	1.50	1.83	2.34	2.23	2.72	2.41	2.02	2.18	2.49	0.83	1.58	0.34	≤ 2.00
Feb	0.66	0.84	2.00	1.61	1.96	2.51	2.40	2.71	2.57	2.07	2.25	2.63	0.86	1.68	0.35	≤ 2.00
Mar	0.63	0.83	1.93	1.57	1.94	2.46	2.44	2.69	2.55	1.99	2.40	2.60	0.81	1.66	0.33	≤ 2.00
Apr	0.52	0.61	1.91	1.38	1.59	2.51	1.98	1.76	2.93	1.31	2.58	2.66	0.56	1.23	0.23	≤ 2.00
May	0.42	0.51	1.88	0.97	1.13	2.03	1.91	1.38	1.79	2.02	1.86	1.86	0.39	0.87	0.16	≤ 2.00

Appendix A9: Monthly variation of Chemical Oxygen Demand (±0.1 mg/l)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	FEPA Limit
Jun	35.08	36.49	49.92	40.84	41.94	46.50	53.25	61.72	52.35	58.23	48.33	53.10	37.91	43.00	35.91	≤ 20.00
Jul	33.79	35.00	47.88	39.18	40.23	44.60	51.08	58.17	50.18	55.82	46.06	50.61	36.13	39.96	33.37	≤ 20.00
Aug	34.32	35.55	48.64	39.79	40.86	45.30	51.88	59.08	50.97	56.70	46.79	51.41	36.70	40.59	33.90	≤ 20.00
Sep	36.04	37.33	51.07	41.78	42.91	47.57	54.48	62.05	53.53	59.55	49.13	53.98	38.54	42.62	35.59	≤ 20.00
Oct	37.99	39.35	53.83	44.04	45.22	50.14	57.42	65.40	56.41	62.76	51.78	56.89	40.62	44.92	37.51	≤ 20.00
Nov	40.12	41.55	56.84	46.51	47.76	52.95	60.64	69.06	59.58	66.28	54.69	60.09	42.90	47.45	39.63	≤ 20.00
Dec	41.46	42.95	58.76	48.07	49.36	54.73	62.68	71.38	61.58	68.50	56.53	62.11	44.34	49.04	40.96	≤ 20.00
Jan	43.26	44.80	61.29	50.15	51.50	57.10	65.39	74.48	64.25	71.47	58.97	64.79	46.26	51.16	42.73	≤ 20.00
Feb	43.84	45.41	62.13	50.83	51.18	57.93	66.34	75.56	65.18	72.51	59.83	65.74	46.93	51.91	43.35	≤ 20.00
Mar	44.39	45.98	62.91	51.47	52.85	58.59	67.09	76.42	65.93	73.34	60.51	66.48	47.46	52.49	43.84	≤ 20.00
Apr	45.07	46.68	63.86	52.25	53.66	59.49	68.13	77.59	66.94	74.46	61.44	67.50	48.19	53.30	44.51	≤ 20.00
May	36.21	37.51	51.32	41.98	43.11	47.80	54.74	62.35	53.78	59.82	49.37	54.24	38.72	42.83	35.77	≤ 20.00

Appendix A10: Monthly variation of total nitrogen (±0.01 mg/l)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	FEPA Limit
Jun	0.96	0.79	0.73	0.80	0.80	0.67	0.73	0.87	0.74	0.82	0.74	0.74	0.87	0.79	0.91	≤ 1.00
Jul	0.88	0.73	0.67	0.73	0.74	0.63	0.68	0.82	0.69	0.77	0.69	0.70	0.80	0.73	0.84	≤ 1.00
Aug	0.85	0.70	0.65	0.71	0.72	0.59	0.65	0.77	0.66	0.72	0.67	0.66	0.78	0.71	0.81	≤ 1.00
Sep	0.83	0.69	0.64	0.69	0.69	0.64	0.64	0.83	0.65	0.78	0.65	0.71	0.76	0.69	0.79	≤ 1.00
Oct	0.90	0.75	0.69	0.75	0.76	0.73	0.70	0.95	0.70	0.89	0.71	0.81	0.81	0.75	0.85	≤ 1.00
Nov	1.11	0.92	0.85	0.92	0.93	0.92	0.85	1.20	0.85	1.12	0.86	1.02	1.00	0.92	1.05	≤ 1.00
Dec	1.24	1.03	0.95	1.04	1.05	1.22	0.96	1.59	0.96	1.49	0.98	1.36	1.13	1.04	1.18	≤ 1.00
Jan	1.39	1.15	1.06	1.16	1.16	1.27	1.07	1.66	1.07	1.56	1.08	1.42	1.26	1.15	1.32	≤ 1.00
Feb	1.77	1.47	1.36	1.48	1.48	1.41	1.36	1.84	1.37	1.72	1.38	1.57	1.61	1.47	1.68	≤ 1.00
Mar	1.93	1.60	1.48	1.61	1.62	1.46	1.49	1.91	1.50	1.79	1.51	1.63	1.75	1.61	1.83	≤ 1.00
Apr	2.18	1.80	1.66	1.81	1.82	1.55	1.67	2.02	1.68	1.89	1.70	1.72	1.98	1.81	2.07	≤ 1.00
May	1.43	1.18	1.09	1.19	1.19	1.02	1.09	1.33	1.10	1.25	1.11	1.13	1.30	1.18	1.36	≤ 1.00

Appendix A11: Monthly variation of total phosphorus (±0.05 mg/l)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	FEPA Limit
Jun	0.140	0.115	0.107	0.117	0.117	0.098	0.107	0.114	0.108	0.120	0.109	0.108	0.127	0.115	0.133	≤ 0.100
Jul	0.128	0.107	0.098	0.107	0.108	0.092	0.099	0.106	0.101	0.112	0.102	0.102	0.117	0.107	0.123	≤ 0.100
Aug	0.124	0.102	0.095	0.104	0.105	0.101	0.095	0.119	0.096	0.105	0.096	0.096	0.114	0.104	0.118	≤ 0.100
Sep	0.121	0.101	0.093	0.101	0.102	0.097	0.093	0.115	0.095	0.114	0.096	0.104	0.111	0.101	0.115	≤ 0.100
Oct	0.131	0.110	0.100	0.110	0.111	0.107	0.102	0.122	0.103	0.130	0.104	0.118	0.118	0.110	0.124	≤ 0.100
Nov	0.162	0.134	0.124	0.134	0.136	0.129	0.124	0.148	0.125	0.164	0.126	0.149	0.146	0.134	0.153	≤ 0.100
Dec	0.181	0.150	0.139	0.152	0.153	0.145	0.140	0.193	0.141	0.218	0.141	0.200	0.165	0.152	0.172	≤ 0.100
Jan	0.203	0.168	0.155	0.169	0.169	0.161	0.156	0.217	0.156	0.228	0.157	0.207	0.184	0.168	0.193	≤ 0.100
Feb	0.258	0.215	0.200	0.216	0.216	0.204	0.199	0.236	0.200	0.251	0.201	0.229	0.235	0.215	0.245	≤ 0.100
Mar	0.282	0.234	0.216	0.235	0.237	0.226	0.218	0.244	0.219	0.261	0.220	0.238	0.256	0.235	0.267	≤ 0.100
Apr	0.318	0.263	0.242	0.264	0.266	0.251	0.244	0.258	0.245	0.276	0.246	0.251	0.289	0.264	0.302	≤ 0.100
May	0.209	0.172	0.159	0.174	0.174	0.164	0.159	0.160	0.161	0.183	0.163	0.165	0.190	0.172	0.198	≤ 0.100

Appendix A12: Monthly variation of iron (±0.001 mg/l)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	FEPA Limit
Jun	0.181	0.188	0.257	0.210	0.216	0.239	0.269	0.312	0.265	0.292	0.243	0.265	0.186	0.210	0.175	≤ 0.300
Jul	0.165	0.172	0.235	0.193	0.198	0.220	0.248	0.287	0.243	0.269	0.222	0.245	0.169	0.194	0.159	≤ 0.300
Aug	0.208	0.216	0.296	0.242	0.248	0.275	0.310	0.359	0.300	0.337	0.275	0.306	0.213	0.243	0.200	≤ 0.300
Sep	0.236	0.245	0.298	0.274	0.281	0.312	0.351	0.407	0.345	0.382	0.316	0.346	0.242	0.275	0.228	≤ 0.300
Oct	0.239	0.249	0.300	0.279	0.286	0.317	0.356	0.413	0.350	0.387	0.320	0.351	0.245	0.280	0.230	≤ 0.300
Nov	0.241	0.251	0.343	0.281	0.288	0.319	0.359	0.416	0.353	0.390	0.323	0.354	0.247	0.282	0.232	≤ 0.300
Dec	0.248	0.258	0.353	0.289	0.298	0.330	0.371	0.430	0.365	0.403	0.334	0.366	0.254	0.290	0.239	≤ 0.300
Jan	0.294	0.306	0.419	0.342	0.351	0.389	0.437	0.507	0.430	0.475	0.394	0.431	0.302	0.343	0.284	≤ 0.300
Feb	0.399	0.415	0.568	0.464	0.476	0.528	0.594	0.689	0.584	0.646	0.535	0.586	0.409	0.465	0.385	≤ 0.300
Mar	0.463	0.482	0.659	0.539	0.553	0.613	0.689	0.799	0.662	0.749	0.606	0.680	0.475	0.540	0.447	≤ 0.300
Apr	0.343	0.357	0.488	0.400	0.411	0.456	0.513	0.595	0.505	0.558	0.462	0.506	0.352	0.401	0.331	≤ 0.300
May	0.249	0.259	0.291	0.290	0.298	0.311	0.350	0.406	0.344	0.381	0.314	0.345	0.255	0.291	0.240	≤ 0.300

Appendix A13: Monthly variation of manganese (±0.001 mg/l)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	FEPA Limit
Jun	0.064	ND	0.070	0.074	0.076	0.085	0.095	0.099	0.092	0.103	0.085	0.093	0.066	0.075	0.062	≤ 0.200
Jul	0.106	ND	0.119	0.123	0.125	0.141	0.157	0.166	0.155	0.172	0.143	0.156	0.110	0.124	0.103	≤ 0.200
Aug	0.121	ND	0.136	0.140	0.143	0.161	0.179	0.190	0.176	0.196	0.163	0.177	0.126	0.141	0.119	≤ 0.200
Sep	0.143	0.011	0.155	0.166	0.170	0.190	0.212	0.225	0.209	0.233	0.193	0.211	0.150	0.167	0.141	≤ 0.200
Oct	0.168	0.019	0.186	0.195	0.214	0.247	0.275	0.291	0.271	0.301	0.250	0.272	0.176	0.200	0.166	≤ 0.200
Nov	0.192	0.025	0.200	0.254	0.260	0.292	0.326	0.345	0.321	0.357	0.296	0.323	0.197	0.256	0.185	≤ 0.200
Dec	0.246	0.028	0.255	0.285	0.291	0.326	0.364	0.386	0.359	0.399	0.331	0.361	0.257	0.286	0.242	≤ 0.200
Jan	0.285	0.037	0.312	0.331	0.338	0.380	0.424	0.449	0.417	0.464	0.385	0.419	0.298	0.333	0.280	≤ 0.200
Feb	0.310	0.043	0.346	0.359	0.366	0.412	0.459	0.486	0.451	0.502	0.417	0.454	0.323	0.362	0.304	≤ 0.200
Mar	0.364	0.056	0.374	0.422	0.428	0.482	0.537	0.569	0.529	0.588	0.488	0.532	0.377	0.423	0.355	≤ 0.200
Apr	0.249	0.031	0.322	0.289	0.294	0.330	0.368	0.390	0.362	0.403	0.334	0.364	0.259	0.290	0.244	≤ 0.200
May	0.139	0.018	0.200	0.161	0.165	0.186	0.207	0.219	0.203	0.226	0.188	0.198	0.145	0.163	0.136	≤ 0.200

ND = Not Detected.

APPENDIX B: WATER QUALITY INDEX COMPUTATION TABLES

Appendix B1: Water quality index computation table for sampling location L2 (Kwarau)

	Temp °C	Turb (NTU)	TDS (mg/l)	pH	Cl^- (mg/l)	EC (µS/cm)	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	TN (mg/l)	TP (mg/l)	Fe (mg/l)	Mn (mg/l)
June	26	**49.359**	127	7.3	38.45	189	6.85	0.55	**36.49**	0.79	**0.115**	0.188	ND
July	26	**58.018**	123	7.3	36.58	184	6.92	0.58	**35.00**	0.73	**0.107**	0.172	ND
August	28	**46.199**	115	6.8	31.69	171	6.88	0.59	**35.55**	0.70	**0.102**	0.216	ND
September	26	**27.786**	116	6.7	32.44	173	6.32	0.64	**37.33**	0.69	**0.101**	0.245	0.011
October	24	**18.454**	110	6.8	29.06	164	6.11	0.69	**39.35**	0.75	**0.110**	0.249	0.019
November	22	**8.741**	86	6.8	15.53	128	5.73	0.74	**41.55**	0.92	**0.134**	0.251	0.025
December	22	**7.453**	88	7.4	16.65	131	5.28	0.77	**42.95**	**1.03**	**0.150**	0.258	0.028
January	21	**7.012**	85	7.4	15.15	127	**4.86**	0.83	**44.80**	**1.15**	**0.168**	**0.306**	0.037
February	22	**5.955**	80	7.5	12.14	119	**4.77**	0.84	**45.41**	**1.47**	**0.215**	**0.415**	0.043
March	22	3.938	76	7.6	10.26	114	**4.50**	0.83	**45.98**	**1.60**	**0.234**	**0.482**	0.056
April	23	2.843	75	7.3	9.51	112	**4.19**	0.61	**46.68**	**1.80**	**0.263**	**0.357**	0.031
May	26	**38.994**	121	7.3	35.45	181	5.04	0.51	**37.51**	**1.18**	**0.172**	0.259	0.018
Objective	≤ 40	≤ 5.0	≤ 500	6.5-8.5	≤ 250	≤ 750	≥ 5.0	≤ 2.0	≤ 20	≤ 1.0	≤ 0.1	≤ 0.3	≤ 0.2

3) Temp = Temperature, Turb = Turbidity, TDS = Total Dissolved Solids, Cl^- = Chloride, DO = Dissolved Oxygen, BOD_5 = 5-days Biochemical Oxygen Demand, COD = Chemical Oxygen Demand, TN = Total Nitrogen, TP = Total Phosphorous, Fe = Iron, Mn = Manganese, ND = Not Detected, ≤ = less than or equal to, ≥ = greater than or equal to.

4) Bold values do not meet the objective.

