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SCHOOL OF PHYSICAL AND MATHEMATICAL SCIENCES

ASSESSMENT OF THE WATER AND SEDIMENT QUALITY OF SOME LAGOONS WITHIN THE GREATER ACCRA REGION

BY
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DECLARATION

I, **KETEMEPI HILARY KWESI** of the Chemistry Department of the University of Ghana, do hereby declare that except for the references and quotations which I have duly acknowledged and cited, this work is the result of my own research under the supervision of DR. L.K. DOAMEKPOR and DR. R. K. KLAKE and that it has not been presented for any other degree elsewhere.

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DEDICATION

I dedicate this work to the Almighty God, my parents - Mr. and Mrs. Ketemepi and my siblings - Isidora, Gregory, Philipine and Imelda. I really appreciate the love, support and encouragement you gave me throughout my studies.

I love you all very much and may the Almighty God bless you all abundantly.

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God richly bless you all.

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LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
APHA	American Public Health Association
AWWA	American Water Works Association
BDH	British Drugs House
BDL	Below Detection Limit
Cf	Contamination Factor
CoV	Coefficient of Variation
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethene
DDT	Dichlorodiphenyltrichloroethane
DMS	Degrees Minutes Seconds
EC	Electrical Conductivity
ECD	Electron Capture Detector
EPA	Environmental Protection Agency
GAEC	Ghana Atomic Energy Commission
GC	Gas Chromatography
GPS	Geographical Positioning System
GSA	Ghana Standards Authority
HDPE	High-density polyethylene
Igeo	Geo-Accumulation Index

LOD	Limit of Detection
MRLs	Maximum Residue Limit
MRM	Multi Residue Method
ND	Not Detected
PAHs	Polyaromatic Hydrocarbons
PCBs	Polychlorinated biphenyls
PVC	Polyvinylchloride
Ppm	Parts Per Million
RFE	Rotary Film Evaporator
Stdev	Standard Deviation
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
UNEP	United Nations Environmental Program
VMR	Van Waters and Rogers
WHO	World Health Organisation

ABSTRACT

The Ghanaian ecosystem plays host to various lagoons which serve different purposes. The most important of them is being home for different types of fish species. Examples are *Sarotherodon melanotheron* (Cichlidae) which is popularly called blackchin tilapia and *Tilapia guineensis* (Bleeker) also known as redchin tilapia. Quality assessment was done to ascertain the level of pollution in water and sediment samples from Sakumo, Chemu and Kpeshie lagoons. Physicochemical parameters (pH, TSS, alkalinity, EC, TDS, Cl^-, NO_3^- and PO_4^{3-}), heavy metals (Cu, Pb, Fe, Ni, Zn and Mn) and pesticide residues (DDT, DDD, DDE, aldrin, dieldrin, fenitrothion and chlorpyrifos) were analysed in this work. The atomic absorption spectrophotometer used for the determination of heavy metals was VARIAN AA 240FS (Fast Sequential Atomic Absorption Spectrometer) fitted with a deuterium background corrector. Varian CP-3800 Gas Chromatograph with a Combi PAL Autosampler, Electron Capture Detector and Pulse Flame Photometric Detector was used for the analyses of pesticide residues. Sampling was done in the wet and dry seasons. The results obtained were compared with EPA, WHO and USEPA recommended limits. The results indicated that there were significant differences in concentrations of the physicochemical parameters and heavy metals between the two seasons. Most of the physicochemical parameters and heavy metal concentrations generally recorded mean values above their respective EPA, WHO and USEPA recommended limits. Correlations between metals in the sediment samples were investigated to possibly identify metals that might possess the same sources. Statistically significant and positive correlations were found between Cu and Pb, Cu and Fe, Cu and Ni, Cu and Zn, Cu and Mn, Pb and Fe, Pb and Ni, Pb and Zn, Pb and Mn, Fe and Ni, Fe and Zn, Fe and Mn, Ni and Zn, Ni and Mn, and Mn and Zn. This suggests that, metals in each combination were originating from a particular source.

Results were below detection limit for the study of pesticide residues in water and sediment samples in this research. This gives a general indication that the lagoons were unpolluted with respect to pesticide residues studied in this research and thus, there could be a possibility of pollution by other pesticide residues beyond the scope of this study.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of Study

All forms of life depend on water in one way or the other for survival. As such, water can be said to be one of the most precious resources on Earth. Water covers approximately 71% of the Earth's surface (Gleick, 1998).

Water bodies are important part of the environment because they serve as home to wild life, support to the water table and also, a source of recreation. Some water bodies are used by humans for agricultural purposes, transportation, domestic purposes and tourism (Wetlands & Strategy, 1999).

There are various water bodies at different geographical locations in the world. Amongst these are rivers, lakes, lagoons, seas and oceans (Zibordi *et al*., 2009; Emery & Uchupi, 1972).

Most water bodies are unique in their own way but of interest to this research is the lagoon. This is because lagoons have added uniqueness of constituting both fresh and salty waters. The Ghanaian ecosystem plays host to various lagoons which serve different purposes. The most important of them is being home for different types of fish species. Examples are *Sarotherodon melanotheron* (Cichlidae) which is popularly called blackchin tilapia, *Tilapia guineensis* (Bleeker) also known as redchin tilapia and *Ethmalosa fimbriata* (Bowdwich) which is commonly known as bonga shad (Dankwa, 2004). Sakumo, Chemu and Kpeshie lagoons which are found in the Greater Accra Region of Ghana and Fosu lagoon, which is found in the Central Region of Ghana were for some time past good sources of fish, most especially tilapia (Essumang *et al*., 2009).

