EFFECTS OF AGROCHEMICALS ON SOIL AND WATER QUALITY IN PARTS OF RIVERS NIGER AND KADUNA CATCHMENTS, NORTH CENTRAL NIGERIA

BY

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ABSTRACT

Contamination of soil and surface water due to unsustainable use of pesticides and fertilisers by farmers and subsequent socioeconomic effects on communities' livelihoods is a major problem in the study area. Comprehensive data on this problem is of great interest as the existing ones are scanty. The objectives are to investigate the patterns of pesticides and fertilisers use; determine the spatial concentrations of physicochemical properties of sediment and water samples; determine the spatial concentrations of plant minerals and the extent of occurrence of organochlorine pesticide residues in water and soil; investigate the socioeconomic challenges; and appraise the effectiveness of relevant environmental laws and extant regulations on agrochemical use in the study area. An extensive field survey was conducted using various participatory appraisal techniques, namely, questionnaires, scheduled interviews, and village-level group discussions. Subsequently, seasonal water and sediment samples was collected, analysed *in-situ* (for water only) and in the laboratory for physico-chemical properties, plant minerals and pesticide residue concentrations. Collated data were analysed using descriptive statistical methods (frequency percentage), spatial analysis and non-parametric analysis. Survey results indicated that a significant percentage of the study population (97.5%) used synthetic fertilizers in their farming. Percentage volume of fertilizers and pesticide application per hectare indicated that the study population uses high quantities of agrochemicals across the zones. Physico-chemical properties identified in this study showed that the value of pH range (5.2 to 7.4), salinity (28.0 to 76.0 PSU), temperature (22.1 to 28.1 °C), EC (10.0 to 43.0 μs/cm), DO (5.3 to 8.6 ppm), TDS (6.7 to 23.60 ppm), turbidity (12 to 47 0 NTU), COD (13.80 to 45.06 ppm), BOD (7.05 to 18.15 ppm), TSS (15.8 to 54.0 ppm), Mn (0.08 to 2.86 ppm), TH (3.55 to 10.52 ppm), chloride (16.08 to 106.5 ppm), sulphate (0.447 to 22.68 ppm) and potassium (0.13 to 62.75 ppm). Plant mineral concentrations were detected and spatially distributed across the study zones in surface water and sediment samples during rainy and dry seasons, with concentrations ranging from NO_3^- (0.02 to 3.147 ppm), NO_2^- (0.02 to 1.16 ppm) and PO_4^- (0.228 to 5.771 ppm). Organochlorine pesticide compounds which include endosulfan, alpha endosulfan, endosulfan ether, delta endosulfan, endosulfan sulfate, mehoxychlor, alpha lindane, delta lindane, endrin ketone, dieldrin, DDT, DDMU, mitotane and heptachlor epoxide were detected and quantified with concentrations ranging from 0.01 ppm to 15.97 ppm in water and sediment samples analysed. Conclusively, it can be stated that there exist unsustainable patterns of agrochemical use which has obviously led to contamination of water, sediments and socioeconomic effects in the study area owing to weak regulations. Thus, it is recommended that visible and effective environmental management policies in respect of agrochemical use in the study area be put in place. Also, Green chemistry technology should be adapted for agrochemical formulations, organic farming and the use of biobased products should be encouraged and promoted among farmers to minimize or prevent the use of environmental unfriendly agrochemicals. This will guarantee cleaner and healthier environment for all.

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ADP Agricultural Development Programme

AAS Atomic Absorption Spectrophotometer

AChE Acetyl cholinesterase

AI Active Ingredient

APHA American Public Health Association

ATSDR Agency for Toxic Substance and Disease Registration

AWWA American Water Work Association

BDL Below Detection Limit

BHC Benzene hexachloride

BOD Biochemical Oxygen Demand

$Ca(NO_3)_2$ Calcium ammonium nitrate (26%)

CRIN Cocoa Research Institute of Nigeria

CAs Carbamate pesticide

CAN Calcium ammonium

Cd Cadmium

Cl Chlorine

Cl^- Chloride ion

CNS Central Nervous System

COD Chemical Oxygen Demand

Cu Copper

$CuSO_4$ Copper sulphate

DDT Dichlorodiphenyltrichloroethane

DPSIR Drivers, Pressure, State, Impact and Response

DDE DichloroDiphenyldichloroethylene

DDD Dichlorodiphenyltrichloroethane

DO Dissolve Oxygen

EDCs Endocrine Disrupting Compounds

EDTA Ethylenediaminetetraacetic acid

ECD Electron Capture Detector

ETU Ethylene thiourea

EC Electrical Conductivity

EI Electron Ionization

EU European Union

FAS Ferrous ammonium sulphate

FID Flame Ionization Detector

FAO Food and Agriculture Organization (FAO)

FPD Flame Photometric Detector

FAOSTAT Food and Agriculture Organization Corporate Statistical Database

FMEnv Federal Ministry of Environment of Nigeria

GC-MS Gas Chromatography/Mass Spectrometry

GIS Geographical Information System

GPS Global Positioning System

GDP Gross Domestic Product

HCH Hexachlorocyclohexane

HP Hewlett-Packard

HPLC High Performance Liquid Chromatography

H_2SO_4 Sulphuric acid

HCl Hydrogen chloride

HCB Hexachlorobenzene

IARC International Agency for Research on Cancer

IITA International Institute of Tropical Agriculture

IPM Integrated Pest Management

IPSI Index of Potential Source Influence

ISO International Organisation of Standardization

KCl Potassium chloride

LD50 Lethal Dose

LGA Local Government Area

LC Liquid Chromatography

LLE Liquid Liquid Extraction

LZ Lower Zone

MARPOL International Convention for Prevention of Pollution from Ships

MS Spectrometry

MEAs Multilateral Environmental Agreements

Mn Manganese

MRLs Maximum Residual Limits

MRL Maximum Recommended Level

MDZ Middle Zone

Na_2SO_4 Sodium Sulphate – anhydrous granulated

$(NH_2)_2CO$ Diamino methanol (46%)

NESREA National Environmental Standards and Regulations Enforcement Agency

$NH_4CH_3O_2$ Ammonium acetate

NAFDAC National Agency for Foods and Drugs Control

N-hexane Normal hexane

NISEPA Niger State Environmental Protection Agency

NOAEL No-Observed Adverse Effect Level

NSPRI Nigeria Stored Products Research Institute

NBS National Bureau of Statistics

NC Not classified

ND Not detected

NO_2^- Nitrite ion

NO_3^- Nitrate ion

NPD Nitrogen Phosphorous Detector

NPK Nitrogen Phosphorus Potassium

NW North West

OECD Organisation for Economic Co-operation and Development

OCls Organochlorine pesticides

Ops Organophosphorus pesticides

OC Organochlorine

OPP Organophosphorus Pollutants

PEC Predicted Environmental Concentrations

PNEC Predicted No Effect Concentrations

PO_4^{3-} Phosphate

PO_4^{-3} Orthophosphate

POPs Persistent Organic Pollutants

PAHs Polycyclic Aromatic Hydrocarbons

PCBs Polychlorinated biphenyl

PECAN Pest Control Association of Nigeria

PAN Pesticides Action Network

PPE Personal Protective Equipment

pH Potential for Hydrogen

RN River Niger

RK River Kaduna

SO_4^{2-} Sulphate

S1-S8 Sediment Sample Points One to Eight

T11 Eleven Table

TDS Total Dissolve Solids

TSS Total Suspended Solid

TG Target group

THC Total hydrocarbon

TCD Thermal Conductivity Detector

OCP Organochlorine Phosphate

USEPA United State Environmental Protection Agency

UN United Nation

US United State

W1-W8 Water Sample Points One to Eight

WAAPP-Nigeria West African Agricultural and Productivity Programme

WEF Water Environmental Federation

WHO World Health Organization

SPMDs Semipermeable Membrane Devices

SPE Solid Phase Extraction

SME Small and Medium Scale Enterprises

SPSS Statistical Package for Social Sciences

SAICM Strategic Approach to International Chemical Management

UZ Upper Zones

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Agrochemical is a common name for chemicals (pesticides and fertilizers) used in farming to enhance growth and protection of plants. Precisely, they are agriculture chemicals (Leong *et al.*, 2020). Although, they are originally used to increase yields, they have been reported to have negative effects on soil and water quality (Sun *et al.,* 2019; Corcoran *et al.,* 2020). In addition to the obvious effects on plants and food chains, they are widely used. Because of these many uses, they move into the surrounding water, which has a wide range of effects on physical, chemical, and biological processes within aquatic ecosystems (Lakhani, 2015; Bassi *et al.*, 2016; Joko *et al.*, 2017; Kaur *et al.*, 2019).

Modern agriculture depends heavily on the use of chemicals (Sánchez-Bayo and Tennekes, 2017; Sarker *et al.,* 2020). It has been estimated that every year, 150 million tons of fertilizers and millions of tons of pesticides are applied to crop fields globally with the only objective of increasing agricultural production (Bernhardt *et al.,* 2017; Gilbertson, 2020). While there is evidence that the use of herbicides can increase yields in many crops (Gianessi, 2013; Karim *et al.,* 2020), there is also evidence that most fungicides and insecticides do not help increase such yields (Lechenet *et al.,* 2017).

On the other hand, the ecological risks of these chemical inputs to the environment are often ignored by the public, when not dismissed by those who assert that a growing human population needs to be fed at all costs (Popp *et al.,* 2013). Concerns about the massive use of agricultural pesticides, in particular insecticides, in agriculture was raised half a century ago (Sánchez-Bayo and Tennekes, 2017) sparking an environmental movement that has lasted to this day. Regulations about the safety of individual pesticides were enacted in the developed countries in the 1970s, while most developing and underdeveloped countries remained oblivious to their negative effects (Khan *et al*., 2015) until their routine misuse impacted on human health (Alinejad *et al.*, 2017; Valcke *et al.*, 2017; Ha *et al.*, 2018) and brought about other negative environmental consequences (Scholz *et al.*, 2012).

An environment that is free of pollutants is essential for ideal environmental safety, fitness of human health and economic development (Ja'agi and Baba, 2015). Polluted water due to microbial infections causes visible diarrhoeal diseases, on the other hand, chemical and toxic contaminations result into acute or chronic sicknesses in human and kill insidiously (Wimalawansa and Wimalawansa, 2014). Contamination of water by agrochemicals are a worldwide problem and a serious issue in developing countries, where the difficulties are associated in part to slack environmental laws. Subsequently, water pollution creates an enable avenue of contamination of the human food chain. Water and food are firmly associated and cannot be separated easily. Numerous transmissible and non-transmissible human diseases are often correlated to water, soil-geochemistry, and environmental pollution (Kolpakova, 2004; Wimalawansa and Wimalawansa, 2014).

In addition to degrading the physical, chemical, and biological status of hydrologic systems, pesticides and plant minerals can have significant social and economic costs on communities through polluting drinking water, degrading fisheries, and potentially increasing food risks. Excess nitrogen and phosphates in rivers, lakes, reservoirs, and ponds can lead to massive overgrowth of algae and deplete the oxygen levels that fish, shellfish and other aquatic organisms need for survival (Knauer, 2016). High levels of nitrogen in drinking water can pose particular risk to infants and children. Water pollution arising from pesticide use can affect many non-targeted biotic systems, such as fish, birds, beneficial insects, and plants. An assessment of pesticide residues in sediment, water and living organisms of rivers in agricultural areas in most countries shows that pesticides and other toxic agrochemicals are increasingly polluting the aquatic environment (Lawrence *et al*., 2015; Lindstrom *et al*., 2015). As a result of monitoring, pesticide residues are often found in surface waters (Lindstrom *et al.,* 2015), and concentrations of pesticide residues have been reported in several studies that are expected to affect aquatic organisms or communities (Ali *et al.*, 2014; Knauer, 2016; Houbraken *et al.*, 2017).

In Nigeria, agrochemicals (pesticides and fertilizers) are widely used to enhance crop production and productivity, right from farming, storage to marketing, distribution of grain, and in seed dressing before planting (Ogunjimi and Farinde, 2012). Farming is a major occupation in the study area which the communities, mostly depend on for a livelihood. Interestingly, several relevant organizations and bodies have taken constructive initiative towards ensuring sustainable use of agrochemicals in Nigeria. These regulatory and enforcement authorities address mostly key stakeholders in the form of organized groups like farmers, marketers at the registration level devoid of proper monitoring and enforcement.

Studies on pollution of aquatic environment caused by various chemicals have been carried out in several areas in North Central Nigeria and reported by various researchers. A study in fadama area of Minna, Nigeria revealed the presence of residues of pesticides in water and soil samples analysed (Ogbonnaya *et al*., 2017). A related study also in Tunga-Kawo area irrigation scheme revealed contamination of water by agrochemicals (Jimoh *et al.,* 2003). A study on identification of pollution sources and water quality in Kaduna River in Niger State also indicated the influence of anthropogenic effects on the river (Ogwueleka. 2014). Ojutiku *et al*. (2016) also worked on phytoplankton distribution and physico-chemical characteristic of Lapai-Agaie Dam in Minna, Niger State, Nigeria. Sidi *et al.* (2016) worked on assessment of the chemical quality of water from shallow alluvial aquifers in and around Badeggi, Central Bida Basin, Nigeria. The study suggested, however, that continued monitoring is needed as a means of protecting the flood plain aquifers from potential contamination. All these studies were not spatial enough, but approached through laboratory, analytical dimension, and without consideration for community or stakeholder participation.

In view of this important limitation, there exists an excellent opportunity to consider a study with spatial coverage beyond laboratory analytical dimensions. Subsequently, while most of these studies were targeted at investigating the physico-chemical properties, and fertilizer contamination separately, few studies have been done on pesticide contamination. No studies have so far been carried out targeted at comprehensive investigation of the effects of agrochemicals on soil and water quality in parts of Rivers Niger and Kaduna catchments. Thus, with the continuous high influx of agrochemical products from increasing population in areas close to water resources, the magnitude of the problem cannot be underestimated. Unfortunately, there is a lack of sufficient information that represent high risk of agrochemical use effect on soil and water quality in the study area. This informed the need for this research.

1.2 Statement of the Research Problem

Reports has it that the use of pesticides and synthetic fertilizers in farming for crop protection and improvement respectively, compromises soil and water quality and consequently threatens the survival of biota and human health (Mensah *et al.,* 2014). According to Mensah *et al*. (2014), World Health Organisation (WHO) considers most chemical pesticides to be hazardous. A good number of agricultural pesticides namely endosulfan, endrin and dichlorodiphenyltrichloroethane (DDT) have been banned or restricted for use by many countries owing to environmental and health reasons, yet they are still in use by farmers in developing countries like Nigeria (Keri and Directorate, 2009; Ojo, 2016). Aside pesticides, synthetic fertilizer use in various parts of the developing nations are on the increase (Ramteke and Shirgave, 2012).

Rivers Niger and Kaduna catchments are arable land where people practice farming involving intensive use of agrochemicals (Ogwueleka, 2014). This practice can result into soil and water quality degradation and disproportionate negative consequence on the socio-economic wellbeing of the communities. Due to the threats from unsustainable use of agrochemicals and obvious weaknesses in conservation of aquatic resources measures which has resulted in increase in the negative effects on soil and water and the general environment beyond expectations and rapid increase in human population coupled with change in climate has resulted to a motivating factor for farmers to depend more on agrochemicals in agricultural activities near rivers (Knauer, 2016).

Communities depend on these rivers for the livelihood and lack of research information about the area that represent a risk of agrochemical pollution informed the need for immediate assessment of qualities of its resources to guaranty socioeconomic sustainability. Inadequate information about risk of agrochemical pollution has been reported to be one of the factors responsible for weak legislation coupled with poor enforcement of available legislation in Nigeria (Ojo, 2016). There is presently little research attention on agrochemical effects on soil and water quality in the study area and has resulted to scary research information about the study area that represent high risk of agrochemicals pollution. So far, no research evidence indicating a well targeted and detailed analysis has been done in the study area.

Further, several related researches such as Jimoh *et al.* (2003); Ogwueleka (2014); Lawrence *et al.* (2015); Dirisu *et al.* (2016); Ojutiku *et al.* (2016); Sidi *et al.* (2016); Ogbonnaya *et al.* (2017); Bamigboye *et al.* (2017); Njoku *et al.* (2017) have been carried out in North Central Nigeria and other parts of Nigeria, however, all these studies were not spatial enough, but approached through laboratory analytical dimension, and without consideration for community or stakeholder's participation. In view of this limitation, there exists an excellent opportunity to consider a study with comprehensive spatial coverage beyond laboratory analytical dimensions.

More so, while several studies on chemical contamination of soil and water have been conducted in some parts of the study area such as Jimoh *et al.* (2003), Ojutiku *et al.* (2016), and Sidi et *al.* (2016), which were targeted at investigating physico-chemical properties, plant minerals or fertilizer contamination, fewer studies have been done on pesticide contamination. No studies have so far been conducted which is targeted for comprehensive investigation of physico-chemical properties, fertilizers or plant minerals and pesticide residue contamination, and their socio-economic effects on the wellbeing of communities in the study area altogether. This study was envisioned to bridge this gap.

1.3 Research Questions

(i) What are the patterns of pesticides and fertilizer use in the study area?

(ii) What are the spatial concentrations of physicochemical properties of water and sediment samples in the study area?

(iii) What are the spatial concentrations of plant minerals and the extent of occurrence of organochlorine pesticide residues in sediment and surface water samples in the study area?

(iv) What are the likely socio-economic problems of pesticide residues and fertilizer contamination of the aquatic environment of communities in the area? And

(v) How effective are the relevant environmental laws and extant regulations for management of agrochemical use near sensitive and vulnerable areas?

1.4 Aim and Objectives

This study aimed to investigate the effects of agrochemicals on soil and water quality in parts of Rivers Niger and Kaduna catchment, North Central Nigeria. The objectives of the study are to:

(i) investigate the patterns of pesticides and fertilizer use in the study area;

(ii) determine the spatial concentration of physicochemical properties of sediment and water samples in the study area;

(iii) determine the spatial concentration of plant minerals, and the extent of occurrence of organochlorine pesticide residues in sediment and surface water samples in the study area;

(iv) investigate the socioeconomic challenges of pesticide residues and fertilizes contamination of aquatic environments in the communities; and

(v) appraise the effectiveness of relevant environmental laws and extant regulations on agrochemical use near sensitive and vulnerable areas.

1.5 Justification for the Study

This study investigated the effects of agrochemical on soil and water quality of communities in parts of Rivers Niger and Kaduna catchments in parts of North Central Nigeria. It was conceived since Rivers Niger and Kaduna catchments are highly affected by intense agricultural activities (Ogwueleka, 2014). Furthermore, considering that the threats of unsustainable uses of agrochemical and weak conservation measures of aquatic resources, leading to more serious negative impact on water and general environment beyond expectation. Also, rapid increase in human population coupled with change in climate has resulted to a more reasons for farmers to use more agrochemicals in farming activities near Rivers (Knauer, 2016). Communities' dependant on these Rivers for livelihood and lack of research information about the area that represent a risk of agrochemical pollution informed the need for immediate assessment of qualities of its resources to guaranty socioeconomic sustainability.

It is understood that the unsustainable use of agrochemicals (pesticides and fertiliser) has continued to alter the physico-chemical patterns of water and its resources, which has resulted in poor water quality in the study area. As a comprehensive information on the distribution of water quality parameters in the study area is of great interest, there exists an excellent opportunity to consider a study spatial coverage beyond laboratory analytical dimensions.

1.6 Scope and Limitation of the Study

1.6.1 Scope of the study

This study focused mainly on investigating agrochemical effects on soil and water quality in parts of Rivers Niger and Kaduna Catchments, North Central Nigeria. The study was carried out within four Local Government Areas (LGAs) in the Niger State (Mokwa, Lavun, Katcha and Agaie). It covers the area from Rabba village in Mokwa LGA to Baro in Agaie LGA along River Niger and from Wuya village in Lavun LGA to Muregi along River Kaduna.

1.6.2 Limitations of the study

Within the period of this study, no known comprehensive investigation in respect of plant, mineral contamination, pesticide residue concentrations, socio-economic cost and regulatory roles have been conducted in the study area, which resulted to major hindrance in generating enough background or site-specific literature for the study. Other hindrances in this study were; lack of reference analytical laboratory nearby which informed the consideration of only organochlorine pesticide compounds due to their strong ability to remain undegraded for lengthy time under any environmental conditions as the samples were to be sent far away (Dr Olukoya Research Laboratory, University of Lagos) from their collection point for analysis. It also limited the environmental media analysed to water and sediment; also, there was an initial refusal from some key stakeholders to make input to the work, but this limitation was overcome by educating them on the need for their inputs; permissions were also refused by regulatory and enforcement authorities to take the picture evidences of the interactions.

1.7 Study Area

The study area in this investigation is riverine communities in parts of Rivers Niger and Kaduna catchment areas, North Centra, Nigeria, located within Longitude 3˚30'N and 7˚20'E and Latitude 8˚22'N and 11˚30'N; located at the Guinea Savanah vegetation zone at the north central area of Nigeria (Figure 1.1). Rivers Niger and Kaduna catchments are cultivatable land where much farming is in practice close near the rivers (Ahmed, 2001; and Ogwueleka, 2014).

The landscape border area of the river is flat shaped and swampy. It is characterized by several channels and lakes for floods, particularly in the western part. An important feature aspect of this landscape is quite the existence of a large area of Fadamas, where the rivers flow from the complex of basement to the area of the Nupe sandstone. The floodplains on the Kaduna and Niger Rivers are a few kilometres wide at the border of the Nupe basement, the two main streams of Yanko Iko, Dumi, Ebigi all drain their water into the Niger River (Ahmed, 2001).

The study area was divided into zones (Figures 1.1 and 3.2). Along River Niger, the Upper zone is from a Rabba village in Mokwa Local Government Area (LGA), Middle zone is at Muregi and the Lower zone is after Muregi in Mokwa LGA down to the Baro village in Agaie LGA. A study area along River Kaduna was divided into two zones. Upper zone is from Wuya village in Lavun LGA and the Lower zone from halfway down to Muregi. The communities living in the study area rely mostly on agriculture and fishing for economic survival. These are key leading sector for livelihoods, employment, and significant means for the socio-economic wellbeing of the community dwellers (Ahmed, 2001).

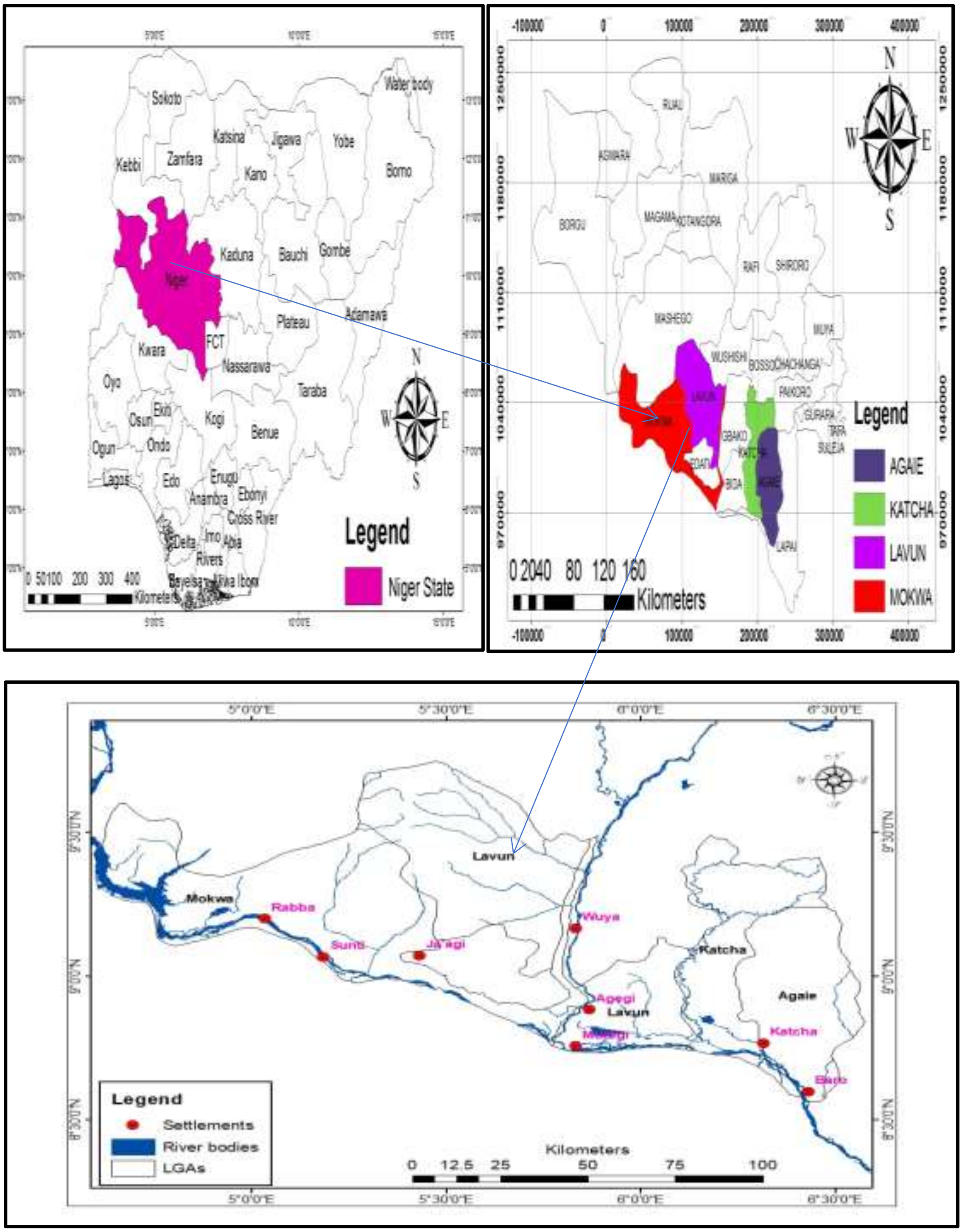


Figure 1.1: The Study Area (Parts of River Niger and Kaduna Basin, North Central Nigeria)

Source: Modified from National Space Research & Development Agency, 2017

1.7.1 River Kaduna

The River Kaduna is a key tributary of the Niger in central Nigeria. The river originates from the northwestern part of Jos in the plateau area of Vom, and flows northwest through Kaduna at altitude of 1500 m above the sea level. Then crossing southern to western parts and south before ending along the 550 km to Niger near Muregi (across from Patigi). The river flows through many villages, towns, and cities. The river is the main source of fresh water in agriculture and has thousands of residents throughout its territory (Ogwueleka, 2014). The river was found to be contaminated by agricultural activities, waste from the textiles and daily industry (Ahmed, 2001; Ogwueleka, 2014; Ja'agi and Baba, 2015).

1.7.2 River Niger

River Niger is a famous river in Nigeria; it is in Niger State. The name comes from the Latin "Niger", which means "black". Natives call it by different names such as *Edu* or *Ndaduma* in Nupe dialect, *'Jeliba'* or *'Joliba'* in *Manding* dialect which means 'Great River'. It is called *'Orimiri'* or *'Orimili'* in Igbo language, which means 'great water'. *'Egerew* n-*Igerewen'* in Tuareg dialect which means River of Rivers. *'Isa Ber'* in Songhay dialect which means 'big River'. Kwara, in Hausa dialect and lastly, it is called *'Oya'* in Yoruba dialect. The name Niger State and Nigeria originated from this river; thus, it is commonly called; The Niger River; or ‘River Niger’ all of which mean the same thing. This river and its catchments provide both domestic and economic values to Nigeria and the neighbouring countries (Ja'agi and Baba, 2015; Ihenacho *et al.,* 2019).

1.7.2.1 Climate of the study area

A climate of River Niger and Kaduna catchments shows significant variability. There is a significant decrease in annual rainfall in the north of more than 160 inches in the Delta region to less than 10 inches in Timbuktu. The top and bottom of the river drainage area with rainfall of more than 50 inches per year. Precipitation decreases at the middle parts with highest amount of evaporation being recorded in the same area (Ahmed, 2001; Amanambu *et al.*, 2019).

1.7.2.2 Hydrology of the study area

As a result of climatic variations, the rivers flood occurs annually at different time in all parts of the basins. High water discharges occur in June in the upper parts, and low water season occurs during December. In the mid parts of the rivers, high water discharge that is the white flood type (so called because the sediment content of the water is light) occurs between July and October, soon after the rainy season. Also, black flood (so called because the sediment content is greater) which is the second rise, starting in December upon arrival of flood waters from the upstream part (Ahmed, 2001; Amanambu *et al.,* 2019).

Low-water months at the mid parts stretch occur between May and June annually. Only one high-water season occurs in Benue. Due to the southerly location of Benue, it usually occurs between May and through October, much earlier than the middle parts. Higher water period of River Niger which normally begin in May or June in lower Niger below its confluence with the Benue earlier than in the mid part of Niger and a low-water period, which is mostly shorter with less than a month, due to the earlier onset of the rains South ward (Ahmed, 2001; Amanambu *et al.,* 2019).

1.7.2.3 Spatial extent of the Rivers Niger and Kaduna catchments

Rivers Niger is the longest river in Nigeria; it covers an area of about 4,180 km (2600 miles). The river rises on the Fouta Djallon Plateau, South West (SW) Guinea, flowing North East (NE) through Guinea into Mali and Niger before entering Nigeria through Lokoja, where it forms part of its borders with Benin before emptying into Gulf of Guinea within the Atlantic Ocean via the Niger Delta. River Niger has been classified as the third longest in Africa continent and ranked 11th longest river in the World. This river gets its source from the Guinea Highlands, while its main tributaries are from Kaduna River, Sokoto River, Bani River and Benue River. The volume of the river does not remain the same throughout the year as it fluctuates from time to time. Other factors such as increased water abstraction for irrigation farming and seasonal fluctuation (Climate change) have largely affected the volume and flow of the Niger River (Ahmed, 2001; Ifejika *et al*., 2013; Abrate *et al.,* 2013).

River Kaduna, a tributary of the Niger River rises on the Jos Plateau 18 miles (29 km) southwest of Jos town near Vom and flows in a northwesterly direction to a bend 22 miles (35 km) northeast of Kaduna town. It then adopts a southwesterly and southerly course before completing it 340-mile (550-kilometre) flow to the Niger at Muregi (Ifejika et al., 2013).

1.7.2.4 Flow pattern of Niger River and Kaduna catchments

River Niger flows in an unusual direction; its flow is unusual because its source is precisely 240 km which is equal to 150 miles from the Atlantic Ocean. Niger instead of flowing directly into the nearby Atlantic Ocean, it rather flows straight ward Far from the sea into the Sahara, then takes sharp to the right closed to the ancient city of Timbuktu and move directly southeast to the Gulf of Guinea. The unusual flow is because of the two ancient rivers that join the Niger River together (Ahmed, 2001; Ifejika *et al.,* 2013; Idowu and Zhou, 2019). The Kaduna River is a tributary of the Niger River, which flows for 550 kilometres (340 mi) through Nigeria. It starts in Plateau State on the Jos Plateau 29 kilometres (18 mi) southwest of Jos town, flows through its namesake Kaduna State and through its capital Kaduna, and meets the Niger River in Niger State at Muregi. Most of its course passes through savanna woodland, but its lower section has cut several gorges above its entrance into the extensive Niger floodplains (Idowu and Zhou, 2019).

1.7.2.5 Economic importance of Rivers Niger and Kaduna catchments

Rivers Niger and its catchments provide water for irrigation farming during the arid season, particularly for inhabitants living close the river; the inhabitant of Niger State mostly depend on this river to irrigate their crops. The point where the river (River Niger and Benue) meets to form a confluence provides the needed volume and speed to power the energy for the generation of hydroelectric power stations. This energy serves Nigeria and other some neighbouring countries, hence, contributing to the economic development of Nigeria. River Niger and its catchments offers sources of livelihood to the Niger State through fishing and selling of surplus fish to the market. Niger River and its catchments serve as a home to different water creatures such as the African lion, African manatee (sea cow), catfish, carp, Nile perch, hippopotamuses, and crocodiles among other animals.

Large-scale farming takes place at the bank of the River Niger and its catchments; most of these crops are sold within the country, while the majority of these are exported to other countries (Ahmed, 2001; Ifejika *et al.,* 2013; Meseko *et al.,* 2018). The river helps provide job opportunity for sailor and local fishers, as the waters are deep enough for different species of fish. The river serves as the main water source for domestics and industrial activities in Niger State, mostly after it has been purified. River Niger and its catchments have a significant length and depth, which makes it possible for navigation; they are often used for commercial shipping for transporting heavy goods to Onitsha from the Atlantic Ocean all over the year. The river has enough deposits of sand, both the Sand, mud is usually removed from the bottom of the river for construction of roads and houses. Irrigation farming taking place in Bamako, the capital city of Mali on the bank of the Niger River (Ahmed, 2001; Ifejika *et al.,* 2013: Meseko *et al.*, 2018).

River Kaduna is used for fishing and for transport of local produce. Gbari (Gwari) people have utilized the Kaduna's upper floodplains for swamp rice cultivation, and in the southern plains, in Nupe tribal territory, rice and sugarcane production has become a major economic activity. Near Bida, the Edozhigi and Badeggi natural irrigation projects are major rice-growing ventures.

CHAPTER TWO

2.0 LITERATURE REVIEW

To investigate pesticides and fertilizers effects on soil and water quality in parts of River Niger and Kaduna catchments, North Central Nigeria, empirical studies conducted by researchers in the field of pesticides and synthetic fertilizers which are mainly used in farming activities and their impact on the aquatic environment and livelihoods of surrounding communities were examined. Research gaps, missing links and deficiencies in existing knowledge groups was also identified. This chapter begins with a conceptual framework that provides a roadmap for the research. The rest of the review is devoted to each specific purpose of the study. It has been classified as a general overview of the pesticide use in farming, driving forces, the resultant negative effects on environment, health and economic development, and the role of regulation.

2.1 Conceptual Framework

Considering exploratory research finding by Ogwueleka (2014) who concluded that agricultural runoff is the main source of pollution in Kaduna Basin, this study assumed that the effects of agrochemicals in the rivers is triggered by the driving forces which could be a manifestation in expansion of agricultural activities involving intense use of agrochemicals. The assumed drivers could activate pressure of the like of water pollution in the catchment areas, consequently causing pollution in Rivers Niger and Kaduna catchments. Degradation in the rivers could include reducing the population of living organisms in the area, increasing the concentrations of chemicals in the surrounding area and the threat of bioaccumulation and human health in the community. In view of this, the concept of Drivers, Pressure, State, Impact and Response (DPSIR) framework developed by Kristensen (2004) was adopted in this study (Figure 2.1).

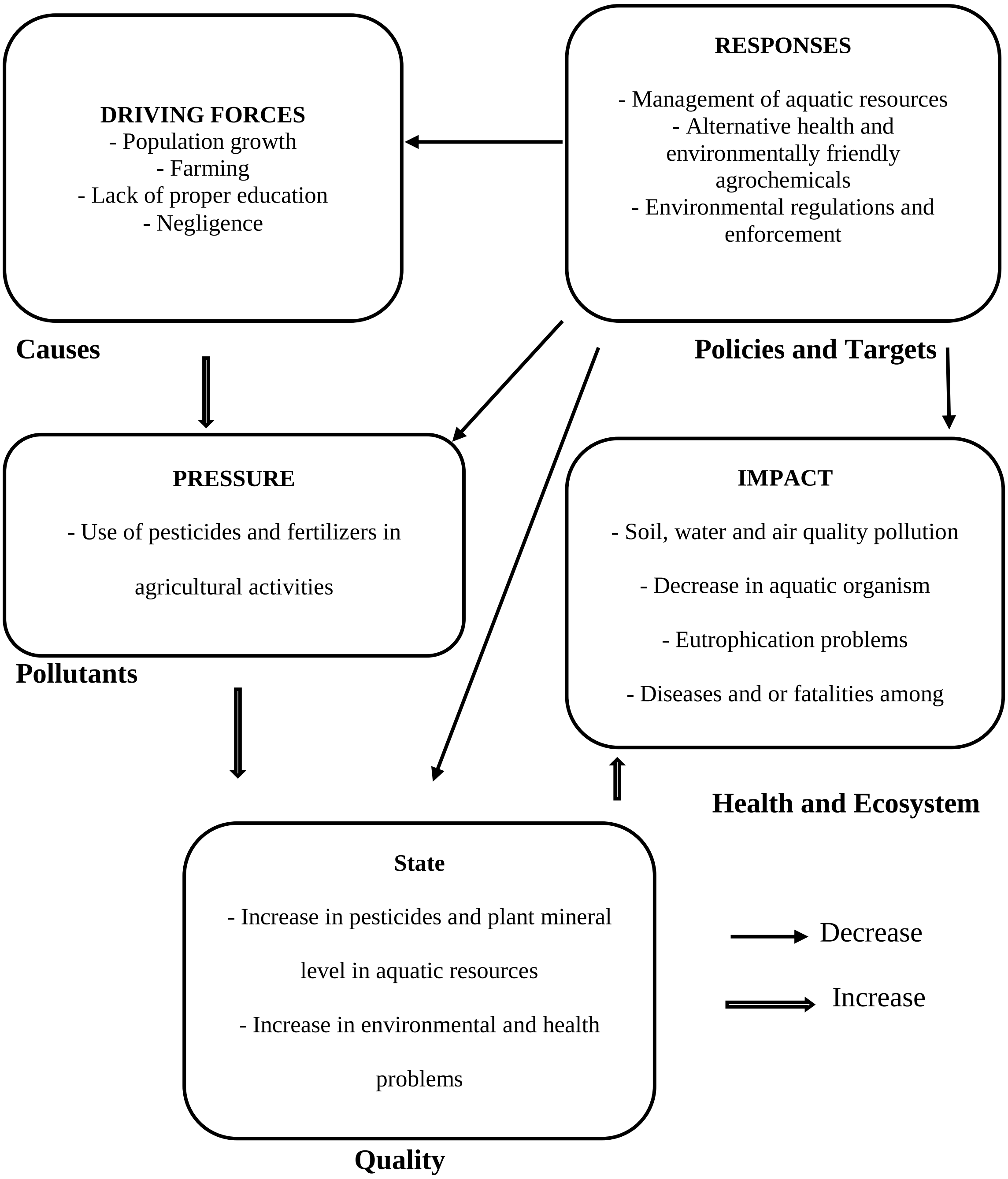


Figure 2.1: The Conceptual Framework for the Use of Agrochemicals and Effect in Parts of Rivers Niger and Kaduna Catchment

Source: Adapted and modified from Kristensen, (2004)

2.1.1 Driving forces and pressure to agrochemical use

According to Panchal and Kapoor (2013), high demand for farmlands coupled with the increasing need for food grains and decreases in farmlands in many parts of the world, especially in India have led to the high pressure on the need for improved farm yields and reducing losses in crop arising from pest attacks. The market for improvement and protection of crops continue to grow strongly in the past time and there are high expectations for further growth.

Agriculture in Nigeria provides about 29.15% of national income, which provides employment opportunities for about 70% of Nigerians (National Bureau of Statistics (NBS), 2017). Agriculture is directly linked to other sectors of the economy through the processing, consumption, and export of agricultural products (NBS, 2017). Nigeria's agricultural development shows significantly increase over the past few years due to availability of large and qualitative raw material resources to improve the quality and quantity of the crop. Agrochemicals such as pesticides and fertilisers are widely use in Nigeria, particularly for farming (Ojo, 2016).

2.1.2 State and responses of the use of agrochemicals

The physical conditions or state of the environment affected by pressure is mainly a chain of cause-and-effect relationships beginning with driving forces, such as human activity and the economy, due to pressure (waste generations and emissions into the atmosphere) in physical, chemical, and biological conditions. To make an impact on ecological systems, human health, and subsequent political reactions in the form of setting priorities, setting goals, regulating, and implementing, indicators and much more.

As advanced in a study conducted in Sri Lanka which revealed that proactive measures are being taken by the government aimed at controlling the unsustainable use of pesticides and fertilizers by farmers. Adverse effects of unsustainable use of Agrochemicals have been reported to significantly causing damages to biodiversity, soil and water contamination resulting to several acute and chronic health issues, specifically kidney disease, especially in many rural areas of the Northern, Central and Eastern provinces of Sri Lanka thereby incurring high cost for the country (Kudagammana and Mohotti, 2018). In this respect government across the world has embarked on visible measures to contain unsustainable agriculture pesticides and fertilizer use by adopting the promotion of the use of environmentally friendly agrochemicals in farm lands (Rahman, 2013; Irangani and Shiratake, 2013; Kudagammana and Mohotti, 2018).

Human exposure to pesticide and poisoning has been regarded as a serious neglected public health issue in developing countries, particularly Nigeria (Bertrand, 2019; Ojo, 2016). There exists a serious lack of awareness of this problem by policymakers and citizens because of absence of valid or scanty information with regards to the subject. Prevention of pesticide exposure and poisoning has been identified as a visible option to manage the harmful effects on communities from widespread exposure and high health consequences in the developing world (Lewis *et al.*, 2016). In view of the above, this study demonstrated local scientific ground for the development of policies and strategies for the purpose of reducing and controlling the pollution of the agricultural community by preventing exposure to environmental pesticides.

2.2 Agricultural Production and Exposure to Agrochemicals

Agricultural activity has been classified as a non-point sources of environmental contaminants. Around the world, an average of about 70 percent of water pollutants has been attributed to agriculture, pollution (United States Environmental Protection Agency (US-EPA), 2012; Evans *et al.,* 2019). Contaminants due to agriculture activities majorly include pesticides and chemical fertilizers (US-EPA, 2012; Evans *et al.,* 2019). Synthetic pesticides and fertilizers are mainly used for vector control in agricultural production and in public health facilities (Osorio, 2017; Valcke *et al.*, 2017). Exposure to agrochemicals have been understood to constitute a major occupational hazard in many communities (Ozkara *et al.*, 2016).

Obviously, highest consequences of unsustainable agrochemical use include human poisoning and many illnesses. In United State, about 67,000 pesticide related poisoning are reported yearly (Watson *et al.,* 2005). The worst situation has been reported in developing world were 80% of agrochemicals that are produced worldwide are used (Ojo, 2016). Pesticide poisonings and death mostly occur in developing world were weak legislation, enforcement, illiteracy, and insufficient pesticides hazard knowledge have been reported (Ojo, 2016).

2.3 Agriculture Fertilizers

Agricultural fertilizers have been described as chemical substances which are meant at providing plants with essential minerals needed for their growth and development. Several chemical supplements or minerals are essential for normal plant growth, which are usually supplied by fertilizers (Mekonnen *et al.*, 2016; Ramteke and Shirgave, 2012).

In general, fertilizers are divided into two main groups based on sources containing synthetic and organic fertilizers.

2.3.1 Synthetic fertilizers

Generally, synthetic fertilizers are readily available basically in two (2) forms (liquid and solid form). Ammonia, ammonium sulphate, nitrogen, ammonium nitrate, ammonium chloride, phosphate, superphosphate, urea, and potassium are some of the common fertilizers available (Kihampa *et al.*, 2010). These synthetic chemical fertilizers have been understood to be an essential tool for the purpose of increasing agriculture productivity (Mekonnen *et al.*, 2016). Major concern of synthetic fertilizers has been that only 14% of large amount of nitrogen usually produced are been useful for the plant need (Mekonnen *et al.*, 2016).

2.3.2 Organic fertilizers

Organic matter derived from plant and animal manure are the main source of organic fertilizers. They are produced by the way of composting without any trace of additives or chemicals (Kihampa, 2010; Jokha, 2015). Organic fertilizers are meant to enrich or maintain good quality and essential mineral content in the soil for the purpose of plant growth (Jokha, 2015). Several studies have advanced that organic fertilizers are effective as chemical fertilizers with no negative effects like synthetic fertilizers (Mtambanengwe and Kosina, 2007). Plant minerals such as nitrogen and phosphorus are essential to crop production. Yet, unsustainable use of these chemical fertilizers can present serious negative threat to water quality, air quality and contribute significantly to global warming (greenhouse effect) (Jokha, 2015).

2.4 Agriculture Pesticides

According to the Foods and Agricultural Organization (FAO), and the World Health Organization (WHO) (2016), pesticides are mixture of several substances intended to prevent, respond to, kill and reduce pests, such as vectors or human diseases, non-useful plants species or animals which cause harm in the process of agriculture production, processing, storage, transportation, trade in agriculture products, wood products, animal feed, or any substances use in controlling insects in animal productions, arachnids or other pests within or outside the body (FAO and WHO, 2016).

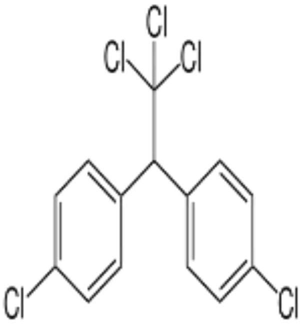
Agricultural pesticides are known to contribute positively to agriculture yields, yet present potential risks to health of human and all aspects of environment (Kim *et al.*, 2017). The risks from pesticide vary significantly depending on natural toxicity of pesticide and exposure. Pesticides are classified in many ways. These classifications are based on function such as herbicides, insecticides, and fungicides, and based on chemicals nature like organochlorine, organophosphorus and the carbamates (Kim *et al*., 2017).

2.4.1 Pesticides classification based on the chemical nature

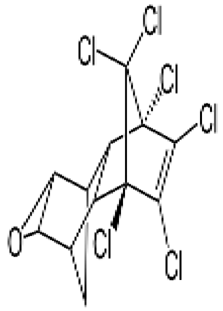
Depending on the type of chemical, the classification of pesticides is divided into several classes. The main ones are organochlorine, organophosphorus and carbamate pesticides.

2.4.1.1 Organochlorine pesticides

Organochlorine is a pesticide of chlorinated hydrocarbon compounds with general characteristics of oral toxicity and chronic residual action with very stable chemical compounds that can withstand the effects of various environmental factors. The most famous insecticide within the group is (1) DDT, which was synthesized within 1874. Several more chlorinated hydrocarbon insecticides were made following the discovery of DDT considering it effectiveness insect control. Other synthetic organochlorine compounds include (2) dieldrin, (3) methoxychlor, (3) chlordane, (4) heptachlor, (6) aldrin, (7) endrin, (8) toxaphene, (9) mirex and (10) Lindane. It was introduced in the 1940s and 1950s (Kim *et al.*, 2017). This compound is mainly used in agriculture, healthcare and at home (Enerst, 2004; Kim *et al*., 2017). They are structurally represented in Figure 2.2.



(1)



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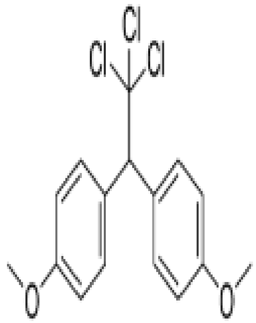

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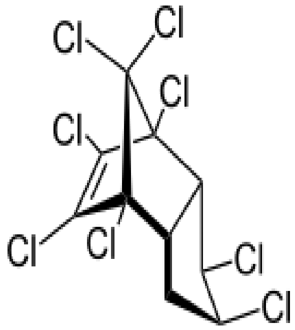

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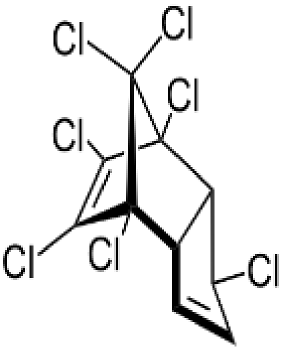

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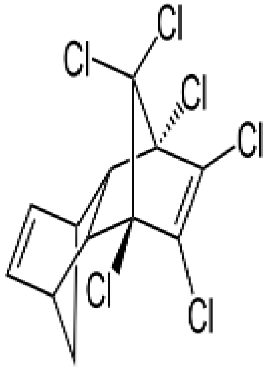

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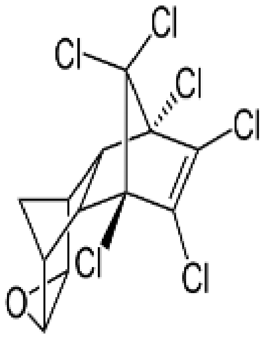

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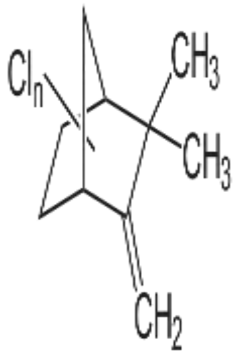

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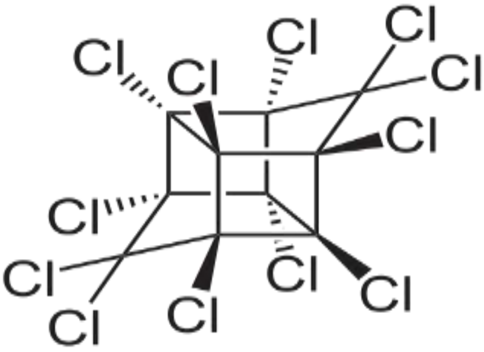

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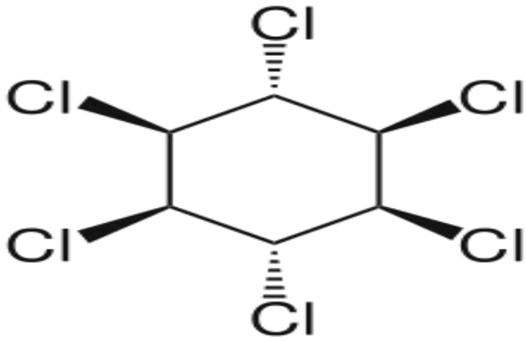


(10)

Figure 2.2: Structural Representations of Organochlorine Insecticides
Source: (Enerst, 2004; Kim *et al*., 2017).

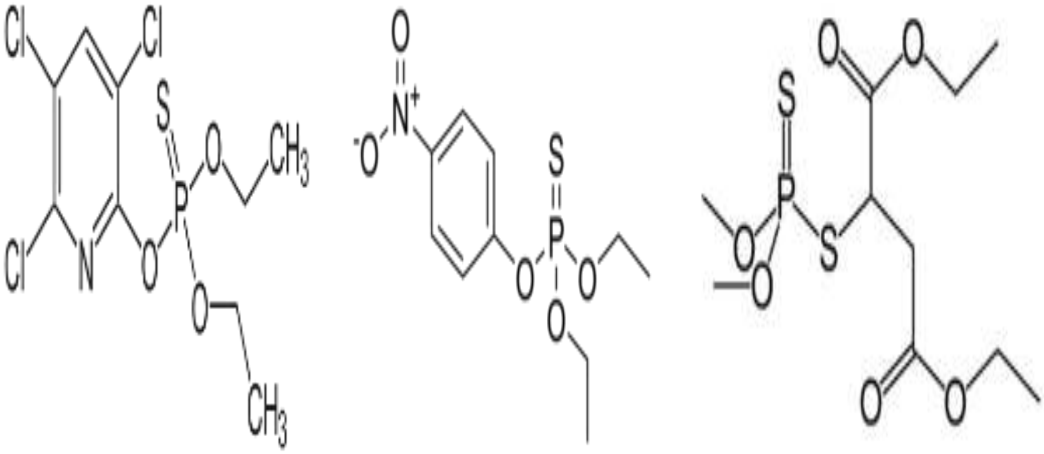
The health and environmental effects arising from DDTs and other organochlorine compounds was recognised in the 1970s. Subsequently, the US Environmental Protection Agency (US-EPA) pronounced it banned along with all its formulations used in agriculture production (Pesticides Actions Networks- PAN-UK, 2008). Major point of concern is that organochlorine compounds are highly insoluble in water and quickly dissolves fast in organic solvent and fats in living tissues. Half-life of DDT is normally within 2 to 25 years long (Howard, 2017). They bioaccumulate in animal tissue over very long period. This happens when DDT enters and accumulates in food chain. Meaning that, as in humans, animals at the highest point of the chain are expected to have the highest concentrations of DDT (Howard, 2017).

In studies of El-Bouraie *et al*. (2011) on DDT and the metabolites; Isomers of chlorinated hydrocarbon residues like dichlorodiphenyl dichloroethylene (DDE), dichlorodiphenyl dichloroethane (DDD), hexachlorocyclohexane (HCH) and dieldrin were found in water. Seasonal variation indicates higher residues in rainy season compared with the corresponding dry season. High residual concentrations during the rainy season are associated with surface runoff.

2.4.1.2 Organophosphorus pesticides

Organophosphorus pesticide are insecticides compounds made up of phosphoric acid esters; it has been in use since the middle 1940s. They persist moderately in the environment from a few hours to many months with less chance of accumulation in human food chain (Eto, 2018). Organophosphorus pesticides constitute less health problem compared with organochlorine insecticides as contaminants of water and soil due to short persistence (Eto, 2018). Conversely, the mechanism of organophosphorus can present significant effects on non-target species like human beings. In Nigeria, organophosphorus insecticide is commonly used in farming and has been understood to contribute to significant percentage of all pesticides in the country (Uchendu *et al*., 2018; Ezemonye *et al.,* 2015).

Various chemical structures of organophosphorus insecticide are represented in Figure 2.3. These include (11) Chlorpyrifos, (12) Parathion and (13) Malathion (Nagaraju, 2012).



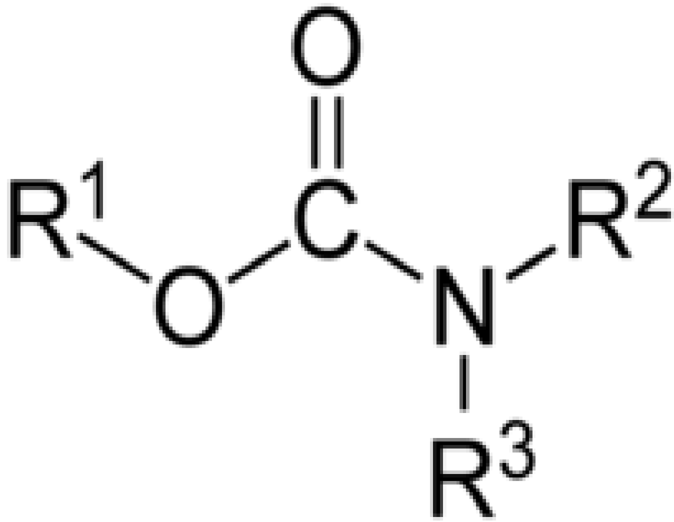
(11) (12) (13)

Figure 2.3: Examples of Organophosphorus Insecticide Structures

Source: Nagaraju, (2012)

2.4.1.3 Carbamate pesticides

Carbamate pesticide firstly gotten from Calabar bean, mostly grown in West Africa. The bean extracts clearly contain compounds physostigmine which is methylcarbamate ester (Kumari, 2011). The insecticides are derived from carbamic acid which does not persist in the environment. Its use as insecticide was dated back to 1950s. Currently, about 25 compounds of Carbamates are in use as pesticides or in pharmaceutical processes. Carbamate pesticide is among the most common pesticide used domestically (Kumari, 2011). Its toxicity varies according to the functional groups. Cabaryl is a widely used carbamate insecticide in use presently (14) (Figure 2.4) (Nagaraju, 2012; Merwin *et al.*, 2017).



(14)

Figure 2.4: Carbamate Insecticide Structure
Source: Nagaraju, (2012)

2.4.2 Pesticides classification according to function

Classification of pesticide according to function is mainly divided into several classes. The most significant of such classifications is herbicide which are targeted at controlling weeds, fungicides meant for fungal controls, rodenticide for rodents' controls and fumigants generally identified by their mode of use (Jurado *et al.*, 2011; Kim *et al.*, 2017; Merwin *et al*., 2017; Kumari and John, 2018; Foy, 2018; Gunier *et al*., 2018).

2.5 Use of Agrochemicals in Developing Countries

Agricultural chemicals are in use in developing world for crop improvement in their usual efforts to eliminate farm insects and diseases, to achieve adequate food production for growing population (Kumari and John, 2018). In Zimbabwe, for example organochlorine and organophosphorus pesticides are used by subsistence farmers for diseases control and farm pest (Zinyemba *et al*., 2018). Also in Ghana, the use of agricultural chemicals increases significantly recently (Kwakye *et al*., 2018). In a study on farmers understanding, thoughts on farm pests and disease management in Botswana, there revealed high use of pesticides which constitute 95.4% that is above other methods of crop protection (Gwenzi and Chaukura, 2018).

Use of agriculture pesticides significantly inncreases recently in East African nations like Kenya and Uganda (Atuhaire *et al.*, 2017). In Uganda specifically, pesticide use has been adopted recently by many communities who depends on sale of tomatoes for socioeconomic survival (Atuhaire *et al.*, 2017). There exist many evidences which indicated that vegetables are sprayed and sold immediately for consumption thereby risk the health of the consumers who are ill informed about the effects of pesticides (Atuhaire *et al.*, 2017). A research by Nyakundi *et al*. (2017) showed that agriculture pesticide use within Kenya have resulted to serious expansion of farming activities which clearly boost food production.

Study by Njoku (2017) revealed that subsistent vegetable farmers in some parts of Nigeria use many types of pesticide compounds, many of which are classified by WHO to be highly hazardous. While developed nations tend to use minimal chemicals and less persistent products, developing countries have adopted different trend by often using cheap products such as organochlorines as DDT and lindane which are very persistent in the environment. Especially in the tropics, these pesticides are generally used in massive quantities, in both small farming and in cash crops such as industrial plantations (Donga and Eklo, 2018).

According to FAO database, ten countries with the highest pesticide use intensity on arable and permanent cropland, six of these countries are considered as developing countries (United Nations (UN), 2012). It should be noted that data are missing for some countries, such as Brazil, Russia, Canada, Australia, and a lot of African and Asian countries. Ecuador had a pesticide use intensity of 6, 44 kg.ha-1.yr-1 during the period 2005-2010 (Food and Agricultural Organization Corporate Statistical Database (FAOSTAT), 2013).

Developing countries are often more vulnerable to pesticide pollution than developed countries, owing to little or absence of training in pesticide use and technical related services to the farmers and insufficient legal regulations, including a lack of controls. This leads to negative storage and transportation conditions, excessive application, and overuse near Rivers (Barraza *et al.,* 2011). Sosan and Akingbohungbe. (2009) found that empty containers of pesticides in a cocoa producing region in Nigeria are often thrown away on choices locations including children's playground or reused for storing other products like palm oil or kerosene. Leftover spray mixture was often emptied into the streams or closed to well at the village (Sosan and Akingbohungbe, 2009).

Provision of proper training does not assure that farmers apply the acquired knowledge (Barraza *et al.,* 2011). Besides, the awareness on the potential adverse effects of pesticide on ecosystems and people's health tend to be rather low. For example, the Costa Ricans who participated in the surveys of Barraza *et al.* (2011) stated that if there is no mouth contact, there will not be any health issues, thereby ignoring the dermal and respiratory exposure routes. The lack of education and literacy in developing countries contributes significantly to the low levels of awareness about proper pesticide use (Sosan and Akingbohungbe, 2009).

Next to the individual-focused determinants such as carelessness and ignorance, structural larger-scale factors, such as political and economic factors, play a key part in the risk perception of pesticide (Brisbois, 2016). Cole *et al.* (2011) modelled individuals and the community determining factor of synthetic pesticides related health effects in Ecuadorean Andes and found a significant effects of community level poverty and inequalities. Workers in the Banana farms in Ecuador tend to be highly vulnerable to exploitations by the wealthy farm owners, which are in turn contractually engaged by the multinational banana exporters to sell bananas with financial risks due to the low prices they earn for their products. These risks are shifted upside down by parties in the supply chain, leading to unsatisfactory working conditions for the employees (Hutter *et al.,* 2017).

Brisbois (2016) pointed at the illegal, but common practices that occur in the Ecuadorean banana industry. The Ecuadorean government and even the whole banana-consuming world also play a crucial role in pesticide exposure and health issues of locals, as they support these multinationals and large-scale farm owners and their systems, often ignoring small-scale banana producers and organic or fair-trade market niches (Brisbois, 2016).

2.6 Agriculture Pesticides in the Aquatic Environment

When pesticides are applied directly on soils and crops, only 1% of the sprayed pesticide is delivered to the intended target (Ozkara *et al.*, 2016). Large part of the pesticide never gets to the target but drifted into other part of the environment (including the hydrosphere) due to diffusion from the spray nozzles and aerial transport. In addition, the pesticides that do reach the target can also end in the aquatic environment through runoff, drainage and volatilization followed by deposition through rainfall and peculate into the groundwater (Richards, 2017; Legleiter *et al.*, 2018). Majority of hazardous pesticide in agriculture settings have been designated to be responsible for the deaths of many aquatic organisms (Singh and Singh, 2017; Ortiz-Santaliestra *et al.*, 2018). Pesticides application can spread easily into the ecosystem environment, where it can be detrimental to aquatic life and health of people through the contamination of water, soil, and air (Lakhani, 2015).

2.6.1 Occurrence of agrochemical residues in natural water

Contamination of natural water by agrochemical residues are presently a great concern and due to their excessive use, the residues have been scientifically detected in soil, water, and air. Chemical contamination arising from agriculture activities can affect several biological components of the environment (Aydogdu *et al.*, 2017; Lehmann *et al.*, 2017).

2.6.2 Occurrence of agrochemical residues in sediments

Soil is known to play a major role in contamination than air and water. Agriculture chemicals do get to the soil via direct form of application to the target crops. When application is made on the farmlands, they mostly persist in the soil where they are deposited inside water body (Nannou *et al.*, 2018). Contaminations due to pesticides in sediment of many water bodies have strong affinity of rendering the water unfit for survival of biota. Though, many organochlorines pesticide have been banned or restricted, there is little, or no attentions paid so far to the constant monitoring needs of these banned and restricted pesticide to ensure that the environment is protected (Mobeen *et al.*, 2012; Nannou *et al.*, 2018).

2.7 Effects of Agriculture Pesticides on Aquatic Environment

The capacity of a pesticides to harm aquatic organisms is mostly a function of its toxicity and the exposure of the organisms to the chemical. The latter depends on the exposure time and dose rate, and on physicochemical properties of pesticide such as bioavailability, bioconcentrations and persistency in the environment (Singh and Singh, 2017). Bioavailability means the number of pesticides in the media that are available for organisms, whereas bioconcentrations means the accumulation of pesticide in the tissue of animal at levels higher than those in the water. This should not be confused with biomagnification, which means the accumulation of pesticide at each level of the food chain. The bioavailability is determined by the environmental fate of the pesticide. For example, some pesticides will degrade very quickly after application, whereas others will adsorb strongly to solid particles or rapidly volatize into the air, thereby reducing their availability to water organisms (Singh and Singh, 2017).

Aquatic animals can be exposed in three different ways: absorption through the skin (dermal exposure), direct uptake through the gills during respiration (breathing) and by drinking contaminated water or feeding on contaminated prey (oral exposure) (Singh and Singh, 2017). The most direct result of pesticide poisoning is reduced organism's abundance caused by increased mortality of aquatic organisms living in the contaminated area (Landa and Soldan, 2013; Rockets and Rusty, 2007; Singh and Singh, 2017). Biota from a given habitat sometime display a high variety of tolerance to toxicants with concern that a toxicant may elicit lethal effects on species, but cause no visible effects on some others (Sohn *et al.,* 2018; Di Poi *et al.,* 2018).

2.7.1 Agriculture pesticides effects on human health

Pesticide's poisoning can cause acute effects and or chronic symptoms. Acute toxicity of pesticide is primarily defined as the ability of a substance to cause side effect over a short period following exposure (hours, days, weeks), whereas chronic toxicity refers to observed negative effects resulting from a long-term exposure (months, years, decades) to a certain substance (Budzinski and Couderchet, 2018). Some examples of acute effects from pesticides are headache, nausea, eye irritation, muscle weakness, shortness of breath and heart failure. Chronic poisoning may persist after acute poisoning or may be attributable to low or subacute exposure. These effects include neurological and neurodevelopmental effects, carcinogenic effects, disrupting of endocrine systems and asthma (Budzinski and Couderchet, 2018). The risk for pesticide poisoning depends on intrinsic hazard (toxicity) of the pesticides and the exposure to it. Regarding the latter, both time and level of contact with the pesticides determine the risk (Bateman, 2015).

When handling pesticidal products, human exposure may be due to skin contact, inhalation through dust or splashes, and due to ingestion of contaminated food or water (Kim *et al.,* 2017; Hammond *et al.,* 2016). Especially in developing countries, pesticide poisoning constitutes a serious problem due to improper handling of pesticides. Common ailments as vomiting and diarrhoea in a local banana producing community in Costa Rica are associated with aerial spraying of pesticides (Barraza *et al.,* 2011). Most of the cocoa farmers interviewed by Sosan *et al.* (2009) in Nigeria experienced acute symptoms such as headache, dizziness, body weakness, nausea, restlessness, and excessive sweating after spraying operations (Kim *et al.,* 2017).

2.8 Agrochemical Use Pattern

Agrochemicals are used extensively in Nigeria for crop production and control of pest in farming. Their unsustainable use patterns can potentially lead to degradation of soil, water quality and adverse health effects. A study on agrochemical use pattern conducted in the district of Meknes in Morocco via survey method, identified significant use of carcinogenic agrochemicals among the study population and several issues attributable to agrochemical use among the same population where also discovered (Imane *et al.*, 2016). This study was solely on occupational problems without consideration for indirect effects such as contamination of soil and water quality. A related study by Tyagi *et al.* (2015) using structured questionnaire, formal and informal interviews, group discussions revealed serious use of many brands of pesticides by the target groups. This study was short of laboratory investigation of environmental media and regulatory roles on agrochemical use.

Further, a related study by Banerjee *et al.* (2014) in West Bengal, India using questionnaire approach suggested that farmers of Burdwan were directly exposed to highly hazardous, restricted, and banned pesticide compounds, owing to insufficient protection. This study was based on occupational problems without consideration for indirect effects such as contamination of water quality. Also, a work by Wang *et al.* (2018) revealed excessive use of pesticides in the surveyed area. This study was restricted to agrochemical pesticides without consideration for plant minerals contamination.

Bowmer (2013) highlighted agricultural chemicals, including fertilizers (nitrogen and phosphorus) and biocides (insecticides, fungicides, and the pesticides), and submitted that their environmental effects in surface waters include high algal blooms and disruption to ecological function. It has been suggested that river protection strategies from eutrophication include improving farmland management, maintaining agricultural practices, recycling, or storing drainage and runoff waters, and using buffers and riparian vegetation for filtration. This study was based on paper reviews and did not put into cognizance field or laboratory approach.

Adeola (2012) explored how farmers perceive the pesticide impacts on vegetable production in Ogbomoso, Nigeria. He found a high level of awareness of pesticide risks and recommended strengthening advisory services to educate farmers on the safest use of pesticides in the vegetable industry. Umar *et al.* (2013) used an interview plan on his work for the purpose of empowering farmers on safe use of pesticides in Niger State of Nigeria. They observed that the target group's awareness to safety rules was weak. This was mainly based on occupational safety awareness of pesticides and does not also covers plant minerals.

In another study by Runa *et al.* (2017) who conducted a study by assessing the loads and impact of agrochemical used at Rajnagar upazilla near the Kawadighi haor using questionnaires, the study observed that farmers of Kawadighi Haor at Rajnagar Upazilla used fertilizer and pesticides indiscriminately which had negative impacts on fisheries resources of this haor and adjacent areas. Ikpesu and Ariyo (2013) described the health effects of excessive abuse and use of pesticides in rural areas of developing countries. This review gives an overview of the benefits of using pesticides and the dangers to humans, wildlife, and ecosystems. They suggested that producers and consumers should have a greater responsibility to reduce the risk of using short- and long-term pesticides.

2.9 Physiochemical Composition of Sediment and Water Samples

Measurement of physico-chemical composition or properties of sediment and the water samples are quite important because they affect rates of degradation, transportation, mobility of chemical in environmental media and quality of water (Chapman, 2002; Chau, 2018; Nwakife, 2015; Behailu *et al.*, 2018; Alpatova *et al.*, 2018).

2.9.1 Physico-chemical related studies in the study area

A study by Ogwueleka (2014) on water quality and pollution sources identification in River Kaduna using laboratory analytical tools identifies influence of anthropogenic activities as chief sources of pollution in the river. The study was not specifically conducted on agrochemicals contaminant but diverse pollutant sources. It was mainly laboratory without consideration for participatory appraisals. In a related study conducted in Lapai-Agaie Dam, Minna, Niger State, Nigeria, through laboratory analytical tools. The study indicates anthropogenic deposit of inorganic waste and high influx of organic waste from surface run offs. The study area was only concentrated on Lapai-Agaie Dam and did not cover the area under consideration. It was mainly laboratory without consideration for participatory appraisals.

A study by Sidi *et al.* (2016) in and around Badeggi, Central Bida Basin, Nigeria using laboratory-based assessment, concluded that water quality in Badeggi and its environs has not been adversely affected by anthropogenic factors. The study suggested however, that continued monitoring is needed as a means of protecting the flood plain aquifers from potential contamination. The area of coverage was only Bedeggi central Basin. There was no consideration for participatory appraisals. These are few related studies identified in the study area.

2.10 Spatial Analysis and their Use in Environmental Studies

According to Clarke *et al.* (2019), spatial analyses are any types of data analyses that extract and/or produce spatial information based on operations on different layers of data. GIS provides the organizational framework which allows numerical and statistical analyses to be easily applied on real-world data. The simple, but essential and fundamental ability to overlay a basically unlimited number of GIS layers together with hundreds of tools (GIS functions performing computations on spatial data) used for solving issues of spatial analysis and spatial statistics is what makes GIS so different from using hardcopy maps (Clarke *et al.*, 2019).

The possibility to combine those tools into sequences further increases what they can be used for. Combining tools into sequences allows unique and valuable information needed for a specific type of research to be obtained in an easy and fast way. For example, Mavroulidou *et al.* (2004) designed a simple screening model, composed of a GIS functions, for estimating vulnerability to traffic-induced air pollution based on weighting and combining raster layers such as topography, buildings, and traffic, and this performed successfully compared a dispersion model. In another study, population density together with backward air trajectory density were used to calculate Index of potential source influence (IPSI) for 30 mountain sites across China in studies of (Zheng *et al.*, 2015), to help to explain distribution of Polychlorinated Biphenyl (PCBs) in soils.

Righini *et al.* (2014) used spatial analysis functions embedded in GIS to combine different layers of emission sources of selected pollutants to assess spatial variability of pollution as one of the key parameters for monitoring station location representativeness. In this study, other GIS layers such as road network, settlement and land cover were employed to explain the acquired values of emissions spatial variability. In study of Hafner *et al.* (2005), ArcGIS was used for calculation of population within the radius of 25 km of sample sites to serve as an input to a regression analysis. Sharma *et al.* (2015) used spatial analysis for delineating watersheds and calculating the percentage of glacier-covered area within the watersheds to better estimate the meltwater contribution to the flow of the Ganges River.

Möller (2010) performed a GIS-based assessment of the influence of the growing number of wind turbines on population in northern Denmark, combining elevation, population density, and data from the Danish national wind turbine registry, revealing that less than 5% of population is located outside the viewshed of wind turbines. These are only a few examples of studies where spatial analysis with GIS demonstrates the breadth of its utility in the field of environmental sciences. While spatial analysis studies in respect of environmental contaminants have become a norm in many developed nations, developing countries which include Nigeria have little consideration for this interesting research approach. It is in view of this, that spatial analysis was adopted in this study to overlayed the value of physico-chemical properties, and plant mineral concentrations (about objective II and III in this study) acquired through analytical laboratory processes against each sample points.

2.11 Plant Minerals in Environmental Media

2.11.1 Nitrate and nitrite

Nitrate ions (NO_3-) are a commonly form of nitrogen compound within natural waters. Biochemically through denitrification, it can reduce to nitrite (NO_2-) in anaerobic condition. Nitrite ions quickly oxidize to nitrates. Nitrate is a basic mineral for growth of plants within aquatic system and its seasonal changes or fluctuations can result from plants decay coupled with growth. In mostly rural and sub-urban areas, use of inorganic based nitrate fertilizer can be a key source. When surface water is affected by human activity, it could have nitrate levels upto 5 mgl^{-} NO_3 - N, however some time less than 1 mgl^{-} NO_3 - N. Concentrations above 5 mgl^{-} NO_3-N often indicate contamination with animals or human feces or the emergence of fertilizer (Chapman, 2002; Tarafder and Roychowdhaury, 2018; Yamamoto *et al.*, 2019; Brusseau *et al.*, 2019).

If severe contamination occurs, the concentrations can reach 200 mgl^{-} NO_3-N. WHO recommends 50 mgl-1 (or 11.3 mgl-1 as NO_3-N) as maximum limit for NO_3 in drinking water as higher concentrations can present serious health risks. In lakes, nitrate concentrations above 0.2 mgl^{-} NO_3 - N tend to trigger growth of algae and is an indicator of possible eutrophic conditions. Nitrates occur normally in groundwater by washing the soil, but can reach very high concentrations in areas with high nitrogen fertilizer application (~500 $mgl^{-}1$ NO_3-N) (Chapman, 2002; Mengistu *et al.*, 2018; Tarafder and Roychowdhaury, 2018). In some regions, the sharp increase in concentrations of nitrate in groundwater for the past 20 to 30 years has been associated with an increase in fertilizer consumption, particularly in many local agricultural areas in Europe (Chapman, 2002; Tarafder and Roychowdhaury, 2018; Hijbeek *et al.* 2019).

2.11.2 Phosphorus compounds

Living organisms requires phosphorus as essential minerals which is inform of dissolved in water. In general, it is a limiting mineral for the growth of algae and hence control key performance of water bodies. Artificial increase in concentrations due to human activity is a major cause of eutrophication (Chapman, 2002). In natural water and wastewater, phosphorus mainly occurs as orthophosphate and dissolved polyphosphate and organic bounded compounds. Changes between these forms happened continuously owing to the decomposition and synthesis of organic bounded and oxidized inorganic compounds forms. It is recommended to state the concentrations of phosphate as phosphorus, e.g., mgl^{-} PO_4-P (unlike $mgl^{-}1$ PO_4^{3-}) (Chapman, 2002; Li *et al.,* 2018; Kelly *et al.*, 2019).

In many natural surface waters, the phosphorus content is between 0.005 and 0.020 mgl^{-} PO_4-P. Concentrations up to 0.001 mgl^{-} PO_4 - P can be found or located in some pure water up to 200 mgl^{-} PO_4-P in some closed salt water. The average groundwater level is around 0.02 $mgl^{-}1$ PO_4-P (Chapman, 2002). Since phosphorus plays key roles in the biological cycle of water, it is regularly included within fundamental studies of quality of water processes or in contextual monitoring programs. High concentrations of phosphate can be an indication of contamination and is significantly responsible for conditions refers to as eutrophic. Lakes or reservoirs management especially for the purpose of drinking water supplies, requires deep knowledge of phosphate levels for easy interpretation of algal growth rates (Chapman, 2002; Young and Lipták, 2018).

2.12 Use of Spectrophotometer for Plant Minerals Determination

Spectrophotometers measure the amount of chemicals based on their characteristic absorption spectrum. This is achieved by comparing the samples collected with reference samples, also known as standards. Spectrophotometers are usually quite accurate. Spectrophotometry offers a solution to identify unknown pollutants. This is a process that is needed for many applications, including drinking water or promoting safety and environmental protection. Water quality values are important for a variety of applications, including environmental issues, drinking water and consumption, and for industrial uses where water quality and purity are very important. Simple and convenient tests have been developed that use colour comparison and visual perception to monitor water quality. This measurement tool does not provide the quantitative information needed for effective analysis. Many of these test kits also use chemical reagents to provide visual guidance for analysis that pollute the sample itself (Kaserzon *et al.*, 2017; Dragna *et al.*, 2018).

Spectrophotometric analysis offers a non-destructive alternative to measuring pollutants that may be hidden in water. This form of quantitative analysis is very accurate and can be used easily with much potentials of eliminating the risk of human error. Quality of water and purity standards require objective data via spectrophotometric analysis to meet stringent water quality guidelines. Spectrophotometers are so efficient in providing accurate analysis of water quality and purity (Kaserzon *et al.*, 2017; Dragna *et al.*, 2018). Measurement of mineral components from freshwater and seawater by spectrophotometric analysis gives researchers valuable information that is directly related to water quality and can detect even the smallest changes (Kaserzon *et al.*, 2017; Dragna *et al.*, 2018).

2.13 Pesticides Related Studies and Findings in Nigeria

Studies on pollution of aquatic environment caused by various chemicals have been conducted in North Central Nigeria, and reported by various researchers. In a study by Ogbonnaya *et al*. (2017) on assessment of pesticide in water and soil in Farming Communities in Minna, Nigeria with aid of gas chromatography equipped with mass spectrometric (GC-MS) detections technique. The study detected pesticide residues namely p,p'-DDT, endosulfan-II, heptachlor and δ-BHC in soil and water. This study was restricted to pesticides without consideration for fertilisers' contamination of water and does not cover the study area under consideration. Also, a related study by Jimoh *et al*. (2003) on agrochemical effects on surface water and ground waters around Tunga-Kawo irrigation scheme. The concentrations of each determining factor were determined by means of C100 multi-parameter bench spectrophotometer. The study did not consider socioeconomic impact of agrochemicals.

In a study by Dirisu *et al*. (2016), pesticide in surface waters and sediments of logic and lentic ecosystems in Agbede Wetland were investigated via GC equipped with 63Ni Electron Capture Detector. Residues of lindane were identified in both sediment and water samples analysed. The study was restricted to pesticide residues with no consideration for plant minerals. A study also by Mokwunye *et al*. (2012), cocoa farmers' compliance with approved pesticide uses in cocoa producing states in Nigeria was assessed using survey approach. The survey revealed use of banned agrochemicals are still in practice in Nigeria.

Williams (2013) carried out analysis on pesticide in sediments and water in Agboyi Creek in Lagos using GC with a 63Ni electron capture detector (GC-MS-µECD Agilent 7890A). Divers' pesticide residue was detected in the epipellic and benthic sediments and water samples. In a related study by Njoku *et al*. (2017) who investigated pesticide residue levels in two vegetables commonly consumed in Lagos State using GC/MS. The findings revealed existence of pesticide residues in all samples from all the markets were above WHO maximum limit (0.02 mg/kg). The study was mainly laboratory without consideration for participatory appraisals.

Stehle and Schulz (2015) reported agricultural insecticides that threaten surface water throughout the world. The study offers a comprehensive multiple-analysis of 838 peer studies where surface water exposure to toxic agricultural insecticides was assessed. The results show that pesticide residues are rare and there is total absence of scientific monitoring data for about 90% worldwide. Therefore, the biotic integrity of the universal water resources is very at risk. In a study by Shinggu *et al.* (2015), using gas chromatography mass spectrometer (GC-MS), which was equipped with electron capture detectors, assessed amount of pesticide in fish, water and sediments in the Biu dam (Borno reservoir), Nigeria. Different concentrations of pesticides, namely aldrin, endrin, dieldrin, alpha-BHK, endosulfan I, endosulfan II, and heptachlor, have been found in all environmental and food segments in the study area due to widespread use and abuse.

These pesticide compounds according to Ghosh *et al.* (2018) have shown the potential for biomagnification / accumulation in animal tissue, human blood, adipose tissue, and breast milk. Ezemonye *et al.* (2015) recorded organochlorine, organophosphate, and carbamate concentrations in the Wari River, Niger Delta, Nigeria. In addition, many researches have been conducted in which pesticide residues were found in aquatic animal's samples from Lagos lagoon (Adeyemi *et al.*, 2008). In 2011, research in Borno, Nigeria showed that lindane, diazinon and aldrin were present in cereal samples before storage, while DDT and Dichlorvos were present in both samples before and after storage (Oyeyiola *et al.*, 2017).

Although agrochemical pesticides are beneficial, improper use can be counterproductive and endanger the survival of important ecosystems by disrupting predator relationships and loss of biodiversity, increasing pest resistance, killing natural pest predators, and potentially causing serious health problems to human (Pan *et al.,* 2018) and as such must be subject to apparently safe and appropriate use. Although, use of pesticide by farmers is increasing in developing countries, consumer awareness of health and environmental hazards is low or not at all understood (Pan *et al.,* 2018). Many consumers are not sufficiently aware of potential short-term and long-term risks, and the precautions needed for proper administration of these toxic chemicals are not always taken (Renn, 2017). Information about its use, distribution and environmental impact is lacking in Nigeria. The inherent danger of pesticides toxicity and the ability to poison "make it important to ensure the safety of users, our population, and the environment (National Environmental Standards and Regulations Enforcement Agency (NESREA), 2014a).