The number of variables (parameters) not meeting the objectives is 6 (i.e Turb, DO, COD, TN, TP, and Fe) while the total number of variables is 13. Therefore,

Scope, $F_1 = \left[\frac{6}{13}\right] \times 100 = 46.15$

The number of tests not meeting the objectives is 48 while the total number of tests is 156. Hence,

Frequency, $F_2 = \left[\frac{48}{156}\right] \times 100 = 30.77$

Normalized sum of excursions, $nse = \frac{\sum_{i=1}^{n=48} excursion_{\ i}}{number\ \ of\ tests} = \frac{66.55}{144} = 0.4622$

Amplitude, $F_3 = \frac{nse}{0.01nse + 0.01} = \left[\frac{0.4622}{0.01(0.4622) + 0.01}\right] = \frac{0.4622}{0.014622} = 31.61$

$$WQI = 100 - \frac{\sqrt{\left({F_1}^2 + {F_2}^2 + {F_3}^2\right)}}{1.732} = 100 - \frac{\sqrt{(46.15^2 + 30.77^2 + 31.61^2)}}{1.732} = 63.14$$

Appendix B2:Water quality index computation table for sampling location L3 (NNPC)

	Temp °C	Turb (NTU)	TDS (mg/l)	pH	Cl^- (mg/l)	EC (µS/cm)	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	TN (mg/l)	TP (mg/l)	Fe (mg/l)	Mn (mg/l)
June	26	**150.893**	103	7.3	25.26	154	7.72	1.63	**49.92**	0.73	**0.107**	0.257	0.070
July	26	**176.495**	107	6.9	27.88	161	8.15	1.37	**47.88**	0.67	0.098	0.235	0.119
August	27	**142.359**	97	6.8	21.89	145	8.23	1.33	**48.64**	0.65	0.095	0.296	0.136
September	28	**79.907**	102	6.8	24.89	153	8.06	1.42	**51.07**	0.64	0.093	0.298	0.155
October	25	**56.246**	88	7.3	17.02	132	7.85	1.68	**53.83**	0.69	0.100	0.300	0.186
November	23	4.254	78	7.5	11.40	117	7.52	1.84	**56.84**	0.85	**0.124**	**0.343**	0.200
December	21	3.673	84	7.4	14.78	126	6.99	1.94	**58.76**	0.95	**0.139**	**0.353**	**0.255**
January	22	3.430	79	7.5	12.15	119	6.27	1.98	**61.29**	**1.06**	**0.155**	**0.419**	**0.312**
February	21	2.914	62	7.5	2.42	93	5.93	2.00	**62.13**	**1.36**	**0.200**	**0.568**	**0.346**
March	19	1.902	61	7.4	2.04	92	5.37	1.93	**62.91**	**1.48**	**0.216**	**0.659**	**0.374**
April	24	1.387	59	7.4	0.63	88	5.06	1.91	**63.86**	**1.66**	**0.242**	**0.488**	**0.322**
May	27	**119.473**	94	7.3	20.39	141	6.42	1.88	**51.32**	**1.09**	**0.159**	0.291	0.200
Objective	≤ 40	≤ 5.0	≤ 500	6.5-8.5	≤ 250	≤ 750	≥ 5.0	≤ 2.0	≤ 20	≤ 1.0	≤ 0.1	≤ 0.3	≤ 0.2

1) Temp = Temperature, Turb = Turbidity, TDS = Total Dissolved Solids, Cl^- = Chloride, DO = Dissolved Oxygen, BOD_5 = 5-days Biochemical Oxygen Demand, COD = Chemical Oxygen Demand, TN = Total Nitrogen, TP = Total Phosphorous, Fe = Iron, Mn = Manganese, ≤ = less than or equal to, ≥ = greater than or equal to.
2) Bold values do not meet the objective.

The number of variables (parameters) not meeting the objectives is 6 (i.e Turb, COD, TN, TP, Fe and Mn) while the total number of variables is 13. Therefore,

Scope, $F_1 = \left[\frac{6}{13}\right] \times 100 = 46.15$

The number of tests not meeting the objectives is 42 while the total number of tests is 156. Hence,

Frequency, $F_2 = \left[\frac{42}{156}\right] \times 100 = 28.77$

Normalized sum of excursions, $nse = \frac{\sum_{i=1}^{n=42} excursion_{\ i}}{number\ \ of\ tests} = \frac{174.05}{156} = 1.116$

Amplitude, $F_3 = \frac{nse}{0.01nse + 0.01} = \left[\frac{1.116}{0.01(1.116)+0.01}\right] = \frac{1.116}{0.02116} = 52.74$

$$WQI = 100 - \frac{\sqrt{\left({F_1}^2 + {F_2}^2 + {F_3}^2\right)}}{1.732} = 100 - \frac{\sqrt{(46.15^2 + 28.77^2 + 52.74^2)}}{1.732} = 56.26$$

Appendix B3:Water quality index computation table for sampling location L4 (Kuyi)

	Temp °C	Turb (NTU)	TDS (mg/l)	pH	Cl^- (mg/l)	EC (µS/cm)	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	TN (mg/l)	TP (mg/l)	Fe (mg/l)	Mn (mg/l)
June	27	**83.361**	113	6.7	31.33	169	6.51	1.01	**40.84**	0.80	**0.117**	0.210	0.074
July	25	**98.072**	116	6.7	32.84	173	6.68	1.04	**39.18**	0.73	**0.107**	0.193	0.123
August	26	**77.818**	106	6.5	27.18	158	6.23	1.06	**39.79**	0.71	**0.104**	0.242	0.140
September	27	**43.280**	108	6.6	28.69	162	5.97	1.17	**41.78**	0.69	**0.101**	0.274	0.166
October	26	**31.340**	99	6.8	23.40	148	5.46	1.24	**44.04**	0.75	**0.110**	0.279	0.195
November	22	**9.054**	86	6.7	15.86	128	5.17	1.31	**46.51**	0.92	**0.134**	0.281	**0.254**
December	22	**7.777**	83	6.8	14.35	124	**4.86**	1.44	**48.07**	**1.04**	**0.152**	0.289	**0.285**
January	22	**7.337**	80	7.3	12.84	120	**4.39**	1.50	**50.15**	**1.16**	**0.169**	**0.342**	**0.331**
February	21	**6.159**	73	7.3	8.69	109	**4.33**	1.61	**50.83**	**1.48**	**0.216**	**0.464**	**0.359**
March	20	4.073	70	7.4	7.18	105	**4.20**	1.57	**51.47**	**1.61**	**0.235**	**0.539**	**0.422**
April	23	2.935	65	7.2	4.16	97	**4.05**	1.38	**52.25**	**1.81**	**0.264**	**0.400**	**0.289**
May	26	**66.093**	100	6.9	24.16	150	5.72	0.97	**41.98**	**1.19**	**0.174**	0.290	0.161
Objective	≤ 40	≤ 5.0	≤ 500	6.5-8.5	≤ 250	≤ 750	≥ 5.0	≤ 2.0	≤ 20	≤ 1.0	≤ 0.1	≤ 0.3	≤ 0.2

1) Temp = Temperature, Turb = Turbidity, TDS = Total Dissolved Solids, Cl^- = Chloride, DO = Dissolved Oxygen, BOD_5 = 5-days Biochemical Oxygen Demand, COD = Chemical Oxygen Demand, TN = Total Nitrogen, TP = Total Phosphorous, Fe = Iron, Mn = Manganese, ≤ = less than or equal to, ≥ = greater than or equal to.
2) Bold values do not meet the objective.

The number of variables (parameters) not meeting the objectives is 7 (i.e Turb, DO, COD, TN, TP, Fe and Mn) while the total number of variables is 13. Therefore,

Scope, $F_1 = \left[\frac{7}{13}\right] \times 100 = 53.85$

The number of tests not meeting the objectives is 55 while the total number of tests is 156. Hence,

Frequency, $F_2 = \left[\frac{55}{156}\right] \times 100 = 35.27$

Normalized sum of excursions, $nse = \frac{\sum_{i=1}^{n=55} excursion_{\ i}}{number\ \ of\ tests} = \frac{106.8}{156} = 0.6846$

Amplitude, $F_3 = \frac{nse}{0.01nse + 0.01} = \left[\frac{0.6846}{0.01(0.6846)+0.01}\right] = \frac{0.6846}{0.016846} = 40.64$

$$WQI = 100 - \frac{\sqrt{\left({F_1}^2 + {F_2}^2 + {F_3}^2\right)}}{1.732} = 100 - \frac{\sqrt{(46.15^2 + 35.27^2 + 40.64^2)}}{1.732} = 59.07$$

Appendix B4:Water quality index computation table for sampling location L5 (Barnawa)

	Temp °C	Turb (NTU)	TDS (mg/l)	pH	Cl^- (mg/l)	EC (µS/cm)	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	TN (mg/l)	TP (mg/l)	Fe (mg/l)	Mn (mg/l)
June	26	**81.003**	103	7.3	25.64	155	7.27	1.20	**41.94**	0.80	**0.117**	0.216	0.076
July	27	**95.127**	107	6.8	27.88	161	7.32	1.23	**40.23**	0.74	**0.108**	0.198	0.125
August	26	**76.018**	99	6.7	23.01	148	6.84	1.30	**40.86**	0.72	**0.105**	0.248	0.143
September	27	**42.579**	101	6.8	24.51	152	6.50	1.52	**42.91**	0.69	**0.102**	0.281	0.170
October	26	**30.117**	93	7.4	19.64	139	6.17	1.57	**45.22**	0.76	**0.111**	0.286	**0.214**
November	22	**9.400**	82	7.6	12.53	120	5.88	1.65	**47.76**	0.93	**0.136**	0.288	**0.260**
December	23	**8.030**	80	7.4	12.88	120	5.69	1.74	**49.36**	**1.05**	**0.153**	0.298	**0.291**
January	21	**7.657**	75	7.5	9.91	113	**4.87**	1.83	**51.50**	**1.16**	**0.169**	**0.351**	**0.338**
February	22	**6.350**	66	7.3	4.66	99	**4.61**	1.96	**51.18**	**1.48**	**0.216**	**0.476**	**0.366**
March	20	4.254	58	7.4	0.17	87	**4.48**	1.94	**52.85**	**1.62**	**0.237**	**0.553**	**0.428**
April	23	3.030	59	7.5	0.92	89	**4.22**	1.59	**53.66**	**1.82**	**0.266**	**0.411**	**0.294**
May	26	**63.764**	95	7.4	20.77	142	5.96	1.13	**43.11**	**1.19**	**0.174**	0.298	0.165
Objective	≤ 40	≤ 5.0	≤ 500	6.5-8.5	≤ 250	≤ 750	≥ 5.0	≤ 2.0	≤ 20	≤ 1.0	≤ 0.1	≤ 0.3	≤ 0.2

1) Temp = Temperature, Turb = Turbidity, TDS = Total Dissolved Solids, Cl^- = Chloride, DO = Dissolved Oxygen, BOD_5 = 5-days Biochemical Oxygen Demand, COD = Chemical Oxygen Demand, TN = Total Nitrogen, TP = Total Phosphorous, Fe = Iron, Mn = Manganese, ≤ = less than or equal to, ≥ = greater than or equal to.
2) Bold values do not meet the objective.

The number of variables (parameters) not meeting the objectives is 7 (i.e Turb, DO, COD, TN, TP, Fe and Mn) while the total number of variables is 13. Therefore,

Scope, $F_1 = \left[\frac{7}{13}\right] \times 100 = 53.85$

The number of tests not meeting the objectives is 55 while the total number of tests is 156. Hence,

Frequency, $F_2 = \left[\frac{55}{156}\right] \times 100 = 35.26$

Normalized sum of excursions, $nse = \frac{\sum_{i=1}^{n=55} excursion_{\ i}}{number\ \ of\ tests} = \frac{105.64}{156} = 0.6772$

Amplitude, $F_3 = \frac{nse}{0.01nse + 0.01} = \left[\frac{0.6772}{0.01(0.6772) + 0.01}\right] = \frac{0.6772}{0.016772} = 40.38$

$$WQI = 100 - \frac{\sqrt{\left({F_1}^2 + {F_2}^2 + {F_3}^2\right)}}{1.732} = 100 - \frac{\sqrt{(53.85^2 + 35.26^2 + 40.38^2)}}{1.732} = 56.13$$

Appendix B5:Water quality index computation table for sampling location L6 (Kutimbi)

	Temp °C	Turb (NTU)	TDS (mg/l)	pH	Cl^- (mg/l)	EC (µS/cm)	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	TN (mg/l)	TP (mg/l)	Fe (mg/l)	Mn (mg/l)
June	28	**95.416**	**542**	**6.3**	**273.25**	**812**	**4.72**	1.81	**46.50**	0.67	0.098	0.239	0.085
July	26	**111.871**	**576**	**6.3**	**292.28**	**863**	**4.77**	1.84	**44.60**	0.63	0.092	0.220	0.141
August	27	**90.258**	**550**	**6.2**	**277.35**	**823**	**4.56**	1.86	**45.30**	0.59	**0.101**	0.275	0.161
September	25	**50.348**	**518**	**6.4**	**259.82**	**776**	**4.22**	**2.02**	**47.57**	0.64	0.097	**0.312**	0.190
October	25	**35.735**	**507**	6.6	**253.47**	**759**	**3.97**	**2.07**	**50.14**	0.73	**0.107**	**0.317**	**0.247**
November	23	**6.869**	**502**	6.8	**250.86**	**752**	**3.66**	**2.12**	**52.95**	0.92	**0.129**	**0.319**	**0.292**
December	22	**5.859**	401	6.8	194.52	601	**3.39**	**2.21**	**54.73**	**1.22**	**0.145**	**0.330**	**0.326**
January	21	**5.542**	387	6.9	186.68	580	**3.28**	**2.34**	**57.10**	**1.27**	**0.161**	**0.389**	**0.380**
February	21	4.622	345	6.8	162.80	516	**3.23**	**2.51**	**57.93**	**1.41**	**0.204**	**0.528**	**0.412**
March	19	3.091	333	6.7	156.46	499	**3.15**	**2.46**	**58.59**	**1.46**	**0.226**	**0.613**	**0.482**
April	22	2.194	329	6.6	154.22	493	**3.11**	**2.51**	**59.49**	**1.55**	**0.251**	**0.456**	**0.330**
May	27	**75.276**	389	**6.4**	187.80	583	**3.93**	**2.03**	**47.80**	**1.02**	**0.164**	**0.311**	0.186
Objective	≤ 40	≤ 5.0	≤ 500	6.5-8.5	≤ 250	≤ 750	≥ 5.0	≤ 2.0	≤ 20	≤ 1.0	≤ 0.1	≤ 0.3	≤ 0.2

1) Temp = Temperature, Turb = Turbidity, TDS = Total Dissolved Solids, Cl^- = Chloride, DO = Dissolved Oxygen, BOD_5 = 5-days Biochemical Oxygen Demand, COD = Chemical Oxygen Demand, TN = Total Nitrogen, TP = Total Phosphorous, Fe = Iron, Mn = Manganese, ≤ = less than or equal to, ≥ = greater than or equal to.
2) Bold values do not meet the objective.