The increase in human activities around the environs of most of these lagoons have caused their deterioration and as a result, led to a decrease in the biodiversity of these lagoons (Stumpp *et al.*, 2011; Adamus *et al.*, 2001). It is therefore important to monitor the water quality of the lagoons to assess any dangers to the lives of organisms and people that depend directly or indirectly on these lagoons for their survival.

1.2 The Effect of Anthropogenic Activities on the Nature of Water and Sediment in the Sakumo, Chemu and Kpeshie lagoons

The World Health Organization (WHO, 1997) has defined water pollution as the incorporation of any foreign material either from point or nonpoint sources into a water body, in this manner altering the normal characteristics of the water and making it useless for its intended purpose. Water pollution has been ranked the second most significant environmental issue after air pollution (Helmer *et al.*, 1997).

Pressures and instabilities such as changes in land use and major developmental projects (factors which may negatively affect the water and sediment quality of Sakumo, Chemu and Kpeshie lagoons) include; blocked inlet channels, building across river channels, transformation of environmental living spaces into homesteads (a farmhouse and its adjacent outbuildings), damming of freshwater channels, over-exploitation of mangroves, over-fishing, over-grazing, over-population, refuse dumping in lagoons to reclaim lands, and use of pesticides for cultivation (Ramsar, 2007).

Lagoons are vulnerable to various anthropogenic contaminations (Schaffelke *et al.*, 2012; Hering *et al.*, 2010; Green *et al.*, 2008). The contaminants can be classified as inorganic contaminants such as heavy metals (e.g. Pb, Hg, Cu, Zn and Cd) (Campbell, 1994; Brown *et al.*, 1990) and organic contaminants i.e. polyaromatic hydrocarbons (PAHs), pyrethroid pesticides (Maltby *et al.*, 1995) and polychlorinated biphenyls (PCBs) (Adamus *et al.*, 2001; Dunier & Siwicki, 1993).

Nitrogen and phosphorus are dissolved nutrients that occur in small quantities in natural aquatic environments. Increased quantities of nitrogen and phosphorus in water can cause the level of eutrophication to upsurge. Eutrophication is the process by which a water body becomes enriched with nutrients and this frequently occurs due to run-off. The nutrients dissolve and stimulate a dense growth of aquatic plant life which usually results in the depletion of dissolved oxygen (Fitzhugh *et al*., 2001; Stauffer & Brooks, 1997).

1.3 Problem Statement

Common anthropogenic activities around the Sakumo and Kpeshie lagoons include farming, fishing and tourism. Settlements, fuel stations, lorry stations and commercial ventures can be found in the environs of Kpeshie and Chemu lagoons. Roads and bridges can likewise be seen over each of these three lagoons. Degradation of the environment is visibly shown by the shifting vegetation and land uses, predominance of dense aquatic weeds, coastal erosion and siltation (Gbogbo & Attuquayefio, 2010; Rivera & Caicedo, 1998).

Sakumo, Chemu and Kpeshie lagoons with their associated environments are valuable to the communities encompassing them. Inhabitants around the lagoons depend on the lagoons for their livelihood by fishing and farming (Bempah *et al.*, 2013).

Most of the industries surrounding the lagoons do not often treat their waste before discharging them into the nearby water bodies. These wastes eventually wash down into the lagoons, leading to a wide variety of pollutants being released into the lagoons. This affects the living organisms in the lagoons and the people that depend on these lagoons to meet their various needs. There is therefore the need for regular monitoring of these lagoons in order to acquire baseline information which will serve as reference for future and further monitoring and also guide policy makers in decision making.

1.4.0 Primary Focus of Research Project

1.4.1 Aim of Study

The study seeks to measure and evaluate the levels of heavy metals, pesticide residues and some physicochemical parameters of water and sediments in Sakumo, Chemu and Kpeshie lagoons in the Greater Accra Region of Ghana.

1.4.2 Objectives of Study

The specific objectives of this study are to:

i. Determine the concentrations of some heavy metals in water and sediment samples by the use of atomic absorption spectrophotometry.

ii. Assess the levels of some physicochemical parameters of the lagoon water samples both in the field and in the laboratory by the use of appropriate methodologies.

iii. Identify the presence of some pesticide residues (organochlorine and organophosphate contaminants) suspected to be present in the water and sediment samples from the lagoons by the use of gas chromatography.

iv. Evaluate the extent of pollution in the sediments by the use of pollution indices.

1.5 Justification of Study

The coastal areas of Ghana particularly Tema, Accra and Takoradi have been the hub of industrial development and activities for some time. In present times, they are still the areas with high industrial activities. This has led to an increase in rural-urban migration and as a result, an increase in the population of the coastal zone of Ghana, leading to a great burden on the coastline of Ghana.

There is no doubt that the coastline of Ghana hosts a great number of lagoons, some of which are Sakumo, Chemu, Kpeshie, Korle, and Mokwe lagoons which are found in the Greater Accra Region of Ghana and Fosu lagoon which is found in the Central Region of Ghana.

Increased industrialisation has led to a proportional increase in rural-urban migration hence, an increase in human activities in the environment. This has furthermore led to an increase in the release of pollutants into the environment.

The Sakumo Ramsar site is the smallest of the five known wetlands of international importance in Ghana and it is situated in the light industrial area which is experiencing high population growth and rapid industrialisation. This wetland is an important economic resource to the country and acts as a nature conservation site. Even though the Sakumo Lagoon is a protected site, some people defy the laws that protect the lagoon and undertake unauthorised activities around the lagoon. As such, all kinds of pollutants which constitute organic and inorganic pollutants are released into the lagoon. Release of pollutants into lagoons are particularly worrisome because of their potential toxic impact, non-biodegradable and bioaccumulative capacity and their ability to transform into other more toxic compounds within an aquatic environment (Dhaneesh *et al.*, 2012; Mendil & Uluözlü, 2007; Censi *et al.*, 2006).