2.14 Synopsis of Some Organochlorine Pesticides and their Environmental Concerns

Pesticide studies in Nigeria mostly focus on organochlorines because of their environmental and health problems (Adeyemi *et al.,* 2008; Ezemonye *et al.,* 2015; Dirisu *et al.,* 2016).

2.14.1 Aldrin

Aldrin, whose chemical structure is named as 1,2.3.4,10-haxachloro-1.4,4a.5,8.8a-hexahydro-1.4:5.8-methanophthalene, is used for the control of soil-based insects like termites and locusts (Gyawali, 2018). This is often used in protecting plants like potatoes and corn and effectively protect wood structures from termites. It has been banned in many countries (Gyawali, 2018). Aldrin get metabolized quickly to become dieldrin in animals and plants. Aldrin residue is not mostly detected in food and in animals, but only in little amounts. It is highly bonded to some particles of soil with high resistance to leaching in ground water. Owing to her constant and natural hydrophobicity, Aldrin is well known for its bio concentrations, especially as a conversion product. Aldrin and its metabolites are poisonous to human beings. Lethal dose rate for adult men is projected to be around 5.0 g, which corresponds to 3 mg/kg of the body weight per 60 kg people (Gyawali, 2018). Signs and symptoms of aldrin poisoning can be in the form of headaches, dizziness, general malaise, vomiting, and nausea accompanied by muscle and cramps (Gyawali, 2018; Taiwo, 2019).

2.14.2 Dieldrin

Its chemical structure name is 3.4.5.6.9.9-Hexachloro-1.2.2.3.6.6,7.7-Octahydro-2.7.3.6-dimethanonaptha [2,3-b]oxirene. Dieldrin is used in farming to control soil-based insects and various disease carriers (Youssouf *et al.*, 2019). The latter is prohibited in many countries, including Nigeria, for socio-economic reasons. Important modern applications are limited to the control of termite, trees, and textile pests (Abong'o, 2018). Owing to its constant nature and usual hydrophobicity, Dieldrin is well known for its bio-concentrate (Youssouf *et al*., 2019; Gyawali, 2018).

In many countries, measures have been taken to ban dieldrin but in many other countries its use is strictly limited. In laboratory studies, acute oral LD levels in rats ranged from 37 mg/kg by weight to 330 mg/kg in hamsters. The level of side effects observed in rats, the Non-Observed Adverse Effect Level (NOAEL) is 0.5 mg/kg of food, and body weight is 0.025 mg/kg. There exist convincing evidences of carcinogenicity of aldrin in human beings, data are limited to experimental animals and are clearly classified as International Agency for Research on Cancer (IARC) group III (Abong'o, 2018; Jhamtani *et al.*, 2019).

2.14.3 DDT

DDT, whose chemical structure name is 1,1-(2. 2. 2-trichloroethylidene) bis (4-chlorobenzene), protects military personnel and the civilian population from World War II against spread of malaria, typhoid fever, and many other infectious diseases. Following the war, DDT is extensively used in various cultures for disease vector control. In some countries, it is still in production and used for control of vectors. As concerns on the serious environmental impacts, particularly that of wild birds, have intensified, serious limitations and restrictions arose in several developed nations at early 1970s (Abong'o, 2018). DDT was commonly used in agriculture for cotton, which represents more than 80% before it was banned in 1972. DDT is restricted for use in closed air to control animal malaria in many countries, including Nigeria. DDT is slightly soluble in water, but highly soluble in many organic solvents. It is known to be semi-volatile and is expected to be released and get into the atmosphere. Its existence is everywhere in the general environment, and fragmented in the air. It is lipophilic in nature and is easily separated from the fats of all living organisms. Decomposition products of DDT such as 1,1-dichloro - 2,2-bis (4-chlorophenyl) ethane (DDD or DDE) and 1,1-dichloro-2,2-bis (4-chlorophenyl) ethylene (DDE) are also available (Abong'o, 2018).

Use of DDT is prohibited in thirty-four countries and is strictly limited by many countries. (NESREA, 2014a). DDT that was banned in developed countries long ago was banned for use recently in Nigeria. Studies conducted in the temperate regions have shown that the organochlorine pesticides p. p'-DDT along with its actual metabolite p. p'-DDE have high persistence in the environment and are thus considered serious environmental toxins (Ren *et al.*, 2017; Garcia-Heras *et al.,* 2018; de Souza Guida *et al.*, 2018; Abong'o, 2018). DDT and its metabolites are still reported as a key water pollutant and are still some of the main pollution indicators in pollutant monitoring surveys owing to their bioaccumulation in sediments and aquatic organisms (Sousa *et al.*, 2017; Lundebye *et al.*, 2017; Verhaert *et al.*, 2017). The DDT has been found to dissipate fast and highly effective in disease vector control (Cardarelli, 2018).

2.14.4 Endrin

Endrins whose chemical structure name, 1.2.3.4.10.10-hexachloro-6. 7-epoxy-1.4. 4a.5.6.7.8.8a-octahydro-1,4-endo-5.8-dimethanonaphthalene was found in cotton plant. It is mainly used as insecticide for leave and cereal protection. It is also used in form of rodenticide for rats' control and birthmarks. It is metabolized quickly by the animals and it does not accumulate anyway in animal fat as to the same level as other chemical compounds with the same structures to dieldrin. It enters easily into the atmosphere through evaporation and pollute the surface water because of surface leakage. It is banned in several countries, and the use of it is very limited in many other countries. Studies on people involved in the production of endrin and other synthetic compounds such as aldrin and dieldrin have shown that endrin is not present in the blood without accidental exposure. The study has several limitations, but this study showed significant increase in the liver and bile duct cancer. Lack of quantitative information on exposure. Evidence indicated that cyclodien, like endrin, may suppress the immune response (Ingber, 2019).

2.14.5 Endosulfan

Endosulfan, whose chemical name is 6,7.8.9,10.10-Hexachlor-1.5.5a.6. 9.9a - hexahydro -6.9-methano-2.4,3-benzodioxathiene-3-oxide, is an organochlorine neurotoxic insecticide based on cyclodiene - A destructive insecticide is very toxic and endocrine disruptor. This is prohibited in countries such as Germany, Norway, and the Philippines.

It is still common in many countries, including India. Manufacturers have used several brands, such as Thionex and Thiodan, Phaser and benzoifin. Used in agriculture around the world to control pests, including aphids and leaves. Colorado potato beetle, cabbage beetle and other pests. It is also used to control the tsetse fly, preserve trees and gardening. The endosulfan plant usually decomposes within a few weeks, but it may take years to adhere to the soil particles and completely collapse. This compound is hardly soluble in water. In surface waters, it binds with soil particles that float in water or attach to sediments in the soil (Abong'o, 2018; Bisht *et al.*, 2019). Endosulfan can affects the normal functioning of central nervous system (CNS). Overdose, severe dependence can lead to death due to hyperactivity in adults, nausea, dizziness, headache, vomiting, diarrhoea, or seizures. It is an acute neurotoxic substance for insects and mammals, including human.

2.14.6 Heptachlor

Heptachlor whose chemical name is 1.4.5,6.7.8heptachloro-3.4.4.7.-tetrahydro-4.7methanol-1-indent is an unstructured system and contact insecticide, mainly used for termites and soil insects. It is mostly use in controlling grasshoppers, cotton insects, plant pests and mosquito. Heptachlor compound is very insoluble in the water and soluble in the organic solvents. This is very variable, as a result it can decompose into the atmosphere. Easily binds on sediment of water and bioconcentrates with the fat in living tissues. Heptachlor compound is metabolized to heptachlor epoxides in animals, its toxicity is very similar to that of the heptachlor and can also get stored in fat of animals. The use of this compound is prohibited in some developed and developing countries. A study by factory workers involved in production process of endrin and heptachlor showed a high increase in bladder cancer cases. This result was highly unexpected because the plant did not use carcinogens for the bladder. A small number of deaths are difficult to interpret. Although mortality from stroke was higher than expected, mortality from cancer of the liver or bile ducts was not observed. There is little evidence which shows that cyclodienes, like heptachlor, can affect a person's immune response. Oral acute form of LD^{50} heptachlors in laboratory experimental animals range from 4 mg/kg of body weight in mice to 116 mg/kg in the rabbits. Symptoms in animals include tremors and cramps (Fulton, 2019).

2.14.7 Lindane

Hexachlorocyclohexane (HCH), officially known as benzene hexachloride (BHC), occurs in eight isomers. The various isomers are usually named after the hydrogen atom positions in the chemical structures. The HCH series (or y-HCH commercially available lindane) is used as a pesticide for animals, rooms for animals, as well as for fruits, vegetables, and forest plants. Can be used for pesticides such as powders, powders, and liquid concentrates. It can also be purchased as a prescription drug (in form of lotion, shampoo, or cream) for treatment and care of human skin and ticks (Parish, 2013). Virtually all pesticidal properties are due to the gamma isomer (lindane). Information on isomers is limited. In the atmosphere, various forms can exist in the form of vapours binded to small particles like dust. Particles can precipitate from the air via rain or decompose in the atmosphere by other compounds. Depending on environmental conditions, HCH can persist in air for quite long time and transported for long distance. In soil, sediment, and water, HCH is less toxic to algae, fungi, and the bacteria, but this process can take long time (Parish, 2013).

In all-purpose, HCH isomers and the products that they produce in the body can be temporarily stored in body fat. Isomers and products produced by the body are excreted in small quantities with urine and faeces. HCH breaks down into many other substances in the body. In humans, inhaling toxic amounts of y-HCH and 6-HCH can trigger blood infections, headaches, dizziness, and change in the level of hormones inside the blood. This effect occurs in people exposed to vapours of HCH during the production and management of pesticides. Lots of cramps and swallowers. Some people who often use y-IK H for their skin experience blood disorders or cramps. No causal relationship was found between exposure to y-HCH and human blood disorders. Animals fed y- and u-HCH experience cramps. All HCH isomers can affect the liver and kidneys (Yasser and Lubbad, 2018). The US Department of Health has determined that all HCH isomers can cause cancer in humans. IARC classifies HCH (all isomers) as potentially carcinogenic. The Federal Environmental Protection Agency (FEPA) has found plenty of evidence that lindane (y-HCH) is carcinogenic, but this is not enough to assess the likelihood of carcinogenesis in humans (Parish, 2013).

2.14.8 Methoxychlor

With the chemical or structural name of 1,1-(2. 2. 2-trichlorocthylide) bis [4 -methoxybenzene), methoxychlor is an insecticide for the protection of plants and ornamental plants. It is also use for the control of cockroaches, cows and pets' fleas, the mosquitoes, and many other insects. It has also been used as a substitute for the DDT because it gets metabolized rapidly and never cause bioaccumulation (Abong'o, 2018). Methoxychloride is like DDT, but has structural and chemical properties that are easier to damage. Aquatic organisms turn it to other less toxic substances because of metabolism and do not cause serious bioaccumulation. The amount of methoxychloride in the environment is seasonal, as it is widely used in agriculture. Sprayed methoxychloride precipitates in the soil and decomposes faster in aerated soil than in anoxic soil. It is not easy to navigate wet soil because it is firmly attached to the soil and does not easily dissolve in water (Abong'o, 2018).

Groundwater risk should be low, but it may be higher if the level of use is very high or the mass of water is very high. The movement of pesticides is most likely associated with the adsorption of suspended soil particles in wastewater. In hydrosols (sedimentation in an aqueous medium), the decomposition of methoxychloride to methoxychloroolefin (methoxydichloroethane MDE) is carried out only under aerobic conditions. Methoxychlor vaporizes slowly, but evaporation can help the product enter the environment. Available data indicate that high-dose technical methoxychlorine (88 to 90% pure) or its metabolites can have reproductive effects (Abong'o, 2018; Fulton, 2019).

2.15 Choice of Compounds for the Pesticide Residues Analysis

Insecticides used in agriculture and health care institutions can get into environment in many ways depending on type and potential for use owing to deliberate, accident or illegal disposal of unwanted products (Cox, 2002; Deknock, 2019). Pesticide residues are mainly deposits of active ingredients of pesticides, metabolites or degradation products, which are contained in several environmental components after being used, spilled or disposed of. Residue analysis measures the type and level of contamination and chemical stability in the environment. It is often difficult to compare environmental pesticide residues with their effects on fauna and / or the environment. One can indicate whether an animal or object has been exposed to chemicals and identify potential problems in the future. The selected sampling program can be used to: study the level of pesticide residues in the environment, their movements, and their relative degradation; identify contaminated areas and / or sources of pollution; Check the intake of pesticides from food chain components; and determine whether pesticides are the cause of death (Cox, 2002; Zubrod *et al.*, 2019).

All pesticides can be decomposed and / or metabolized as soon as they are released into the environment. The extent of damage and spread varies greatly from pesticide to pesticide and from situation to situation. The purpose of residue analysis is to show the residues available during sampling and every precaution must be taken to ensure that samples received in the laboratory cannot be affected in a way that affects them. Some chemical losses and / or changes cannot be avoided and vary depending on the conditions and types of pesticides available. When sampling for residual analysis, the aim is to minimize this loss and thereby maximize the relationship between the results of the sample taken and the amount of residue that is present at the sample location (Cox, 2002; Deknock, 2019).

The difficulty of sampling biotic and abiotic pesticide residues in tropical countries is exacerbated in remote areas by inappropriate storage locations or by the analytical laboratory itself. Any delay in sample storage or extraction of pesticide residues increases the risk of degradation of all available residues and increases uncertainty about the results of the analysis and interpretation. If a short-term analysis (such as organophosphate or carbamate) is needed, the risk of loss is high. Some pesticides (especially chlorinated pesticides are more resistant and some herbicides) have a lower risk of loss. Loss rates for all types of connections are higher in the tropics than under moderate conditions (Cox, 2002; Deknock, 2019).

2.15.1 Knowledge of the pesticide's properties for sampling

Knowledge of nature and characteristics of pesticide is very important when developing any sampling plan for residue analysis (Cox, 2002; Csuros, 2018; Luo *et al.*, 2019; WHO, 2019). It is difficult to make a general statement about the interpretation of this data because individual connections are very different. An increase in water solubility indicates a greater potential for displacement / leaching from the soil (although the type of soil in the treated area is important for this consideration, for example, clay is more protected than sandy soil). Part-time data (i.e., the time in which half of the active ingredient is lost due to degradations or dissipation) is a very useful indicator of the likelihood of persistence, especially relating to the time scale, when designing the proposed sampling program. The importance of known metabolite / degradation products must also be considered (Cox, 2002; Matthews, 2019).

2.15.2 Techniques for sampling

Water sampling

Water, especially from water pipes that are sprayed excessively, shows pesticide residues only shortly after application. There are some exceptions, but overall, even if the solubility is relatively high or if the degradation rate is low, pesticides are often absorbed in sediments or other organic matter and are removed from aqueous solutions. With some pesticide compositions, residues can form surface films instead of being dispersed (Sultana *et al.,* 2018).

Water samples often contain suspended substances. In most cases, suspended solids can contain much higher pesticide residues than the water itself, and their entry must be carefully considered. For many purposes, water and suspended solids are often considered together, but for others it needs to be separated for separate analysis with filtering. Suspended solids can also be difficult for analysts, and separation can be a practical necessity. If the components are analysed separately, values can be seen separately or together (Sultana *et al.,* 2018).

The water collection process requires careful consideration, and the starting point is the question "Why are samples taken?" The answer to this question helps determine the correct sampling point. Additional considerations are: Samples from near shore or further to rivers / lakes? In the latter case, a ship may be needed. At what depth should samples be taken - surface, underground or medium water? (Depending on the temperature, there may be differences whether there is a surface water layer from pollutants or decaying vegetation or whether sediment is at a certain depth.) This affects the sampling device used and methodological details. Flow entering a river or lake must be sampled and the results compared with samples from other locations on the river or lake, e.g., above the entry point of flow (Cox, 2002; Sultana *et al.,* 2018).

Sediment sampling

Sediment sampling can be difficult, but it is important for residual sampling. Soil dirt usually does not flow quickly in stagnant water or rivers and streams and must be removed using appropriate equipment depending on the depth of the water. Commercial sampling devices are inexpensive, but can be relatively expensive and not always portable. Spoons or other containers attached to stems, etc., can work in relatively shallow water. Water can be filtered to collect suspended solids in running water. A large amount of water must be filtered to obtain a significant amount of sludge sample. This is tedious and can take a lot of time (Cox, 2002; Csuros, 2018).

2.16 Extraction Methods for Organochlorine Pesticides from Various Matrices

For sediment, soil and weed samples classical Soxhlet extraction method has been widely used. For water samples classical techniques for extraction such as liquid-liquid extraction (LLE) and or solid-phase extractions (SPE) have commonly been employed (Berijani *et al.*, 2006; Abong'o, 2018; Carmona and Picó, 2018).

2.16.1 Soxhlet extraction of sediments

The analysis of pesticide residue in sediments uses classical Soxhlet extraction. It allows use of large amount of sample (e.g., 10-30 g), no filtration is required after the extraction, the technique is not matrix dependent, and many Soxhlet extractors can be set up to perform in unattended operation (Carmona and Picó, 2018).

2.16.1.1 Solid phase extraction (SPE) for water samples

Sample volume measured is usually adjusted to a specified point followed by extraction with the aid of Solid Phase Extraction (SPE) laboratory tool. Analytes of choice are eluted from the solid-phase media with the aid of methylene chloride (dichloromethane) or other suitable solvents (Carmona and Picó, 2018). The extract obtained is then dried using sodium sulphate and finally concentrated. The extract which is concentrated can be exchanged with solvent that is the same with further clean up procedures and or procedures used to determine the measurements of the target analyses (Berijani *et al.*, 2006; Abong'o, 2018).

2.16.1.2 Liquid-liquid extraction for water samples

The problems of dichlorination of organochlorine pesticides, hydrolysis of bonded phase silica <C,8) and clogging of solid-phase media makes liquid-liquid extraction a method

of choice for compounds of pesticides including organochlorine pesticide analyses in turbid river water over solid phase extraction (SPE) (Abong'o, 2018; Carmona and Picó, 2018).

2.17 Applications of Gas Chromatography in Environmental Monitoring

Chemical monitoring in the Environmental remains key subject of research to be undertaken in many African countries such as Nigeria. Nigeria is facing many environmental challenges, such as pesticide use in farming activities that can lead to persistent of organic pollutants in all environmental media. GC-MS provides an important tool for analysing pesticides and other synthetic contaminants such as plant minerals (Abong'o, 2018; Carmona and Picó, 2018).

In Egypt, bacterial strains that decompose melon from wastewater are isolated and are molecular in nature (Mohamed *et al.,* 2010). Monitoring of the residual undiluted melon in a liquid culture of isolates of bacterial was the aim of the study. Recent studies have shown that past and present data in respect of organochlorine pollution status in the aquatic environment of South Africa are not available (Degger *et al.,* 2011). Spatial models from polycyclic aromatic hydrocarbons (PAHs) and polyfluorinated biphenyl-PCB impurities were determined after the preparation of suitable samples with aid of GC-MS along with other laboratory analytical methods. Spatial differences were significantly observed. The findings show that there is no correlation between the passive device and the implanted sheath (Degger *et al.,* 2011).

The flexibility of GC-MS technique can further be demonstrated by its capabilities to simultaneously identify environmentally significant analytes. Example, in Southern

Africa (Olujimi *et al.,* 2011), 17 endocrine disruptors (EDCs) were identified with aid of GC-MS. Analysis using GC-MS techniques was conducted on the untreated and pure extracts of urban wastewater treatment plants. The results showed the presence of measured phenol after proper sample preparation. This study also shows the trend of phenol in wastewater treatment plants. PAHs are important worldwide owing to its presence in ubiquitous form, toxicity, and the carcinogenicity. GC-MS is used widely as a data collection tool for distribution of PAHs in Southern African soil and sediments. These samples are provided in industrial, residential, or agricultural areas. It has been established that the most probable cause is pyrogenic activity, and automatic emissions make a minimal contribution (Nieuwoudt *et al.,* 2011).

Recently, organic atmospheric pesticides were measured using GC-MS tool in South Durban (Butterman *et al.,* 2008). Particles and steam samples collected at three sampling points between 2004 and 2005 were tested for this analyte. High isomers of DDT and DDD were found, including dieldrin, chlordane, hexachlorobenzene (HCB) and aldrin. It shows that these pollutants need to be constantly monitored in African countries, especially Nigeria, due to the high evaporation of air pollution in Africa. PAHs from water samples and sediments from 5 rivers in Southern Africa were evaluated with the aid of GC-MS (Sulej-Suchomska *et al.,* 2016). In general terms, the Polyaromatic Compounds (PAC) value for a steel sample is lower than the recommended Maximum Residue Limits (MRL) for a water sample, so there is no risk to the health of the downstream users surveyed.

An interesting study was conducted on GC-MS use in Botswana, pesticide residues were recovered from sediments in the Okavango Delta (Mmualefe *et al.,* 2008). In the study, levels of chlorinated pesticides like aldrin HCB, and 4,4-dichlorodiphenyl trichloroethane (4,40-DDT) were determined and clearly quantified. Researchers have also noted that pesticide concentrations increase at the direction of the water flow from delta entry points. Although the prevalence of GC-MS is widespread in many parts of Africa, the various geographical locations of the continents testify to this. For example, in Tanzania, GC-MS was used to evaluate PAC, including 16 USEPA priority PAHs in sediments and oysters (Gaspare *et al.*, 2009).

The results of this study were then used to conduct a risk assessment showing the potential effects on the oyster community and the oyster population in six of eight regions. The authors determined an additional correlation of PAH consumption when eating oysters, which have a carcinogenic effect on humans. Another GC-MS study in Tanzania determined the level of precipitation from sellers by identifying organochlorine pesticide and their corresponding metabolites in the *Mangifera Indica* (Mango) tree leaves (Marco and Kishimba, 2007). Also, other leaves came from *Anacardium occidentale* (cashew), *Manihot esculenta* (cassava), *Eucalyptus sp*., and *Prunus domestica* (plum) (Marco and Kishimba, 2007).

Another interesting study conducted at Nigerian oil refineries using GC-MS is to detect the appearance of crude oil (Sonibare *et al.,* 2008). Offshore samples of crude oil are characterized using biomarkers and isotopic compositions. Studies of organic materials, such as the pentacyclic triterbane in oil-certified hofan and Olean frames are used to track the origin or mixing of oil sources. Kerogen at sea and on land. Other variables, such as olein concentrations, are used to classify wells. In addition, it was shown that other maturation variables that can also be calculated in favour of the oils, such as aromatic form of sulphur compounds (thiophene) and aromatic biomarkers, increase slightly in thermal maturity with increasing storage depth (Sonibare *et al.,* 2008).

GC-MS based studies in the Niger Delta region have revealed various ecological species which include aquatic organisms like fish. Four type of fish species (*Liza dumerillii, Parachanna obscura, Clarais gariepinnus and Pseudolithus elongatus*) were tested for PAHs using GC-MS (Anyakora and Coker, 2007). All of the four fishes contain significantly high levels of PAHs, particularly high molecular weight of indeno[1,2,3cd]pyrene, benzo[ghi]perylene and the dibenzo[a,h]anthracene (Anyakora and Coker, 2007).

An additional GC-MS study was reported in the Niger Delta on 16 USEPA PAE priorities (Tuncel and Topal, 2015). In this study, 16 PAHs were found in some of 13 samples taken at high concentrations in different places. Further studies of fish, bottom sediments, and water in water samples from fishing villages show the importance of monitoring with PAHs GC-MS techniques in the Niger Delta region cannot be emphasized (Anyakora *et al.,* 2005). It is alleged that the area was poisoned by oil spills at an oil refining terminal. To emphasize the importance of this study of PAHs using GC-MS techniques in the Niger Delta region, the chemicals and environmental toxicity of PAHs in sediments was evaluated (Olajire *et al.,* 2005).

In addition to 16 major USEPA contaminants in high concentrations, two 6 PAH rings have been identified. The capability of the GC-MS to detect small amounts of analytes efficiently with good selectivity is not comparable with many analytical methods. For example, organic phosphorus pollutants (OPPs) have clearly been reported commonly in the aquatic environmental media of pesticide plants in Egypt (Abdel-Halim *et al.,* 2006). Samples of water, mud, and fish was collected over six seasons and analysed using GC-MS detection technique. Majority of the samples significantly indicated the presence of chlorpyrifos, chlorpyrifosmethyl, malathion, pyrimiphosmethyl diazinon and profenofos at ppb concentrations. Study in Egypt also reported aromatic and aliphatic fractions from dust samples (Mostafa *et al.,* 2009).

GC-MS can be used to solve more complex problems in the context of related technologies (Mostafa *et al.,* 2009). The ability to analyse multiple analytes with the aid of GC-MS is also another feature that designated this technology unique and special in its application. An analysis of many pesticide in Ethiopia was performed via GC-MS (Daba *et al.,* 2011) in a single cycle. Kata samples contain very high concentrations of p, p'-DDT. Diazinon were also found in several samples of the smelter. Other test residues using GC-MS detection technique which also affects people's health have also been reported in many regions (e.g., pesticide residues from samples of smoked fishes in north-eastern Nigeria) (Musa *et al.,* 2010).

Due to fast human population growth which has led to increase in agricultural activities involving intense use of agrochemicals and other chemical pollutants around sensitive and vulnerable resources, GC-MS have taken a centre stage in monitoring environmental pollution due to its effectiveness and sensitivity in chemical detection and analysis. This informed the need for the choice of GC-MS laboratory analytical tool for the empirical aspect of this proposed study.

2.18 Socioeconomic Impacts of Environmental Contamination

Environmental pollution has been identified as one of the biggest problems in the world, which increases yearly and causing serious socio-economic effects. Pollution consists of five main types: air, soil, water, noise, and light (Slovic, 1987; Brnjas *et al.*, 2015). The field of science related to pollution is ecology, especially ecotoxicology. Ecotoxicity is due to the study of the side effects of chemicals on the environment. We have seen countless global environmental disasters that inevitably cause an imbalance in ecosystems and have a very negative impact on human health. The risk assessment and management system in ecotoxicology includes data on the effects of chemicals on animals, plants, and other living organisms as part of standard environmental toxicity studies. Toxic chemicals are of particular concern for environmental impacts. They can enter the environment through artificial activity or with additional undesirable effects from various activities. When toxic chemicals enter the environment, there are potential risks that need to be managed to minimize potential side effects (Brnjas *et al.*, 2015).

2.18.1 Socioeconomic analysis of the agriculture chemicals

Analysis of socio-economic consequences is one of the key components of a complex management process that identifies the risks of chemical pollution. This process should include all participants involved in pollution, because only a comprehensive approach to risk management will ensure sustainable development of the community. The role of socio-economic analysis in this process is very important. This is an analytical framework funded by science and experience to initiate a risk management process in the pollution assessment process. (Antonievich and Kurchich, 2012).

Socio-economic analysis is strategically oriented towards social and economic development and allows us to understand the current state, especially to identify important problems and limit the side effects of pollution. The purpose of this analysis is to develop strategies and suggest steps to address potential pollution risks. (Antonievich and Kurchich, 2012). Ecology, especially ecotoxicology, is associated with the harmful effects of chemicals on the environment. Over the past decades, a series of terrible events caused by global environmental disasters, which inevitably led to environmental imbalances, have had a very negative impact on human health. (Antonievich and Kurchich, 2012).

2.18.2 Socioeconomic analysis as a part of the risk assessment and mitigation

The environmental toxicity risk assessment paradigm consists of four main steps. The first stage is risk identification, and the second stage is the study of the side effects of certain concentrations of toxic substances on the environment. The third is an impact assessment, and the fourth is a risk profile. After successfully completing these steps in risk assessment and risk characterization, you can determine if the risk is acceptable to a particular living target organism. If analysis indicates that the risk is unacceptable, measures should be taken to eliminate the risk of contamination. Socio-economic analysis is an important and necessary part of this process, and it is very important to do this in a timely manner, considering all relevant factors (Hagenauer Helbich, 2018).

The risk of chemical contamination can be considered unacceptable if the analytical concentrations of the chemical in a specific aspect of the environment exceeds the confirmed value (projection of the ineffective concentrations-PNEC), where no harmful effects occur. Due to their persistence, the properties of chemicals reflect their environmental life. The time required to reduce the concentrations to half the initial concentrations. Bioconcentrations show that chemicals can penetrate living organisms. For example, the concentrations of fish can be 100 times higher than that of water. Finally, biodiversity demonstrates the ability of chemicals to increase their presence in the food chain, which poses a risk to human health (Gobas *et al.,* 2018).

2.18.3 The constituent of socio-economic analysis and impact assessment

The process of socio-economic analysis of hazardous chemicals includes determining the anthropogenic activities in which these chemicals are present, and assessing environmental changes and adverse effects on human health, environmental and economic development because of these activities (Finnveden and Morberg, 2005).

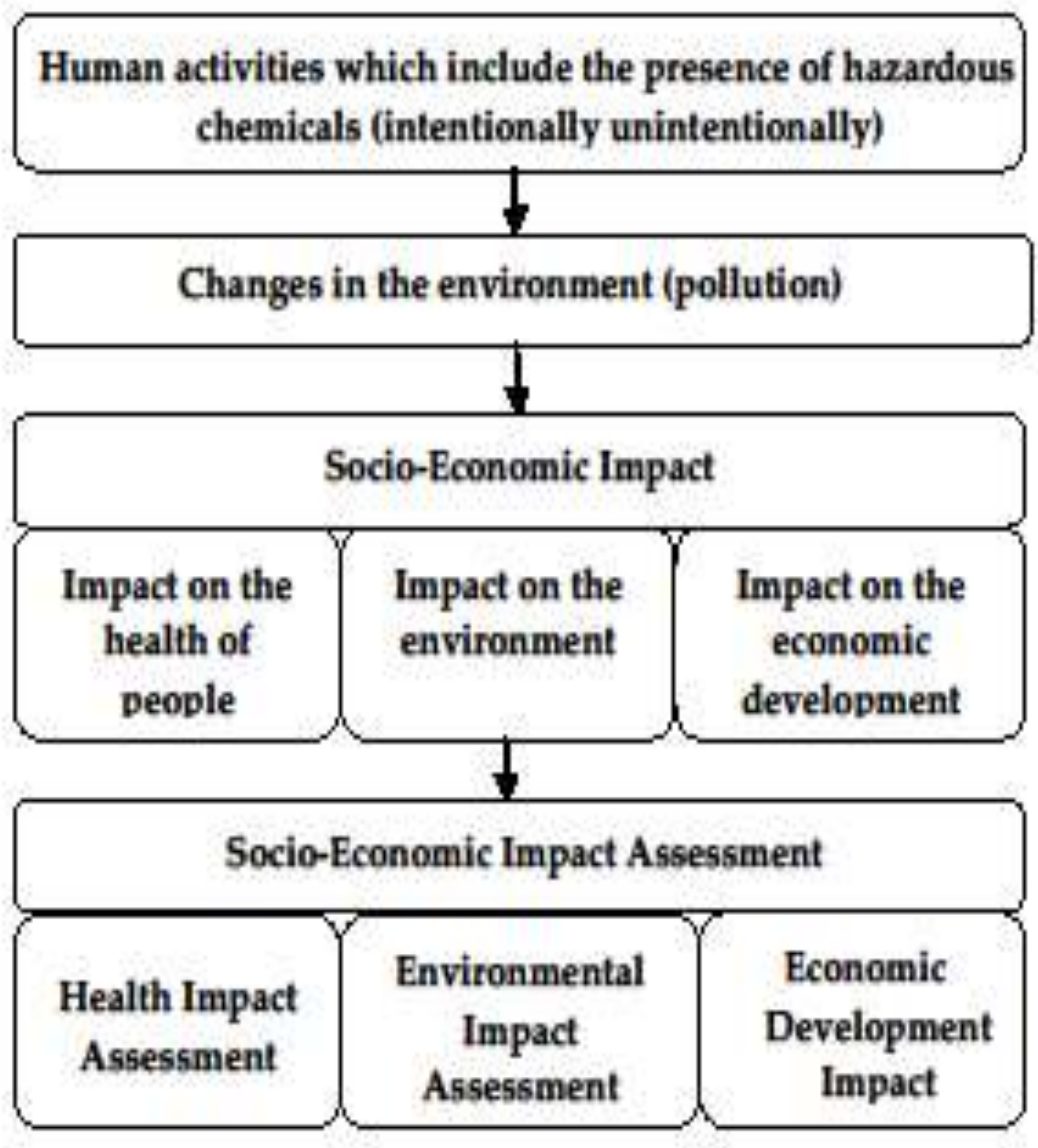


Figure 2.5: Socio-Economic Impacts of Chemicals and Analyses

Source: Finnveden and Moberg, (2005)

The social and economic consequences associated with chemical risk management include: Damage to human health: Hazardous chemicals have several side effects that negatively affect the human body, many of which have been confirmed by research. Laboratory research and many years of experience worldwide; Loss or increase of livelihood: hazardous chemicals affect people's health, which may affect their ability to work productively and sustain life. They also significantly damage natural resources and reduce the livelihoods of people and communities. At the same time, we must bear in mind that certain activities related to chemistry can be an important source of certain benefits for certain social groups. Changes in cost of living: the above effects sometimes, they naturally lead to very high costs. The cost of treatment, the loss of working days due to sick leave, the cost of maintaining contaminated water and air; The level of child labour. Hazardous chemical activities include child labour, especially in underdeveloped and developing countries (Finnveden and Moberg, 2005).

Changes in the level of balanced distribution of social wealth: many activities (especially agriculture) are a source of income for poor social groups, and threats to them can aggravate the situation. Development opportunities for companies (including small businesses): In addition to the many negative economic consequences, activities leading to persistent organic pollutants (POPs) can be an opportunity for small and medium enterprises (SMEs). Recycle the zone and eliminate the negative effects of POPs. Changes in the demand for public services such as healthcare, education, and infrastructure: hazardous chemicals are in the health sector (special skills must be provided to deal with the damage caused by these chemicals), educational (need to develop) skills and knowledge (Finnveden and Moberg, 2005). All these aspects were the subject of special studies aimed at assessing the negative effect of chemicals on human healthiness, especially in the workplace (Finnveden and Moberg, 2005).

Today's social pollution is inevitable, and industrial countries always produce a certain level of pollutants. Some pollutants that can be harmful to the environment are also very beneficial to society. A good example is pesticides, which not only contribute to possible side effects, but also make a significant contribution to increasing food production worldwide. Medicines that require organic chemicals that are potentially hazardous to production by prolonging organic life (Alam *et al.,* 2016).

In study conducted by Alam *et al.* (2016) in Bangladesh. It assesses the direct impact of pesticides and fertilizers on fish production and biodiversity of two important grain types. The results showed that 2.92 kgha-1 of pesticides and 2.95 kgha-1 of Kumari-beers were used for Hilne pepper. The number of hilne beans increased 1.41 times between 2005 and 2009 and 1.44 times for Kumari beers. The results show that fish production in both beers decreases as pesticide use increases.

2.18.4 Key informant interviews and Village-Level Group approaches to conducting socioeconomic survey

Exploratory survey methods such as Key Informant Interviews and Village-Level Group Interviews methods has been used successfully by International institute of Tropical Agriculture IITA (Oliphant *et al.,* 2019; Bera *et al.,* 2019) to conduct socioeconomic inventory of farming activities. Survey is a useful tool for conducting a socio-economic inventory of the effects of pollution. Individual or home interviews are useful tools for social research. This survey takes longer time than the village group surveys, and is usually not used as exploratory survey (Oliphant *et al.*, 2019: Bera *et al.*, 2019).

- *Key Informant Interviews*

Informant interview is a useful tool for research information mining. The "main sources of information" are people with special experience, selected to provide information about well-known issues. You can consciously select experienced district officials, advisers, or senior agricultural and health officials to provide information on local issues affecting your community. The main sources of information cannot be randomly selected. Researchers can use their grades to select the participants who are most familiar with the subject. Important informant interviews may be informal or formal. You can use a public or closed questionnaire format or a checklist approach. Using the checklist method, researchers list topics for discussion in a discussion form. The researcher checks the questionnaire and asks each question one by one. Many socio-economic issues can be explored through major interviews (Oliphant *et al.,* 2019; Bera *et al.,* 2019).

- *Village-Level Group Interviews*

Village group interviews are used as survey methods. The villages are randomly selected from the study area. Village contacts are established using agents. The session is booked days before. Small and large farmers from 15 to 20 representatives of people are invited to the meeting.

2.19 Environmental Regulations and Enforcement of Hazardous Chemicals

Initially, agricultural regulation was aimed at the development of industry, and even if environmental problems arise, the basic model of agricultural support has not changed significantly and has not been regulated (Matata, 2013). Low public visibility of violations further reduces the risk of detection and sanctions. Enforcement is the main driver in enforcing environmental laws. Without the regulations, the law would be a toothless bull dog. Compliance with environmental requirements will give the company a good opportunity to invest in improving and enhancing the efficiency of the production processes and increasing the value of products due to the specific consumption of resources, energy, and raw materials (National Environmental Standards, and Regulations Enforcement Agency, NESREA, 2014a).

The National Environmental Standards, and Regulations Enforcement Agency (NESREA) has the obligation to enforce compliance with all Nigerian environmental laws, policies, guidelines, regulations, and standards. Prohibit the processes and the use of technologies that affect the quality of the environment. The agency is also responsible for complying with Nigeria's environmental agreements, protocols, conventions, and international agreements. In addition to the oil and gas-based industry, NESREA has the right to import, export, produce, distribute, store, sell, use, and dispose of hazardous chemicals and waste. Thus, the agency regulates the import of restricted, banned chemicals and other hazardous chemicals, as well as certain products and equipment. This was done by issuing environmental import permits. National Environmental Regulations for Issues Related to Imported Goods: National Environmental Regulations (Hazardous Chemicals and Pesticides), 2014b.

Nigeria has also signed several international agreements on chemicals and their role in implementation (NESREA, 2014a). The Multilateral Environmental Agreement (MEA) is an agreement between several countries on the implementation of specific measures to protect the environment and conserve natural resources. Such initiatives are often caused by global concerns about the significant impact of human activities, which is environmentally friendly and sometimes serious (NESREA, 2014a). Exposure to harmful chemicals and pesticides can seriously affect the environment and health, such as diarrhoea, convulsions, immune / reproductive damage, certain types of cancer, birth defects, increased susceptibility to diseases and reduced intelligence. Toxic Chemicals and hazardous waste are elixirs of life and harbingers of diseases and death. Many people are injured or die each year due to exposure to toxic chemicals and wastes due to lack of information on handling, use and trade. Prevention of Human Exposure to Toxic

Chemicals and wastes is the Best Antidote. As a signatory/party to all the enumerated MEAs, Nigeria is obliged to enforce compliance with the provisions of these MEAs; NESREA as the environmental enforcement Agency in Nigeria is obliged to ensure that Nigeria fulfils her enforcement obligations (NESREA, 2014a).

Numerous studies have shown that law enforcement agencies were not properly reviewed, environmental indicators were unsatisfactory, and violations of environmental laws were common. Important factors leading to violations are slow managerial and economic reforms, complex legal frameworks and poor economic conditions, people who do not believe in fair rules and undermine the rule of law (Matata, 2013). Williams (2017) and Doonan *et al.* (2005) investigated the impact of inspection and the risk of inspection on the level of water pollution at pulp and paper mills. Shimshack and Ward (2008) extend the analysis to include non-monetary enforcement measures. Each of these studies shows that deferred implementation and monitoring activities increase regulatory compliance. This study examines the number of violations before and after a change in administrative regulations, so it does not include data on actual application or fines.

Environmental damage affects human health through exposure to chemicals (e.g., pesticides and heavy metals), which present serious threat to health of human well-being and the general environment in many parts of Africa (Kishi, 2020). The danger of pesticides is widespread and serious in widely used developing countries. Some pesticides, such as DDT, have been banned elsewhere due to environmental damage and human problems caused by poisons (Lippmann and Leikauf, 2020). Risks to people and the environment in developing countries have increased significantly, along with existing laws and a lack of coordination between health and agriculture and related laws to enforce pesticide regulations. In Nigeria, pesticide use in agriculture has grown rapidly over the years (Ojo, 2016). Although the significant contribution of pesticides to increasing crop yields and reducing vector-borne diseases is widely recognized, limited attention has so far been paid to concerns about harmful human effects and the general environment (Ojo, 2016).

Insecticides are generally toxic to many target species, causing pollution problems when released into the environment. Water is the main recipient of pesticidal pollutants. According to key data, countries with stringent environmental standards expected at the level of capital in GDP are experiencing economic growth. The type of pollution from pesticide abuse poses significant regulatory challenges. This dangerous pesticide pollutes the soil, water, air, and food sources (Lippmann and Leikauf, 2020).

Mwatawala and Yeyeye (2016) define education, training, and legal awareness as factors for the systematic compliance with plant protection laws. Descriptive statistics, mainly frequency, was used in analysing the data. According to the findings, respondents generally learned that, there were laws on agriculture, the environment, and consumer health, but were unable to comment on any laws. The result means that clear provisions are required regarding the safely uses and handling of pesticide and related violations, and compulsory compliance should be through training, not coercion. The result implies the creation of mechanisms and structures for the destruction of pesticides to reduce the hazardous disposal of pesticide containers. It is better to educate farmers on the proper use of pesticides. Farmer awareness of laws regarding food, environment and agriculture is needed. This study did not include plant minerals.

2.19.1 The table of eleven approach to appraisals of environmental laws and regulations

Dr Ruimshotel's Table (Appendix J) is an 11-dimensional tool based on behavioural sciences (Matata, 2013; Organization for Economic Co-operation, and Development (OECD), 2004). This dimension was created to make policy development and implementation policies as practical as possible. Dimensions provide the basis for assessing the suitability of existing laws. This law refers to a certain level of conformity of the target group. Ministry of Justice law enforcement experts coordinate the use and development of Table 11 as part of the Dutch program. “Table 11” includes compliance with 11 standards. It is divided into two groups: a voluntary compliance group and an implementation level group. Voluntary measurement of target group compliance is motivated by rules. The level of enforcement that defines risk is controlled by the government, and the definition of government sanctions policies affects two perceptions. This idea was chosen because it was easiest to determine compliance by law enforcement.

They directly predict aspects of voluntary compliance, which is very important for preventive implementation. The analysis table provides a systematic overview of the reasons for compliance and non-compliance. You can make a more objective assessment. In addition, it may be useful to find the pros and cons of the application and adhere to such rules. The Dutch law enforcement agency of the Ministry of Justice developed many tools for assessing the qualities of newly or existing regulations. Elven’s Table (T11) was formulated as an important standard checklist of a government agency, when evaluating the filing of new formulated regulatory proposals and considering implementation issues and other issues related to the existing regulations. This is very clear list of consistent dimensions (i.e., internal, and external key factors) that help in determining compliance and help governments to understand the main potential or behaviours of the existing target groups regarding compliance / noncompliance and develop more effective regulations. This method can be used in administrative and criminal related laws. In policy development projects, you can use the T11 method of investigation to properly process and develop policies at any level that may affect compliance.

2.20 Information Gaps

Use of agrochemicals are of major and important mechanisms of chemical revolution, which has changed agricultural methods (Sternfeld, 2018; Abong'o, 2018). Components that make alternative farming methods, such as the use of pesticides and fertilizers, are commendable. The weaknesses and threats arising from their unsustainable use cannot be overlooked. With the extensive use of agricultural pesticides and fertilisers, many countries have become independent in whole food needs. Some agricultural pesticides and fertilisers being toxic compounds to target materials could have a harmful effect to non-target creatures (Moreira-Santos *et al.*, 2019; Parrish, 2019).

Currently, there is no evidence presently which shows that a comprehensive analysis of agriculture chemicals use, occurrence distribution and fate has been done in water, and sediments within the proposed study area to date. Agricultural sector in Nigeria heavily depends on agrochemicals (Ojo, 2016). Although there are scarce data available in respect of residue level of agriculture chemicals within soil, waters, fish, and sediment from several rivers in Nigeria (Dirisu *et al.,* 2016; Mokwunye *et al*., 2012; Williams, 2013) there is very little or no information that represent higher agrochemicals risk in the study area. Absence of this information has led to little or no surveillance programs of agriculture chemical residue levels in the farming and fishing communities of the study area. Water bodies in the catchments supports fishing and farming and remain the main source of socioeconomic wellbeing of communities in the area and beyond. Experts warn that all these might be lost if laxity can continue in this industry (Abong'o, 2018). Monitoring of agrochemical residues levels in soil, fish, water, and agricultural products around the world's water has recently attracted a lot of interest for research.

Determination of multiclass, semi-polar pesticide residues in fatty fish muscle tissue using gas and liquid chromatography - mass spectrometry has revealed that water, fish and soil pesticide residues and decomposition products are increasing all over the world (Colazzo *et al.*, 2019). This study is very important because the total load can easily reach values that damage the irrevocable hydrological system. Another study, which attempts to provides basic information on residue concentrations of organochlorine pesticides in the water, shows the proportion of DDE to DDT, indicating the use of pesticides and the use of lindane and endosulfan (Jimoh *et al*., 2003; Mokwunye *et al*, 2012; Williams, 2013; Dirisu *et al.*, 2016; Ogbonnaya *et al*., 2017; Abong'o, 2018). Most of these compounds are administered every year without a full comprehension or understanding of their environmental effects, especially on people's health and the risk to aquatic life. They have two effects on humans: immediate short-term toxicity and long-term exposure reactions. Both effects can lead to chronic symptoms and death (Abong'o, 2018).

To date, there is no data for targeted studies, and comprehensive analysis of the study has not been conducted. The levels of agriculture chemical residues in the area under consideration remain unknown to date. Data from the study of agrochemical residue levels in the area is therefore needed. Poor farming practices like cultivating on a slope adjacent to rivers and on river banks have led to massive soil erosion (Ogwueleka, 2014).

As a result of this, the rivers in the area around River Kaduna are carriers of sediments and mineral loads that shocked the rivers (Ogwueleka, 2014). Sediments are the main carriers of agrochemical residues and many other inorganic and organic pollutants. Study on Rivers Niger and Kaduna catchments which are the major basis for socioeconomic wellbeing of communities in the area and beyond is becoming paramount to ensure sustainable development.

It should be noted that socio-economic analysis is an important part of chemical risk management in the field of environmental toxicity. It is important to anticipate and apply all necessary precautions in managing risk in a timely manner. We emphasize the general aspects of socio-economic analysis and how useful risk management solutions are. We expect this approach to be used soon in the preparation of all other emergency situations, especially strategic accident management plans, including pollution reduction. Economic and financial interests can also bring valuable benefits to society.

CHAPTER THREE

3.0 MATERIALS AND METHODS

Preamble

To appropriately understand the effects of agrochemical on soil and water quality in parts of Rivers Niger and Kaduna catchments, North Central Nigeria, Drivers, Pressure, State, Impact and Response (DPSIR) framework which was formulated by Kristensen (2004) was adapted in structuring the objectives of this study.

3.1 Study Design

According to Nwoko (2014), choice of topic and its design and process ought to reflect the overall research strategy and how the methodology is applied to solve a particular problem. In this study, Figure 3.1 reveals how the research method was designed and processed, to enable collection of sufficient data to aid the study. A study like this which assumed agrochemical use degrades soil, water, and aquatic resources with disproportionate effects on socioeconomic wellbeing of communities should involve multiple research methods. The multiple research approach was used to answer five questions posed by this study. This certainly requires a convincing approach that aquatic environment is under threat from unsustainable agrochemical use with potential effects on socioeconomic wellbeing of communities in the study area.

The field studies were important to achieve the aim of this study. The two approaches of data collection and analysis were employed in this study, and were designed and directed towards identifying, experimenting, analysing, and presenting the information obtained during the study. In the first aspect (involving objectives I, IV, and V) of the investigation, it involves the use of questionnaires, schedule interview survey techniques, designed and administered to carefully selected target respondents and key stakeholders in the study area. In addition, visual assessment through direct observations in the study area was used.

The second aspect (involving objective II and III), sediments and water samples were collected in two seasons (rain and dry seasons), while chemical experimentation and spatial analysis were conducted in the field and in the laboratory using various analytical instruments such as HANNA Multiparameter Analyzer, spectrophotometer, flame photometer, atomic absorption spectrophotometer and gas chromatograph/mass spectrometer. The investigation was commenced with extensive field survey involving observations, interaction with relevant stakeholders, identification, and geotagging of sampling points for Geo-database using GPS devices and overall understanding of the study area.

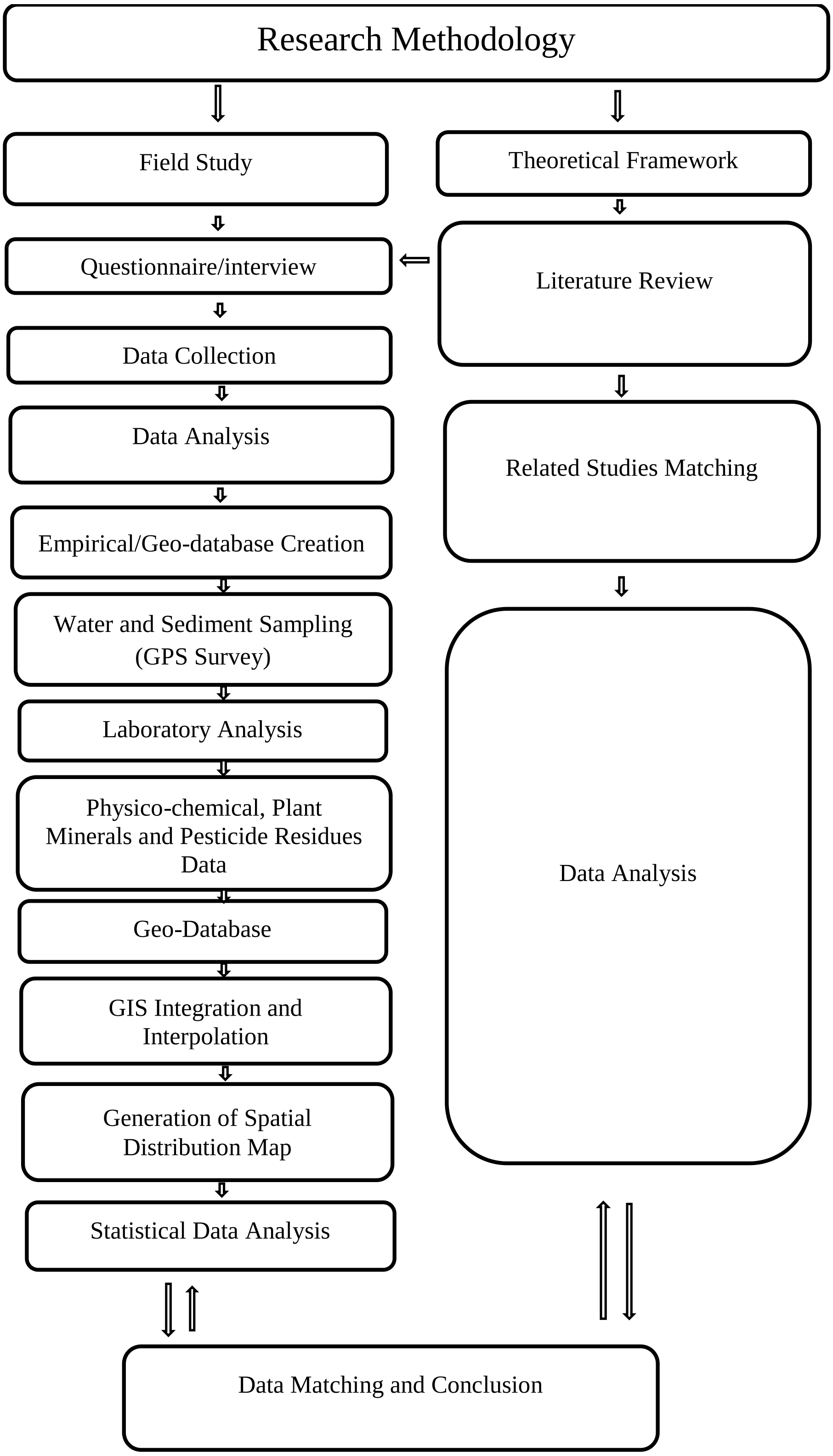


Figure: 3.1: Flowchart of the Research Process

Source: Adapted and modified from Nwoko, (2014)

3.2 Sampling Procedures

3.2.1 Sampling frame/size

The study covered communities from Raba in Mokwa LGA down to Baro in Agaie LGA along River Niger and Wuya in Lavun LGA down to Muregi along River Kaduna. This area was selected because it is characterised by intense agricultural activities involving use of agrochemicals. Also, people in the community depend on the rivers in the area for socio-economic survival. Target group for this study included officials of the National Environmental Standards and Regulations Enforcement Agency (NESREA), Niger State Environmental Protection Agency (NISEPA), Niger State Ministry of Agriculture, agrochemical vendors, health workers and farmers in the study areas. For convenience and according to agroecological factors and altitude, the area was divided into zones as described by Jokha, (2015).

Along River Niger, the Upper zone is from Raba village in Mokwa LGA, Middle zone is in Muregi in Mokwa LGA and the Lower zone is after Muregi down to the Baro village in Agaie LGA. A study area along River Kaduna was divided into two zone. Upper zone is from Wuya village in Lavun LGA and the Lower zone is at Gbara axis down to Muregi. Based on convenience, total of number of 30 villages were located and sampled randomly participatory appraisals using questionnaires and interview schedules. These villages were Raba, Edogi, Lwafu, Ja'agi, Sunti, Dukun, Zhiwu and Ketso at upper zone catchment; Muregi, Twasha, Egbagi, Dokomba, Sunlati, Jifu and Lenfa at middle zone catchment, and Katcha, Baro, Loguma, Akwanu, Esun, Soje, Bawaallagi and Ndalaka, villages at lower zone catchment along River Niger. While Wuya, Ganzhe, Estutasha and Emiworongi, villages at upper zone catchments and Agegi, Dzakagi, and Gbara down zone along River Kaduna.

3.2.2 Research instruments/materials

The study utilizes various research instrument which include scheduled interview for acquiring narrative data that enables this study to appraised the views of the study population in greater depth, survey questionnaire for obtaining information in respect of social related characteristics of participants, recent and previous behaviour, standard in conducts, their attitudes, beliefs coupled with the behavioural causes associated with this survey. Visual assessment for direct site view of activities in relation to the study area. A GPS device for mapping and designation of sampling points coordinates. Also, available tools such as shovel for sediment collection, bottles and ice flask were used for water samples.

Field and laboratory analytical instruments such as HANNA multiparameter analyser, GENESYS 180 985W172006 series UV-Vis Spectrophotometer, flame photometer and atomic absorption spectrophotometer were used for physico-chemical chemical analysis of water and sediment samples, while pesticide residues were analysed in sediment and water samples using Model 7890A of gas chromatography / mass spectrometry (GC-MSD) Agilent technology. Spectrophotometer was chosen because they measure the amount of chemicals based on their characteristic absorption spectrum (Kaserzon *et al.,* 2017; Dragna *et al.,* 2018). This is achieved by comparing the collected samples with reference samples known as standards. Spectrophotometers are usually very accurate. (Kaserzon *et al.,* 2017; Dragna *et al.,* 2018).

Gas chromatography/Mass Spectrometry (GC-MSD) detection techniques was adopted because it provides an important tool for analysing pollution caused by humans, such as pesticides and mineral contamination (Abong'o, 2018). It has become the most used method for separation and quantification of pesticides in various matrices. Gas Chromatography/Mass Spectrometry accomplishes the separation partitioning solutes in the middle of a mobile gas phase and stationary phase, which may be a liquid held in a solid adsorbent support.

3.2.3 Design of questionnaires

From the extensive literatures reviewed, stakeholders' interactions and field observations, the overall aspects of the relevant objectives in this study were identified. The identified aspects were subsequently used to prepare the assessment questionnaires and scheduled interviews used in this study (Appendices B, I and J).

3.2.3.1 Validation of questionnaires

Before the preliminary testing, focused group discussion was conducted in the field to present the quality and discussion of the work on the questionnaire and the planning of the interview. Corresponding changes were made, and the veracity of the content was verified by visiting several national and state agencies and villages in the area. After adjustment, before the testing of the revised questionnaire, an interview with five respondents followed. This was done to confirm the content, validity, and reliability of the problem. Preliminary test comments were included in the final survey questionnaires prepared for data collection (Appendices B, I and J).

3.3 Data Collection

In other to effectively achieve the objectives of this study, data were acquired from primary and secondary sources.

3.3.1 Primary data

Primary data were obtained through field observation, acquisition of the study area and sample point coordinates, questionnaires, interviews (key informant interview and village-level interview) and *in-situ* and laboratory analysis of sediments and water samples (collected in the rainy and dry seasons). Physicochemical analysis was conducted *in-situ* using HENNA Multiparameter Analyser for and in the laboratory following method outlined by Federation and American Public Health Association (FAPHA) (2005). Plant minerals were analysed spectrometrically in accordance with the methods designed by American Public Health Association/American Water Work Association/Water Environmental Federation (APHA/AWWA/WEF) (2005). Pesticide residue analysis was achieved using Gas Chromatography (GC) following Agilent method and Mass Spectrometry (MS) as described by Łozowicka *et al.* (2017) and Carmona and Picó (2018).

3.3.2 Secondary data

Secondary data were obtained from the study area map and relevant literature materials to identify gaps and missing links in the existing body of knowledge. In addition, this information includes national and international standards documents relevant to the regulation and use of pesticide, namely the regulations of the International Organization for Standardization (ISO), the National Gazetted Regulations from National Environmental Standards, and Regulations Enforcement Agency (NESREA), the Nigerian National Agency for Food and Drug Administration, and Control (NAFDAC), National Policy on Environment, and other relevant documents.

3.4 Investigation of Patterns of Pesticides and Fertilizers Use

Pesticides and Fertilizers use patterns for farming activities was achieved through a prospective cross-sectional study in the study area. The study utilized primary data from structured questionnaires (Appendix B), interview and visual observations as described by Banerjee *et al.* (2014). The questionnaire is an established survey instrument in the field of social science research used for the collection of relevant information in respect of participants' social characteristics, current and previous behaviours, standards of behaviours as well as their key reasons for acting on the subject to be examined (Bird, 2009). When it comes to pollution monitoring, questionnaires are an important tool widely used to obtain knowledge and perception information (Bird, 2009).

Questionnaires are relatively ignored when describing social research methods (Bird, 2009), and pollution monitoring studies are no exception. Interviews are more effective for collecting descriptive data than questionnaires, so researchers can more closely examine people's perspectives (Alshenqeeti, 2014). Similarly, Alshenqeeti (2014) added that the interview was "a useful way to study the construction and harmonization of meaning in a natural environment " The visual assessment, and point coordinates were mainly for sight view of the farming activities in the study area involving intense use of agriculture chemicals and to identify the sampling points for sediments and water samples intended for laboratory analysis (Alshenqeeti, 2014).

The number of farmers included in the study (participants) was determined using Yamani's formula. This formula uses a normal estimate with confidence level of 95% and an error rate of 5%.

In this case, the size of the sample is determined by $n = \frac{N}{1 \pm N(e)^2}$ 3.1

Where: n = the sample size

N = population

e = the limit of tolerance (0.05)

$$Therefore,\ n = \frac{30.229}{1+30{,}229(0.05)^2} = \frac{30.229}{1+30{,}229(0.0025)} = \frac{30{,}229}{1+75.5} = \frac{30{,}229}{76.5}$$

$n = 390\ respondent$

The number of respondents were made up to 395 to argument possible shortage. A questionnaire was subsequently distributed randomly amongst the study population who were farmers in the study area. Three hundred and ninety-five (395) copies of questionnaires were distributed and three hundred and fifty (350) was returned. Interview schedules were directed to Key Informants, which included experienced district officers, extension agents and agrochemical vendors in the study area. The respondents were approached by the study team. The objective of the study was explained to them following which their consents were obtained.

3.5 Determination of Spatial Concentrations of Physicochemical Properties of Water and Sediment Samples

The measurement of physicochemical properties of the water and bottom sediments is important for the following: they influence the rate of degradation, transportation, and mobility of chemicals in environmental media.

3.5.1 Geo-data base

Thirty-two (32) water and sediment samples required was collected at eight sample points in the study area (Figure 3.2). The eight sampling points were selected based on agro-ecological factors, altitude and information gotten from key stakeholders in this work as described by Jokha (2015). To validate the points further for proper sample collection, qualitative information from field survey were used. All samples were properly collected using standard procedures of collection, storage, and preservation of water samples. Samples were collected within two seasons. Rainy season (July – August, when agriculture activities and chemical use are high) and dry season (December to January, when agriculture activities and chemical use are less), for the purpose of determining the seasonal variability between variables.

Each sampling point was georeferenced using Global Position System (GPS) device, while *in-situ* and laboratory analysis was conducted using various analytical tools including HANNA Multiparameter Analyser, spectrophotometer, atomic absorption spectrophotometer and flame photometer. Spectrophotometer measures the amount of chemicals based on their characteristic absorption spectrum (Kaserzon *et al.,* 2017; Dragna *et al.,* 2018). This was achieved by comparing the collected samples with reference samples known as standards. Spectrophotometer is usually very accurate (Kaserzon *et al.,* 2017; Dragna *et al.,* 2018).

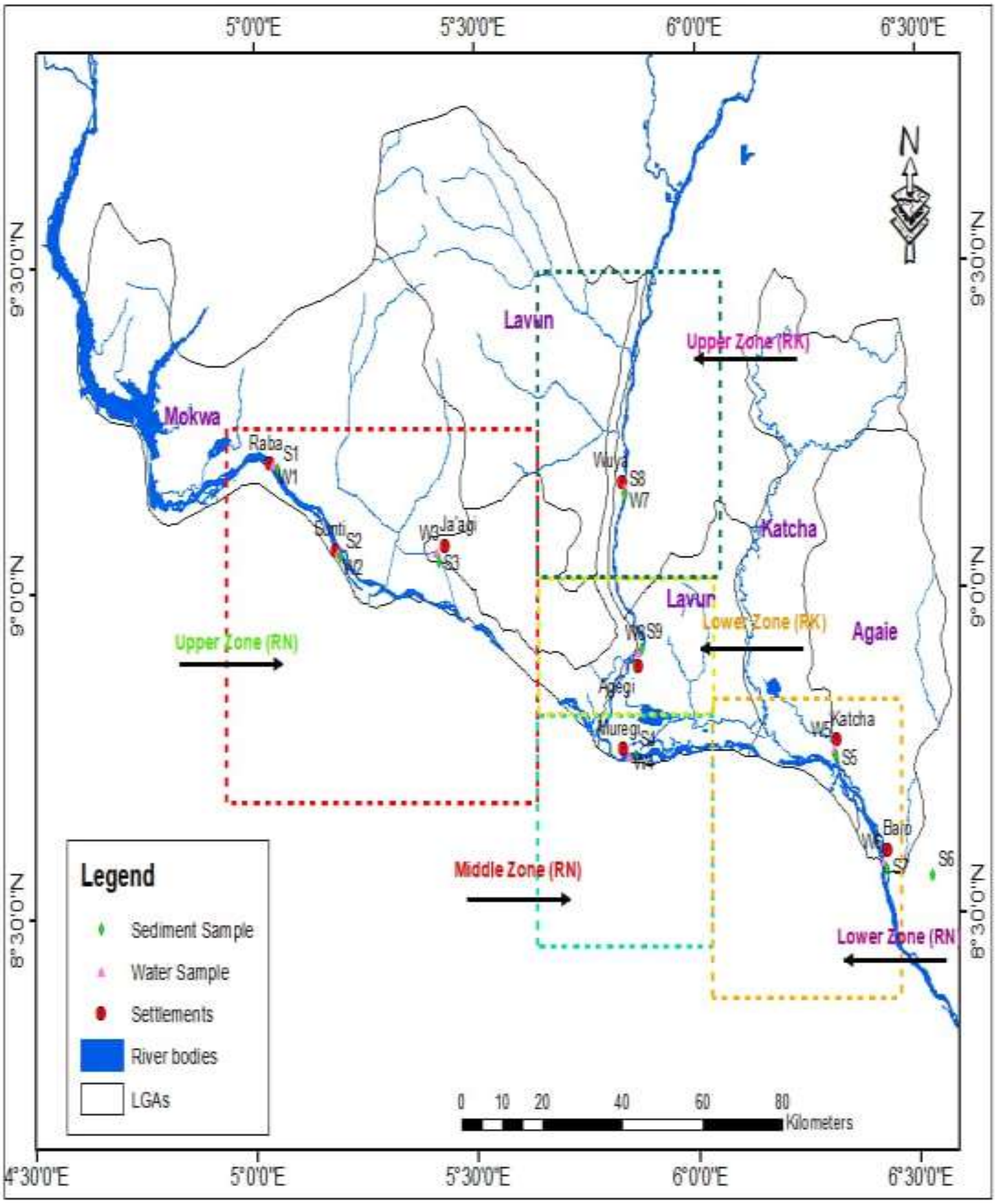


Figure 3.2: Water and Sediments Sample Zones and Points within Rivers Niger and Kaduna catchments

Source: Author's Field Survey, (2018)

3.5.2 Water sampling and *in-situ* analysis

A total of sixteen (16) samples for physico-chemical properties determination in rainy and dry seasons was collected by grab technique, analysed *in-situ* for seven physico-chemical parameters which include Potential for hydrogen (pH), Turbidity, Total Dissolved Solids (TDS), Temperature, Electrical Conductivity, Dissolved Oxygen and Salinity, later stored, cooled, and finally delivered to the reference laboratory at Dr Olukoya Research Laboratory, Lagos, Nigeria for further analysis. In the reference laboratory, water samples for other physico-chemical parameters were analysed immediately upon arrival.

3.5.3 Sediment sampling and preservation

Total number of sixteen (16) samples for physico-chemical properties determination was collected at carefully selected river banks during rainy and dry seasons. Sediment sample points were randomly selected at 0–20 cm depths in each sampling site, simply because sediments at this depth are anticipated to be the more contaminated and having probable exchanges with a column of water. The samples were collected using a shovel, then wrapped safely in aluminium foil sheets, clearly labelled, sealed in closed air plastic bags, cooled in an ice-flasks, and finally delivered to analytical laboratory at the Dr Olukoya Research Laboratory, Lagos, Nigeria where the samples were well kept at the 20 OC prior to extraction and subsequent analysis.

3.5.4 Sediment samples extraction for physico-chemical properties determination

Sediment samples were air dried and ground into fine form. About 5 g of the dried samples was weighed into conical flask, about 50 ml of a mixture of n-hexane and dichloromethane was added. Cold solvent extraction was carried out by ultra-sonication.

The mixture was shaken carefully and allowed to remain for 30 min followed by filtration. Extraction was repeated and filtered. The solvent extracts were then combined and cleaned up.

3.5.5 Measurement of physicochemical properties of water samples

Specific analytical methods for different physico-chemical parameters in this study were determined and summarized as follows.

Potential for Hydrogen (pH), Turbidity, Total Dissolved Solids (TDS), Dissolved Oxygen, Temperature, Electrical Conductivity, and Salinity were measured *in-situ* using Multiparameter Analyser, HANNA HI93194.

Total suspended solids (TSS): Total suspended solids were determined using Gravimetric Method, American Society for Testing and Materials (ASTM D1868). The residue from the glass fibre filter paper used was placed in the oven at 105 °C and then dried to a constant weight. Differences in the weight of filter paper were used to calculate the TSS. The minimum detectable limit is 1 mg/l.

$$TSS\ (mg/l) = \frac{(A-B) \times 10^3}{Sample\ volume\ (ml)} \qquad \textbf{3.2}$$

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

B = weight of glass fibre (mg).

Chloride (Cl^-): Chloride was determined in this study using an Argentometric method (ASTM D512). The chloride was determined by the Mohr Argentometric method. This involves titrating a given volume of sample (50 ml) with silver nitrate solution following treatment of the sample. The silver nitrate reacts with the chloride and appearance of chromate brick red colour indicates the end point of the reaction. For highly saline samples, aliquots were taken and diluted before analysis. Detection limit is 1 mg/l.

$$Chloride\ (mg/l) = \frac{Titre \times N\ 35{,}450}{Sample\ volume\ (ml)} \qquad \textbf{3.3}$$

Where: N = Normality of the silver nitrate solution Salinity (As Chloride)

Determination of biochemical oxygen demand (BOD_5): Biochemical oxygen demand was determined using the dilution method (APHA 5210-B). It involves taking two (2) DO readings; Initial DO or DO_1 (DO recorded on the first day) and DO_5 (DO recorded on the fifth day). The Initial Dissolved Oxygen (DO_1) of the BOD sample collected in amber bottle was fixed with Winkler 1 and 11 solutions in the field and the concentrations was determined by acidifying 250 ml of the fixed sample and titrating fixed samples using 0.25 N sodium thiosulphate solution. For DO_5, the BOD bottles (amber bottles) containing the desired diluted samples were then incubated at relative room temperature for five days. After 5 days of incubation, the concentrations of DO in the sample were determined following the same process for DO_1. The DO_5 concentrations are;

$$BOD5\ (mg/l) = F\ (DO_1 - DO_5) \qquad \textbf{3.4}$$

Where : DO_1 = Initial DO in the diluted sample

DO_5 = DO in diluted sample after 5 days of incubation

F = Dilution factor

F= total volume following dilution (ml)/volume of the undiluted sample (ml)

Chemical oxygen demand (COD): Chemical oxygen demand was determined using the Dichromate method (ASTM D1252, APHA 508). It was determined by redox titration with sample digestion and relaxing. The method involved measuring 25 ml to 50 ml of the water sample into a reflux flask, followed by the addition of 1 g of mercuric sulphate in an ice bath, 5.0 ml cans. H_2SO_4 and then mixed thoroughly to complete digestion. Chemical oxygen demand (COD): Chemical oxygen demand was determined using the Dichromate method (ASTM D1252, APHA 508). It was determined by redox titration with sample digestion and relaxing. The method involved measuring 25 ml to 50 ml of the water sample into a reflux flask, followed by the addition of 1 g of mercuric sulphate in an ice bath, 5.0 ml cans. H_2SO_4 and then mixed thoroughly to complete digestion.

$$COD\ mg/L = \frac{(A-B) \times N \times 8000}{ml\ sample} \quad \textbf{3.5}$$

Where:

A = ml Ferrous Ammonium Sulphate (FAS) used for sample

B = ml FAS used for blank

N = molarity of FAS

Sulphate: Sulphate was determined using Spectrophotometric Method. In principle, sulphate ions are precipitated in the form of $BaSO_4$ in an acidic medium (HCl) together with barium chloride. The absorption of this precipitate suspension was measured by light scattering using a 420 nm spectrophotometer.

Calculate

$$mg/L\ SO_4 = \frac{mg\ SO_4 \times 1000}{ml\ sample} \quad \textbf{3.6}$$

Manganese: Manganese (Mn) was determined following metals (ASTM D3110) method. Metals were analysed using an atomic absorption spectrophotometer. Sampling was carried out by acid decomposition followed by the filtration through a 0.45-micron membrane filter. An aliquot of the filtrate was then used to analyse iron, copper, chromium, lead, and zinc. The minimum detectable limit is 0.001 mg/l.

Potassium: Potassium was determined using a flame photometer. Potassium present in the aqueous sample was extracted with 1 mole of neutral ammonium acetate. It is believed that plant K can be used for water. This was evaluated by a photometer. A molar solution of molar ammonium acetate was carefully prepared by dissolving 77 g of the ammonium acetate ($NH_4C_2H_3O_2$) in 1 litre of water. The pH value was checked using a pH meter. Since the observed pH was not neutral, acetic acid was added to neutralize to a pH of 7.0. A standard potassium solution was then prepared carefully dissolving 1.908 g of pure KCl in a litre of distilled water. This solution contains 1 mg K/ml, 100 ml of this solution was removed and diluted to 1 litre with a solution of ammonium acetate. This gives 0.1 mg K/ml as a stock solution. A flame photometer was set by default, after which potassium in the filtrate is determined by a flame photometer.

3.5.6 Measurement of physicochemical properties of sediment samples

Chloride: Chloride (Cl) in sediment was determined using an Argentometric method by titration of the chloride ions in the Sediment filtrate with known molar concentrations of silver nitrate solution.

Sulphate (SO_4^{2-}): The sulphate in the Sediment was extracted with a 500 ml solution of potassium orthophosphate and the sulphate determined by $BaCl_2.2H_2O$ Gelatic turbidimetric method.

Manganese: Manganese (Mn) was determined following metals (ASTM D3110) method. Metals were analysed using an atomic absorption spectrophotometer. Sampling was carried out by acid decomposition followed by filtration through a 0.45-micron membrane filter. An aliquot of the filtrate was used to analyse iron, copper, chromium, lead, and zinc. The minimum detectable limit is 0.001 mg/l.

Potassium: Potassium present in soil samples was extracted with 1 mole of neutral ammonium acetate. It is considered suitable for K plants in the soil. This was evaluated by a photometer. A molar solution of molar ammonium acetate was prepared by dissolving 77 g of ammonium acetate ($NH_4C_2H_3O_2$) in 1 litre of precipitate extract. The pH value was checked using a pH meter. Since the observed pH was not neutral, acetic acid was added to neutralize to a pH of 7.0. A standard potassium solution was prepared by dissolving 1.908 g of pure KCl in a litre of distilled water. This solution contains 1 mg K/ml, 100 ml of this solution was removed and diluted to litre with a solution of ammonium acetate. This gives 0.1 mg K/ml as a stock solution. The flame photometer was set up in accordance with standards following which potash in the filtrates was determined using a flame photometer.

3.6 Determination of Spatial Concentrations of Plant Minerals and the Extent of Occurrence of Organochlorine Pesticide Residues in Surface Water and Sediment Samples

3.6.1 Geo-data base

A total of thirty-two (32) samples of water and sediment for plant minerals and pesticide residues determination was collected during the rainy and dry seasons. Each sampling point was georeferenced using Global Position System (GPS) device (Table 3.1), while laboratory analysis was conducted using GENESYS 180 985W172006 series UV-Vis Spectrophotometer and Gas Chromatography/Mass Spectrometry Agilent technologies 7890A model. Gas chromatography/Mass Spectrometry (GC-MSD) detection techniques provides an important tool for analysing pollution caused by humans, such as pesticides and mineral contamination (Abong'o, 2018).

It has become the most used method for the separation and quantification of pesticides in various matrices. Gas Chromatography/Mass Spectrometry accomplishes the separation partitioning solutes in the middle of a mobile gas phase and stationary phase, which may be a liquid held in a solid adsorbent support. Spectrophotometers measure the amount of chemicals based on their characteristic absorption spectrum (Kaserzon *et al.,* 2017; Dragna *et al.,* 2018). This is achieved by comparing the collected samples with reference samples known as standards. Spectrophotometers are usually very accurate. (Kaserzon *et al.,* 2017; Dragna *et al.,* 2018).

3.6.2 Sampling and preservation of water and bed sediment samples

Water and sediment samples were collected from eight carefully selected sampling points in rainy (July-August) and dry (December-January) seasons. The sampling points were designated based on agro-ecological factors, altitude and the information obtained from key stakeholders during field visits. The positioning of proposed sampling sites in the study area was done using Global Positioning System (GPS) device (Table 3.1).

3.6.3 Water sampling and preservation

A total of sixteen (16) water samples was collected by grab techniques to determine plant minerals and pesticide residues during the rainy and dry seasons. The samples were well preserved, stored in a cooler and then transported to the Dr Olukoya Research Laboratory, Lagos, Nigeria. One litre bottle of the Teflon Stop Cork sample was used to collect water samples for determination of plant minerals. Before collecting water samples, the sample bottles were immersed in 10% HCl overnight and then rinsed with distilled water and rinsed with water samples. The bottles were then filled with water samples and preserved using H_2SO_4 concentrate, which were analysed immediately after arriving at the laboratory. Water samples for measuring pesticide residues were also collected in a litre sample bottle equipped with sealed Teflon. Before the laboratory sampling, the test tube was washed thoroughly with detergent, washed several times with tap water and distilled water, and finally, after drying in the oven, it was washed with acetone. During laboratory sampling, the bottles were rinsed three times with a sample of water, then carefully filled so that air bubbles do not pass through the sample. Samples were stored at 0-4 °C until extraction and analysis.

3.6.4 Sediment sampling and preservation

A total of sixteen (16) samples of sediment meant for plant minerals and pesticide residues determination was collected at the bank of the rivers during rainy and dry seasons. All sampling points were selected at a depth of 0 to 20 cm. This is because sediment at these levels is expected to be the most contaminated and has a better chance of water column. Samples were collected using a spoon, carefully wrapped with aluminium foil, carefully marked, placed in an airless bag, stored in ice flask, and finally transported to the Dr Olukoya Research Laboratory, Lagos, Nigeria, stored at 20 °C before the extraction and analysis.

3.6.5 Analytical laboratory analysis of plant minerals

Plant minerals were analysed spectrometrically in water samples immediately upon arrival in the laboratory using GENESYS 180 985W172006 series UV-Vis Spectrophotometer, while sediment samples were also analysed using the same laboratory analytical instrument following liquid-liquid extraction. Nitrate nitrogen (NO_3^-–N) was determined by the cadmium reduction process, where NO_3^- is quantitatively reduced to nitrite NO_2^- in the presence of cadmium using Cd copper sulphate ($CuSO_4$) granules which are commercially available to form Cu layers. The resulting NO_2^- is then determined by diazotization with sulfanylamide and combined with N-(1-naphthyl) ethylenediamine to form a very colourful azo dye, which was measured by colorimetry process. Adjustments were made for originally like NO_2^-, which were initially analysed without a reduction step. Nitrite nitrogen (NO_2^-–N) was determined by the formation of azo red-violet dyes, which were obtained at pH 2.0 to 2.5 by combining diazotized sulfanylic acid with N-(1-naphthyl) ethylenedine dehydrochloride.

Phosphate (PO_4^{3-}–P) was measured using the methods of ascorbic acid, ammonium molybdate and potassium antimony tartrate, which reacts in acidic media with orthophosphate to form heteropoly acid - phosphomolibdic acid - which is reduced to strong coloured molybdic acid. Colour intensity was measured spectrophotometrically using an infrared photo tube at 880 nm. The quality of the analysed data obtained is carefully ensured by blind and double analysis in accordance with standard work instructions from the reference analysis laboratory.

3.6.6 Water samples extraction for pesticide residues determination

Water samples were extracted via liquid-liquid extraction. 200 ml each of water samples were extracted with 50 ml of HPLC grade dichloro-methane in a separating funnel. The process of extraction was then repeated with 50 ml dichloromethane and the final extracts were combined. Column chromatography was used for the clean-up of the extracts. Glass separating column was packed with activated silica gel and washed down and conditioned with dichloromethane/hexane (50/50). The extracts were de-moisturized over 1g of anhydrous granulated Na_2SO_4. The extract could run through the column and then eluted using a mixture of dichloromethane/hexane/acetonitrile (50/49/1.0). The fractions were concentrated to 1 ml and ready for GC-MS analysis.

3.6.7 Water samples clean-up for pesticide residues determination

Following the extraction, organic layer in the extract was filtered via plug wool, which contains anhydrous sodium sulphate (30 g) for drying. Subsequently, dichloromethane (2 x 3 ml) was prepared following which sodium sulphate was rinsed in it. The extract concentrations were combined in the vacuum at 30 °C and was observed changed to cyclohexane. It was followed by adjustments of the volume in a stream of 2 ml in ratio of 9:1 cyclohexane and acetone (v/v) vials kept ready for analysis. The water extract appears very clean and thus needless of further clean up.

3.6.8 Sediment samples extraction and clean-up for pesticide residues determination

Sediment samples were air dried and ground into fine form. About 5 g of the dried samples was weighed into conical flask, about 50 ml of a mixture of n-hexane and dichloromethane was added. Cold solvent extraction was carried out by ultra-sonication. The mixture was carefully shaken and then allowed to stand for 30 min and then filtered. The extraction was repeated and filtered. The solvent extracts were then combined and cleaned up.

3.6.9 Sediment samples clean-up for pesticide residues determination

Column chromatography was used for purification using Florisil (magnesium silicate). A 5 g (60 cm x 22 mm) glass column packed with the Florisil, glass wool and anhydrous sodium sulphate was then used. 50 ml of cyclohexane is added to the glass column and run through several turns of drops until a very small amount remains at the top of the column. The concentrate sample were then poured into a column and dried to obtain 2 ml of the sample, which is then transferred to a Teflon cork bottle and stored at 4 °C until final analysis.