The number of variables (parameters) not meeting the objectives is 12 (i.e Turb, TDS, pH, Cl^-, EC, DO, BOD_5, COD, TN, TP, Fe and Mn) while the total number of variables is 13. Therefore,

Scope, $F_1 = \left[\frac{12}{13}\right] \times 100 = 92.31$

The number of tests not meeting the objectives is 96 while the total number of tests is 156. Hence,

Frequency, $F_2 = \left[\frac{96}{156}\right] \times 100 = 61.54$

Normalized sum of excursions, $nse = \frac{\sum_{i=1}^{n=96} excursion_i}{number\ \ of\ tests} = \frac{128.18}{156} = 0.8217$

Amplitude, $F_3 = \frac{nse}{0.01nse + 0.01} = \left[\frac{0.8217}{0.01(0.8217) + 0.01}\right] = \frac{0.8217}{0.018217} = 45.11$

$$WQI = 100 - \frac{\sqrt{\left({F_1}^2 + {F_2}^2 + {F_3}^2\right)}}{1.732} = 100 - \frac{\sqrt{(92.31^2 + 61.54^2 + 45.11^2)}}{1.732} = 30.85$$

Appendix B6:Water quality index computation table for sampling location L7 (Living Faith)

	Temp °C	Turb (NTU)	TDS (mg/l)	pH	Cl^- (mg/l)	EC (µS/cm)	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	TN (mg/l)	TP (mg/l)	Fe (mg/l)	Mn (mg/l)
June	27	**110.073**	103	7.2	25.64	155	7.23	1.85	**53.25**	0.73	**0.107**	0.269	0.095
July	25	**128.159**	105	6.8	26.76	158	7.19	1.81	**51.08**	0.68	0.099	0.248	0.157
August	28	**103.856**	99	6.7	23.39	149	6.77	1.73	**51.88**	0.65	0.095	**0.310**	0.179
September	26	**57.650**	100	6.8	23.76	150	6.59	1.72	**54.48**	0.64	0.093	**0.351**	**0.212**
October	25	**41.542**	91	7.3	18.90	137	6.14	1.77	**57.42**	0.70	**0.102**	**0.356**	**0.275**
November	24	4.939	91	7.7	18.52	136	5.09	1.94	**60.64**	0.85	**0.124**	**0.359**	**0.326**
December	22	4.206	93	7.5	19.64	139	**4.51**	**2.08**	**62.68**	0.96	**0.140**	**0.371**	**0.364**
January	22	3.947	82	7.4	13.65	123	**4.12**	**2.23**	**65.39**	**1.07**	**0.156**	**0.437**	**0.424**
February	20	3.311	77	7.5	10.66	115	**3.95**	**2.40**	**66.34**	**1.36**	**0.199**	**0.594**	**0.459**
March	20	2.211	68	7.4	5.79	102	**3.86**	**2.44**	**67.09**	**1.49**	**0.218**	**0.689**	**0.537**
April	22	1.564	75	7.6	9.91	113	**3.67**	1.98	**68.13**	**1.67**	**0.244**	**0.513**	**0.368**
May	25	**87.182**	98	7.3	22.64	147	5.38	1.91	**54.74**	**1.09**	**0.159**	**0.350**	**0.207**
Objective	≤ 40	≤ 5.0	≤ 500	6.5-8.5	≤ 250	≤ 750	≥ 5.0	≤ 2.0	≤ 20	≤ 1.0	≤ 0.1	≤ 0.3	≤ 0.2

1) Temp = Temperature, Turb = Turbidity, TDS = Total Dissolved Solids, Cl^- = Chloride, DO = Dissolved Oxygen, BOD_5 = 5-days Biochemical Oxygen Demand, COD = Chemical Oxygen Demand, TN = Total Nitrogen, TP = Total Phosphorous, Fe = Iron, Mn = Manganese, ≤ = less than or equal to, ≥ = greater than or equal to.
2) Bold values do not meet the objective.

The number of variables (parameters) not meeting the objectives is 8 (i.e Turb, DO,BOD_5, COD, TN, TP, Fe and Mn) while the total number of variables is 13. Therefore,

Scope, $F_1 = \left[\frac{8}{13}\right] \times 100 = 61.54$

The number of tests not meeting the objectives is 60 while the total number of tests is 156. Hence,

Frequency, $F_2 = \left[\frac{60}{156}\right] \times 100 = 38.46$

Normalized sum of excursions, $nse = \frac{\sum_{i=1}^{n=60} excursion_{\ i}}{number\ \ of\ tests} = \frac{143.66}{156} = 0.9209$

Amplitude, $F_3 = \frac{nse}{0.01nse + 0.01} = \left[\frac{0.9209}{0.01(0.9209)+0.01}\right] = \frac{0.9209}{0.019209} = 47.94$

$$WQI = 100 - \frac{\sqrt{\left({F_1}^2 + {F_2}^2 + {F_3}^2\right)}}{1.732} = 100 - \frac{\sqrt{(61.54^2 + 38.46^2 + 47.94^2)}}{1.732} = 49.78$$

Appendix B7:Water quality index computation table for sampling location L8 (Kigo)

	Temp °C	Turb (NTU)	TDS (mg/l)	pH	Cl^- (mg/l)	EC (µS/cm)	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	TN (mg/l)	TP (mg/l)	Fe (mg/l)	Mn (mg/l)
June	26	**188.258**	**561**	**6.4**	**284.40**	**841**	**4.80**	**2.04**	**61.72**	0.87	**0.114**	**0.312**	0.099
July	27	**221.251**	**598**	**6.2**	**305.08**	**896**	**4.86**	**2.09**	**58.17**	0.82	**0.106**	0.287	0.166
August	25	**176.613**	**569**	**6.2**	**288.91**	**853**	**4.73**	**2.05**	**59.08**	0.77	**0.119**	**0.359**	0.190
September	27	**100.436**	**587**	**6.3**	**299.06**	**880**	**4.39**	**2.12**	**62.05**	0.83	**0.115**	**0.407**	**0.225**
October	26	**71.810**	**529**	6.5	**266.36**	**793**	**4.12**	**2.19**	**65.40**	0.95	**0.122**	**0.413**	**0.291**
November	22	1.833	**506**	6.6	**253.20**	**758**	**3.90**	**2.55**	**69.06**	**1.20**	**0.148**	**0.416**	**0.345**
December	22	1.560	460	6.8	227.64	690	**3.44**	**2.68**	**71.38**	**1.59**	**0.193**	**0.430**	**0.386**
January	23	1.460	408	7.1	197.94	611	**3.37**	**2.72**	**74.48**	**1.66**	**0.217**	**0.507**	**0.449**
February	21	1.232	388	7.3	187.03	582	**3.15**	**2.71**	**75.56**	**1.84**	**0.236**	**0.689**	**0.486**
March	19	0.878	351	7.4	165.98	526	**3.11**	**2.69**	**76.42**	**1.91**	**0.244**	**0.799**	**0.569**
April	24	0.583	392	6.8	188.91	587	**2.18**	1.76	**77.59**	**2.02**	**0.258**	**0.595**	**0.390**
May	24	**149.927**	466	**6.3**	230.64	698	**2.97**	1.38	**62.35**	**1.33**	**0.160**	**0.406**	**0.219**
Objective	≤ 40	≤ 5.0	≤ 500	6.5-8.5	≤ 250	≤ 750	≥ 5.0	≤ 2.0	≤ 20	≤ 1.0	≤ 0.1	≤ 0.3	≤ 0.2

1) Tem = Temperature, Turb = Turbidity, TDS = Total Dissolved Solids, Cl^- = Chloride, DO = Dissolved Oxygen, BOD_5 = 5-days Biochemical Oxygen Demand, COD = Chemical Oxygen Demand, TN = Total Nitrogen, TP = Total Phosphorous, Fe = Iron, Mn = Manganese, ≤ = less than or equal to, ≥ = greater than or equal to.
2) Bold values do not meet the objective.

The number of variables (parameters) not meeting the objectives is 12 (i.e Turb, TDS, pH, Cl^-, EC, DO, BOD_5, COD, TN, TP, Fe and Mn) while the total number of variables is 13. Therefore,

Scope, $F_1 = \left[\frac{12}{13}\right] \times 100 = 92.31$

The number of tests not meeting the objectives is 103 while the total number of tests is 156. Hence,

Frequency, $F_2 = \left[\frac{102}{156}\right] \times 100 = 65.38$

Normalized sum of excursions, $nse = \frac{\sum_{i=1}^{n=102} excursion_{\ i}}{number\ \ of\ tests} = \frac{240.98}{156} = 1.545$

Amplitude, $F_3 = \frac{nse}{0.01nse + 0.01} = \left[\frac{1.545}{0.01(1.545)+0.01}\right] = \frac{1.545}{0.02545} = 60.71$

$$WQI = 100 - \frac{\sqrt{\left({F_1}^2 + {F_2}^2 + {F_3}^2\right)}}{1.732} = 100 - \frac{\sqrt{(92.31^2 + 65.38^2 + 60.71^2)}}{1.732} = 25.88$$

Appendix B8:Water quality index computation table for sampling location L9 (Down Quaters)

	Temp ^{o}C	Turb (NTU)	TDS (mg/l)	pH	Cl^- (mg/l)	EC (µS/cm)	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	TN (mg/l)	TP (mg/l)	Fe (mg/l)	Mn (mg/l)
June	25	**109.712**	102	7.2	24.89	153	7.09	1.70	**52.35**	0.74	**0.108**	0.265	0.092
July	27	**128.492**	107	6.9	27.51	160	7.13	1.75	**50.18**	0.69	**0.101**	0.243	0.155
August	26	**103.782**	97	6.8	21.89	145	6.81	1.73	**50.97**	0.66	0.096	0.300	0.176
September	26	**58.174**	101	6.9	24.14	151	6.54	1.87	**53.53**	0.65	0.095	**0.345**	**0.209**
October	25	**41.230**	91	6.7	18.90	137	6.10	1.85	**56.41**	0.70	**0.103**	**0.350**	**0.271**
November	23	**5.223**	82	6.9	13.65	123	5.07	1.96	**59.58**	0.85	**0.125**	**0.353**	**0.321**
December	21	4.443	82	7.2	13.02	123	**4.10**	1.99	**61.58**	0.96	**0.141**	**0.365**	**0.359**
January	22	4.148	80	7.4	12.53	120	**4.02**	**2.41**	**64.25**	**1.07**	**0.156**	**0.430**	**0.417**
February	20	3.523	69	7.4	6.16	103	**3.56**	**2.57**	**65.18**	**1.37**	**0.200**	**0.584**	**0.451**
March	20	2.307	66	7.4	4.66	99	**3.44**	**2.55**	**65.93**	**1.50**	**0.219**	**0.662**	**0.529**
April	23	1.670	71	7.3	7.28	106	**3.23**	**2.93**	**66.94**	**1.68**	**0.245**	**0.505**	**0.362**
May	26	**86.979**	91	7.2	18.52	136	5.84	1.79	**53.78**	**1.10**	**0.161**	**0.344**	**0.203**
Objective	≤ 40	≤ 5.0	≤ 500	6.5-8.5	≤ 250	≤ 750	≥ 5.0	≤ 2.0	≤ 20	≤ 1.0	≤ 0.1	≤ 0.3	≤ 0.2

1) Temp = Temperature, Turb = Turbidity, TDS = Total Dissolved Solids, Cl^- = Chloride, DO = Dissolved Oxygen, BOD_5 = 5-days Biochemical Oxygen Demand, COD = Chemical Oxygen Demand, TN = Total Nitrogen, TP = Total Phosphorous, Fe = Iron, Mn = Manganese, ≤ = less than or equal to, ≥ = greater than or equal to.
2) Bolded values do not meet the objective.

The number of variables (parameters) not meeting the objectives is 8 (i.e Turb, DO,BOD_5, COD, TN, TP, Fe and Mn) while the total number of variables is 13. Therefore,

Scope, $F_1 = \left[\frac{8}{13}\right] \times 100 = 61.54$

The number of tests not meeting the objectives is 61 while the total number of tests is 156. Hence,

Frequency, $F_2 = \left[\frac{61}{156}\right] \times 100 = 39.10$

Normalized sum of excursions, $nse = \frac{\sum_{i=1}^{n=61} excursion_{\ i}}{number\ \ of\ tests} = \frac{164.97}{156} = 1.056$

Amplitude, $F_3 = \frac{nse}{0.01nse + 0.01} = \left[\frac{1.056}{0.01(1.056)+0.01}\right] = \frac{1.056}{0.02056} = 51.36$

$$WQI = 100 - \frac{\sqrt{\left({F_1}^2 + {F_2}^2 + {F_3}^2\right)}}{1.732} = 100 - \frac{\sqrt{(61.54^2 + 39.10^2 + 51.36^2)}}{1.732} = 48.51$$

Appendix B9: Water quality index computation table for sampling location L10 (Breweries)

	Temp °C	Turb (NTU)	TDS (mg/l)	pH	Cl^- (mg/l)	EC (µS/cm)	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	TN (mg/l)	TP (mg/l)	Fe (mg/l)	Mn (mg/l)
June	28	**167.500**	**562**	**8.9**	**286.59**	**844**	**4.24**	**2.16**	**58.23**	0.82	**0.120**	0.292	0.103
July	29	**196.424**	**604**	**8.8**	**310.27**	**907**	**4.37**	**2.24**	**55.82**	0.77	**0.112**	0.269	0.172
August	27	**158.866**	**609**	**8.7**	**313.28**	**915**	**4.29**	**2.32**	**56.70**	0.72	**0.105**	**0.337**	0.196
September	26	**88.930**	**600**	**8.9**	**308.02**	**901**	**4.06**	**2.41**	**59.55**	0.78	**0.114**	**0.382**	**0.233**
October	26	**63.460**	**593**	**8.9**	**303.88**	**890**	**3.71**	**2.46**	**62.76**	0.89	**0.130**	**0.387**	**0.301**
November	22	2.308	**547**	**9.0**	**278.32**	**822**	**3.55**	**2.66**	**66.28**	**1.12**	**0.164**	**0.390**	**0.357**
December	23	1.961	**525**	**9.1**	**265.91**	**789**	**3.46**	**2.88**	**68.50**	**1.49**	**0.218**	**0.403**	**0.399**
January	23	1.847	**504**	**9.2**	**253.88**	**757**	**2.61**	**2.02**	**71.47**	**1.56**	**0.228**	**0.475**	**0.464**
February	21	1.553	474	**9.1**	236.59	711	**2.19**	**2.07**	**72.51**	**1.72**	**0.251**	**0.646**	**0.502**
March	20	1.024	470	**9.3**	234.71	706	**2.43**	1.99	**73.34**	**1.79**	**0.261**	**0.749**	**0.588**
April	23	0.737	485	**9.2**	242.98	728	**2.29**	1.31	**74.46**	**1.89**	**0.276**	**0.558**	**0.403**
May	26	**132.964**	**505**	**9.0**	**254.63**	**759**	**3.14**	**2.02**	**59.82**	**1.25**	**0.183**	**0.381**	**0.226**
Objective	≤ 40	≤ 5.0	≤ 500	6.5-8.5	≤ 250	≤ 750	≥ 5.0	≤ 2.0	≤ 20	≤ 1.0	≤ 0.1	≤ 0.3	≤ 0.2

1) Temp = Temperature, Turb = Turbidity, TDS = Total Dissolved Solids, Cl^- = Chloride, DO = Dissolved Oxygen, BOD_5 = 5-days Biochemical Oxygen Demand, COD = Chemical Oxygen Demand, TN = Total Nitrogen, TP = Total Phosphorous, Fe = Iron, Mn = Manganese, ≤ = less than or equal to, ≥ = greater than or equal to.
2) Bold values do not meet the objective.