The pollution of lagoons is of major concern because lagoons serve as habitat for fish and other aquatic organisms like lobsters, prawns, oysters and mussels which are major sources of protein for most people in Ghana (Essumang *et al.*, 2009). In addition, the levels and distribution of heavy metals and some suspected pesticide residues in water and sediment of lagoons which are crucial for deciding the water quality of lagoons must be assessed.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Wetlands

A wetland is defined by the International Ramsar Convention as an area of marsh, fern, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water. At low tide, the depth does not exceed six meters. In simple terms, a wetland is a place where the land is covered by water. The water could be salty, fresh or somewhere in between. Lagoons, lakes, rivers, marshes and swamps are some examples of wetlands. Wetlands exist at the interface between terrestrial and aquatic environments. Figure 2.1 shows wetlands sharing terrestrial and aquatic environment. Wetlands constitute an important fish habitat. Many local communities depend on fish from wetlands for their livelihood (Mitsch & Gosselink, 2000; Ramsar Convention, 1972).

Generally, wetlands act as sinks for sediments. The wetlands that are connected to adjacent aquatic ecosystems (e.g. rivers) may trap more sediment as compared to wetlands that lack such connectivity. Human pressures engineered by pollution, run-off (drainage), over-exploitation, conversion, and other land-use practices like agriculture and mining threaten many wetlands (Fryirs *et al.*, 2007; Mitsch & Gosselink, 2000; Dunne & Leopold, 1978).

Wetlands cover about 1% of the total surface area which is about 345,000 km^2 in Africa. Some significant wetlands include; the Sudd in the Upper Nile (Egypt and Sudan), the Zaire swamps, the floodplains of the Rivers Niger and Zambezi, the Lake Victoria basin, the Chad basin and the Okavango Delta (Botswana) (Mitsch & Gosselink, 2000).

Wetland ecosystems in Ghana constitute about 10% of the country's total land surface. Ghana's 550 km coastline includes over ninety lagoons. Coastal areas form an important interface between land and sea. Although the coastline cover only 10% of the Earth‘s land area, they are home to over 60% of the world’s population (Athuman & Nkotagu, 2012; Tudor & Williams, 2000).

According to Ramsar Convention, wetlands in any country fall into three main groups. They are marine/coastal wetlands (e.g. lagoons, rocky shores and coral reefs), inland/freshwater wetlands (e.g. rivers, lakes, ponds, swamps and bogs) and man-made wetlands (e.g. reservoirs, fish pond, salt pans, flooded mineral workings and sewage farms and canals) (Johnson, 2007; Levin, 2001; William, 1990). Activities involved in industry, agriculture, extraction of natural resources, trade and transportation that occur both on and around wetlands have led to wetlands getting intensified attention.

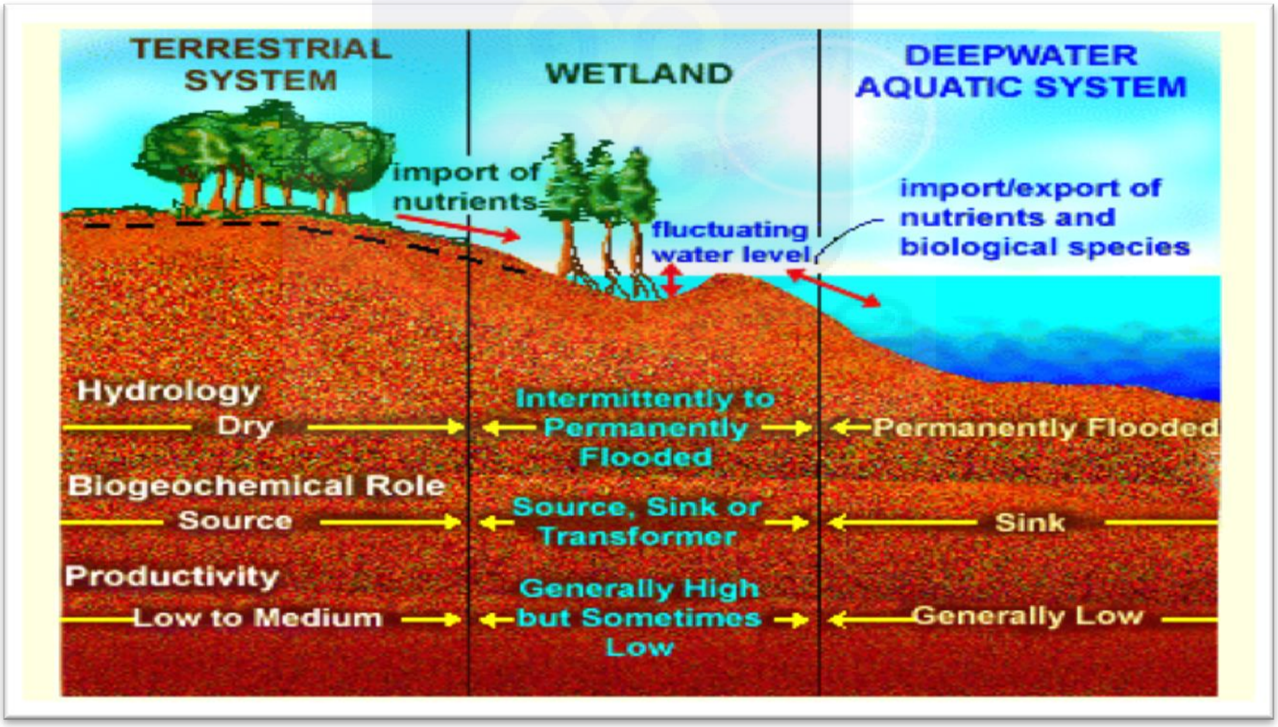


Figure 2.1: Wetlands sharing terrestrial and aquatic environment

(Mitsch & Gosselink, 2000); http://ces.iisc.ernet.in/energy/Lake2002abs/ses1724.gif