3.6.10 Analytical quality assurance for the sediment samples

100 ml aliquots of each dichloromethane, cyclohexane, ethyl acetate and acetone were concentrated to 2 ml and used to check contamination by solvents used previously. Two matrices blank from bed sediments were gotten from virgin land. The same extraction and analysis procedures used for sediment samples were carried out. Recovery was calculated using a blank matrix with standard organochlorine pesticides in concentrations between 0.02 to 1.1 μm.g/ml of each of the analyte distributed.

3.6.11 Analytical quality assurance for the water samples

Each aliquot of 100 ml of n-hexane, dichloromethane, cyclohexane, ethyl acetate and acetone were concentrated to 2 ml and then used to check contamination by solvents used previously. One litre of distilled water was obtained in the same manner as in the process of extracting water samples. Recovery was evaluated using an empty matrix with standards organochlorine pesticides in concentrations between 0.01 to 1.1-microns g/ml of each of the analyte distributed.

3.6.12 Gas chromatography analysis

Analysis of pesticide residues was carried out using GC-MSD. The injection volume of the detector is 1 microliter. The GC model is Agilent Technologies 7890A with a column length of 0.25 microns. Gas chromatography / mass spectrometry (GC-MS) instruments separate chemical mixtures (GC-MSD components) and identify components at the molecular level (MS components). This is one of the current and most accurate and precise tools for analysing many environmental samples. GC-MSD operates on the principle that the mixture is separated into separate substances when heated. The heated gas is transferred through an inert gas column (like helium). When released substances leave the column opening, they flow into mass spectrometry. Mass spectrometry identifies compounds based on molecular mass of the analyte. Mass spectrometry is considered the only final analytic detector.

3.6.13 Identification and quantification of the pesticide residues

Residues were identified by running samples and external reference standards in GC-MSD and then comparing chromatograms. Pesticide detection limits are based on the lowest concentrations that can be obtained consecutively in the laboratory (> 70%). The identified pesticides were quantified by comparing the area of the peak of the analyte at unknown concentrations with reference standards for known concentrations, which were operated under the same analytical conditions as the sample. This study uses an external standard technique in which the same volume (2 ml) of the reference standard is injected between the injection samples.

3.7 Investigation of Socioeconomic Challenges of Pesticides and Fertilisers Contamination of Soil and Water

Primary data were sought to achieve this objective. Based on convenience or opportunity sampling technique, a total of 395 questionnaires (Appendix I) was conveniently distributed across the sampled population (Equation 3.1), three hundred and fifty questionnaires were returned thereafter. Also, 25 villages were selected conveniently across the zones for group discussions. Exploratory survey methods which include Key

Informant Interviews and Village-Level Group Interview methods were also adopted aimed at validating the information acquired from administered questionnaires following procedures described by Oliphant *et al.* (2019) and Bera *et al.* (2019). The survey is a useful tool for conducting a socio-economic inventory of the effects of pollution. Personal or household-level interviews are useful tools for social research. This survey takes longer time than the key informant or Village-Level surveys, and is usually not used as exploratory survey (Oliphant *et al.*, 2019).

- *Key Informant Interviews*

Key informant interviews are a useful research instrument for exploratory surveys. A "key informant" is a person with a special expertise, who is selected to provide information on known matters. Sequel to this understanding, community experienced district officers, extension agents, senior members of the farming community and health workers were purposely selected to provide information on local problems affecting the community. Personal judgement was used in selecting knowledgeable participants about the subject under investigation. The informal and formal meeting was adopted based on convenience. Discussions were held on socio-economic impact of agrochemical use on the communities' wellbeing in relation to environment, health, and socio-economic development.

- *Village-Level Group Interviews*

Village group interview are used as survey methods. The villages surveyed were selected randomly from the study area. A total of 25 villages was considered for selection from the group discussions based on convenience or opportunity sampling methods. Village contacts were established with the help of extension officers and village leaders. Meetings were scheduled a few days in advance. Ten to twenty locals representing small and large farmers, men and women were invited to attend the scheduled meetings. Closed questionnaire formats were used during the discussions. Relevant questions were asked and explore in a detail during and after discussions.

3.8 Appraisal of Effectiveness of Relevant Environmental Laws and Extant Regulations on Agrochemical Use near Sensitive and Vulnerable Areas

Primary data were collected using questionnaires (Appendix J). Two visible forms of the questionnaire were developed based on "Table Eleven" (Matata, 2013). The Table of Eleven developed by Dr Ruimschotel is an 11-dimensional behaviour science tool. It was used to formulate questions to achieve objective five in this study. Both questionnaires were open and closed questions deemed relevant to the study objectives. The target populations were farmers from the study area, regulatory and enforcement officials from NESREA, NISEPA, District Agriculture Officers, and Extension Officers. Two standard forms of questionnaire were developed. They were given the detailed interview instructions, and finally administered.

Consequently, two data sets were created.

(1) Farmers and agrochemical vendor's questionnaire were administered to educated farmers and agrochemical vendors as compliers of the rules and regulations. A total of thirty (30) farmers with formal education and agrochemical vendors were interviewed using a structured questionnaire. Additional information was collected during group discussions with law enforcement agencies and farmers from the studied population.

(2) Enforcement official Questionnaire: A total of thirty (30) questionnaires was conveniently administered to regulatory and enforcement officials from NESREA,

NAFDAC, NISEPA and Agric Extension Officers from Agriculture Development Program ADP. It aims to obtain information on the application of agricultural chemical regulations.

3.9 Data Analysis

3.9.1 Analysis of pesticides and fertilizers use patterns

Analysing objective one in this study, collected data from administering questionnaires on farmers in the area were checked for errors, coded, and were processed in Microsoft Excel by the way of descriptive analysis (frequency percentage). Descriptive statistics are easy to use for summarizing survey data in a simple and understandable way (Chapman and World Health Organization (WHO), 1996). The results of the analysis were represented in tables and figures for clarity and accurate assessment of the data

The choice of result presentation in tables was made in this study because tables are useful for showing data with precise numerical values, particularly when there is large data set. Tables also allow you to compare numerical values between groups. Also, figures and charts are great for highlighting trends, patterns, and relationships between different aspects of the data set. In other words, figure is useful when trends in the data are more important to communicate than the numerical values themselves.

Frequency percentage equation is given as follow:

$$Frequency - Percentage = \left(\frac{number\ of\ observed}{Total\ Nunber}\right) 100\% \qquad \textbf{3.7}$$

Further, data from the planned interview with agrochemical vendors and extension officers were manually analysed by summing up the respondents' opinions and personal visual observations of the study area situation. The findings were further compared with the related findings around the world.

3.9.2 Analysis of spatial concentrations of physicochemical properties of water and sediment samples

In analysing the spatial concentrations of physicochemical properties in this study, sampled coordinates and names recoded using Geographical Positioning System (GPS) device in longitude and latitude in Degree, Minutes and Seconds (DMS) format (Table 3.1) format were transferred into Excel package of the Microsoft Office software, sorted, and saved in Tab delimited file format that is compatible in ArcGIS environment.

Table 3.1 Description of the surface water and sediment sampling sites

s/n	Site Reference	Coordinates	Site Characteristics
1	Upper Zone RN		
	S1 & W1	9°14′53″N 5°85′37″E	Domestic activities, faming,
	S2 & W2	9°11′09″N 5°26′19″E	fishing, and settlements
	S3 & W3	9°11′43″N 5°18′38″E	
2	Middle Zone RN		Domestic activities, faming,
	S4 & W4	9°45′25″N 5°50′38″E	fishing, and settlements
3	Lower Zone RN		Domestic activities, faming,
	S5 & W5	9°35′11″N 5°25′59″E	fishing, and settlements
	S6 & W6	9°46′12″N 5°18′42″E	
4	Upper Zone RK	9°09′24″N 5°49′39″E	Domestic activities, faming,
	S7 & W7		fishing, and settlements
5	Lower Zone RK	9°50′35″N 5°50′39″E	Domestic activities, faming,
	S8 & W8		fishing, and settlements

Key: RN = River Niger. RK = River Kaduna. S = Sediment sampling sites. W = Water sampling sites

Source: Author's Field Survey, 2018

Interpolation-GIS model

ArcMap was lunched and the prepared dataset was imported into the table of content in the GIS interface using the tab delimited as file format, Universal Transverse Mercator (UTM) Projection system was chosen and set to Zone 32 N. Therefore, Interpolation was done using the spatial analysis extension toolbox of the ArcGIS (version 10.5). The Inverse Distance Weighted (IDW) technique was chosen because it uses the measured values surrounding the prediction location to predict a value for any unsampled location, based on the assumption that things that are close to one another are more alike than those that are further apart.

Finally, at the tab of IDW interface, the sample points (physico-chemical parameters of rainy and dry Seasons) were selected separately and imported, the output was saved, each sample point was assigned by a unique code and stored in the point attribute table and named appropriately for easy identification in defined folder and then OK for processing. The data base file now contains values of all physico-chemical parameters in separate columns along with a sample code for each sampling station. Therefore, since the resulting interpolated surface exceeded the study area boundary, extraction was done to limit it to the Area of Interest (AOI) using the study area shapefile.

The IDW maps generated include potential for hydrogen (pH), salinity, temperature, dissolved oxygen, electrical conductivity, total dissolved oxygen, turbidity, sulphate, manganese, chloride, COD, BOD, TSS, total hardness and potassium. These maps were then exported in JPEG format after adding a neat-line, grid, north arrow, scale and legend for presentation and discussion.

Geographical information systems, GIS tool was adopted because it is highly important and helpful in clear reporting and in developing solutions for water resources and related problems and general understanding of the natural environment on a local and or regional scale. From GIS analysis, spatial distribution mapping for various pollutants can easily be done. The resulting information is highly useful for policy makers by presenting better remedial measures (Chatterjee and Lataye, 2020).

3.9.3 Analysis of spatial concentrations of plant minerals and the extent of occurrence of organochlorine pesticide residues in surface water and soil samples

In analysing the spatial concentrations of plant, mineral concentrations in this study, sampled coordinates and names recoded using Geographical Positioning System (GPS) device in longitude and latitude in Degree, Minutes and Seconds (DMS) format (Table 3.1) format were transferred into Excel package of the Microsoft Office software, sorted, and saved in Tab delimited file format that is compatible in ArcGIS environment.

Interpolation-GIS model

ArcMap was lunched and the prepared dataset was imported into the table of content in the GIS interface using the tab delimited as file format, Universal Transverse Mercator (UTM) Projection system was chosen and set to Zone 32 N. Therefore, Interpolation was done using the spatial analysis extension toolbox of the ArcGIS (version 10.5).

Finally, at the tab of IDW interface, the sample points (plant minerals parameters of rainy and dry Seasons) were selected separately and imported, the output was saved, each sample point was assigned by a unique code and stored in the point attribute table and named appropriately for easy identification in defined folder and then OK for processing. The data base file now contains values of all plant minerals parameters in separate columns along with a sample code for each sampling station. Therefore, since the resulting interpolated surface exceeded the study area boundary, extraction was done to limit it to the Area of Interest (AOI) using the study area shapefile.

The IDW maps generated include potential for nitrate, nitrite, and phosphate. These maps were then exported in JPEG format after adding a neat-line, grid, north arrow, scale and legend for presentation and discussion.

Subsequently, concentrations of plant minerals acquired from the laboratory were further processed in Microsoft Excel by way of descriptive analysis, namely percentage and represented in charts for proper demonstration of the percentage occurrence of plant minerals in water and sediment samples of rainy and dry seasons across the sample points.

Accordingly, raw dataset resulting from the GC/MSD analyses of organochlorine pesticide compounds was checked for errors, processed in Microsoft Excel, while the concentrations (in ppm) and the retention time (in minutes) were represented against Maximum Residue Limits which were represented in tables for clarity. The choice of residues analysis results presentation in tables was made in this study because tables are useful for showing data with precise numerical values, particularly when there is large data set. Tables also allow you to compare numerical values between groups. Further, the GC/MSD data checked for errors were further subjected to descriptive analysis, namely percentage (equation 3.7) to determine the percentage occurrence of organochlorine pesticide residues within and below to detect limit in water and sediment samples of rainy and dry seasons across the sample points. Descriptive analysis is mostly used easily to summarise data sets of water quality arising from laboratory, analytical processes into simpler and more understandable forms (Chapman and World Health Organization, 1996). The results of the percentage occurrence were then represented in charts for clarity. Charts and figures are great for highlighting trends, patterns, and relationships between different aspects of the data set. In other words, charts and figures are useful when trends in the data are more important to communicate than the numerical values themselves. The findings were further compared with the related findings around the world.

3.9.4 Analysis of socioeconomic challenges of pesticides and fertilisers contamination

Analysing the socioeconomic challenges of pesticides and fertilisers contamination of water in the study area, collated data obtained from questionnaires administered to the farming communities were checked for errors, manually coded, and analysed using descriptive analysis, namely frequency-percentages (equation 3.7) and non-parametric method of data analysis which is based on relative ranking of data values (knowledge of the exact shape of the population is not required). Accordingly, three key socio-economic variables, which include environmental effects arising from agrochemical contamination, human health impacts and impacts on economic development were analysed from the coded data. The results of the analysis were finally represented in tables and charts for clarity.

Further, dataset resulting from Key Informant Interviews namely experienced district officers, extension agents and health workers, and village-level group interviews which were purposefully meant to validate the findings from administered questionnaires, were presented in summaries for further clarity.

3.9.5 Analysis of effectiveness of relevant environmental laws and extant regulations on agrochemical use near sensitive and vulnerable areas

Analysing the effectiveness of relevant environmental laws and extant regulations on agrochemical use near sensitive and vulnerable areas, the data collected from the farmers and agrochemical vendors in the study area through questionnaire, and regulatory and enforcement agencies staff through interview schedules were checked for possible errors and analysed using non-parametric method of data analysis and descriptive statistics namely frequency-percentages (equation 3.7) and finally presented in tables and summaries for clarity.

The Rating Criteria for Appraising the Responses Were:

1 = very weak, 2 = weak, 3 = moderate, 4 = strong and 5 = very strong in accordance with the standard of Organisation for Economic Co-operation and Development (OECD) as indicated in Matata, (2013) and OECD, (2004). The findings were further compared with the related findings around the world.

Table 3.2: Summary of Material and Methods Used in the Study

Objectives	Type of Data	Sources of data	Data Analysis
Objective I	Primary data (structured questionnaire, schedule interview and field observations	Field surveys and direct interactions, with the study population.	Frequency and simple percentage analysis
Objective II	Primary data (sample points coordinates, field observation, and physicochemical data)	GPS device, field observations, *in-situ* and laboratory analysis using Hana Multiparameter Analyser and Spectrophotometer	*In-situ* laboratory analysis, ArcGIS 10.2, and simple percentage analysis
Objective III	Primary data (sample points coordinates, field observations, plant minerals, and pesticide residues data)	GPS device, field observations and laboratory analysis using standard methods, Spectrophotometer, GC-MS techniques.	Laboratory analysis, ArcGIS 10.2, frequency, and simple percentage analysis
Objective IV	Primary data (structured questionnaires, scheduled interview, and field observations)	Survey, Key Informants Interviews and Village-Level Group Interviews	Simple percentage and non-parametric analysis
Objective V	Primary data (structured questionnaire)	Survey and direct interactions	Non parametric and simple percentage analysis

Source: Author's Work, 2017

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Investigation of the Patterns of Pesticides and Fertilizers Use

4.1.1 Farmland analysis

Table 4.1 revealed that the hectare of land used by the study population ranges between 2 and 15. In 2-to-5-hectare range, UZ ranked highest with 19.7%, while MDZ ranked the least with 6.0%. In 6-to-10-hectare range, LZ ranked highest with 13.7%, while MDZ ranked the least with 5.7%. In 11 to 15-hectare range, MDZ ranked highest with 12.9%, while LZ ranked least with 8.6%.

Table 4.1: Number of Hectare of Land Used in Rivers Niger and Kaduna Catchments

Zones	2-5 hectare (%)	Frequency	6-10 hectare (%)	Frequency	10-15 hectare (%)	Frequency
UZ	19.7%	69	8.8%	31	12%	42
MDZ	6.0%	21	5.7%	20	12.9%	45
LZ	12.9%	45	13.4%	47	8.6%	30
Total	**38.6%**	**135**	**27.9%**	**98**	**33.5%**	**117**

Key: UZ = Upper zones. MDZ = Middle zone. LZ = Lower zones.

Source: Author's Work, 2018

The findings imply that most of the study population in all the zones were subsistence farmers since they used between 2-10 hectares of land. Rice, maize, beans, groundnut, millet, and melon are the most grown crops across the zones. Most of the farm lands have been in use for over 30 years. The farmers in the area also practised crop rotation involving maize, beans, sorghum, melon, and pepper. Interview findings from experienced district officers, extension agents and agrochemical vendors corroborated all the submissions from the farmers in the area. The similar farming system has been reported around riverine areas in developing countries like Kenya indicating majority of communities practicing subsistence farming as contained in a study by Githinji *et al.*

(2019). This finding is contrary to situations in the developed countries where studies have shown large scale farming activities along riverine areas as reported by Albizua *et al.* (2019).

4.1.2 Planting season

Table 4.2 indicated that a significant percentage of the study population affirmed that they plant, most of their crops in both seasons. Rainy season ranked highest with 78.2% and dry season ranked the least with 21.8%. The percentage of farmers involved in rainy season farming in the upper, middle, and lower zones was 78.2%. Those involved in dry season farming at UZ, MDZ and LZ were 21.8%.

Table 4.2: Planting Season Adopted by Farmers in Rivers Niger and Kaduna Catchments

Zones	Rainy season (%)	Frequency	Dry season (%)	Frequency
UZ	30.5%	107	4.6%	16
MDZ	18.6%	65	6%	21
LZ	29.1%	102	11.2%	39
Total	**78.2%**	**274**	**21.8%**	**76**

Key: UZ = Upper zones. MDZ = Middle zone. LZ = Lower zones.

Source: Author's Work, 2018

This implies that a significant percentage of the study population plant, most of their crops in the rainy season. Crops identified being cultivated in the seasons include vegetables, rice, and sugarcane. The farmers were asked as to why they prefer rainy season farming and the response was due to abundant rain and availability of farming accessories at lower cost. Those that adopt farming in both seasons gave the reasons that there are less pest infestations during the dry season except bird attack which can easily be contained. The study also identified that several farmers do plant some of their crop three times during rainy and dry seasons in a year. These crops include maize, rice sugarcane and vegetables. This study also revealed that almost all the farmers complained about the problems of pest infestations, weeds, and late unset and early stoppage of rain.

They further submitted that dependant on agrochemicals has been the viable method adopted by them to minimize the effects of the challenges. Interview findings also indicated that a significant percentage of study population plant their crops in the rainy season due to abundant moisture. They also acknowledged farming activities in both season and presence of pest infestations during all seasons in the area. The planting season and cropping pattern identified in this study is in line with the pattern in practice in northern Nigeria as reported by Ugbah *et al.* (2019).

4.1.3 Use of fertilizer and pesticide in farming

Table 4.3 indicated that there was high use of pesticides and fertilizers in farming activities in the study area. The LZ ranked highest with the use of pesticides and fertilizer (39.4%); UZ ranked second with 33.5% and MDZ ranked the least with 24.5%. The study population of 97.5% affirmed the use of pesticides and fertilizers and 2.7% disaffirmed the use of pesticides and fertilizers in their farms.

Table 4.3: Use of Fertilizers and Pesticides in Rivers Niger and Kaduna Catchments

Zones	Yes	% Respondent	No	% Respondent
UZ	117	33.5%	06	1.9%
MDZ	85	24.3%	01	0.3%
LZ	139	39.7%	02	0.6%
Total	**341**	**97.5%**	**9**	**2.7%**

Key: UZ = Upper zones. MDZ = Middle zone. LZ = Lower zones.

Source: Author's Work, 2018

Revelations from field interview indicated that most farmers across the zones have dropped the idea of traditional ways of crop improvements and presently adopted the use of synthetic fertilizers and pesticides. The reason behind this is that government subsidies, interventions and gifts from politicians have made it easier to acquire agrochemicals. The 2.7 percent of the study population who do not use agrochemicals was due to inadequate financial support to farming and inadequate legitimately borrowing facilities in the study area. This implies that majority of study population used fertilizer and pesticide for farming activities in the study area.

Other reasons are scarcity of animal manure as the people in the area are not much involved in animal farming, and faster results due to use of synthetic fertilizers. The study also revealed that pest infestations have been the reasons for pesticide use for farming in the study area. Stakeholders' interview showed intense use of agrochemicals by all farmers in the study area. Stakeholders' views for agrochemical use also corroborated revelations by the farmers in the survey area. Similar indicators in this study have been reported among smallholder farmers in developing countries as contained in a study of Njoroge *et al.* (2019). The finding is contrary to the situation in developed countries where organic farming is fully adopted by all farmers as reported in a study by Willer *et al.* (2019).

4.1.4 Characteristics of the fertilizers and pesticide used in the study area

Table 4.4 describes the types of fertilizers that were used across the zones in the study area for over 15 years. The type of fertilizers used in the study area includes: nitrogen, phosphorus, and potassium fertilizer (17:17:17); Nitrogen, phosphorus, and potassium (23:23:0); diaminomethanal; and calcium ammonium nitrate. The study revealed that majority of the farmers use nitrogen and phosphate-based fertilizer for cropping and dressing in the area.

Table 4.4: List of Compounds of Fertilizers Used in Rivers Niger and Kaduna Catchments

Fertilizer	Trade name	Active Ingredients	Use
Nitrogen, phosphorus, and Potassium	NPK 17:17:17	-	Growing
Nitrogen, phosphorus, and potassium	NPK 23:23:0	-	Growing
Nitrogen, phosphorus, and potassium	NPK 20:20:0	-	Growing
Diaminomethanal (46%)	UREA	$(NH_2)_2CO$	Dressing
Calcium ammonium nitrate (26%)	CAN	$Ca(NO_3)_2$	Dressing

Source: Author's Field Work, 2018

These identified compounds of fertilizers have been designated to present potential health hazards as revealed in a study by Solgi *et al.* (2018). Interview from experienced district officers, extension agents and agrochemical vendors in the study area affirmed the use of all agrochemicals revealed to be in use by the farmers.

4.1.5 List of Pesticide Compounds Used in Rivers Niger and Kaduna Catchments

Table 4.5 described the twenty-three (23) types of pesticide formulations that were used in the study area. They include organophosphorus, synthetic auxins, thiadiazines, organochlorine, synthetic pyrethroids, triazoles flumiclorac pentyl-lactofen, triazine-amide, pyrazoles and organophosphorus-pyrethroids (Table 4.5).

Table 4.5: List of Pesticide Compounds Used in Rivers Niger and Kaduna Catchments

S/N	Trade Name	Generic Name	Chemical Formulation	Use	WHO Class
1	Prime force (Dichlorvos)	Dichlorvos	Organophosphorus	Insecticide	II
2	2.4-D	2.4-Dichlorophenoxy-acetic acid	Synthetic Auxin herbicide	Selective Herbicide	2B
3	Bentazone	Bentazone	Thiadiazines	Contact Herbicide	II
4	Aldrec	Aldrin	Organochlorine	Insecticide	O
5	Cypermethrin	Cypermethrin	Pyrethroids	Insecticide	II
6	Fungicide hexaconazole	Hexaconazole	Triazoles	Fungicide	III
7	Tracer 480SC	Spinosyn	Organochlorine	Insecticide	II
8	Stellar Star	Flumiclorac Pentyl/Lactofen 3.1EC	Flumiclorac Pentyl-Lactofen	Herbicide	2B
9	Fungicide red force	Copper oxide	Fungicide	Fungicide	II
10	Fungicides mancozeb 80wp	Mancozeb	Fungicide	Fungicide	Ib
11	Luxan chlordane	Chlordane	Organochlorine	Insecticide	II
12	Ridomil Gold M2 68 WG	Metalaxyl-M	Fungicide	Fungicide	III
13	Thionex/Thiodan	Endosulfan	Organochlorine	Insecticide	II
14	Ethephon Ripener	Ethephon	Organophosphorus	Growth and Ripener	Ib
15	Gramaxone super	Gramaxone	Organochlorine	Contact Herbicide	Ib
16	Primextra Gold 660sc	Atrazine Metolachlor	Triazine and Amide	Selective Herbicide	II
17	Maxi force	Fipronil	Pyrazoles	Insecticide	II
18	Abamec	Abamectin	Pyrethroid	Insecticide	II
19	Paraquat (paraforce)	Paraquat	Organochlorine	Contact Herbicide	II
20	Dieldrin	Dieldrex 18EC	Organochlorine	Insecticide	O
21	Xtraforce	Atrazine Metolachlor	Triazine and Amide	Selective Herbicide	II
22	Pyrinex	Chlorpyrifos Bifenthrin	Organophosphorus-Pyrethroid	Insecticide	II
23	Apron star	Mefenoxam	Organochlorine	Fungicide-insecticide	II

*WHO hazards classification: Class Ia - extremely hazardous, Ib - highly hazardous, II - moderately hazardous, O - obsolete as pesticide, 2B - possible human carcinogen and III - slightly hazardous.

Source: Author's Field Work, 2018

Revelations by farmers, experienced district officers, extension agents and agrochemical vendors in the study area showed all these pesticides are currently in use to control weed, pests and diseases. Among them is organochlorine-based pesticide compound DDT which is banned in Nigeria (Appendix G). Other organochlorine pesticides identified in this study which include abamectin, chlordane, dieldrin, endosulfan and aldrin are either banned or restricted by authorities for local use and export in the European Union.

4.1.5.1 Percentage Distribution of Type of Pesticide Compounds Used in Rivers Niger and Kaduna Catchments

Figure 4.1 indicated that percentage of pesticide compounds used by farmers in the study area were organophosphorus (8.69%), synthetic auxins (4.35%), thiadiazines (4.35%), organochlorine (34.78%), synthetic pyrethroids (8.69%), triazoles (4.35%), flumiclorac pentyl-lactofen (13.04%), fungicides (8.69%), triazine-amide (4.35%), pyrazoles (4.35%) and organophosphorus-pyrethroids (4.35%).

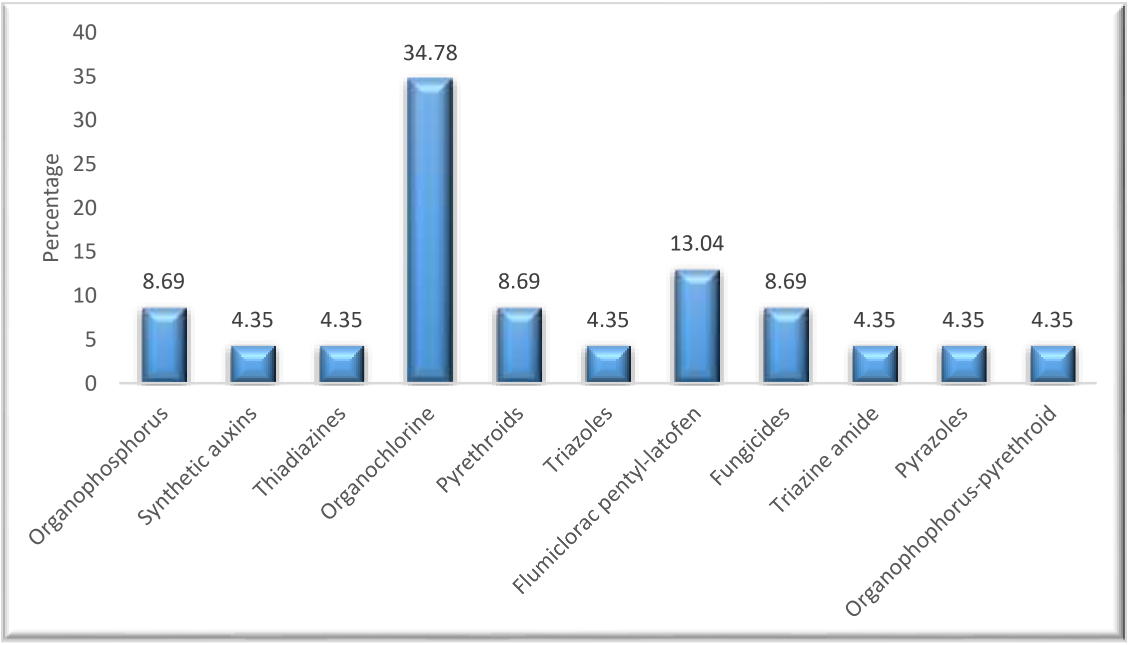


Figure 4.1: Percentage Distribution of Type of Pesticide Compounds Used in Rivers Niger and Kaduna Catchments
Source: Author's Work, 2018

Similar studies in developing countries reveal the heavy use of pesticides in farming with much use of organochlorine pesticides as observed in several studies (Buah-Kwofie *et al*. 2019; Adeshina *et al.* 2019; Unyimadu *et al.* 2019). This is against the current practices in the developed world where organic farming and integrated pest management system are fully adopted by farmers as reported by Willer *et al.* (2019).

4.1.6 Fertilizer application per hectare

Table 4.6 revealed that fertilizer application per hectare ranges from 50 kg to 170 kg across the zones. 121–170 kg fertilizer application ranked the highest in LZ and 101–120 kg ranked the least in MDZ.

Table 4.6: Fertilizers Application per Hectare in Rivers Niger and Kaduna Catchments

Zones	50-100kg (%)	Frequency	101-120kg (%)	Frequency	121-170kg (%)	Frequency
UZ	13.4%	47	12.9%	45	8.9%	31
MDZ	6.0%	21	5.7%	20	12.9%	45
LZ	11.7%	41	8.8%	31	19.7%	69
Total	**31.1%**	**109**	**27.4%**	**96**	**41.5%**	**145**

Key: UZ = Upper zones. MDZ = Middle zone. LZ = Lower zones.

Source: Author's Work, 2018

This implies that the study population applied high rate of fertilizer during farming activities since a significant percentage (41.5%) applied 121-120 kg of fertilizers which improved crop yield but in turn lead to water quality degradation. Field interview also revealed that all the farmers applied fertilizers to their crops manually by direct application to crop or hand spray. Fertilizers were mostly applied during land preparation and the crops growing. The farmers, mostly get their fertilizers from agrochemical vendors, government subsidies, intervention, and gifts from politicians. Farmers' interview in the area revealed that they have never been trained on agrochemical use but usually receive some guides from the local vendors. A significant percentage of the farmers in the study area revealed that the have been using fertilizers for the past fifteen (15) years. During interviews and field observations the study observed that most of the farmers do not care about sustainable use of fertilizers in their farming as it was evident that more quantities of fertilizers were been used above recommended rate. The implication of this finding is that it could have serious negative effect on environment, health risk and subsequent impacts of economic development in the study area. Similar situation of excessive and unsuitable use of fertilizers has been reported in most developing countries including Nigeria as indicated in related studies such as Igué *et al.* (2018), and Hassan and Hussain, (2018).

4.1.7 Pesticides application per hectare

Table 4.7 indicated that pesticide application per hectare ranges from 5 to 10 litres in the study area. 10 litres and above of pesticide application ranked the highest in LZ with 19.7% of the study population and 5–7 litres ranked the least in MDZ with 5.7% of the study population.

Table 4.7: Pesticide Application per Hectare in Rivers Niger and Kaduna Catchments

Zones	5-7litres (%)	Frequency	8-9litres (%)	Frequency	10litres and above (%)	Frequency
UZ	11.7%	41	12.9%	45	10.6%	37
MDZ	5.4%	19	5.7%	20	13.4%	47
LZ	11.7%	41	8.8%	31	19.7%	69
Total	**28.8%**	**102**	**27.4%**	**96**	**43.7%**	**153**

Key: UZ = Upper zones. MDZ = Middle zone. LZ = Lower zones.

Source: Author's Work, 2018

This implies that the study population applied high rate of pesticide during farming activities for a significant percentage (43.7%) applied 10 litre and above obviously improved crop protection and yield but in turn lead to water quality degradation. The farmers in the area revealed that they get the pesticide used in farming from local vendors, government intervention and gifts from politicians. These pesticides are applied by all the farmers across the zones using knapsack sprayer. There was no consideration of wind direction, timing considerations and proximity to vulnerable areas by farmers during application.

The study also discovered that the farmers do not abide by the inscribed instructions or directives on the agrochemical containers and uses their own discretion for measurement and mixing, by so doing, higher rate of pesticides is being applied on the farmlands beyond recommended rates. Most of the farmers revealed using pesticides on their farming since past ten years but much in last four to five years. Finding also shows that only 35% of the study population were aware of banned and restricted pesticides in Nigeria but could not tell the categories of those pesticides involved. The implication of these indicators will be counterproductive in achieving healthy socioeconomic wellbeing of communities in the study area. Indicators identified in this study are like findings in existing studies in developing countries including Nigeria as revealed by Bertrand (2019), Machekano *et al.* (2019), and Adeshina *et al.* (2019).

4.1.8 Disposal Mechanism of Empty Pesticide Containers/Bottles

Figure 4.2 indicated that, empty pesticide containers were disposed into the pits, throw in the latrines, discard in the bushes or farm land, destroy, burn, or bury and keep re-use. Discard in the farmland ranked highest with 58% of the study population, discard in the nearby bushes ranked second with 20%, disposing into the disposal pits ranked third with 14.3% and dispose in latrine ranked the list with 7.7% (Figure 4.2).

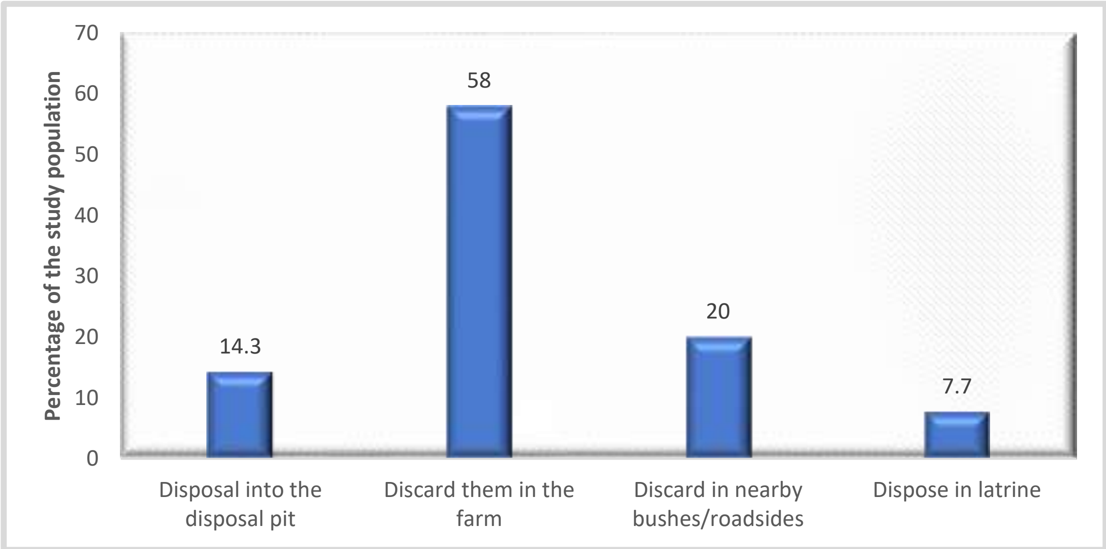


Figure 4.2: Disposal Mechanism of Empty Pesticide Containers/Bottles
Source: Author's Work, 2018

This means that most of the population surveyed disposed of their empty pesticide bottles on their farm lands and this will lead to increase of plastic wastes in the survey area as well as environmental pollution. The findings from further appraisals revealed that most of the farmers in the area washed the application tools after spraying in the rivers, streams, and ponds. Virtually all the farmers have little or no measures towards water conservation and protection in the study area. These attitudes discovered could lead to water quality degradation, biodiversity disruption and subsequent negative effect on economic development in the survey area.

A similar situation has been reported by Sosan and Akingbohungbe (2009). Also, the leftover spray mixture was often emptied into streams or near a near water bodies in the study location. This finding is in line with discovery in several studies in Nigeria such as Adewoye *et al.* (2019), and Anifowose and Oyebode (2019). Several studies have shown that agrochemicals waste is well managed in developed countries where liquid waste is sustainably contained and the solid waste are well treated for recycling purposes as reported by Picuno *et al.* (2019).

In summary, this objective has revealed that most of the student population in all the zones were subsistence farmers since they used between 2–10 hectares of land in the study area. The similar farming system has been reported around riverine areas in developing countries like Kenya indicating majority of communities practicing subsistence farming as contained in a study by Githinji *et al.* (2019). This finding is contrary to situations in the developed countries where studies have shown large scale farming activities along riverine areas as reported by Albizua *et al.* (2019). Further finding in this study shows that majority of study population depends on synthetic fertilizers and pesticide for farming in the study area.

Revelations also from field interviews indicated that most of the farmers across the zones have dropped the idea of traditional ways of crop improvements and presently adopted the use of synthetic fertilizers and pesticide. They gave the reasons that government subsidies, interventions and gifts from politicians have made it easier to acquire agrochemicals. Other reasons are scarcity in getting animal manure as the people in the area are not much involved in animal farming and faster results due to usage of synthetic fertilizers. Stakeholders' views for agrochemical use also corroborated revelations by the farmers in the survey area. Similar indicators in this finding have been reported among smallholder farmers in developing countries as contained in a study of Njoroge *et al.* (2019). The finding is contrary to the situation in developed countries where organic farming is fully adopted by all farmers as reported in a study by Willer *et al.*, (2019).

The findings further revealed most of the farmers use nitrogen and phosphate-based fertilizers for cropping and dressing in the area. These identified compounds of fertilizers have been designated to present potential health hazards as revealed in a study by Solgi *et al.* (2018). Interview from experienced district officers, extension agents and agrochemical vendors in the study area affirm the use of all agrochemicals revealed to be in use by farmers in the study area. Pesticide formulations that are currently in use across the zones in the study area include organophosphorus, synthetic auxins, thiadiazines, organochlorine, synthetic pyrethroids, triazoles flumiclorac pentyl-lactofen, triazine-amide, pyrazoles and organophosphorus-pyrethroids. Among them is pesticides banned in Nigeria such as organochlorine insecticide DDT. The implication of this findings could have serious negative effect on environment, health risk and subsequent impacts on economic development in the study area. Similar situation of excessive and unsuitable use of agrochemicals have been reported many developing countries including Nigeria as indicated in several studies such as Igué *et al*. (2018), and Hassan and Hussain (2018).

The study further revealed that most of the population disposes their used packaging material of pesticides in their farm lands, spraying cans and use bottles washed directly into the rivers, streams, and pounds in the study area. Virtually all the farmers have little or no measures towards water conservation and protection in the study area.

These attitudes discovered could lead to water quality degradation, biodiversity disruption and subsequent negative impact on economic development in the survey area. Finally, the finding present the basis for analytical investigations of water, sediment, and biota to determine the possibility of the presence or occurrence of agrochemical compounds identified earlier in these environmental media, and that lead us to objectives II and III in this study.

4.2 Determination of the Spatial Concentrations of Physicochemical Properties in Water and Sediment Samples in the Study Area

4.2.1 Spatial distribution of physico-chemical properties of rainy and dry season in water and sediment samples

4.2.1.1 Spatial distribution of pH in water samples during rainy Season

The results of hydrogen potential (pH) in water samples (W1 to W8) during the rainy season are spatially represented in Figure 4.3. The study shows that pH values were distributed within the range of 5.2 and 7.4 across the study area (Appendix C).

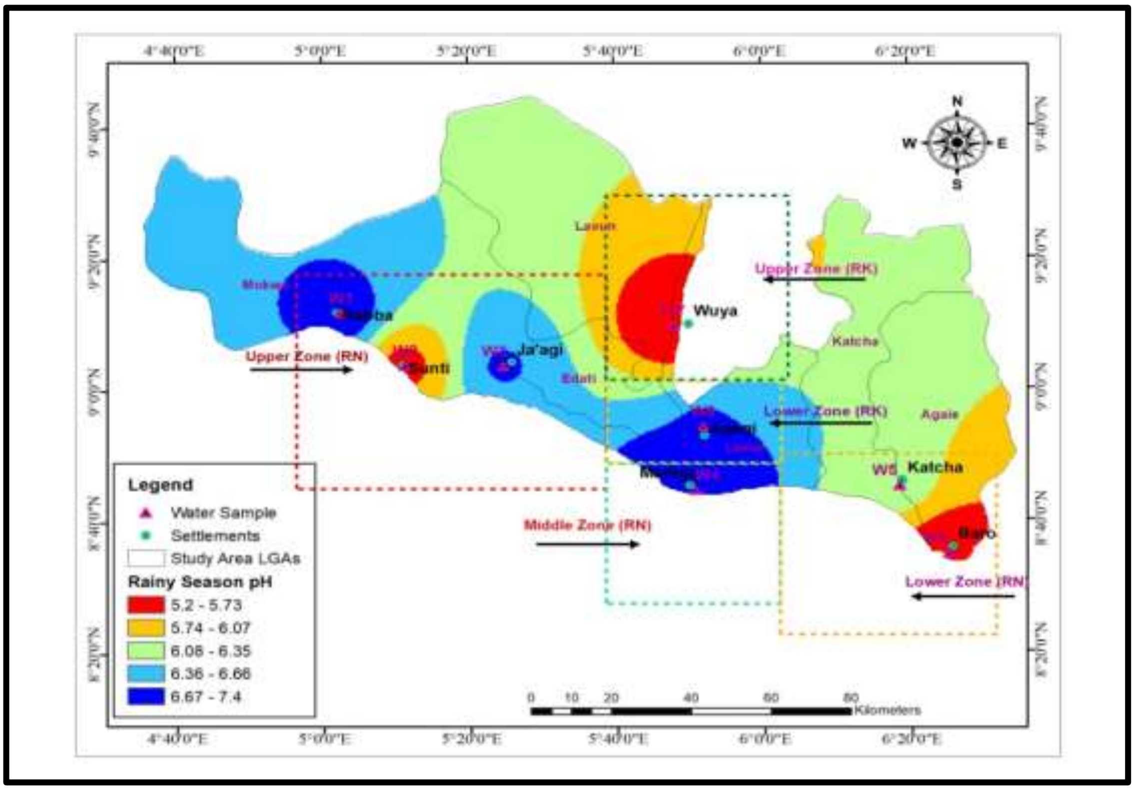


Figure 4.3: Interpolated Distance Weighted Map of pH in Water Samples during Rainy Season

Source: Author's Work, 2019

4.2.1.2 Spatial distribution of pH in water samples during dry season

The results of hydrogen potential (pH) in water samples (W1 to W8) during the dry season are spatially represented in Figure 4.4. The study shows that pH values were distributed within the range of 5.4 and 6.9 across the study area (Appendix C).

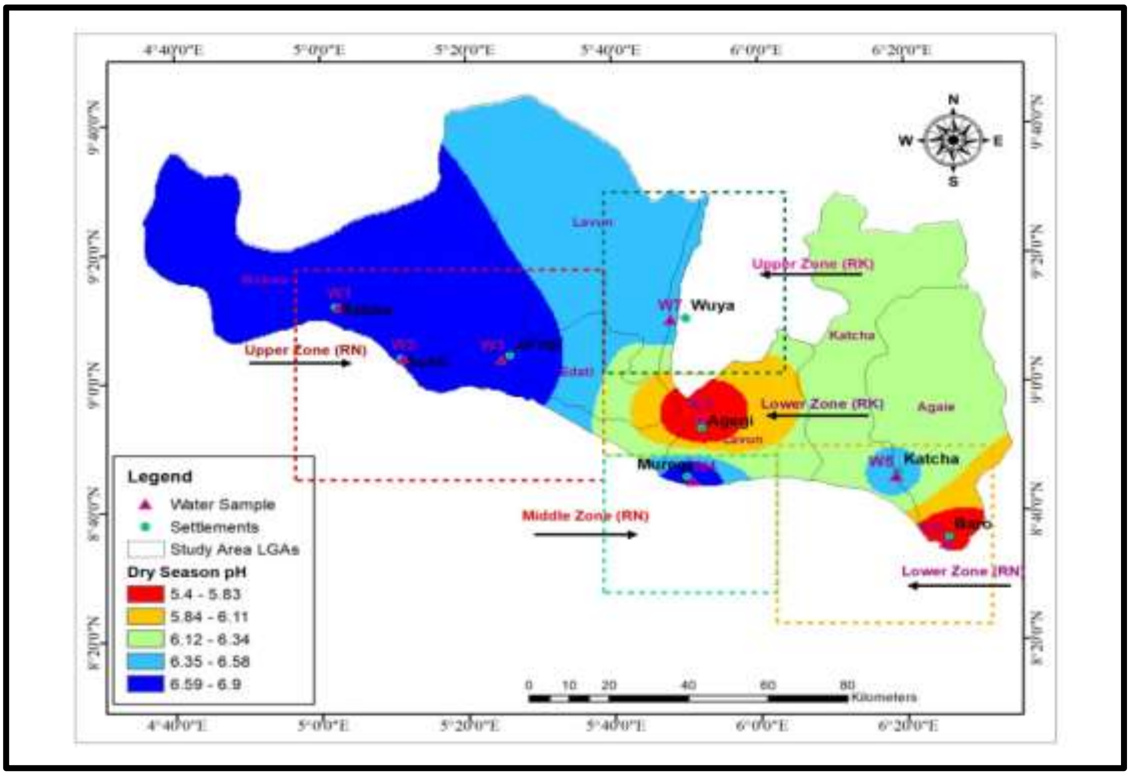


Figure 4.4: Interpolated Distance Weighted Map of pH in Water Samples during Dry Season
Source: Author's Work, 2019

As indicated in Figures 4.3 and 4.4, the findings imply that all (except W4 rainy season) pH values in both seasons were acidic. pH at these levels can increase plant nutrient concentrations and pesticide residues in the rivers and as such higher plant nutrient and pesticide residues are expected. The rate of chemical degradation depends on pH. Highest pH values during the rainy season were at upper, middle zones of River Niger catchments and lower zone of River Niger catchments. Highest pH values in the dry season were at upper, middle zone of River Niger catchments. The pH values in this study at W2 in dry season, W6 in both seasons, W7 in rainy season and W8 in dry season disagree with a similar study in Northern Nigeria (Onyenechere *et al.*, 2021). The reason for the disagreement may be because the study was conducted within cities which is contrary to the present study. These pH values are also below Nigeria National Standards permissible limit for surface water and biota protection which range between 6.5 and 9 (National Environmental Standards and Regulations Enforcement Agency (NESREA), 2010) (Appendix H). The acidic pH values identified in this study can increase the concentrations of agrochemicals and affect water quality in the study area.

4.2.1.3 Spatial distribution of salinity in water samples during rainy season

The results of salinity in water samples (W1 to W8) during the rainy season are spatially represented in Figure 4.5. The study showed that salinity values were distributed within the range of 41 PSU and 81 PSU across the study area (Appendix C).

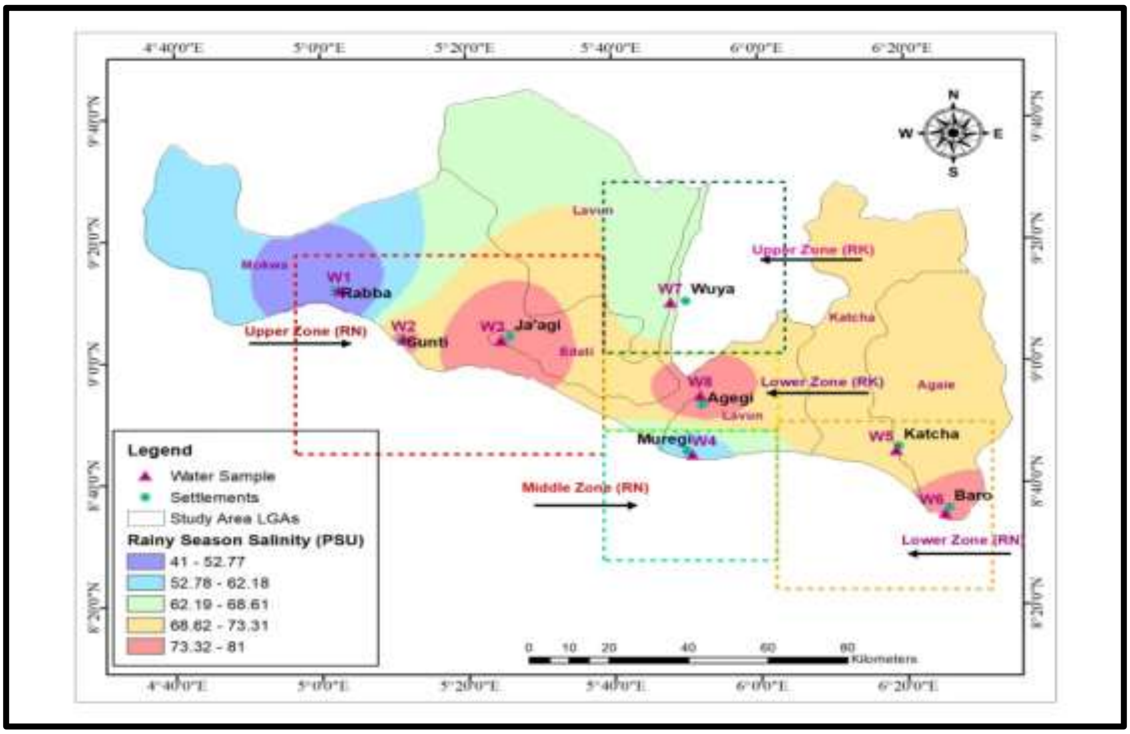


Figure 4.5: Interpolated Distance Weighted Map of Salinity in Water Samples during Rainy Season

Source: Author's Work, 2019

4.2.1.4 Spatial distribution of salinity in water samples during dry season

The results of salinity in water samples (W1 to W8) during the dry season are spatially represented in Figure 4.6. The study showed that salinity values were distributed within the range of 28 PSU and 64 PSU across the study area (Appendix C).

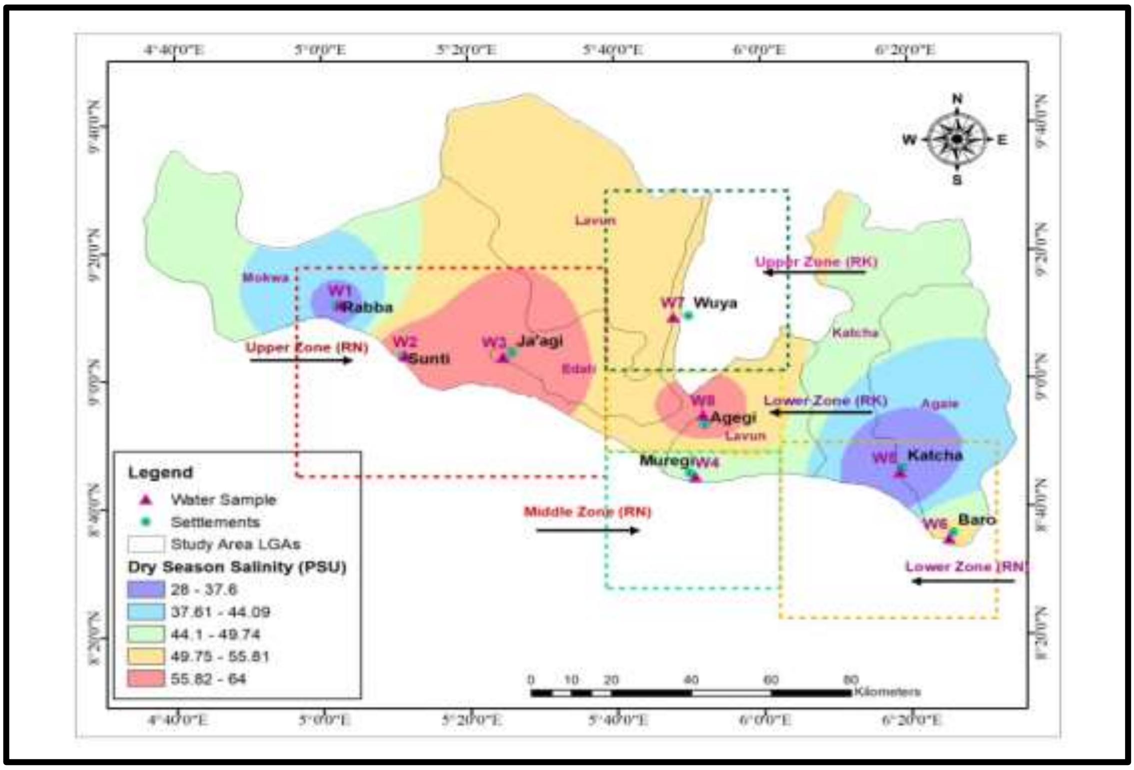


Figure 4.6: Interpolated Distance Weighted Map of Salinity in Water Samples during Dry Season

Source: Author's Work, 2019

As indicated in Figures 4.5 and 4.6, the value of salinity across the study area shows significance higher value in rainy season than the dry season, which may be ascribed to high use of agrochemicals in the rainy season. Highest salinity values were recorded at upper, lower zones of River Niger catchments and lower River Kaduna catchments during rainy season, while the highest values in dry season were recorded at lower, lower zones of Rivers Niger and Kaduna catchments. The salinity values identified in this study agree with a similar study in Sokoto, Nigeria (Uke and Haliru, 2021). All values are within the

Nigeria regulatory limit for surface water and biota protection (NESREA, 2010) (Appendix H).

4.2.1.5 Spatial distribution of temperature in water samples during rainy season

The results of temperature in water samples (W1 to W8) during the rainy season are spatially represented in Figure 4.7. The study shows that temperature values were distributed within the range of 22.1 °C and 23.3 °C across the study area (Appendix C).

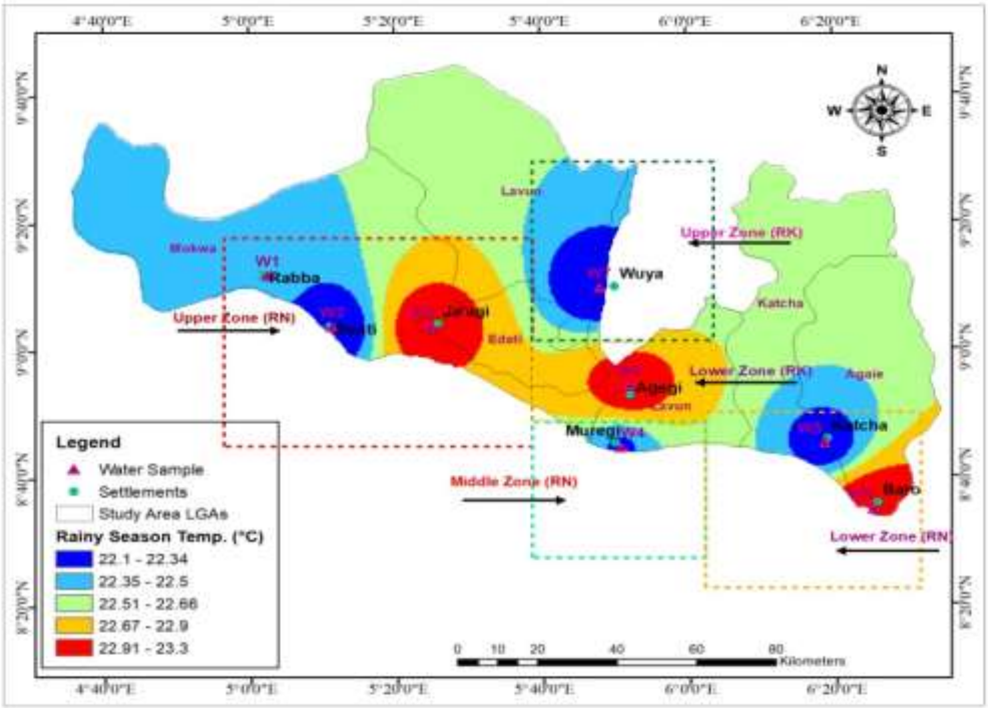


Figure 4.7: Interpolated Distance Weighted Map of Temperature in Water Samples during Rainy Season

Source: Author's Work, 2019

4.2.1.6 Spatial distribution of temperature in water samples during dry Season

The results of temperature in water samples (W1 to W8) during the dry season are spatially represented in Figure 4.8. The study shows that temperature values were distributed within the range of 25.12 °C and 28.1 °C across the study area (Appendix C).

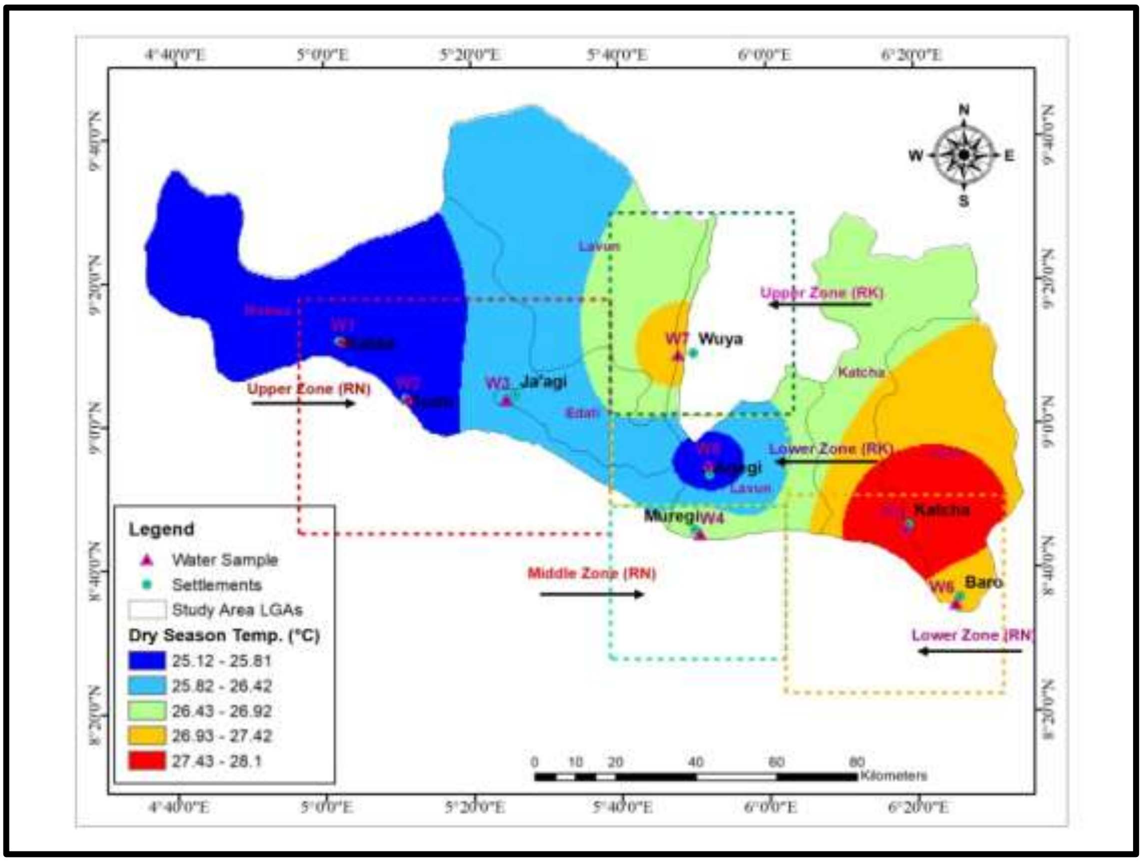


Figure 4.8: Interpolated Distance Weighted Map of Temperature in Water Samples during Dry Season

Source: Author's Work, 2019

As indicated in Figures 4.7 and 4.8, the findings imply that values of temperature recorded in rainy season were significantly lower in dry season. The degree of chemical degradation is majorly influenced by the physicochemical properties of water like temperature. Therefore, in higher temperature, higher pesticide residues and plant nutrients are expected. Highest temperature during the rainy season were recorded at upper, lower zones of River Niger catchments and lower zone River Kaduna catchments, while highest temperature was recorded at the lower zone River Kaduna catchments during dry season. The temperature range identified in this study agrees with a similar study in Keffi, central Nigeria (Reuben *et al.,* 2018). All the values are within Nigeria regulatory limits for surface water and biota range of 40 °C (Appendix H).

4.2.1.7 Spatial distribution of dissolved oxygen concentrations in water samples during rainy season

The results of dissolved oxygen (DO) in water samples (W1 to W8) during the rainy season are spatially represented in Figure 4.9. The study showed that dissolved oxygen values were distributed within the range of 6.9 mg/l and 8.6 mg/l (Appendix C).

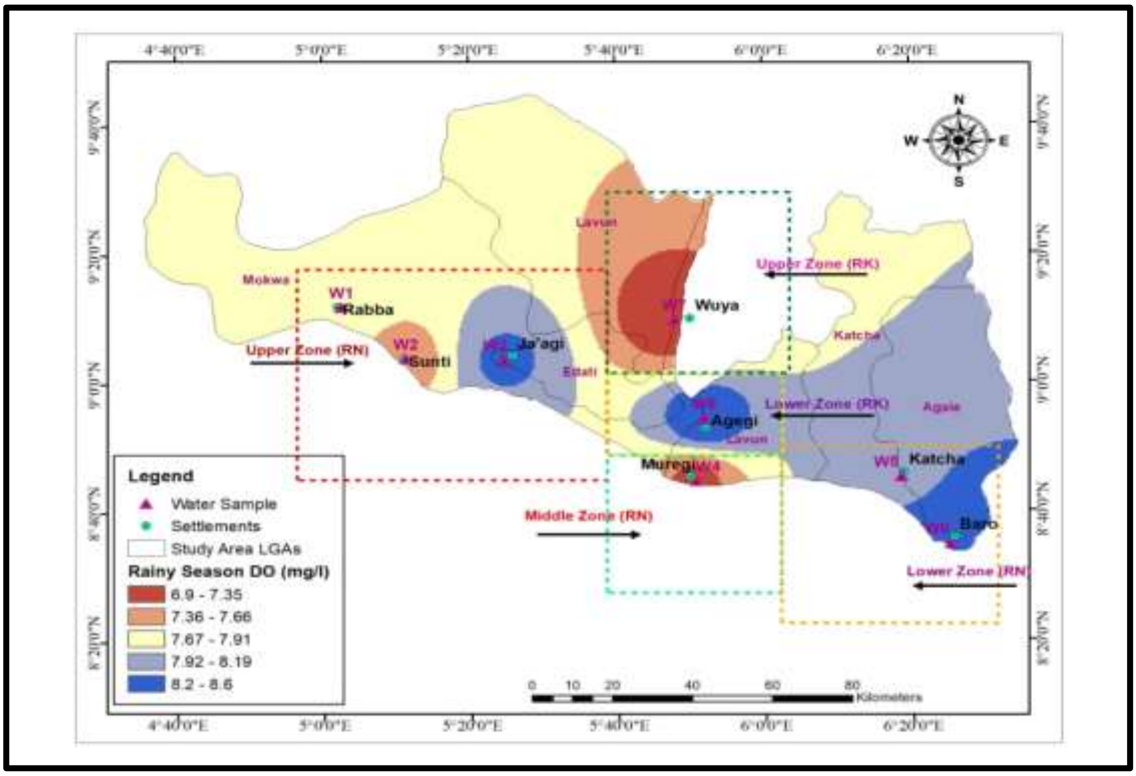


Figure 4.9: Interpolated Distance Weighted Map of Dissolved Oxygen in Water Samples during Rainy Season
Source: Author's Work, 2019

4.2.1.8 Spatial distribution of dissolved oxygen concentrations in water samples during dry season

The results of dissolved oxygen (DO) in water samples (W1 to W8) during the dry season are spatially represented in Figure 4.10. The study showed that dissolved oxygen values were distributed within the range of 5.3 mg/l and 6.6 mg/l (Appendix C).

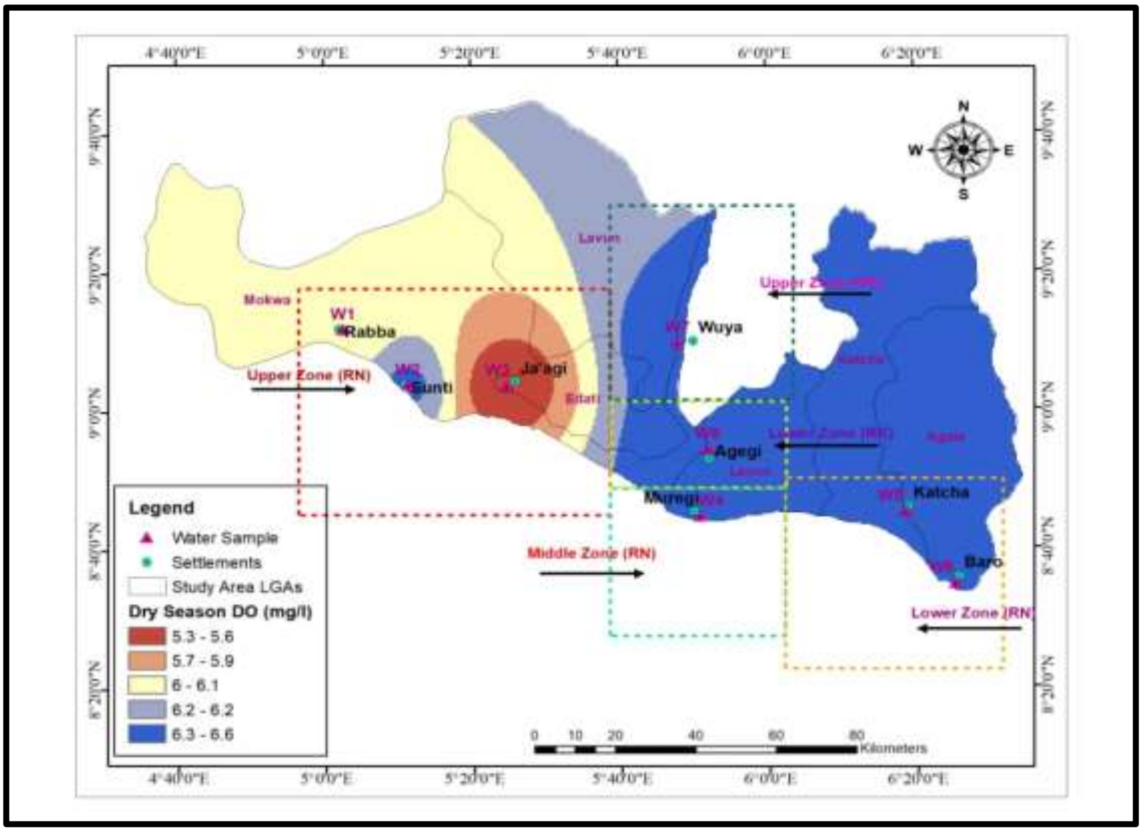


Figure 4.10: Interpolated Distance Weighted Map of Dissolved Oxygen in Water Samples during Dry Season
Source: Author's Work, 2019

As indicated in Figures 4.9 and 4.10, the finding implies that a decrease in the concentrations of DO across the sample points from rainy to dry season can be attributed to absence of precipitation, decaying organic matter, pesticides, and plant mineral accumulation. The highest concentrations of devolve oxygen were recorded at upper, lower zones of River Kaduna catchments and lower zone River Kaduna catchments, while highest concentrations in dry season were recorded at upper, middle, lower zones of River Niger catchments and upper, lower zones of River Kaduna catchments. Values of DO in this study agree with similar study in Keffi, central Nigeria (Reuben *et al.*, 2018). The DO concentrations are largely above Nigeria regulatory limit of 0.25 ppm (Appendix H) and the values are indication of excessive oxygen that can be harmful to survival of aquatic life and affect water quality.

4.2.1.9 Spatial distribution of electrical conductivity in water samples during rainy season

The results of electrical conductivity (EC) in water samples (W1 to W8) during the rainy season are spatially represented in Figure 4.11. The study showed that electrical conductivity (EC) values were distributed within the range of 16 μs/cm and 43μs/cm (Appendix C).

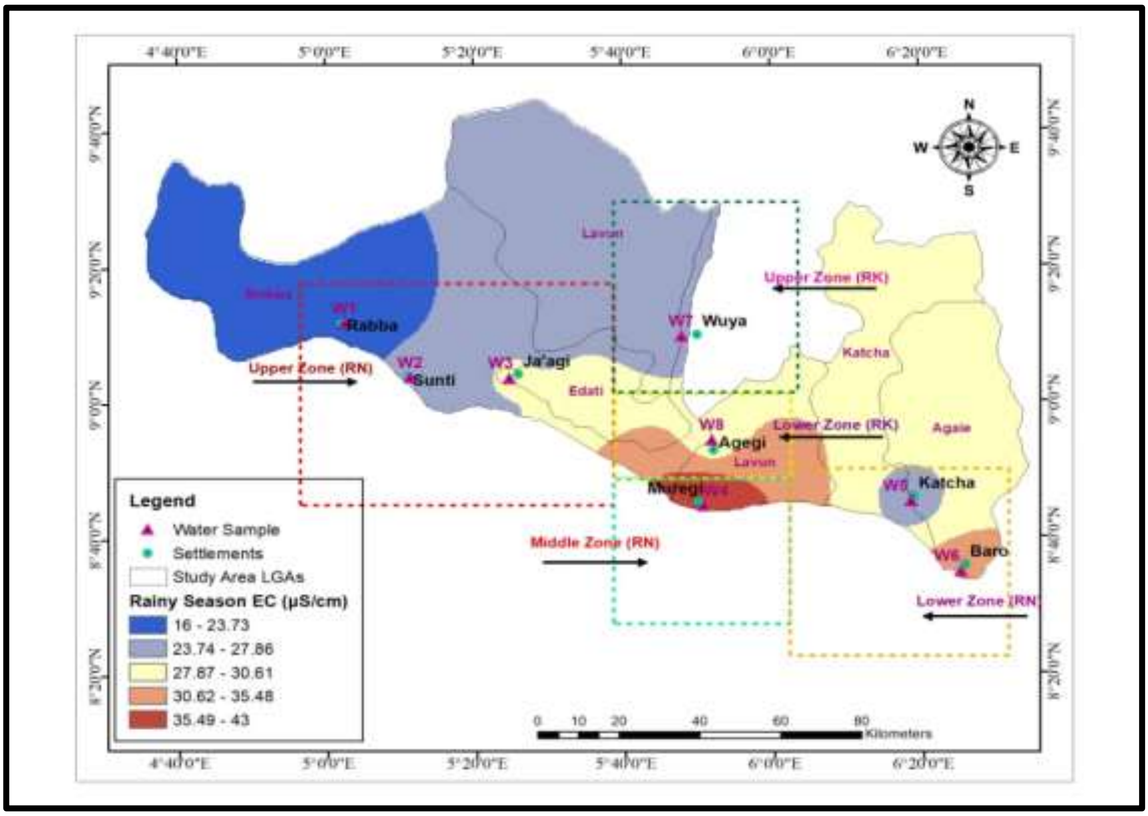


Figure 4.11: Interpolated Distance Weighted Map of Electrical Conductivity in Water Samples during Rainy Season
Source: Author's Work, 2019

4.2.1.10 Spatial distribution of electrical conductivity in water samples during dry season

The results of electrical conductivity (EC) in water samples (W1 to W8) of the dry season are spatially represented in Figure 4.12. The study showed that electrical conductivity (EC) values were distributed within the range of 10μs/cm and 30μs/cm (Appendix C).

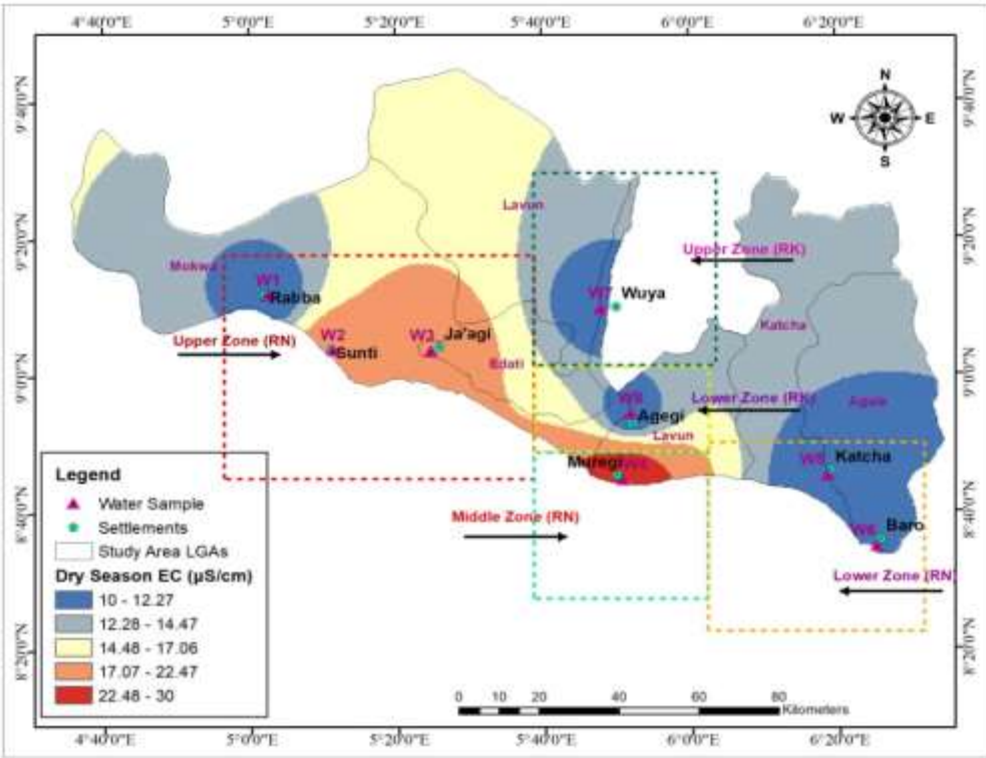


Figure 4.12: Interpolated Distance Weighted Map of Electrical Conductivity in Water Samples during Dry Season

Source: Author's Work, 2019

As indicated in Figures 4.11 and 4.12, the findings imply that EC values at all the sample points declined from rainy season to dry season. The highest value in the rainy season can be attributed clearly to run off from agriculture lands in the area where high application of agrochemicals was. Values of the EC in this study are low when compared with a similar study in Keffi, central Nigeria (Reuben *et al.*, 2018).

4.2.1.11 Spatial distribution of total dissolved solid concentrations in water samples during rainy season

The results of total dissolved solid (TDS) in water samples (W1 to W8) during the rainy season are spatially represented in Figure 4.13. The study shows that total dissolved solid (TDS) values were distributed within the range of 17.8 ppm and 23.6 ppm (Appendix C).

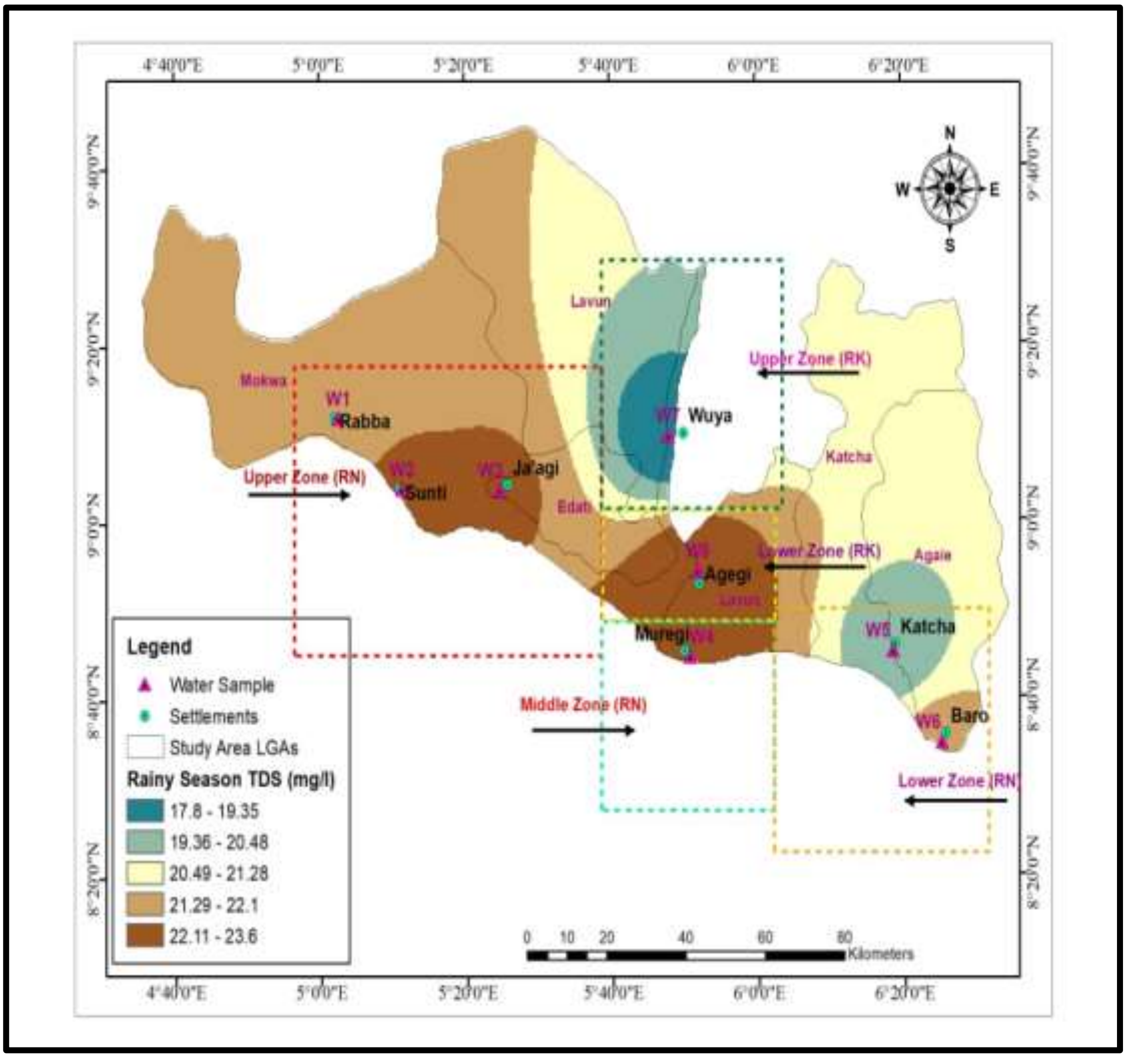


Figure 4.13: Interpolated Distance Weighted Map of Total Dissolved Solid in Water Samples during Rainy Season
Source: Author's Work, 2019

4.2.1 12 Spatial distribution of total dissolved solid concentrations in water samples during dry season

The results of total dissolved solid (TDS) in water samples (W1 to W8) during the dry season are spatially represented in Figure 4.14. The study shows that total dissolved solid (TDS) values were distributed within the range of 6.7 ppm and 20.1 ppm (Appendix C).

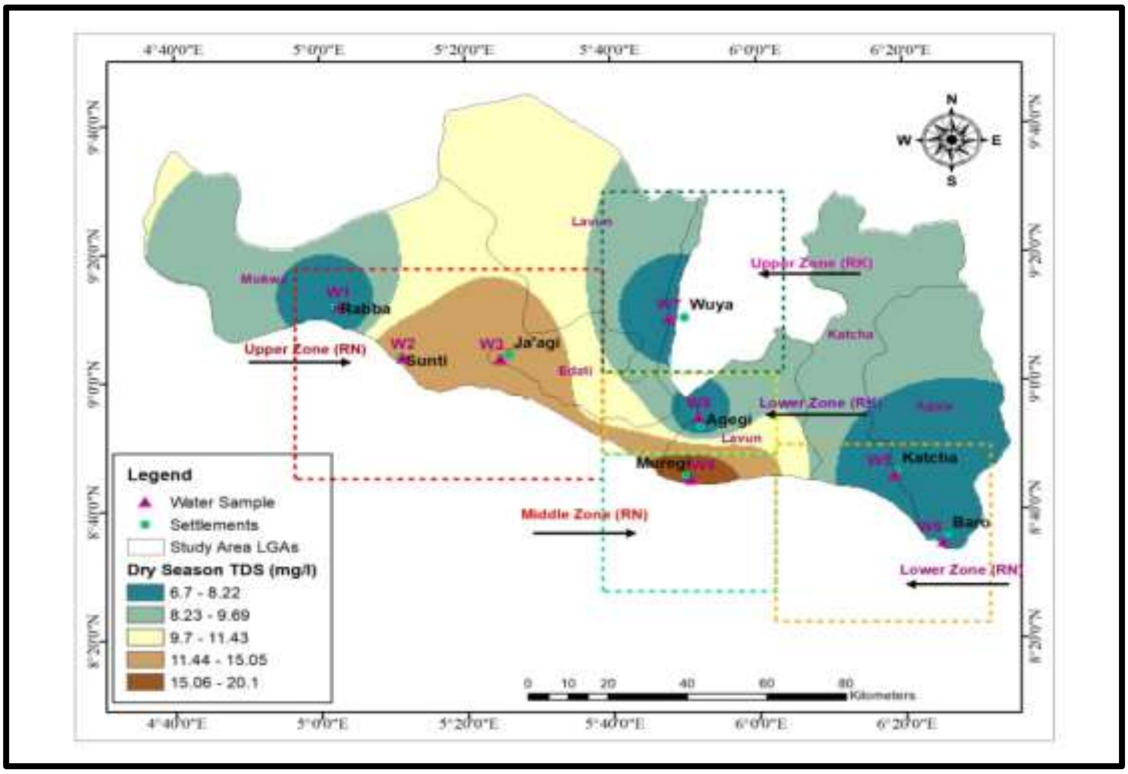


Figure 4.14: Interpolated Distance Weighted Map of Total Dissolved Solid in Water Samples during Dry Season
Source: Author's Work, 2019

As indicated in Figures 4.13 and 4.14, TDS concentrations were higher in the rain season than dry season across all the sample points. The higher TDS concentrations in the rainy season samples may be attributed to high run off from agriculture area where herbicides are used intensely by farmers, increase in salt concentrations, organic and inorganic matter resulting also from intense use of herbicide as revealed by farmers and stakeholders' interview in this study. The highest concentrations of TDS were recorded in upper, middle zones River Niger catchments and lower zone River Kaduna catchments during rainy season, while highest TDS concentrations were recorded during the dry season at the middle zone River Niger catchments. Values of TDS in this study are low when compared with a similar study in Keffi, central Nigeria (Reuben *et al.,* 2018). All TDS concentrations obtained are above the Nigeria regulatory limit (Appendix H). High concentrations of TDS obtained are an indication of polluted water, which can lead to reduction in dissolved oxygen and can increase the concentrations of plant minerals and pesticide residues in waters and its resources thereby eliciting serious negative socio-economic effects on the livelihoods of communities in the study area.