The number of variables (parameters) not meeting the objectives is 12 (i.e Turb, TDS, pH, Cl^-,EC,DO,BOD_5, COD, TN, TP, Fe and Mn) while the total number of variables is 13. Therefore,

Scope, $F_1 = \left[\frac{12}{13}\right] \times 100 = 92.31$

The number of tests not meeting the objectives is 117 while the total number of tests is 156. Hence,

Frequency, $F_2 = \left[\frac{117}{156}\right] \times 100 = 75.00$

Normalized sum of excursions, $nse = \frac{\sum_{i=1}^{n=117} excursion_i}{number\ of\ tests} = \frac{222.22}{156} = 1.424$

Amplitude, $F_3 = \frac{nse}{0.01nse + 0.01} = \left[\frac{1.424}{0.01(1.424)+0.01}\right] = \frac{1.424}{0.02424} = 58.75$

$$WQI = 100 - \frac{\sqrt{\left({F_1}^2 + {F_2}^2 + {F_3}^2\right)}}{1.732} = 100 - \frac{\sqrt{(92.31^2 + 75.00^2 + 68.75^2)}}{1.732} = 23.41$$

Appendix B10:Water quality index computation table for sampling location L11 (Ungwa Mu'azu)

	Temp °C	Turb (NTU)	TDS (mg/l)	pH	Cl^- (mg/l)	EC (µS/cm)	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	TN (mg/l)	TP (mg/l)	Fe (mg/l)	Mn (mg/l)
June	28	**107.554**	105	7.2	26.39	157	7.01	1.72	**48.33**	0.74	**0.109**	0.243	0.085
July	27	**126.126**	107	6.8	27.51	160	7.04	1.59	**46.06**	0.69	**0.102**	0.222	0.143
August	26	**101.178**	99	6.7	23.01	148	6.75	1.46	**46.79**	0.67	0.096	0.275	0.163
September	27	**56.826**	101	6.9	24.51	152	6.42	1.43	**49.13**	0.65	0.096	**0.316**	0.193
October	27	**41.026**	89	7.2	17.77	134	5.97	1.49	**51.78**	0.71	**0.104**	**0.320**	**0.250**
November	21	**5.465**	87	7.4	16.27	130	**4.81**	1.54	**54.69**	0.86	**0.126**	**0.323**	**0.296**
December	22	4.640	95	7.5	21.14	143	**3.77**	1.97	**56.53**	0.98	**0.141**	**0.334**	**0.331**
January	22	4.412	88	7.7	17.02	132	**3.64**	**2.18**	**58.97**	**1.08**	**0.157**	**0.394**	**0.385**
February	20	3.671	83	7.8	14.40	125	**3.49**	**2.25**	**59.83**	**1.38**	**0.201**	**0.535**	**0.417**
March	20	2.439	78	7.9	11.40	117	**3.16**	**2.40**	**60.51**	**1.51**	**0.220**	**0.606**	**0.488**
April	24	1.746	81	7.5	12.90	121	**3.07**	**2.58**	**61.44**	**1.70**	**0.246**	**0.462**	**0.334**
May	27	**85.932**	97	7.3	21.89	145	5.33	1.86	**49.37**	**1.11**	**0.163**	**0.314**	0.188
Objective	≤ 40	≤ 5.0	≤ 500	6.5-8.5	≤ 250	≤ 750	≥ 5.0	≤ 2.0	≤ 20	≤ 1.0	≤ 0.1	≤ 0.3	≤ 0.2

1) Temp = Temperature, Turb = Turbidity, TDS = Total Dissolved Solids, Cl^- = Chloride, DO = Dissolved Oxygen, BOD_5 = 5-days Biochemical Oxygen Demand, COD = Chemical Oxygen Demand, TN = Total Nitrogen, TP = Total Phosphorous, Fe = Iron, Mn = Manganese, ≤ = less than or equal to, ≥ = greater than or equal to.
2) Bold values do not meet the objective.

The number of variables (parameters) not meeting the objectives is 8 (i.e Turb, DO,BOD_5, COD, TN, TP, Fe and Mn) while the total number of variables is 13. Therefore,

Scope, $F_1 = \left[\frac{8}{13}\right] \times 100 = 61.54$

The number of tests not meeting the objectives is 60 while the total number of tests is 156. Hence,

Frequency, $F_2 = \left[\frac{60}{156}\right] \times 100 = 38.46$

Normalized sum of excursions, $nse = \frac{\sum_{i=1}^{n=60} excursion_{\ i}}{number\ \ of\ tests} = \frac{137.11}{156} = 0.8789$

Amplitude, $F_3 = \frac{nse}{0.01nse + 0.01} = \left[\frac{0.8789}{0.01(0.8789)+0.01}\right] = \frac{0.8789}{0.018789} = 46.78$

$$WQI = 100 - \frac{\sqrt{\left({F_1}^2 + {F_2}^2 + {F_3}^2\right)}}{1.732} = 100 - \frac{\sqrt{(61.54^2 + 38.46^2 + 46.78^2)}}{1.732} = 50.15$$

Appendix B11:Water quality index computation table for sampling location L12 (Rigassa)

	Temp °C	Turb (NTU)	TDS (mg/l)	pH	Cl^- (mg/l)	EC (µS/cm)	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	TN (mg/l)	TP (mg/l)	Fe (mg/l)	Mn (mg/l)
June	26	**111.495**	**529**	6.5	**267.01**	**793**	**4.09**	1.67	**53.10**	0.74	**0.108**	0.265	0.093
July	27	**130.509**	**532**	**6.4**	**268.87**	**798**	**4.83**	1.96	**50.61**	0.70	**0.102**	0.245	0.156
August	27	**106.309**	**524**	**6.4**	**264.38**	**786**	**4.52**	**2.04**	**51.41**	0.66	0.096	**0.306**	0.177
September	26	**59.061**	**508**	**6.3**	**255.39**	**762**	**4.49**	**2.10**	**53.98**	0.71	**0.104**	**0.346**	**0.211**
October	25	**42.063**	**504**	**6.4**	**252.77**	**755**	**4.17**	**2.19**	**56.89**	0.81	**0.118**	**0.351**	**0.272**
November	22	4.642	**502**	6.7	**251.64**	**752**	**3.91**	**2.36**	**60.09**	**1.02**	**0.149**	**0.354**	**0.323**
December	23	3.955	498	6.8	249.77	747	**3.91**	**2.42**	**62.11**	**1.36**	**0.200**	**0.366**	**0.361**
January	22	3.747	476	7.9	237.04	713	**3.86**	**2.49**	**64.79**	**1.42**	**0.207**	**0.431**	**0.419**
February	21	3.131	454	7.2	225.05	681	**3.54**	**2.63**	**65.74**	**1.57**	**0.229**	**0.586**	**0.454**
March	20	2.087	422	7.4	207.07	633	**3.29**	**2.60**	**66.48**	**1.63**	**0.238**	**0.680**	**0.532**
April	21	1.481	451	6.8	223.18	676	**3.08**	**2.66**	**67.50**	**1.72**	**0.251**	**0.506**	**0.364**
May	26	**88.159**	468	**6.4**	232.92	702	**3.61**	1.86	**54.24**	**1.13**	**0.165**	**0.345**	0.198
Objective	≤ 40	≤ 5.0	≤ 500	6.5-8.5	≤ 250	≤ 750	≥ 5.0	≤ 2.0	≤ 20	≤ 1.0	≤ 0.1	≤ 0.3	≤ 0.2

1) Temp = Temperature, Turb = Turbidity, TDS = Total Dissolved Solids, Cl^- = Chloride, DO = Dissolved Oxygen, BOD_5 = 5-days Biochemical Oxygen Demand, COD = Chemical Oxygen Demand, TN = Total Nitrogen, TP = Total Phosphorous, Fe = Iron, Mn = Manganese, ≤ = less than or equal to, ≥ = greater than or equal to.
2) Bold values do not meet the objective.

The number of variables (parameters) not meeting the objectives is 12 (i.e Turb, TDS, pH, Cl^-,EC,DO,BOD_5, COD, TN, TP, Fe and Mn) while the total number of variables is 13. Therefore,

Scope, $F_1 = \left[\frac{12}{13}\right] \times 100 = 92.31$

The number of tests not meeting the objectives is 98 while the total number of tests is 156. Hence,

Frequency, $F_2 = \left[\frac{98}{156}\right] \times 100 = 62.82$

Normalized sum of excursions, $nse = \frac{\sum_{i=1}^{n=98} excursion_{\ i}}{number\ \ of\ tests} = \frac{152.36}{156} = 0.9767$

Amplitude, $F_3 = \frac{nse}{0.01nse + 0.01} = \left[\frac{0.9767}{0.01(0.9767)+0.01}\right] = \frac{0.9767}{0.019767} = 49.41$

$$WQI = 100 - \frac{\sqrt{\left({F_1}^2 + {F_2}^2 + {F_3}^2\right)}}{1.732} = 100 - \frac{\sqrt{(92.31^2 + 62.82^2 + 49.41^2)}}{1.732} = 29.50$$

Appendix B12:Water quality index computation table for sampling location L13 (Maigiginya)

	Temp °C	Turb (NTU)	TDS (mg/l)	pH	Cl^- (mg/l)	EC (µS/cm)	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	TN (mg/l)	TP (mg/l)	Fe (mg/l)	Mn (mg/l)
June	26	**75.891**	104	7.2	26.01	156	7.58	0.41	**37.91**	0.87	**0.127**	0.186	0.066
July	28	**87.894**	108	6.7	28.26	162	8.02	0.43	**36.13**	0.80	**0.117**	0.169	0.110
August	26	**70.858**	98	6.7	22.64	147	7.79	0.43	**36.70**	0.78	**0.114**	0.213	0.126
September	25	**39.301**	102	6.8	24.89	153	7.08	0.47	**38.54**	0.76	**0.111**	0.242	0.150
October	25	**28.653**	92	7.2	19.27	138	6.48	0.54	**40.62**	0.81	**0.118**	0.245	0.176
November	22	**17.116**	81	7.4	12.53	120	5.02	0.69	**42.90**	1.00	**0.146**	0.247	0.197
December	23	**14.633**	80	7.6	12.69	120	**4.36**	0.76	**44.34**	**1.13**	**0.165**	0.254	**0.257**
January	21	**13.805**	75	7.8	9.91	113	**4.05**	0.83	**46.26**	**1.26**	**0.184**	**0.302**	**0.298**
February	20	**11.586**	69	7.7	6.54	104	**3.98**	0.86	**46.93**	**1.61**	**0.235**	**0.409**	**0.323**
March	19	**7.749**	67	7.8	5.41	101	**3.82**	0.81	**47.46**	**1.75**	**0.256**	**0.475**	**0.377**
April	24	**5.454**	77	7.3	11.03	116	**3.64**	0.56	**48.19**	**1.98**	**0.289**	**0.352**	**0.259**
May	27	**60.210**	93	7.1	19.64	139	5.20	0.39	**38.72**	**1.30**	**0.190**	0.255	0.145
Objective	≤ 40	≤ 5.0	≤ 500	6.5-8.5	≤ 250	≤ 750	≥ 5.0	≤ 2.0	≤ 20	≤ 1.0	≤ 0.1	≤ 0.3	≤ 0.2

1) Temp = Temperature, Turb = Turbidity, TDS = Total Dissolved Solids, Cl^- = Chloride, DO = Dissolved Oxygen, BOD_5 = 5-days Biochemical Oxygen Demand, COD = Chemical Oxygen Demand, TN = Total Nitrogen, TP = Total Phosphorous, Fe = Iron, Mn = Manganese, ≤ = less than or equal to, ≥ = greater than or equal to.
2) Bold values do not meet the objective.

The number of variables (parameters) not meeting the objectives is 7 (i.e Turb, DO, COD, TN, TP, Fe and Mn) while the total number of variables is 13. Therefore,

Scope, $F_1 = \left[\frac{7}{13}\right] \times 100 = 53.85$

The number of tests not meeting the objectives is 56 while the total number of tests is 156. Hence,

Frequency, $F_2 = \left[\frac{56}{156}\right] \times 100 = 35.90$

Normalized sum of excursions, $nse = \frac{\sum_{i=1}^{n=56} excursion_{\ i}}{number\ \ of\ tests} = \frac{104.47}{156} = 0.6697$

Amplitude, $F_3 = \frac{nse}{0.01nse + 0.01} = \left[\frac{0.6697}{0.01(0.6697)+0.01}\right] = \frac{0.6697}{0.016697} = 40.11$

$$WQI = 100 - \frac{\sqrt{\left({F_1}^2 + {F_2}^2 + {F_3}^2\right)}}{1.732} = 100 - \frac{\sqrt{(53.85^2 + 35.90^2 + 40.11^2)}}{1.732} = 56.04$$

Appendix B13:Water quality index computation table for sampling location L14 (Romi)

	Temp °C	Turb (NTU)	TDS (mg/l)	pH	Cl^- (mg/l)	EC (µS/cm)	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	TN (mg/l)	TP (mg/l)	Fe (mg/l)	Mn (mg/l)
June	25	**84.856**	127	7.4	39.25	190	6.88	0.95	**43.00**	0.79	**0.115**	0.210	0.075
July	26	**99.946**	132	7.3	41.87	197	6.97	0.99	**39.96**	0.73	**0.107**	0.194	0.124
August	28	**80.700**	124	7.3	37.75	186	6.56	1.08	**40.59**	0.71	**0.104**	0.243	0.141
September	26	**44.615**	121	7.4	35.88	181	6.39	1.16	**42.62**	0.69	**0.101**	0.275	0.167
October	25	**31.930**	116	7.5	33.26	174	6.11	1.35	**44.92**	0.75	**0.110**	0.280	0.200
November	24	**9.072**	102	7.6	25.02	152	5.60	1.47	**47.45**	0.92	**0.134**	0.282	**0.256**
December	23	**7.746**	94	7.5	20.52	140	**4.81**	1.54	**49.04**	**1.04**	**0.152**	0.290	**0.286**
January	23	**7.327**	89	7.7	17.90	133	**4.48**	1.58	**51.16**	**1.15**	**0.168**	**0.343**	**0.333**
February	21	**6.141**	85	7.7	15.66	127	**4.11**	1.68	**51.91**	**1.47**	**0.215**	**0.465**	**0.362**
March	20	4.107	79	7.8	12.66	119	**3.93**	1.66	**52.49**	**1.61**	**0.235**	**0.540**	**0.423**
April	24	2.911	84	7.6	15.28	126	**3.62**	1.23	**53.30**	**1.81**	**0.264**	**0.401**	**0.290**
May	28	**67.141**	114	7.5	32.13	171	5.09	0.87	**42.83**	**1.18**	**0.172**	0.291	0.163
Objective	≤ 40	≤ 5.0	≤ 500	6.5-8.5	≤ 250	≤ 750	≥ 5.0	≤ 2.0	≤ 20	≤ 1.0	≤ 0.1	≤ 0.3	≤ 0.2

1) Temp = Temperature, Turb = Turbidity, TDS = Total Dissolved Solids, Cl^- = Chloride, DO = Dissolved Oxygen, BOD_5 = 5-days Biochemical Oxygen Demand, COD = Chemical Oxygen Demand, TN = Total Nitrogen, TP = Total Phosphorous, Fe = Iron, Mn = Manganese, ≤ = less than or equal to, ≥ = greater than or equal to.
2) Bold values do not meet the objective.