2.2.0 Lagoon Ecosystems

2.2.1 Lagoons in Ghana

Over ninety lagoons of varying sizes which are covered by intertidal mud or sand flats and in a couple of zones bordered by mangrove bogs are found along the coastline of Ghana. The coastal lagoons cover about 550 km stretch of the coastline of Ghana (Koranteng *et al.*, 1997). Some of the notable and prominent coastal lagoons in Ghana are Chemu, Sakumo, Kpeshie and Korle lagoons which are located in Greater Accra Region, Keta and Nyanya lagoons in the Volta Region, Fosu, Nakwa, Susu and Benya lagoons located in the Central Region and Domini lagoon in the Western Region of Ghana. Most of these lagoons constitute crucial ecosystems suitable for a variety of crabs, fish, shrimps, molluscs and polychaete species. Over the years, most of these lagoons have been exploited and in some cases, form the basis for small-scale fishing. *Sarotherodon melanotheron* (Cichlidae) popularly known as blackchin tilapia contributes significantly to the fresh and brackish water fishery of West Africa (Ofori-Danson & Kumi, 2006).

Some lagoons are also known as Ramsar Sites. A Ramsar Site is a wetland site designated of international importance under the Ramsar Convention. The Convention on Wetlands, known as the Ramsar Convention, is an intergovernmental environmental treaty established in 1971 by UNESCO and came into force in 1975 (Matthews, 2013; Bureau & Agency, 1997). Ramsar Sites serve both national and international purposes by hosting migratory birds. Examples of Ramsar Sites in Ghana are Keta Lagoon Complex, situated to the East of the Volta River estuary; Muni-Pomadze Ramsar Site, located in Winneba; Densu Delta, located at about 11 km West of Accra; Sakumo Ramsar Site, located at the West of Tema; and Songor Lagoon, located in Ada (Ntiamoa–Baidu, 1991).

2.2.2 Types of Lagoons in Ghana

Two basic types of coastal lagoons exist in Ghana. They are the "open" and "closed" lagoons. The open lagoons have a stable opening to the sea and are frequently supported by drains that stream all through the year. In Ghana, the open lagoon generally occurs in the Central (e.g. Benya Lagoon at Elmina) and Western (e.g. Butuah Lagoon in the Sekondi-Takoradi Metropolis) parts of the coastline which encounter higher rainfall bringing about more predictable stream of waterways (Sutton *et al.*, 2012; Armah, 1991).

The sand barrier normally secludes closed lagoons from the sea. They happen in the Eastern parts (e.g. Songor, Muni and Keta Lagoons) of the coastline where rainfall is little but very regular. Some closed lagoons join the sea in the rainy season when floodwaters break the sand fence (Kwei, 1977). Storms may likewise wear out the sandbars and open up shut lagoons to the sea. The sandbar might be physically broken during rainy seasons and this increases the danger of flooding neighbouring settlements. In some cases, this becomes a threat in diverse ways (Armah, 1991).

2.2.3 Physical Characteristics of Lagoons

The extent to which any lagoon loses or gains water through evaporation, precipitation, surface run-off, groundwater input, and exchange with the sea, greatly affects the quality and quantity of the lagoon water (Uri *et al.*, 2009; Allen *et al.*,1993; Nichols & Allen, 1981). Tides and wave activities are great determining factors in lagoon-sea interchange and often form the significant fragment of lagoon water equilibrium. Through interchange with the climate, silt and sea, heat can either be gained or lost (Piccolo, 2009; Uri *et al.*, 2009; Smith, 1994; Zimmerman, 1981).

Flushing rate defines the rate at which water enters, moves through, and exits a lagoon. Flushing rate is one of the principal physical properties that regulates the retaining time of aquatic components. When there is restricted exchange of lagoons with the sea, and there is an increase of phytoplankton and aquatic plants, and the possibility of high toxin fixations, lagoons will tend to have low flushing rates (Uri *et al.*, 2009; Spalding, 1994). The dimension and profile of a lagoon, tidal reach, the level of availability with the sea, and freshwater stream, are also determinants of flushing rates (Mahapatro *et al.*, 2013; Phleger, 1981).

2.2.4 Economic Significance of Lagoons

Lagoons in Ghana are indispensable as they offer favourable conditions and qualities to coastal inhabitants. Locally, lagoons offer appreciable resources to business and livelihood. Large quantities of fish and crabs that are caught in the lagoons are processed and sold in the coastlands of Ghana (Gordon *et al.*, 1998).

Reeds are cut and used as thatch for roofing of buildings. Some of the reeds are also woven into mats. Water that is drawn by hand from wells along the edges of the lagoons are used to irrigate nursery beds (Biney *et al.*, 1994).

2.2.5 Threats to lagoons

The reproducing cycles of nesting or settling species, such as fish, and sea turtle hosted by the lagoons can be affected by excessive anthropogenic activities. The release of industrial and residential sewage and also agricultural run-off into lagoons increase the organic load of the lagoons. This results in an increase in the biochemical oxygen demand (BOD) of the aquatic ecology and leads to decreased supply of oxygen which sustains animal and plant life (Agyenim & Gupta, 2010).

In addition, some species have their eggs regularly trodden by grazing cows and domesticated animals. These could lead to loss of species and loss of habitat as a result (Bempah *et al.*, 2013; Ntiamoa–Baidu, 1991). Figure 2.2 shows some cattle grazing in the marshland alongside feeding white egrets.