4.2.1.13 Spatial distribution of turbidity in water samples during rainy season

The results of turbidity in water samples (W1 to W8) during the rainy season are spatially represented in Figure 4.15. The study showed that turbidity values were distributed within the range of 47 NTU and 96 NTU (Appendix C).

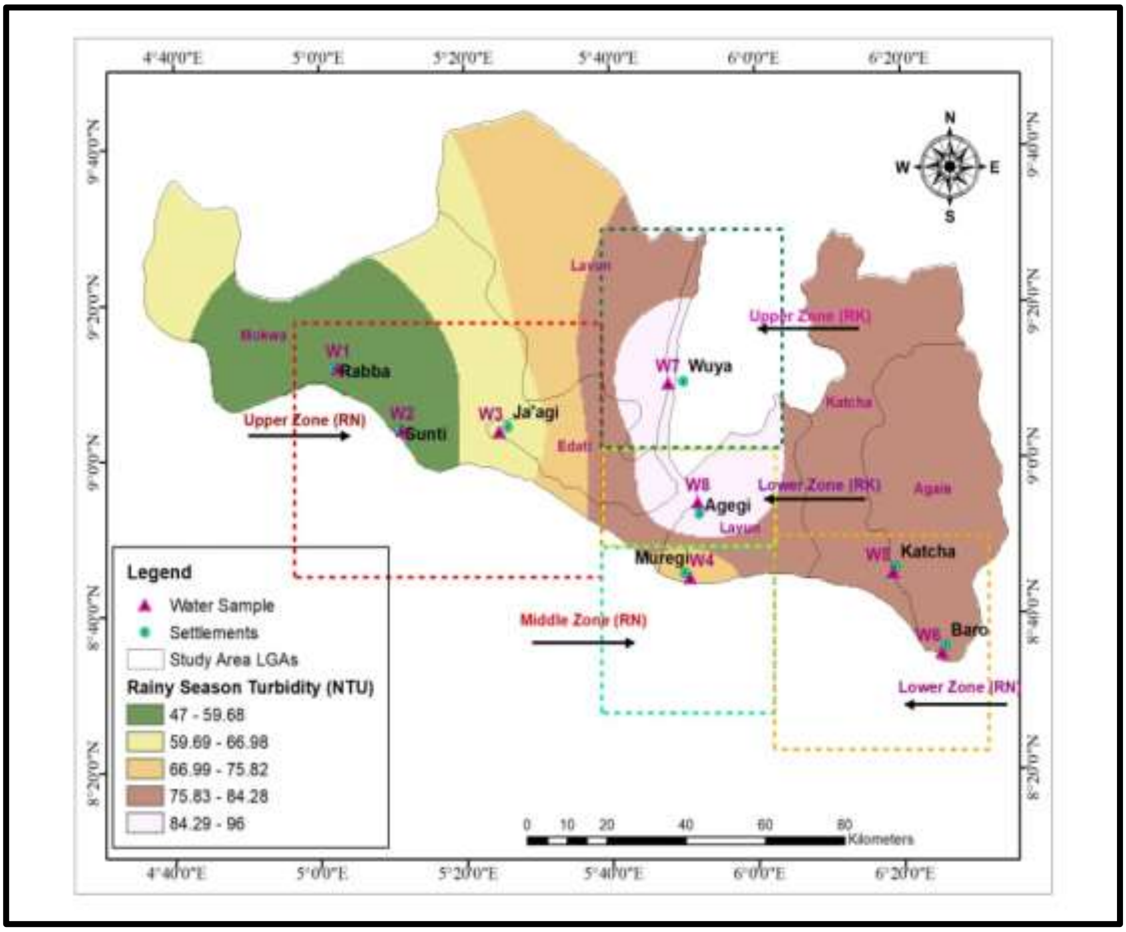


Figure 4.15: Interpolated Distance Weighted Map of Turbidity in Water Samples during Rainy Season

Source: Author's Work, 2019

4.2.1.14 Spatial distribution of turbidity in water samples during dry season

The results of turbidity in water samples (W1 to W8) of the dry season are spatially represented in Figure 4.16. The study shows that turbidity values were distributed within the range of 12.71 NTU and 88 NTU (Appendix C).

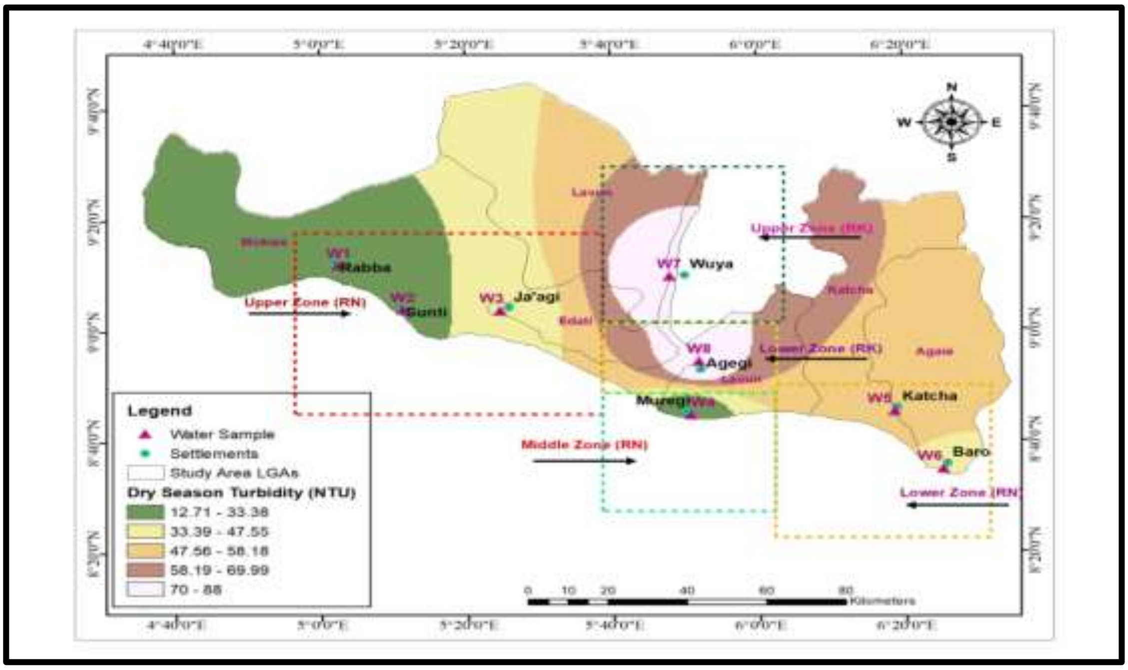


Figure 4.16: Interpolated Distance Weighted Map of Turbidity in Water Samples during Dry Season
Source: Author's Work, 2019

As indicated in Figures 4.15 and 4.16, the findings imply that the values of turbidity at rain season were generally higher than the corresponding dry season. The highest values of turbidity were recorded at upper, lower zones of River Kaduna catchments, while in the dry season, the highest concentrations were also recorded at upper, lower zones of River Kaduna catchments. The values of turbidity in the rainy season are largely above the Nigeria regulatory limit of 50 NTU (Appendix H) which can be attributed to high agriculture runoff and decay organic matter resulting from intense herbicides use during the season as revealed in this study. Values of turbidity in this study are largely high when compared with a similar study in Keffi, central Nigeria (Reuben *et al.,* 2018). Values of turbidity in 62.5 % of the sample points in this study are above Nigeria regulatory limit and it is a clear indication of polluted water, which can lead to reduction in dissolved oxygen and can increase the concentrations of plant minerals and pesticide residues in waters and it resources thereby eliciting serious negative socio-economic effects on livelihoods of communities in the study area.

4.2.1.15 Spatial distribution of sulphate concentrations in water samples during rainy season

The results of sulphate in water samples (W1 to W8) of the rainy season are spatially represented in Figure 4.17. The study shows that sulphate values were distributed within the range of 0.74 ppm and 1.95 ppm (Appendix D).

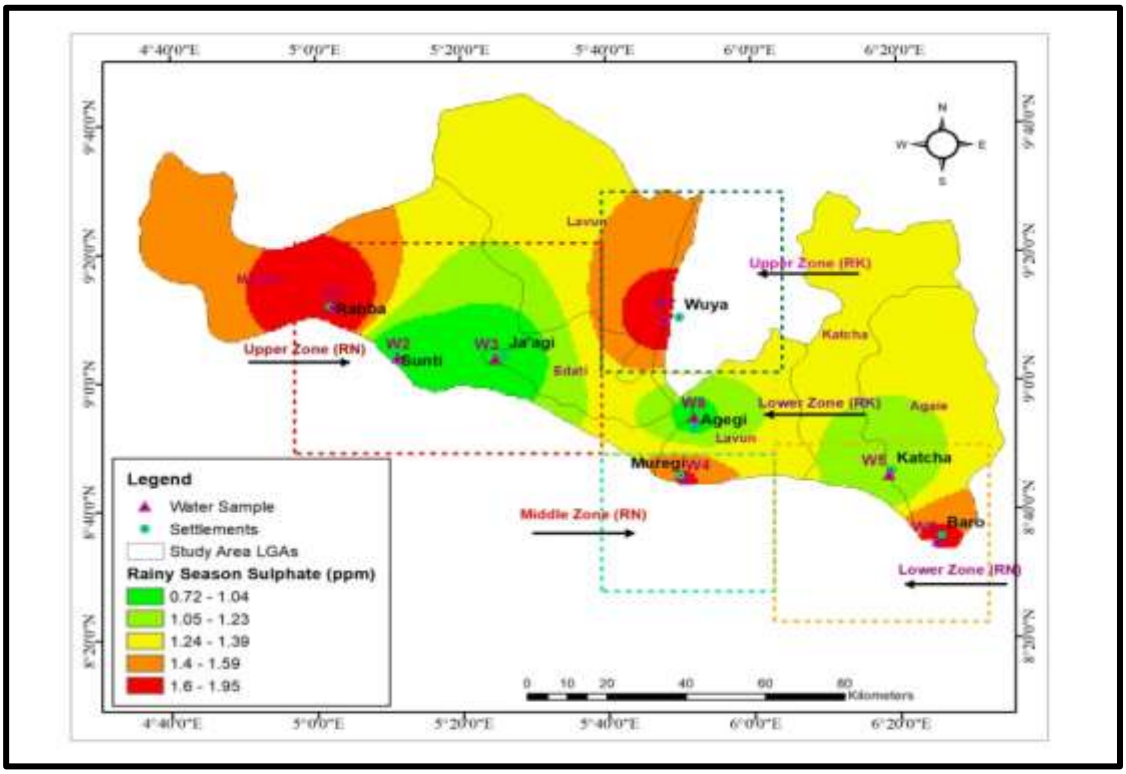


Figure 4.17: Interpolated Distance Weighted Map of Sulphate in Water Samples during Rainy Season

Source: Author's Work, 2019

4.2.1.16 Spatial distribution of sulphate concentrations in water samples during dry season

The results of sulphate in water samples (W1 to W8) of the dry season are spatially represented in Figure 4.18. The study shows that sulphate values were distributed within the range of 0.69 ppm and 2.15 ppm (Appendix D).

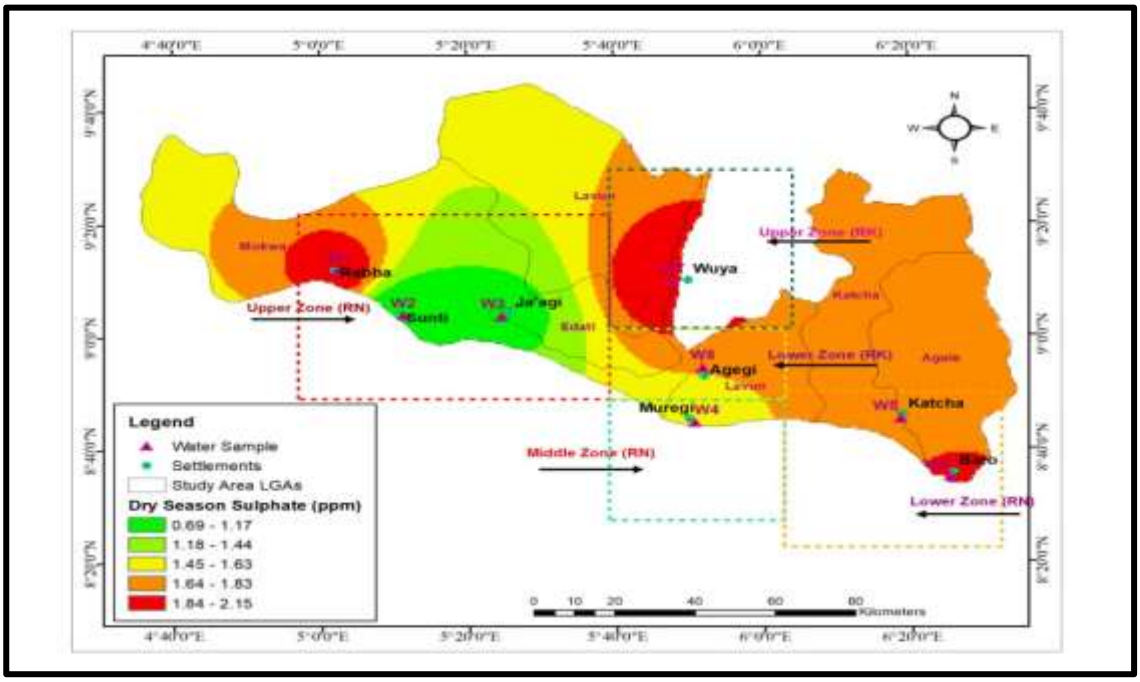


Figure 4.18: Interpolated Distance Weighted Map of Sulphate in Water Samples during Dry Season
Source: Author's Work, 2019

As indicated in Figures 4.17 and 4.18, the findings imply that concentrations of sulphate in all rain season samples were largely less than that of the dry season. It shows an increase of sulphate concentrations across the study zones from rainy season to dry season. The highest concentrations of sulphate were recorded at upper, middle, lower zones of River Niger catchments, and lower zones River Kaduna catchments during rainy season, while highest concentrations in dry season were recorded at upper lower zones of River Niger catchments and lower zone River Kaduna catchments. Values of sulphate in this study are low when compared with a similar study in Keffi, central Nigeria (Reuben *et al.*, 2018). All concentrations of sulphate in both seasons are within Nigeria regulatory limits for surface water and biota protection (Appendix H). The presence of sulphate concentrations in water samples from the study area even though they are within regulatory limits of surface water and biota protection is indications of potential water pollution, which can increase the concentrations of plant minerals and pesticide residues in waters, sediments and biota thereby eliciting serious negative socio-economic effects on livelihoods of communities in the study area.

4.2.1.17 Spatial distribution of manganese concentrations in water samples during rainy season

The results of manganese (Mn) in water samples (W1 to W8) during the rainy season are spatially represented in Figure 4.19. The study shows that Mn values were distributed within the range of 0.15 ppm and 0.98 ppm (Appendix D).

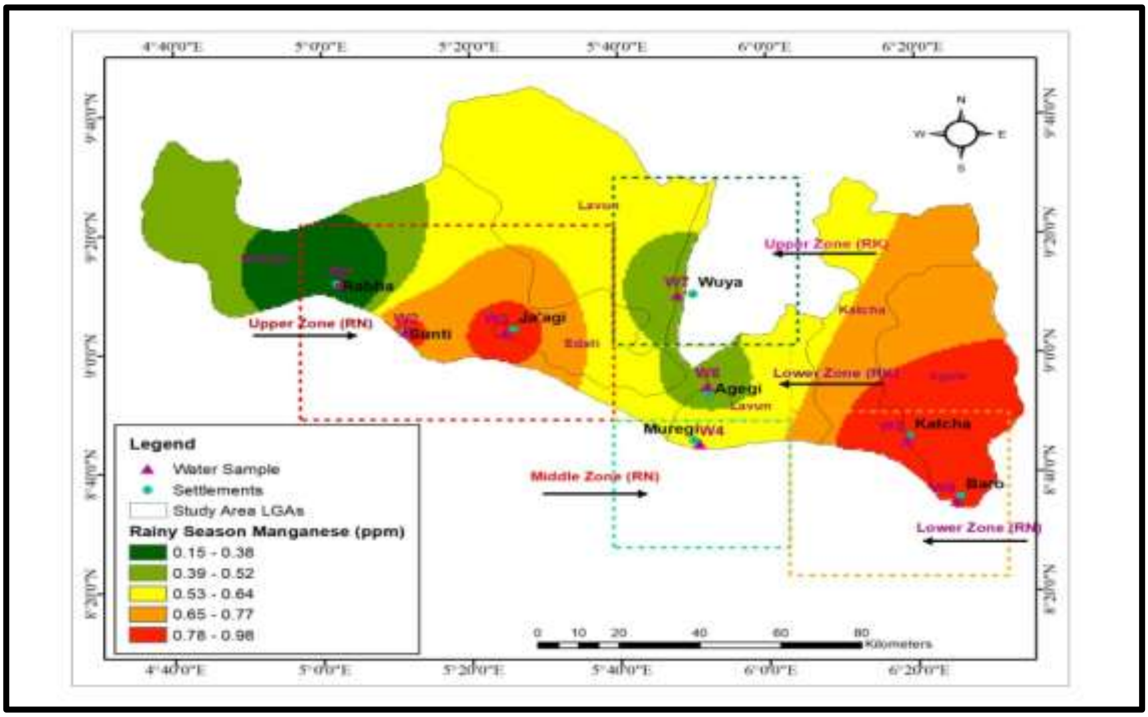


Figure 4.19: Interpolated Distance Weighted Map of Manganese in Water Samples during Rainy Season

Source: Author's Work, 2019

4.2.1.18 Spatial distribution of manganese concentrations in water samples during dry season

The results of manganese (Mn) in water samples (W1 to W8) during the dry season are spatially represented in Figure 4.20. The study sshos that Mn values were distributed within the range of 0.08 ppm and 1.06 (Appendix D).

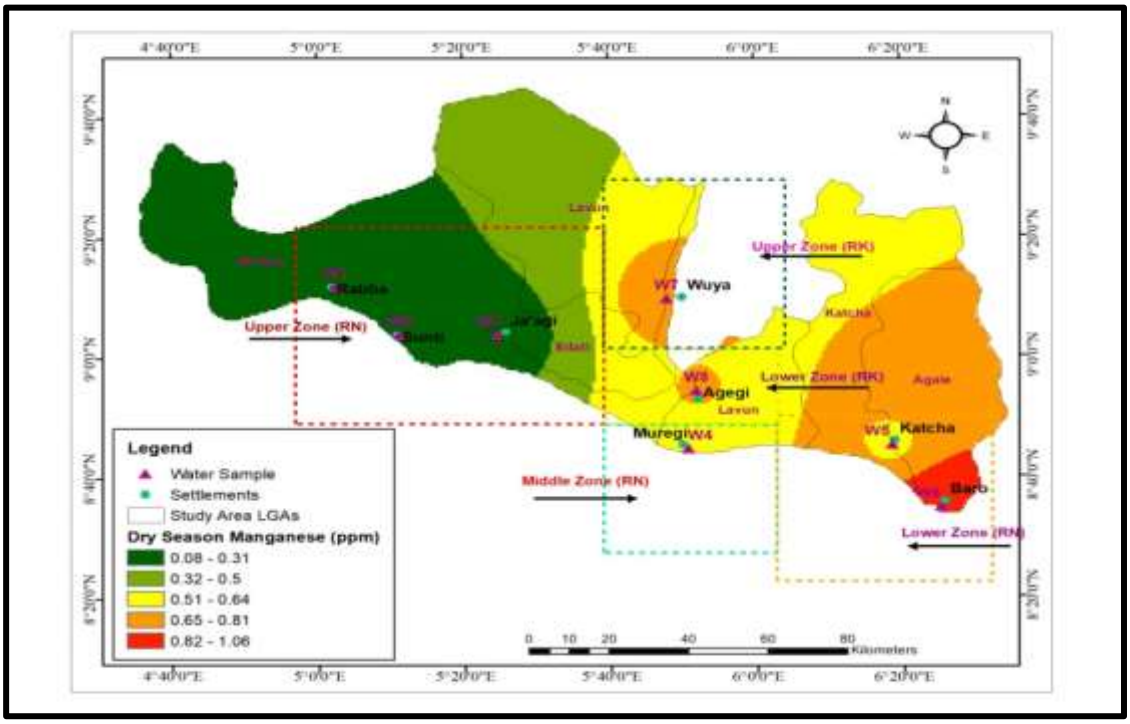


Figure 4.20: Interpolated Distance Weighted Map of Manganese in Water Samples during Dry Season
Source: Author's Work, 2019

As indicated in Figures 4.19 and 4.20, manganese concentrations were randomly higher in the dry season samples. These values increase from rain season samples to the dry season samples. The highest values were recorded at the upper, lower zones of River Niger catchments in rainy season and lower zone River Niger catchments during dry season. The flow pattern of manganese concentrations is an indication of downstream movement of agrochemicals. The values of Mn identified in this are low when compared with a similar study in Northern Nigeria (Wada *et al.*, 2021). Mn concentrations at sample points W2, W3, W4, W5, and W6 in rainy season and W1, W5, W6, W7 and W8 in dry season were above regulatory limit of Nigeria national standards for surface water quality (Appendix H). The presence of Mn concentrations in the water samples from the study area above regulatory limit are indications of polluted water which can increase the concentrations of plant minerals and pesticide residues in waters, sediments and biota thereby eliciting serious negative socio-economic effects on livelihoods of communities in the study area (Appendix D).

4.2.1.19 Spatial distribution of chloride concentrations in water samples during rainy season

The results of chloride in water samples (W1 to W8) during the rainy season are spatially represented in Figure 4.21. The study shows that chloride values were distributed within the range of 18.51 ppm and 78.79 ppm (Appendix D).

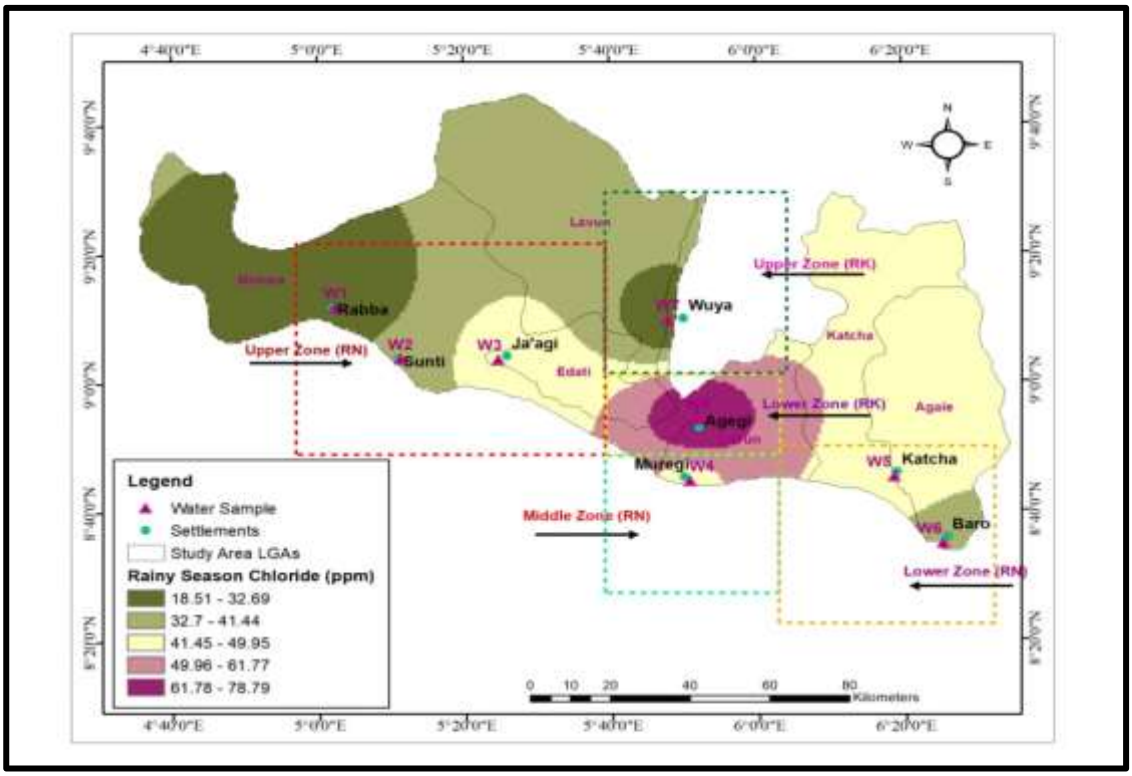


Figure 4.21: Interpolated Distance Weighted Map of Chloride in Water Samples during Rainy Season

Source: Author's Work, 2019

4.2.1.20 Spatial distribution of chloride concentrations in water samples during dry season

The results of chloride in water samples (W1 to W8) during the dry season are spatially represented in Figure 4.22. The study shows that chloride values were distributed within the range of 35.51 ppm and 105.98 ppm (Appendix D).

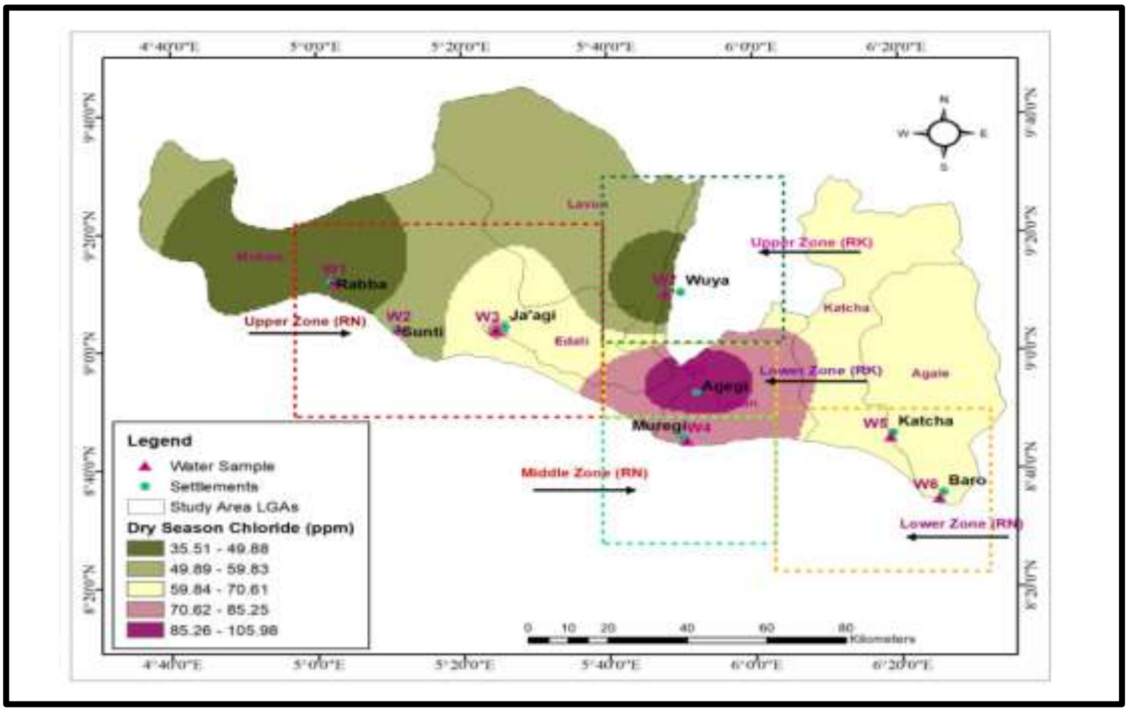


Figure 4.22: Interpolated Distance Weighted Map of Chloride in Water Samples during Dry Season
Source: Author's Work, 2019

As indicated in Figures 4.21 and 4.22, chloride concentrations in all sample points during the rainy season were significantly less than that of the dry season sample. Lower concentrations of chloride during the rainy season can be attributed to precipitations. The highest concentrations of chloride during rainy and dry seasons were detected at the lower zone River Kaduna catchments. Values of chloride in this study are high when compared with a similar study in Keffi, central Nigeria (Reuben *et al.,* 2018). All concentrations of chloride across the sample points in both seasons are within the Nigeria regulatory limit for surface water and biota protection (Appendix H). The presence of chloride concentrations in the water samples from the study area even though they are within regulatory limit of biota protection are indications of potential water pollution, which can increase the concentrations of plant minerals and pesticide residues in waters, sediments and biota thereby eliciting serious negative socio-economic effects on livelihoods of communities in the study area.

4.2.1.21 Spatial distribution of chemical oxygen demand values in water samples during rainy season

The results of chemical oxygen demand (COD) in water samples (W1 to W8) during the rainy season are spatially represented in Figure 4.23. The study showed that COD values were distributed within the range of 13.8 ppm and 23.85 ppm (Appendix D).

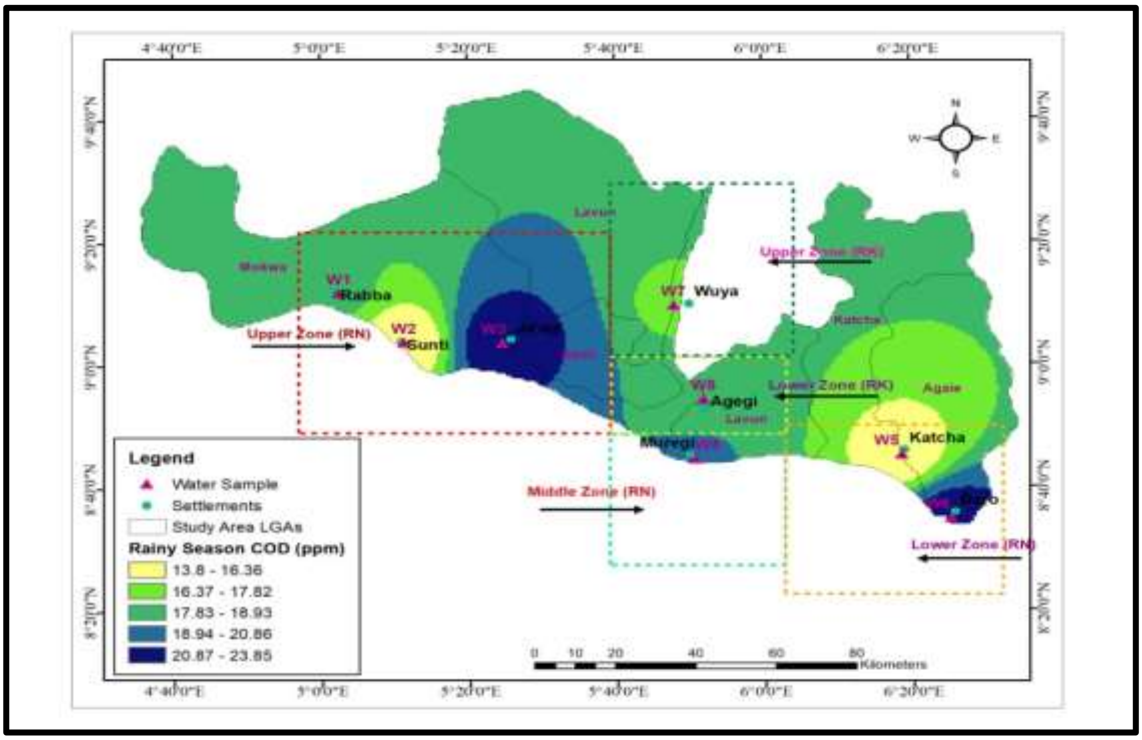


Figure 4.23: Interpolated Distance Weighted Map of COD in Water Samples during Rainy Season

Source: Author's Work, 2019

4.2.1.22 Spatial distribution of chemical oxygen demand values in water samples during dry season

The results of chemical oxygen demand (COD) in water samples (W1 to W8) during the dry season are spatially represented in Figure 4.24. The study showed that COD values were distributed within the range of 24.81 ppm and 44.99 ppm (Appendix D).

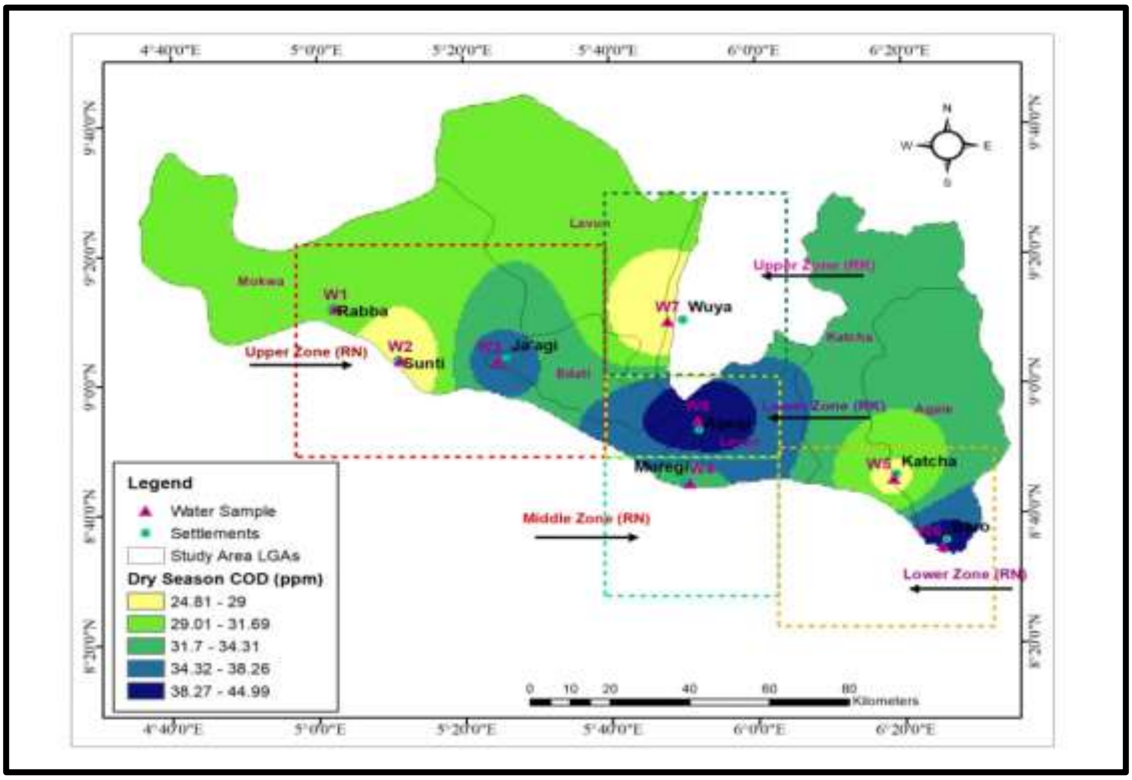


Figure 4.24: Interpolated Distance Weighted Map of COD in Water Samples during Dry Season
Source: Author's Work, 2019

As indicated in Figures 4.23 and 4.24, COD values were generally higher in the dry season samples than rain season. These values increase from the rainy season samples to the dry season samples. The highest values were recorded at the upper, lower zones of River Niger catchments during rainy season, and lower, the lower zones of Rivers Niger and Kaduna catchments during dry season. The concentrations of COD in this study are low when compared with a similar study in Keffi, central Nigeria (Reuben *et al.*, 2018). COD values of sample points W3, W4, W6 and W8 in dry season were above regulatory limits of Nigeria national standards for surface water quality (Appendix H). High values of COD in a significant number of water samples from the study area above regulatory limit are confirmation of polluted water, which can decrease DO and increase the concentrations of plant minerals and pesticide residues in waters, sediments and biota thereby eliciting serious negative socio-economic effects on livelihoods of communities in the study area.

4.2.1.23 Spatial distribution of biochemical oxygen demand values in water samples during rainy season

The results of biological oxygen demand (BOD) in water samples (W1 to W8) during the rainy season are spatially represented in Figure 4.25. The study shows that BOD values were distributed within the range of 7.05 ppm and 12.56 ppm (Appendix D).

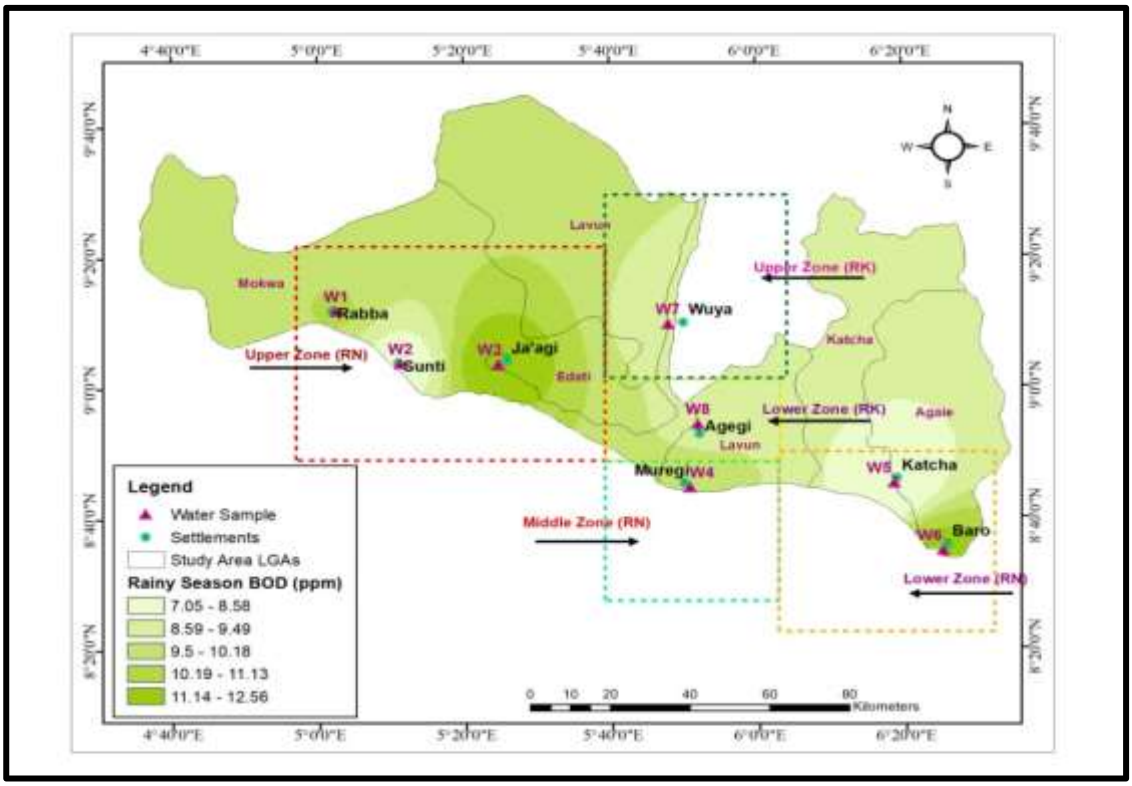


Figure 4.25: Interpolated Distance Weighted Map of BOD in Water Samples during Rainy Season
Source: Author's Work, 2019

4.2.1.24 Spatial distribution of biochemical oxygen demand values in water samples during dry season

The results of biological oxygen demand (BOD) in water samples (W1 to W8) of the dry season are spatially represented in Figure 4.26. The study shows that BOD values were distributed within the range of 9.82 ppm and 18.1 ppm (Appendix D).

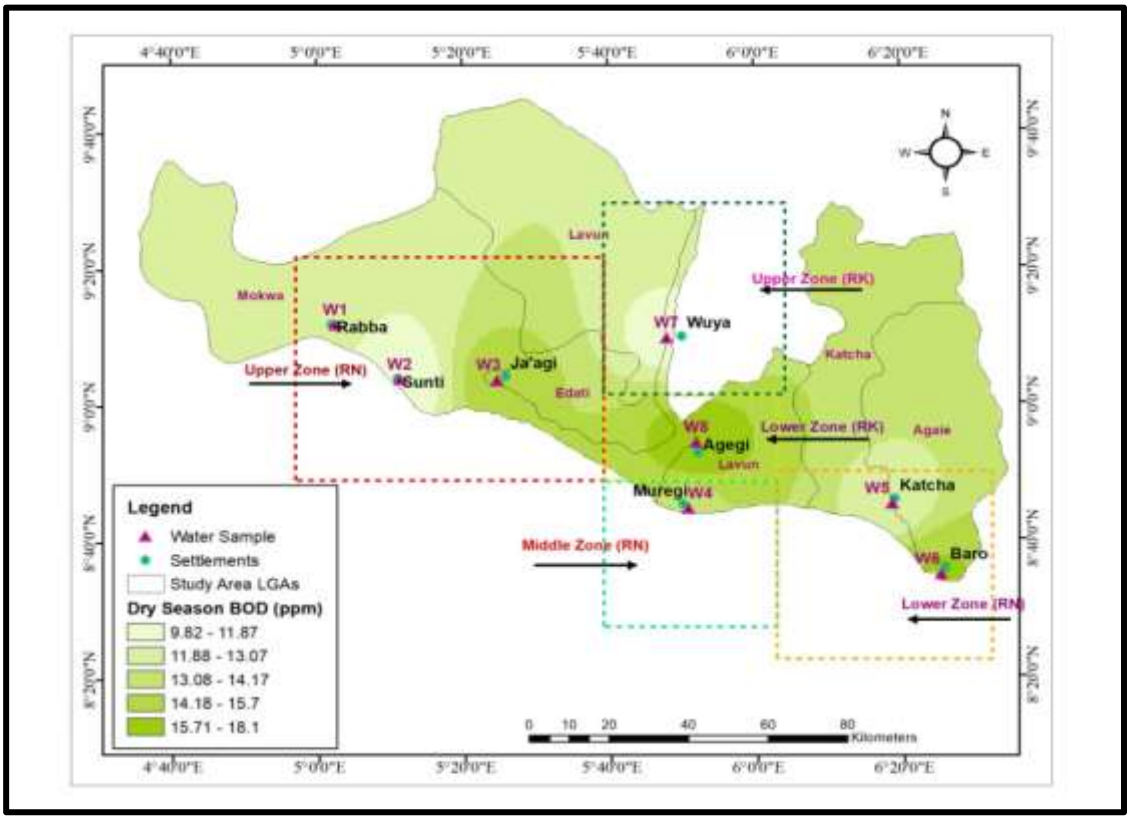


Figure 4.26: Interpolated Distance Weighted Map of BOD in Water Samples during Dry Season

Source: Author's Work, 2019

As indicated in Figures 4.25 and 4.26, BOD values were generally higher in the dry season samples than rain season. These values increase from the rainy season samples to the dry season samples. The highest values were recorded at the upper, lower zones of River Niger catchments during rainy season, and lower zones River Kaduna catchments during dry season. The concentrations of BOD in this study agree with a similar study in Keffi, central Nigeria (Reuben *et al.,* 2018). BOD values at all the sample points of both seasons were above regulatory limits of Nigeria national standards of surface water quality (Appendix H). High values of BOD in all water samples from the study area above regulatory limit are confirmation of polluted water which can increase the concentrations of plant minerals and pesticide residues in waters, sediments and biota thereby eliciting serious negative socio-economic effects on the livelihoods of communities in the study area.

4.2.1.25 Spatial distribution of total suspended solid values in water samples during rainy season

The results of total suspended solid (TSS) in water samples (W1 to W8) of the rainy season are spatially represented in Figure 4.27. The study shows that TSS values were distributed within the range of 15.81 ppm and 38.87 ppm (Appendix D).

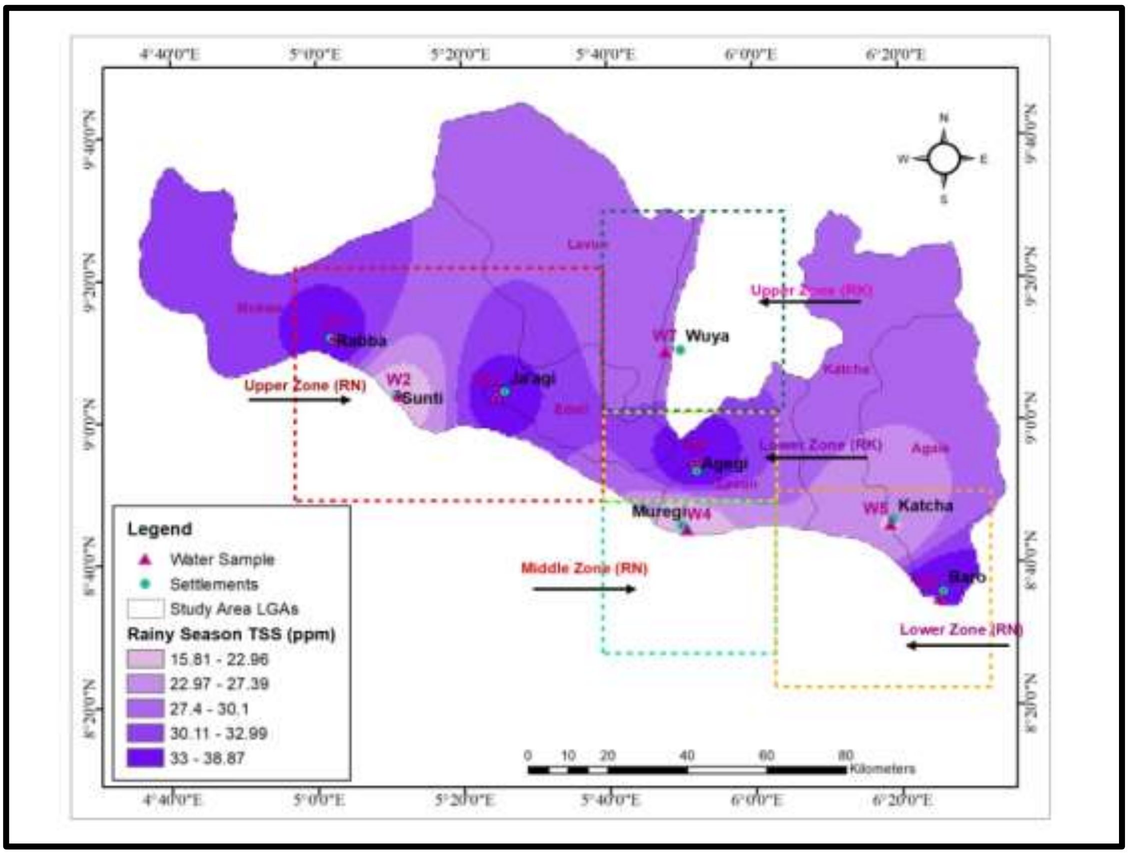


Figure 4.27: Interpolated Distance Weighted Map of TSS in Water Samples during Rainy Season

Source: Author's Work, 2019

4.2.1.26 Spatial distribution of total suspended solid values in water samples during dry season

The results of total suspended solid (TSS) in water samples (W1 to W8) during the dry season are spatially represented in Figure 4.28. The study shows that TSS values were distributed within the range of 30.0 ppm and 53.0 ppm (Appendix D).

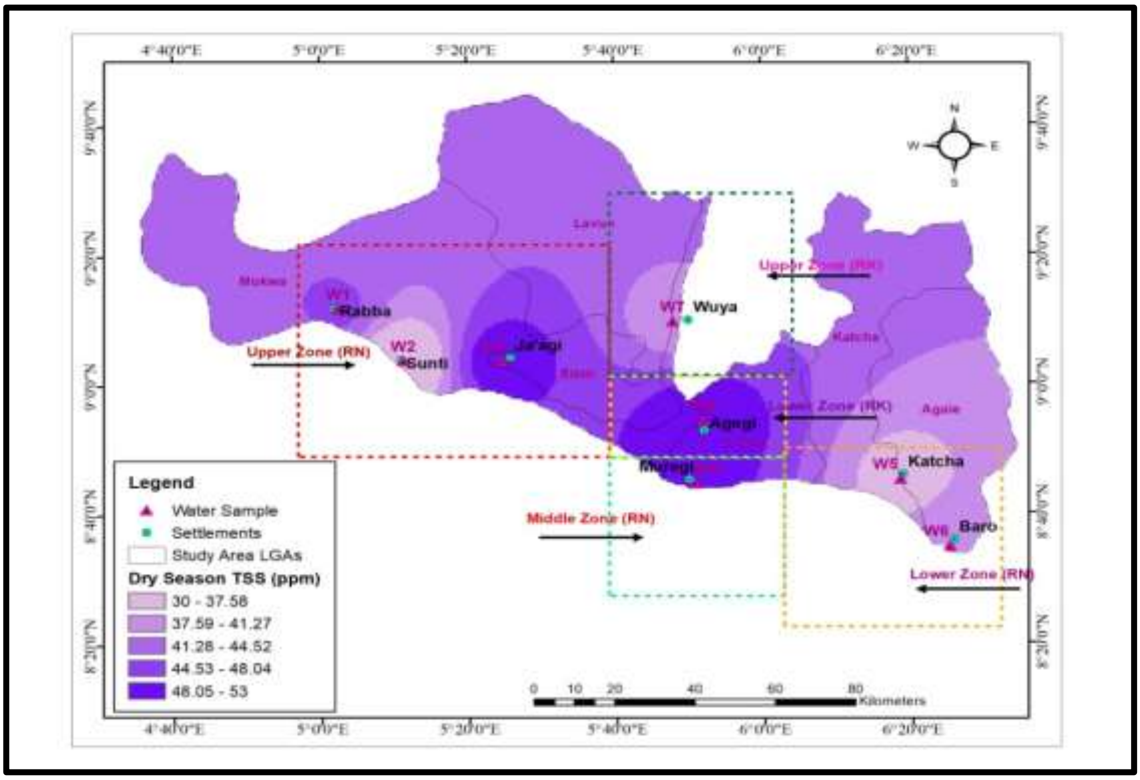


Figure 4.28: Interpolated Distance Weighted Map of TSS in Water Samples during Dry Season

Source: Author's Work, 2019

As indicated in Figures 4.27 and 4.28, TSS values were generally higher in the dry season samples than rain season. These values increase from the rainy season samples to the dry season samples. The highest values were recorded at the upper, lower zones of Niger River catchments during rainy season and lower zone River Kaduna catchments during rainy season. In the dry season, the highest values were recorded at upper, middle zones of River Niger catchment and lower zone River Kaduna catchments. TSS values in sample points W1, W3, W6 and W8 during rainy season, and all sample points of dry season were above regulatory limits Nigeria national standards of surface water quality (Appendix H). The TSS values identified in this study are higher when compared with a similar study in Southern Kaduna, Nigeria (Yohanna *et al.*, 2021). High values of TSS in larger parts of these samples' locations during both seasons above regulatory limit are confirmation of polluted water which can increase the concentrations of plant minerals and pesticide residues in waters, sediments and biota thereby eliciting serious negative socio-economic effects on livelihoods of communities in the study area.

4.2.1.27 Spatial distribution of total hardness concentrations in water samples during rainy season

The results of total hardness (TH) in water samples (W1 to W8) during the rainy season are spatially represented in Figure 4.29. The study showed that TH values were distributed within the range of 3.52 ppm and 7.65 ppm (Appendix D).

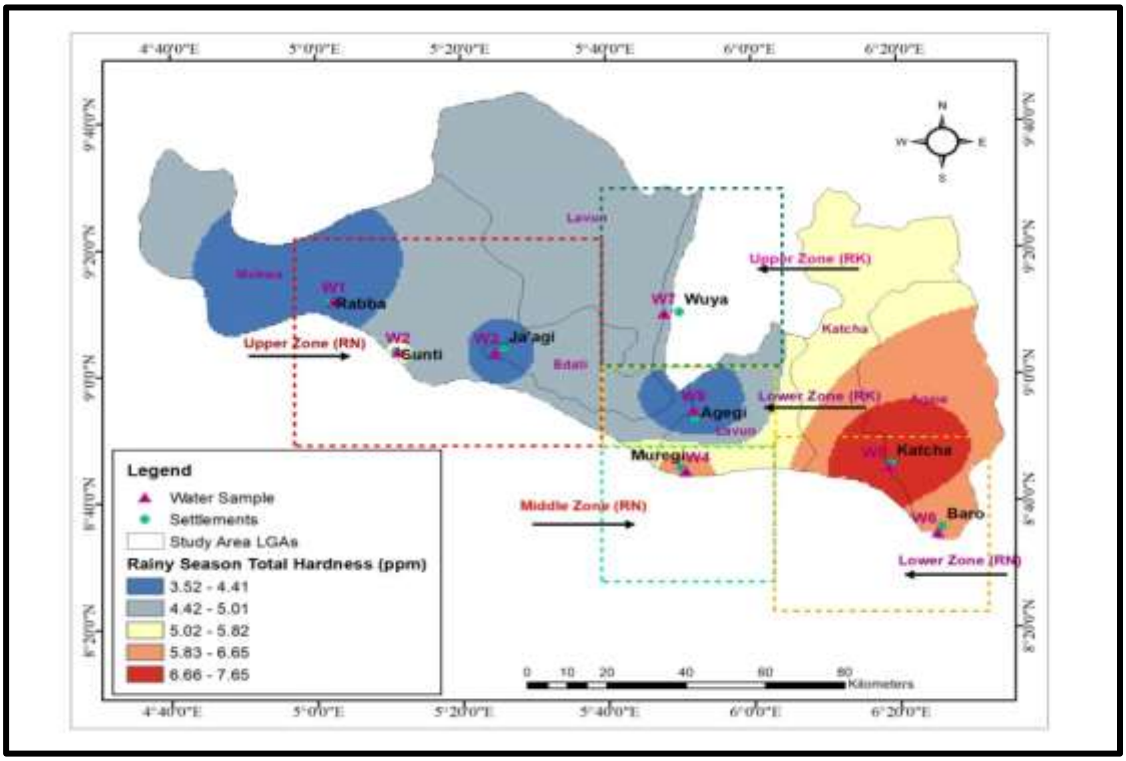


Figure 4.29: Interpolated Distance Weighted Map of TH in Water Samples during Rainy Season

Source: Author's Work, 2019

4.2.1.28 Spatial distribution of total hardness concentrations in water samples during dry season

The results of total hardness (TH) in water samples (W1 to W8) during the dry season are spatially represented in Figure 4.30. The study showed that TH values were distributed within the range of 4.6 ppm and 10.52 ppm (Appendix D).

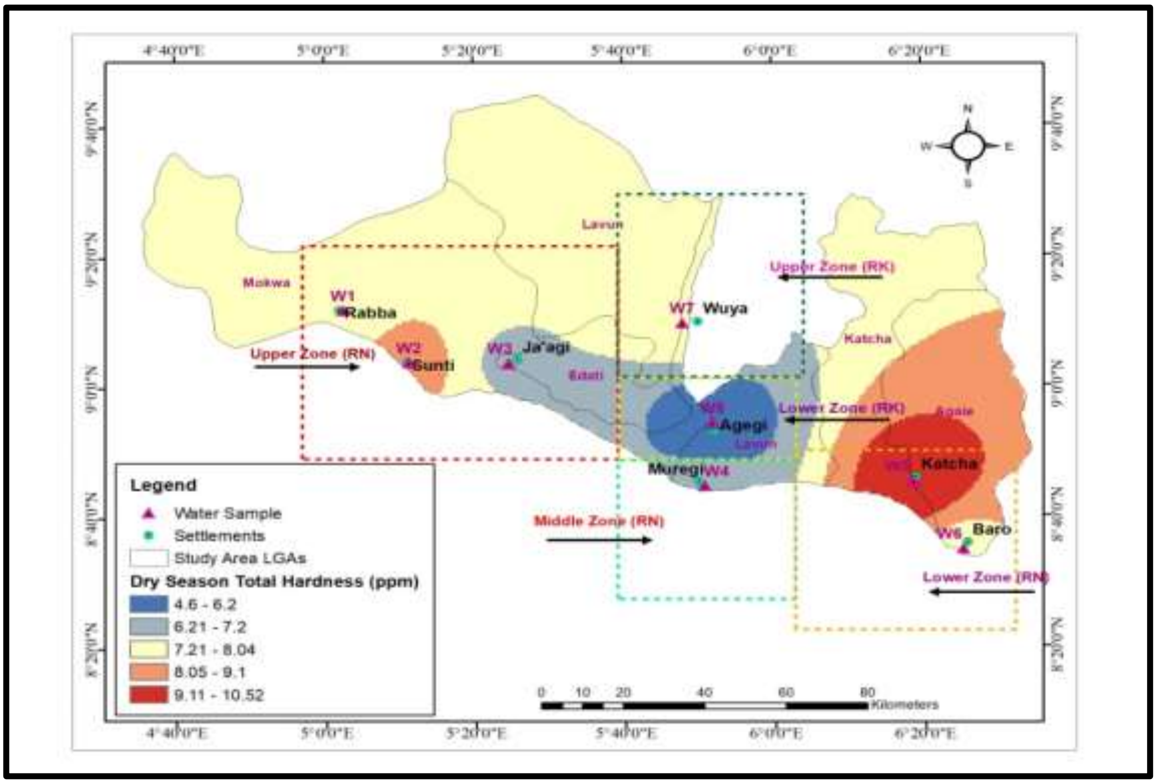


Figure 4.30: Interpolated Distance Weighted Map of TH in Water Samples during Dry Season
Source: Author's Work, 2019

As indicated in Figures 4.29 and 4.30, TH values were generally higher in the dry season samples than rain season. These values increase from the rainy season samples to the dry season samples. The highest values were recorded at the lower, lower zones of Rivers Niger and Kaduna catchments during both seasons. The values of TH identified in this study are low when compared with a similar study in Keffi, central Nigeria (Reuben *et al.*, 2018). TH values at all the sample points of both seasons are within regulatory limits of Nigeria national standards of surface water quality (Appendix H).

4.2.1.29 Spatial distribution of potassium concentrations in water samples during rainy season

The results of potassium concentrations in water samples (W1 to W8) during the rainy season are spatially represented in Figure 4.31. The study showed that potassium concentrations were distributed within the range of 0.08 mg/kg and 1.54 mg/kg (Appendix D).

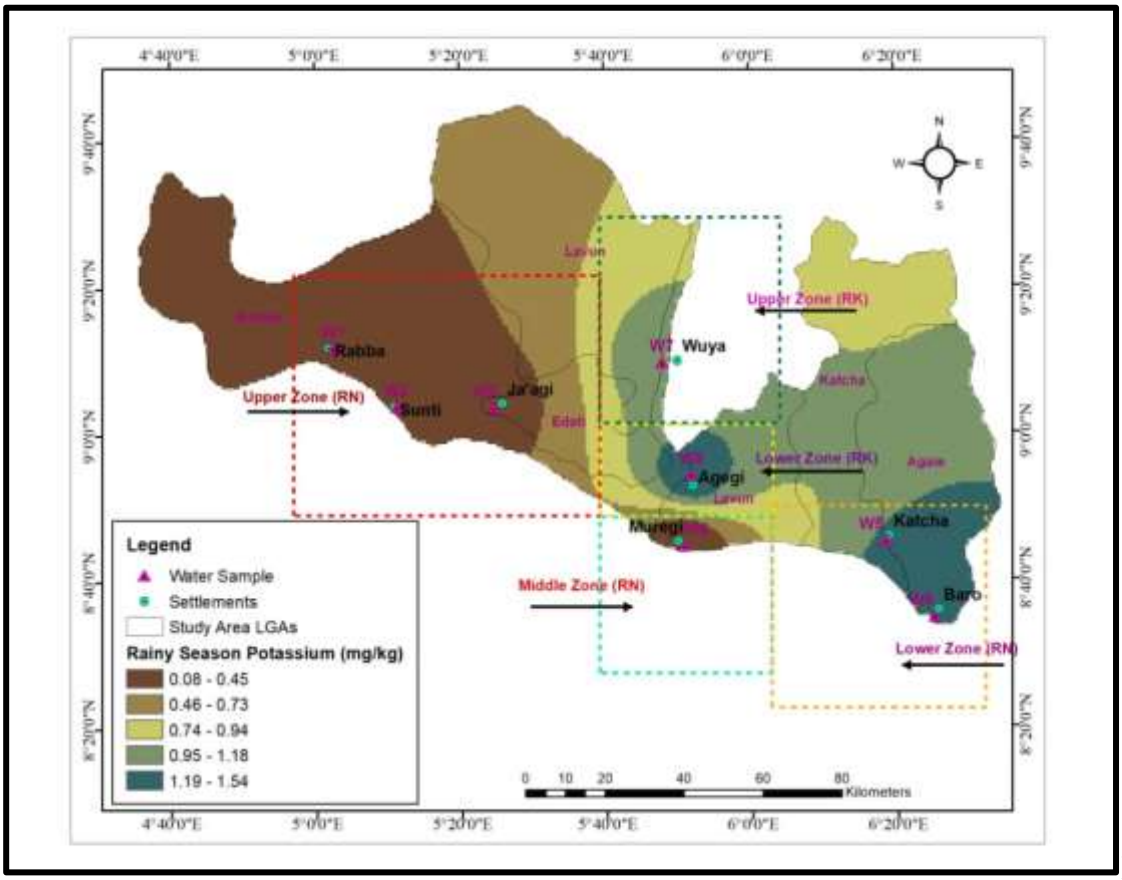


Figure 4.31: Interpolated Distance Weighted Map of Potassium in Water Samples during Rainy Season

Source: Author's Work, 2019

4.2.1.30 Spatial distribution of potassium concentrations in water samples during dry season

The results of potassium concentrations in water samples (W1 to W8) of the dry season are spatially represented in Figure 4.32. The study showed that potassium concentrations were distributed within the range of 0.13 mg/kg and 2.07 mg/kg (Appendix D).

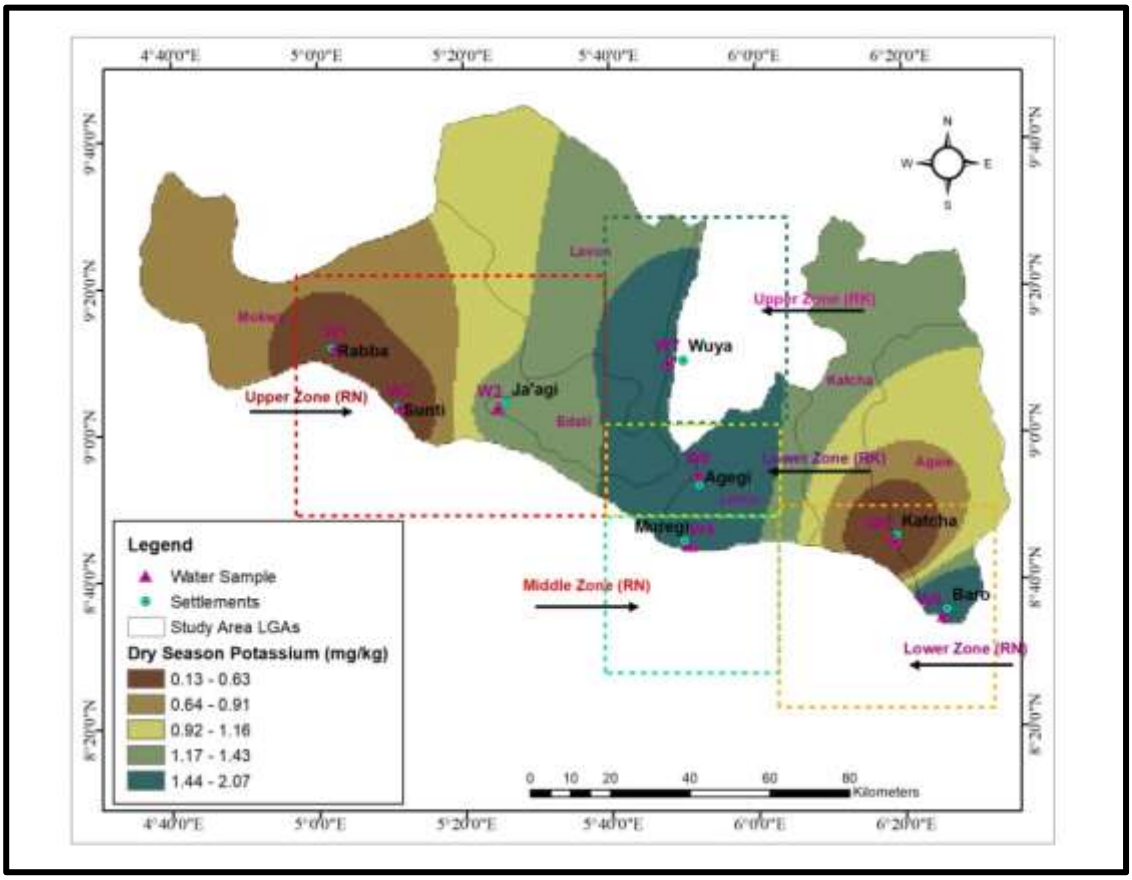


Figure 4.32: Interpolated Distance Weighted Map of Potassium in Water Samples during Dry Season
Source: Author's Work, 2019

As indicated in Figures 4.31 and 4.32, potassium concentrations in all the rainy season sample were less than that of the dry season which can be attributed to high dilution due to precipitations in rain season. The highest concentrations of potassium were recorded at the lower zone of River Niger catchment, while in of River Kaduna catchment, the highest concentrations were recorded at lower zone during rainy season. In the dry season, the highest concentrations were recorded at middle, lower zones of River Niger catchments and upper, lower zone catchments of River Kaduna catchments. The potassium concentrations identified in this study are low when compared with a similar study in Abuja central Nigeria (Aleke and Nwachukwu, 2018). All the concentrations of potassium in both seasons are within Nigeria regulatory limits (Appendix H).

4.2.1.31 Spatial distribution of sulphate concentrations in sediment samples during rainy season

The results of sulphate concentrations in sediment samples (S1 to S8) during the rainy season are spatially represented in Figure 4.33. The study shows that sulphate concentrations were distributed within the range of 4.61 ppm and 8.62 ppm (Appendix D).

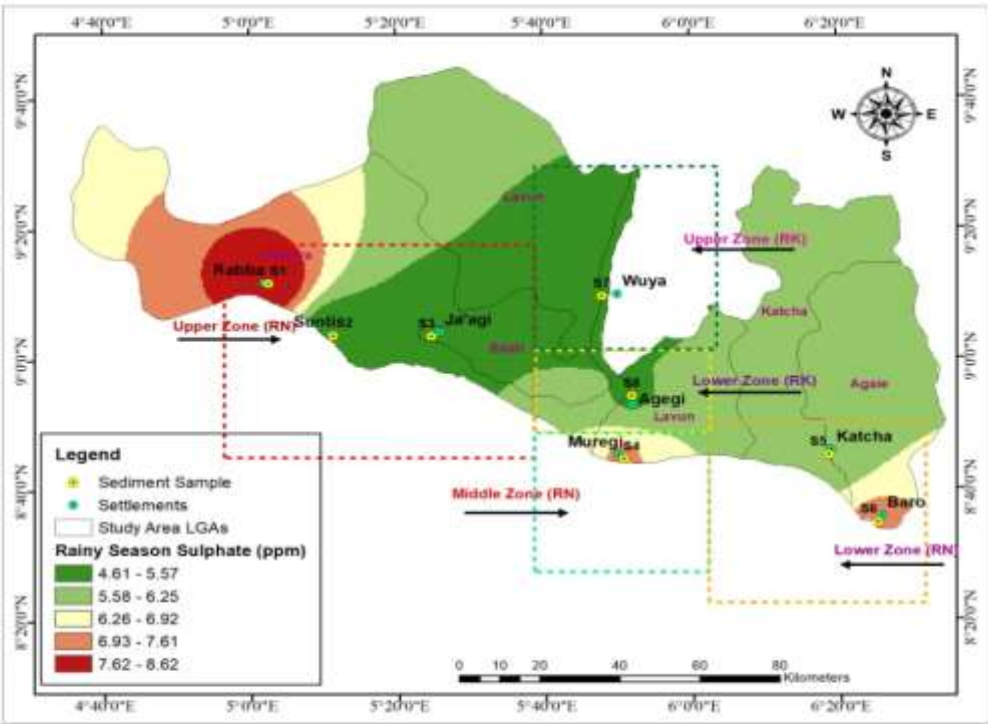


Figure 4.33: Interpolated Distance Weighted Map of Sulphate in Sediment Samples during Rainy Season

Source: Author's Work, 2019

4.2.1.32 Spatial distribution of sulphate concentrations in sediment samples during dry season

The results of sulphate concentrations in sediment samples (S1 to S8) during the dry season are spatially represented in Figure 4.34. The study shows that sulphate concentrations were distributed within the range of 5.28 ppm and 22.68 ppm (Appendix D).

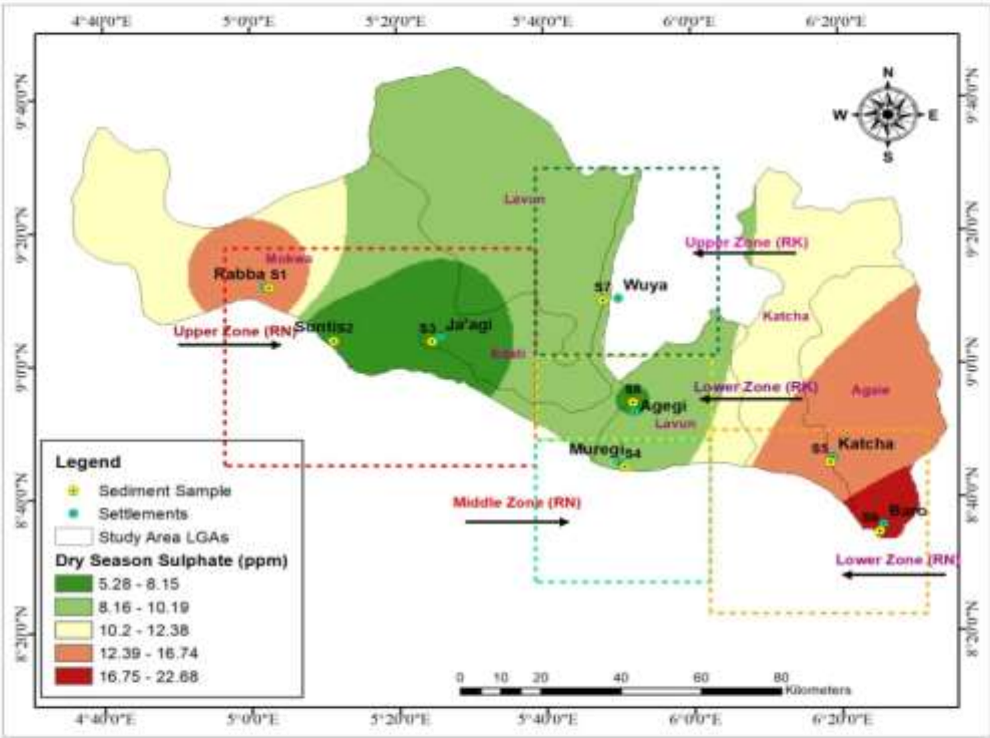


Figure 4.34: Interpolated Distance Weighted Map of Sulphate in Sediment Samples during Dry Season

Source: Author's Work, 2019

As indicated in Figures 4.33 and 4.34, the findings imply that concentrations of sulphate in all rain season samples were less than that of the dry season. It shows an increase of sulphate concentrations across the study zones from rainy season to dry season. The highest concentrations of sulphate were recorded at upper zones of River Niger catchment during rainy season, while during the dry season, the highest concentrations were recorded at the lower zone of River Niger catchment indicating movement of chemical downstream. All the concentrations of sulphate in the rainy season are within Nigeria regulatory limits of biota protection (Appendix H). The sample point S1 and S6 during the dry season are above the Nigeria regulatory limit of biota. The concentrations of sulphate were higher in sediment samples than water in this study, which may be due to chemical retention abilities of soil. The presence of sulphate concentrations in the sediment samples from the study area even though they are within regulatory limit of biota protection are indications of potential water pollution, which can increase the concentrations of plant minerals and pesticide residues in waters, sediments and biota thereby eliciting serious negative socio-economic effects on livelihoods of communities in the study area.

4.2.1.33 Spatial distribution of manganese concentrations in sediment samples during rainy season

The results of Mn concentrations in sediment samples (S1 to S8) during the rainy season are spatially represented in Figure 4.35. The study shows that Mn concentrations were distributed within the range of 0.96 ppm and 2.86 ppm (Appendix D).

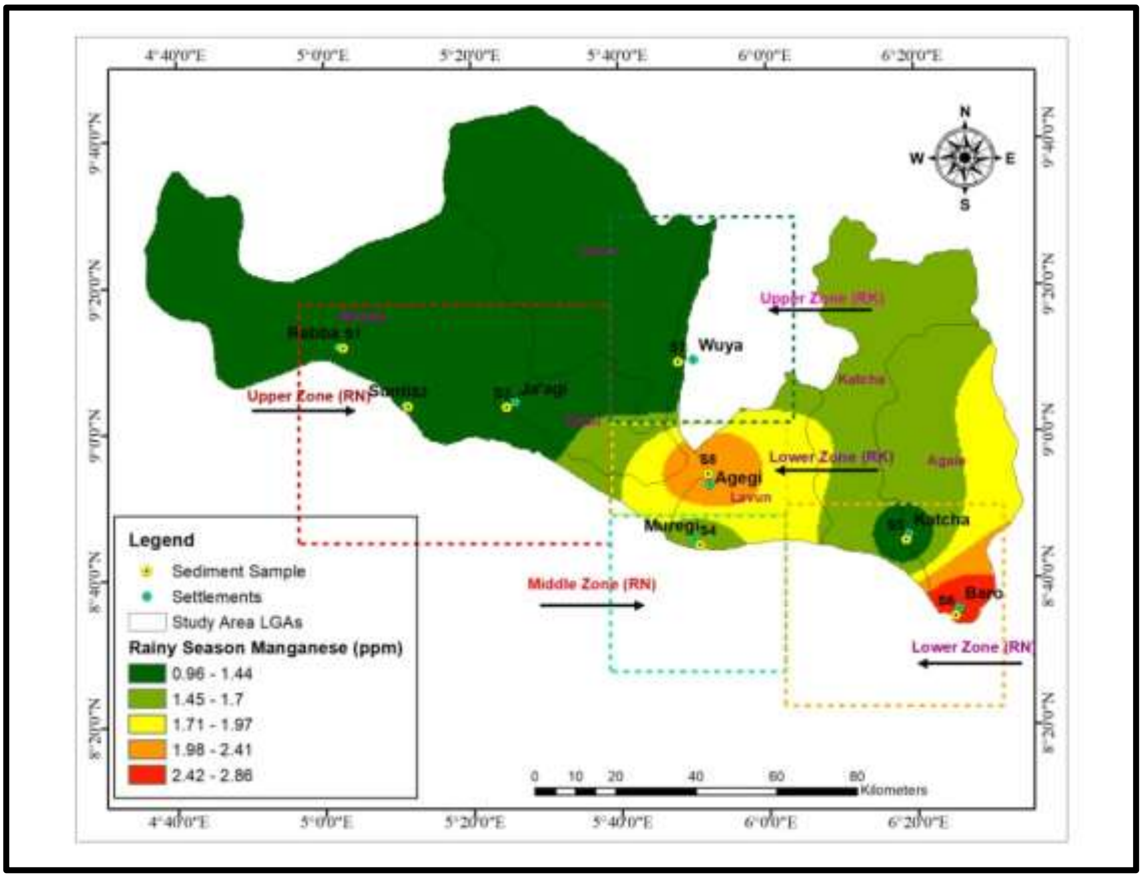


Figure 4.35: Interpolated Distance Weighted Map of Manganese in Sediment Samples during Rainy Season

Source: Author's Work, 2019

4.2.1.34 Spatial distribution of manganese concentrations in sediment samples during dry season

The results of Mn concentrations in sediment samples (S1 to S8) during the dry season are spatially represented in Figure 4.36. The study shows that Mn concentrations were distributed within the range of 0.2 ppm and 2.79 ppm (Appendix D).

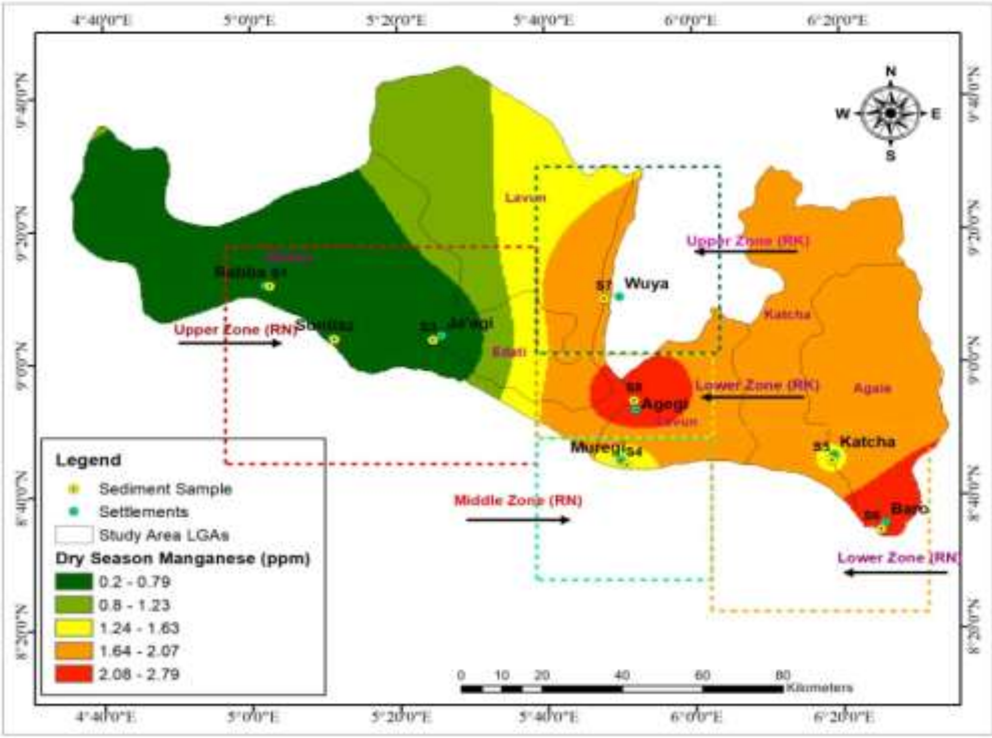


Figure 4.36: Interpolated Distance Weighted Map of Manganese in Sediment Samples during Dry Season
Source: Author's Work, 2019

As indicated in Figures 4.35 and 4.36, manganese concentrations were largely higher in rain season samples. These values decrease from the rainy season samples to the dry season samples. The highest values were recorded at the lower zone River Niger catchments during rainy season, while in the dry season, the highest concentrations were recorded at lower, lower zones of Rivers Niger and Kaduna catchments indicating downstream movement of agrochemical concentrations. The concentrations of Mn were observed to be low in sediment samples than water in this study. All concentrations are within the Nigeria regulatory limit of biota protection (Appendix H). The presence of Mn concentrations in the sediment samples from the study area even though they are within regulatory limit of biota protection are indications of potential water pollution, which can increase the concentrations of plant minerals and pesticide residues in waters, sediments and biota thereby eliciting serious negative socio-economic effects on livelihoods of communities in the study area.