The number of variables (parameters) not meeting the objectives is 7 (i.e Turb, DO,COD, TN, TP, Fe and Mn) while the total number of variables is 13. Therefore,

Scope, $F_1 = \left[\frac{7}{13}\right] \times 100 = 53.85$

The number of tests not meeting the objectives is 55 while the total number of tests is 156. Hence,

Frequency, $F_2 = \left[\frac{55}{156}\right] \times 100 = 35.27$

Normalized sum of excursions, $nse = \frac{\sum_{i=1}^{n=55} excursion_{\ i}}{number\ \ of\ tests} = \frac{109.88}{156} = 0.7044$

Amplitude, $F_3 = \frac{nse}{0.01nse + 0.01} = \left[\frac{0.7044}{0.01(0.7044) + 0.01}\right] = \frac{0.7044}{0.017044} = 41.33$

$$WQI = 100 - \frac{\sqrt{\left({F_1}^2 + {F_2}^2 + {F_3}^2\right)}}{1.732} = 100 - \frac{\sqrt{(53.85^2 + 35.27^2 + 41.33^2)}}{1.732} = 55.83$$

Appendix B14:Water quality index computation table for sampling location L15 (Railway Bridge)

	Temp °C	Turb (NTU)	TDS (mg/l)	pH	Cl^- (mg/l)	EC (µS/cm)	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	TN (mg/l)	TP (mg/l)	Fe (mg/l)	Mn (mg/l)
June	26	**55.270**	103	7.2	25.64	155	7.58	0.17	**35.91**	0.91	**0.133**	0.175	0.062
July	25	**65.061**	108	6.8	28.26	162	8.01	0.18	**33.37**	0.84	**0.123**	0.159	0.103
August	27	**52.077**	99	6.7	23.01	148	7.76	0.18	**33.90**	0.81	**0.118**	0.200	0.119
September	25	**28.877**	101	6.8	24.14	151	7.08	0.19	**35.59**	0.79	**0.115**	0.228	0.141
October	24	**20.788**	92	7.3	19.27	138	6.44	0.22	**37.51**	0.85	**0.124**	0.230	0.166
November	22	**21.199**	81	7.5	13.28	122	5.04	0.28	**39.63**	**1.05**	**0.153**	0.232	0.185
December	23	**18.077**	80	7.6	12.53	120	**4.38**	0.31	**40.96**	**1.18**	**0.172**	0.239	**0.242**
January	20	**17.146**	77	7.7	10.66	115	**4.09**	0.34	**42.73**	**1.32**	**0.193**	0.284	**0.280**
February	21	**14.350**	71	7.7	7.28	106	**4.01**	0.35	**43.35**	**1.68**	**0.245**	**0.385**	**0.304**
March	19	**9.598**	69	7.8	6.16	103	**3.82**	0.33	**43.84**	**1.83**	**0.267**	**0.447**	**0.355**
April	24	**6.849**	77	7.4	11.03	116	**3.64**	0.23	**44.51**	**2.07**	**0.302**	**0.331**	**0.244**
May	27	**43.776**	94	7.2	20.39	141	5.19	0.16	**35.77**	**1.36**	**0.198**	0.240	0.136
Objective	≤ 40	≤ 5.0	≤ 500	6.5-8.5	≤ 250	≤ 750	≥ 5.0	≤ 2.0	≤ 20	≤ 1.0	≤ 0.1	≤ 0.3	≤ 0.2

1) Temp = Temperature, Turb = Turbidity, TDS = Total Dissolved Solids, Cl^- = Chloride, DO = Dissolved Oxygen, BOD_5 = 5-days Biochemical Oxygen Demand, COD = Chemical Oxygen Demand, TN = Total Nitrogen, TP = Total Phosphorous, Fe = Iron, Mn = Manganese, ≤ = less than or equal to, ≥ = greater than or equal to.
2) Bold values do not meet the objective.

The number of variables (parameters) not meeting the objectives is 7 (i.e Turb, DO, COD, TN, TP, Fe and Mn) while the total number of variables is 13. Therefore,

Scope, $F_1 = \left[\frac{7}{13}\right] \times 100 = 53.85$

The number of tests not meeting the objectives is 56 while the total number of tests is 156. Hence,

Frequency, $F_2 = \left[\frac{56}{156}\right] \times 100 = 35.90$

Normalized sum of excursions, $nse = \frac{\sum_{i=1}^{n=56} excursion_{\ i}}{number\ \ of\ tests} = \frac{87.22}{156} = 0.5591$

Amplitude, $F_3 = \frac{nse}{0.01nse + 0.01} = \left[\frac{0.5591}{0.01(0.5591)+0.01}\right] = \frac{0.5591}{0.015591} = 35.86$

$$WQI = 100 - \frac{\sqrt{\left({F_1}^2 + {F_2}^2 + {F_3}^2\right)}}{1.732} = 100 - \frac{\sqrt{(53.85^2 + 35.90^2 + 35.86^2)}}{1.732} = 57.28$$

APPENDIX C: EXCURSION VALUES FOR CALCULATED WQI

Appendix C1: Excursion values for sampling location L1 (Malali)

$e_1 = 14.68$	$e_{11} = 0.74$	$e_{21} = 1.19$	$e_{31} = 0.43$	$e_{41} = 1.82$	$e_{51} = 0.245$
$e_2 = 17.40$	$e_{12} = 11.41$	$e_{22} = 1.22$	$e_{32} = 0.40$	$e_{42} = 2.18$	
$e_3 = 13.85$	$e_{13} = 0.75$	$e_{23} = 1.25$	$e_{33} = 0.28$	$e_{43} = 1.09$	
$e_4 = 7.27$	$e_{14} = 0.69$	$e_{24} = 0.81$	$e_{34} = 0.24$	$e_{44} = 0.33$	
$e_5 = 4.87$	$e_{15} = 0.72$	$e_{25} = 0.11$	$e_{35} = 0.21$	$e_{45} = 0.54$	
$e_6 = 4.37$	$e_{16} = 0.80$	$e_{26} = 0.24$	$e_{36} = 0.31$	$e_{46} = 0.14$	
$e_7 = 3.57$	$e_{17} = 0.90$	$e_{27} = 0.39$	$e_{37} = 0.62$	$e_{47} = 0.23$	
$e_8 = 3.28$	$e_{18} = 1.01$	$e_{28} = 0.77$	$e_{38} = 0.81$	$e_{48} = 0.43$	
$e_9 = 2.64$	$e_{19} = 1.07$	$e_{29} = 0.93$	$e_{39} = 1.03$	$e_{49} = 0.55$	
$e_{10} = 1.44$	$e_{20} = 1.16$	$e_{30} = 1.18$	$e_{40} = 1.58$	$e_{50} = 0.82$	

$$\sum_{i=1}^{n=51} excursion_i = 114.995$$

Appendix C2: Excursion values for sampling location L2 (Kwarau)

$e_1 = 8.87$	$e_{11} = 0.03$	$e_{21} = 1.15$	$e_{31} = 0.80$	$e_{41} = 1.15$
$e_2 = 10.60$	$e_{12} = 0.05$	$e_{22} = 1.24$	$e_{32} = 0.18$	$e_{42} = 1.34$
$e_3 = 8.24$	$e_{13} = 0.11$	$e_{23} = 1.27$	$e_{33} = 0.15$	$e_{43} = 1.63$
$e_4 = 4.56$	$e_{14} = 0.19$	$e_{24} = 1.30$	$e_{34} = 0.07$	$e_{44} = 0.72$
$e_5 = 2.69$	$e_{15} = 0.82$	$e_{25} = 1.33$	$e_{35} = 0.02$	$e_{45} = 0.02$
$e_6 = 0.75$	$e_{16} = 0.75$	$e_{26} = 0.88$	$e_{36} = 0.01$	$e_{46} = 0.38$
$e_7 = 0.49$	$e_{17} = 0.78$	$e_{27} = 0.03$	$e_{37} = 0.10$	$e_{47} = 0.61$
$e_8 = 0.40$	$e_{18} = 0.87$	$e_{28} = 0.15$	$e_{38} = 0.34$	$e_{48} = 0.19$
$e_9 = 0.19$	$e_{19} = 0.97$	$e_{29} = 0.47$	$e_{39} = 0.50$	
$e_{10} = 6.80$	$e_{20} = 1.08$	$e_{30} = 0.60$	$e_{40} = 0.68$	

$$\sum_{i=1}^{n=48} excursion_i = 66.55$$

Appendix C3: Excursion values for sampling location L3 (NNPC)

$e_1 = 29.18$	$e_{11} = 1.69$	$e_{21} = 0.48$	$e_{31} = 0.59$	$e_{41} = 0.87$
$e_2 = 34.30$	$e_{12} = 1.84$	$e_{22} = 0.66$	$e_{32} = 0.14$	$e_{42} = 0.61$
$e_3 = 27.47$	$e_{13} = 1.94$	$e_{23} = 0.09$	$e_{33} = 0.18$	
$e_4 = 14.98$	$e_{14} = 2.06$	$e_{24} = 0.07$	$e_{34} = 0.40$	

$e_5 = 10.25$	$e_{15} = 2.11$	$e_{25} = 0.24$	$e_{35} = 0.89$
$e_6 = 22.89$	$e_{16} = 2.15$	$e_{26} = 0.39$	$e_{36} = 1.20$
$e_7 = 1.50$	$e_{17} = 2.19$	$e_{27} = 0.55$	$e_{37} = 0.63$
$e_8 = 1.39$	$e_{18} = 1.57$	$e_{28} = 1.00$	$e_{38} = 0.28$
$e_9 = 1.43$	$e_{19} = 0.06$	$e_{29} = 1.16$	$e_{39} = 0.56$
$e_{10} = 1.55$	$e_{20} = 0.36$	$e_{30} = 1.42$	$e_{40} = 0.73$

$$\sum_{=1}^{n=42} excursion_i = 174.05$$

Appendix C4: Excursion values for sampling location L4 (Kuyi)

$e_1 = 15.67$	$e_{11} = 0.03$	$e_{21} = 1.33$	$e_{31} = 0.61$	$e_{41} = 0.69$	$e_{51} = 0.43$
$e_2 = 18.61$	$e_{12} = 0.14$	$e_{22} = 1.40$	$e_{32} = 0.81$	$e_{42} = 1.16$	$e_{52} = 0.66$
$e_3 = 14.56$	$e_{13} = 0.15$	$e_{23} = 1.51$	$e_{33} = 0.19$	$e_{43} = 1.35$	$e_{53} = 0.80$
$e_4 = 7.66$	$e_{14} = 0.19$	$e_{24} = 1.54$	$e_{34} = 0.17$	$e_{44} = 1.64$	$e_{54} = 1.11$
$e_5 = 5.27$	$e_{15} = 0.23$	$e_{25} = 1.57$	$e_{35} = 0.07$	$e_{45} = 0.74$	$e_{55} = 0.45$
$e_6 = 0.81$	$e_{16} = 1.04$	$e_{26} = 1.61$	$e_{36} = 0.04$	$e_{46} = 0.14$	
$e_7 = 0.56$	$e_{17} = 0.96$	$e_{27} = 1.10$	$e_{37} = 0.01$	$e_{47} = 0.55$	
$e_8 = 0.47$	$e_{18} = 0.99$	$e_{28} = 0.04$	$e_{38} = 0.10$	$e_{48} = 0.80$	
$e_9 = 0.23$	$e_{19} = 1.09$	$e_{29} = 0.16$	$e_{39} = 0.34$	$e_{49} = 0.33$	
$e_{10} = 12.22$	$e_{20} = 1.20$	$e_{30} = 0.48$	$e_{40} = 0.52$	$e_{50} = 0.27$	

$$\sum_{i=1}^{n=55} excursion_i = 106.8$$

Appendix C5: Excursion values for sampling location L5 (Barnawa)

$e_1 = 15.20$	$e_{11} = 0.03$	$e_{21} = 1.46$	$e_{31} = 0.82$	$e_{41} = 1.16$	$e_{51} = 0.46$
$e_2 = 18.03$	$e_{12} = 0.08$	$e_{22} = 1.58$	$e_{32} = 0.19$	$e_{42} = 1.37$	$e_{52} = 0.69$
$e_3 = 14.20$	$e_{13} = 0.12$	$e_{23} = 1.56$	$e_{33} = 0.17$	$e_{43} = 1.66$	$e_{53} = 0.83$
$e_4 = 7.52$	$e_{14} = 0.18$	$e_{24} = 1.64$	$e_{34} = 0.08$	$e_{44} = 0.74$	$e_{54} = 1.14$
$e_5 = 5.02$	$e_{15} = 1.10$	$e_{25} = 1.68$	$e_{35} = 0.05$	$e_{45} = 0.17$	$e_{55} = 0.47$
$e_6 = 0.88$	$e_{16} = 1.01$	$e_{26} = 1.16$	$e_{36} = 0.02$	$e_{46} = 0.59$	
$e_7 = 0.61$	$e_{17} = 1.04$	$e_{27} = 0.05$	$e_{37} = 0.11$	$e_{47} = 0.84$	
$e_8 = 0.53$	$e_{18} = 1.15$	$e_{28} = 0.16$	$e_{38} = 0.36$	$e_{48} = 0.37$	
$e_9 = 0.27$	$e_{19} = 1.26$	$e_{29} = 0.48$	$e_{39} = 0.53$	$e_{49} = 0.07$	
$e_{10} = 11.75$	$e_{20} = 1.39$	$e_{30} = 0.62$	$e_{40} = 0.69$	$e_{50} = 0.30$	

$$\sum_{i=1}^{n=55} excursion_i = 105.64$$

Appendix C6: Excursion values for sampling location L6 (Kutimbi)

$e_1 = 18.08$	$e_{17} = 0.03$	$e_{33} = 0.06$	$e_{49} = 0.17$	$e_{65} = 1.39$	$e_{81} = 0.04$
$e_2 = 21.37$	$e_{18} = 0.05$	$e_{34} = 0.05$	$e_{50} = 0.26$	$e_{66} = 0.22$	$e_{82} = 0.06$
$e_3 = 17.05$	$e_{19} = 0.02$	$e_{35} = 0.10$	$e_{51} = 0.23$	$e_{67} = 0.27$	$e_{83} = 0.06$
$e_4 = 9.07$	$e_{20} = 0.02$	$e_{36} = 0.18$	$e_{52} = 0.26$	$e_{68} = 0.41$	$e_{84} = 0.10$
$e_5 = 6.15$	$e_{21} = 0.09$	$e_{37} = 0.26$	$e_{53} = 0.02$	$e_{69} = 0.46$	$e_{85} = 0.30$

$e_6 = 0.37$	$e_{22} = 0.17$	$e_{38} = 0.37$	$e_{54} = 1.33$	$e_{70} = 0.55$	$e_{86} = 0.76$
$e_7 = 0.17$	$e_{23} = 0.11$	$e_{39} = 0.47$	$e_{55} = 1.23$	$e_{71} = 0.02$	$e_{87} = 1.04$
$e_8 = 0.11$	$e_{24} = 0.04$	$e_{40} = 0.52$	$e_{56} = 1.27$	$e_{72} = 0.01$	$e_{88} = 0.52$
$e_9 = 14.06$	$e_{25} = 0.01$	$e_{41} = 0.55$	$e_{57} = 1.38$	$e_{73} = 0.07$	$e_{89} = 0.04$
$e_{10} = 0.08$	$e_{26} = 0.00$	$e_{42} = 0.59$	$e_{58} = 1.51$	$e_{74} = 0.29$	$e_{90} = 0.34$
$e_{11} = 0.15$	$e_{27} = 0.08$	$e_{43} = 0.61$	$e_{59} = 1.65$	$e_{75} = 0.45$	$e_{91} = 0.46$
$e_{12} = 0.10$	$e_{28} = 0.15$	$e_{44} = 0.27$	$e_{60} = 1.74$	$e_{76} = 0.61$	$e_{92} = 0.63$
$e_{13} = 0.04$	$e_{29} = 0.10$	$e_{45} = 0.01$	$e_{61} = 1.86$	$e_{77} = 1.04$	$e_{93} = 0.90$
$e_{14} = 0.01$	$e_{30} = 0.03$	$e_{46} = 0.04$	$e_{62} = 1.90$	$e_{78} = 1.26$	$e_{94} = 1.06$
$e_{15} = 0.00$	$e_{31} = 0.01$	$e_{47} = 0.06$	$e_{63} = 1.93$	$e_{79} = 1.51$	$e_{95} = 1.41$
$e_{16} = 0.03$	$e_{32} = 0.00$	$e_{48} = 0.11$	$e_{64} = 1.97$	$e_{80} = 0.64$	$e_{96} = 0.65$

$$\sum_{i=1}^{n=96} excursion_i = 128.18$$

Appendix C7: Excursion values for sampling location L7 (Living Faith)