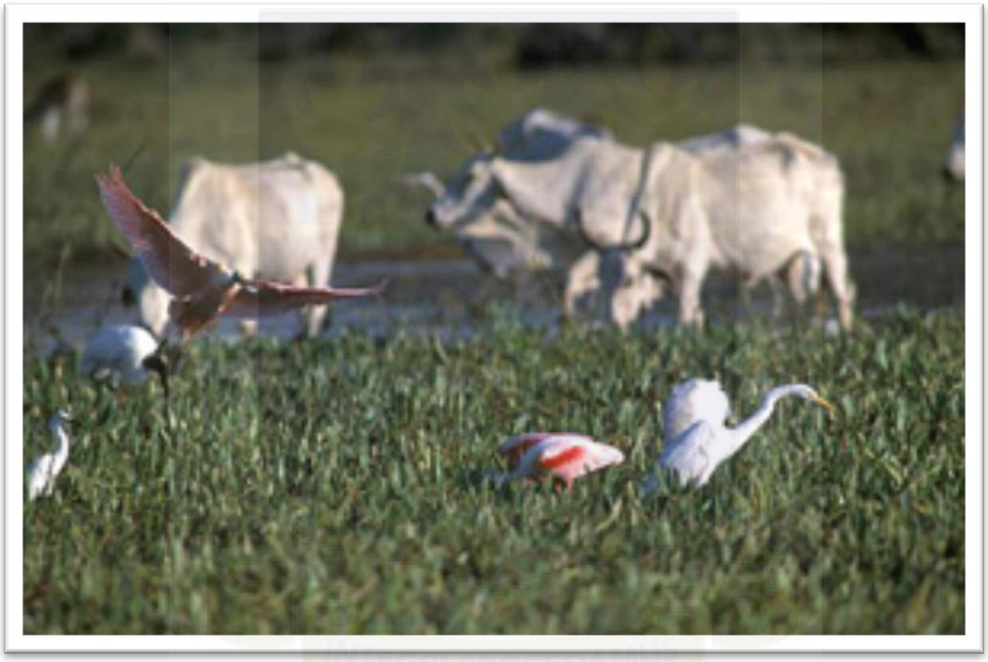


Figure 2.2: Some cattle grazing in the marshlands alongside feeding white egrets

Due to threat on certain species, the international law for conservation of biodiversity which is referred to as the 1992 Biodiversity Convention was well developed in 1992 (Sands, 1995). The extinction of biodiversity of plants and animals is a major concern worldwide (Nweke & Sanders III, 2009).

2.3 Review of Previous Studies on Anthropogenic Impact on Water and Sediment Quality of Sakumo, Chemu and Kpeshie lagoons

A study was done by Apau *et al.*, in 2012, on the Kpeshie lagoon of which the physical and chemical qualities of the water were determined. The study revealed that a great deal of human activity is concentrated near the lagoon and the lagoon is steadily transformed into a waste site. From their study, they observed that nutrient and organic matter were the most regular source of contamination around the lagoon with average concentrations of phosphate, sulphate and nitrate being 487.14 ± 257.02 mg/L, 11,852 ± 2,915.08 mg/L, and 2,905.7 ± 616.52 mg/L respectively. Results and analysis found out that aluminum (Al) and iron (Fe) recorded the highest concentrations of 13.6 ± 4.29 mg/L and 13.2 ± 3.47 mg/L respectively. The concentrations of potassium (K) and calcium (Ca) were observed to be 5,949.94 ± 87.30 mg/kg and 15,709 ± 75.35 mg/kg, respectively from the fish analysis while Al and sodium (Na) were found to be 708.47 ± 4.95 mg/kg and 3,775.70 ± 24.80 mg/kg, respectively. There was an indication that the lagoon was highly polluted when the results were compared with the WHO guidelines (Fianko *et al.*, 2013).

The Chemu lagoon is the primary point of direct or indirect disposal of industrial effluents in Tema. Some physicochemical analysis was done by Doku (2015), on the Chemu lagoon and he observed that pH, conductivity, COD and BOD values ranged from 6 to 7.4, 204 to 6850 µS/cm, 90 to 2050 mg/L and 17 to 312 mg/L as against 6 to 9, 1500 µS/cm, 250 mg/L and 50 mg/L, respectively (Doku, 2015).

Concentrations of heavy metals were determined in sediment samples for Sakumo lagoon by Klake *et al.* (2012). In their research, they found out that the concentration of metals ranged from

46.49 to 81.03 µg/g, 42.93 to 84.73 µg/g, 6.47 to 53.98 µg/g and 279.98 to 655.12 µg/g for zinc (Zn), copper (Cu), lead (Pb) and manganese (Mn) respectively (Klake *et al.*, 2012).

2.4.0 General Characteristics of Heavy Metals

Heavy metals are characteristic segments of the Earth's crust (Plan *et al.*, 1996). They have been well-defined distinctively by numerous areas of the scholarly world; some in view of density, others based on atomic weight, and others by their chemical properties or toxicity (Master & Laboratories, 2012). Heavy metal refers to any metallic or metalloid element that has a relatively high density ranging from 4 g/cm^3 to 7 g/cm^3 and is toxic, even at very low concentrations (State *et al.*, 2014). Heavy metals are not biodegradable and are consequently detrimental to human health, plants and aquatic animals at certain levels of exposure because they bioaccumulate (Soylak & Erdogan, 2006). The increase in the levels of chemicals in a natural life form after some time, compared with the concentrations of chemicals in the environment is simply termed bioaccumulation. Nonetheless, some heavy metals (e.g., selenium, manganese, iron, zinc and copper) in small quantities are important for life and metabolism of the human body. Some of these metals are normally obtained in fruits, vegetables, foodstuffs and in commercially accessible multivitamin products. Nevertheless, they can be toxic at higher concentrations (Loewenson, 2001). Temperature, pH, carbon dioxide, redox, hardness, chelating agents, ligands and the concentration of metal ions are some factors that affect the metals (Lente *et al.*, 2012).