4.2.1.35 Spatial distribution of chloride concentrations in sediment samples during rainy season

The results of chloride concentrations in sediment samples (S1 to S8) during the rainy season are spatially represented in Figure 4.37. The study shows that chloride concentrations were distributed within the range of 5.13 ppm and 32.65 ppm (Appendix D).

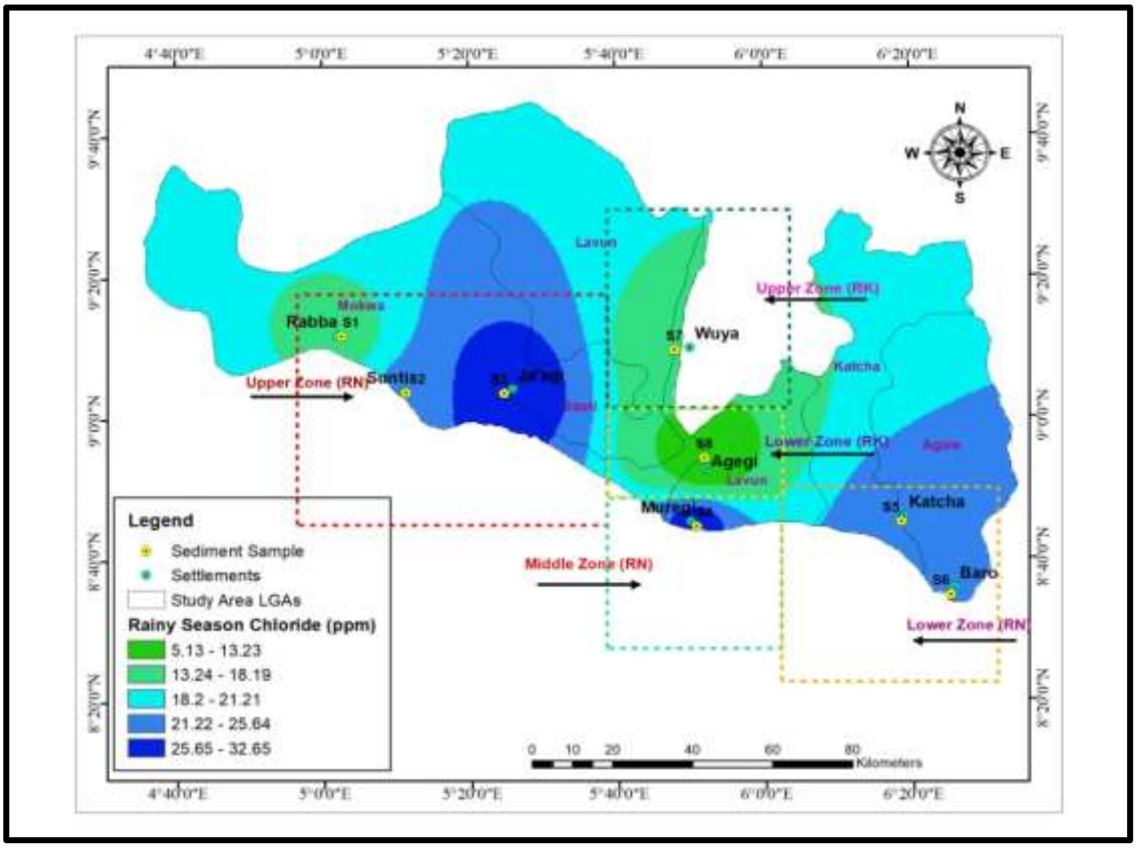


Figure 4.37: Interpolated Distance Weighted Map of Chloride in Sediment Samples during Rainy Season

Source: Author's Work, 2019

4.2.1.36 Spatial distribution of chloride concentrations in sediment samples during dry season

The results of chloride concentrations in sediment samples (S1 to S8) of the dry season are spatially represented in Figure 4.38. The study shows that chloride concentrations were distributed within the range of 22.78 ppm and 72.41 ppm (Appendix D).

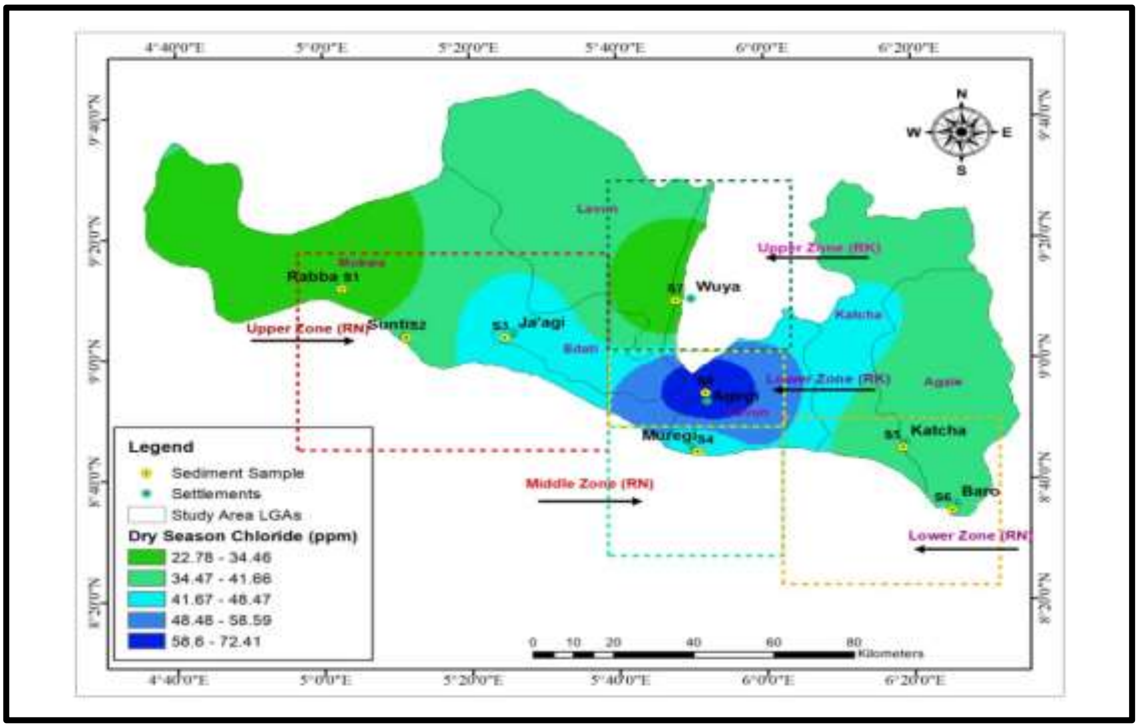


Figure 4.38: Interpolated Distance Weighted Map of Chloride in Sediment Samples during Dry Season
Source: Author's Work, 2019

As indicated in Figures 4.37 and 4.38, chloride concentrations in all sample points during the rainy season were less than that of the dry season sample. Lower concentrations of chloride during the rainy season can be attributed of precipitations. The highest concentrations of chloride during the rainy season were detected at upper, middle zones of River Niger catchments, while in the dry season, the highest concentrations were detected at the lower zone River Kaduna catchments. All concentrations of chloride across the sample points in both seasons are within the Nigeria regulatory limit of biota protection (Appendix H). The presence of chloride concentrations in the sediment samples from the study area even though they are within regulatory limit of biota protection are indications of potential water pollution, which can increase the concentrations of plant minerals and pesticide residues in waters, sediments and biota thereby eliciting serious negative socio-economic effects on livelihoods of communities in the study area.

4.2.1.37 Spatial distribution of potassium concentrations in sediment samples during rainy season

The results of potassium concentrations in sediment samples (S1 to S8) of the rainy season are spatially represented in Figure 4.39. The study showed that potassium concentrations were distributed within the range of 4.6 mg/kg and 52.69 mg/kg (Appendix D).

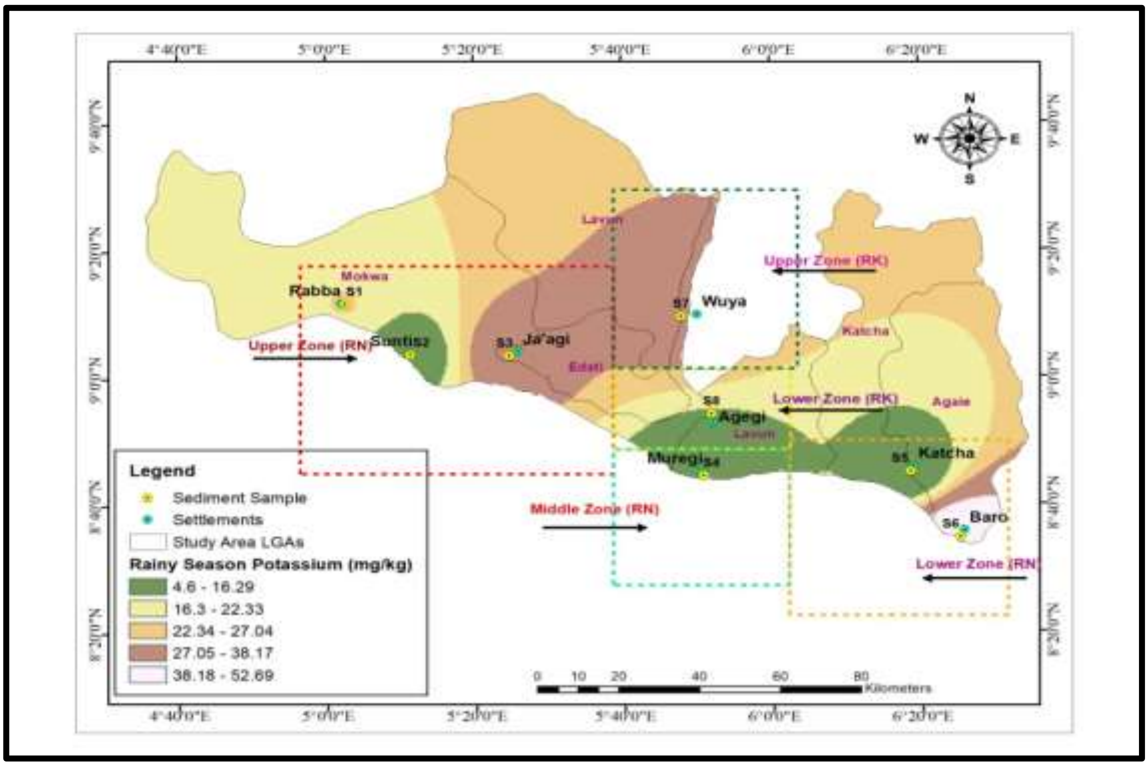


Figure 4.39: Interpolated Distance Weighted Map of Potassium in Sediment Samples during Rainy Season
Source: Author's Work, (2019)

4.2.1.38 Spatial distribution of potassium concentrations in sediment samples during dry season

The results of potassium concentrations in sediment samples (S1 to S8) during the dry season are spatially represented in Figure 4.40. The study showed that potassium concentrations were distributed within the range of 10.56 mg/kg and 62.74 mg/kg (Appendix D).

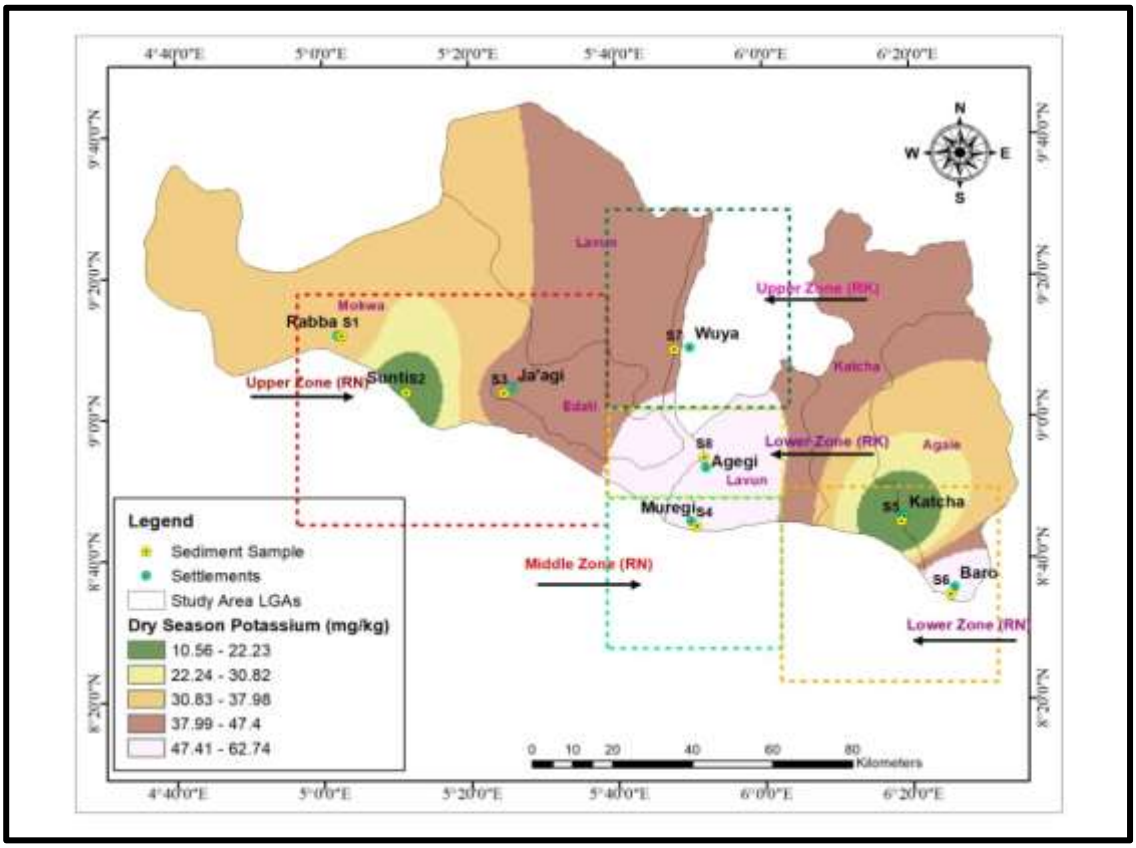


Figure 4.40: Interpolated Distance Weighted Map of Potassium in Sediment Samples during Dry Season

Source: Author's Work, 2019

As indicated in Figures 4.39 and 4.40, potassium concentrations in all the rainy season sample were less than that of the dry season which can be attributed to high dilution due to precipitations in rain season. The highest concentrations of potassium were recorded at lower zone River Niger catchment during rainy season, while in the dry season, the highest concentrations were recorded at middle, lower zones River Niger catchments and upper, lower zone catchments River Kaduna catchments. The presenters of potassium in the samples are indications of potential water pollution, which can lead to reduction in dissolved oxygen and can increase the concentrations of plant minerals and pesticide residues in waters and its resources thereby eliciting serious negative socio-economic effects on the livelihoods of communities in the study area.

In summary, this objective demonstrated the effectiveness GIS tools in overlaying the physico-chemical characteristics of water and sediments. It has been able to established that a significant number of physico-chemical parameters of water and sediment spatially analysed in situ and analytically in the laboratory were above regulatory limit, can increase the concentrations of pesticides and fertilizers in the environmental media analysed, affect water quality and subsequent negative socio-economic effects on wellbeing of communities in the study area. These concentrations are significant in both seasons and spatially distributed across all the sample points with higher concentrations recorded largely at the lower zones which are clearly an indication of downstream movement of agrochemicals in the study area.

4.3 Determination of Spatial Concentrations of Plant Minerals and the Extent of Occurrence of Organochlorine Pesticide Residues in Surface Water and Sediment Samples in the Study Area

4.3.1 Spatial distribution of plant mineral concentrations in water and sediment samples during rainy and dry seasons

4.3.1.1 Spatial distribution of nitrate concentrations in water samples during rainy season

The results of nitrate (NO_3^-) concentrations in water samples (W1 to W8) during the rainy season are spatially represented in Figure 4.41. The study shows that nitrate concentrations were distributed within the range of 1.01 ppm and 1.5 ppm (Appendices D and E).

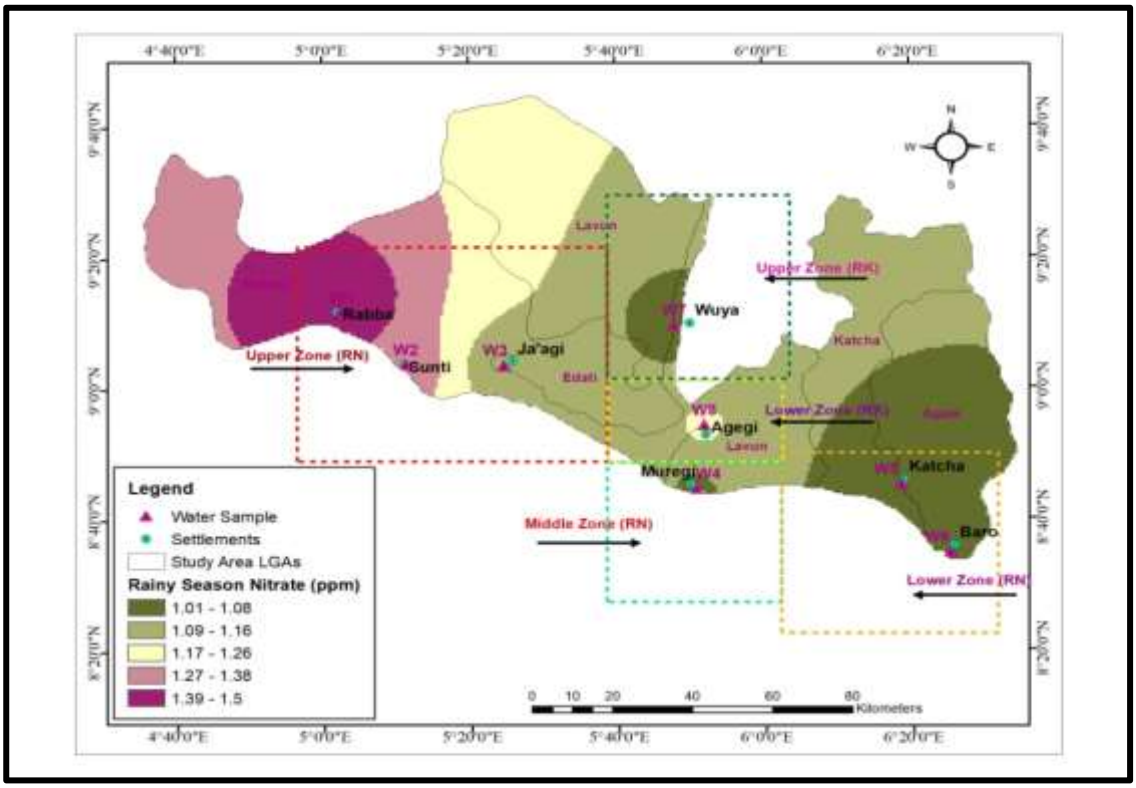


Figure 4.41: Interpolated Distance Weighted Map of Nitrate in Water Samples during Rainy Season
Source: Author's Work, 2019

4.3.1.2 Spatial distribution of nitrate concentrations in water samples during dry season

The results of nitrate (NO_3^-) concentrations in water samples (W1 to W8) during the dry season are spatially represented in Figure 4.42. The study shows that nitrate concentrations were distributed within the range of 0.26 ppm and 2.63 ppm (Appendices D and E).

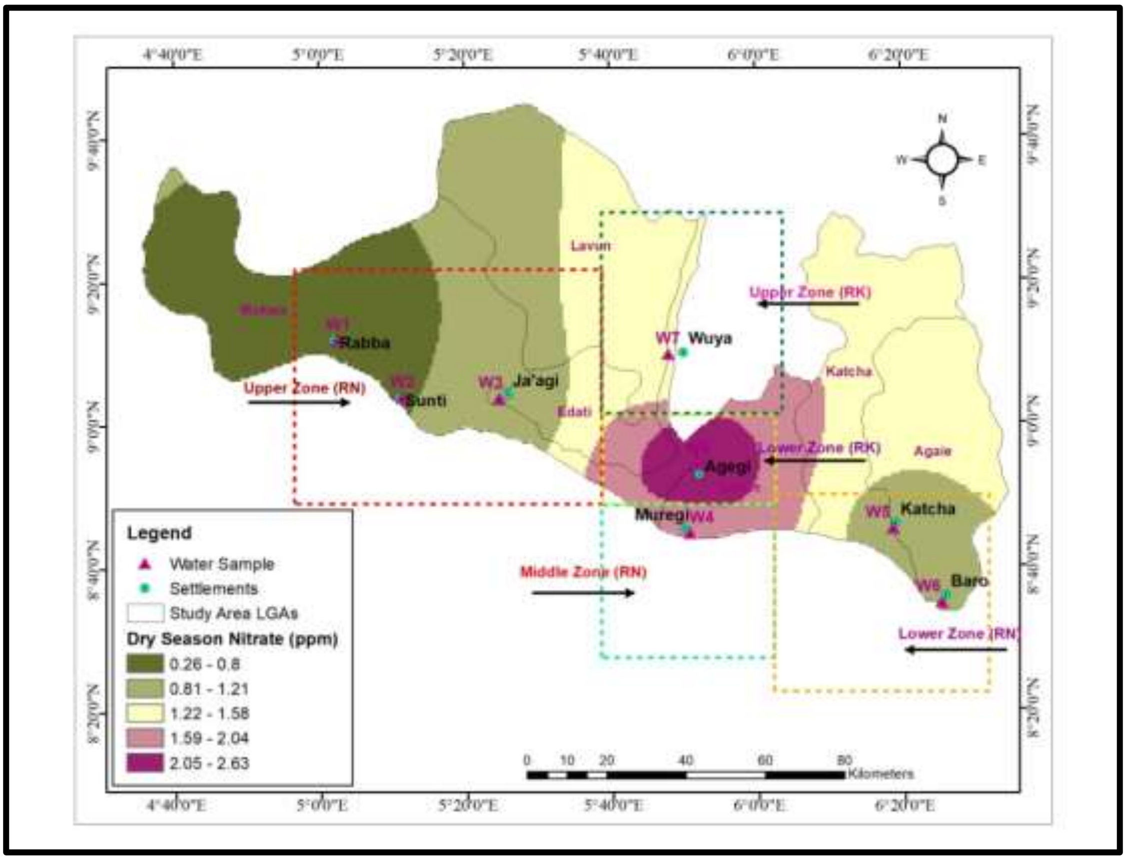


Figure 4.42: Interpolated Distance Weighted Map of Nitrate in Water Samples during Dry Season

Source: Author's Work, 2019

As indicated in Figures 4.41 and 4.42, the finding implies that the significant presence of nitrate concentrations in both seasons can be attributed to use of nitrate-based fertilizers used in the study area as affirmed by farmers and all stakeholders in this study. The value obtained in both seasons is within Nigeria regulatory limits (Appendix H). The highest concentrations during the rainy season were at the upper zone River Niger catchments, while the highest concentrations during the dry season is at lower zone River Kaduna. Nitrate concentrations in this study are low when compared with a similar study in Keffi, central Nigeria (Reuben *et al.*, 2018). The presence of nitrate in sediments of the area even though within Nigeria regulatory limits should be considered a great concern as increase in these concentrations can trigger negative socioeconomic wellbeing of communities in the study area.

4.3.1.3 Spatial distribution of nitrite concentrations of water samples during rainy season

The results of nitrite (NO_2^-) concentrations in water samples (W1 to W8) during the rainy season are spatially represented in Figure 4.43. The study shows that nitrite concentrations were distributed within the range of 0.03 ppm and 0.13 ppm (Appendices D and E).

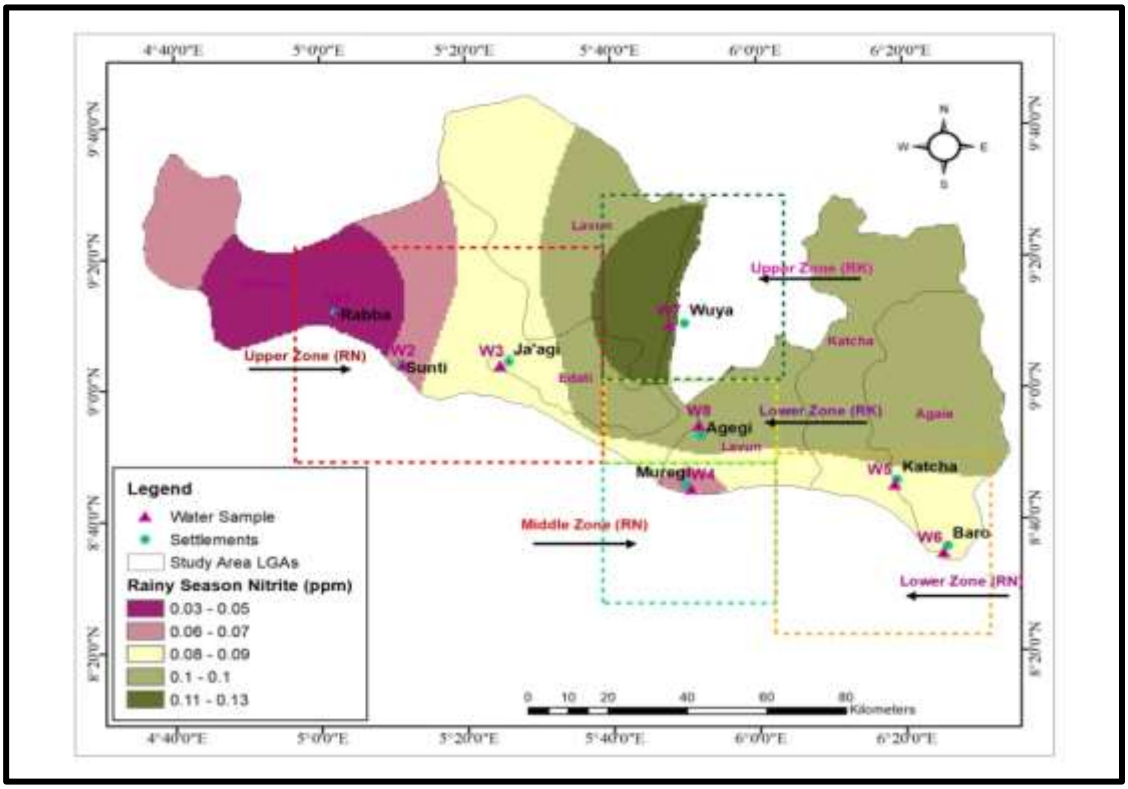


Figure 4.43: Interpolated Distance Weighted Map of Nitrite in Water Samples during Rainy Season

Source: Author's Work, 2019

4.3.1.4 Spatial distribution of nitrite concentrations in water samples during dry season

The results of nitrite (NO_2^-) concentrations in water samples (W1 to W8) during the dry season are spatially represented in Figure 4.44. The study shows that nitrite concentrations were distributed within the range of 0.02 ppm and 0.56 ppm (Appendices D and E).

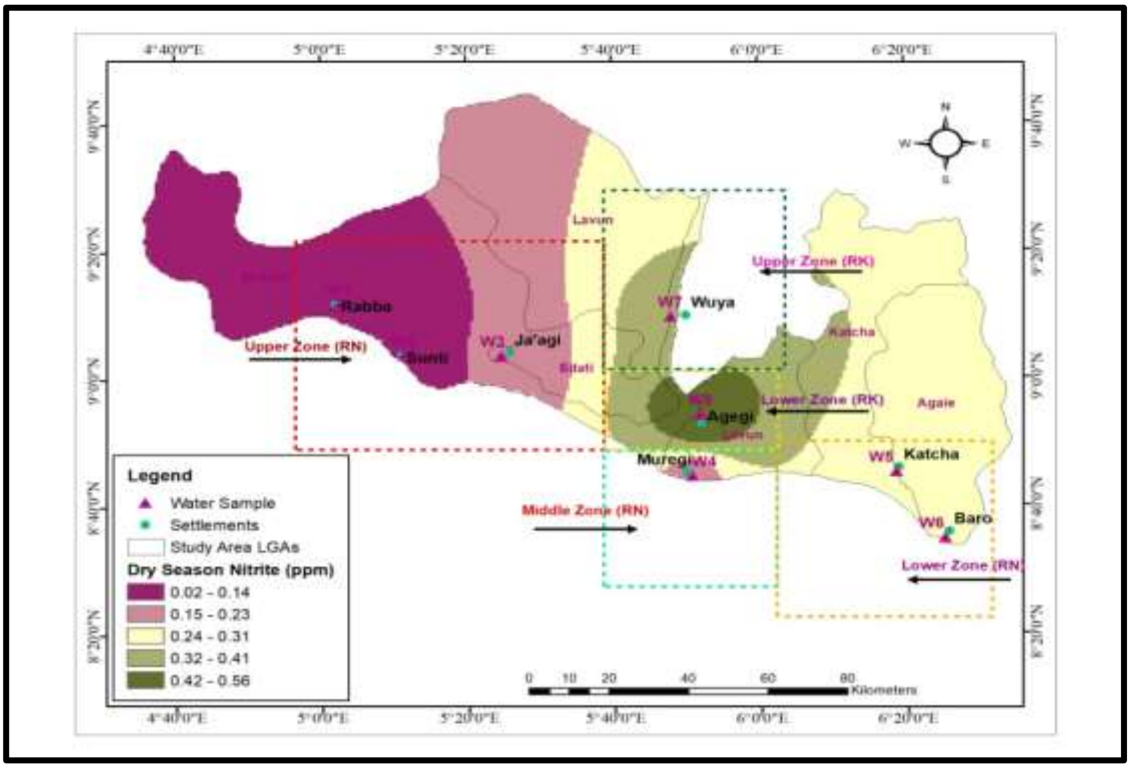


Figure 4.44: Interpolated Distance Weighted Map of Nitrite in Water Samples during Dry Season

Source: Author's Work, 2019

As indicated in Figures 4.43 and 4.44, the significant presence of nitrite concentrations in both seasons can be attributed to use of nitrate-based fertilizers as affirmed by farmers and all stakeholders in this study. Nitrite does not present in large quantity because of its rapid conversion to nitrite under normal circumstance. The value obtained at W3, W4, W7 and W8 of rainy season and W3, W4, W5, W6, W7 and W8 of dry season were above Nigeria regulatory limits of surface water (Appendix H). The highest concentrations of nitrite during the rainy season were at the upper zone River Kaduna catchments while the highest concentrations during the dry season is at lower zone River Kaduna. The high concentrations of nitrate in water of the study area above regulatory limits should be considered a great concern as these concentrations can trigger negative socio-economic wellbeing of the immediate communities. Similar concentrations of nitrite were reported in a study at Kafin-Koro, central Nigeria (Waziri *et al.*, 2019).

4.3.1.5 Spatial distribution of phosphate concentrations in water samples during rainy season

The results of orthophosphate (PO_4^{-3}) concentrations in water samples (W1 to W8) during the rainy season are spatially represented in Figure 4.45. The study shows that orthophosphate concentrations were distributed within the range of 0.71 ppm and 2.5 ppm (Appendices D and E).

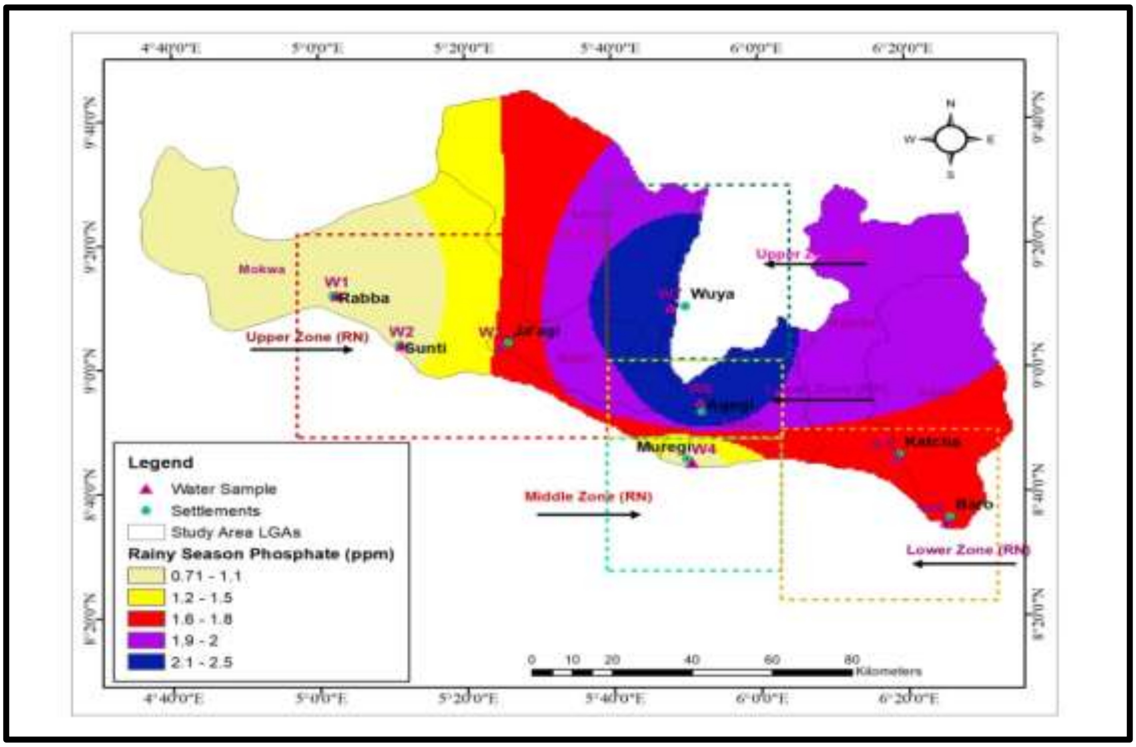


Figure 4.45: Interpolated Distance Weighted Map of Phosphate in Water Samples during Rainy Season
Source: Author's Work, 2019

4.3.1.6 Spatial distribution of phosphate concentrations in water samples during dry season

The results of orthophosphate (PO_4^{-3}) concentrations in water samples (W1 to W8) during the dry season are spatially represented in Figure 4.46. The study shows that orthophosphate concentrations were distributed within the range of 0.23 ppm and 4.56 ppm (Appendices D and E).

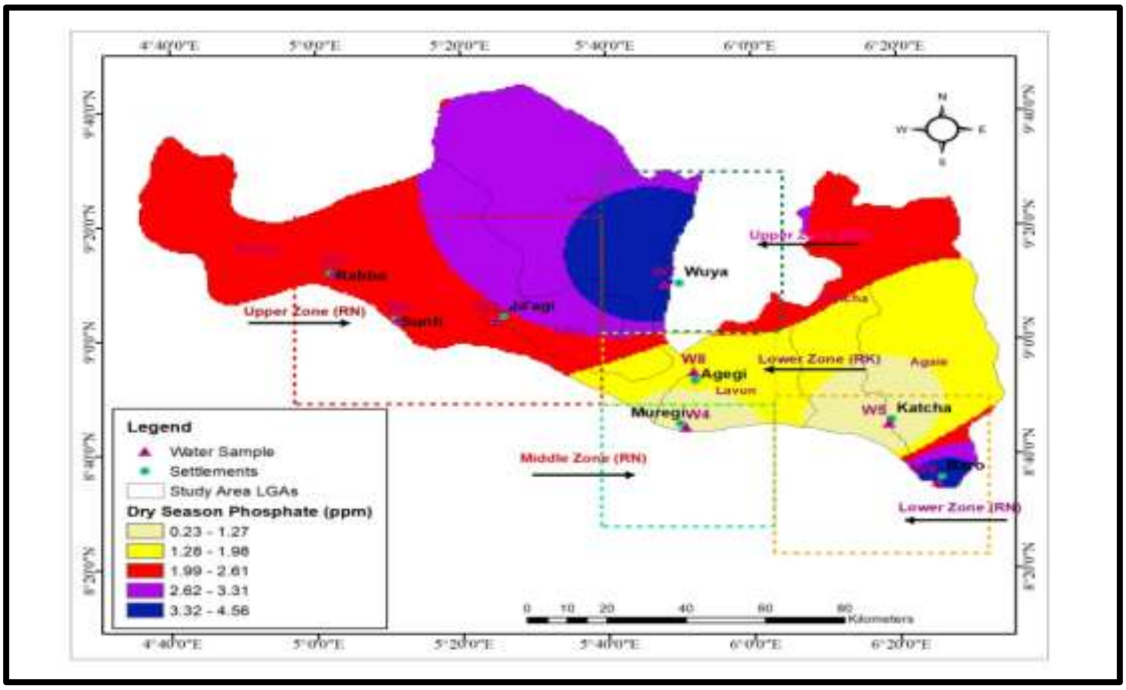


Figure 4.46: Interpolated Distance Weighted Map of Phosphate in Water Samples during Dry Season
Source: Author's Work, 2019

As indicated in Figures 4.45 and 4.46, the findings imply that concentrations of phosphates were significantly less during rainy season in some points than the dry season samples. This can be attributed to dilutions due to precipitations in rainy season. The significant presence of phosphate concentrations in both seasons can be attributed to use of phosphate-based fertilizers as affirmed by farmers and all stakeholders in this study. The value obtained in W6 and W8 during the dry season is above the Nigeria regulatory limit of surface water (Appendix H). The highest concentrations of phosphate during the rainy season were at the upper, lower zones River Kaduna catchments while the highest concentrations during the dry season is at lower zone River Niger catchments and upper zone River Kaduna catchments. Similar concentrations were reported in a study in some cities in Northern Nigeria (Onyenechere *et al.*, 2021). The presence of phosphate concentrations in water of the area even though is largely within the Nigeria regulatory limit of biota protection should be considered a great concern increase in these concentrations can trigger negative socio-economic wellbeing of communities in the study area.

4.3.1.7 Spatial distribution of nitrate concentrations in sediment samples during rainy season

The results of nitrate (NO_3^-) concentrations in sediment samples (S1 to S8) during the rainy season are spatially represented in Figure 4.47. The study shows that nitrate concentrations were distributed within the range of 1.09 ppm and 2.4 ppm (Appendices D and E).

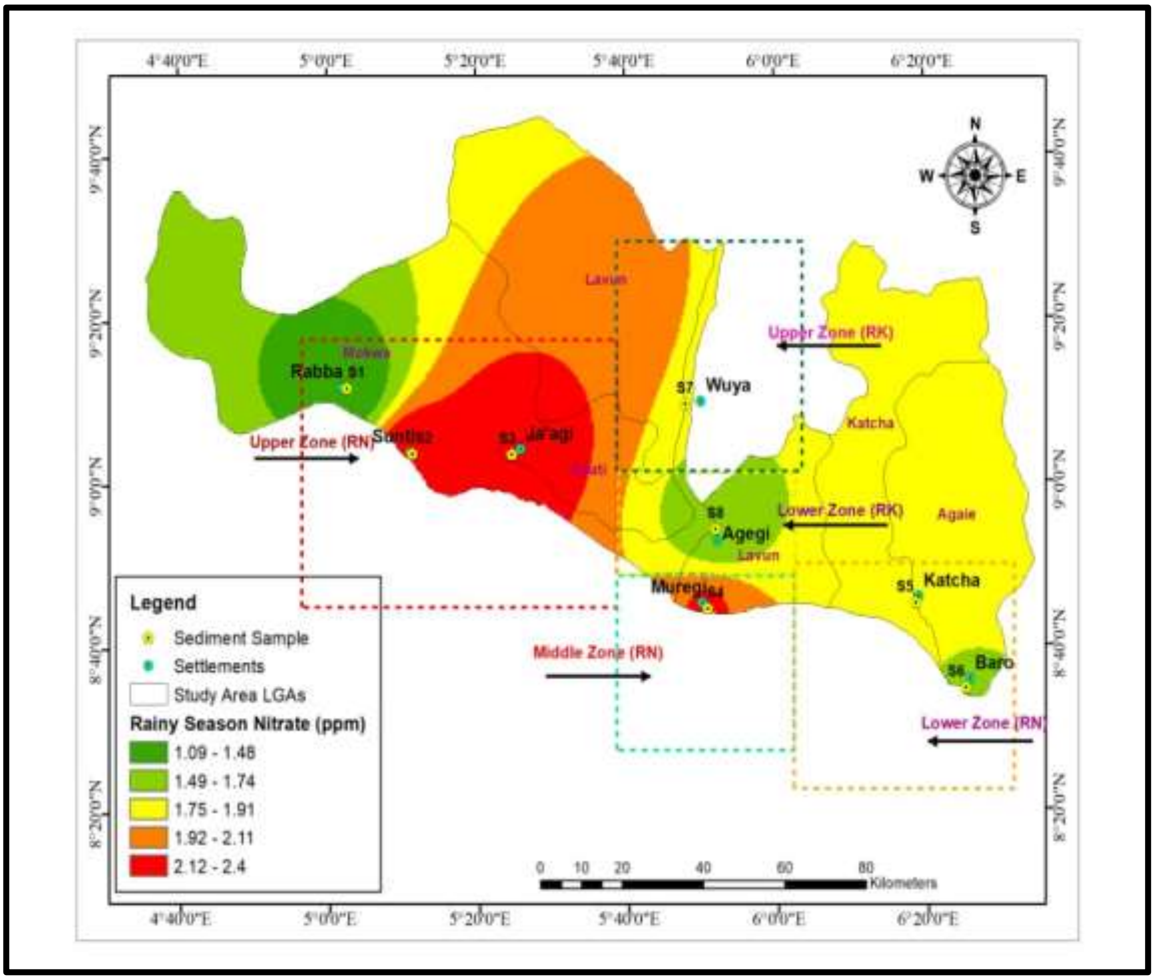


Figure 4.47: Interpolated Distance Weighted Map of Nitrate in Sediment Samples during Rainy Season

Source: Author's Work, 2019

4.3.1.8 Spatial distribution of nitrate concentrations in sediment samples during dry season

The results of nitrate (NO_3^-) concentrations in sediment samples (S1 to S8) during the dry season are spatially represented in Figure 4.48. The study shows that nitrate concentrations were distributed within the range of 1.9 ppm and 3.15 ppm (Appendices D and E).

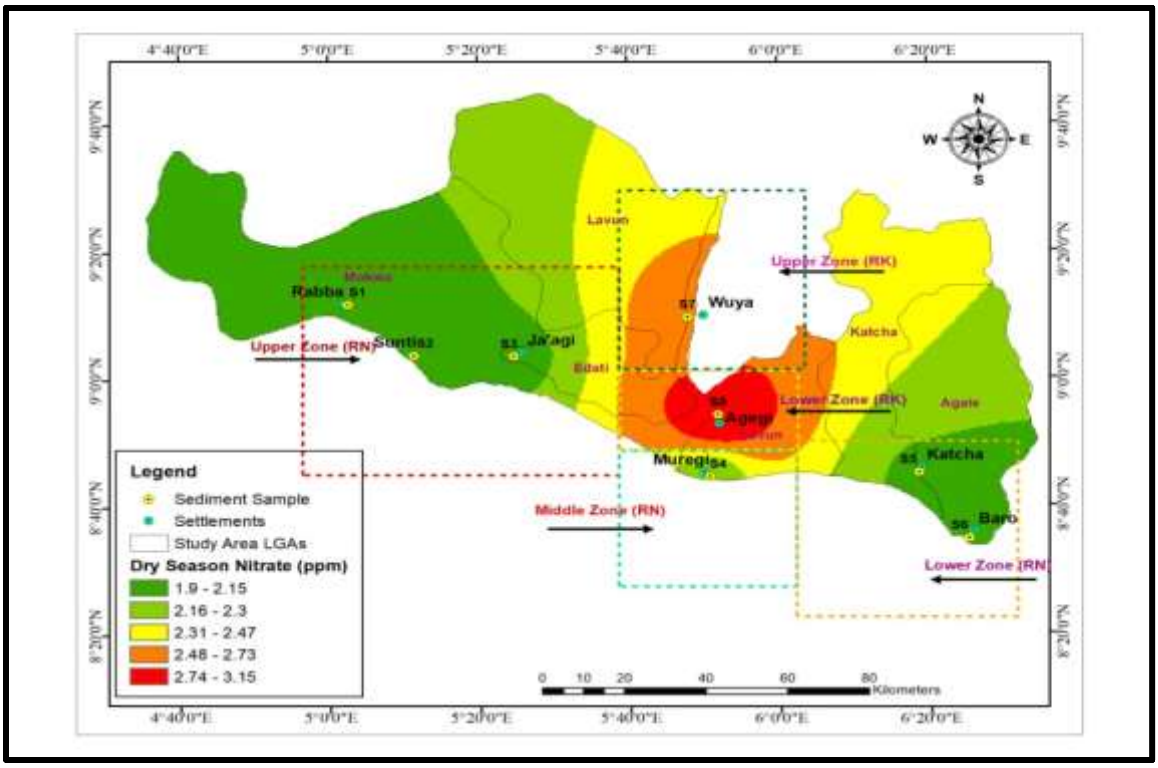


Figure 4.48: Interpolated Distance Weighted Map of Nitrate in Sediment Samples during Dry Season

Source: Author's Work, 2019

As indicated in Figures 4.47 and 4.8, the finding implies that the significant presence of nitrate concentrations in both seasons can be attributed to use of nitrate-based fertilizers as affirmed by farmers and all stakeholders in this study. The value obtained in both seasons is within the Nigeria regulatory limit (Appendix H). The highest concentrations during the rainy season were at the upper and middle zones River Niger catchments, while the highest concentrations during the dry season is at lower zone River Kaduna. Nitrate concentrations in this study are low when compared with a similar study in Keffi, central Nigeria (Reuben *et al.,* 2018). The presence of nitrate in sediments of the area even though within Nigeria regulatory limit of should be considered a great concern as increase in these concentrations can trigger negative socioeconomic wellbeing of communities in the study area.

4.3.1.9 Spatial distribution of nitrite concentrations in sediment samples during rainy season

The results of nitrite (NO_2^-) concentrations in sediment samples (S1 to S8) during the rainy season are spatially represented in Figure 4.49. The study shows that nitrite concentrations were distributed within the range of 0.15 ppm and 0.95 ppm (Appendices D and E).

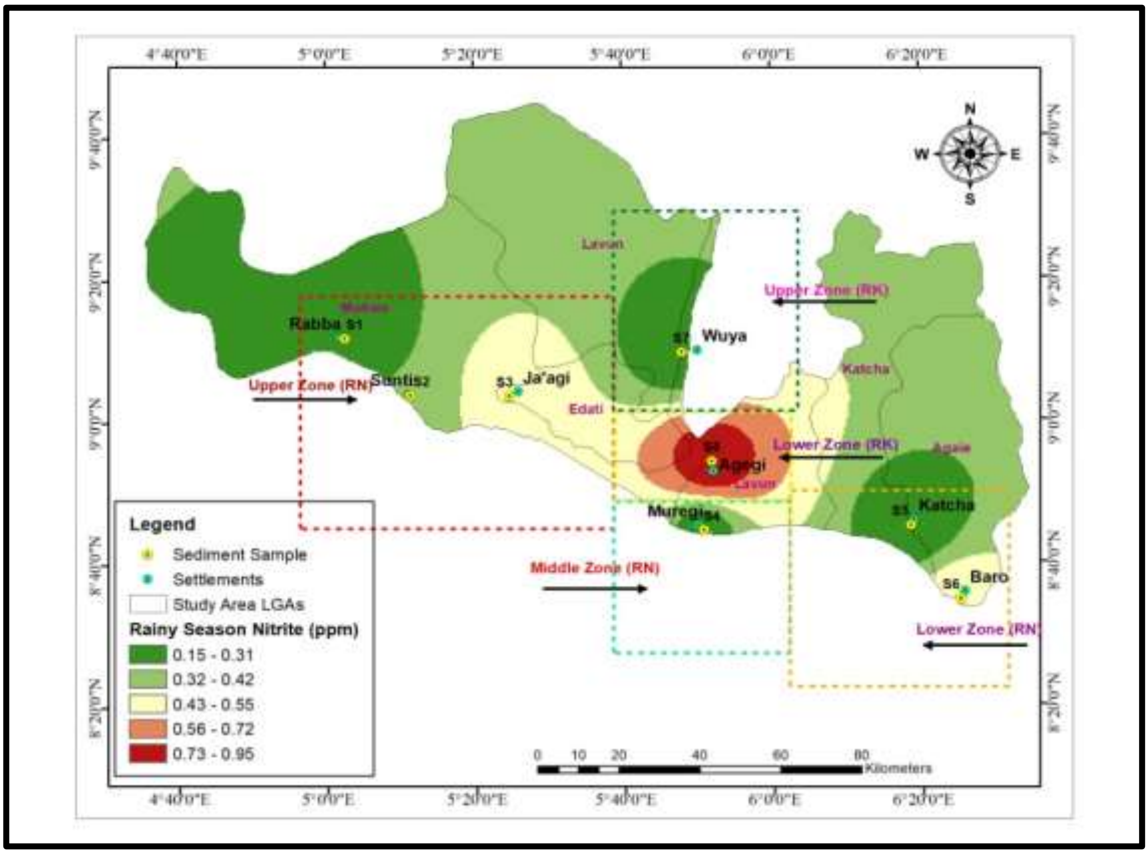


Figure 4.49: Interpolated Distance Weighted Map of Nitrite in Sediment Samples during Rainy Season
Source: Author's Work, 2019

4.3.1.10 Spatial distribution of nitrite concentrations in sediment samples during dry season

The results of nitrite (NO_2^-) concentrations in sediment samples (S1 to S8) during the dry season are spatially represented in Figure 4.50. The study shows that nitrite concentrations were distributed within the range of 0.07 ppm and 1.16 ppm (Appendices D and E).

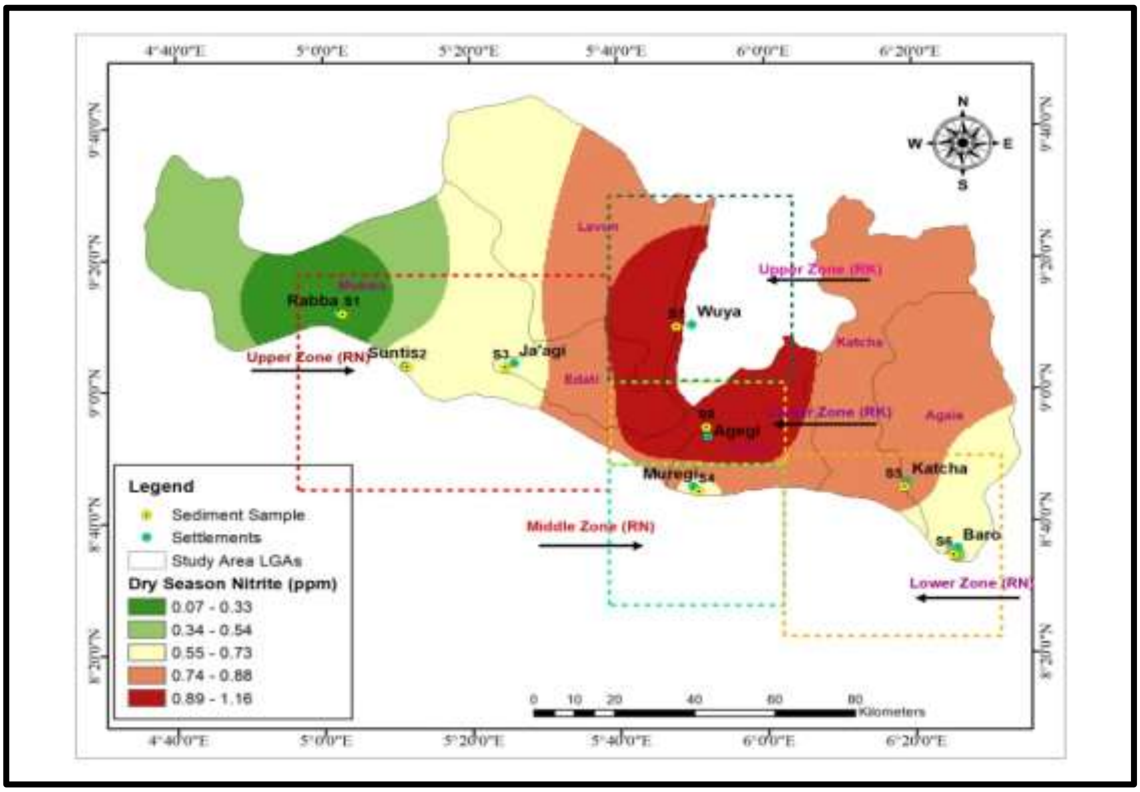


Figure 4.50: Interpolated Distance Weighted Map of Nitrite in Sediment Samples during Dry Season

Source: Author's Work, 2019

As indicated in Figures 4.39 and 4.40, the significant presence of nitrite concentrations in both seasons can be attributed to use of nitrate-based fertilizers as affirmed by farmers and all stakeholders in this study. Nitrite does not present in large quantity because of its rapid conversion to nitrite under normal circumstance. The highest concentrations of nitrite during the rainy season were at the lower zone River Kaduna catchments, while the highest concentrations during the dry season is at upper, lower zones River Kaduna. Similar concentrations of nitrite were reported in a study at Kafin-Koro, central Nigeria (Waziri *et al.*, 2019). The significant presence of nitrite in sediments of the area should be considered a great concern as these concentrations can trigger negative socioeconomic wellbeing of communities in the study area.

4.3.1.11 Spatial distribution of phosphate concentrations in sediment samples during rainy season

The results of orthophosphate (PO_4^{-3}) concentrations in water samples (S1 to S8) during the rainy season are spatially represented in Figure 4.51. The study shows that orthophosphate concentrations were distributed within the range of 0.45 ppm and 1.53 ppm (Appendices D and E).

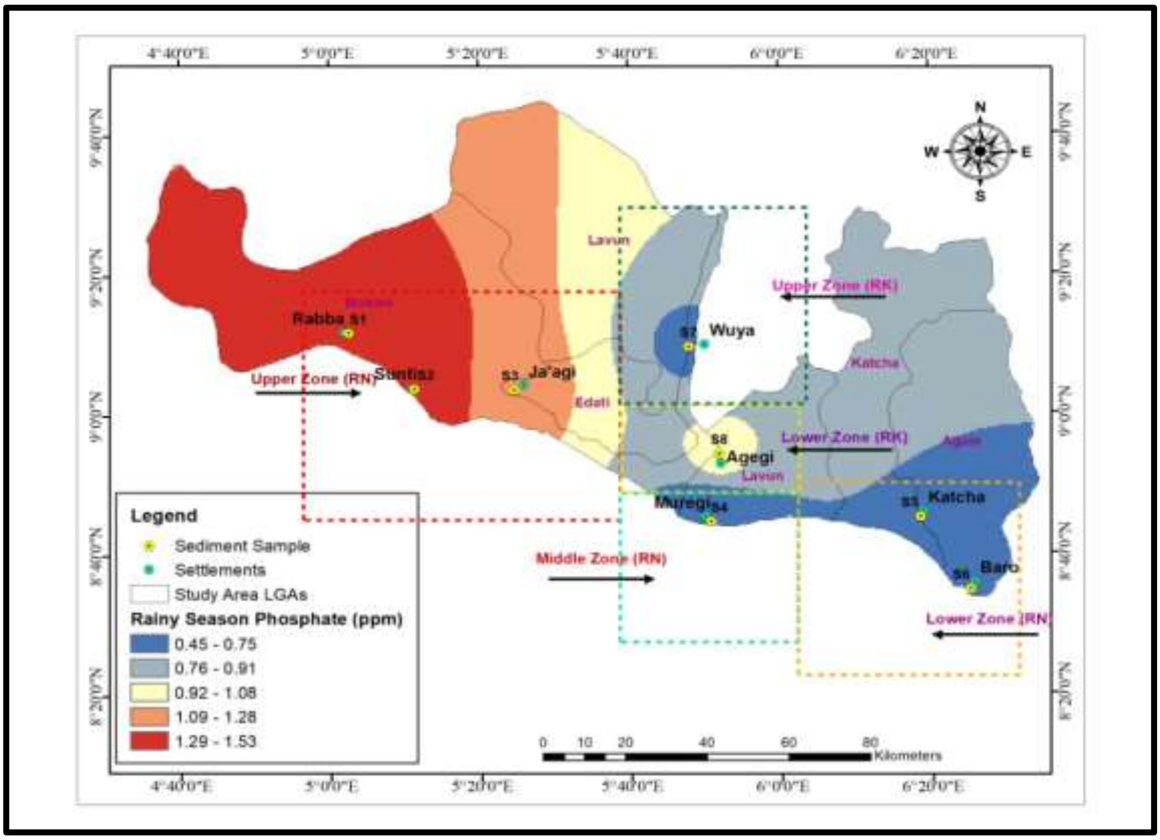


Figure 4.51: Interpolated Distance Weighted Map of Phosphate in Sediment Samples during Rainy Season

Source: Author's Work, 2019

4.3.1.12 Spatial distribution of phosphate concentrations in sediment samples during dry season

The results of orthophosphate (PO_4^{-3}) concentrations in the water samples (S1 to S8) during dry season are spatially represented in Figure 4.52. The study shows that orthophosphate concentrations were distributed within the range of 1.27 ppm and 5.77 ppm (Appendices D and E).

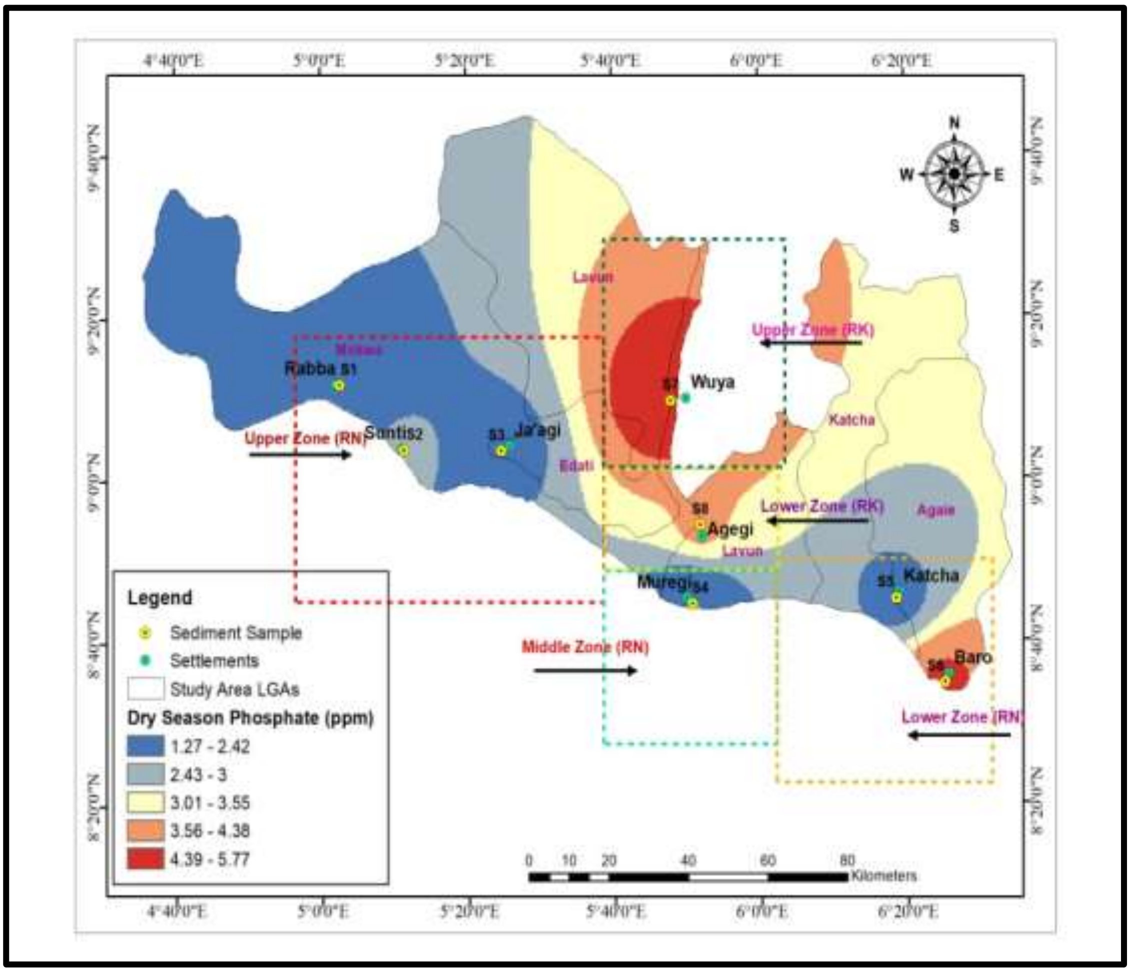


Figure 4.52: Interpolated Distance Weighted Map of Phosphate in Sediment Samples during Dry Season
Source: Author's Work, 2019

As indicated in Figures 4.42 and 4.42, the findings imply that concentrations of phosphates were significantly less during the rainy season than dry season sediment samples. This can be attributed to dilutions due to precipitations in rainy season. The significant presence of phosphate concentrations in both seasons can be attributed to use of phosphate-based fertilizers as affirmed by farmers and all stakeholders in this study. The value obtained in both seasons (except for S7 which is 5.771 ppm) are within Nigeria regulatory limit of biota protections (Appendix H). The highest concentrations of phosphate during the rainy season were in the upper zone Niger River catchments, while the highest concentrations during the dry season is at the lower zone Niger River catchments and upper zone Kaduna River catchments. Similar concentrations were reported in a study in some cities in Northern Nigeria (Onyenechere et al., 2021). The presence of phosphate concentrations in sediments of the area even though is largely within Nigeria regulatory limits should be considered a great concern increase in these concentrations can trigger negative socioeconomic. The presence of phosphate concentrations in sediments of the area even though is largely within Nigeria regulatory limits should be considered a great concern increase in these concentrations can trigger negative socioeconomic wellbeing of communities in the study area.

4.3.1.13 Percentage occurrence of plant minerals detected in water samples during rainy and dry seasons across the sample points

As indicated in Figure 4.53, percentage occurrence of plant minerals detected in water samples across the eight-sample point show nitrate (NO_3^-) in water samples were detected in 87.5% each of the sample points in both seasons. Nitrite (NO_2^-) in water samples were detected in 62.5% of the sample points in rainy season and 100% of the sample points in dry season, while orthophosphate (PO_4^{-3}) in water samples were also detected in 50% of the sample points in rainy season and 100% of the sample points in the dry season sample.

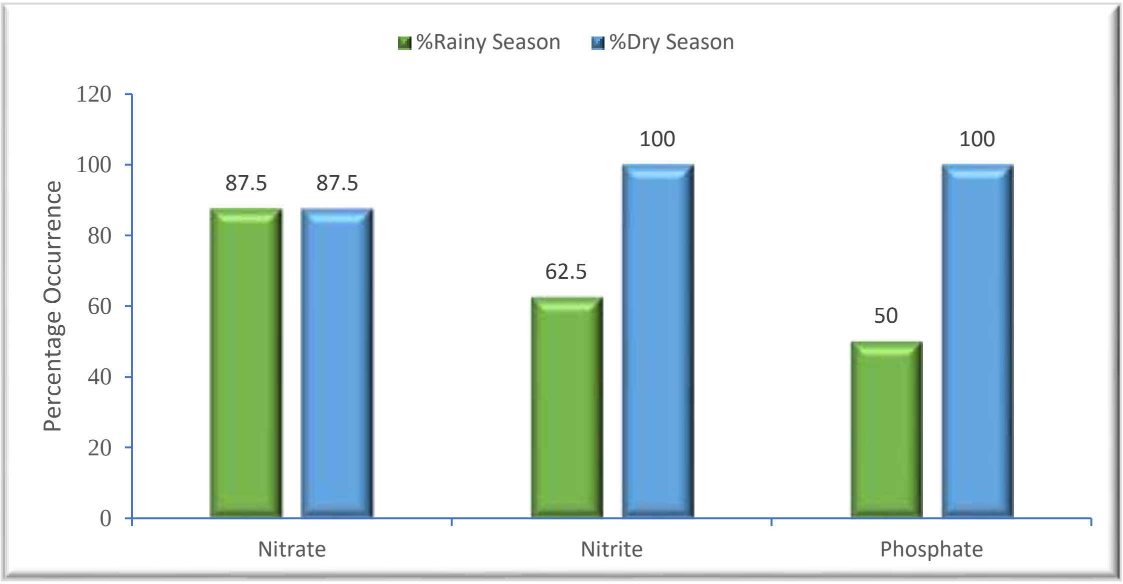


Figure 4.53: Percentage Occurrence of Plant Minerals Detected in Water Samples across the Sample Points during Rainy and Dry season
Source: Author's Work, 2019

The finding implies that 87% of the surface water sample points in the study area were contaminated by nitrate during rainy and dry season. The finding also implies that 62.5% of the surface water sample points in the area were contaminated by nitrite during rainy season, the concentrations increase to 100% in dry season covering the whole sample points. The nitrite values at all the sample points in both seasons were largely above regulatory limits which make the water in the area unfit for consumption and domestic use. Finding further shows that 50% surface water sample points in the area were contaminated with phosphate during rainy season, which increases to 100% in dry season covering the whole sample points. The higher concentrations of nitrite and phosphate in the dry season samples can be related to high values of several physico-chemical parameters like the pH and temperature during the season. Although, the concentrations of nitrate and phosphate are within regulatory limit, unsuitable use of nitrate and phosphate-based fertilizers will lead to more accumulation and elicit negative socio-economic effects on communities in the study area as total dependence on the river for socio-economic livelihoods by the communities was observed during the study. A similar situation has been reported by several researchers in developing countries including Nigeria as indicated by Iliya *et al.* (2019) and Adeyinka, and Olayinka (2019).

4.3.1.14 Percentage occurrence of plant minerals detected in Sediment samples during rainy and dry across the sample points

As indicated in Figure 4.54, percentage occurrence of plant minerals detected in sediment samples across the eight-sample point show nitrate (NO_3^-) was detected in 87.5% of the sample points during rainy season and 100% of the sample in the dry season sample. Nitrite (NO_2^-) in sediment samples were both detected in 100% of the sample points, while orthophosphate (PO_4^{-3}) in sediment samples were also detected in 75% of the sample points in rainy season and 100% of the sample in dry season.

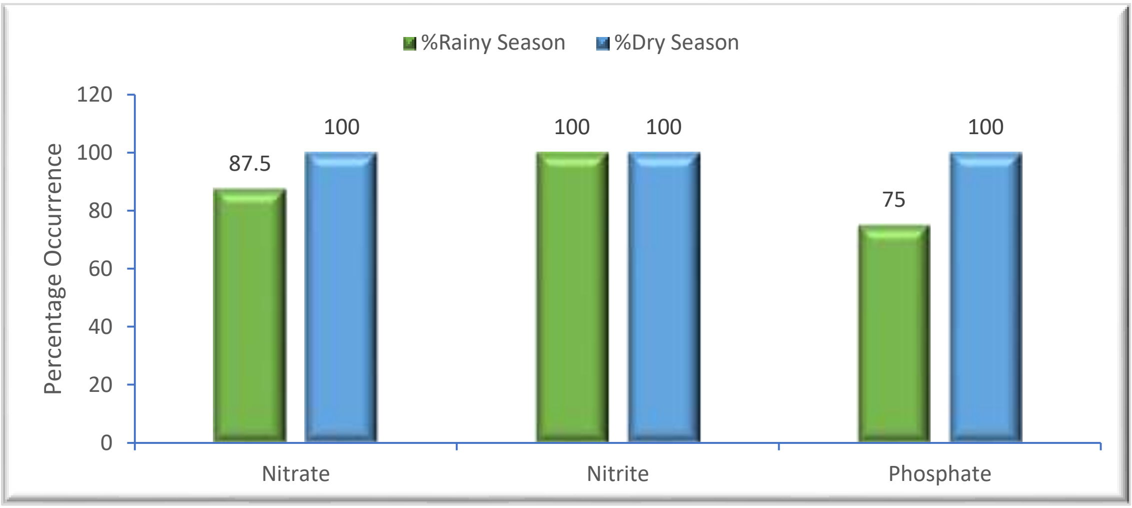


Figure 4.54: Percentage Occurrence of Plant Minerals Detected in Sediment Samples Across the Sample Points during Rainy and Dry season
Source: Author's Work, 2019

The finding implies that 87% of the sediment sample points were contaminated with nitrate during rainy season, which increases to 100% of all the sample points during the dry season in the study area. The finding also implies that 100% of the sample points in both rainy and dry were contaminated by nitrite. Finding further imply that 75% of the sample points were contaminated with phosphate during rainy season, which increases to 100% in dry season covering the whole sample points. The higher concentrations of nitrate, nitrite and phosphate in the dry season samples can be linked to high values of several physico-chemical parameters which include pH and temperature during the season. A similar situation has been reported in developing countries including Nigeria as indicated in a research finding by Magami and Sani (2019). Under certain environmental conditions, nitrate, nitrite, and phosphate concentrations in the soil can get released back to the water or absolved by plant, animals and get them contaminated, leading to negative socio-economic effects on communities in the survey area as high dependence on the river for socio-economic livelihoods of the communities was observed during the study.

4.3.2 Seasonal concentrations of organochlorine pesticide residues detected in water and sediment samples

4.3.2.1 Seasonal concentrations of organochlorine pesticide residues detected in water samples W1

As indicated in Table 4.8, divers' organochlorine pesticide residues were instrumentally detected in both seasons. They include alpha.-lindane, endosulfan ether, .alpha.-endosulfan, dieldrin, endosulfan and mitotane. Four other compounds of organochlorine pesticide residues are also present in the sample but below instrument's detection. These include heptachlor, aldrin, endrin and endosulfan (Appendix F). Among all organochlorine pesticide compounds sought in this sample, percentage detection revealed organochlorine pesticide compounds detected in the rainy and dry season constituted 16%

and 31.3%, respectively, those present but below detection limit were 5.3% and 18.75% in rainy and the dry season samples respectively.

Table 4.8: Seasonal Concentrations of Organochlorine Pesticide Residues Detected in Water Samples W1

	Rainy Season, 2018		Dry Season, 2018		
Compound	**RT. (mins)**	**Conc. (ppm)**	**RT. (mins)**	**Conc. (ppm)**	**MRL (ppm)**
.delta.-Pentachlorocyc...	0.000	N.D	0.000	N.D	-
.delta.-Lindane	0.000	N.D	0.000	N.D	2
.alpha.-Lindane	0.000	N.D	10.082	0.01	2
Endosulfan ether	14.491	0.02	10.868	0.07	N.C
Heptachlor	0.000	N.D	11.473	0.00	0.03
Aldrin	0.000	N,D	12.125	0.00	0.03
Isodrin	0.000	N.D			
Heptachlor epoxide	0.000	N.D	0.000	N.D	0.03
Chlordane	0.000	N.D	0.000	N.D	-
DDMU	0.000	N.D	0.000	N.D	2
trans-Nonachlor	0.000	N.D			
.alpha.-Endosulfan			13.863	0.01	NC
Dieldrin	18.937	0.01	14.287	0.01	0.03
Endrin	0.000	N.D	14.554	0.00	N.C
Endosulfan	20.173	0.00	15.025	0.02	N.C
Endosulfan sulfate	0.000	N.D	0.000	N.D	N.C
o,p'-DDT			0.000	N.D	2
p,p'-DDE		No Calib			2
Endrin ketone	0.000	N.D	0.000	N.D	-
Mitotane	20.173	0.21			2
Methoxychlor	0.000	N.D			20

Key: N.D. = Not Detected. n = 19 and 16 compounds analysed. RT = Retention Time. MRL = Maximum Residue Limit (WHO, 2001; FAO and WHO, 2016). N.C – Not classified.

Source: Author's Work, 2019

A mitotane, a derivative of o,p'-DDT, analysed only in the rainy season sample, detected at residual concentrations of 0.21 ppm is the most detected organochlorine compound in the sample location. The value of mitotane in this sample is within maximum residue limit. Residue of endosulfan ether, a degradation of endosulfan with the same health and environmental effects as the parent compound detected in rainy season at concentrations of 0.07 ppm, decreases to 0.02 ppm in the dry season sample. Higher concentrations of endosulfan ether during rainy season can be ascribed to intense use of endosulfan in farming as indicated by farmers and stakeholders interviewed in the study area. The parent endosulfan residues detected in the rainy season sample at residual concentrations of 0.02 ppm and Below Detected Level (BDL) in the dry season sample confirmed the field interview finding which shows the use of endosulfan under the trade name thionex and thiodan. Residue of endosulfan and its derivatives are generally not classified because they are considered banned and not tolerated in any quantities (WHO, 2001; FAO and WHO, 2016). The absence of. Alpha. -Lindane in the rainy season sample can be attributed to heavy precipitation against residual concentrations of 0.01 ppm in the dry season sample. The residual concentrations of 0.01 ppm of. Alpha. -Endosulfan analysed in the dry season is within maximum residue limits. Dieldrin residues detected in both seasons' samples at lowest value of 0.01 ppm confirmed the qualitative information gotten in this study. The value of dieldrin in this sample is within maximum residue limit. Similar concentrations of organochlorine compounds have reported in a study by Adeshina *et al.* (2019) and Adeyinka *et al.* (2019). The presence of heptachlor, aldrin, endrin and endosulfan residues below instrumental detection in the rainy season sample may be attributed to previous uses, transboundary chemical movement, and trace quantities in currently use pesticide compounds.

4.3.2.2 Seasonal concentrations of organochlorine pesticides detected in water samples W2

As indicated in Table 4.9, divers' organochlorine pesticide residues were instrumentally detected in both seasons. They include endosulfan ether, Isodrin, .alpha.-endosulfan, dieldrin, endosulfan, mitotane, o,p'-DDT and heptachlor epoxide (Appendix F). Among all organochlorine pesticide compounds sought, percentage detection revealed organochlorine pesticide compounds detected in the rainy and the dry season samples constituted 15.8% and 31.3% respectively, those present but below detection limit were 5.3% and 12.5% in rain and dry season respectively.

Table 4.9: Seasonal Concentrations of Organochlorine Pesticide Residues Detected Water Samples W2

	Rainy Season, 2018		Dry Season, 2018		
Compound	RT. (mins)	Conc. (ppm)	RT. (mins)	Conc. (ppm)	MRL (ppm)
.delta.-Pentachlorocyc...	0.000	N.D	0.000	N.D	-
.delta.-Lindane	0.000	N.D	0.000	N.D	2
.alpha.-Lindane	0.000	N.D	0.000	N.D	2
Endosulfan ether	14.525	0.01	10.858	0.01	N.C
Heptachlor	0.000	N.D	0.0000	N.D	0.03
Aldrin	0.000	N.D	12.177	0.00	0.03
Isodrin	16.774	0.01			
Heptachlor epoxide	0.000	N.D	13.168	0.00	0.03
Chlordane	0.000	N.D	0.000	N.D	-
trans-Nonachlor	0.000	N.D			
DDMU	0.000	N.D	0.000	N.D	2
.alpha.-Endosulfan			14.101	0.01	N.C
Dieldrin	18.862	N.D	14.292	0.01	0.03
p,p'-DDE	0.000	N.D			2
Endrin	0.000	N.D	0.000	N.D	N.C
Endosulfan	20.058	0.00	14.935	0.01	N.C
Mitotane	20.178	0.13			2
Endosulfan sulfate	0.000	N.D	0.000	N.D	N.C
o,p'-DDT			16.539	0.02	2
Endrin ketone	0.000	N.D	0.000	N.D	N.C
Methoxychlor	0.000	N.D			20

Key: N.D. = Not Detected. n = 19 and 16 compounds analysed. RT = Retention Time. MRL = Maximum Residue Limit (WHO, 2001; FAO and WHO, 2016). N.C – Not classified.
Source: Author's Work, 2019

A mitotane, a derivative of o,p'-DDT, analysed only on the rainy season sample, detected at residual concentrations of 0.13 ppm is the most detected organochlorine compound in the sample location. The value of mitotane is within maximum residue limit. Residues of endosulfan ether, a degradation of endosulfan with the same health and environmental effects as the parent compound detected in both seasons at concentrations of 0.01 ppm confirmed the qualitative information from all stakeholders in this study. Endosulfan ether is not classified, not tolerated in any quantities, and considered banned. Isodrin, an isomer of aldrin analysed only in the rainy season sample detected at residual concentrations of 0.01 ppm confirmed qualitative information indicating its use in the study area. .alpha.-endosulfan detected at concentrations of 0.01 ppm confirmed the submission by stakeholders in the area. Detection of dieldrin only in the dry season sample at residual concentrations of 0.01 ppm confirmed qualitative information gotten in this study. The value obtained of dieldrin is within maximum residue limit. Endosulfan residues detected in both season sample BDL and 0.01 ppm confirms the field interview finding which shows the use of endosulfan under the trade name thionex and thiodan. Endosulfans are generally not classified because they are considered banned and not tolerated in any quantities (WHO, 2001; FAO and WHO, 2016). Residual concentrations of 0.02 ppm of o,p'-DDT detected only in the dry season sample can be attributed to absence of precipitation.

4.3.2.3 Seasonal concentrations of organochlorine pesticide residues detected in water samples W3

As indicated in Table 4.10, divers' organochlorine pesticide residues were instrumentally detected in both seasons. They include Endosulfan ether, dieldrin, endosulfan, mitotane, heptachlor epoxide and endrin ketone. Residues of .delta.-lindane, heptachlor, aldrin, heptachlor epoxide and o,p'-DDT were also detected at BDL in the area (Appendix F). Among all organochlorine pesticide compounds sought, percentage detection revealed organochlorine pesticide compounds detected in the rainy and the dry season samples constituted 15.8% and 20%, those present but below detection limit were 5.3% and 40% in rainy and the dry season samples respectively.

Table 4.10: Seasonal Concentrations of Organochlorine Pesticide Residues Detected in Water Samples W3

	Rainy Season, 2018		Dry Season, 2018		
Compound	RT. (mins)	Conc. (ppm)	RT. (mins)	Conc. (ppm)	MRL (ppm)
.delta.-Pentachlorocyc...	0.000	N.D	0.000	N.D	-
.delta.-Lindane	0.000	N.D	9.482	0.00	2
.alpha.-Lindane	0.000	N.D	0.00	N.D	2
Endosulfan ether	14.508	0.04	10.844	0.04	N.C
Heptachlor	0.000	N.D	11.178	0.00	0.03
Aldrin	0.000	N.D	12.116	0.00	0.03
Isodrin	0.000	N.D			
Heptachlor epoxide	0.000	N.D	12.901	0.00	0.03.
Chlordane	0.000	N.D	0.000	N.D	-
DDMU	0.000	N.D	0.000	N.D	2
trans-Nonachlor	0.000	N.D			
.alpha.-Endosulfan			0.000	N.D	N.C
Dieldrin	18.862	0.01	14.287	0.00	0.03
p,p'-DDE	0.000	N.D			2
Endrin	0.000	N.D	0.000	N.D	N.C
Endosulfan	20.167	0.00	14.892	0.01	N.C
Mitotane	20.155	1.04			2
Endosulfan sulfate	0.000	N.D			N.C
o,p'-DDT			15.620	0.00	2
Endrin ketone	0.000	N.D	16.506	0.13	N.C
Methoxychlor	0.000	N.D			20

Key: N.D. = Not Detected. n = 19 and 16 compounds analysed. RT = Retention Time. MRL = Maximum Residue Limit (WHO, 2001; FAO and WHO, 2016). N.C – Not classified.

Source: Author's Work, 2019

A mitotane, a derivative of o,p'-DDT, analysed only on the rainy season sample, detected at residual concentrations of 1.04 ppm is the most detected organochlorine compound in the sample location. The concentrations of mitotane in this sample is within maximum residue limit. Residues of endosulfan ether, a degradation of endosulfan with the same health and environmental effects as the parent compound detected in both seasons at concentrations of 0.04 ppm each confirmed qualitative information indicating its use in the study area. Endosulfan ether are not classified due to high toxicity and considered banned. Endrin ketone was second highest detected organochlorine compound in the sample at 0.13 ppm in dry season but not detected in rainy season. Its presence in dry season can be attributed to higher pH in the season. Endrin are not classified due to high toxicity. Dieldrin residues detected higher in rainy seasons sample at concentrations of 0.01 ppm against BDL in the dry season sample, confirmed the qualitative information gotten in this study. The value of dieldrin residue in this sample is within maximum residue limit. The residual concentrations of endosulfan detected in rainy and the dry season samples at BDL and 0.01 ppm respectively, confirmed the field interview finding which shows the use of endosulfan under the trade name thionex and thiodan. Endosulfans are generally not classified because they are considered banned and not tolerated in any quantities (WHO, 2001; FAO and WHO, 2016). o,p'-DDT was analysed and detected only in the dry season sample at BDL. Heptachlor, aldrin, heptachlor epoxide, endrin and o,p'-DDT detected in the dry season sample all at BDL may be attributed to previous uses, transboundary chemical movement and trace quantities in currently use pesticide compounds.