$e_1 = 21.01$	$e_{11} = 0.36$	$e_{21} = 2.03$	$e_{31} = 0.67$	$e_{41} = 0.59$	$e_{51} = 0.17$
$e_2 = 24.63$	$e_{12} = 0.04$	$e_{22} = 2.13$	$e_{32} = 0.09$	$e_{42} = 0.03$	$e_{52} = 0.06$
$e_3 = 19.77$	$e_{13} = 0.12$	$e_{23} = 2.27$	$e_{33} = 0.07$	$e_{43} = 0.17$	$e_{53} = 0.38$
$e_4 = 10.53$	$e_{14} = 0.20$	$e_{24} = 2.32$	$e_{34} = 0.02$	$e_{44} = 0.19$	$e_{54} = 0.63$
$e_5 = 7.31$	$e_{15} = 0.22$	$e_{25} = 2.35$	$e_{35} = 0.24$	$e_{45} = 0.20$	$e_{55} = 0.82$
$e_6 = 16.44$	$e_{16} = 1.66$	$e_{26} = 2.41$	$e_{36} = 0.40$	$e_{46} = 0.24$	$e_{56} = 1.12$
$e_7 = 0.11$	$e_{17} = 1.55$	$e_{27} = 1.74$	$e_{37} = 0.56$	$e_{47} = 0.46$	$e_{57} = 1.30$
$e_8 = 0.21$	$e_{18} = 1.59$	$e_{28} = 0.07$	$e_{38} = 0.99$	$e_{48} = 0.98$	$e_{58} = 1.69$
$e_9 = 0.27$	$e_{19} = 1.72$	$e_{29} = 0.36$	$e_{39} = 1.18$	$e_{49} = 1.30$	$e_{59} = 0.84$
$e_{10} = 0.30$	e_{20} 1.87 =	$e_{30} = 0.49$	$e_{40} = 1.44$	$e_{50} = 0.71$	$e_{60} = 0.04$

$$\sum_{i=1}^{n=60} excursion_i = 143.66$$

Appendix C8: Excursion values for sampling location L8 (Kigo)

$e_1 = 36.65$	$e_{18} = 0.14$	$e_{35} = 0.28$	$e_{52} = 2.09$	$e_{69} = 1.02$	$e_{86} = 0.38$
$e_2 = 43.25$	$e_{19} = 0.22$	$e_{36} = 0.45$	$e_{53} = 1.91$	$e_{70} = 0.33$	$e_{87} = 0.39$
$e_3 = 34.32$	$e_{20} = 0.16$	$e_{37} = 0.48$	$e_{54} = 1.95$	$e_{71} = 0.14$	$e_{88} = 0.43$
$e_4 = 19.09$	$e_{21} = 0.20$	$e_{38} = 0.59$	$e_{55} = 2.10$	$e_{72} = 0.06$	$e_{89} = 0.69$
$e_5 = 13.36$	$e_{22} = 0.07$	$e_{39} = 0.61$	$e_{56} = 2.27$	$e_{73} = 0.19$	$e_{90} = 1.30$
$e_6 = 28.99$	$e_{23} = 0.01$	$e_{40} = 1.29$	$e_{57} = 2.45$	$e_{74} = 0.15$	$e_{91} = 1.66$
$e_7 = 0.12$	$e_{24} = 0.12$	$e_{41} = 0.68$	$e_{58} = 2.57$	$e_{75} = 0.22$	$e_{92} = 0.98$
$e_8 = 0.20$	$e_{25} = 0.19$	$e_{42} = 0.02$	$e_{59} = 2.72$	$e_{76} = 0.48$	$e_{93} = 0.35$
$e_9 = 0.14$	$e_{26} = 0.14$	$e_{43} = 0.05$	$e_{60} = 2.78$	$e_{77} = 0.93$	$e_{94} = 0.13$
$e_{10} = 0.17$	$e_{27} = 0.17$	$e_{44} = 0.03$	$e_{61} = 2.82$	$e_{78} = 1.17$	$e_{95} = 0.46$
$e_{11} = 0.06$	$e_{28} = 0.06$	$e_{45} = 0.06$	$e_{62} = 2.88$	$e_{79} = 1.36$	$e_{96} = 0.73$
$e_{12} = 0.01$	$e_{29} = 0.01$	$e_{46} = 0.10$	$e_{63} = 2.12$	$e_{80} = 1.44$	$e_{97} = 0.93$
$e_{13} = 0.02$	$e_{30} = 0.04$	$e_{47} = 0.28$	$e_{64} = 0.20$	$e_{81} = 1.58$	$e_{98} = 1.25$
$e_{14} = 0.05$	$e_{31} = 0.03$	$e_{48} = 0.34$	$e_{65} = 0.59$	$e_{82} = 0.60$	$e_{99} = 1.43$
$e_{15} = 0.05$	$e_{32} = 0.06$	$e_{49} = 0.36$	$e_{66} = 0.66$	$e_{83} = 0.04$	$e_{100} = 1.85$

$e_{16} = 0.03$	$e_{33} = 0.14$	$e_{50} = 0.36$	$e_{67} = 0.84$	$e_{84} = 0.20$	$e_{101} = 0.95$
$e_{17} = 0.03$	$e_{34} = 0.21$	$e_{51} = 0.35$	$e_{68} = 0.91$	$e_{85} = 0.36$	$e_{102} = 0.10$

$$\sum_{i=1}^{n=102} excursion_i = 240.98$$

Appendix C9: Excursion values for sampling location L9 (Down Quaters)

$e_1 = 20.94$	$e_{12} = 0.55$	$e_{23} = 2.08$	$e_{34} = 0.08$	$e_{45} = 0.17$	$e_{56} = 0.80$
$e_2 = 46.70$	$e_{13} = 0.21$	$e_{24} = 2.21$	$e_{35} = 0.01$	$e_{46} = 0.18$	$e_{57} = 1.09$
$e_3 = 19.76$	$e_{14} = 0.29$	$e_{25} = 2.26$	$e_{36} = 0.03$	$e_{47} = 0.22$	$e_{58} = 1.26$
$e_4 = 10.63$	$e_{15} = 0.28$	$e_{26} = 2.30$	$e_{37} = 0.25$	$e_{48} = 0.43$	$e_{59} = 1.65$
$e_5 = 7.25$	$e_{16} = 0.47$	$e_{27} = 2.35$	$e_{38} = 0.41$	$e_{49} = 0.95$	$e_{60} = 0.81$
$e_6 = 0.04$	$e_{17} = 1.62$	$e_{28} = 1.69$	$e_{39} = 0.56$	$e_{50} = 1.21$	$e_{61} = 0.02$
$e_7 = 16.39$	$e_{18} = 1.51$	$e_{29} = 0.07$	$e_{40} = 1.00$	$e_{51} = 0.68$	
$e_8 = 0.22$	$e_{19} = 1.55$	$e_{30} = 0.37$	$e_{41} = 1.19$	$e_{52} = 0.15$	
$e_9 = 0.24$	$e_{20} = 1.68$	$e_{31} = 0.50$	$e_{42} = 1.45$	$e_{53} = 0.05$	
$e_{10} = 0.40$	$e_{21} = 1.82$	$e_{32} = 0.68$	$e_{43} = 0.61$	$e_{54} = 0.36$	
$e_{11} = 0.45$	$e_{22} = 1.98$	$e_{33} = 0.10$	$e_{44} = 0.15$	$e_{55} = 0.61$	

$$\sum_{i=1}^{n=61} excursion_i = 164.97$$

Appendix C10: Excursion values for sampling location L10 (Breweries)

$e_1 = 32.50$	$e_{21} = 0.06$	$e_{41} = 0.19$	$e_{61} = 0.21$	$e_{81} = 0.49$	$e_{101} = 0.29$
$e_2 = 38.28$	$e_{22} = 0.07$	$e_{42} = 0.10$	$e_{62} = 0.23$	$e_{82} = 0.56$	$e_{102} = 0.30$
$e_3 = 30.77$	$e_{23} = 0.08$	$e_{43} = 0.05$	$e_{63} = 0.33$	$e_{83} = 0.72$	$e_{103} = 0.34$
$e_4 = 16.97$	$e_{24} = 0.07$	$e_{44} = 0.01$	$e_{64} = 0.44$	$e_{84} = 0.79$	$e_{104} = 0.58$
$e_5 = 11.69$	$e_{25} = 0.09$	$e_{45} = 0.01$	$e_{65} = 0.01$	$e_{85} = 0.89$	$e_{105} = 1.15$
$e_6 = 25.59$	$e_{26} = 0.08$	$e_{46} = 0.18$	$e_{66} = 0.04$	$e_{86} = 0.25$	$e_{106} = 1.50$
$e_7 = 0.12$	$e_{27} = 0.06$	$e_{47} = 0.14$	$e_{67} = 0.01$	$e_{87} = 0.20$	$e_{107} = 0.86$
$e_8 = 0.21$	$e_{28} = 0.15$	$e_{48} = 0.17$	$e_{68} = 1.91$	$e_{88} = 0.12$	$e_{108} = 0.27$
$e_9 = 0.22$	$e_{29} = 0.24$	$e_{49} = 0.23$	$e_{69} = 1.79$	$e_{89} = 0.05$	$e_{109} = 0.17$
$e_{10} = 0.20$	$e_{30} = 0.25$	$e_{50} = 0.35$	$e_{70} = 1.84$	$e_{90} = 0.14$	$e_{110} = 0.51$
$e_{11} = 0.19$	$e_{31} = 0.23$	$e_{51} = 0.41$	$e_{71} = 1.98$	$e_{91} = 0.30$	$e_{111} = 0.79$
$e_{12} = 0.09$	$e_{32} = 0.22$	$e_{52} = 0.45$	$e_{72} = 2.14$	$e_{92} = 0.64$	$e_{112} = 0.10$
$e_{13} = 0.05$	$e_{33} = 0.11$	$e_{53} = 0.92$	$e_{73} = 2.31$	$e_{93} = 1.18$	$e_{113} = 1.32$
$e_{14} = 0.01$	$e_{34} = 0.06$	$e_{54} = 1.28$	$e_{74} = 2.43$	$e_{94} = 1.28$	$e_{114} = 1.51$
$e_{15} = 0.01$	$e_{35} = 0.02$	$e_{55} = 1.06$	$e_{75} = 2.57$	$e_{95} = 1.51$	$e_{115} = 1.94$
$e_{16} = 0.05$	$e_{36} = 0.02$	$e_{56} = 1.18$	$e_{76} = 2.63$	$e_{96} = 1.61$	$e_{116} = 1.02$
$e_{17} = 0.04$	$e_{37} = 0.13$	$e_{57} = 0.59$	$e_{77} = 2.67$	$e_{97} = 1.76$	$e_{117} = 0.13$
$e_{18} = 0.02$	$e_{38} = 0.21$	$e_{58} = 0.08$	$e_{78} = 2.72$	$e_{98} = 0.83$	
$e_{19} = 0.05$	$e_{39} = 0.22$	$e_{59} = 0.12$	$e_{79} = 1.99$	$e_{99} = 0.12$	
$e_{20} = 0.05$	$e_{40} = 0.20$	$e_{60} = 0.16$	$e_{80} = 0.12$	$e_{100} = 0.27$	

$$\sum_{i=1}^{n=117} excursion_i = 222.22$$

Appendix C11: Excursion values for sampling location L11 (Ungwa Mu'azu)

$e_1 = 20.51$	$e_{11} = 0.43$	$e_{21} = 1.46$	$e_{31} = 0.38$	$e_{41} = 1.01$	$e_{51} = 1.02$
$e_2 = 24.23$	$e_{12} = 0.58$	$e_{22} = 1.59$	$e_{32} = 0.51$	$e_{42} = 1.20$	$e_{52} = 0.54$
$e_3 = 19.24$	$e_{13} = 0.63$	$e_{23} = 1.73$	$e_{33} = 0.70$	$e_{43} = 1.46$	$e_{53} = 0.05$
$e_4 = 10.37$	$e_{14} = 0.09$	$e_{24} = 1.83$	$e_{34} = 0.11$	$e_{44} = 0.63$	$e_{54} = 0.25$
$e_5 = 7.21$	$e_{15} = 0.13$	$e_{25} = 1.95$	$e_{35} = 0.09$	$e_{45} = 0.05$	$e_{55} = 0.48$
$e_6 = 0.09$	$e_{16} = 0.20$	$e_{26} = 1.99$	$e_{36} = 0.02$	$e_{46} = 0.07$	$e_{56} = 0.66$
$e_7 = 16.19$	$e_{17} = 0.29$	$e_{27} = 2.03$	$e_{37} = 0.04$	$e_{47} = 0.08$	$e_{57} = 0.93$
$e_8 = 0.04$	$e_{18} = 1.42$	$e_{28} = 2.07$	$e_{38} = 0.26$	$e_{48} = 0.11$	$e_{58} = 1.09$
$e_9 = 0.33$	$e_{19} = 1.30$	$e_{29} = 1.47$	$e_{39} = 0.41$	$e_{49} = 0.31$	$e_{59} = 1.44$
$e_{10} = 0.37$	$e_{20} = 1.34$	$e_{30} = 0.08$	$e_{40} = 0.57$	$e_{50} = 0.78$	$e_{60} = 0.67$

$$\sum_{i=1}^{n=60} excursion_i = 137.11$$

Appendix C12: Excursion values for sampling location L12 (Rigassa)