Heavy metals possess a higher possibility of staying in solution when complexed to chelating ligands. At different pH values, metals precipitate as oxides or hydroxides. When pH values increase, the amphoteric elements come back into solution. As such, pH can be said to greatly affect the mobility of metals (Alloway & Ayres, 1998).

Beyersmann and Hartwig (2008) came to a conclusion that, the harmfulness of heavy metals and their compounds to a great extent relies upon their bioavailability and bioaccumulation concentrations.

2.4.1 Processes by which Metals Enter the Environment

There are two processes by which metals enter into the environment. They are natural processes and the processes resulting from human activities.

Natural processes include forest fires, disintegration of metal bearing rocks, volcanic action, and wind-blown dust while the processes that result from human activities consist of direct release of pollutants into air, soil and water (Clark, 2001). Agrochemicals (fertilizers and pesticides), metalliferous mining and refining, and burning are all significant human activities that lead to the release of heavy metals into the environment (Alloway, 1995).

In present times, heavy metals have been released into the world's watercourse as a result of rapid urbanisation (Sin *et al.*, 2001). Occurrences of heavy metal pollution of coastal lagoons by anthropogenic activities presently are common even in the less industrialised countries (Wu *et al.*, 2007; An, 2006).

2.4.2 Toxicity of Metals in Biological Systems

Metals are generally mined as ores from rocks as either sulphides or oxides. In either state, they are not found purely as sulphides or oxides of a particular metal but with other metal sulphides or oxides. Heavy metal ores of copper (Cu) and iron (Fe) occur together with sulphides of lead (Pb), cadmium (Cd), arsenic (As) and mercury (Hg) (WHO, 2004).

As indicated by Duffy in 2011, biologically, the mechanism of the toxic activity of heavy metals is usually based on the strong affinity of cations for sulfur. The enzymes which control the rate of basic metabolic reactions that occur in the human body contain the sulfhydryl group (–SH). The sulfhydryl group is a family of organic compounds that contains an R group bound to a sulfur atom and a hydrogen atom (an R group is a side chain that has a carbon or hydrogen atom attached to the rest of a molecule). The resultant metal-sulfur bonding affects the effectiveness of the enzyme to function normally and as a result, the health of humans is adversely affected. Heavy-metal cations M^{2+} (where M is Cd, Hg or Pb) react with the sulfhydryl group of enzymes R–S–H to produce stable systems like R–S–M–S–R (where R is an alkyl or aryl group and S is sulfur). Reaction with simple inorganic chemical hydrogen sulfide (H_2S), yields insoluble solid M–S (Duffy, 2011).

2.4.3 Heavy Metal Toxicity

The concentration at which metal is required to bring about an intense reaction generally death or sub-deadly reaction is usually characterised as the toxicity of a metal (Smith & Huyck, 1999). Attempting to predict effects of exposure of metals on living organisms is very complicated because metals are either non-essential or essential. Practically, most metals can have harmful effects even when consumed in small amounts (Newman & Clements, 2007). For instance, constant exposure to cadmium (Cd) may bring about side effects of zinc (Zn) deficiency since Cd dislodges Zn in metalloenzymes. Extreme quantities of non-essential tungsten (W) could bring about an obvious inadequacy of molybdenum (Mo) which is a vital and chemically comparative element (Mertz, 1981).

In general, heavy metals exhibit their toxicity in biological organisms by forming complexes or "ligands" with organic compounds which may incapacitate certain essential enzymes, systems, and some protein structures. The altered biological molecules lose their capacity to work appropriately, and this leads to breakdown or death of the affected cells. Hence, heavy metals could be said to be endocrine disruptors or endocrine disruptor compounds (Machado–Estrada *et al.*, 2013; Master & Laboratories, 2012).

2.5.0 Water Quality Parameters and Sediment Pollution

The United Nations Environment Program (UNEP) states that "water quality is neither a static condition of a system, nor can it be defined by the measurement of only one parameter". This is as a result of a wide scope of biological, chemical and physical constituents that regulate the quality of the water (Secretariat, 2006).

The concentration and distribution of pollutants in aquatic environments rely upon various factors such as size of the deposited particulate matter, chemical composition, and biological activity happening at the bottom (sediments) of the water. They are again powerfully affected by a variety of chemical and physical parameters like pH, conductivity, temperature, dissolved oxygen and turbidity. These parameters can thus be measured and analysed to find out the quality of water (Coccioni, 2009).

2.5.1.0 Hydrogen Ion Concentration (pH)

"pH" is an abbreviation for the French expression, "Pouvoir Hydrogène," which means "the power of protons or hydrogen nuclei". pH quantifies acidity or basicity of a solution. To the analytical chemist, pH is a technique of stating hydrogen ion concentration in terms of the power of 10 with the pH value being the negative logarithm of the hydrogen ion concentration (pH = – $\log_{10}[H^+]$). To the water chemist, pH is critical in characterising the alkalinity equilibrium levels of carbonate, bicarbonate, hydroxide ions and carbon dioxide. Metals discharged from sediments at the sediment-water interface are to a great extent regulated by pH of a sediment structure (Manahan, 2011; Peters *et al.*, 2005). pH levels at some points can increase as a result of increase in the level of photosynthesis by thick phytoplankton sprouts. pH greater than 7 however and lesser than 8.5 is perfect for biological efficiency, but pH less than 4 is unfavourable to aquatic life (Abowei, 2010).