4.3.2.4 Seasonal concentrations of organochlorine pesticide residues detected in water Samples W4

As indicated in Table 4.11, divers' organochlorine pesticide residues were instrumentally detected in both seasons. They include Endosulfan ether, .alpha.-endosulfan, endosulfan, mitotane and endrin ketone. Residues of heptachlor, aldrin, heptachlor epoxide, endrin and o,p'-DDT were also detected at concentrations of BDL (Appendix F). Among all organochlorine pesticide compounds sought, percentage detection revealed organochlorine pesticide compounds detected in the rain and the dry season samples cconstituted 1% and 33% respectively, those present but below detection limit were 6% and 33% in rain and the dry season respectively.

Table 4.11: Seasonal Concentrations of Organochlorine Pesticide Residues Detected in Water Samples W4

	Rainy Season, 2018		Dry Season, 2018		
Compound	RT. (mins)	Conc. (ppm)	RT. (mins)	Conc. (ppm)	MRL (ppm)
.delta.-Pentachlorocyc...	0.000	N.D	0.000	N.D	-
.delta.-Lindane	0.000	N.D	0.000	N.D	2
.alpha.-Lindane	0.000	N.D	0,000	N.D	2
Endosulfan ether	14.525	0.06	10.873	0.13	N.C
Heptachlor	0.000	N.D	11.825	0.00	0.03
Aldrin	0.000	N.D	12.111	0.00	0.03
Isodrin	0.000	N.D			
Heptachlor epoxide	0.000	N.D	12.982	0.00	0.03
Chlordane	0.000	N.D	0.000	N.D	-
DDMU	0.000	N.D	0.000	N.D	2
.alpha.-Endosulfan			13.711	0.01	N.C
Dieldrin	18.902	0.00	14.287	0.01	0.03.
p,p'-DDE	0.000	N.D			2
Endrin	0.000	N.D	15.097	0.00	N.C
Endosulfan	0.000	N.D	14.892	0.01	N.C
o,p'-DDT			15.963	0.00	2
Mitotane	20.167	0.27			2
Endosulfan sulfate	0.000	N.D			N.C
Endrin ketone	0.000	N.D	16.530	0.06	N.C
Methoxychlor	0.000	N.D			20

Key: N.D. = Not Detected. n = 18 and 15 compounds analysed. RT = Retention Time. MRL = Maximum Residue Limit (WHO, 2001; FAO and WHO, 2016). N.C – Not classified.

Source: Author's Work, 2019

A mitotane, a derivative of o,p'-DDT, analysed only on the rainy season sample, detected at residual concentrations of 0.27 ppm is the most detected organochlorine compound in the sample location. The value obtained of mitotane residue is within maximum residue limit. Residues of endosulfan ether, a degradation of endosulfan with the same health and environmental effects as the parent compound detected in the rainy season sample at residual concentrations of 0.06 ppm, increases in the dry season sample at residual concentrations of 0.13 ppm. .alpha.-endosulfan was analysed only in the dry season sample and was detected at residual concentrations of 0.01 ppm. The presence of these endosulfan derivatives corroborated qualitative information obtained in this study that indicated the use of their parent compound. Endosulfan ether and. alpha.-endosulfan residues are considered banned and not classified due to their toxicity. Dieldrin residue detected at BDL in rainy seasons sample increases to 0.01 ppm at the dry season sample. Low concentrations in the rainy season sample may be due precipitation and lower temperature. The value of dieldrin residue is within maximum residue limit. Its presence in the samples confirmed the qualitative information on dieldrin use in this study.

Residues of endosulfan detected in the rainy season samples at BDL increases to 0.01 ppm in dry season, confirming the field interview finding which shows the use of endosulfan under the trade name thionex and thiodan. Endosulfans are generally not classified because they are considered banned and not tolerated in any quantities (WHO, 2001; FAO and WHO, 2016). o,p'-DDT analysed and detected only in the dry season sample at BDL. Its trace presence can be attributed to past uses, transport boundary chemical migration or trace presence in active ingredient of currently used pesticides in the area. Residue of endrin ketone detected in the dry season sample only at concentrations of 0.06 ppm. Endrin ketone is considered banned and not classified due to high toxicity. Heptachlor, aldrin, heptachlor epoxide, o,p'-DDT detected in the dry season sample all at BDL can be attributed to their past uses.

4.3.2.5 Seasonal concentrations of organochlorine pesticide residues detected in water samples W5

As indicated in Table 4.12, divers' organochlorine pesticide residues were detected in both seasons. They include endosulfan ether, .alpha.-endosulfan, dieldrin, endosulfan, mitotane and endrin ketone. Aldrin and DDMU were detected BDL (Appendix F). Among all organochlorine pesticide compounds sought, percentage detection revealed organochlorine pesticide compounds detected in the rainy and the dry season samples constitute 15.8% and 25% respectively, those present but below detection limit were 10.5% and 12.5% in rainy and dry season respectively.

Table 4.12: Seasonal Concentrations of Organochlorine Pesticide Residues Detected in Water Samples W5

	Rainy Season, 2018		Dry Season, 2018		
Compound	RT. (mins)	Conc. (ppm)	RT. (mins)	Conc. (ppm)	MRL (ppm)
.delta.-Pentachlorocyc...	0.000	N.D	0.000	N.D	-
.delta.-Lindane	0.000	N.D	0.000	N.D	2
.alpha.-Lindane	0.000	N.D	0,000	N.D	2
Endosulfan ether	14.514	0.03	10.863	0.04	-
Heptachlor	0.000	N.D	0.000	N.D	0.03
Aldrin	0.000	N.D	12.220	0.00	0.03
Isodrin	0.000	N.D			
Heptachlor epoxide	0.000	N.D	0.000	N.D	0.03
Chlordane	0.000	N.D	0.000	N.D	-
DDMU	17.706	0.00	0.000	N.D	-
trans-Nonachlor	0.000	N.D			
.alpha.-Endosulfan			13.854	0.01	-
Dieldrin	18.914	0.01	14.273	0.00	0.03
p,p'-DDE	0.000	N.D			2
Endrin	0.000	N.D	0.000	N.D	N.C
Endosulfan	20.230	0.00	14.730	0.01	N.C
Mitotane	20.150	0.23			
Endosulfan sulphate	0.000	N.D	0.000	N.D	-
o,p'-DDT			0.000	N.D	2
Endrin ketone	0.000	N.D	16.515	0.12	-
Methoxychlor	0.000	N.D			20

Key: N.D. = Not Detected. n = 18 and 15 compounds analysed. RT = Retention Time. MRL = Maximum Residue Limit (WHO, 2001; FAO and WHO, 2016). N.C – Not classified.

Source: Author's Work, 2019

Mitotane, a derivative of o,p'-DDT, analysed only on the rainy season sample, detected at residual concentrations of 0.23 ppm is the most detected organochlorine compound in the sample location. The concentrations of mitotane in this sample is within maximum residue limit. Endosulfan ether, a degradation of endosulfan with the same health and environmental effects as the parent compound detected in the rainy season sample at residual concentrations of 0.03 ppm, increases to 0.4 ppm in the dry season sample. The increase concentrations in the dry season sample may be due higher temperature. .alpha.-endosulfan analysed only in the dry season sample and detected at residual concentrations of 0.01 ppm. Its presence can be ascribed to the use of its parent compound in the area as confirmed in this study. Dieldrin residue detected at residual concentrations of 0.01 ppm in the rainy season sample declined to BDL in the dry season sample. Dieldrin presence in the area confirmed the qualitative information on it use in this study. Residual concentrations of dieldrin is within maximum residue limit. Endosulfan residue detected in the dry season sample at residual concentrations of 0.01 ppm decrease to BDL in rainy season, confirming the field interview finding which shows the use of endosulfan under the trade name thionex and thiodan in the study area. Endosulfans are generally not classified because they are considered banned and not tolerated in any quantities (WHO, 2001; FAO and WHO, 2016). Residue of endrin ketone detected in the dry season sample only at concentrations of 0.12 ppm can be attributed to higher temperature in the season. Residues of aldrin and DDMU detected at BDL in dry and the rainy season samples can also be attributed to agriculture runoff.

4.3.2.6 Seasonal concentrations of organochlorine pesticide residues detected in water samples W6

As indicated in Table 4.13, divers' organochlorine pesticide residues were instrumentally detected during rainy and dry seasons. They include .delta.-pentachlorocyclohexane, .delta.-lindane, .alpha.-lindane, endosulfan ether, .alpha.-endosulfan, dieldrin, endosulfan, mitotane, endrin ketone, p.p'-DDE, endrin, aldrin and heptachlor epoxide (Appendix F). Among all organochlorine pesticide compounds sought, percentage detection revealed organochlorine pesticide compounds detected in the rainy and the dry season samples constituted 37.5% and 31.3% respectively, those present but below detection limit were 25% and 12.5% in rainy and dry season respectively.

Table 4.13: Seasonal Concentrations of Organochlorine Pesticide Residues Detected in Water Samples W6

	Rainy Season, 2018		Dry Season, 2018		
Compound	RT. (mins)	Conc. (ppm)	RT. (mins)	Conc. (ppm)	MRL (ppm)
.delta.-Pentachlorocyc...	10.182	0.03	0.000	N.D	-
.delta.-Lindane	14.496	0.02	0.000	N.D	2
.alpha.-Lindane	13.106	0.01	0,000	N.D	2
Endosulfan ether	14.485	0.04	10.859	0.03	N.C
Heptachlor	0.000	N.D	0.000	N.D	0.03
Aldrin	0.000	N.D	12.097	0.00	0.03
Heptachlor epoxide	0.000	N.D	12.906	0.00	0.03
Chlordane	0.000	N.D	0.000	N.D	-
DDMU	-	-	0.000	N.D	2
.alpha.-Endosulfan	18.124	0.00	13.825	0.01	N.C
Dieldrin	18.771	0.01	14.268	0.01	0.03
p,p'-DDE	18.902	0.00	-	-	2
Endrin	19.320	0.00	0.000	N.D.	N.C
Endosulfan	19.732	0.00	14.735	0.01	N.C
Mitotane	20.258	0.17	-	-	2
Endosulfan sulfate	0.000	N.D	0.000	N.D	N.C
o,p'-DDT	-	-	0.000	N.D	2
Endrin ketone	0.000	N.D	16.540	0.10	N.C

Key: N.D. = Not Detected. n = 16 and 16 compounds analysed. RT = Retention Time. MRL = Maximum Residue Limit (WHO, 2001; FAO and WHO, 2016). N.C – Not classified.

Source: Author's Work, 2019

.delta.-Pentachlorocyclohexane was detected at residual concentrations of 0.03 ppm in the rainy season sample can be attributed to agriculture runoff. Residue of .delta.-lindane detected at concentrations of 0.02 ppm in rainy season and .alpha.-lindane at residual concentrations of 0.01 ppm in rainy season can be attributed to trace quantities in currently use pesticide compounds being used in the study area. Endosulfan ether, a degradation of endosulfan with the same health and environmental effects as the parent compound detected in the rainy season sample at residual concentrations of 0.04 ppm, decreases to 0.3 ppm in the dry season sample. The higher concentrations in the rainy season sample may be due higher application of endosulfan pesticides in the season as revealed by the stakeholders in this study. .alpha.-endosulfan residues detected at BDL in the rainy season sample increases to 0.01 ppm in the dry season sample. Its presence can be ascribed to the use of its parent compound in the area as confirmed in this study. Dieldrin residue detected at residual concentrations of 0.01 ppm each in both seasons confirmed the qualitative information on it use in this study. Residual concentrations of dieldrin is within maximum residue limit. Endosulfan residue detected in the rainy season sample at residual concentrations of BDL increases to 0.01 ppm in dry season. The higher concentrations in the dry season sample can be ascribed to higher temperature in the season. It presence in the location confirmed the field interview finding which shows the use of endosulfan under the trade name thionex and thiodan in the study area. Endosulfans are generally not classified because they are considered banned and not tolerated in any quantities (WHO, 2001; FAO and WHO, 2016). Residue of endrin ketone detected in the dry season sample only at concentrations of 0.12 ppm can be attributed to higher temperature in the season.

Mitotane, a derivative of o,p'-DDT, analysed only in the rainy season sample, detected at residual concentrations of 0.17 ppm is the most detected organochlorine compound in the sample location. The concentrations of mitotane in this sample is within maximum residue limit. Residues of p.p'-DDE and endrin detected at BDL in the rainy season sample, and aldrin and heptachlor epoxide also detected at BDL in dry season can also be attributed to agriculture runoff.

4.3.2.7 Seasonal concentrations of organochlorine pesticide residues detected in water samples W7

As indicated in Table 4.14, divers' organochlorine pesticide residues were instrumentally detected during rainy and dry seasons. They include endosulfan ether, heptachlor, isodrin, .alpha.-endosulfan, dieldrin, endrin, endosulfan, mitotane, endrin ketone, .delta.-

pentachlorocylohezene, .alpha.-lindane, methoxychlor and Aldrin (Appendix F). Among all organochlorine pesticide compounds sought, percentage detection revealed organochlorine pesticide compounds detected in the rainy and the dry season samples constituted 26% and 31.3% respectively, those present but below detection limit were 21% and 18.8% in rainy and dry season respectively.

Table 4.14: Seasonal Concentrations of Organochlorine Pesticides Detected in Water Samples W7

	Rainy Season, 2018		Dry Season, 2018		
Compound	RT. (mins)	Conc. (ppm)	RT. (mins)	Conc. (ppm)	MRL (ppm)
.delta.-Pentachlorocyc...	10.445	0.00	0.000	N.D	-
.delta.-Lindane	0.000	N.D	0.000	N.D	2
.alpha.-Lindane	11.538	0.00	0,000	N.D	2
Endosulfan ether	14.514	0.02	10.858	0.05	N.C
Heptachlor	0.000	N.D	11.525	0.03	0.03
Aldrin	0.000	N.D	12.206	0.00	0.03
Isodrin	16.625	0.01	-	-	0.03
Heptachlor epoxide	0.000	N.D	0.000	N.D	0.03
Chlordane	0.000	N.D	0.000	N.D	-
DDMU	0.000	N.D	0.000	N.D	-
trans-Nonachlor	0.000	N.D.	-	-	-
.alpha.-Endosulfan	-	-	13.392	0.01	NC
Dieldrin	18.908	0.02	14.306	0.00	0.03
p,p'-DDE	0.000	N.D	-	-	2
Endrin	19.520	0.01	14.697	0,00	N.C
Endosulfan	19.944	0.00	14.868	0.01	N.C
Mitotane	20.041	0.10	-	-	2
Endosulfan sulfate	0.000	N.D	0.000	N.D	NC
o,p'-DDT			0.000	N.D	2
Endrin ketone	0.000	N.D	16.501	0.02	N.C
Methoxychlor	23.514	0.00	-	-	20

Key: N.D. = Not Detected. n = 19 and 16 compounds analysed. RT = Retention Time. MRL = Maximum Residue Limit (WHO, 2001; FAO and WHO, 2016). NC – Not classified.
Source: Author's Work, 2019

Mitotane, a derivative of o,p'-DDT, analysed only on the rainy season sample, detected at residual concentrations of 0.10 ppm is the most detected organochlorine compound in the sample location. Mitotane value in this sample is within maximum residue limit. Endosulfan ether, a degradation of endosulfan with the same health and environmental effects as the parent compound detected in the rainy season sample at residual concentrations of 0.02 ppm, increases to 0.05 ppm in the dry season sample. Higher concentrations in the dry season sample can be attributed to higher temperature in the area. Heptachlor was not detected in the rainy season sample which can be attributed to to high precipitation but was detected in the dry season sample at concentrations of of 0.03 ppm. The detected concentrations are within maximum residue limit. Isodrin, an isomer of aldrin analysed only in the rainy season sample and detected at residual concentrations of 0.01 ppm is within maximum residue limit. The presence of residue of adrian derivatives corroborated the qualitative information revealed by the stakeholders in this study. .alpha.-endosulfan analysed only in the dry season sample and detected at residual concentrations of 0.01 ppm confirmed the use of its parent compound in the sample location. Dieldrin residues detected at residual concentrations of 0.02 ppm in the rainy season sample decreases to BDL in the dry season sample. The detected concentrations are within maximum residue limit. Dieldrin presence in the area confirmed the qualitative information on it use in this study. Endrin residue detected in the rainy season sample at concentrations of 0.01 ppm declined to BDL in dry season. Endrin is not classified ND as it is considered banned and not tolerated in any quantities. Endosulfan residue detected at concentrations of BDL in the rainy season sample increases to 0.01 ppm in the dry season sample, confirming the field interview finding which shows the use of endosulfan under the trade name thionex and thiodan in the study area. Endosulfans are generally not classified because they are considered banned and not tolerated in any quantities (WHO, 2001; FAO and WHO, 2016).

Endrin ketone, a degredate of endrin with the same health and environmental effects was not detected in the rainy season sample but detected at residual concentrations of 0.02

ppm in the dry season sample which may be attributed to high precipitation and higher temperature in rainy season. Residues of. delta.-pentachlorocylohezene, .alpha.-lindane and methoxychlor detected at BDL in the rainy season sample can be attributed to agriculture runoff and precipitation during the season. Aldrin residue detected BDL in the dry season sample but not detected in the rainy season sample can be attributed to past uses or trace quantities in the presently use pesticide compounds in the study area.

4.3.2.8 Seasonal concentrations of organochlorine pesticide residues detected in water samples W8

As indicated in Table 4.15, divers' organochlorine pesticide residues were instrumentally detected in both seasons. They include .delta.-lindane, .alpha.-lindane, endosulfan ether, isodrin, DDMU, DDT, .alpha.-endosulfan, dieldrin, endrin, endosulfan, mitotane, endosulfan sulphate, endrin ketone, methoxychlor, heptachlor, aldrin and heptachlor epoxide (Appendix F). Among all organochlorine pesticide compounds sought, percentage detection revealed organochlorine pesticide compounds detected in the rain and the dry season samples constituted 2% and 31.3% respectively, those present but below detection limit were 15.8% and 25% in rain and the dry season respectively.

Table 4.15: Seasonal Concentrations of Organochlorine Pesticide Residues Detected in Water Samples W8

	Rainy Season, 2018		Dry Season, 2018		
Compound	RT. (min)	Conc. (ppm)	RT. (min)	Conc. (ppm)	MRL (ppm)
.delta.-Pentachlorocyc...	9.908	0.00	0.000	N.D	-
.delta.-Lindane	14.416	0.07	9.044	0.00	2
.alpha.-Lindane	11.767	0.76	10.839	N.D	2
Endosulfan ether	14.502	15.97	11.258	0.10	N.C
Heptachlor	15.647	0.00	12.173	0.00	0.03
Aldrin	0.000	N.D	12.954	0.00	0.03
Isodrin	16.660	0.02	-	-	-
Heptachlor epoxide	0.000	N.D	12.954	0.00	0.03
Chlordane	0.000	N.D	0.000	N.D	-
DDMU	18.067	0.01	0.000	N.D	-
trans-Nonachlor	0.000	N.D	-	-	-
.alpha.-Endosulfan	-	-	13.777	0.01	N.C
Dieldrin	18.857	0.00	14.282	0.01	0.03
p,p'-DDE	18.983	No Calib	-	-	2
Endrin	19.543	4.71	0.000	N.D	N.C
Endosulfan	19.870	0.01	14.911	0.01	N.C
Mitotane	20.259	0.11	-	-	2
Endosulfan sulfate	21.088	0.03	0.000	N.D	N.C
o,p'-DDT	-	-	0.000	N.D	2
Endrin ketone	0.000	N.D	16.520	0.11	N.C
Methoxychlor	23.371	0.10	-	-	20

Key: N.D. = Not Detected. n = 19 and 16 compounds analysed. RT = Retention Time. MRL = Maximum Residue Limit (WHO, 2001; FAO and WHO, 2016). N.C – Not classified.

Source: Author's Work, 2019

Residues of .delta.-lindane detected at concentrations of 0.07 ppm in the rainy season sample and ND in the dry season sample can be attributed to past uses or trace quantities in in currently use pesticide compounds in study area. .alpha.-lindane, a degradation of lindane also detected at residual concentrations of 0.76 ppm in rain season and ND in the dry season sample. The values of .delta.-lindane and .alpha.-lindane are both within maximum residue limit. The presence of derivatives of lindane in the area can be attributed to past uses, trace quantities in currently use pesticide compounds, or agriculture runoff. Endosulfan ether, a degradation of endosulfan with the same health and environmental effects as the parent compound detected in the rainy season sample at residual concentrations of 15.97 ppm, decreases to 0.10 ppm in the dry season sample.

The high residues of endosulfan degredate can be attributed to intense use of endosulfan compounds as affirmed by the respondents in the study area. Isodrin, an isomer of aldrin was only analysed in the rainy season sample, detected at residual concentrations of 0.02 ppm, confirmed the qualitative information indicating the use of its parent compound. The concentrations are within maximum residue limit. DDMU, a derivative of DDT detected in the rainy season sample at residual concentrations of 0.01 ppm declined to ND in the dry season sample. Concentrations of DDMU in this sample is within maximum residue limit. .alpha.-endosulfan analysed only in the dry season sample with residual concentrations of 0.01 ppm confirmed the qualitative information indicating the use of its parent compound in the sample location. Dieldrin residual value in the rainy season sample detected at BDL increases to 0.01 ppm detection in the dry season sample. The detected concentrations are within maximum residue limit. Dieldrin presence in the area confirmed the qualitative information on it use in this study. Endrin residue detected in the rainy season sample at concentrations of 4.71 ppm can be attributed to agriculture runoff or past uses. Endrin is not classified as it is considered banned and not tolerated in any quantities. Endosulfan residue detected at concentrations of 0.01 ppm each in rainy and the dry season samples confirming the field interview finding which shows the use of Endosulfan under the trade name thionex and thiodan in the study area. Endosulfans are generally not classified because they are considered banned and not tolerated in any quantities (WHO, 2001; FAO and WHO, 2016).

Mitotane, a derivative of o,p'-DDT, analysed only in the rainy season sample with residual concentrations of 0.11 ppm is within maximum residue limit. Endosulfan sulphate residue detected at concentrations of 0.03 ppm in rainy season declined to ND in the dry season sample. Endrin ketone, a degredate of endrin with the same health and environmental effects was not detected in the rainy season sample which may be attributed to high precipitation in rainy season but detected at residual concentrations of 0.11 ppm in the dry season sample. Methoxychlor was analysed only in the rainy season sample and detected at residual concentrations of 0.10 ppm. Its presence can be attributed to agriculture runoff. Heptachlor residue detected BDL in both season which can be attributed to previous uses or traces in currently use pesticide compounds in the area. Residues of aldrin and heptachlor epoxide also detected BDL in the dry season sample can be attributed to past uses or trace quantities in the presently use pesticide compounds in the study area.

4.3.2.9 Seasonal concentrations of organochlorine pesticide residues detected in sediment samples S1

As indicated in Table 4.16, divers' organochlorine pesticide residues were instrumentally detected during rainy and dry seasons (Appendix F). They include. delta.-pentachlorocyclohexane, .delta.-lindane, .alpha.-lindane, endosulfan ether, isodrin, DDMU, .alpha.-endosulfan, dieldrin, endrin, endosulfan, mitotane, endosulfan sulphate, endrin ketone, methoxychlor, aldrin, o.p'-DDT and chlordane. Among all organochlorine pesticide compounds sought, percentage detection revealed organochlorine pesticide compounds detected in the rainy and the dry season samples constituted 52.6% and 43.8% respectively, those present but below detection limit were 5.3% and 18.8% in rain and the dry season respectively.

Table 4.16: Seasonal Concentrations of Organochlorine Pesticides Detected in Sediment Sample S1

	Rainy Season, 2018		Dry Season, 2018		
Compound	RT. (mins)	Conc. (ppm)	RT. (mins)	Conc. (ppm)	MRL (ppm)
.delta.-Pentachlorocyc...	9.713	0.01	-	-	-
000319-86-8 .delta.-Li...	-	-	0.000	N.D	N.C
Cyclohexene, 1,3,4,5,6...	-	-	-	N.D	-
.delta.-Lindane	14.462	0.01	0.000	N.D	2
.alpha.-Lindane	11.727	0.02	0,000	N.D	2
Endosulfan ether	14.548	0.02	10.877	0.03	N.C
Heptachlor	0.000	N.D	0.000	N.D	0.03
Aldrin	0.000	N.D	12.192	0.00	0.03
Isodrin	16.722	0.01			
Heptachlor epoxide	0.000	N.D	0.000	N.D	0.03
Chlordane	0.000	N.D	13.601	0.00	-
DDMU	0.000	N.D	13.677	0.03	2
trans-Nonachlor	0.000	N.D	-	-	-
.alpha.-Endosulfan	-	-	13.730	0.03	N.C
Dieldrin	18.914	0.02	14.273	0.02	0.03
p,p'-DDE	19.234	No Calib	-	-	2
Endrin	19.583	0.04	-	-	N.C
Endosulfan	19.818	0.00	14.882	0.04	N.C
Mitotane	20.235	0.18	-	-	2
Endosulfan sulfate	20.996	0.01	15.820	0.06	NC
o,p'-DDT	-	-	15.796	0.00	2
Endrin ketone	0.000	N.D	16.882	1.05	N.C
Methoxychlor	23.257	0.03	-	-	20

Key: N.D. = Not Detected. n = 19 and 16 compounds analysed. RT = Retention Time. MRL = Maximum Residue Limit (WHO, 2001; FAO and WHO, 2016). N.C – Not classified.

Source: Author's Work, 2019

Residual concentrations of .delta.-pentachlorocyclohexane detected in the rainy season sample was at residual concentrations of 0.01 ppm decreases down to ND in the dry season sample. Its presence in rainy season can be attributed to agriculture runoff from intense farming involving use of pesticides in the area. Residues of .delta.-lindane detected at concentrations of 0.01 ppm in the rainy season sample declined to ND in the dry season sample. Although lindane was not mentioned by farmers and the stakeholders during field interviews, its presence can be attributed to past uses or trace quantities in in currently use pesticide compounds in study area. .alpha.-lindane, a degradation of lindane was detected at residual concentrations of 0.02 ppm in rainy season also declined to ND in the dry season sample. The values of .delta.-lindane and. .alpha.-lindane are both within maximum residue limit. Endosulfan ether, a degradation of endosulfan with the same health and environmental effects as the parent compound detected in the rainy season sample at residual concentrations of 0.02 ppm, increases to 0.03 ppm in the dry season sample. The increase in dry season concentrations can be attributed to higher temperature during the season. The presence of endosulfan degredate can be attributed to intense use of endosulfan compounds as affirmed by the respondents in the study area. Isodrin, an isomer of was aldrin analysed in the rainy season sample and detected at residual concentrations of 0.01 ppm confirmed the use of the parent compound in the study location, confirming the qualitative information in this study. DDMU, a derivative of DDT detected in the dry season sample at residual concentrations of 0.03 ppm can be attributed to higher temperature during the season. Concentrations of DDMU in this sample is within maximum residue limit. .alpha.-endosulfan analysed only in the dry season sample at residual concentrations of 0.03 ppm can be attributed to higher temperature in the season. Dieldrin residual value in rainy and the dry season sample at residual concentrations of 0.02 ppm each, confirmed the qualitative information on it use in this study. The detected concentrations are within maximum residue limits. Endrin residue detected in the rainy season sample at concentrations of 0.04 ppm declined down to ND in the dry season sample. Endrin is not classified as it is considered banned and not tolerated in any quantities. Endosulfan residue detected at concentrations of BDL in the rainy season sample increases to 0.04 ppm in the dry season sample, confirming the field interview finding which shows the use of endosulfan under the trade name thionex and thiodan in the study area. Endosulfans are generally not classified because they are considered banned and not tolerated in any quality (WHO, 2001; FAO and WHO, 2016). The increase in concentrations of endosulfan in dry season can be attributed to higher temperature in the season. Mitotane, a derivative of o,p'-DDT, analysed only in the rainy season sample, detected at residual concentrations of 0.18 ppm is within maximum residue limit. Endosulfan sulphate residue detected at concentrations of 0.01 ppm in rainy season increases to 0.06 ppm in the dry season sample which may be attributed to high temperature in the season. Endrin ketone, a degredate of endrin with the same health and environmental effects was not detected in the rainy season sample which may be attributed to high precipitation in rainy season but detected at residual concentrations of 1.05 ppm in the dry season sample. Higher concentrations of endrin ketone in the dry season sample can be ascribed to higher temperature and evaporation. Methoxychlor analysed only in the rainy season sample and detected at residual concentrations of 0.03 ppm can be attributed to agriculture runoff. Residues of aldrin, chlordane and o,p'-DDT detected BDL in the dry season sample can be attributed to past uses or trace quantities in the presently use pesticide compounds in the study area.

4.3.2.10 Seasonal concentrations of organochlorine pesticide residues detected in sediment samples S2

As indicated in Table 4.17, divers' organochlorine pesticide residues instrumentally were detected during rainy and dry seasons. They are endosulfan ether, .alpha.-endosulfan, dieldrin, mitotane, endrin ketone, .delta.-lindane, endosulfan, methoxychlor, heptachlor and aldrin (Appendix F). Among all organochlorine pesticide compounds sought, percentage detection revealed organochlorine pesticide compounds detected in the rainy and the dry season samples constituted 15.8% and 18.6% respectively, those present but below detection limit were 15.8% and 18.8% in rainy and dry season respectively.

Table 4.17: Seasonal Concentrations of Organochlorine Pesticide Residues Detected in Sediment Sample S2

	Rainy Season, 2018		Dry Season, 2018		
Compound	RT. (mins)	Conc. (μ/L)	RT. (mins)	Conc. (μ/L)	MRL (ppm)
.delta.-Pentachlorocyc...	0.000	N.D	0.000	N.D	-
.delta.-Lindane	14.456	0.00	0.000	N.D	2
.alpha.-Lindane	0.000	N.D	0,000	N.D	2
Endosulfan ether	14.519	0.06	10.896	0.05	N.C
Heptachlor	0.000	N.D	11.920	0.00	0.03
Aldrin	0.000	N.D	12.268	0.00	0.03
Isodrin	0.000	N.D			0.03
Heptachlor epoxide	0.000	N.D	0.000	N.D	0.03
Chlordane	0.000	N.D	0.000	N.D	-
DDMU	0.000	N.D	0.000	N.D	-
trans-Nonachlor	0.000	N.D			
.alpha.-Endosulfan			14.116	0.01	N.C
Dieldrin	18.862	0.01	14.282	0.00	0.03
p,p'-DDE	0.000	N.D			2
Endrin	0.000	ND	0.000	N.D	N.C
Endosulfan	19.806	0.00	0.000	N.D	N.C
Mitotane	20.155	0.26			2
Endosulfan sulfate	0.000	N.D	0.000	N.D	N.C
o,p'-DDT			0.000	N.D	2
Endrin ketone	0.000	N.D	16.511	0.06	N.C
Methoxychlor	23.268	0.00			20

Key: N.D. = Not Detected. n = 19 and 16 compounds analysed. RT = Retention Time. MRL = Maximum Residue Limit (WHO, 2001; FAO and WHO, 2016). N.C – Not classified.

Source: Author's Work, 2019

Endosulfan ether, a degradation of endosulfan with the same health and environmental effects as its parent compound detected in the rainy season sample at residual concentrations of 0.06 ppm decreases to 0.05 ppm in the dry season sample. The presence of endosulfan degradation can be attributed to intense use of endosulfan compounds as affirmed by the respondents in the study area. .alpha.-endosulfan analysed only in the dry season sample with residual concentrations of 0.01 ppm confirmed the use of its parent compound in the sample location. Dieldrin residual value in the rainy season sample detected at 0.01 ppm declined to BDL in the dry season sample. The detected concentrations is within maximum residue limit. Dieldrin presence in the area confirmed the qualitative information on it use in this study. Mitotane, a derivative of o,p'-DDT, analysed only on the rainy season sample is the most detected organochlorine compound with residual concentrations of 0.26 ppm. Mitotane residual value in this sample is within maximum residue limit. Endrin ketone, a degradation of endrin with the same health and environmental effects was not detected in the rainy season sample which may be attributed to high precipitation in rainy season but detected at residual concentrations of 0.06 ppm in the dry season sample which can be attributed to higher temperature in the season. delta.-lindane, endosulfan and methoxychlor detected at BDL in the rainy season sample can be attributed to agriculture runoff and precipitation during the season. Heptachlor and aldrin were also detected at BDL in the dry season sample attributable to past uses or trace quantities in the presently use pesticide compounds in the study area.

4.3.2.11 Seasonal concentrations of organochlorine pesticide residues detected in sediment samples S3

As indicated in Table 4.18, divers' organochlorine pesticide residues were instrumentally detected during rainy and dry seasons. They include .delta.-lindane, .alpha.-lindane, endosulfan ether, isodrin, heptachlor epoxide, .alpha.-endosulfan, dieldrin, endrin, endosulfan, mitotane, endrin ketone, .delta.-pentachlorocyclohexane, DDMU, o,p'-DDT, aldrin, heptachlor and methoxychlor (Appendix F). Among all the organochlorine pesticide compounds sought, percentage detection revealed organochlorine pesticide compounds detected in the rainy and the dry season samples constituted 31.6% and 43.8% respectively, those present but below detection limit were 21% and 37.5% in rainy and dry season respectively.

Table 4.18: Seasonal Concentrations of Organochlorine Pesticides Detected in Sediment Sample S3

	Rainy Season, 2018		Dry Season, 2018		
Compound	RT. (mins)	Conc. (ppm)	RT. (mins)	Conc. (ppm)	MRL (ppm)
.delta.-Pentachlorocyc...	9.999	0.00	0.000	N.D	-
.delta.-Lindane	0.000	N.D	9.211	0.01	2
.alpha.-Lindane	11.813	0.01	10.011	0.00	2
Endosulfan ether	14.502	0.05	10.835	0.11	-
Heptachlor	0.000	N.D	11.749	0.00	0.03
Aldrin	0.000	N.D	12.201	0.00	0.03
Isodrin	16.659	0.05	-	-	-
Heptachlor epoxide	0.000	N.D	12.625	0.01	0.03
Chlordane	0.000	N.D	0.000	N.D	-
DDMU	18.073	0.00	13.530	0.00	-
trans-Nonachlor	0.000	N.D	-	-	-
.alpha.-Endosulfan	-	-	13.768	0.01	-
Dieldrin	18.885	0.01	14.292	0.01	0.03
p,p'-DDE	0.000	N.D	-	-	-
Endrin	19.526	0.01	14.844	0.00	N.C
Endosulfan	19.944	0.00	14.906	0.01	N.C
Mitotane	20.373	0.13	-	-	-
Endosulfan sulfate	0.000	N.D	0.000	N.D	-
o,p'-DDT	-	-	16.087	0.00	2
Endrin ketone	0.000	N.D	16.501	0.06	-
Methoxychlor	23.497	0.00	-	-	20

Key: N.D. = Not Detected. n = 19 and 16 compounds analysed. RT = Retention Time. MRL = Maximum Residue Limit (WHO, 2001; FAO and WHO, 2016). N.C – Not classified.
Source: Author's Work, 2019

Residue of .delta.-lindane detected at concentrations of 0.01 ppm in the rainy season sample decreases down to ND in the dry season sample. Although lindane was not mentioned by farmers and the stakeholders during field interviews, its presence can be attributed to past uses or trace quantities in in currently use pesticide compounds in study area. .alpha.-lindane, a degradation of lindane was also detected at residual concentrations of 0.01 ppm in rainy season which declined to BDL in the dry season sample. The values of .delta.-lindane and. .alpha.-lindane are both within maximum residue limit. Endosulfan ether, a degradation of endosulfan with the same health and environmental effects as the parent compound detected in the rainy season sample at residual concentrations of 0.05 ppm, increases to 0.11 ppm in the dry season sample. Seasonal differential in the concentrations can be ascribed to higher temperature during dry season. The presence of endosulfan degradation can be attributed to intense use of endosulfan compounds as affirmed by the respondents in the study area. Isodrin, and isomer of aldrin analysed only in the rainy season sample and detected at residual concentrations of 0.05 ppm, confirming the use of its parent compound in the sample location. The detected residual concentrations of heptachlor epoxide at 0.01 ppm in the dry season sample can be ascribed to higher temperature and lack of precipitation in the season. .alpha.-endosulfan analysed only in the dry season sample with residual concentrations of 0.01 ppm can be attributed to the use of its parent compound in the sample location. Dieldrin residual value in both rainy and the dry season sample detected at concentrations of 0.01 ppm each, confirmed the response from the field interview in this study. The detected concentrations is within maximum residue limit. Endrin residue detected in the rainy season sample at concentrations of 0.01 ppm and BDL in the dry season are attributable to agriculture runoff or past uses. Endrin is not classified as it is considered banned and not tolerated in any quantities. Endosulfan residue detected at concentrations of BDL in the rainy season sample increases to 0.01 ppm in the dry season sample, confirming the field interview finding which shows the use of endosulfan under the trade name thionex and thiodan in the study area. Endosulfans are generally not classified because they are considered banned and not tolerated in any quantities (WHO, 2001; FAO and WHO, 2016). Mitotane, a derivative of o,p'-DDT, analysed only on the rainy season sample, detected residual concentrations of 0.13 ppm can be attributed to past uses in the area. Mitotane residual value in this sample is within maximum residue limit. Endrin ketone, a degredate of endrin with the same health and environmental effects was not detected in the rainy season sample which may be attributed to high precipitation in rainy season but detected at residual concentrations of 0.06 ppm in the dry season sample which attributable to higher temperature in the season. Residues of delta.-pentachlorocyclohexane, DDMU, o,p'-DDT, aldrin, heptachlor and methoxychlor were detected in the samples at BDL which are attributable to past uses or trace quantities in the presently use pesticide compounds in the study area.

4.3.2.12 Seasonal concentrations of organochlorine pesticide residues detected in sediment samples S4

As indicated in Table 4.19, divers' organochlorine pesticide residues were instrumentally detected during rainy and dry seasons. They include delta.-pentachlorocyclohexane, .delta.-lindane, .alpha.-lindane, endosulfan ether, isodrin .alpha.-endosulfan, endrin, endosulfan, mitotane, endrin ketone, methoxychlor, aldrin, dieldrin, endosulfan, heptachlor, aldrin, heptachlor epoxide and dieldrin (Appendix F). Among all organochlorine pesticide compounds sought, percentage detection revealed organochlorine pesticide compounds detected in the rainy and the dry season samples constituted 2% and 25% respectively, those present but below detection limit were 21% and 25% in rainy and dry season respectively.

Table 4.19: Seasonal Concentrations of Organochlorine Pesticide Residues Detected in Sediment Sample S4

	Rainy Season, 2018		Dry Season, 2018		
Compound	RT. (mins)	Conc. (ppm)	RT. (mins)	Conc. (ppm)	MRL (ppm)
.delta.-Pentachlorocyc...	9.713	0.01	-	-	-
000319-86-8 .delta.-Li...		-	0.000	N.D	-
Cyclohexene, 1,3,4,5,6...		-	0.000	N.D	2
.delta.-Lindane	14.473	0.02	0.000	N.D	2
.alpha.-Lindane	11.721	0.02	0.000	N.D	2
Endosulfan ether	14.531	0.19	10.858	0.03	N.C
Heptachlor	0.000	N.D	11.468	0.00	0.03
Aldrin	16.104	0.00	12.192	0.00	0.03
Isodrin	16.636	0.10	-	-	0.03
Heptachlor epoxide	0.000	N.D	12.616	0.00	0.03
Chlordane	0.000	N.D	0.000	N.D	-
DDMU	0.000	N.D	0.000	N.D	2
trans-Nonachlor	0.000	N.D	-	-	
.alpha.-Endosulfan		-	13.373	0.01	N.C
Dieldrin	18.925	0.00	14.282	0.00	0.03
p,p'-DDE	18.914	No Calib	-	-	2
Endrin	19.503	0.01	-	-	N.C
Endosulfan	19.886	0.00	15.120	0.01	N.C
Mitotane	20.276	0.46	-	-	2
Endosulfan sulfate	20.997	0.00	0.000	N.D	N.C
o,p'-DDT			0.000	N.D	2
Endrin ketone	0.000	N.D	16.497	0.11	N.C
Methoxychlor	23.268	0.02			20

Key: N.D. = Not Detected. n = 19 and 16 compounds analysed. RT = Retention Time. MRL = Maximum Residue Limit (WHO, 2001; FAO and WHO, 2016). NC – Not classified.

Source: Author's Work, 2019

Residual concentrations of .delta.-pentachlorocyclohexane detected in the rainy season sample at 0.01 ppm can be attributed to intense applications of various pesticides by farmers in the study area. Residues of .delta.-lindane and alpha.-lindane detected at concentrations of 0.02 ppm each in the rainy season samples, even though lindane was not mentioned by farmers and the stakeholders during field interviews, its presence can be attributed to past uses or trace quantities in in currently use pesticide compounds in study area. The values of .delta.-lindane and. .alpha.-lindane are both within maximum residue limit. Endosulfan ether, a degradation of endosulfan with the same health and environmental effects as the parent compound detected in the rainy season sample at residual concentrations of 0.19 ppm, decreases to 0.03 ppm in the dry season sample can be attributed to intense use of endosulfan compounds particularly in rainy season as affirmed by the respondents in the study area. Isodrin, a derivative of aldrin analysed in the rainy season sample only and detected at residual concentrations of 0.10 ppm confirmed the use of its parent compound in the sample location as revealed by stakeholders in this study. .alpha.-endosulfan analysed only in the dry season sample with residual concentrations of 0.03 ppm can be attributed to the use of its parent compound in the sample location as revealed in this study. Endrin residue detected in the rainy season sample at concentrations of 0.01 ppm may be attributed to agriculture runoff. Endrin is not classified as it is considered banned and not tolerated in any quantities. Endosulfan residue detected at concentrations of BDL in the rainy season sample and 0.01 ppm in the dry season sample, confirmed the field interview finding which shows the use of endosulfan under the trade name thionex and thiodan in the study area. Endosulfans are generally not classified because they are considered banned and not tolerated in any quantities (WHO, 2001; FAO and WHO, 2016). Mitotane, a derivative of o,p'-DDT, analysed only on the rainy season sample is the most detected organochlorine compound with residual concentrations of 0.46 ppm. Mitotane residual value in this sample is within maximum residue limit. Endrin ketone, a degradation of endrin with the same health and environmental effects was not detected in the rainy season sample which may be attributed to high precipitation in rainy season but detected at residual concentrations of 0.11 ppm in the dry season sample. Methoxychlor analysed only in the rainy season sample and detected at residual concentrations of 0.02 ppm can be attributed to trace quantities in currently use pesticides pesticide compounds in the study area.

Residues of aldrin, dieldrin and endosulfan sulphate detected BDL in the rainy season sample and heptachlor, aldrin, heptachlor epoxide and dieldrin detected at BDL in the dry season sample can be attributed to past uses or trace quantities in the presently use pesticide compounds in the study area.

4.3.2.13 Seasonal concentrations of organochlorine pesticide residues detected in sediment samples S5

As indicated in Table 4.20, divers' organochlorine pesticide residues were instrumentally detected in both seasons. They include endosulfan ether, Isodrin, .alpha.-endosulfan, dieldrin, endosulfan, mitotane, endrin ketone, .delta.-lindane, methoxychlor, heptachlor, aldrin and heptachlor epoxide (Appendix F). Among all organochlorine pesticide compounds sought, percentage detection revealed organochlorine pesticide compounds detected in the rainy and the dry season samples constituted 21% and 31.3% respectively, those present but below detection limit were 15.8% and 18.8% in rain and the dry season respectively.

Table 4.20: Seasonal Concentrations of Organochlorine Pesticide Residues Detected in Sediment Sample S5

	Rainy Season, 2018		Dry Season, 2018		
Compound	RT. (mins)	Conc. (ppm)	RT. (mins)	Conc. (ppm)	MRL (ppm)
.delta.-Pentachlorocyc...	0.000	N.D	-	-	-
000319-86-8 .delta.-Li...	-	-	0.000	N.D	-
Cyclohexene, 1,3,4,5,6...	-	-	0,000	N.D	-
.delta.-Lindane	14.457	0.00	0.000	N.D	2
.alpha.-Lindane	0.000	N.D	0,000	N.D	-
Endosulfan ether	14.554	0.03	10.868	0.03	N.C
Heptachlor	0.000	N.D	11.092	0.00	0.03
Aldrin	0.000	N.D	12.182	0.00	0.03
Isodrin	16.488	0.01	-	-	-
Heptachlor epoxide	0.000	N.D	12.768	0.00	0.03
Chlordane	0.000	N.D	0.000	N.D	-
DDMU	0.000	N.D	0.000	N.D	2
trans-Nonachlor	0.000	N.D	-	-	-
.alpha.-Endosulfan	-	-	13.854	0.01	N.C
Dieldrin	18.880	0.01	14.306	0.01	0.03
p,p'-DDE	0.000	N.D	-	-	-
Endrin	0.000	N.D	-	-	N.C
Endosulfan	20.018	0.00	15.130	0.01	N.C
Mitotane	20.241	0.27	-	-	2
Endosulfan sulfate	0.000	N.D	0.000	N.D	N.C
o,p'-DDT	-	-	0.000	N.D	2
Endrin ketone	0.000	N.D	16.520	0.12	NC
Methoxychlor	23.263	0.00	-	-	20

Key: N.D. = Not Detected. n = 19 and 16 compounds analysed. RT = Retention Time. MRL = Maximum Residue Limit (WHO, 2001; FAO and WHO, 2016). NC – Not classified.

Source: Author's Work, 2019

Endosulfan ether, a degradation of endosulfan with the same health and environmental effects as the parent compound detected in both the rainy season sample at residual concentrations of 0.03 ppm each, can be attributed to intense use of endosulfan compounds particularly in rainy season as affirmed by the respondents in the study area. Isodrin, a derivative of aldrin analysed in the rainy season sample only and detected at residual concentrations of 0.01 ppm confirmed the use of its parent compound in the sample location as revealed by stakeholders in this study. .alpha.-endosulfan was analysed only in the dry season sample with residual concentrations of 0.01 ppm which can be attributed to the use of its parent compound in the sample location as revealed in this study. Residual concentrations of dieldrin at 0.01 ppm in both seasons confirmed the qualitative information indicating its use in the study area as indicated by farmers and stakeholders. The residual concentrations of dieldrin in the sample is within maximum residue limit.

Endosulfan residue detected at concentrations of BDL in the rainy season sample and 0.01 ppm in the dry season sample, confirmed the field interview finding which shows the use of Endosulfan under the trade name thionex and thiodan in the study area. Endosulfans are generally not classified because they are considered banned and not tolerated in any quantities (WHO, 2001; FAO and WHO, 2016). Mitotane, a derivative of o,p'-DDT, analysed only on the rainy season sample is the most detected organochlorine compound with residual concentrations of 0.27 ppm. Mitotane residual value in this sample is within maximum residue limit. Endrin ketone, a degredate of endrin with the same health and environmental effects was not detected in the rainy season sample which may be attributed to high precipitation in rainy season but detected at residual concentrations of 0.12 ppm in the dry season sample. .delta.-lindane and methoxychlor detected at BDL in rainy, and heptachlor and aldrin detected in the dry season sample can be attributed to past uses or trace quantities in the presently use pesticide compounds in the study area.

4.3.2.14 Seasonal concentrations of organochlorine pesticide residues detected in sediment samples S6

As indicated in Table 4.21, divers' organochlorine pesticide residues were instrumentally detected during rainy and dry seasons. They include .delta.-Pentachlorocyclohexane, .delta.-lindane, .alpha.-lindane, endosulfan, isodrin, heptachlor epoxide, .alpha.-

endosulfan, endrin, endosulfan, mitotane, endosulfan sulphate, endrin ketone, dieldrin, methoxychlor, aldrin, dieldrin and o.p'-DDT (Appendix F). Among all organochlorine pesticide compounds sought, percentage detection revealed organochlorine pesticide compounds detected in the rainy and the dry season samples constituted 47% and 25% respectively, those present but below detection limit were 10.5% and 18.8% in rainy and dry season respectively.

Table 4.21: Seasonal Concentrations of Organochlorine Pesticide Residues Detected in Sediment Sample S6

	Rainy Season, 2018		Dry Season, 2018		
Compound	RT. (mins)	Conc. (ppm)	RT. (mins)	Conc. (ppm)	MRL (ppm)
.delta.-Pentachlorocyc...	9.719	0.01	-	-	-
000319-86-8 .delta.-Li...	-	-	0.000	N.D	-
Cyclohexene, 1,3,4,5,6...	-	-	0.000	N.D	-
.delta.-Lindane	14.468	0.02	0.000	N.D	2
.alpha.-Lindane	11.721	0.01	0,000	N.D	2
Endosulfan ether	14.519	0.03	10.858	0.01	N.C
Heptachlor	0.000	N.D	0.000	N.D	0.03
Aldrin	0.000	N.D	12.187	0.00	0.03
Isodrin	16.614	0.01	-	-	2
Heptachlor epoxide	0.000	0.01	0.000	N.D	0.03
Chlordane	0.000	N.D	0.000	N.D	-
DDMU	0.000	N.D	0.000	N.D.	-
trans-Nonachlor	0.000	N.D	-	-	-
.alpha.-Endosulfan	-	-	13.749	0.01	N.C
Dieldrin	18.908	0.00	14.173	0.00	0.03
p,p'-DDE	0.000	N.D	-	-	2
Endrin	19.589	0.02	-	-	N.C
Endosulfan	20.178	0.00	14.892	0.02	N.C
Mitotane	20.293	0.12	-	-	2
Endosulfan sulphate	20.985	0.01	0.000	N.D	-
o,p'-DDT	-	-	15.982	0.00	2
Endrin ketone	0.000	N.D	16.535	0.06	N.C
Methoxychlor	23.434	0.00	-	-	20

Key: N.D. = Not Detected. n = 19 and 16 compounds analysed. RT = Retention Time. MRL = Maximum Residue Limit (WHO, 2001; FAO and WHO, 2016). N.C – Not classified.

Source: Author's Work, 2019

Residual concentrations of .delta.-pentachlorocyclohexane detected in the rainy season sample at 0.01 ppm can be attributed to intense applications of various pesticides by farmers in the study area. Residues of .delta.-lindane and alpha.-lindane detected at concentrations of 0.02 ppm and 0.01 ppm respectively in the rainy season samples, even though lindane was not mentioned by farmers and the stakeholders during field interviews, its presence can be attributed to past uses or trace quantities in in currently use pesticide compounds in study area. The values of .delta.-lindane and. .alpha.-lindane are both within maximum residue limit. Endosulfan ether, a degradation of endosulfan with the same health and environmental effects as the parent compound detected in the rainy season sample at residual concentrations of 0.03 ppm, decreases to 0.01 ppm detected in the dry season sample can be attributed to intense use of endosulfan compounds particularly in rainy season as affirmed by the respondents in the study area. Isodrin, a derivative of aldrin analysed in the rainy season sample only and detected at residual concentrations of 0.01 ppm confirmed the use of its parent compound in the sample location as revealed by stakeholders in this study. Heptachlor epoxide detected at residual concentrations of 0.01 ppm is within maximum residue limit. .alpha.-endosulfan analysed only in the dry season sample with residual concentrations of 0.01 ppm can be attributed to the use of its parent compound in the sample location as revealed in this study. Endrin residue detected in the rainy season sample at concentrations of 0.02 ppm may be attributed to agriculture runoff. Endrin is not classified as it is considered banned and not tolerated in any quantities. Endosulfan residue detected at concentrations of BDL in the rainy season sample and 0.02 ppm in the dry season sample, confirmed the field interview finding which shows the use of endosulfan under the trade name thionex and thiodan in the study area. Endosulfans are generally not classified because they are considered banned and not tolerated in any quantities (WHO, 2001; FAO and WHO, 2016). Mitotane, a derivative of o,p'-DDT, analysed only in the rainy season sample detected at residual concentrations of 0.12 ppm is within maximum residue limit.

Endosulfan sulphate detected at residual concentrations of 0.01 ppm in the rainy season sample confirmed the use of its parent compound in the sample location as revealed by farmers and stakeholders in the study area. Endrin ketone, a degredate of endrin with the same health and environmental effects was not detected in the rainy season sample which may be attributed to high precipitation in rainy season but detected at residual concentrations of 0.06 ppm in the dry season sample. Dieldrin and methoxychlor detected at BDL in rainy, and aldrin, dieldrin and o.p'-DDT detected at BDL in the dry season sample can be attributed to past uses or trace quantities in the presently use pesticide compounds in the study area.

4.3.2.15 Seasonal concentrations of organochlorine pesticide residues detected in sediment samples S7

As indicated in Table 4.22, divers' organochlorine pesticide residues were instrumentally detected in both seasons. They include .delta.-lindane, .alpha.-Lindane, endosulfan, .alpha.-endosulfan, endrin, endosulfan, mitotane, endosulfan sulphate, endrin ketone, dieldrin, p,p'-DDE, methoxychlor, heptachlor, aldrin and dieldrin (Appendix F). Among all organochlorine pesticide compounds sought, percentage detection revealed organochlorine pesticide compounds detected in the rainy and the dry season samples constituted 36.8% and 25% respectively, those present but below detection limit were 15.8% and 18.8% in rainy and dry season respectively.

Table 4.22: Seasonal Concentrations of Organochlorine Pesticide Residues Detected in Sediment Sample S7

	Rainy Season, 2018		Dry Season, 2018		
Compound	RT. (mins)	Conc. (ppm)	RT. (mins)	Conc. (ppm)	MRL (ppm)
.delta.-Pentachlorocyc...	0.000	N.D	0.000	N.D	-
.delta.-Lindane	14.462	0.03	0.000	N.D	2
.alpha.-Lindane	11.727	0.03	0.000	N.D	2
Endosulfan ether	14.537	0.01	10.877	0.06	N.C
Heptachlor	0.000	N.D	11.515	0.00	0.03
Aldrin	0.000	N.D	12.177	0.00	0.03
Isodrin	0.000	N.D	-	-	0.03
Heptachlor epoxide	0.000	N.D	0.000	N.D	0.03
Chlordane	0.000	N.D	0.000	N.D	-
DDMU	0.000	N.D	0.000	N.D	2
trans-Nonachlor	0.000	N.D	-	-	-
.alpha.-Endosulfan	-	-	13.768	0.01	N.C
Dieldrin	18.891	0.00	14.282	0.00	0.03
p,p'-DDE	19.423	0.00	-	-	2
Endrin	19.572	0.03	0.000	N.D	N.C
Endosulfan	19.692	0.01	14.820	0.01	N.C
Mitotane	20.362	0.24	-	-	2
Endosulfan sulfate	20.974	0.01	0.000	N.D	N.C
o,p'-DDT	-	-	0.000	N.D	2
Endrin ketone	0.000	N.D	16.516	0.12	N.C
Methoxychlor	23.377	0.00	-	-	20

Key: N.D. = Not Detected. n = 19 and 16 compounds analysed. RT = Retention Time. MRL = Maximum Residue Limit (WHO, 2001; FAO and WHO, 2016). N.C – Not classified.

Source: Author's Work, 2019

Residue of .delta.-lindane and alpha.-lindane detected at concentrations of 0.03 ppm each in the rainy season samples, even though lindane was not mentioned by farmers and the stakeholders during field interviews, its presence can be attributed to past uses or trace quantities in in currently use pesticide compounds in study area. The values of .delta.-lindane and. .alpha.-lindane are both within maximum residue limit. Endosulfan ether, a degradation of endosulfan with the same health and environmental effects as the parent compound detected in the rainy season sample at residual concentrations of 0.01 ppm, increases to 0.06 ppm detected in the dry season sample can be attributed to intense use of endosulfan compounds particularly in rainy season as affirmed by the respondents in the study area. .alpha.-endosulfan analysed only in the dry season sample with residual concentrations of 0.01 ppm can be attributed to the use of its parent compound in the sample location as revealed in this study. Endrin residue detected in the rainy season sample at concentrations of 0.03 ppm may be attributed to agriculture runoff. Endrin is not classified as it is considered banned and not tolerated in any quantities. Endosulfan residue detected at concentrations of 0.01 ppm each in both season sample, confirmed the field interview finding which shows the use of endosulfan under the trade name thionex and thiodan in the study area. Endosulfans are generally not classified because they are considered banned and not tolerated in any quantities (WHO, 2001; FAO and WHO, 2016). Mitotane, a derivative of o,p'-DDT, analysed only in the rainy season sample detected at residual concentrations of 0.24 ppm is within maximum residue limit. Endosulfan sulphate detected at residual concentrations of 0.01 ppm rainy season confirmed the use of its parent compound in the sample location as revealed by farmers and stakeholders in the study area. Endrin ketone, a degredate of endrin with the same health and environmental effects was not detected in the rainy season sample which may be attributed to high precipitation in rainy season but detected at residual concentrations of 0.12 ppm in the dry season sample. Dieldrin and p,p’-DDE and methoxychlor were identified at BDL in rainy, and heptachlor, aldrin and dieldrin were identified at BDL in the dry season sample can be attributed to past uses or trace quantities in the presently use pesticide compounds in the study area.

4.3.2.16 Seasonal concentrations of organochlorine pesticide residues detected in sediment samples S8

As indicated in Table 4.23, divers’ organochlorine pesticide residues were instrumentally detected in both seasons. They included endosulfan ether, isodrin, .alpha.-endosulfan, dieldrin, endrin, endrin .delta.-pentachlorocyclohexane, .alpha.-lindane, aldrin, DDMU, endosulfan, methoxychlor, heptachlor and aldrin (Appendix F). Among all organochlorine pesticide compounds sought, percentage detection revealed organochlorine pesticide compounds detected in the rainy and the dry season samples constituted 21% and 18.8% respectively, those present but below detection limit were 31.6% and 18.8% in rainy and dry season respectively.

Table 4.23: Seasonal Concentrations of Organochlorine Pesticide Residues Detected in sediment Sample S8

	Rainy Season, 2018		Dry Season, 2018		
Compound	RT. (min)	Conc. (ppm)	RT. (min)	Conc. (ppm)	MRL (ppm)
.delta.-Pentachlorocyc...	10.068	0.00	0.000	N.D	-
.delta.-Lindane	0.000	N.D	0.000	N.D	2
.alpha.-Lindane	11.744	0.00	0.000	N.D	2
Endosulfan ether	14.519	0.11	10.868	0.01	N.C
Heptachlor	0.000	N.D	11.787	0.00	0.03
Aldrin	16.442	0.00	12.163	0.00	0.03
Isodrin	16.648	0.02	-	-	0.03
Heptachlor epoxide	0.000	N.D	0.000	N.D	0.03
Chlordane	0.000	N.D	0.000	N.D	-
DDMU	17.924	0.00	0.000	N.D	2
trans-Nonachlor	0.000	N.D	-	-	-
.alpha.-Endosulfan	-	-	13.749	0.01	N.C
Dieldrin	18.897	0.01	14.292	0.00	0.03
p,p'-DDE	0.000	N.D	-	-	2
Endrin	19.538	0.01	0.000	N.D	N.C
Endosulfan	19.898	0.00	0.000	N.D	N.C
Mitotane	0.000	N.D	-	-	2
Endosulfan sulfate	0.000	N.D	0.000	N.D	N.C
o,p'-DDT	-	-	0.000	N.D	2
Endrin ketone	0.000	N.D	16.520	0.06	N.C
Methoxychlor	23.560	0.00	-	-	20

Key: N.D. = Not Detected. n = 19 and 16 compounds analysed. RT = Retention Time. MRL = Maximum Residue Limit (WHO, 2001; FAO and WHO, 2016). NC – Not classified.

Source: Author's Work, 2019

Endosulfan ether, a degradation of endosulfan with the same health and environmental effects as the parent compound detected in the rainy season sample at residual concentrations of 0.11 ppm decreases to 0.01 ppm detected in the dry season sample can be attributed to intense use of endosulfan compounds particularly in rainy season as affirmed by the respondents in the study area. Isodrin, a derivative of aldrin analysed in the rainy season sample only and detected at residual concentrations of 0.01 ppm confirmed the use of its parent compound in the sample location as revealed by stakeholders in this study. Isodrin, an isomer of aldrin analysed in the rainy season sample and detected at residual concentrations of 0.02 ppm confirmed the qualitative information indicating the use of its parent compound in the sample location. The concentrations is within maximum residue limit. .alpha.-endosulfan analysed only in the dry season sample with residual concentrations of 0.01 ppm can be attributed to the use of its parent compound in the sample location as revealed in this study. Endrin residue detected in the rainy season sample at concentrations of 0.01 ppm may be attributed to agriculture runoff. Endrin is not classified as it is considered banned and not tolerated in any quantities. Endrin ketone, a degredate of endrin with the same health and environmental effects was not detected in the rainy season sample which may be attributed to high precipitation in rainy season but detected at residual concentrations of 0.06 ppm in the dry season sample which may be attributed to absence of precipitation and fast evaporation during the season. .delta.-pentachlorocyclohexane, .alpha.-lindane, aldrin, DDMU, endosulfan and methoxychlor were detected at BDL in rainy, and heptachlor and aldrin were also detected at BDL in the dry season sample can be attributed to past uses or trace quantities in the presently use pesticide compounds in the study area.

4.3.2.17 Percentage occurrence of organochlorine pesticide residues within detected limit in water samples during rainy and dry seasons across the sample points

The organochlorine compounds detected in water samples within detection limit (WDL) as indicated in Figure 4.55 shows that endosulfan ether residue was detected in both seasons at 100% of the sample points. Endosulfan residue was detected in 100% of the sample points during dry season against 12.5% in rainy season. Residue of mitotane were also detected in 100% of the sample points. .alpha.-endosulfan and endrin ketone were detected in 87.5% of all sample points in dry season. Other compounds such as dieldrin, endrin, .alpha.-Lindane, .delta.-lindane, isodrin were detected between 0% and 62.5% of all the sample points.

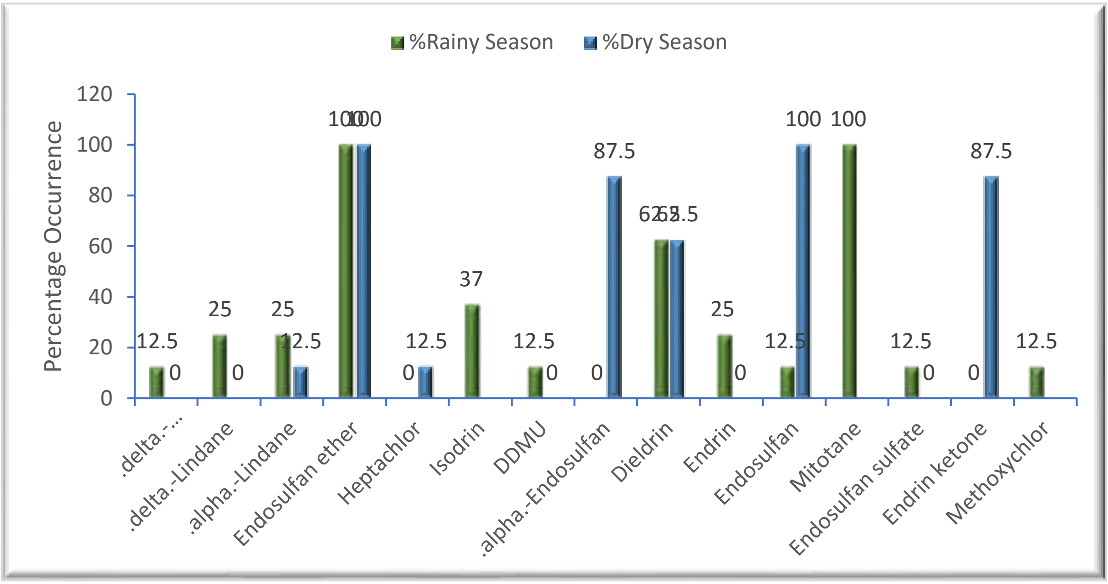


Figure 4.55: Percentage Occurrence of Organochlorine Pesticide Residues within Detected Limit in Water Samples Across the Sample Points during Rainy and Dry Season

Source: Author's Work, 2019

The finding implies that 100% of the surface water sample points in the study area were contaminated by residue of endosulfan ether during rainy and dry season. 100% of surface water sample points in the study area were also contaminated with endosulfan residue in dry season and mitotane residue in rainy season. .alpha.-endosulfan and endrin ketone were also found to contaminate the surface water in 87.5% of the sample points during dry season in the area. Other contaminate ranges between 0% and 62.5% of the sample points. These include dieldrin, endrin, .alpha.-lindane, .delta.-lindane, isodrin. Similar situation has been reported in developing countries including Nigeria as revealed by Adeshina *et al.* (2019) and Adeyinka *et al.* (2019). All these detected pesticide compounds are either banned or restricted in Nigeria and in many other countries. The presence of these organic pollutants in water bodies in the study area will not only affect freshwater species of fishes negatively, but to organisms they feed on. Also, there are potential risks to communities in the area due their dependant on the waters for socioeconomic activities.

4.3.2.18 Percentage occurrence of organochlorine pesticide residues below detected limit in water samples during rainy and dry seasons across the sample points

The organochlorine compounds detected below detection limit (BDL) as indicated in Figure 4.56 shows that aldrin was detected in dry seasons at 100% of the sample points. Mitotane residue was also detected at 100% of the sample points in rainy season. Heptachlor epoxide residue was detected in 75% of the sample points during dry season. Also, endosulfan was detected at 75% of the sample points during dry season. Other compounds which include heptachlor, dieldrin, o,p'-DDT, endrin were detected between 0% and 50% of all the sample points during the seasons.

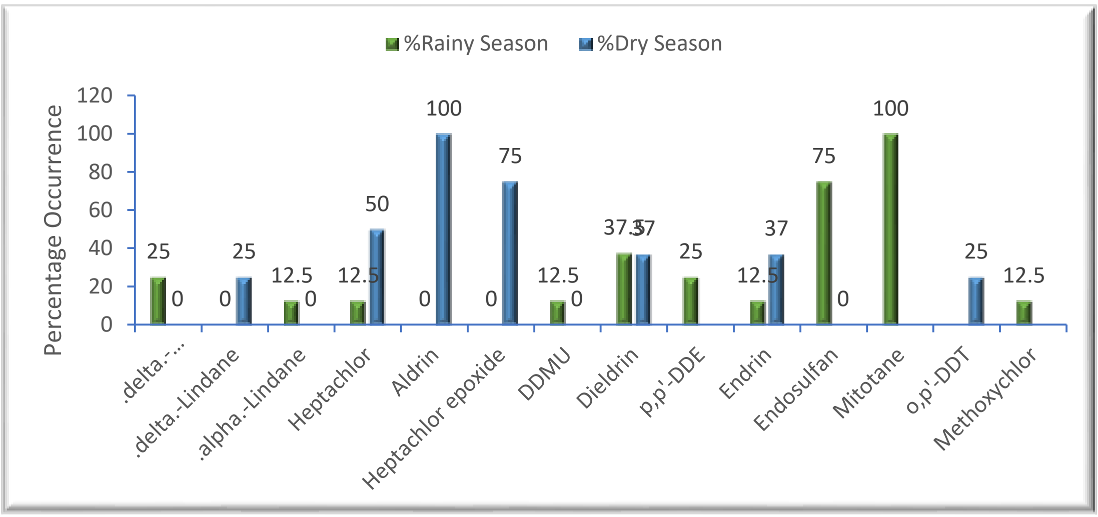


Figure 4.56: Percentage Occurrence of Organochlorine Pesticide Residues Below Detected Limit in Water Samples Across the Sample Points during Rainy and Dry Seasons

Source: Author's Work, 2019

The finding implies that 100% of the surface water sample points in the study area were contaminated by aldrin at BDL during dry season. 100% of surface water sample points in the study area were also contaminated with mitotane residue at BDL in rainy season. Surface water in the area were contaminated at 75% of the sample points by heptachlor epoxide BDL during dry season. The area was also contaminated BDL by endosulfan at 75% of the sample points during rainy season. Other contaminate ranges between 0% and 50% of the sample points. These include heptachlor, dieldrin, o,p'-DDT, endrin. Similar situation has been reported in developing countries including Nigeria (Adeshina *et al.,* 2019; Adeyinka *et al.,* 2019). The presence of these organochlorine pesticide compounds in the area may be attributed to past uses, transboundary chemical movement, and trace quantities in currently use pesticide compounds. The implication of these detected persistent organochlorine pesticides in surface water in which the people in the community depends on for socio-economic livelihoods can trigger serious negative health, environmental and economic development problems in the study area.

4.3.2.19 Percentage occurrence of organochlorine pesticide residues within detected limit in sediment samples across the sample points during rainy and dry seasons

The organochlorine compounds detected in sediment samples within detection limit (WDL) as indicated in Figure 4.57 shows that endosulfan ether residue was detected and distributed in both seasons at 100% of the sample points. .alpha.-endosulfan residue was detected and distributed in 100% of the sample points during dry season. Endrin ketone was detected and distributed in 100% of the sample points during dry season. Isodrin residue was detected and distributed in 87.5% of the sample points in rain season. Mitotane residue was also detected and distributed in 87.5% of the sample points in rain season. Endrin residue was detected in 75% of the sample points in rain season.

Endosulfan residue was also detected and distributed in 75% of the sample points in dry season. Other compounds such as dieldrin, endosulfan sulfate, methoxychlor, .alpha.-lindane, .delta.-lindane, DDMU, were detected between 0% and 62.5% of all the sample points.

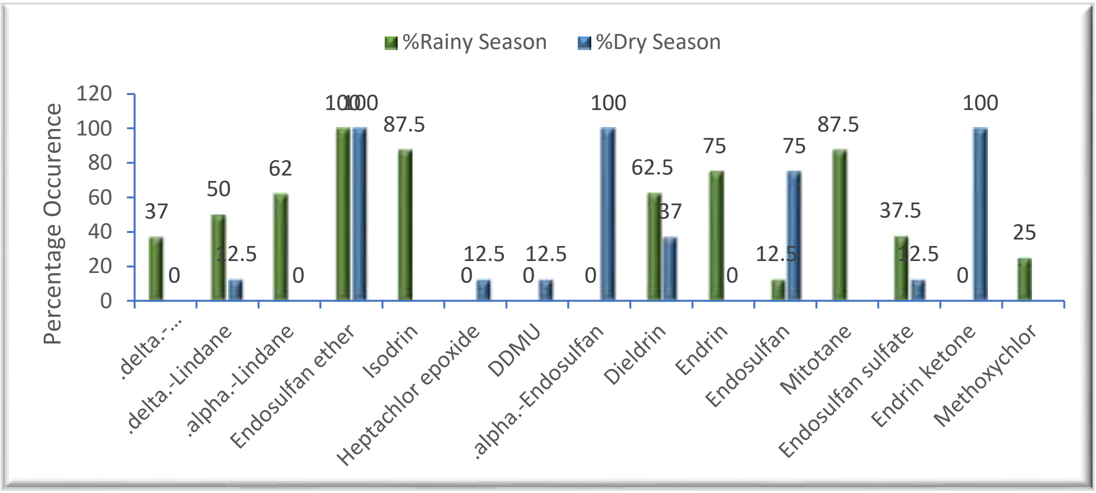


Figure 4.57: Percentage Occurrence of Organochlorine Pesticide Residues within Detected Limit in Sediment Samples Across the Sample Points during Rainy and Dry Seasons
Source: Author's Work, 2019

The finding implies that 100% of the sediment sample points in the study area were contaminated by residue of endosulfan ether during rain and the dry season. Sediment in the study area were contaminated by .alpha.-endosulfan in 100% of the sample points during dry season. Also, sediment samples in the area were contaminated by endrin ketone residues in 100%of the sample points. Isodrin and mitotane residues contaminated 87% each of the sediment sample points across the study area during rainy season. Other contaminants range between 0% and 75% of the sample points in the seasons. These contaminants include endosulfan, endosulfan sulfate, dieldrin, endrin, .alpha.-lindane, .delta.-lindane and methoxychlor. Similar situation has been reported in developing countries including Nigeria Adeshina *et al.* (2019) and Adeyinka *et al.* (2019). All these detected pesticide compounds are banned in Nigeria and in many other countries. The presence of these organic pollutants in water bodies in the study area will not only affect freshwater species of fishes negatively, but to organisms they feed on. Also, there are potential risks to communities in the area due their dependant on the waters for socioeconomic activities.

4.3.2.20 Percentage occurrence of organochlorine pesticides residues below detected limit in sediment samples during rainy and dry season across the sample points

The organochlorine compounds detected in sediment samples Below detection limit (BDL) as indicated in Figure 4.58 shows that aldrin residue was detected BDL in dry seasons in 100% of the sample points. Endosulfan residue was detected BDL in 87.5% of the sample points in rainy season. Heptachlor and dieldrin residues were detected in 75% and 62% of the sample points in the dry season sample respectively. Methoxychlor residue was detected in 75% of the sample points during rainy season. Other compounds such as dieldrin, methoxychlor, .alpha.-lindane, .delta.-lindane, DDMU, o,p'-DDT were detected between 0% and 37.5% of all the sample points.

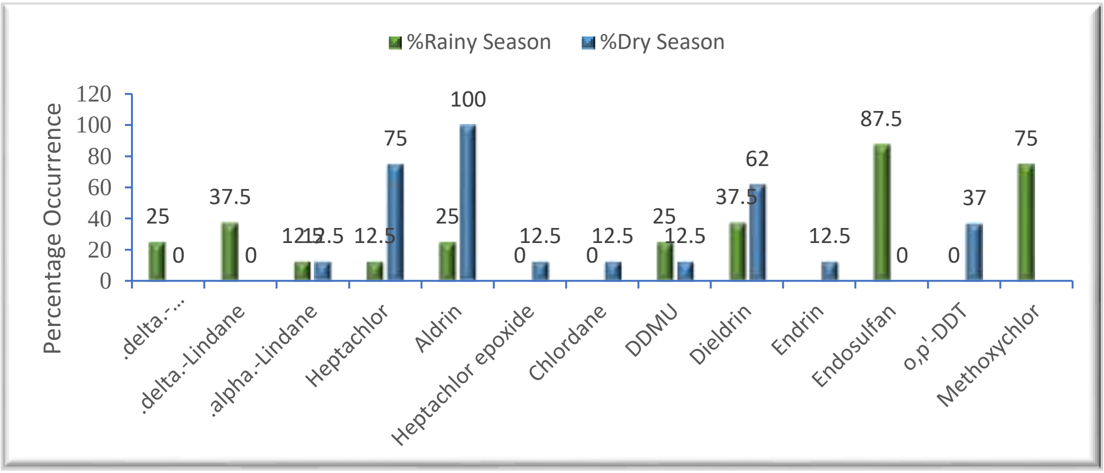


Figure 4.58: Percentage Occurrence of Organochlorine Presides Residues within Detected Limit in Sediment Samples Across the Sample Points during Rainy and Dry seasons

Source: Author's Work, 2019

The finding implies that 100% of the sediment sample points in the study area were contaminated by residue of aldrin BDL during dry season. Sediment in the study area were contaminated by endosulfan BDL in 75% of the sample points during rainy season. Also, sediment samples in the area were contaminated by heptachlor and dieldrin in 75% and 62% of the sample points during dry season dry season respectively. Sediment samples in the study area were contaminated with methoxychlor residues in 75% of the sample points during rainy season. Sediment samples were also contaminated by dieldrin, methoxychlor, .alpha.-lindane, .delta.-lindane, DDMU, o,p'-DDT in 0% to 37.5% of all the sample points in the study area. Similar situation has been reported in developing countries including Nigeria Adeshina *et al.* (2019) and Adeyinka *et al.* (2019). All these detected pesticide compounds are either banned or restricted in Nigeria and in many other countries. The presence of these organic pollutants in water bodies in the study area will not only affect freshwater species of fishes negatively, but to organisms they feed on. Also, there are potential risks to communities in the area due their dependant on the waters for socioeconomic activities.

In summary, this objective demonstrated the effectiveness of GIS tools in overlaying the plant, mineral concentrations in water and sediment. It has also established that water and sediment samples from the study area are largely contaminated with plant minerals which includes nitrates, nitrite, and phosphate, spatially distributed across the sampled points.

Further, diverse compounds of organochlorine pesticides were also confirmed to contaminate all water and sediment samples from the study area. A significant amount of organochlorine pesticide compounds identified corroborated survey findings in this study. All other organochlorine compounds detected, but not affirmed in use by farmers in the study area may be attributed to previous uses, transboundary chemical movement, and trace quantities in currently use pesticide compounds. Disturbingly, all organochlorine pesticide compounds detected in water samples of rain and the dry season samples are of serious health and environmental concern. Organochlorine pesticide compounds detected are either restricted or banned in Nigeria (Appendix G). The presence of these persistent and hazardous compounds in water of the study area can trigger negative socio-economic wellbeing of communities in the study area.

It is noteworthy that plant minerals and organochlorine pesticides identified may lead to severe health issues such as cancer, brain tumour, asopharyngeal, developmental problems and leukaemia. Also, in children and infants, nitrate and nitrite usually bind to haemoglobin and trigger chemically impairs oxygen delivery to tissues resulting in the blue colour of the skin known as "blue baby syndrome ". Acute or chronic health issues such as birth defects, cancer, organ failures, renal complications, brain damage, respiratory disorder, endocrine disruption, sterility, and infertility can arise from the presence of organochlorine pesticide residues identified. A similar situation has been reported in developing countries including Nigeria (Adeshina *et al.*, 2019; Adeyinka *et al.* 2019). In view of the above findings, there is urgent need from all stakeholders to insight individual or collective roll(s) towards proffering visible measures to sustainably contain these socio-economic threats for the purpose of ensuring cleaner and healthier environment for all. Finally, the finding present a convincing ground to investigate the possibility of socio-economic challenges in relation to the identified agrochemical contaminants in environmental media analysed in this study.

4.4 Investigation of the Socioeconomic Challenges of Pesticides and Fertilisers Contamination of Water in the Study Area

The socioeconomic challenges of pesticides and fertilizer contamination for this study include environmental effects, human health impact and economic development impact.

4.4.1 Environmental effects

Table 4.24 indicated that 97.5% of the study population affirmed the presence of environmental concerns across the zones, 2.7% disaffirmed the presence of environmental concerns of agrochemicals in the zones.

Table 4.24: Appraisal of the Awareness of Environmental Concerns

Zones	Affirmed Frequency	%	Disaffirmed Frequency	%
UZs	117	33.5	6	1.8
MDZ	85	24.3	1	0.3
LZs	139	39.7	2	0.6
Total	**341**	**97.5**	**9**	**2.7**

Key: UZs= Upper zones. MDZ = Middle zone. LZs = Lower zones.

Source: Author's Work, 2020

These findings imply that most of the population is aware and affirmed serious concerns of fertilizers and pesticide use on the environment. Information obtained from village group discussions and key informants such as community experienced district officers, extension agents, senior members of the farming community and health workers, which were purposely selected to provide information on local problems affecting the community corroborated all revelations through administered questionnaires. Environmental concerns revealed by all populations include the apparent killing of aquatic organisms leading to their extinction, water pollution and soil quality degradation.

4.4.1.1 Environmental effects of pesticides and fertilizers use

Figure 4.59 indicated that moderately harmful ranked highest with 44.8% of the study population, very harmful ranked second with 23.7%, not harmful ranked third with 17.8%, and the slightly harmful ranked least with 13.4%.

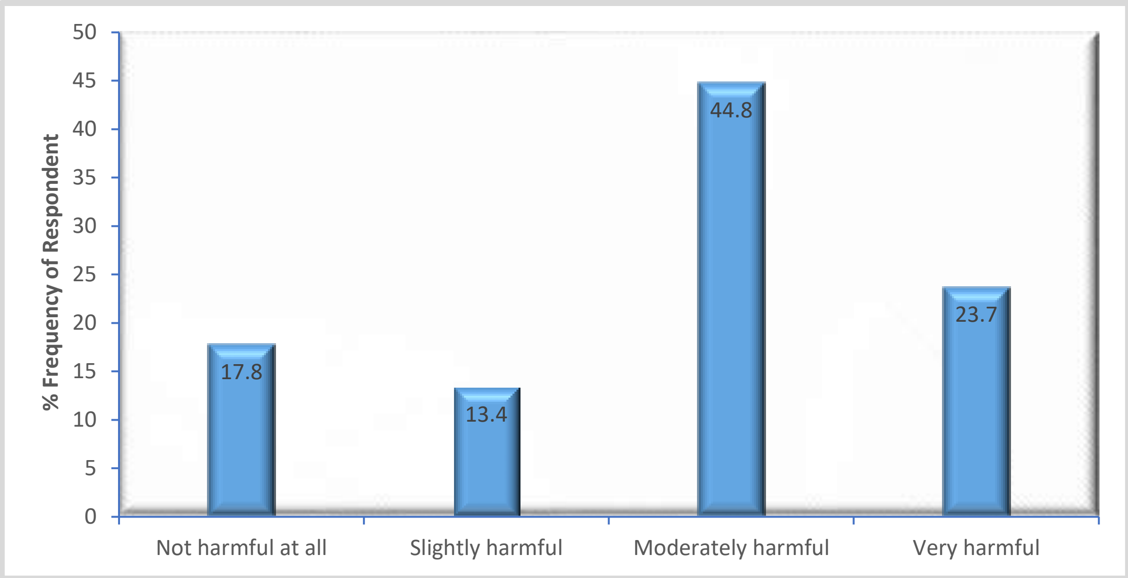


Figure 4.59: Environmental Effects of Pesticides and Fertilizers Use

Source: Author's Work, 2020

These findings imply that most of the population affirmed that the use of pesticide and fertilizers in the study area affects the environment negatively. Information obtained from village group discussions and key informants such as community district officers, Agric extension officers, senior members in the farming community and health workers also corroborated all revelations through administered questionnaires. Environmental effects revealed by the all the targeted audience include the extinction of aquatic organisms such as fishes in which the communities majorly depend on for socio-economic livelihoods, water pollution and soil quality degradation.