$e_1 = 21.30$	$e_{18} = 0.07$	$e_{35} = 0.28$	$e_{52} = 1.53$	$e_{69} = 0.13$	$e_{86} = 0.44$
$e_2 = 25.10$	$e_{19} = 0.08$	$e_{36} = 0.28$	$e_{53} = 1.57$	$e_{70} = 0.08$	$e_{87} = 0.95$
$e_3 = 20.26$	e_{20} 0.06 =	$e_{37} = 0.30$	$e_{54} = 1.70$	$e_{71} = 0.02$	$e_{88} = 1.27$
$e_4 = 10.81$	$e_{21} = 0.02$	$e_{38} = 0.41$	$e_{55} = 1.84$	$e_{72} = 0.04$	$e_{89} = 0.69$
$e_5 = 7.41$	$e_{22} = 0.01$	$e_{39} = 0.52$	$e_{56} = 2.00$	$e_{73} = 0.18$	$e_{90} = 0.15$
$e_6 = 16.63$	$e_{23} = 0.01$	$e_{40} = 0.62$	$e_{57} = 2.11$	$e_{74} = 0.49$	$e_{91} = 0.06$
$e_7 = 0.06$	$e_{24} = 0.06$	$e_{41} = 0.39$	$e_{58} = 2.24$	$e_{75} = 1.00$	$e_{92} = 0.36$
$e_8 = 0.06$	$e_{25} = 0.06$	$e_{42} = 0.02$	$e_{59} = 2.29$	$e_{76} = 1.07$	$e_{93} = 0.62$
$e_9 = 0.05$	$e_{26} = 0.05$	$e_{43} = 0.05$	$e_{60} = 2.32$	$e_{77} = 1.29$	$e_{94} = 0.81$
$e_{10} = 0.02$	$e_{27} = 0.02$	$e_{44} = 0.10$	$e_{61} = 2.38$	$e_{78} = 1.38$	$e_{95} = 1.10$
$e_{11} = 0.01$	$e_{28} = 0.01$	$e_{45} = 0.18$	$e_{62} = 1.71$	$e_{79} = 1.51$	$e_{96} = 1.27$
$e_{12} = 0.00$	$e_{29} = 0.00$	$e_{46} = 0.21$	$e_{63} = 0.02$	$e_{80} = 0.65$	$e_{97} = 1.66$
$e_{13} = 0.02$	$e_{30} = 0.22$	$e_{47} = 0.25$	$e_{64} = 0.36$	$e_{81} = 0.02$	$e_{98} = 0.82$
$e_{14} = 0.02$	$e_{31} = 0.04$	$e_{48} = 0.32$	$e_{65} = 0.42$	$e_{82} = 0.15$	
$e_{15} = 0.03$	$e_{32} = 0.11$	$e_{49} = 0.30$	$e_{66} = 0.57$	$e_{83} = 0.17$	
$e_{16} = 0.02$	$e_{33} = 0.11$	e_{50} 0.33 =	$e_{67} = 0.63$	$e_{84} = 0.18$	
$e_{17} = 0.02$	e_{34} =0.20	$e_{51} = 1.66$	$e_{68} = 0.72$	$e_{85} = 0.22$	

$$\sum_{i=1}^{n=98} excursion_i = 152.36$$

Appendix C13: Excursion values for sampling location L13 (Maigiginya)

$e_1 = 14.18$	$e_{11} = 0.09$	$e_{21} = 0.93$	$e_{31} = 0.26$	$e_{41} = 0.46$	$e_{51} = 0.17$
$e_2 = 16.58$	$e_{12} = 11.04$	$e_{22} = 1.03$	$e_{32} = 0.61$	$e_{42} = 0.65$	$e_{52} = 0.29$
$e_3 = 13.17$	$e_{13} = 0.15$	$e_{23} = 1.15$	$e_{33} = 0.75$	$e_{43} = 0.84$	$e_{53} = 0.49$
$e_4 = 6.86$	$e_{14} = 0.23$	$e_{24} = 1.22$	$e_{34} = 0.98$	$e_{44} = 1.35$	$e_{54} = 0.62$
$e_5 = 4.73$	$e_{15} = 0.26$	$e_{25} = 1.31$	$e_{35} = 0.30$	$e_{45} = 1.56$	$e_{55} = 0.89$
$e_6 = 2.42$	$e_{16} = 0.31$	$e_{26} = 1.35$	$e_{36} = 0.27$	$e_{46} = 1.89$	$e_{56} = 0.30$
$e_7 = 1.93$	$e_{17} = 0.37$	$e_{27} = 1.37$	$e_{37} = 0.17$	$e_{47} = 0.90$	
$e_8 = 1.76$	$e_{18} = 0.90$	$e_{28} = 1.41$	$e_{38} = 0.14$	$e_{48} = 0.01$	
$e_9 = 1.32$	$e_{19} = 0.81$	$e_{29} = 0.94$	$e_{39} = 0.11$	$e_{49} = 0.36$	
$e_{10} = 0.55$	$e_{20} = 0.84$	$e_{30} = 0.13$	$e_{40} = 0.18$	$e_{50} = 0.58$	

$$\sum_{i=1}^{n=56} excursion_i = 104.47$$

Appendix C14: Excursion values for sampling location L14 (Romi)

$e_1 = 15.97$	$e_{11} = 0.40$	$e_{21} = 1.37$	$e_{31} = 0.61$	$e_{41} = 0.68$	$e_{51} = 0.43$
$e_2 = 18.99$	$e_{12} = 0.12$	$e_{22} = 1.45$	$e_{32} = 0.81$	$e_{42} = 1.15$	$e_{52} = 0.67$
$e_3 = 15.14$	$e_{13} = 0.22$	$e_{23} = 1.56$	$e_{33} = 0.18$	$e_{43} = 1.35$	$e_{53} = 0.81$
$e_4 = 7.92$	$e_{14} = 0.27$	$e_{24} = 1.60$	$e_{34} = 0.15$	$e_{44} = 1.64$	$e_{54} = 1.12$
$e_5 = 5.39$	$e_{15} = 0.38$	$e_{25} = 1.62$	$e_{35} = 0.07$	$e_{45} = 0.72$	$e_{55} = 0.45$
$e_6 = 0.81$	$e_{16} = 1.15$	$e_{26} = 1.67$	$e_{36} = 0.04$	$e_{46} = 0.14$	
$e_7 = 0.55$	$e_{17} = 1.00$	$e_{27} = 1.14$	$e_{37} = 0.01$	$e_{47} = 0.55$	
$e_8 = 0.47$	$e_{18} = 1.03$	$e_{28} = 0.04$	$e_{38} = 0.10$	$e_{48} = 0.80$	
$e_9 = 0.23$	$e_{19} = 1.13$	$e_{29} = 0.15$	$e_{39} = 0.34$	$e_{49} = 0.34$	
$e_{10} = 12.43$	$e_{20} = 1.25$	$e_{30} = 0.47$	$e_{40} = 0.52$	$e_{50} = 0.28$	

$$\sum_{i=1}^{n=55} excursion_i = 109.88$$

Appendix C15: Excursion values for sampling location L15 (Railway Bridge)

$e_1 = 10.05$	$e_{11} = 0.37$	$e_{21} = 0.78$	$e_{31} = 0.18$	$e_{41} = 0.24$	$e_{51} = 0.10$
$e_2 = 12.01$	$e_{12} = 7.76$	$e_{22} = 0.88$	$e_{32} = 0.32$	$e_{42} = 0.53$	$e_{52} = 0.21$
$e_3 = 9.42$	$e_{13} = 0.14$	$e_{23} = 0.98$	$e_{33} = 0.68$	$e_{43}\ 0.72 =$	$e_{53} = 0.40$
$e_4 = 4.78$	$e_{14} = 0.22$	$e_{24} = 1.05$	$e_{34} = 0.83$	$e_{44} = 0.93$	$e_{54} = 0.52$
$e_5 = 3.16$	$e_{15} = 0.25$	$e_{25} = 1.14$	$e_{35} = 1.07$	$e_{45} = 1.45$	$e_{55} = 0.78$
$e_6 = 3.24$	$e_{16} = 0.31$	$e_{26} = 1.17$	$e_{36} = 0.36$	$e_{46} = 1.67$	$e_{56} = 0.22$
$e_7 = 2.62$	$e_{17} = 0.37$	$e_{27} = 1.19$	$e_{37} = 0.33$	$e_{47} = 2.02$	
$e_8 = 2.43$	$e_{18} = 0.80$	$e_{28} = 1.23$	$e_{38} = 0.23$	$e_{48} = 0.98$	
$e_9 = 1.87$	$e_{19} = 0.67$	$e_{29} = 0.79$	$e_{39} = 0.18$	$e_{49} = 0.28$	
$e_{10} = 0.92$	$e_{20} = 0.70$	$e_{30} = 0.05$	$e_{40} = 0.15$	$e_{50} = 0.49$	