The determination of pH involves the activity of hydrogen ions by potentiometric measurement with a standard hydrogen electrode and a reference electrode (WHO, 2004).

2.5.1.1 Effects of Alterations of pH on Aquatic Life

Change in pH may cause most organisms to perish because the organisms have adjusted to life in water at a particular pH (Mcmillan *et al.*, 2015). Water becomes deadly to general forms of life when the pH is exceedingly low or high (4.5 or 11.0 respectively). When water becomes extremely acidic, heavy metals are released into various water sections. The metals are then available for ingestion and as such, become part of the food chain. Ammonia compounds change to toxic forms in basic water; the more basic the water, the more toxic the ammonia that is present (Koprivnikar *et al.*, 2010; Oliviero *et al.*, 2003).

2.5.1.2 Electrical Conductivity (EC)

The concentration of salts dissolved in water that makes the water able to conduct electrical current is termed as the conductivity of water (Jain *et al.*, 2006). Discharges into water bodies can alter the conductivity of the water. Most water bodies have a fairly constant range of conductivity under normal circumstances. Hence, substantial fluctuations in conductivity can be an indicator that some other sources of pollution have entered the water. Water with high electrical conductivity has detrimental health effects on humans and aquatic life. This may incorporate unsettling influences of salt and water equilibrium and an antagonistic impact on some myocardic individuals or patients with high blood pressure (Fatoki & Awofolu, 2004). Conductivity is reported as micromhos/cm or microSiemens/cm (μScm^{-1}or μS/cm). Most freshwater systems have low conductivity but contaminated water bodies may have very high conductivity (Team, 2004).

When conductivity is multiplied by a factor, total dissolved solids (TDSs) of water can be determined. This factor may range from 0.055 to 0.900 (Thirumalini & Joseph, 2009).

2.5.1.3 Total Dissolved Solids (TDS)

Total dissolved solids is referred to as the total amount of mobile charged ions, including minerals, metals or salts dissolved in a given volume of water expressed in mg per unit volume of water (mg/L or ppm). Total dissolved solids are products of run-off. TDS does not include gases, colloids or sediments. Conductivity increases with increase in dissolved solids (Rhoades *et al.*, 1996).

TDS can be measured in the field by the use of TDS meter. TDS meter measures the conductivity of water and after that, applies a change element or conversion factor that reports TDS to a known reference solution (e.g. ppm sodium chloride or ppm potassium chloride). One ppm of TDS (when referenced to a NaCl solution) corresponds to a conductivity of two micromhos/cm or microSiemens/cm (APHA, 1992).

2.5.1.4.0 Nutrient Contaminants

Nutrients like nitrogen and phosphorous are essential for the development of algae and different plants. When there is excessive concentration of nutrients, aquatic plant and algae growth become over stimulated leading to eutrophication. In this case, fish and invertebrates are deprived of available oxygen in the water (Roussiez *et al.*, 2006).

2.5.1.4.1 Nitrogen Compounds in Natural Waters

Nitrogen occurs in some natural water in organic and inorganic forms. Hence, they are of great concern to human health. Nitrogen exists in different forms of varying oxidation states which are environmentally important. Table 2.1 shows some common oxidation states of nitrogen with illustrations for each.

Table 2.1: Common Oxidation Numbers for Nitrogen

Oxidation Number of Nitrogen (N)	**Increasing Levels of Nitrogen Oxidation** $\longrightarrow$						
	–3	**0**	**+1**	**+2**	**+3**	**+4**	**+5**
Gas phase	NH_3	N_2	N_2O	NO	—	NO_2	—
Aqueous solution	NH_4^+	—	—	—	NO_2^-	—	NO_3^-
Salt	NH_3	—	—	—	—	—	—

Ammonia (NH_3), and its conjugate acid, the ammonium ion (NH_4^+), are the most reduced forms with oxidation numbers of –3. Nitrate ion (NO_3^-), which exists in salts, aqueous solutions, and nitric acid (HNO_3), is the most oxidised form with oxidation number of +5. The nitrite ion, NO_2^-, and molecular nitrogen, N_2, are the most essential intermediates in solution (Baird & Cann, 2008; Feth, 1966).

There is an equilibrium established between the most highly oxidized and the most highly reduced forms of nitrogen and this is given by the half-reaction:

$$NH_4^+ + 3H_2O \rightleftharpoons NO_3^- + 10H^+ + 8e^-$$

NH_3 oxidises or combines with oxygen to form nitrite ion. The nitrite ion also combines with water to form nitrate ion.

$$NH_3 + O_2 \rightarrow NO_2^- + 3H^+ + 2e^- \text{--------------------} \quad (1)$$

$$NO_2^- + H_2O \rightarrow NO_3^- + 2H^+ + 2e^- \text{--------------------} \quad (2)$$

The oxidation of ammonium ion would not happen under exceedingly acidic conditions because it is very much dependent on pH. Normally, the concentrations of nitrate are stated as “ppm as nitrogen” in water analysis and not as “ppm as nitrate” as requisite for reverse osmosis estimates (Baird & Cann, 2008; Feth, 1966).

2.5.1.4.2 Phosphorus

Phosphorus is an essential element for all forms of life but it naturally occurs in low concentrations. Phosphorus originates from processes like decomposition of organic matter and weathering of rock. The presence of phosphorus indicates the consequential condition of a particular water body, organic enrichment and the status of nutrients (Ismail, 2011).