4.4.1.2 Rating of the risks of agrochemicals effects on soil, air, surface water and aquatic organisms

Table 4.25 indicated that moderately harmful ranked highest with 44.9% of the population and not harmful ranked least with 9.8%.

Table 4.25: Rating of the Risk of Agrochemicals Effects on Soil, Air and Surface Water

Options	Not harmful (%)	Slightly harmful (%)	Moderately harmful (%)	Very harmful (%)
Soil	2.1	6.2	10.3	9.1
Air	0.3	1.5	4.7	1.8
Surface water	1.8	4.4	25.5	10.9
Aquatic organism (fish)	5.6	4.1	4.4	7.6
Total	**9.8**	**16.2**	**44.9**	**29.4**

Source: Author's Work, 2020

This implies that all aspects of the environment are under threat of pesticides and fertilizer use as affirmed by the study population. Information obtained from village group discussions and key informants such as community district officers, Agric extension officers, senior members of the farming community and health workers also corroborated all revelations through administered questionnaires. The study population lamented loss of soil qualities following use of agrochemical pesticides which insights them to use fertilizers excessively for crop improvements. The study population also revealed changes in the smell of air they breathe during heavy application of agrochemical pesticides which a clear indication of air contamination. Further, targeted population also revealed observing changes in the natural colour and taste of surface waters in which they depend on for socio-economic livelihoods which can be attributed to degradation of organic matters resulting from intense use of herbicides for farming in the study area. Death of fishes and other aquatic organisms were observed to be at peak leading to extinctions as revealed by the study population. In view of this finding, continue and unsustainable use of synthetic fertilizers and pesticides in the study without proper check from the responsible authorities and collective efforts by stakeholders will lead to serious socio-economic crises in the study area.

4.4.2 Human health impacts

Table 4.26 indicated that 86.0% of the study population affirmed the existence of health problems attributable to fertilizers and pesticide use in the study area and 14.0% disaffirmed.

Table 4.26: Presence of Health Problems Associated with the use of Fertilizers and Pesticides

Options	Frequency	Percentage (%)
Yes.	301	86.0
No.	49.	14.0
Total.	**350**	**100.**

Source: Author's Work, 2020

The finding implies that the heath of people living in the study area is under threat due to agrochemical contaminations. The health problems revealed to be prevalent and attributable to agrochemical use include skin diseases, eye irritation, stomach ache and respiratory complications. Information obtained from village group discussions and key informants such as community experienced district officers, extension agents, senior members of the farming community and health workers also corroborated all revelations gotten through from the farmers.

4.4.2.1 Reported health problems associated with use of fertilizers and pesticides

Table 4.27 indicated that 110 cases of skin related diseases were recorded between January and December, 2020. Other cases within the same year include 35 eyes, 56 stomach ache and 21 respiratory health related problems.

Table 4.27: Reported Health Problems Associated with use of Fertilizers and Pesticides

Months	Skin	Eyes	Stomach	Respiratory irritations
January	3	0	4	0
February	1	0	1	1
March	0	0	0	3
April	8	3	2	0
May	13	1	4	2
June	10	10	7	5
July	7	6	14	3
August	29	7	5	2
September	15	0	9	0
October	17	4	7	1
November	5	2	3	3
December	2	0	2	1.
Total	**110**	**35**	**56**	**21**

Source: Author's Work, 2020

The findings indicated the presence of human health cases associated with fertilizers and pesticide use among the study population. There were also reported cases of strange illnesses since the study population started using fertilizers and pesticides in the study area and authorities concern are not doing anything reasonable to reduce the impact of using fertilizers and pesticides in the farming operation. The strange health cases revealed to be on the increase by community's health workers and other stakeholders include cancer, brain tumour, neurological disorders, liver damages, kidney failure, developmental problems, and miscarriages which many studies have attributed to agrochemical contaminations.

4.4.3 Economic development impact

Table 4.28 indicated that 92.6% of the study population affirmed the presence of economic development hardship due to agrochemical use, and 7.4% disaffirmed.

Table 4.28: Presence of Environmental and Human Health Problems Attributable to Fertilizers and Pesticides Contamination on the Community's Incomes

Zones	Affirmed/Frequency	%	Disaffirmed/Frequency	%
UZs	119	34.0	11	3.1
MDZ	85	24.3	07	2.0
LZs	120	34.3	08	2.3
Total	**324**	**92.6**	**26**	**7.4**

Key: UZs = Upper zones. MDZ = Middle zone. LZs = Lower zones.

Source: Author's Work, 2020

The study population claimed that environmental and health problems attributable to fertilizers and pesticides contamination has affected the community's incomes Because most of the money generated from there farming operations were spent in hospitals for the treatment of illness they got since they commence the use of fertilizers and pesticides during farming activities. This implies that there are existence of serious negative socio-economic implications of fertilizers and pesticide used in the study area as majority of the farmers spend a lot of their earnings managing their health and high inefficiency due to health problems during farming activities.

Stakeholders' interview corroborated the farmer's submissions and further revealed indebtedness of the farmers to financial institutions from loan money for the purpose of agrochemicals purchase. In many cases, some of the pesticides are adulterated and failed to kill the pest thereby leading to crop failure and left the farmers with huge dept.

4.4.3.1 Measures to reduces agrochemical contaminations in the community

Table 4.29 indicated that planting of early maturing crop varieties was ranked highest with 41.9% of the study population, increase awareness on proper handling of agrochemicals ranked second with 34.3% and continued awareness creation on the danger of agrochemicals is the least with 9.6%.

Table 4.29: Measures to Reduces Agrochemical Contaminations in the Community

S/n	Measures	% VG (3)	% G(2)	% NG (1)
1	Planting drought tolerant crop varieties	8.3	5.9	0
2	Planting of early maturity crop varieties	37.0	4.9	0
3	Continues awareness on the danger of agrochemicals	4.0	5.6	0
4	Increase awareness on proper handling of agrochemicals	31.2	3.1	0
	Total	**80.5**	**19.5**	**0**

Source: Author's Work, 2020

The findings imply that the favoured measure adopted by the respondents reducing agrochemical contaminations of aquatic the study area is planting of early maturity varieties of crops.

In summary, this objective revealed high rates of socioeconomic challenges of pesticides and fertilisers contamination in the study area. These challenges include negative effects on the environment, people’s health, and effects on economic development. In view of the above, there is an urgent need for all stakeholders to adopt individual or collective responsibility in ensuring environmentally sustainable use of agrochemicals in the study area to guarantee the cleaner socio-economic wellbeing of communities in the study area.

A similar situation has been reported in areas characterised by farming activities involving intense use of fertilizers and pesticides around the world (Ramakrishnan and Jayaraman, 2019; Bajpai, 2019; Bashir *et al.*, 2020). Considering the negative attitudes with regards to agrochemical use identified so far in this study coupled with the discovery of agrochemical contaminants in the analysed environmental media and confirmed existence of socioeconomic challenges attributable to agrochemical contaminations in this study, there comes a need to appraised the strength and weaknesses of relevant environmental laws and extant regulations on agrochemical use near sensitive and vulnerable areas in respect of last objective in this study.

4.5 Appraisal of the effectiveness of relevant environmental laws and extant regulations on agrochemical use near sensitive and vulnerable areas

The results of analysis of effectiveness of relevant environmental laws and extant regulations on agrochemical use near sensitive and vulnerable areas are represented in Table 4.30 to Table 4.40.

4.5.1 Responses from the regulated communities

The first category of the questions was the spontaneous compliance dimensions. The findings are represented in Table 4.30 to Table 4.34.

4.5.1.1 Knowledge and Clarity of the Rules

Table 4.30 indicated that over 80% of the study population have weak knowledge and clarity of the rules governing agrochemical use near sensitive and vulnerable area.

Table 4.30: T1 Knowledge and Clarity of the Rules

S/n	Questions	1	2	3	4
1	Does the target group know the legal requirements?	11	19		
2	Is a legal requirement taking too long?	3	27		
3	Is it hard to understand legal requirements?	2	28		
4	Do you have questions about applying the rules?	21	9		
5	Are the legal requirements for the target group too complex?	10	20		
6	Do target group understand what is meant by them and are there need for the rule's comprehension?	1	29		

Key: 1 = very weak, 2 = weak, 3 = moderate, 4 = strong and 5 = very

Source: Author's Work, 2020

The finding shows that agrochemical vendors and farmers in the area exhibit poor consciousness environmentally when compared with best practices stipulated in OECD, (2004). Similar situation has been reported around the world particularly in developing countries (Matata, 2013; Akter *et al.*, 2018; Dugger-Webster and LePrevost, 2018). The finding suggested that there are proliferation of agrochemical laws or multiple amendments to advance them which has led to a loss of simplicity and therefore a loss of ability to comprehend what compliance encompasses. The study also discovered that environmental regulations are unreachable and incomprehensible and mainly affects agrochemicals business and use compliance levels. A similar situation has been reported in a publication by OECD (1999). The implication of the identified gap here could lead to serious regulatory failures considering the weak rating of knowledge and clarity of the rules of agrochemical use by the target groups.

4.5.1.2 Cost-benefit Consideration

Table 4.31 indicated that knowledge of complying with rules was a big effort since the score was strong. It also revealed that non-compliance bringing profit ranked moderate).

Table 4.31: Cost-benefit Consideration

S/n	Questions	1	2	3	4	5
1	Financial / economic Immaterial					
	Is it easy to follow the rules?			3	27	
2	Does the noncompliance save time or money?			25	5	
3	Are there adequate physical conditions to cover non-compliance?	21	9			
4	Are there obvious benefits to following the rules such as monetary incentives?	2	28			
5	Immaterial					
	Does compliance provide emotional or social benefits?	1	29			

Key: 1 = very weak, 2 = weak, 3 = moderate, 4 = strong and 5 = very

Source: Author's Work, 2020

The non-compliance bringing profit, which ranked moderate implies that half of the study population get financial and temporal profit. The remaining three questions which ranked weak is because the study population has weak knowledge of the cost-benefit accrued to them. This finding further shows that agrochemical vendors and farmers in the area sees compliance with the rule as huge burden, enjoys financial benefit from noncompliance. This may probably be due to weakness in knowledge of the cost-benefit accrued to them as reflected in the last three questions. The study population have the understanding that the compliance rates are too high and thinks compliance extents can decline if the conforming cost with the regulation are too high. The findings further show that several elements contribute to compliance costs. These include two high emission and technical standards, short transition time necessary to come into conformity, and inflexible regulations. The implication of the identified gap here could also have led to serious regulatory failures considering the weak rating of weakness in knowledge of financial / economic immaterial.

4.5.1.3 Level of Acceptance

Table 4.32 indicated that, the level of acceptance was very weak since more than 70% of the scores are within very weak score.

Table 4.32: Level of Acceptance

S/n	Question	1	2	3	4	5
1	Does the target group consider the approach to the regulation's requirements reasonable?	19	11			
2	Can the target group feel obligated to solve problems with specific policy or disagreements?	23	7			
3	Can target groups contribute to policy implementation through self-regulation?	29	1			
4	Are the legislators' intents clear, properly formulated and are there gaps in the law?	22	8			

Key: 1 = very weak, 2 = weak, 3 = moderate, 4 = strong and 5 = very

Source: Author's Work, 2020

This implies that farmers around River Niger and Kaduna catchments affirmed the level of acceptance to be very weak. Responses indicated that compliance rules are mostly rejected on the bases that government is concurrently presenting numerous conflicting regulatory tools or policies that send opposing signals. The finding implies that compliance rates are lower or rejected because available regulations are not well fitted with the current market does or not buttressed by the cultural standards and civic establishments. The implication of this finding will lead to unsustainable use of agrochemicals in the area, thereby endangering the socioeconomic wellbeing of communities in the study area.

4.5.1.4 Normative Commitment by the Target Group

Table 4.33 indicated that the normative commitment by the target group was very weak since out of the thirty respondents, more than 88.3% of them affirmed the weakness.

Table 4.33: Normative Commitment by the Target Group

S/n	Questions	1	2	3	4	5
1	Do most of these target groups meet legal requirements?	30				
2	Does target group always follow authority's demands?	29	1			
3	Is there a tradition in this target group that may conflict the requirements?	30				
4	Does this target group have clear perspectives for the authorities?	17	13			

Key: 1 = very weak, 2 = weak, 3 = moderate, 4 = strong and 5 = very

Source: Author's Work, 2020

The finding suggested that an overly rule-based or 'legal' approach to compliance undermines the accomplishment of the anticipated result since people in the study area lose confidence in regulation because they are obligated to conform to the technical rules that do not seem to relate to any substantive drive.

4.5.1.5 Informal Control

Table 4.34 indicated that the informal chance of getting caught and sanction probabilities were weak.

Table 4.34: Informal Control

S/n	Questions	1	2	3	4	5
1	Does the target group quickly recognize noncompliance?	10	20			
2	Does the target group disliked violations at all?	3	27			
3	Is there a strong group spirit among the members of the target group?	14	16			
4	Is there an informal control structure?	2	28			
5	If the target group refuses, is the target group trying to fix it?		30			
6	Does the target group respond negatively to violations through social sanctions such as group exclusion, respect, or loss of status?	4	26			
7	Are there other informal sanctions that may be imposed?	12	18			

Key: 1 = very weak, 2 = weak, 3 = moderate, 4 = strong and 5 = very

Source: Author's Work, 2020

This implies that the informal chance of getting caught were weak since the target group does not quickly notice non-compliance. The target group does not criticise non-compliance, there is no strong group spirit between the target group members, and there are no informal control structures. The informal sanctions were also weak since in the case of disapproval of non-compliance by the target group, the target group do not try to correct it in some way, neither react negatively to non-compliance through social sanctions, like excluding or banishing from the group or loss of veneration or status nor there are no other informal sanctions that can be imposed. The implication of this finding will lead to carelessness in the use of agrochemical in the area thereby endangering the socioeconomic wellbeing of communities in the study area

4.5.2 Responses from the regulatory and enforcement authorities

This section is a category II in this objective which is the control dimensions which connote the effect of enforcement on compliance. The findings are represented in Table 4.35 to Table 4.40.

4.5.2.1 Informal Report Probability

Table 4.35 indicated that that the target group's inclination to report non-compliance with the authorities was very; knowing which authority non-compliance can be reported was also weak; and measures considered to enlarge the approachability of the authorities were also weak.

Table 4.35: Informal Report Probability

S/n	Question	1	2	3	4	5
1	Does the target group tend to report abuses?	28	2			
2	Is the authority to report violations well known?	6	24			
3	Have you taken steps to improve the accessibility of authorities (e.g., complaint desk, phone number to report non-compliance)?	8	22			

Key: 1 = very weak, 2 = weak, 3 = moderate, 4 = strong and 5 = very

Source: Author's Work, 2020

This implies that informal report probability was weak and this in turn showed that effectiveness of relevant authorities to address non-compliance with environmental laws governing the usage of agrochemical in farming was weak in the study area. The finding also implies failures of consultations with the target populations which can result to regulatory failures owing to the facts that regulators may not find out about elements falling into the categories that were described above that could lead to regulatory failure, or owing to lack of sufficient consultation may fail to secure target group support for the proposed regulation.

4.5.2.2 Probability of Being Inspected

Table 4.36 indicated that the objective chance of being checked (control density) was very weak and seriousness of the TG in appraising the chances were also weak.

Table 4.36: Probability of Being Inspected

S/n	Question	1	2	3	4	5
1	What are the chances of being checked?	26	4			
2	How seriously does the target group take this opportunity?	3	27			
3	What really depends on the possibilities of subjective verification?	1	29			

Key: 1 = very weak, 2 = weak, 3 = moderate, 4 = strong and 5 = very

Source: Author's Work, 2020

This implies that the probability of being inspected was weak and this in turn showed that effectiveness of relevant authorities to address non-compliance with environmental laws governing the usage of agrochemicals in farming was weak in the study area. Finding also revealed that that agrochemical regulations are never monitored and could unlikely bring compliance. This is in line with several studies on efficacy of occupational safety and health checks in the United States and Canada as reported by OECD (1999) and OECD (2004).

4.5.2.3 Detection Probability

Table 4.37 indicated that the measurement of detection probability was between weak and very weak.

Table 4.37: Detection Probability

S/n	Question	1	2	3	4	5
1	Is there complete administrative check?	29	1			
2	How problematic is it to spot the differences?	30				
3	Is it easy to fake travel documents or permits?	23	7			
4	Could the life of an inspector be more complicated due to the lack of a sample or standard form?	28	2			
5	Can a inspectors easily spot non-compliance?	21	9			
6	What type and quality of inspection approaches do you use?	24	6			
7	Is it difficult to find the noncompliance because you are connected by time and space?	21	9			

Key: 1 = very weak, 2 = weak, 3 = moderate, 4 = strong and 5 = very

Source: Author's Work, 2020

This implies that detection probability, by the enforcement authorities both in administrative and physical checks were weak and very weak. This will affect the effectiveness and efficiency of the enforcement agencies in dealing with detection of non-compliance of agrochemical use in the study area. The regulated communities in the study area revealed that the government regulatory agencies are unfairly treating them. This has made them refusing to comply with regulatory the requirements.

4.5.2.3 Selectivity

Table 4.38 indicated that the selective check was high while non selective check was lower.

Table 4.38: Selectivity

S/n	Question	1	2	3	4	5
1	Is there a significant level of awareness of selective control rather than non-selective control?				30	
2	Do you think defaulters are checked more often than those who obey them?			3	27	

Key: 1 = very weak, 2 = weak, 3 = moderate, 4 = strong and 5 = very

Source: Author's Work, 2020

This indicated that there was a reasonably higher detection level in the case of selective checks than the non-selective checks with strong score. This shows that the offenders have the sentiment that they are inspected more often than the ones that normally conform. This implies that the selectivity of the control dimension was on the strong side despite weak and very weak control dimension at earlier subsections.

4.5.2.4 Sanction Probability

Table 4.39 indicated that the informal remedy dimension was moderate; difficulty in proving non-compliance was moderate; and the chances of being acquitted in the court also ranked moderate.

Table 4.39: Sanction Probability

S/n	Question	1	2	3	4	5
1	What is the likelihood that sanctions will be imposed after the discovery of non-compliance?		5	25		
2	Is it difficult to prove non-compliance?		1	29		
3	Do offenders have high expectation of chance to be acquitted in court of law?		8	22		

Key: 1 = very weak, 2 = weak, 3 = moderate, 4 = strong and 5 = very

Source: Author's Work, 2020

This implies that the chance that a penalty will be imposed following detection of non-compliance, or that there will be an informal remedy ranked moderate; difficulty to prove non-compliance ranked moderate and offenders having a high estimate of chances to be acquitted in court ranked moderate. This further implies that the probability of sanction dimension has a fair level of effectiveness of environmental laws on agrochemical use near sensitive and vulnerable areas.

4.5.2.5 Sanction Severity

Table 4.40 indicated that the sanction severity indicators which include extent of sanction, financial implications of sanction, and possibility of prosecution were generally weak.

Table 4.40: Sanction Severity

S/n	Question	1	2	3	4	5
1	Does the target group know the type and extent of sanctions for non-compliance?	3	27			
2	Does the target group recognize this sanction as high?	4	26			
3	Do sanctions consider the financial capabilities of the offender?	1	29			
4	To what extent are sanctions swiftly applied?	2	28			
5	Do potential offenders notice that they will be prosecuted (in case of penal law) as more unfriendly than the main sanction?	6	24			
6	Will sanctions create additional flaws for offenders	8	22			

Key: 1 = very weak, 2 = weak, 3 = moderate, 4 = strong and 5 = very

Source: Author's Work, 2020

This implies that the formal level of the sanction and immaterial costs were weak and in turn will lead to low effectiveness of relevant environmental laws on agrochemical usage in the study area by the relevant enforcement agencies. The implication of all identified gaps here could have led to serious regulatory failures considering the weak rating of all the factors affecting the incidence of voluntary compliance, which is the compliance that would occur in absence of enforcement; the influence of enforcement on compliance; and the influence of sanctions on compliance. Similar situations have been reported around the world, particularly in developing countries as revealed by Matata (2013), Akter et al. (2018) and Dugger-Webster and LePrevost (2018).

In summary, analysis of fourth objective in this study shows that the appraisals on the effectiveness of extant regulations and enforcement tools on agrochemical use near sensitive and vulnerable areas among educators, regulators, enforcement authorities and the regulatory communities were largely weak. It was understood that available regulations and enforcement tools on agrochemical use near sensitive and vulnerable areas are largely politically desired, devoid of intent for implementation which has led to serious regulatory failure in the study area. Similar situations have well been reported around the world, particularly in developing countries as revealed by Matata (2013), Akter et al. (2018) and Dugger-Webster and LePrevost (2018). The implication of all identified gaps here has led to serious regulatory failures.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Sequel to the field and empirical investigations in this study, the following conclusions were derived:

i. It was established that farmers in the study area use various compounds of synthetic pesticides and fertilizers in their farming activities. The types of pesticide compounds they used in the study area include: organochlorine and organophosphorus based which are known to present serious negative socio-economic effects. Organochlorine-based pesticides in the study area constitutes highest percentage at 34.78% while organophosphorus based pesticides constitute 8.69%. Nitrate and phosphate-based fertilizers were also identified to be in use in the study area. This conduct by farmers in the area has resulted to contamination of water and soil, and potential negative effects on socio-economic wellbeing of communities in the study area can be expected.

ii. This study has been able to demonstrate the effectiveness of GIS tools in overlaying the physico-chemical characteristics of water and sediments. The physico-chemical properties identified in this study showed that the value of pH range (5.2-7.4), salinity (28.0-76.0 PSU), temperature (22.1-28.1 °C), EC (10.0-43.0 μs/cm), DO (5.3- 8.6 ppm), TDS (6.7-23.60 ppm), turbidity (12-47 0 NTU), COD (13.80-45.06 ppm), BOD (7.05-18.15 ppm), TSS (15.8-54.0 ppm), Mn (0.08.2.86 ppm), TH (3.55-10.52 ppm), chloride (16.08-106.5 ppm), sulphate (0.447-22.68 ppm) and potassium (0.13-62.75 ppm). It has also been able to established that significant number of physico-chemical parameters of water and sediments identified in this study were above regulatory limit and this can affect water quality, increase the concentrations of pesticides and fertilizers in the environmental media analysed and subsequent negative socio-economic effects on wellbeing of communities in the study area. These concentrations are significant in both seasons and distributed across all the sample points with higher concentrations recorded largely at the lower zones which are clear indications of downstream movement of agrochemicals in the study area.

iii. The study also established that water and sediments samples from the study area are largely contaminated with plant minerals which includes nitrate, nitrite, and phosphate and these are spatially distributed across the sampled points. Plant mineral concentrations were detected and spatially distributed across the study zones in surface water and soil samples during rainy and dry seasons, with concentrations ranging from NO_3^- (0.02-3.147 ppm), NO_2^- (0.02-1.16 ppm) and PO_4^- (0.228-5.771 ppm).

Further, diverse compounds of organochlorine pesticides were also confirmed to have contaminated all water and soil samples from the study area. The organochlorine pesticide compounds which include endosulfan, alpha endosulfan, endosulfan ether, delta endosulfan, endosulfan sulfate, mehoxychlor, alpha lindane, delta lindane, endrin ketone, dieldrin, DDT, DDMU, mitotane and heptachlor epoxide were detected and quantified with concentrations ranging from 0.01 ppm to 15.97 ppm in water and sediment samples analysed. A significant numbers of organochlorine pesticide compounds identified corroborated survey findings in this study. All other organochlorine compounds detected, but not affirmed in use by farmers in the study area may be attributed to previous uses, transboundary chemical movement, and trace quantities in currently use pesticide compounds. Disturbingly, all organochlorine pesticide compounds detected in water samples of rain and the dry season are of serious health and environmental concern. Organochlorine pesticide compounds detected are either restricted or banned in Nigeria. The presence of these persistent and hazardous compounds in water of the study area can trigger negative socio-economic wellbeing of communities in the study area.

It is noteworthy that plant minerals and organochlorine pesticides identified may lead to severe health issues such as cancer, brain tumour, asopharyngeal, developmental problems and leukaemia. Also, in children and infants, nitrate and nitrite usually bind to haemoglobin and trigger chemically impairs oxygen delivery to tissues, resulting in the blue colour of the skin known as "blue baby syndrome ". Acute or chronic health issues such as birth defects, cancer, organ failures, renal complications, brain damage, respiratory disorder, endocrine disruption, sterility, and infertility can arise from the presence of organochlorine pesticide residues identified. A similar situation has been reported in developing countries including Nigeria (Adeshina *et al.,* 2019: Adeyinka *et al.,* 2019). In view of the above findings, there is urgent need from all stakeholders to insight individual or collective roll(s) towards proffering visible measures to sustainably contain these socio-economic threats for the purpose of ensuring cleaner and healthier environment for all.

iv. The study also revealed the existence of socioeconomic challenges attributed to pesticides and fertilisers contamination in the study area. These challenges include negative effects on the environment, health, and effects on economic development.

v. The study further revealed that the appraisals on the effectiveness of extant regulations and enforcement tools on agrochemical use near sensitive and vulnerable areas among educators, regulators, enforcement authorities and the regulatory communities were largely weak. It was understood that available regulations and enforcement tools on agrochemical use near sensitive and vulnerable areas are largely politically desired, devoid of intent for implementation which has led to serious regulatory failure in the study area.

Precisely, this study has demonstrated a comprehensive GIS aided spatial distribution of physico-chemical characteristics and plant mineral concentrations in water and soil in the study area. Also, as it is obviously understood that there is a lack of background information on the status of physico-chemical characteristics and plant mineral concentrations in the study area, this study presents a comprehensive background information for further studies.

Further, this study demonstrated urgent need for effective environmental management policies, government dedication, political wills, and collective responsibility of all stakeholders toward agrochemicals management and ensuring sustainable farming practices involving the use of pesticides and fertilizers in the area to guarantee cleaner and healthier environment for all.

5.2 Recommendations

Based on the result of findings in this study so far, the following recommendations have been designated:

i. All stakeholders should adopt individual and collective responsibility in ensuring environmentally sustainable use of agrochemicals through education and targeted awareness creations in the study area. Green chemistry technology, organic farming and the use of biobased products should be encouraged and promoted among farmers to minimize or prevent the use of environmentally unfriendly agrochemicals.

ii. As this study clearly presented the effectiveness of GIS tools in overlaying the physico-chemical characteristics and plant mineral concentrations in water and sediments, it is therefore recommended that this research approach should be encouraged among researchers.

iii. Further studies should be carried out to ascertain the occurrence, concentrations, and distribution of other agrochemical compounds such as organophosphorus, carbamates and synthetic pyrethroids in environmental media in the study area. Research attention should be focused also on the biota such as fishes, crabs, planktons, and other terrestrial animals. Reference laboratories should be made available and strategically located to ensure continued monitoring of environmental media to ascertain levels of contamination of agrochemical residues.

iv. Water treatment facilities for domestic uses should be provided by authorities to minimise potential health hazards of agrochemical contaminants on wellbeing of communities in the study area. Also, there is urgent need for visible awareness creations campaign by responsible authorities on dangers of contaminations of all resources by agriculture chemicals in the study area.

v. Visible policies should be formulated by regulatory and enforcement authorities with regards to use of agrochemicals near sensitive and vulnerable environmental resources in the study area. These will guarantee a cleaner and healthier environment for all.

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Appendix A

Request for Interview

………………………………	**Federal University of Technology**
……………………………...	**Department of Geography.**
……………………………..	**Minna,**
………………………………	**Date …………………….**

Sir/Ma.

Letter of introduction

I am PhD student of the Federal University of Technology Minna carrying out a study on the effects of agrochemicals on soil and water quality in parts of Rivers Niger and Kaduna catchments, North Central Nigeria. As a key stakeholder in this regard, your views are important in this study and I would be grateful if you could respond to the questionnaire attached to this letter and possibly grant me an interview on this important topic.

I would like to assure you that the information you provide in the interview will be treated confidentially and will be used solely for the purpose of this research.

Thank you for your assistance.

Idris, Aliyu Ja'agi

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E-mail: aliyuidrisjaagi@yahoo.com

Appendix B

Questionnaire for the Farmers in Rivers Niger and Kaduna Catchments

Survey of agrochemical use along the Rivers Catchments

Characterizing questions (demographic, education, livelihood strategies, farming system)

Sampling point date of interview…………Questionnaire number……Zone………

(a) Farmer's Details

Age…………….Sex………….

Major source(s) of income for the household………………..

Farmer's level of education…………..Number of Adult………..and children……..in the farmer's house hold………………Language spoken in the household……………….

(b) Information on Farming

(i) How many hectares of land do you have? ....ha

(ii) Which type of farming do you practice? [a] large scale farming [b] subsistence farming

(iii) Which crops do you grow?

How much land have you devoted for each?

For how long have you been using piece of land for this crops?

(iv) Do you practice any crop rotation? [Yes] [No]

If No, why

If [Yes]. For which crops?

(v) When do you plant your crops and why? ………………..

How many times do you plant this type of crops in a year? ....

What problems have you experienced with the crop(s)? …………………

Is it a common problem…………how do you solve it? ....

(vi) Use of fertilizers in farming

Do you use fertilizers in your crop(s) [Yes] [No]

If [No]. Why?

If [Yes]. Which ones and why?

(vii) How much of each do you use per hectare and what is the yield?

How and what do you apply the fertilizers?

Where do you get the fertilizer (s) from?

What is the cost per unit?

How long have you been using the fertilizer on the farm (s)

(C) Use of Pesticides in Farming

Do you use any pesticides for crops? [Yes]. [No]

If [No]. Why?

If [Yes], which one(s)?

How much of each pesticide(s) do you use per hectare and what is the yield?

How and when do you apply the pesticides?

Where do you get pesticide(s) from?

How long have you been using the pesticide(s) on the farm(s)

Do you know of any banned or restricted and pesticides(s)?

If [Yes]. Which one(s)?

How you disposed the used cans? ....

Where do you wash the application tools? …………………

What measures do you take to conserve the River? ....

Do you have any other comments or questions with regard to what we have discussed?

Thank you for your time and assistance

Appendix C
In-Situ Water Sample Analysis (Physicochemical)

Rainy, 2018 and Dry, 2018 Seasons Water Samples W1 – W8

Parameters	W1 - W1	W2 - W2	W3 - W3	W4 - W4	W5 - W5	W6 - W6	W7 - W7	W8 - W8
pH	6.9 - 6.9	5.6 - 6.6	6.7 - 6.8	7.4 - 6.8	6.2 - 6.4	5.3 - 5.6	5.2 - 6.4	6.7 - 5.4
Salinity (PSU)	41.0 - 35.0	74.0 - 61.0	81.0 - 64.0	55.0 - 44.0	70.0 - 28.0	76.0 - 52.0	65.0 - 51.0	81.0l - 61.0
Temp. (°C)	22.4 – 25.12	22.1 - 25.17	23.2 - 26.3	22.3 - 26.8	22.2 - 28.1	23.3 - 27.2	22.1 - 27.2	23.2 - 25.4
DO (mg/l)	7.8 - 5.9	7.5 - 6.3	8.3 - 5.3	7.2 - 6.3	8.1 - 6.4	8.6 - 6.3	6.9 - 6.4	8.6 - 6.6
EC (µS/cm)	16.0 - 10.0	26.0 - 20.0	28.0 - 20.0	43.0 - 30.0	27.0 - 10.0	32.0 - 10.0	26.0 - 10.0	29.0 - 10.0
TDS (mg/l)	21.40 - 6.70	22.40 - 13.40	22.40 - 13.40	23.1 - 20.1	19.60 - 6.70	21.80 - 6.70	17.80 - 6.70	23.60 - 6.70
Turbidity (NTU)	56.0 - 15.0	47.0 - 26.0	64.0 - 39.0	67.5 - 12.7	81.0 - 56.0	80.0 - 43.0	91.0 - 88.0	96.0 - 88.0

SOURCE: Author's Field Work, 2019

Appendix D

Results of Physicochemical Analyses for Rainy, 2018 and Dry, 2018 Seasons of Water (W1-W8) and Sediment (S1-S8) Samples

0.PHYSICOCHEMICAL ANALYSIS ON WATER SAMPLES

PARAMETER	W1	W2	W3	W4	W5	W6	W7	W8
NITRATES (ppm)	0.256	N.D	0.893	1.764	1.080	1.142	1.274	2.626
NITRITE (ppm)	0.05	0.02	0.16	0.18	0.25	0.28	0.34	0.56
AMMONIUM(ppm)	-	-	-	-	-	-	-	-
PHOSPHATE (ppm)	N.D	N.D	N.D	0.715	0.229	3.969	4.564	1.294
SULPHATE (ppm)	2.07	0.69	1.02	1.57	1.68	1.88	2.15	
MANGANESE (ppm)	0.08	0.25	0.16	0.57	0.62	1.06	0.74	0.65
CHLORIDE(ppm)	35.5	53.3	71.0	71.0	60.40	63.90	35.6	106.5
COD (ppm)	30.05	25.65	35.70	32.06	28.30	40.07	24.80	45.06
BOD (ppm)	12.25	9.82	15.60	13.20	12.00	16.02	10.85	18.15
TSS (ppm)	45.6	30.0	52.00	49.62	35.02	40.52	38.65	53.05
TOTAL HARDNESS (ppm)	7.50	8.60	7.01	6.85	10.52	7.60	8.00	4.60
POTASSIUM (ppm)	0.56	0.35	1.27	1.54	0.13	2.07	1.68	1.75

PHYSICOCHEMICAL ANALYSIS ON SEDIMENT SAMPLES

PARAMETER	S1	S2	S3	S4	S5	S6	S7	S8
NITRATES (ppm)	2.004	2.098	2.095	2.144	2.137	1.896	2.556	3.147
NITRITE (ppm)	0.07	0.63	0.71	0.69	0.75	0.54	1.02	1.16
AMMONIUM(ppm)	-	-		-	-	-	-	-
PHOSPHATE (ppm)	1.546	2.552	1.965	1.269	2.099	4.564	5.771	3.776
SULPHATE (ppm)	15.06	5.28	6.57	10.06	12.58	22.68	8.65	7.96
MANGANESE (ppm)	0.20	0.65	0.42	1.49	1.60	2.79	1.95	2.45
CHLORIDE(ppm)	23.08	37.31	48.28	41.89	35.64	40.90	22.78	72.42
COD (ppm)	NA	NA	NA	NA	NA	NA	NA	NA
BOD (ppm)	NA	NA	NA	NA	NA	NA	NA	NA
TSS (ppm)	NA	NA	NA	NA	NA	NA	NA	NA
TOTAL HARDNESS (ppm)	NA	NA	NA	NA	NA	NA	NA	NA
POTASSIUM (mg/kg)	35.02	12.56	40.65	55.65	10.56	62.75	45.09	58.25

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.PHYSICOCHEMICAL ANALYSIS ON WATER SAMPLES

PARAMETER	W1	W2	W3	W4	W5	W6	W7	W8
NITRATES (ppm)	1.504	1.307	1.090	1.071	1.007	N.D	1.045	1.166
NITRITE (ppm)	0.03	N.D	0.08	0.06	N.D	N.D	0.13	0.10
AMMONIUM(ppm)	-	-	-	-	-	-	-	-
PHOSPHATE (ppm)	0.712	N.D	N.D	0.829	N.D	N.D	2.189	2.518
SULPHATE (ppm)	1.95	0.72	0.87	1.61	1.05	1.64	1.76	0.96
MANGANESE (ppm)	0.15	0.79	0.82	0.62	0.86	0.98	0.45	0.46
CHLORIDE(ppm)	18.5	37.31	46.15	45.8	47.1	35.78	24.48	78.81
COD (ppm)	18.43	13.80	23.86	19.24	14.38	22.82	17.36	18.5
BOD (ppm)	10.3	7.54	12.56	10.02	7.05	11.70	8.95	9.25
TSS (ppm)	35.62	18.60	35.57	15.8	22.709	38.87	27.6	38.7
TOTAL HARDNESS (ppm)	3.90	5.05	4.29	6.20	7.65	6.02	4.67	3.52
POTASSIUM (ppm)	0.24	0.18	0.32	0.08	ND	1.54	1.09	1.45

PHYSICOCHEMICAL ANALYSIS ON SEDIMENT SAMPLES

PARAMETER	S1	S2	S3	S4	S5	S6	S7	S8
NITRATES (ppm)	1.090	2.397	2.371	2.161	1.893	1.689	N.D	1.486
NITRITE (ppm)	0.18	0.32	0.54	0.22	0.19	0.51	0.15	0.95
AMMONIUM(ppm)	-	-	-	-	-	-	-	-
PHOSPHATE (ppm)	N.D	1.530	1.158	0.447	N.D	0.787	0.691	0.999
SULPHATE (ppm)	8.62	4.61	5.07	7.05	5.62	7.15	4.87	5.46
MANGANESE (ppm)	1.04	1.24	1.35	1.52	1.29	2.86	0.96	2.36
CHLORIDE(ppm)	16.08	22.08	32.65	28.609	22.98	24.80	15.08	50.13
COD (ppm)	NA	NA	NA	NA	NA	NA	NA	NA
BOD (ppm)	NA	NA	NA	NA	NA	NA	NA	NA
TSS (ppm)	NA	NA	NA	NA	NA	NA	NA	NA
TOTAL HARDNESS (ppm)	NA	NA	NA	NA	NA	NA	NA	NA
POTASSIUM (mg/kg)	22.56	8.50	35.56	42.60	7.65	52.70	33.80	39.57

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Appendix E

Calibration Curves of Plant Mineral Concentrations

Calibration Curves of Nitrate, Nitrite and Phosphate Concentrations for Rainy, 2018 and Dry, 2018 Seasons of Water (W1-W8) and Sediment (S1-S8) Samples

NITRATE

Quant_2_11_2019_9:01:16_PM 1/1

11-Feb-2019 09:23 PM

Method name: Nitrate determination

Method created: 11-Feb-2019 08:57 PM

Method updated: 11-Feb-2019 08:57 PM

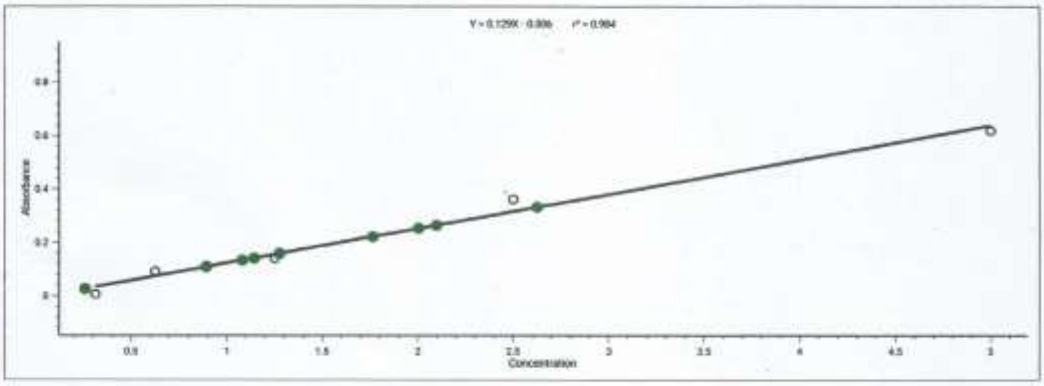
Instrument Serial #: 9A5W172006

Instrument model: GENESYS 180

Software Package Version: 1.1

Signature:

Quant method parameters	
Equation	**Y = 0.129X - 0.006**
R^2:	**0.98**
λ	**410 nm**
Reference λ	



Sample	Absorbance(λ)	Concentration [mg/ml]
Standard 1	0.618	5.000
Standard 2	0.362	2.500

Sample	Absorbance	Concentration [mg/ml]
Standard 3	0.139	1.250
Standard 4	0.092	0.625
Standard 5	0.006	0.313

Sample	Absorbance(λ)	Concentration [mg/ml]
w1	0.027	0.256
w1 2	-0.007	Out of range
w1 3	0.109	0.893
w1 4	0.221	1.764
w1 5	0.133	1.080
w1 6	0.141	1.142
w1 7	0.158	1.274
w1 8	0.332	2.626
w1 9 ⇒ S1	0.252	2.004
w1 10 ⇒ S2	0.264	2.098

Calibration Curves of Nitrate during Rainy Season

Nitrate

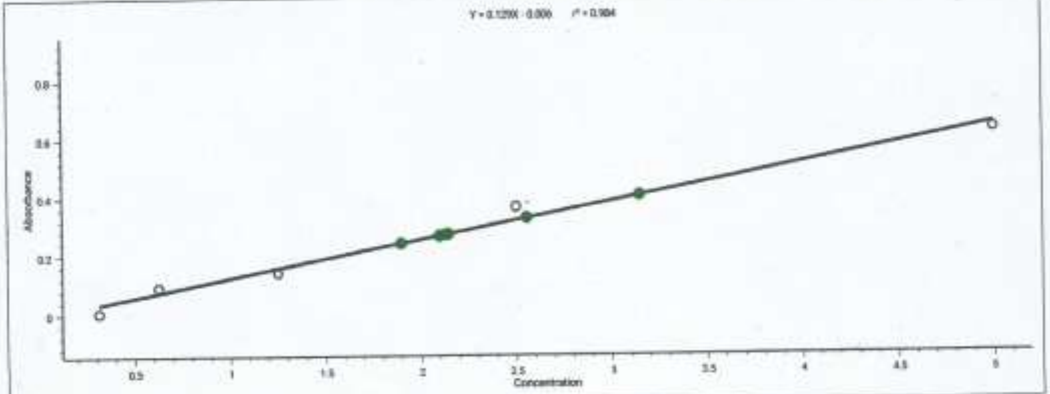
1/1

Quant_2_11_2019_9:01:16_PM
11-Feb-2019 09:34 PM
Method name: Nitrate determination
Method created: 11-Feb-2019 08:57 PM
Method updated: 11-Feb-2019 08:57 PM

Instrument Serial #: 9A5W172006
Instrument model: GENESYS 180
Software Package Version: 1.1

Signature:

Quant method parameters	
Equation	Y = 0.129X - 0.006
R^2:	0.98
λ	410 nm
Reference λ	



Sample	Absorbance(λ)	Concentration [mg/ml]
Standard 1	0.618	5.000
Standard 2	0.362	2.500

Sample	Absorbance	Concentration [mg/ml]
Standard 3	0.139	1.250
Standard 4	0.092	0.625
Standard 5	0.006	0.313

Sample	Absorbance(λ)	Concentration [mg/ml]
S3	0.264	2.098
S4	0.270	2.144
S5	0.269	2.137
S6	0.238	1.896
S7	0.323	2.556
S8	0.399	3.147

Calibration Curves of Nitrate during Dry Season

Nitrate

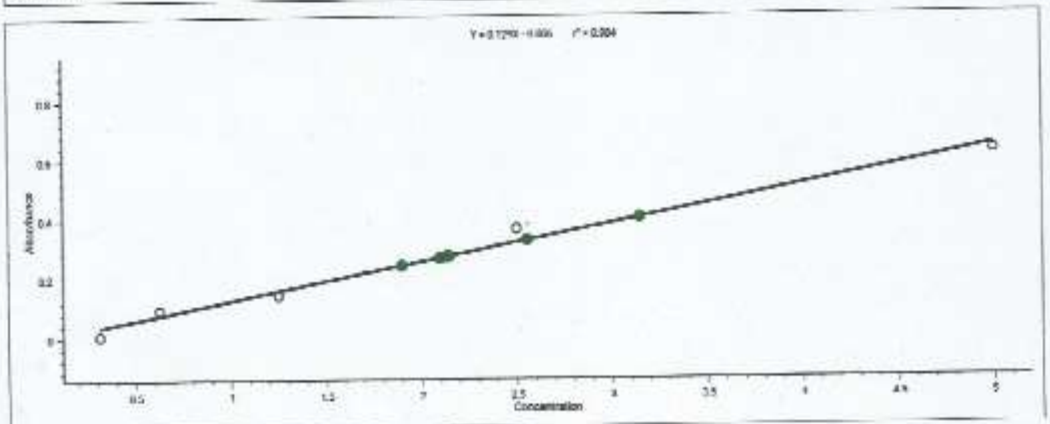
Quant_2_11_2019_9:01:16_PM
11-Feb-2019 09:34 PM
Method name: Nitrate determination
Method created: 11-Feb-2019 08:57 PM
Method updated: 11-Feb-2019 08:57 PM

Instrument Serial #: 9A5W172006
Instrument model: GENESYS 180
Software Package Version: 1.1

Signature:

1/1

Quant method parameters	
Equation	$Y = 0.129X - 0.006$
R^2:	0.98
λ	410 nm
Reference λ	



Sample	Absorbance(λ)	Concentration [mg/ml]
Standard 1	0.618	5.000
Standard 2	0.362	2.500

Sample	Absorbance	Concentration [mg/ml]
Standard 3	0.139	1.250
Standard 4	0.092	0.625
Standard 5	0.006	0.313

Sample	Absorbance(λ)	Concentration [mg/ml]
S3	0.264	2.098
S4	0.270	2.144
S5	0.269	2.137
S6	0.238	1.896
S7	0.323	2.556
S8	0.399	3.147

Calibration Curves of Nitrite during Rainy Season

Quant_2_7_2019_7:04:03_PM → Phosphate

07 Feb 2019 07:25 PM

Method name: Quant 07-Feb-2019_C

Method created: 07 Feb 2019 07:02 PM

Method updated: 07 Feb 2019 07:02 PM

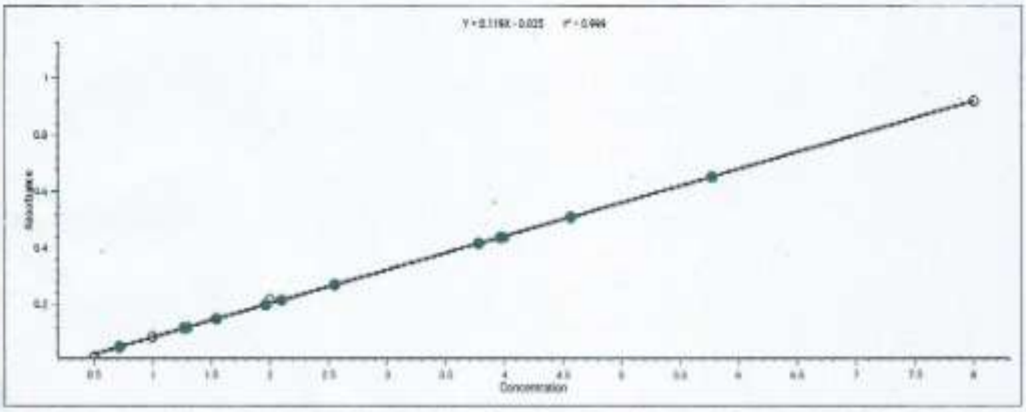
Instrument Serial #: 9A3W172006

Instrument model: GENESYS 180

Software Package Version: 1.1

Signature:

Quant method parameters	
Equation	Y = 0.119X - 0.035
R^2:	1.00
λ	880 nm
Reference λ	



Sample	Absorbance(λ)	Concentration [mg/ml]
Standard 1	0.918	8.000
Standard 2	0.437	4.000

Sample	Absorbance	Concentration [mg/ml]
Standard 3	0.218	2.000
Standard 4	0.085	1.000
Standard 5	0.014	0.500

Sample	Absorbance(λ)	Concentration [mg/ml]
Sample 1 → W_1	-0.057	Out of range
Sample 2 → W_2	-0.071	Out of range
Sample 3 → W_3	-0.048	Out of range
Sample 4 → W_4	0.050	0.715
Sample 5 → W_5	-0.008	0.229
Sample 6 → W_6	0.438	3.969
Sample 7 → W_7	0.509	4.564
Sample 8 → W_8	0.119	1.294
Sample 9 → S_1	0.149	1.546
Sample 10 → S_2	0.269	2.552
Sample 11 → S_3	0.199	1.965
Sample 12 → S_4	0.116	1.269
Sample 13 → S_5	0.215	2.099

Sample	Absorbance	Concentration [mg/ml]
Sample 14 → S_6	0.509	4.564
Sample 15 → S_7	0.653	5.771
Sample 16 → S_8	0.415	3.776

Calibration Curves of Phosphate during Rainy Season

Quant_11_1_2019_11:15:42_PM

1/1

01-Nov-2019 11:34 PM

Method name: Phosphate analysis_C

Method created: 01-Nov-2019 11:12 PM

Method updated: 01-Nov-2019 11:12 PM

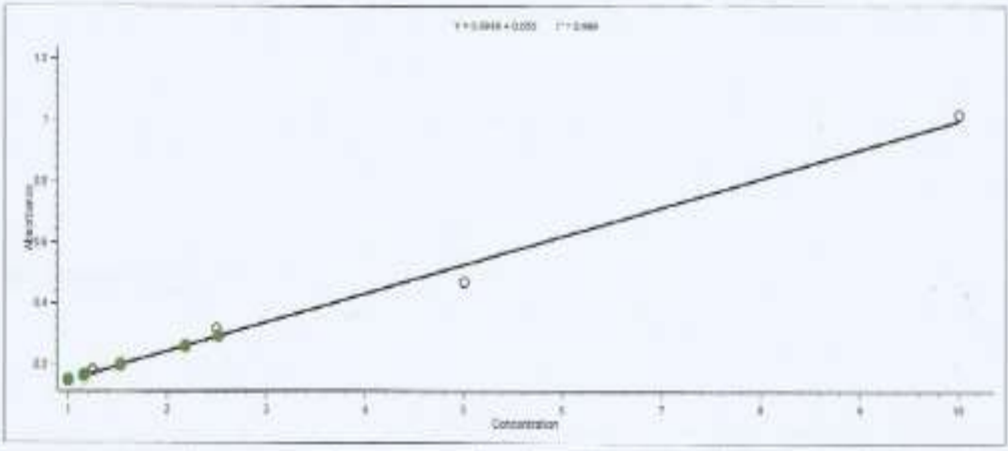
Instrument Serial #: 9A5W172005

Instrument model: GENESYS 180

Software Package Version: 1.1

Signature

Quant method parameters	
Equation	Y = 0.094X + 0.055
R^2	0.99
λ	880 nm
Reference λ	



Sample	Absorbance(λ)	Concentration [mg/ml]
Standard 1	1.017	10.000
Standard 2	0.469	5.000

Sample	Absorbance	Concentration [mg/ml]
Standard 3	0.316	2.500
Standard 4	0.183	1.250

Sample	Absorbance(λ)	Concentration [mg/ml]
Sample 1	0.022	Out of range
Sample 2	0.199	1.530
Sample 3	0.164	1.158
Sample 4	0.097	0.447
Sample 5	0.081	Out of range
Sample 6	0.129	0.787
Sample 7	0.120	0.691
Sample 8	0.149	0.999
Sample 9	0.122	0.712
Sample 10	0.058	Out of range
Sample 11	0.057	Out of range
Sample 12	0.133	0.829
Sample 13	-0.118	Out of range

Sample	Absorbance	Concentration [mg/ml]
Sample 14	0.086	Out of range
Sample 15	0.261	2.189
Sample 16	0.292	2.518

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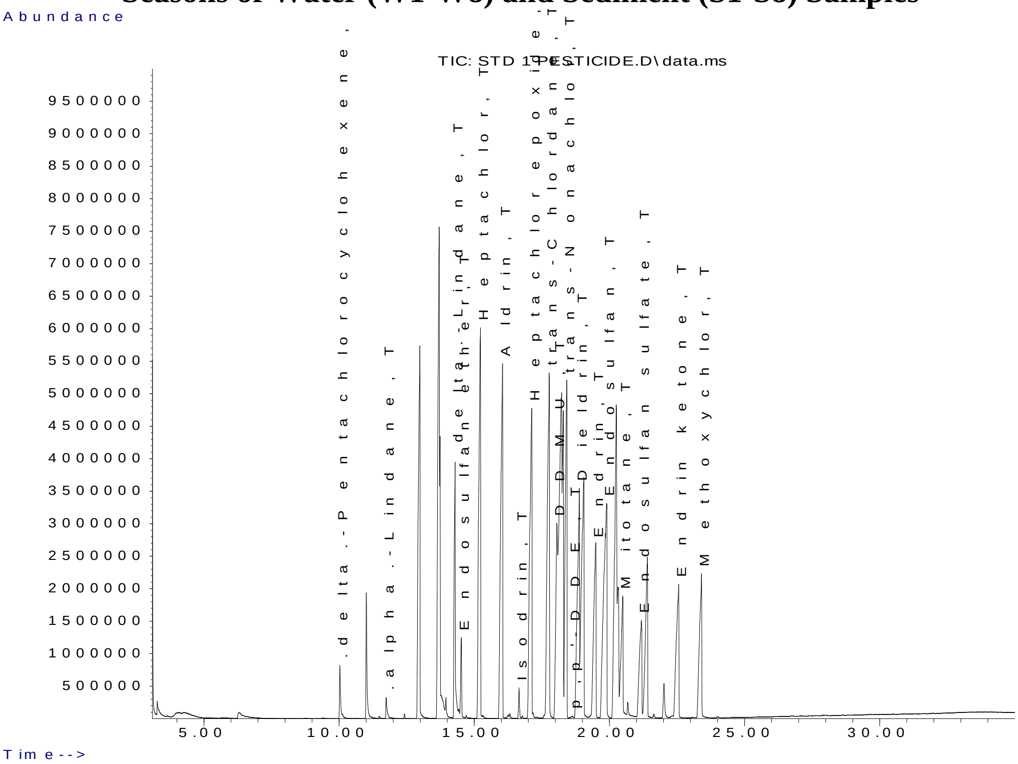
Date 07/11/19

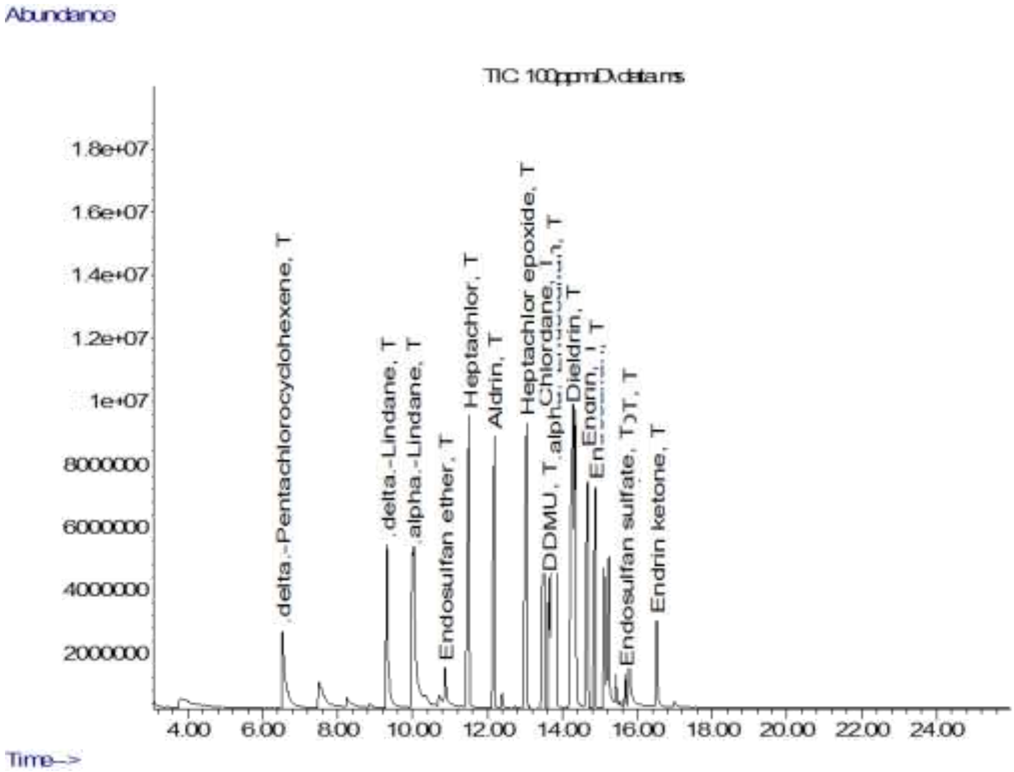
Calibration Curves of Phosphate during Dry Season

Appendix F

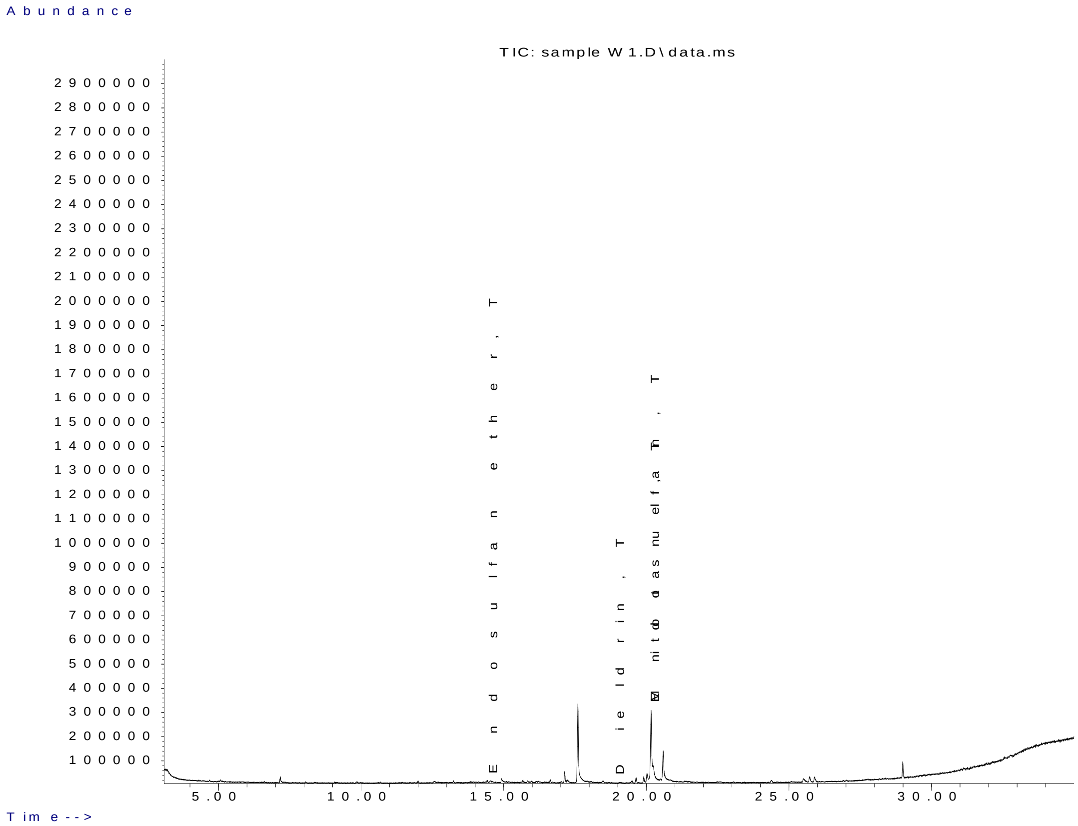
Chromatograms of Organochlorine Compounds in Rainy, 2018 and Dry, 2018 Seasons of Water (W1-W8) and Sediment (S1-S8) Samples



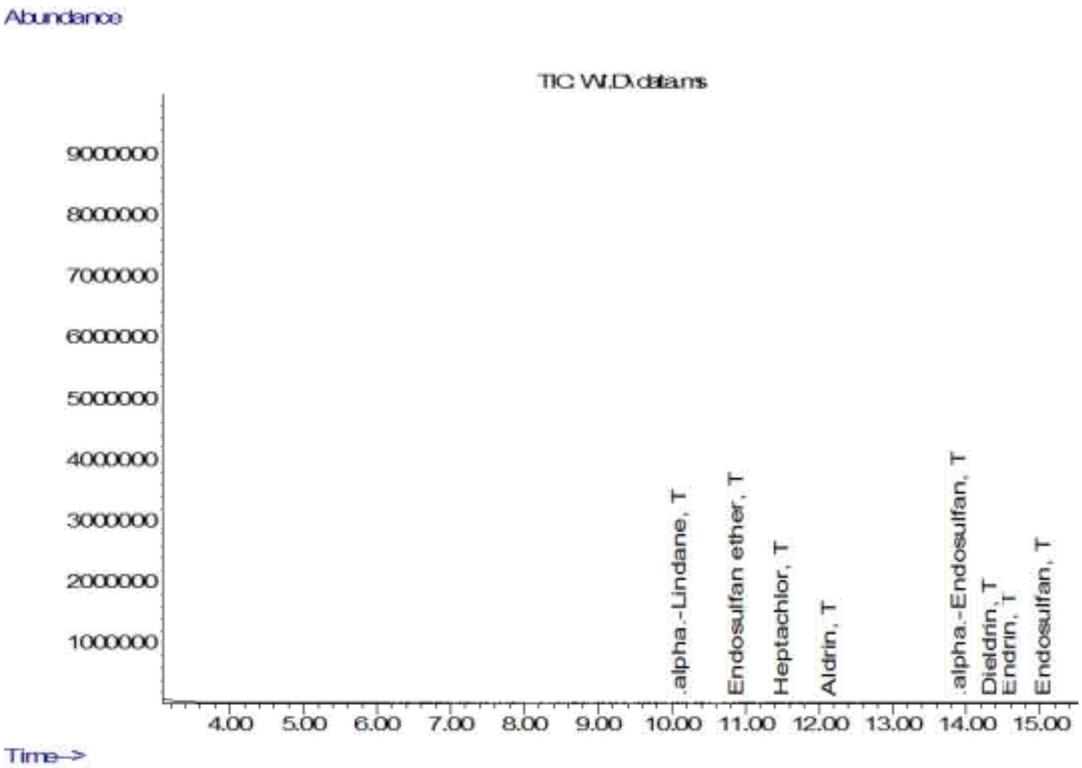
Chromatogram of 19 Organochlorine Standards Pesticide mix of Rainy Season (100ppm).



Chromatogram of 16 Organochlorine Standards Pesticide mix of Dry Season (100ppm).



Chromatogram of Organochlorine Compounds of Water Sample W1 in Rainy Season



Chromatogram of Organochlorine Compounds of Water Sample W1 in Dry Season

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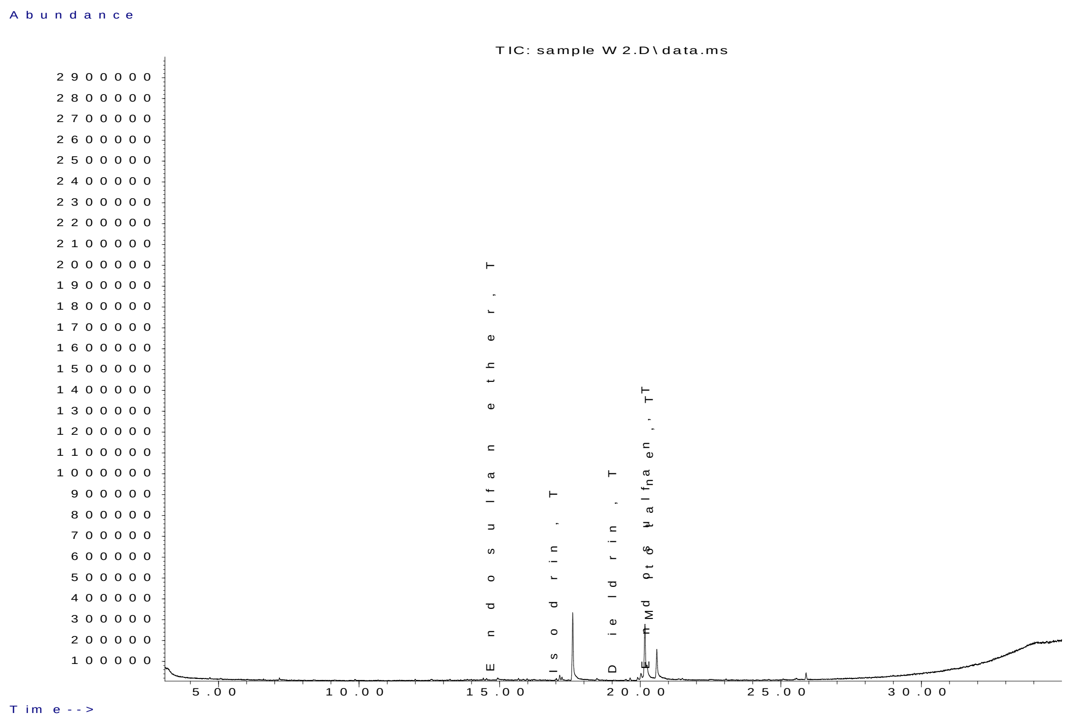
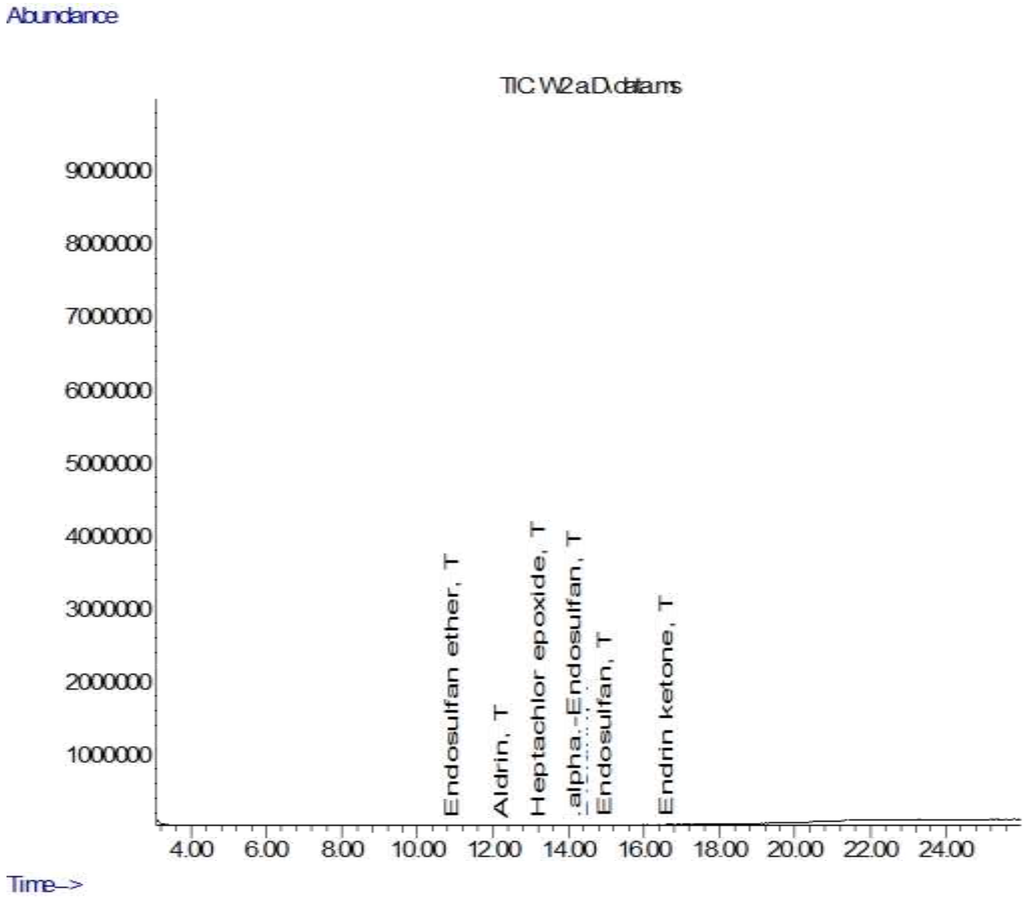
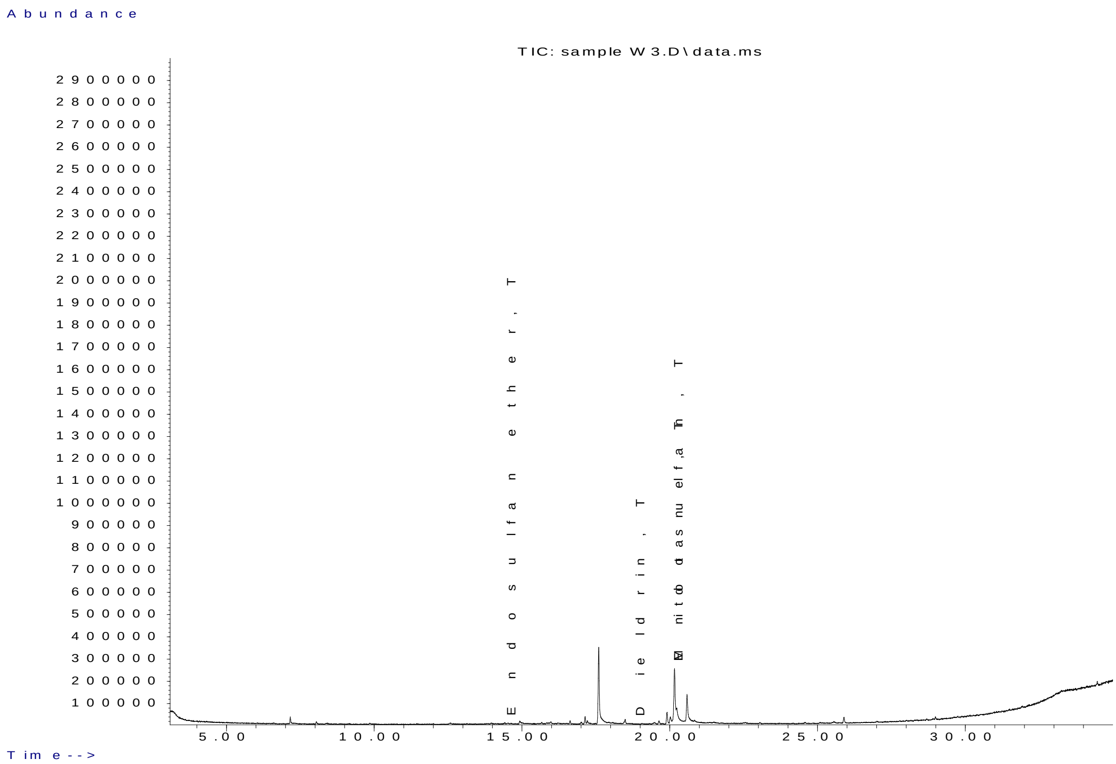


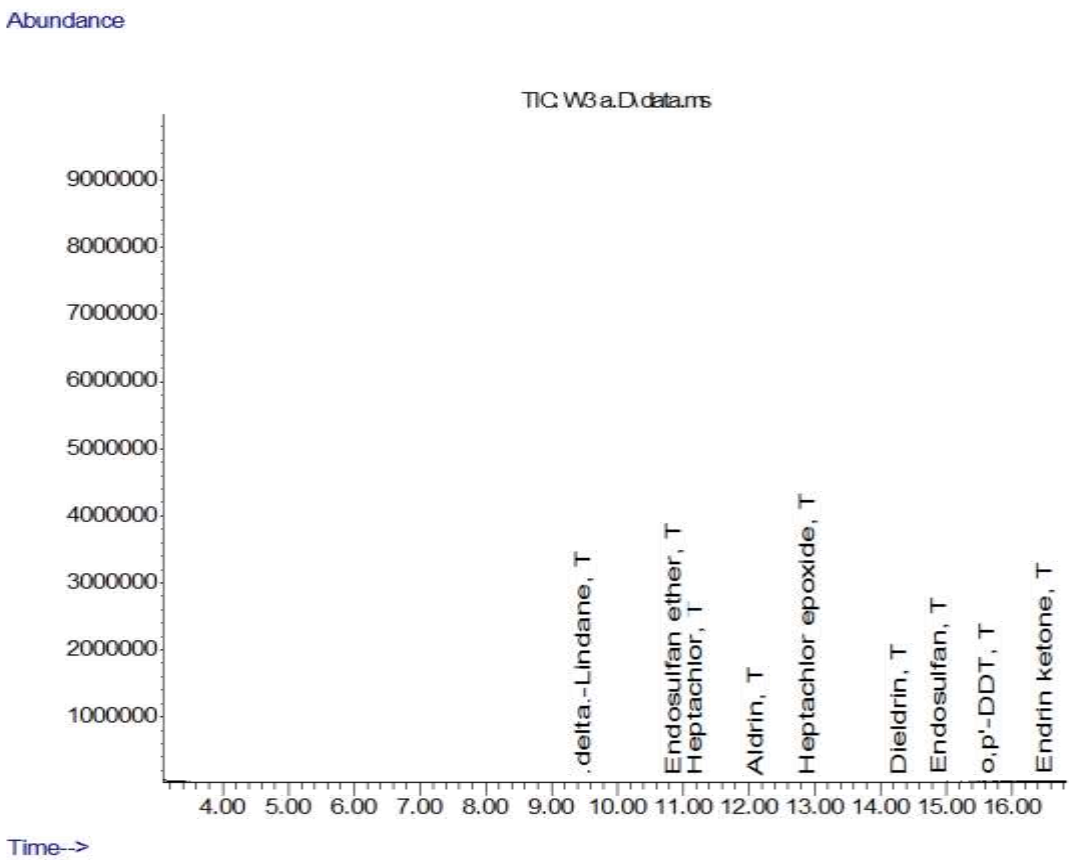
Chromatogram of Organochlorine Compounds of Water Sample W2 in Rainy Season



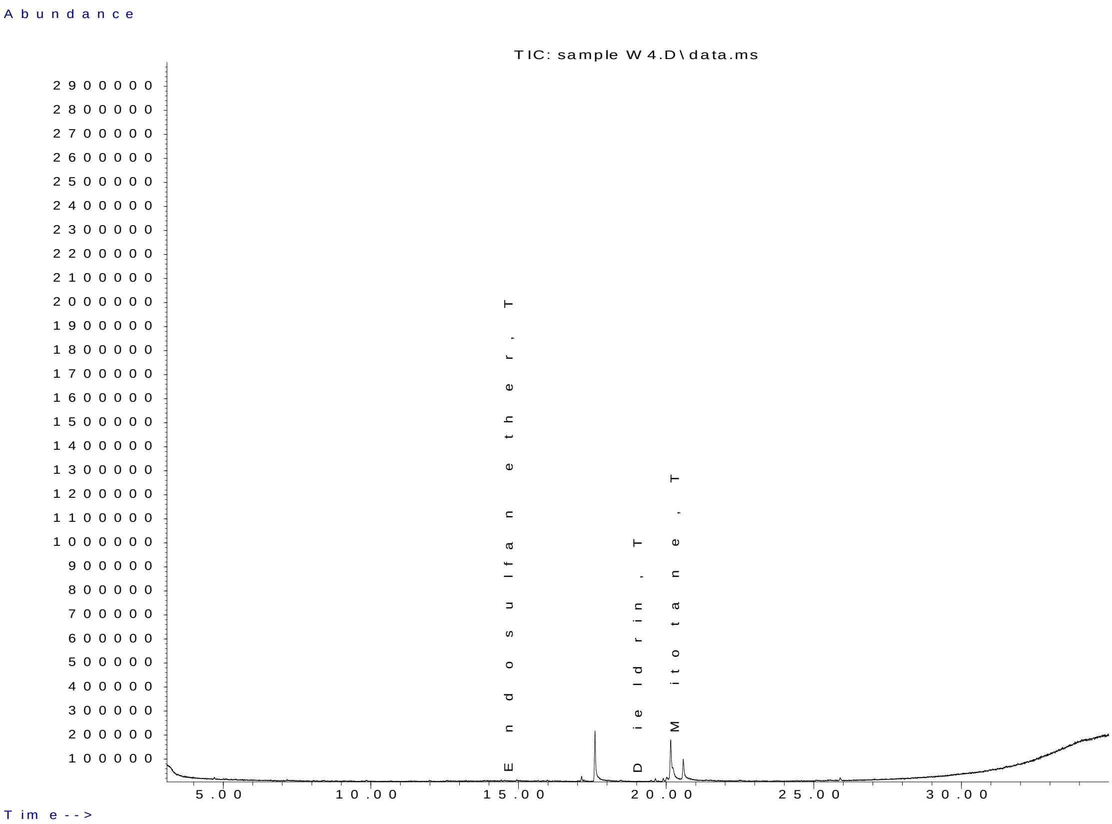
Chromatogram of Organochlorine Compounds of Water Sample W2 in Dry Season



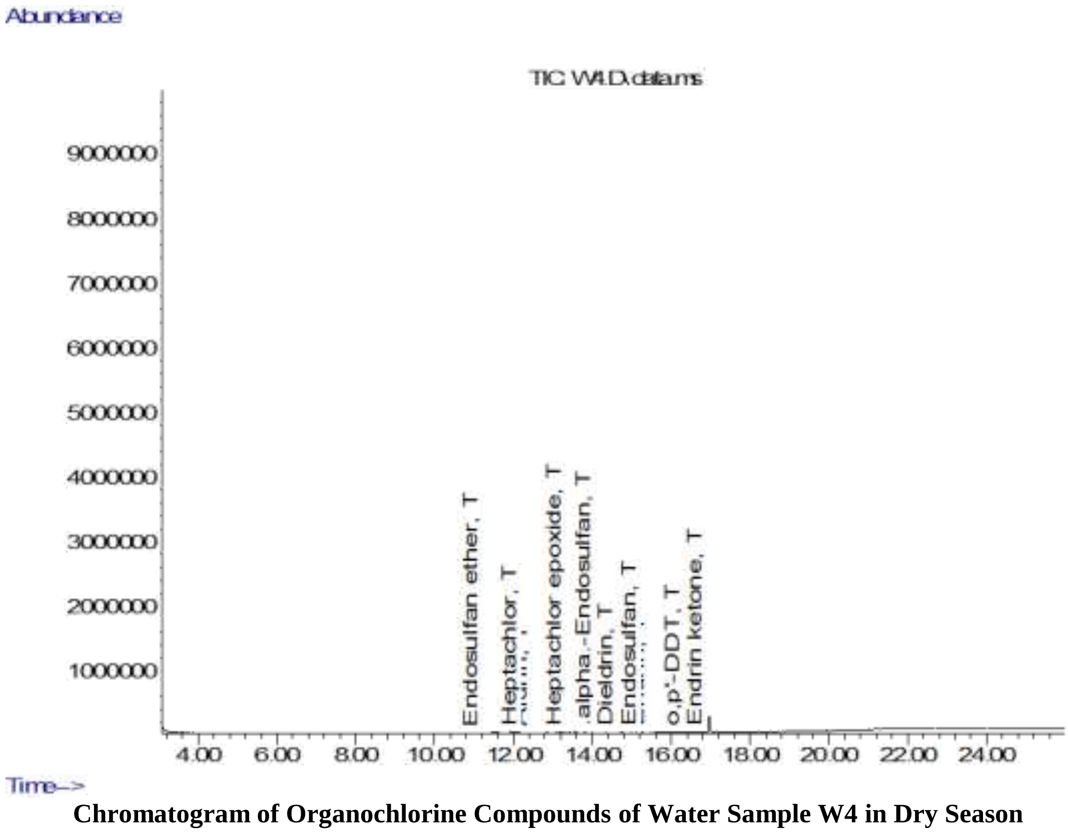
Chromatogram of Organochlorine Compounds of Water Sample W3 in Rainy Season