$$\sum_{i=1}^{n=56} excursion_i = 87.22$$

APPENDIX D: FIGURES FOR GIS MAPPING

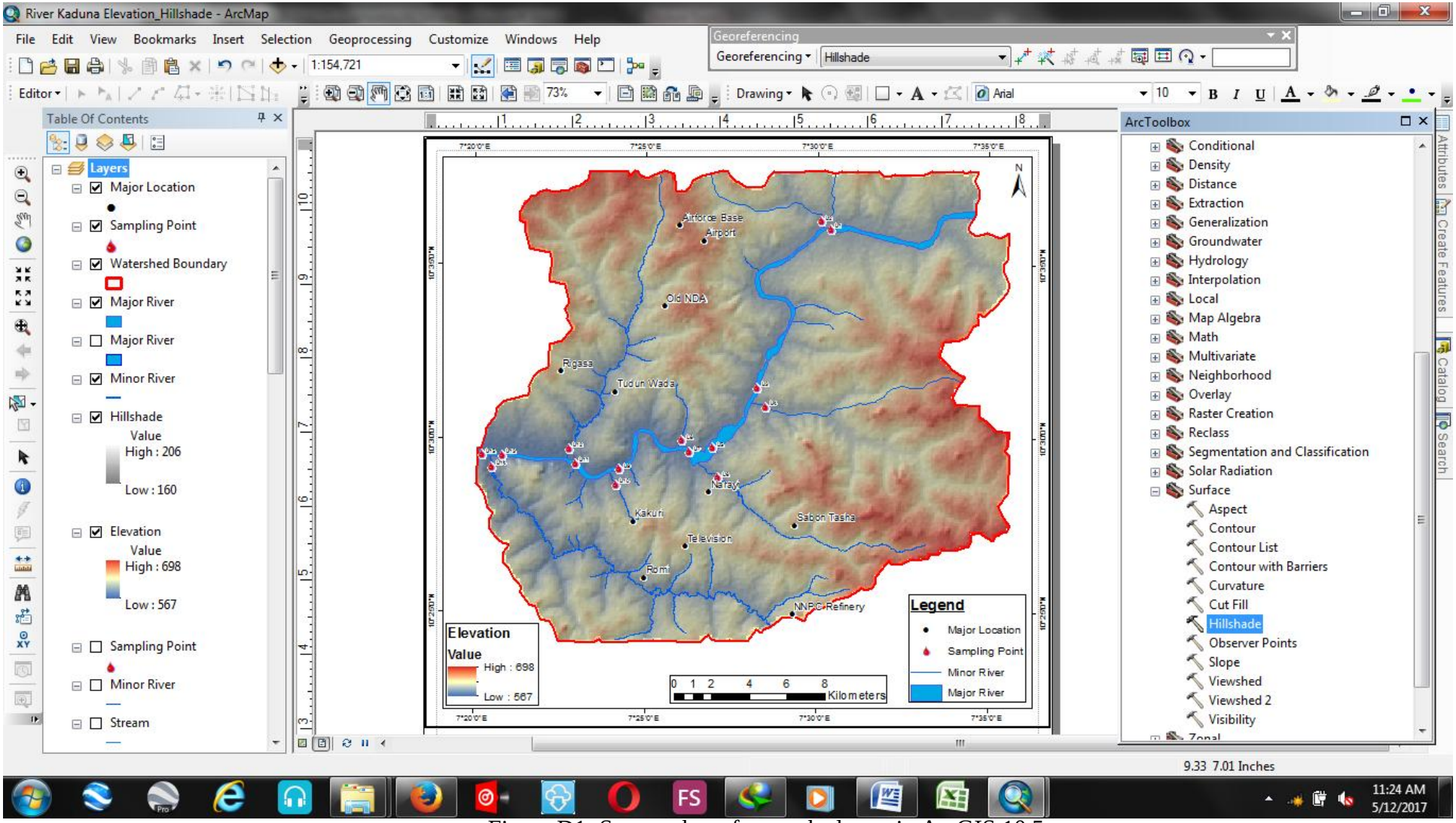


Figure D1: Screen-shot of watershed map in ArcGIS 10.5

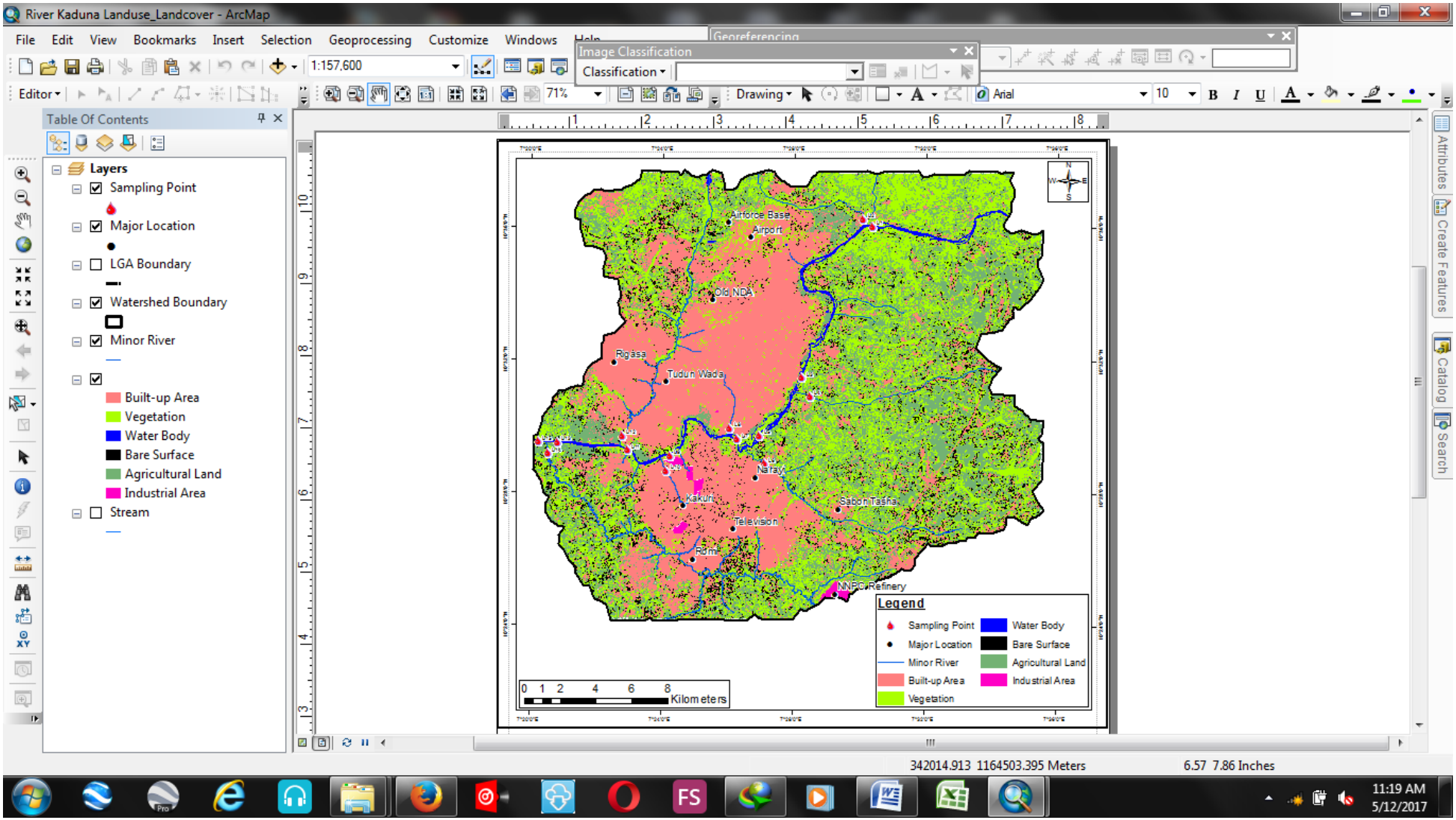


Figure D2: Screen-shot of land cover map in ArcGIS 10.5

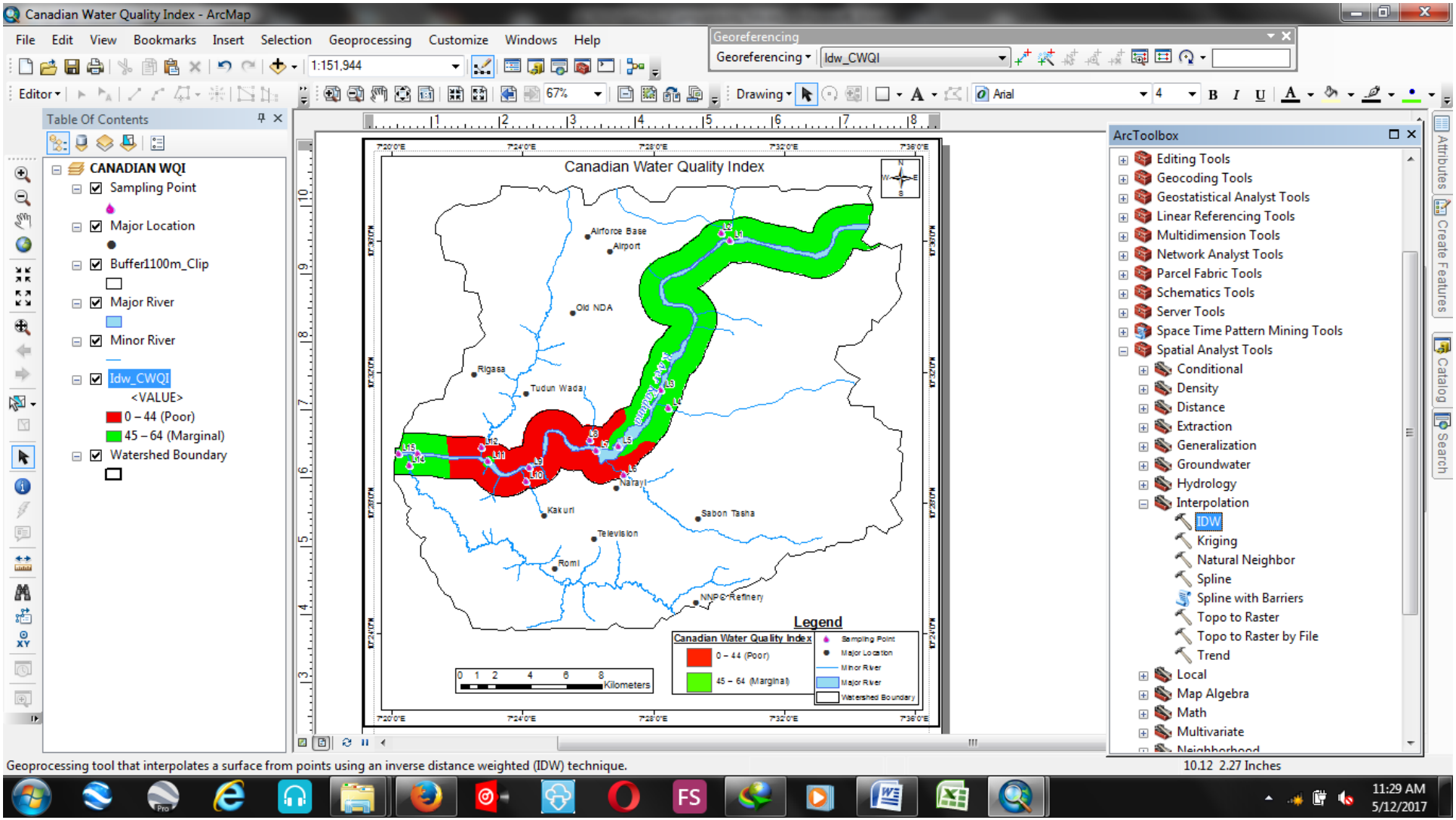


Figure D3: Screen-shot of Canadian WQI map in ArcGIS 10.5

APPENDIX E: CORRELATION MATRIX OF PHYSIOCHEMICAL PARAMETERS

Table E1: Correlation matrix of examined physiochemical parameters

	Temp	**Turb**	**TDS**	**pH**	**Cl^-**	**EC**	**DO**	**BOD_5**	**COD**	**TN**	**TP**	**Fe**	**Mn**
Temp	1												
Turb	0.745**	1											
TDS	0.136	0.293**	1										
pH	−0.314**	−0.260**	0.023	1									
Cl^-	0.135	0.292**	1.000**	0.025	1								
EC	0.136	0.293**	1.000**	0.024	1.000**	1							
DO	−0.550**	0.412**	−0.486**	−0.324**	−0.487**	−0.486**	1						
BOD_5	−0.229**	−0.044	0.530**	0.103	0.531**	0.530**	−0.541**	1					
COD	−0.426**	−0.227**	0.474**	0.301**	0.475**	0.474**	−0.685**	0.856**	1				
TN	−0.668**	−0.585**	−0.041	0.387**	−0.039	−0.041	−0.640**	0.102	0.412**	1			
TP	−0.665**	−0.591**	−0.078	0.409**	−0.076	−0.077	−0.620**	0.076	0.369**	0.991**	1		
Fe	−0.687**	−0.489**	0.185*	0.338**	0.186*	0.185*	−0.703**	0.601**	0.793**	0.702**	0.684**	1	
Mn	−0.727**	−0.574**	0.158*	0.364**	0.159*	0.158*	−0.692**	0.605**	0.752**	0.626**	0.609**	0.854**	1

** Correlation is significant at the 0.01level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed).

APPENDIX F: FIGURES FOR MULTIVARIATE TECHNIQUES

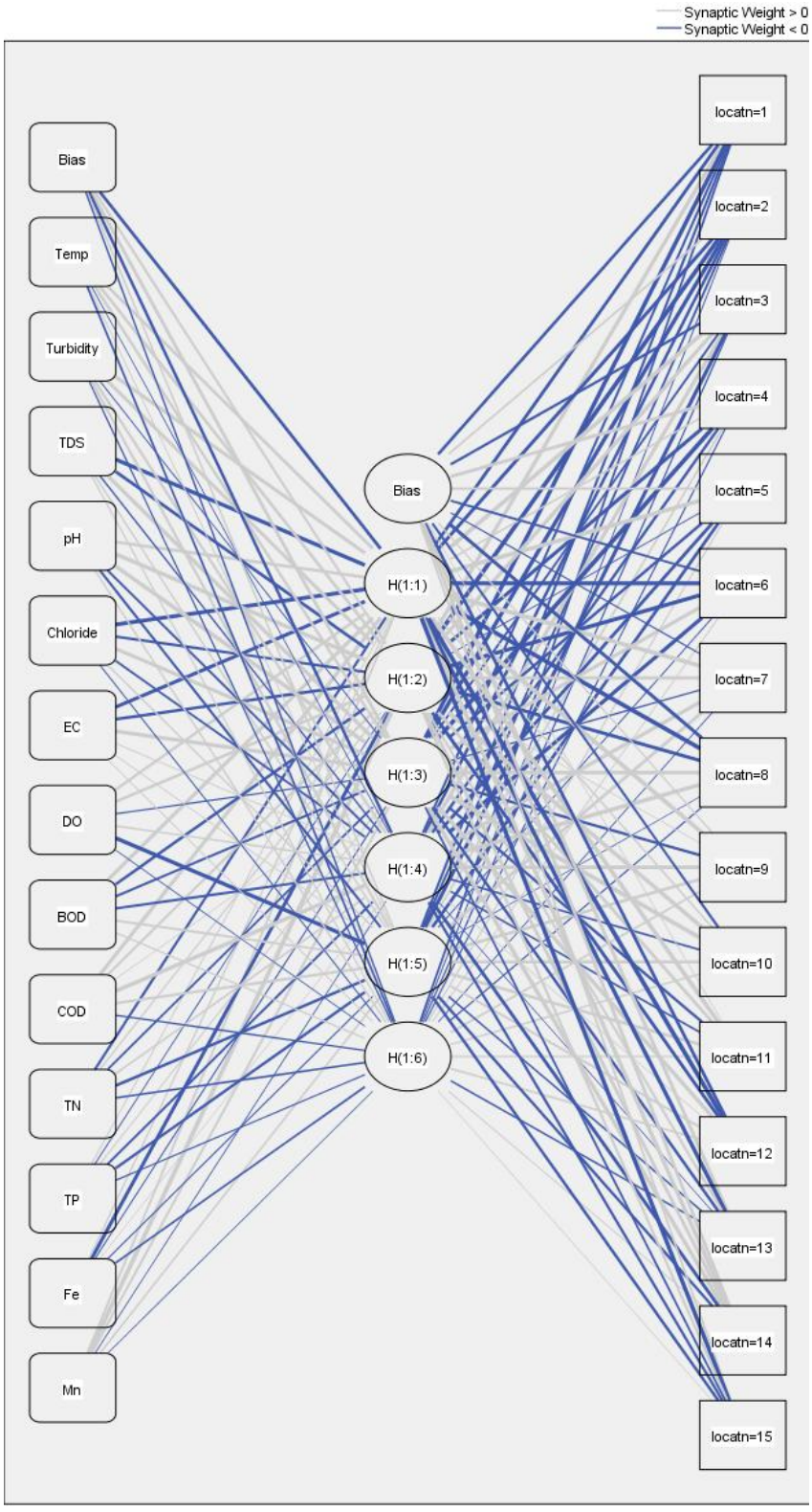


Figure F1: Artificial Neural Network for Physiochemical parameters and sampling locations

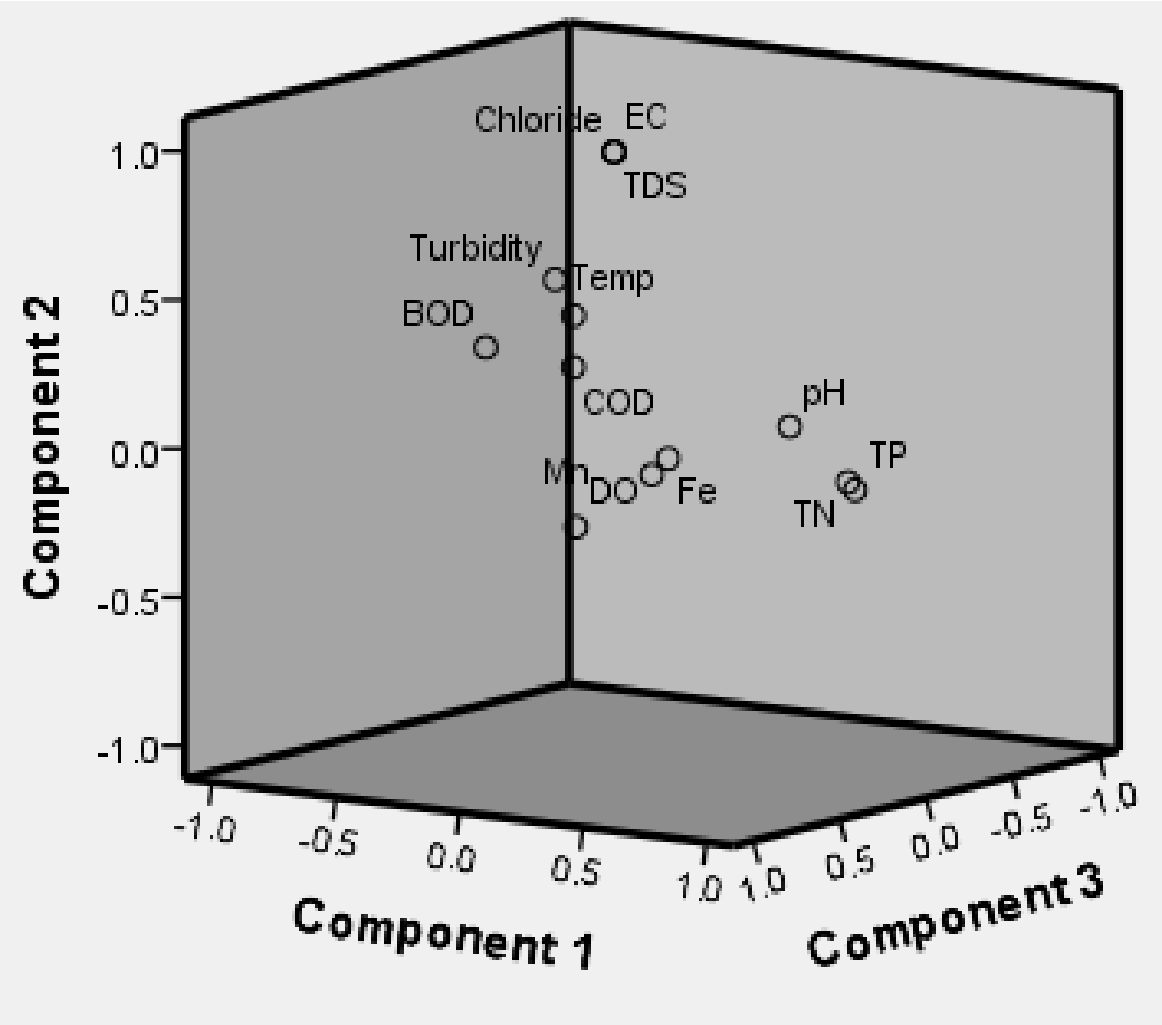


Figure F2: Component plot in rotated space

APPENDIX G: BOD/COD RATIO TABLE

Table G1: BOD/COD ratio for sampling location

Location Code	Location Name	Geographical Coordinate	Dry Season BOD/COD	Rainy Season BOD/COD
L1	*Malalin	10°36'3.09"N; 7°30'21.91"E	0.0146	0.0143
L2	+Kwarau	10°36'16.96"N; 7°30'5.43"E	0.0169	0.0160
L3	*NNPC	10°31'29.23"N; 7°28'14.04"E	0.0317	0.0307
L4	+Kuyi	10°30'56.02"N; 7°28'28.84"E	0.0295	0.0262
L5	*Barnawa	10°29'44.46"N; 7°26'56.86"E	0.0351	0.0314
L6	+Kutimbi	10°28'53.12"N; 7°27'6.71"E	0.0415	0.0413
L7	*Living Faith	10°29'36.82"N; 7°26'16.25"E	0.0335	0.0335
L8	+Kigo	10°29'57.44"N; 7°26'3.32"E	0.0340	0.0322
L9	*Down Quarters	10°29'6.80"N; 7°24'13.53"E	0.0376	0.0337
L10	+Breweries	10°28'40.07"N; 7°24'7.42"E	0.0304	0.0386
L11	*Ungwa Mu'azu	10°29'17.15"N; 7°22'56.89"E	0.0367	0.0327
L12	+Rigassa	10°29'42.63"N; 7°22'45.92"E	0.0393	0.0369
L13	*Maigiginya	10°29'30.84"N; 7°20'48.66"E	0.0163	0.0118
L14	+Romi	10°29'10.65"N; 7°20'31.50"E	0.0301	0.0253
L15	*Railway Bridge	10°29'31.67"N; 7°20'13.77"E	0.0073	0.0059

* = Sampling locations along River Kaduna, + = Sampling locations along tributaries, 30 m away from confluence point.

Note: BOD/COD ratio less than 0.3 signifies that the water may have some toxic components hence, it cannot be easily treatable by biological means.