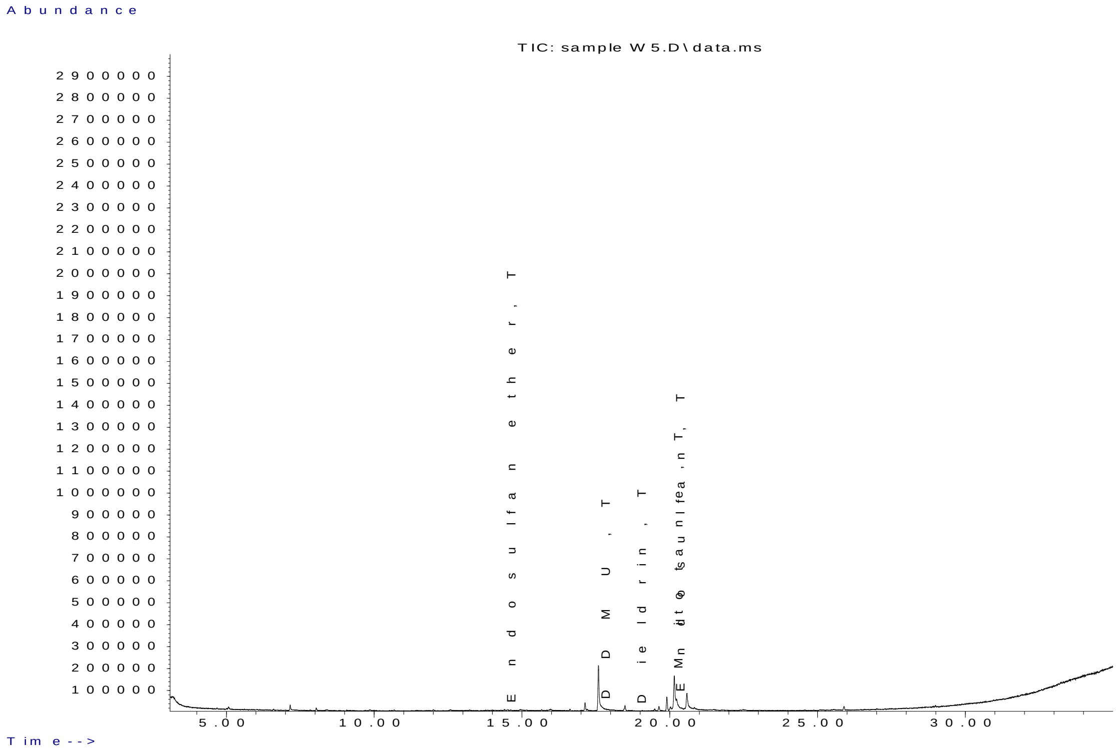
Chromatogram of Organochlorine Compounds of Water Sample W3 in Dry Season



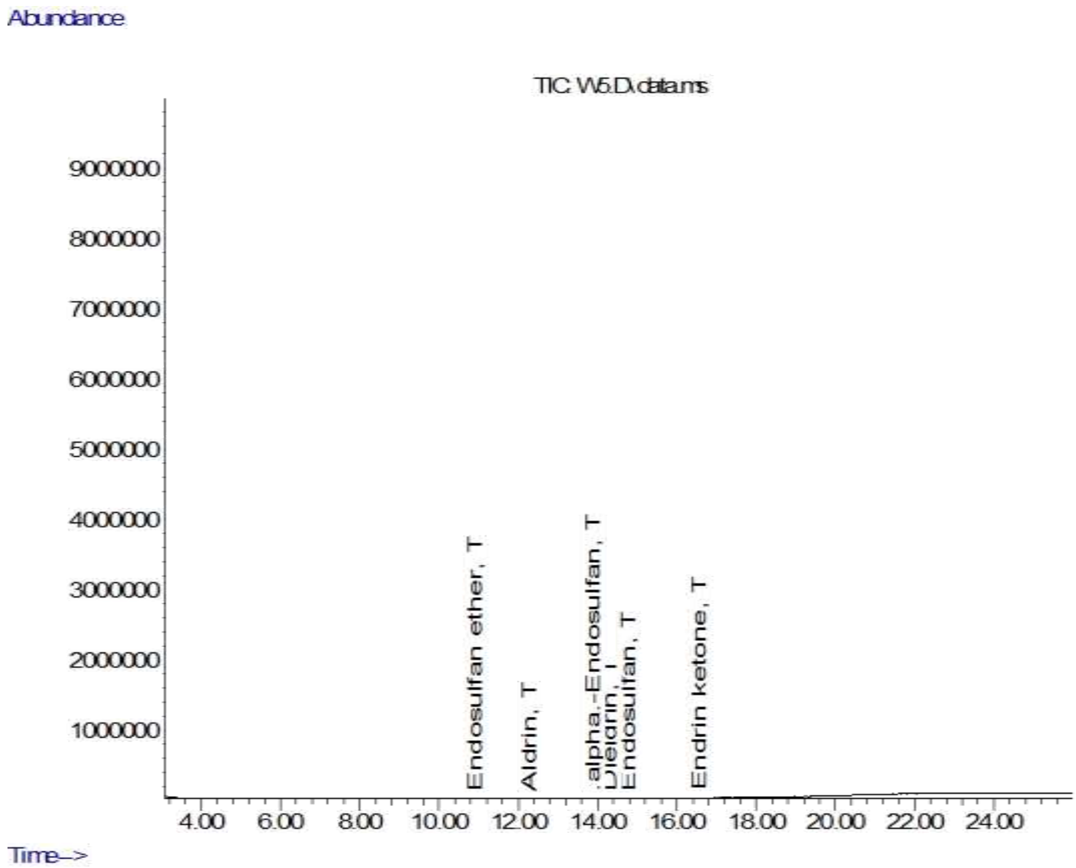
Chromatogram of Organochlorine Compounds of Water Sample W4 Rain Season



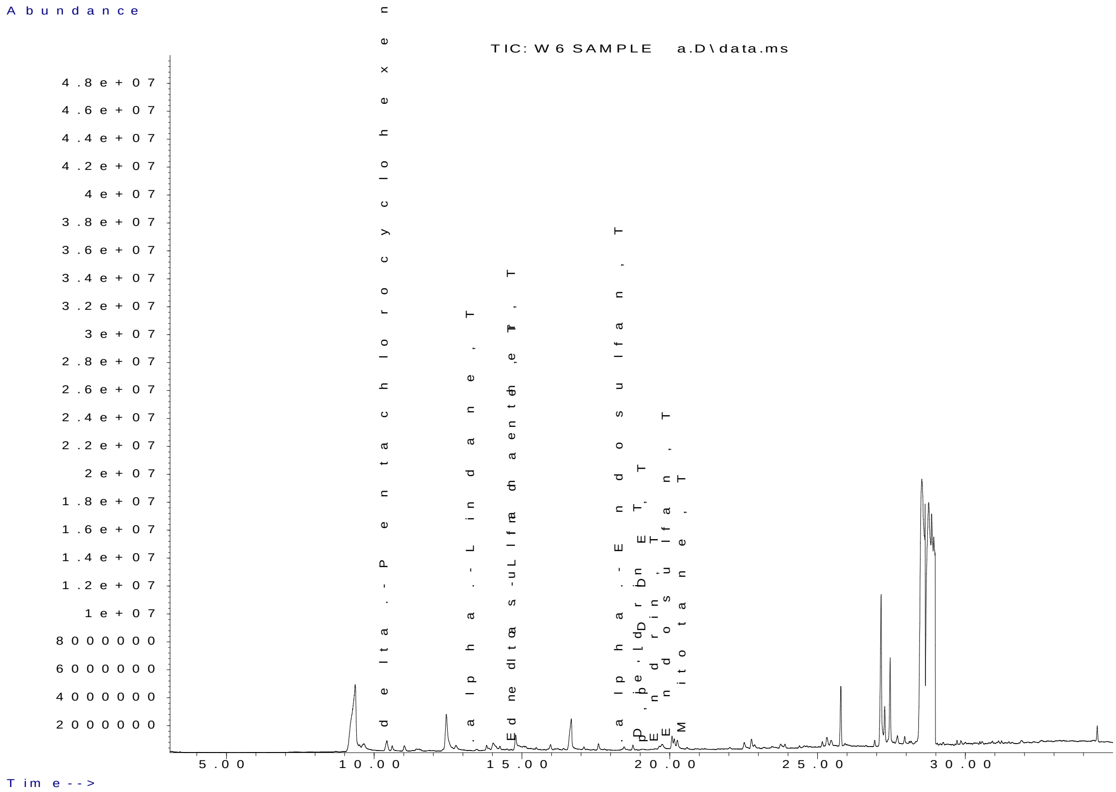
Chromatogram of Organochlorine Compounds of Water Sample W4 in Dry Season



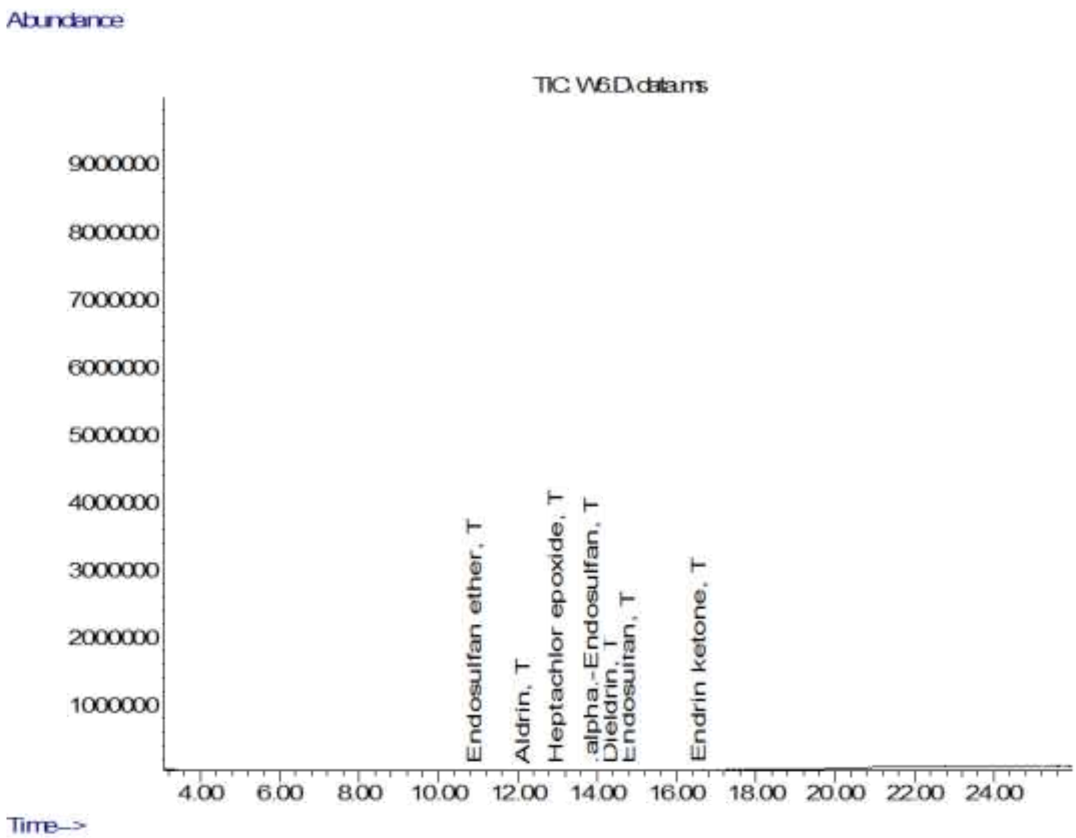
Chromatogram of Organochlorine Compounds of Water Sample W5 in Rainy Season



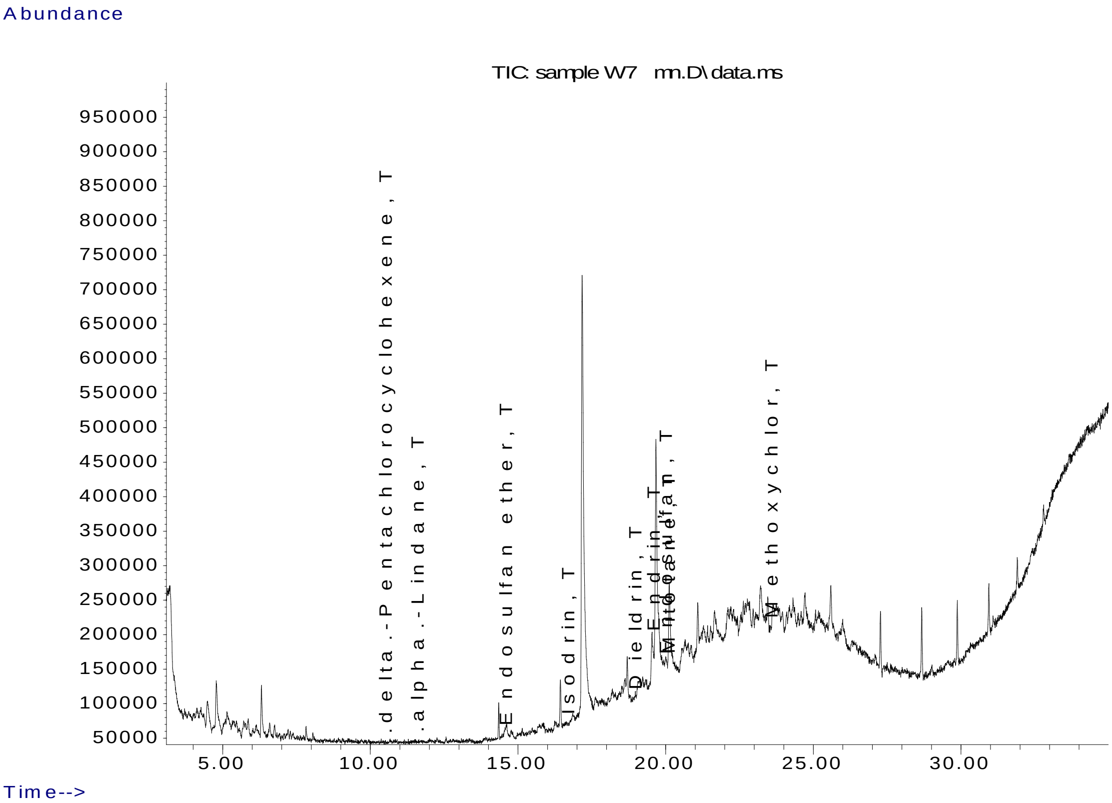
Chromatogram of Organochlorine Compounds of Water Sample W5 in Dry Season



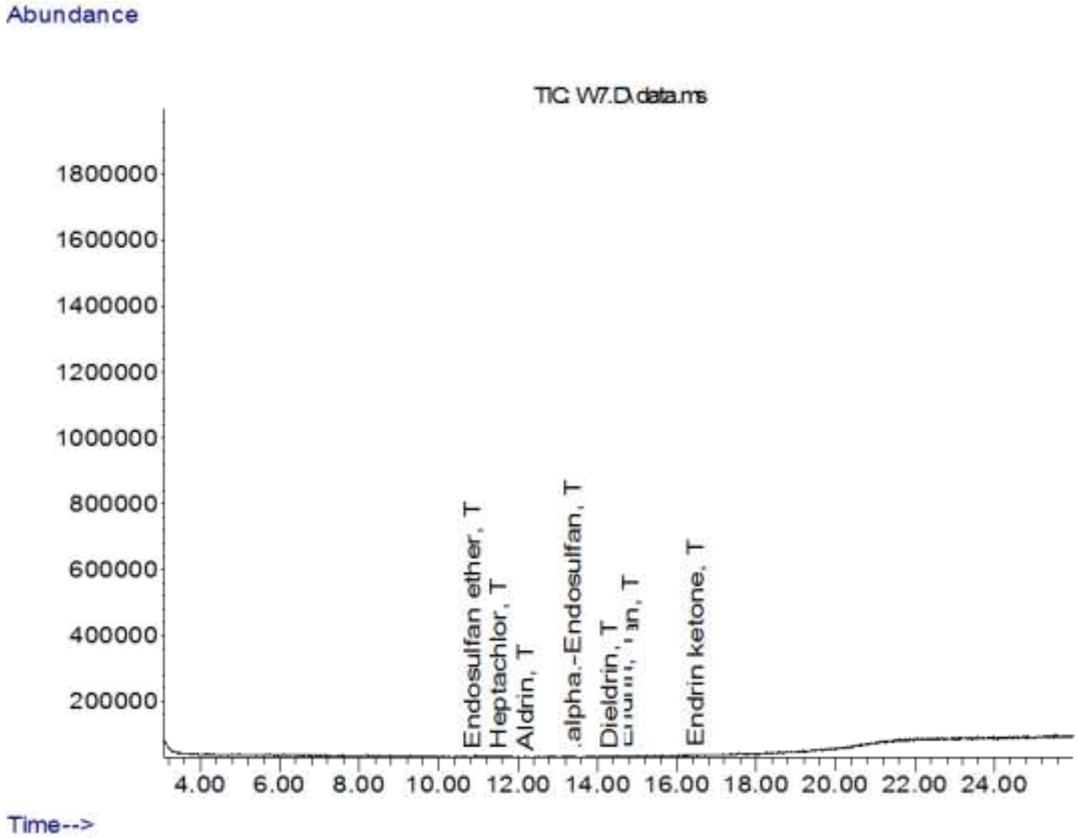
Chromatogram of Organochlorine Compounds of Water Sample W6 in Rainy Season



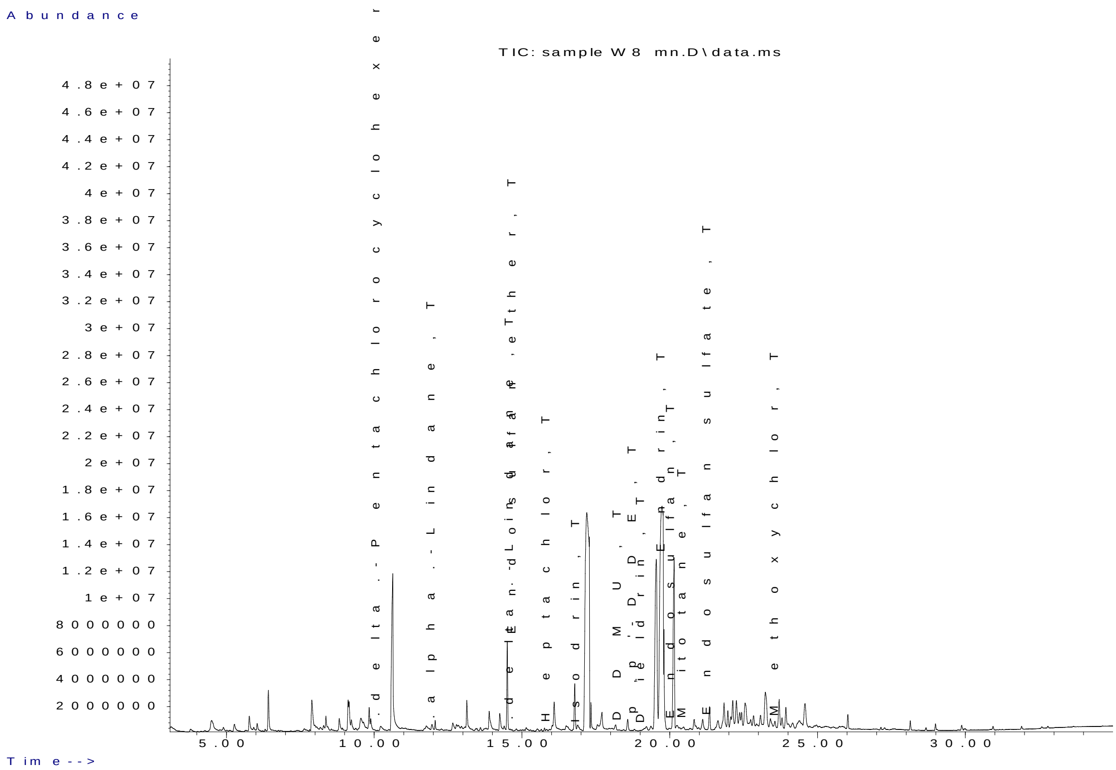
Chromatogram of Organochlorine Compounds of Water Sample W6 in Dry Season



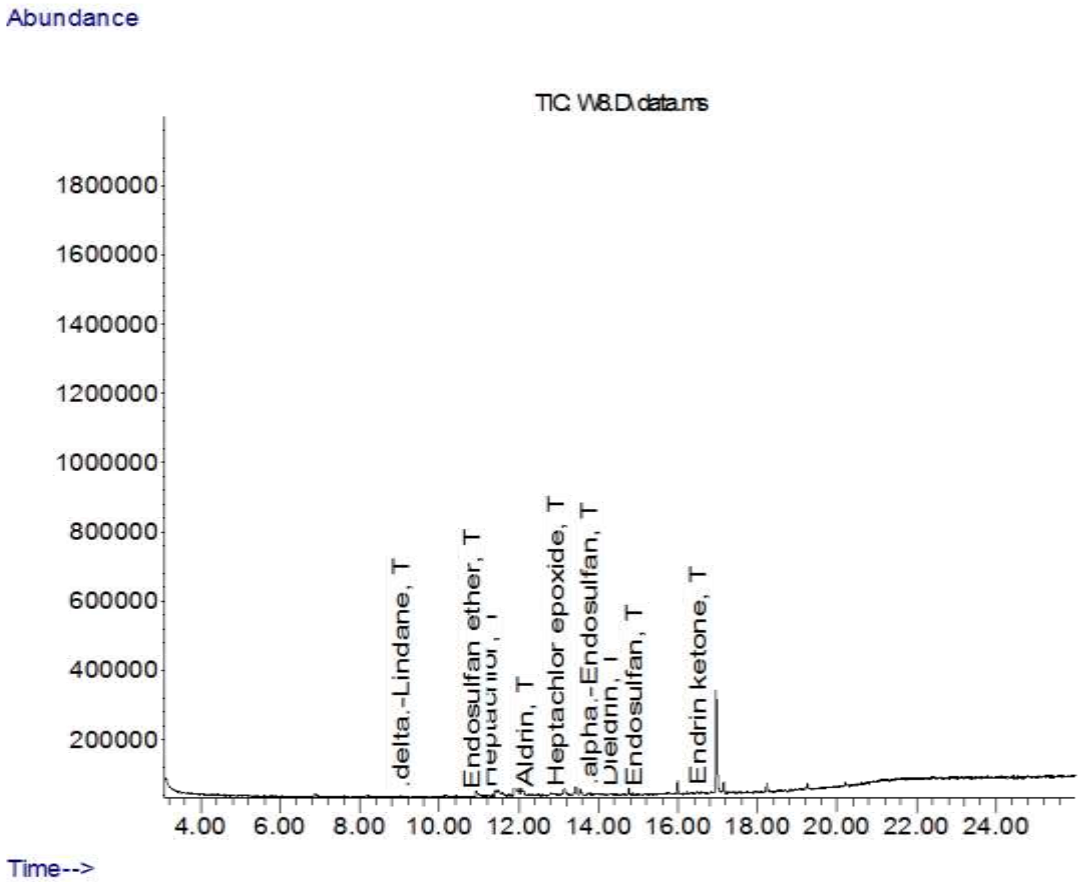
Chromatogram of Organochlorine Compounds of Water Sample W7 in Rainy Season



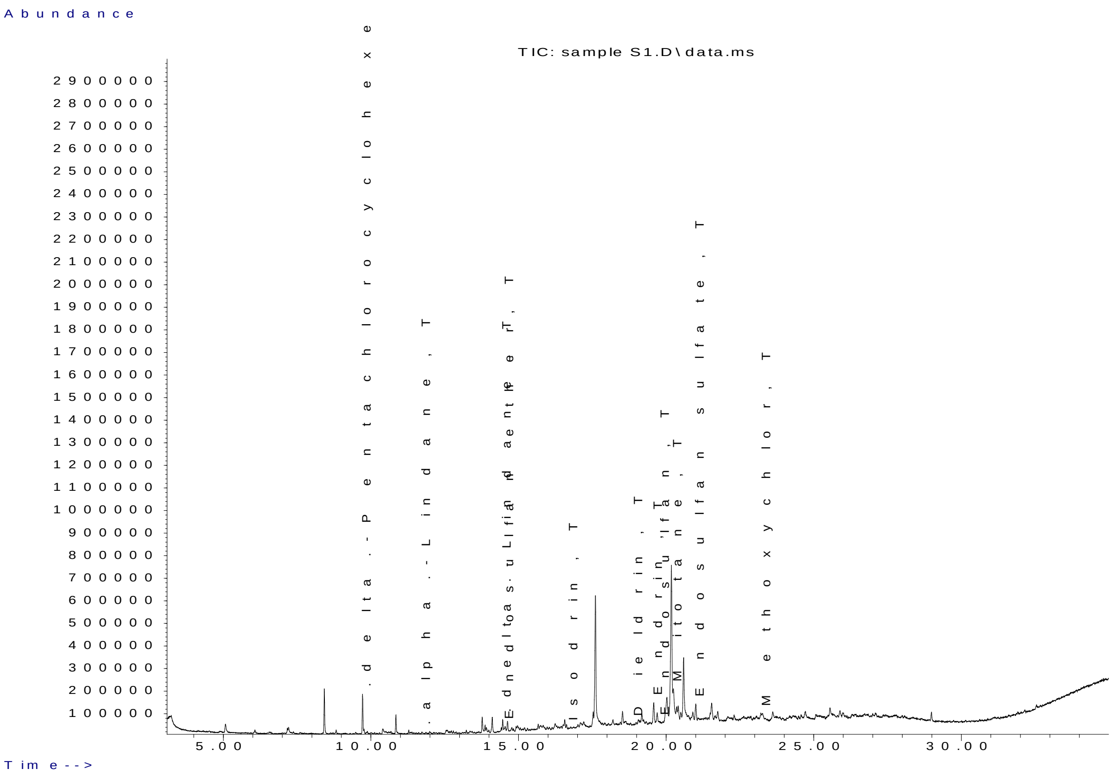
Chromatogram of Organochlorine Compounds of Water Sample W7 in Dry Season



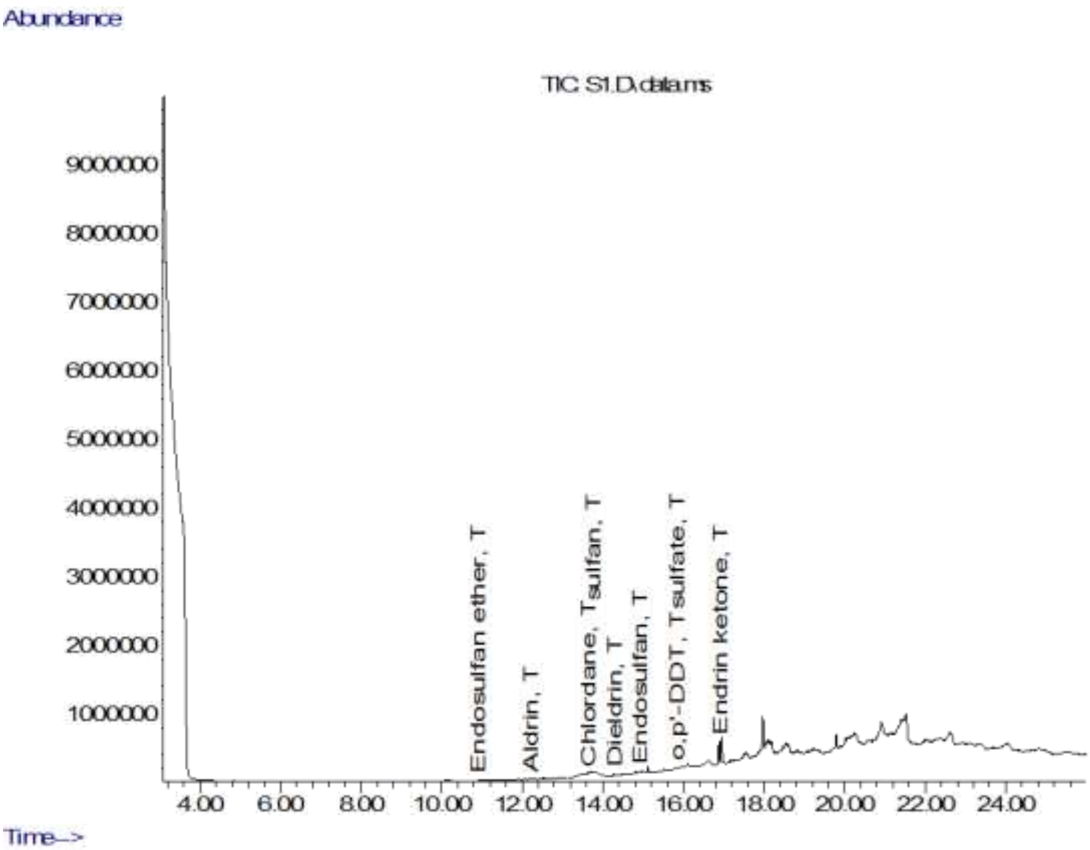
Chromatogram of Organochlorine Compounds of Water Sample W8 in Rainy Season



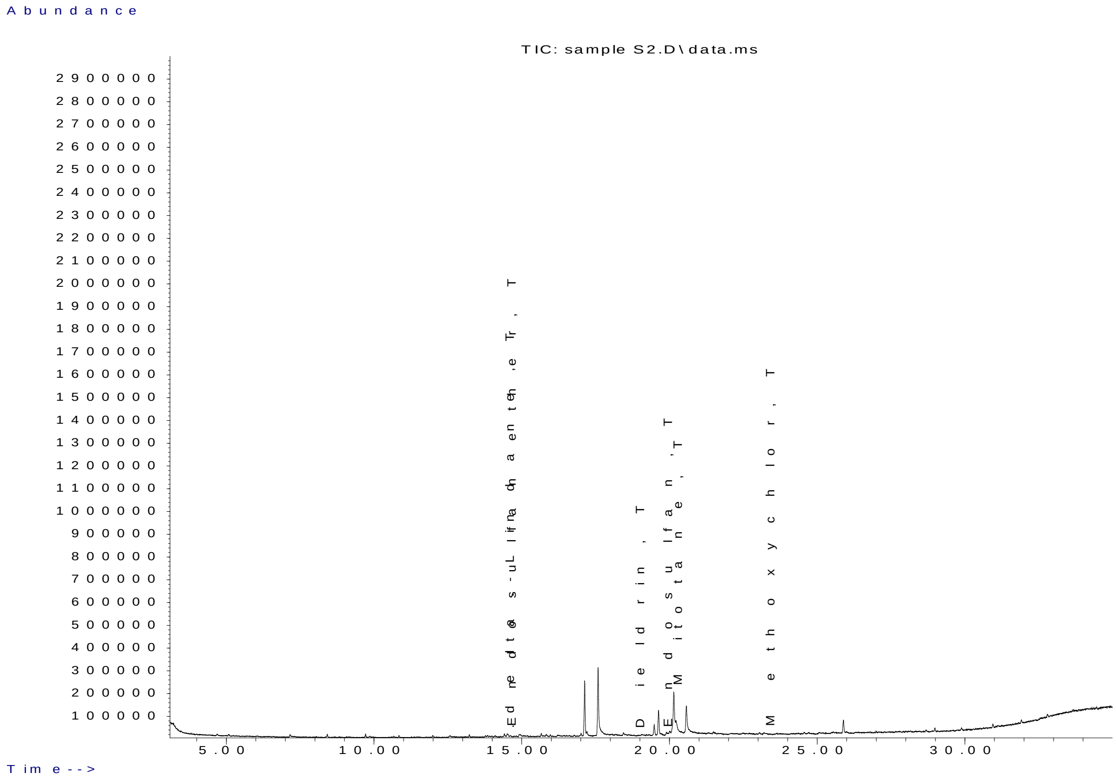
Chromatogram of Organochlorine Compounds of Water Sample W8 in Dry Season



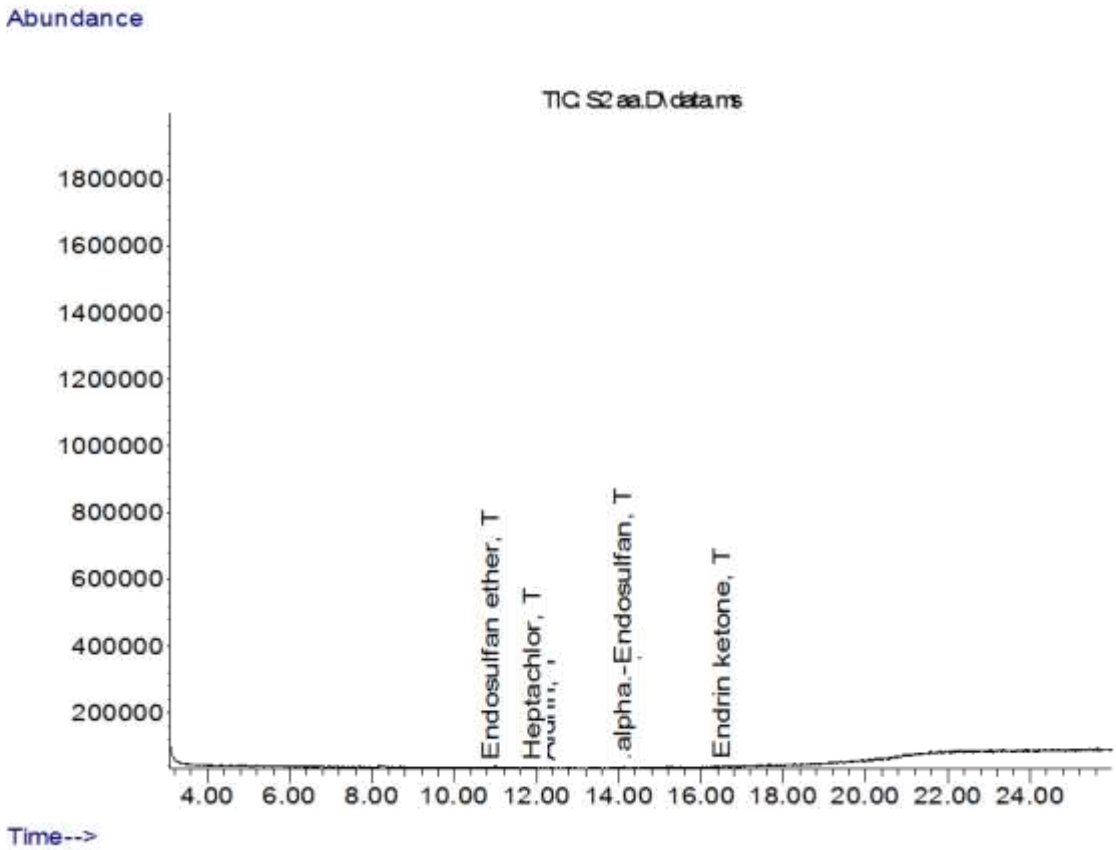
Chromatogram of Organochlorine Compounds of Sediment Sample S1 in Rainy Season



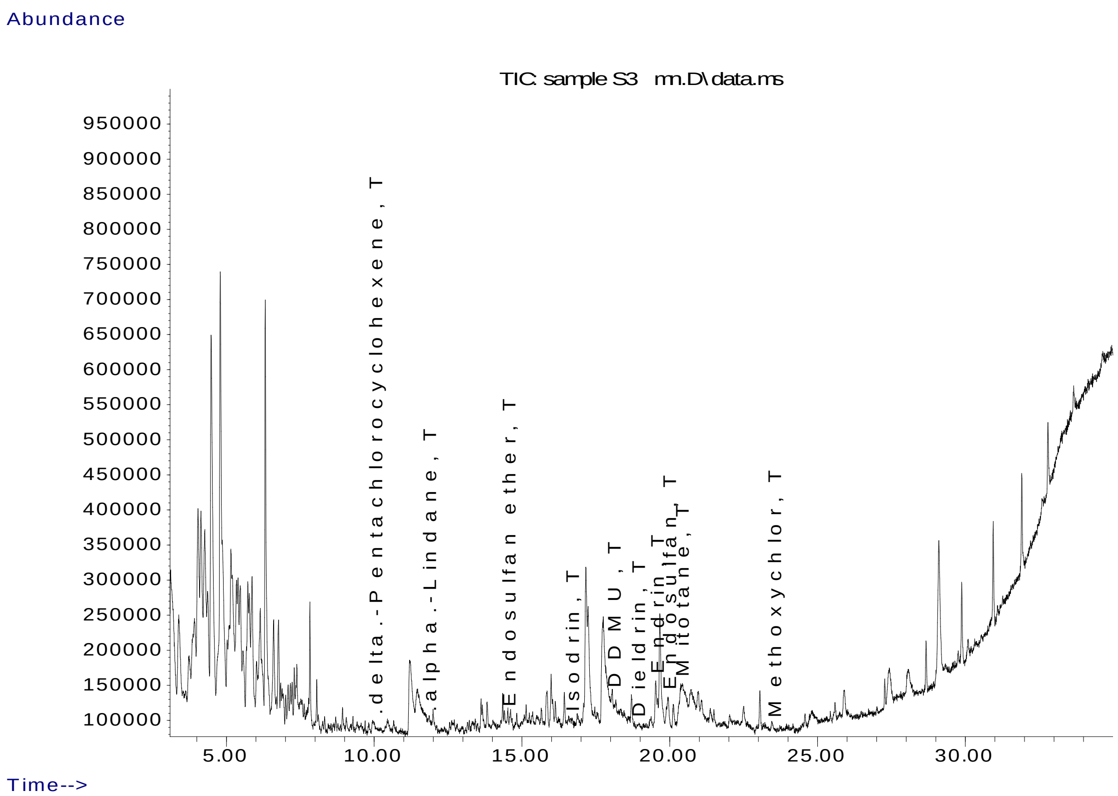
Chromatogram of Organochlorine Compounds of Sediment Sample S1 in Dry Season



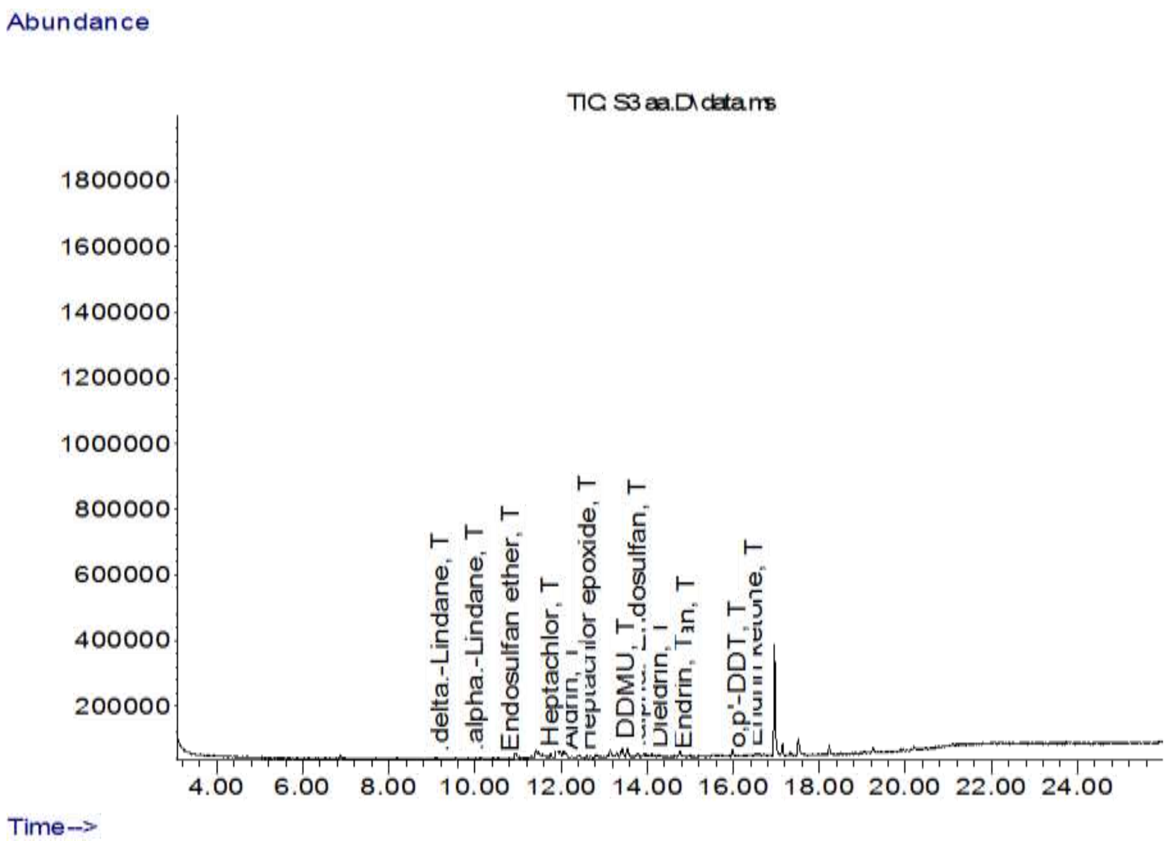
Chromatogram of Organochlorine Compounds of Sediment Sample S2 in Rainy Season



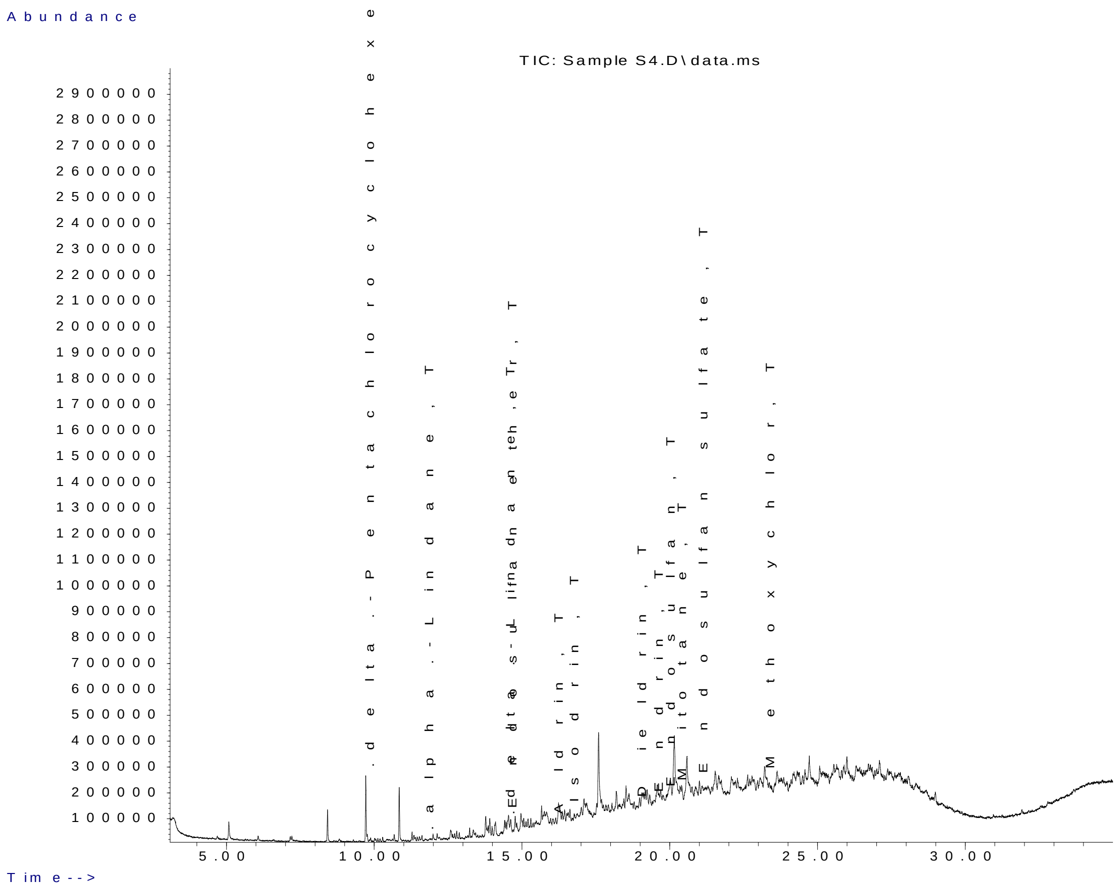
Chromatogram of Organochlorine Compounds of Sediment Sample S2 in Dry Season



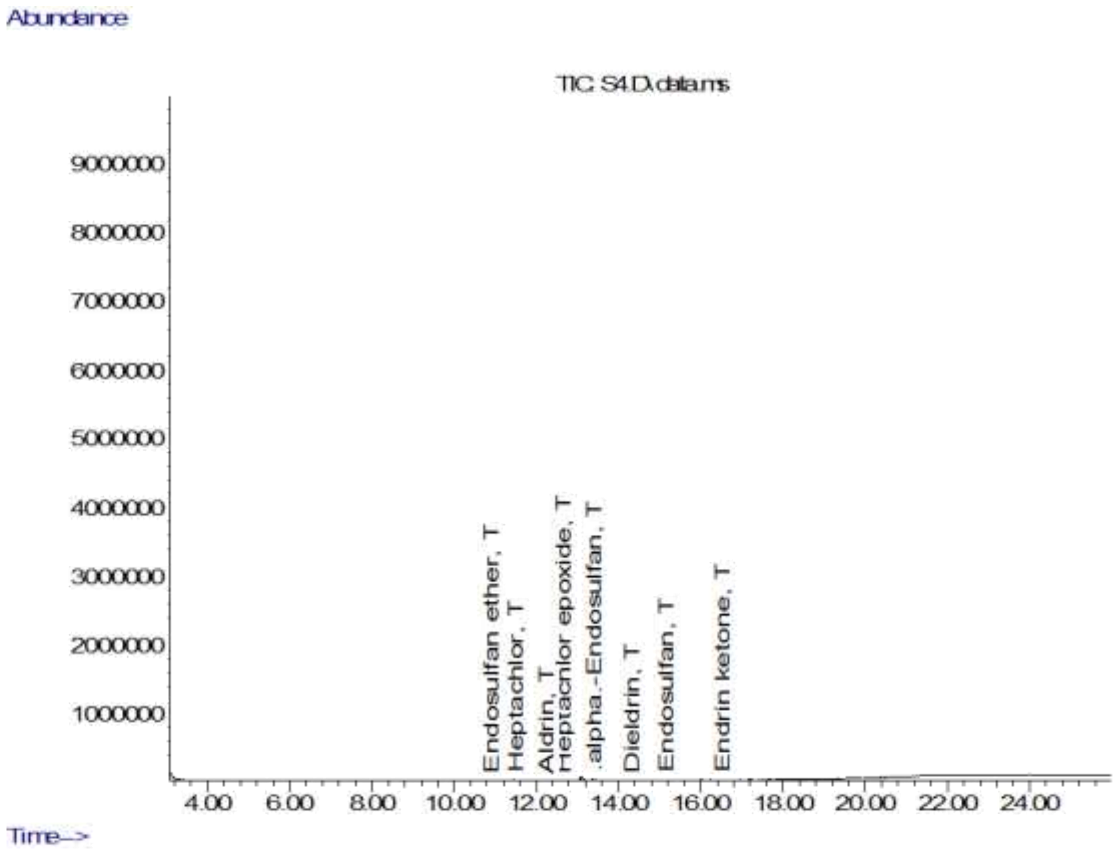
Chromatogram of Organochlorine Compounds of Sediment Sample S3 in Rainy Season



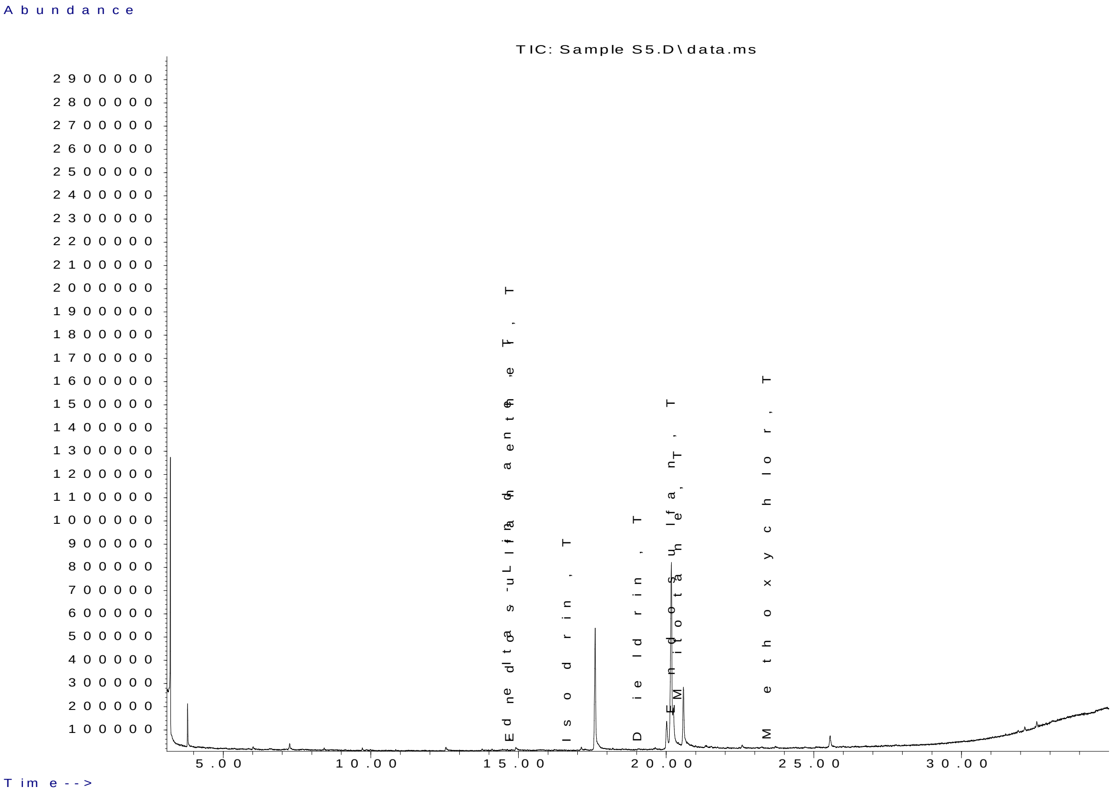
Chromatogram of Organochlorine Compounds of Sediment Sample S3 in Dry Season



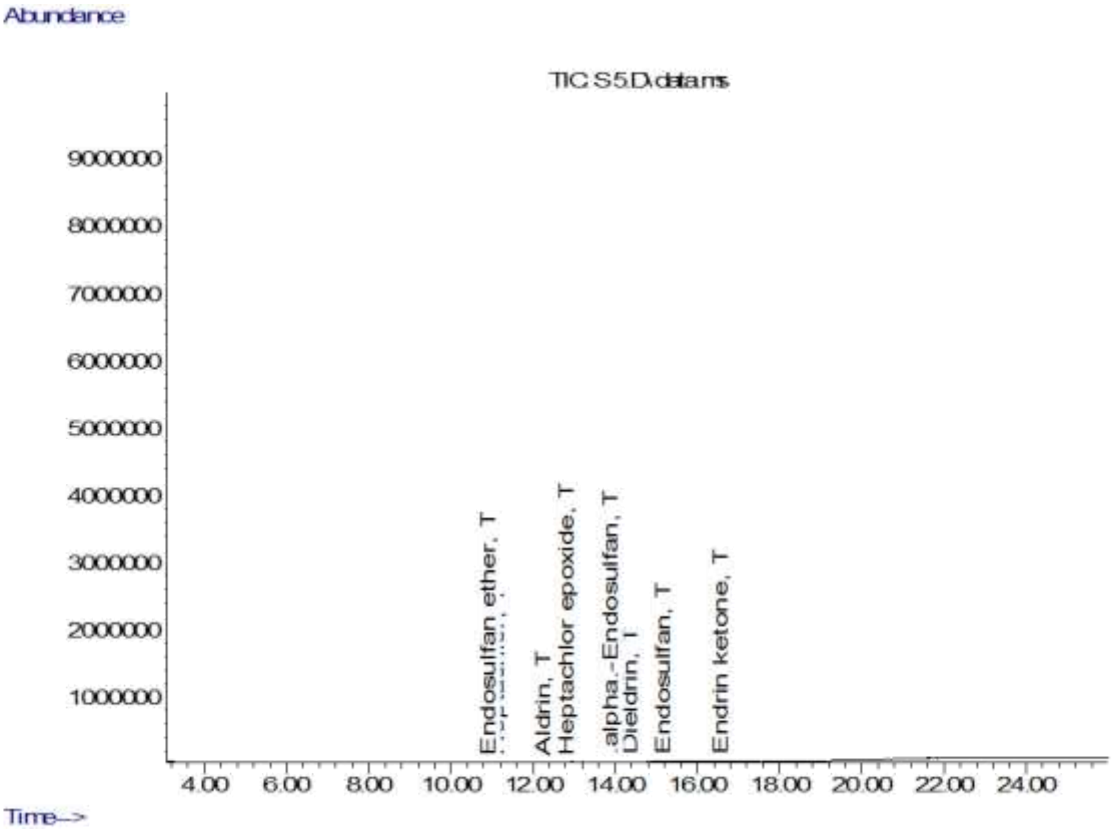
Chromatogram of Organochlorine Compounds of Sediment Sample S4 in Rainy Season



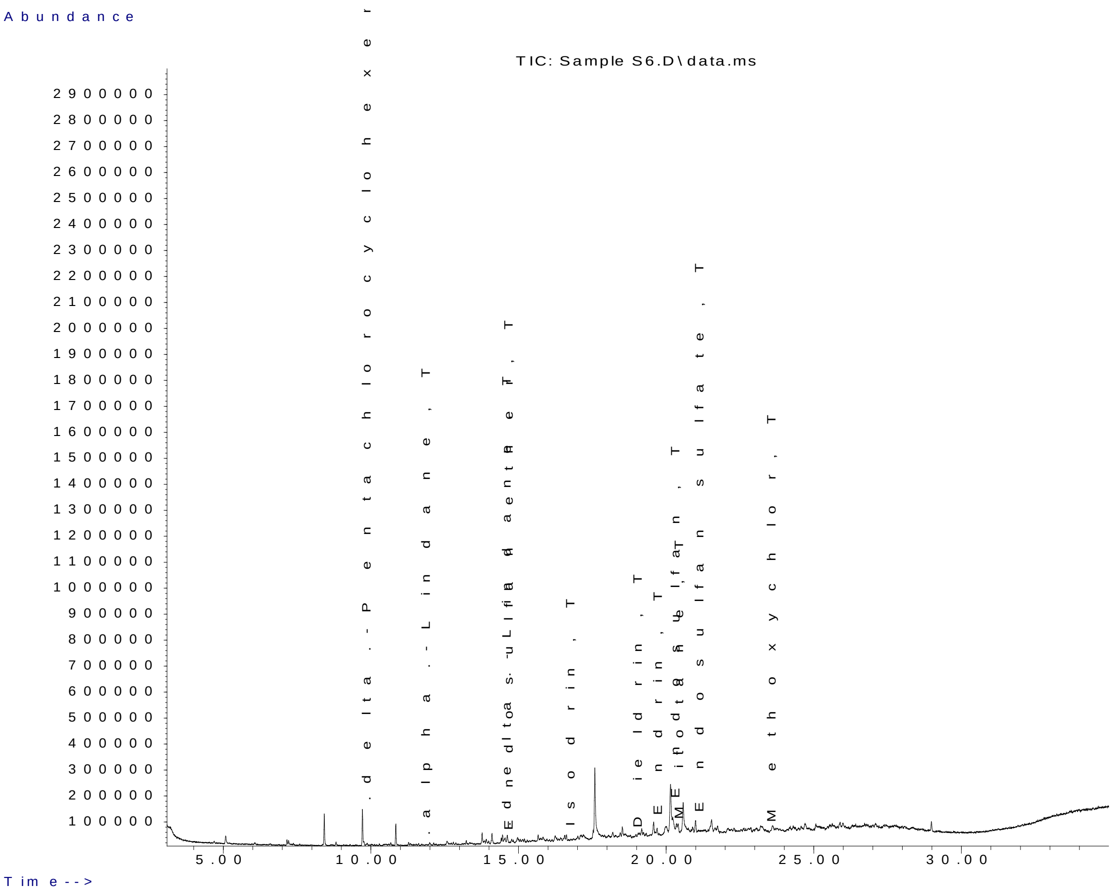
Chromatogram of Organochlorine Compounds of Sediment Sample S4 in Dry Season



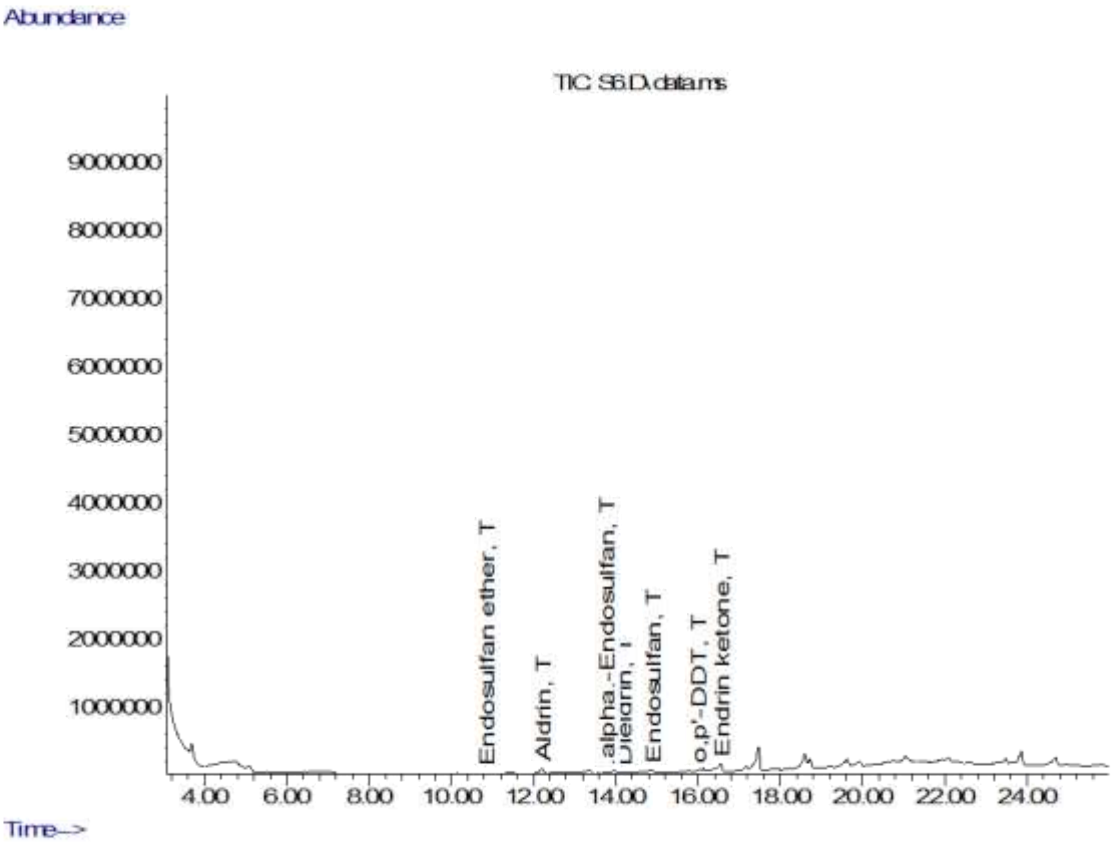
Chromatogram of Organochlorine Compounds of Sediment Sample S5 in Rainy Season



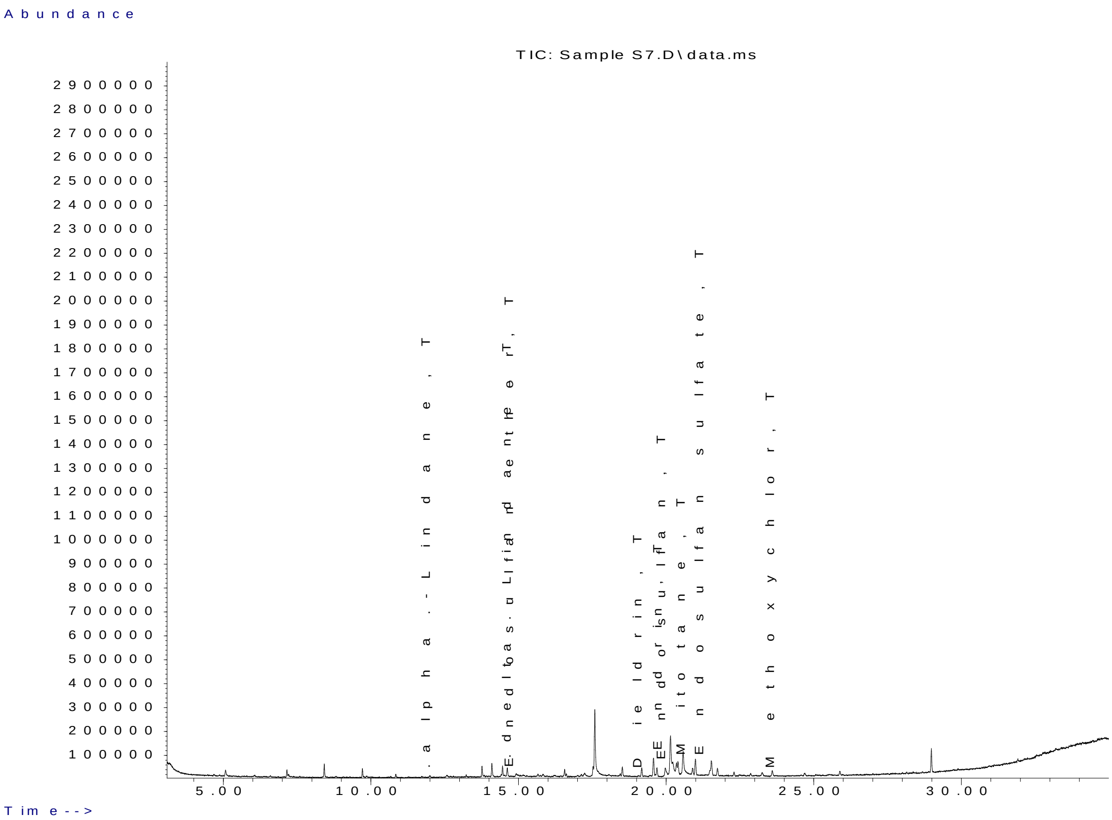
Chromatogram of Organochlorine Compounds of Sediment Sample S5 in Dry Season



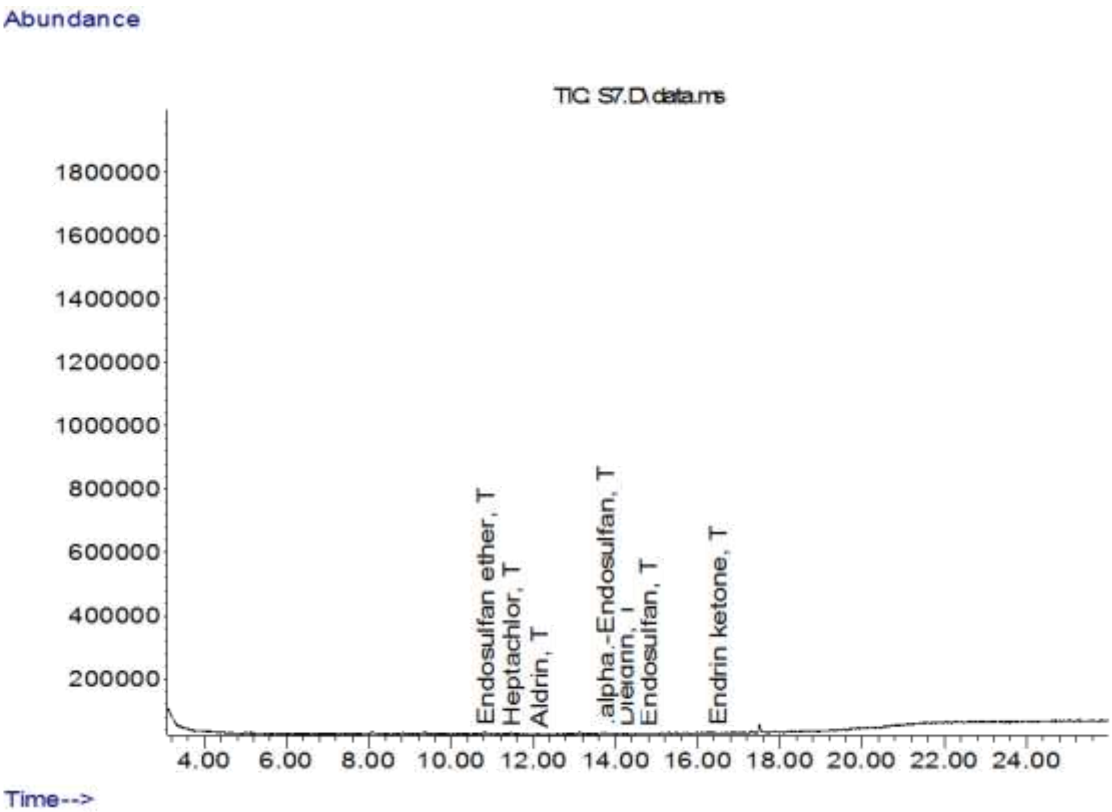
Chromatogram of Organochlorine Compounds of Sediment Sample S6 in Rainy Season



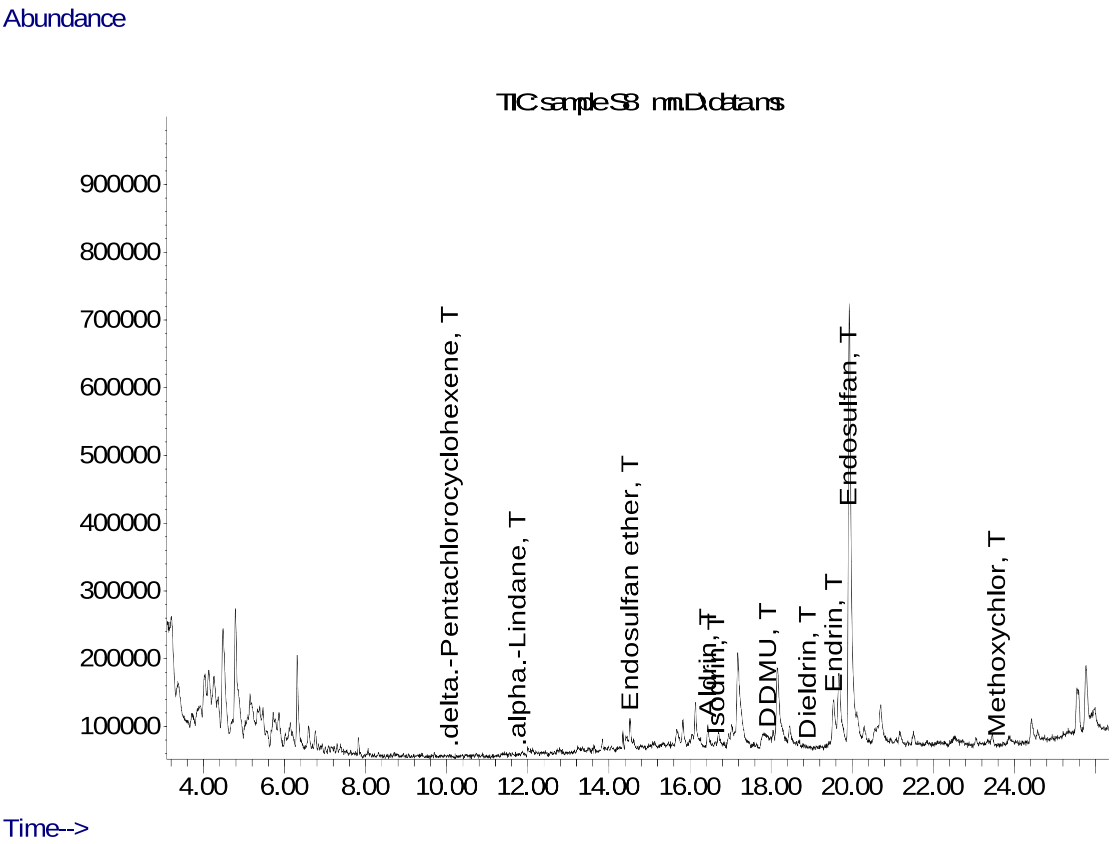
Chromatogram of Organochlorine Compounds of Sediment Sample S6 in Dry Season



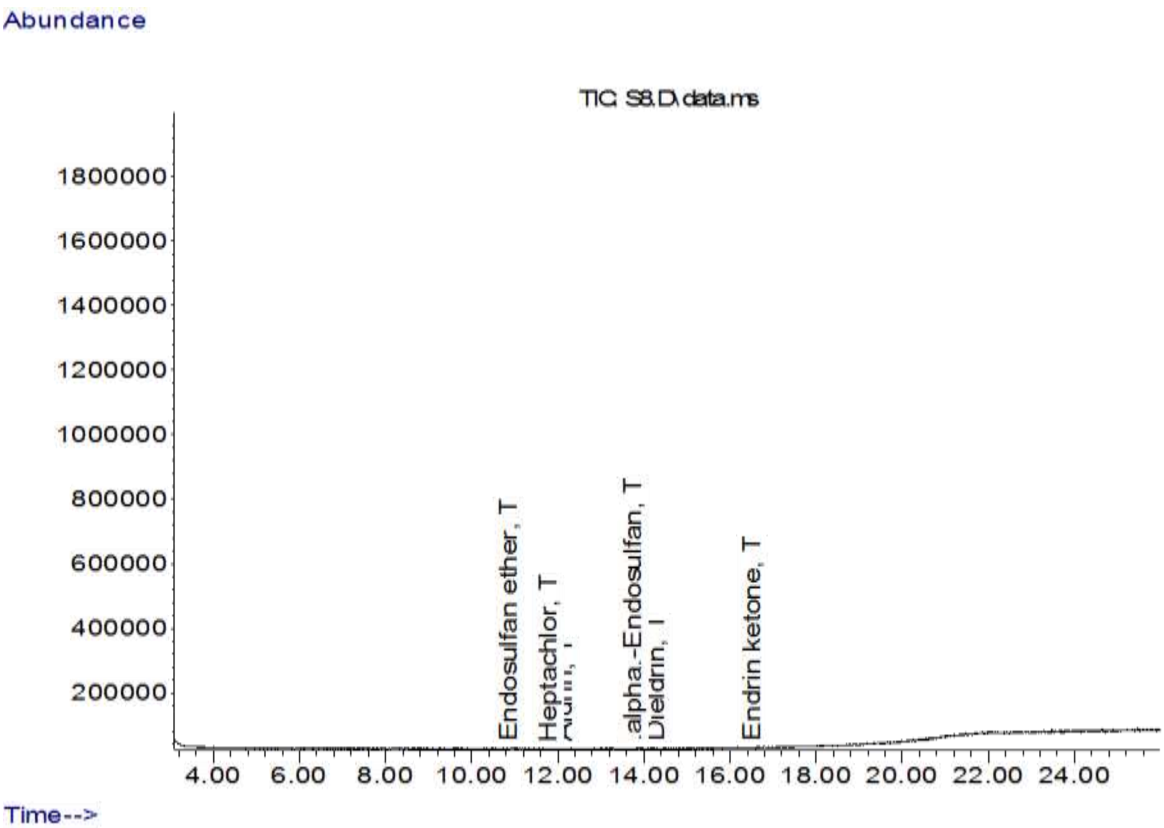
Chromatogram of Organochlorine Compounds of Sediment Sample S7 in Rainy Season



Chromatogram of Organochlorine Compounds of Sediment Sample S7 in Dry Season



Chromatogram of Organochlorine Compounds of Sediment Sample S8 in Rainy Season



Chromatogram of Organochlorine Compounds of Sediment Sample S8 in Dry Season

Appendix G

Banned Pesticides in Nigeria

SN	Trade Names	Uses
1	Aldrin	Used to control soil insects such as termites, corn rootworm, wireworms, rice water weevil, and grasshoppers
2	Captafol	
3	Chlordane	Used extensively in the control of termites
4	Ethylene	
5	Chlordimeform, Bermat, C8514, Ent 27567, EP-333, Fundal, Galecron, SN 3626	Insecticide, acaricide and ovicide
6	Chlorobenzilate	
7	DDT—Organochlorine	Used to control mosquito vectors of malaria in numerous countries
8	Lindane, Aalindan; Africide; Agrocide; Agrocide III; Agrocide WP;Ameisenmittel Merck; Ameisentod; Aparasin; Aphtiria; Aplidal; Arbitex;BBH; Ben-Hex; Bentox; Bexol; Celanex; Chloresene; Codechine;DBH; Detmol-Extrakt; Devoran; Dol; Drill Tox-Spezial Aglukon; ENT7796; Entomoxan; Exagamma; Forlin; Gallogama; Gamaphex;Gammalin; Gammalin 20	Insecticide, Acaracide, Seed treatment and soil treatment
9	Alochlor Lasagrin Lassagrin Lasso Lazo; Metachlor Pillarzo Alanox Alanex Chimichlor	Herbicide for control of annual grasses and broadleaf weeds in crops, primarily on corn, sorghum and soybeans
10	Dieldrin	Used in agriculture for the control of soil insects and several insect vectors of disease
11	Heptachlor	Used primarily against soil insects and termites.
12	Mirex	Used to combat leaf cutters and harvester termites
13	Toxaphene	Used primarily on cotton, cereal grains fruits, nuts and vegetables and to control ticks and mites in livestock.
14	Endrin	Used as a rodenticide to control mice and voles.
15	Hexachlorobenzene (HCB)	Used for seed treatment, especially for control of bunt of wheat.
16	Dinoseb	
17	Fluoroacetamide	
18	HCH	
19	2,4,5-T	
20	Captafol,	
21	Chlordane	
22	1,2-dibromoethane (EDB)	
23	Dinitro – ortho – cresol	
24	Endosulfan	Used in the control of insects and mites
25	Pentachlorophenol	
26	Mercury compounds	
27	Ethylene oxide	
28	Dichloride	
29	Aldicarb	
30	Binapacryl	

Source: National Environmental Standards and Regulations Enforcement Agency, 2014a

Appendix H

Nigeria National Standards for Water Quality

	Nigeria National Standard	
Parameter	**Limit for surface water**	**Limit for biota protection**
PH	6.5-8.5	6-9
Salinity (PSU)	-	600
Temp. (°C)	40°C	40°C
Dissolved Oxygen (ppm)	0.25	-
EC (µS/cm)	-	-
TDS (ppm)	0.25	-
Turbidity (NTU)	50	436
Sulphate (ppm)	100	15
Mn (ppm)	0.5	5
Chloride (ppm)	300	600
COD (ppm)	30.0	
BOD (ppm)	3.0	30
TSS (ppm)	25	25
TH (ppm)	500	-
Potassium (ppm)	50.0	-

Source: NESREA, 2010

Nigeria National Standards for Water Quality

	Nigeria National Standard	
Parameter	Limit for surface water	Limit for biota protection
Nitrate (ppm)	9.1	10
Nitrite (ppm)	0.05	-
Phosphate (ppm)	3.5	5

Source: NESREA, 2010

Appendix I

Key Informant Interviews and Village-Level Group Interviews in Parts Rivers Niger and Kaduna Catchments

Exploratory survey (Key Informant Interviews and Village-Level Group Interviews) of Socioeconomic Challenges of Pesticides and Fertilisers Contamination of Water in the Rivers Catchment

Characterizing interview (environmental impacts, health impacts and impacts on economic development)

Name of community……………….. Zone………………..

(A) Environmental Effects

- It has been established that considerable number of fertilizers and pesticides is being used overtime for farming activities in your domain, do you agree to that [Yes] [No]
- If [Yes], do you have any environmental concerns about the use of these agrochemicals in your community?
- If [No] why?
- If [Yes] what are your concerns?

(B) Human Health Impacts

- What are the prevalent health issues in your community?
- Have you recently observed any health problems suspected or attributable to fertilizers and pesticides contamination in your community?
- If [Yes], when, what type and how was the cases treated?
- If [No], do you have other recent emergence of health problems in the community?
- As residents, have you collectively complained about recently emergence of health issues to government authorities?
- If [Yes], how did the authorities respond to your concerns?
- If [No] why?

(C) Economic Development Impact

- How has environmental and human health problems attributable to fertilizers and pesticides contamination affected the community's incomes?
- What do you think should be done about the agrochemical contamination of aquatic resource in your community?
- Do you have any other comments or questions regarding what we have discussed?

Thank you for your time and assistance

Appendix J

Interview with Farmers and Regulatory and Enforcement Authorities

Effectiveness of Relevant Environmental Laws and Extant Regulations on Agrochemical Use near Sensitive and Vulnerable Areas

The T11 Checklist for Regulated Communities

Name of community………………….	Zone……………………………….
Question	**Answer**
Dimensions for spontaneous compliance	
T1 Knowledge and clarity of the rules	**Score:** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5**
Knowledge - Does the target group (TG) know/is the TG likely to know the legal requirements? - Are the legal requirements too extensive? - Does it take a lot of effort to get acquainted with the legal requirements? Clarity - Is or are there any doubts about the applicability of the rules? - Are the legal requirements too vague or too complicated for the TG? - Do people understand what is meant by them? - Does comprehension of the rules require unjustified expertise from the TG?	
T2 Cost-benefit considerations	**Score:** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5**
Financial / economic Immaterial - Is it a big effort (administratively, financially, technically) to comply with the rules? - Does non-compliance bring profit in terms of time or money? - Are there specific (physical) circumstances that complicate non-compliance? - Are there specific advantages of compliance with the rules, for instance financial incentives? Immaterial - Does compliance with the rules provide emotional or social advantages?	
T3 Level of acceptance	**Score:** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5**
- Does the TG group consider the regulatory approach and requirements reasonable? - Can the TG feel committed to the issue that is addressed through a particular policy/requirement or are there differences of opinion? - Can the TG contribute to the policy implementation (e.g. through self-regulation)? - Are the lawmaker's intentions clear and correctly formulated and are there loopholes in the law?	

T4 Normative commitment by the target group	Score: ▭ 1 ▭ 2 ▭ 3 ▭ 4 ▭ 5
- Does this TG generally comply properly with the legal requirements? - Does this TG always follow authority's demands? - Are there habits/traditions in this TG that can conflict with the requirements? - Does this TG have specific expectations of the authorities?	
T5 Informal control	Score: ▭ 1 ▭ 2 ▭ 3 ▭ 4 ▭ 5
Informal chance of getting caught - Does the TG's environment quickly discover non-compliance? - Does the TG, or its environment, generally disapprove noncompliance? - Is there a strong group spirit between the TG members? - Are there informal control structures? Informal sanctions - In the case of disapproval of non-compliance by the TG's environment, does the TG try to correct it in some way? - Will the members of the TG, or its environment, react negatively to non-compliance through social sanctions, like excluding or expelling from the group or loss of respect or status? - Are there other informal sanctions that could be imposed?	

Source: Matata, 2013

Questionnaire for the Regulatory and Enforcement authorities

Effectiveness of Relevant Environmental Laws and Extant Regulations on Agrochemical Use near Sensitive and Vulnerable Areas

The T11 Checklist for Regulatory and Enforcement Authorities

Question	Answer
Control Dimensions	
T6 Informal Report Probability	Score: ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- Is the TG inclined to report non-compliance to the authorities? - Is it generally known to which authority non-compliance can be reported? - Were measures taken to enlarge the approachability of the authorities (e.g. complaint desk, telephone number to report non-compliance)?	
T7 Probability of being inspected	Score: ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- What is the objective chance of being checked (control density)? - How serious does the TG estimate this chance to be? - What does the subjective chance of being checked mainly depend on?	
T8 Detection probability	Score: ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Administrative checks - Is there a full administrative check; are all data checked? - How difficult will it be to detect non-compliance: must inspectors be (financial) experts to detect fraud? - Can travel documents, transport forms, etc. be easily falsified? - Can life be made more difficult for inspectors because of a lack of models of documents or standard forms? Physical checks - Is it easy or difficult for inspectors to detect non-compliance? - What are the nature and quality of the used inspection methods? - Can non-compliance be detected with difficulty or easily because they are place and/or time-bound?	
T9 Selectivity	Score: ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- Will there be a relatively higher detection level in the case of selective checks instead of non-selective checks? - Do offenders have the feeling that they are checked more often than the ones that comply?	
Sanction Dimension	
T10 Sanction Probability	Score: ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

- How great is the chance that a penalty will be imposed after detection of non-compliance, or that there will be an informal correction? How large does the TG estimate this chance to be? - Is it difficult to prove non-compliance? - Do offenders have a high estimate of the chance to be acquitted in court?	
T11 Sanction Severity	Score: ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Formal level of the sanction - Is the TG aware of the nature and level of the sanction in the case of non-compliance? - Does the TG perceive this sanction as being high? - Does the sanction consider the financial capacity of the offender? - What is the speed with which the sanction is imposed? Immaterial costs - Do potential offenders perceive the fact that they will be prosecuted (in case of penal law) as more unpleasant than the actual sanction? - Does the execution of the sanction cause supplementary disadvantages for the offender?	

Source: Matata, 2013