The elemental form of phosphorus can be subjected to bioaccumulation, and as such become very toxic. Increased levels of phosphates, PO_4^{3-}, may occur as a result of discharge of sewage, detergents, erosion, urban run-off, and local spillovers containing manure, plant and animal matter (George *et al.*, 2003).

Phosphates exist in three forms. They are metaphosphates (polyphosphates), orthophosphate, and organically-bound phosphates. The ‘poly’ forms are used in detergents and in the treatment of boilers. The ‘ortho’ forms are formed by natural courses and are mostly found in sewage. The ‘poly’ forms change to ‘ortho’ forms in water. Organic phosphates are essential in nature. The breakdown of organic pesticides which contains phosphates results in the occurrence of organic phosphates. They exist in solutions such as loose fragments, particles or in the bodies of aquatic organisms (Murhekar, 2011; Glynn & Plummer, 2005).

2.5.1.5 Chlorides

Chlorides (Cl^-) are monovalent anions and ubiquitous in seawater. They are significant anions found in water and are usually combined with sodium, magnesium or calcium. All chloride salts are profoundly soluble in water. The acceptable chloride content ranges from 10 to 100 mg/L. Sea-water contains more than 30,000 mg/L as NaCl. The recommended maximum level for chloride is 250 mg/L. The corrosion rate and the dissolution of ions present in water from funneling, increases as the content of NaCl in the water increases (Bhaduri *et al.*, 2000; USEPA, 1994).

2.5.1.6 Alkalinity Indices for Natural Waters

The actual concentrations of the cations and anions in water analysis cannot simply be assumed to be the theoretical values calculated for calcium, carbonate, and bicarbonate for two main reasons:

- acids or bases may also be present; and
- the water may not be in equilibrium with either solid calcium carbonate or with atmospheric CO_2.

The alkalinity value for a sample is an index formulated by analytical chemists to represent the actual concentration in water of the anions that are basic. Alkalinity is a measure of the capacity of a water sample to act as a base by reacting with hydrogen ions. In other words, the alkalinity of water is the measure of the capacity of a water body to neutralise acids and resist acidification when acid rain falls into it (Project & Document, 2008). Alkalinity which is more properly termed "total alkalinity" is the number of moles of H^+ required to titrate 1 liter of water sample to the end point. By definition, a solution containing carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions, as well as hydroxide (OH^-) and hydrogen (H^+) ions, is:

$$\text{Total alkalinity} = 2\,[CO_3^{2-}] + [HCO_3^-] + [OH^-] - [H^+]$$

The factor of 2 shows up before carbonate ion concentration because the presence of hydrogen ion is first converted by the carbonate ion to bicarbonate ion, which is then converted by a second hydrogen ion to carbonic acid (H_2CO_3):

$$CO_3^{2-} + H^+ \rightleftharpoons HCO_3^- \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$HCO_3^- + H^+ \rightleftharpoons H_2CO_3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Anions of boric, phosphoric, silicic acids, H_2S, and natural organic matter are some examples of minor contributors to the alkalinity of fresh-water systems. The values of alkalinity are usually reported as milligrams of $CaCO_3$ equivalent, rather than moles of H^+, per liter.

In analytical chemistry, a convention has been made where methyl orange is used as an indicator in titrations for the determination of total alkalinity. This is because methyl orange does not change color until the solution is slightly acidic (pH = 4); under such conditions, not only do all the carbonate ions in the sample get converted to bicarbonates, but virtually all the bicarbonate ions get transformed into carbonic acid (Baird & Cann, 2008).

Phenolphthalein alkalinity which is also called carbonate alkalinity is another index encountered in the examination of natural waters. It is a measure of the concentration of carbonate ions and other similarly basic anions (Baird & Cann, 2008).

In order to titrate only CO_3^{2-} leaving out HCO_3^-, the indicator normally used is phenolphthalein. Phenolphthalein changes color in the pH range 8 to 9, so it provides a fairly alkaline end point. Hence,

$$\text{Phenolphthalein alkalinity} = [CO_3^{2-}]$$

Small crystals of calcium carbonate are sometimes detected in water bodies where there is active photosynthesis:

$$CO_2 + H_2O + \text{sunlight} \rightarrow \underset{\text{(as algae)}}{CH_2O \text{ polymer}} + \tfrac{1}{2}O_2$$

The CO_2 available is readily used by algae for photosynthesis. They do so at the expense of permitting an accumulation of hydroxide ion to a degree such that the water turns out to have a relatively high basicity value in some circumstances (Baird & Cann, 2008).

2.6.0 Organic Contaminants

The solubility of organic contaminants in water is low and as a result residues can be detected in water where there is pollution especially on suspended matter in water (Amaraneni, 2002).

Carbon forms many compounds with chlorine and phosphorus. Some of these compounds are found in nature and most often in small quantities. Most of these carbon-chlorine and carbon-phosphorus compounds are produced synthetically. Carbon-chlorine bonds are normally associated with organochlorines (OC) and carbon-phosphorus bonds are usually associated with organophosphorus (OP) (Afful *et al.*, 2010). Some examples of these synthetic compounds are pesticides, toxaphenes, polychlorinated biphenyls (PCBs), and dioxins (Hicks, 2012).

2.6.1.0 Pesticide Residue

Pesticide residue is the residual quantity of active components of a particular pesticide or group of pesticides detected in water, sediment or food sample. Pesticides are regularly mistaken to refer only to insecticides. Pesticides relate to acaricides, fungicides, herbicides and other substances that are used in pest control. Under the US law, a pesticide could be any substance or mixture of substances that is used as a defoliant or used for any kind of pest control (Essumang *et al.*, 2009).

Organochlorine (OC) pesticides are classified among the major types of pesticides. This is because of their high toxicity, their ability to enter the food chain and bio-magnify, and their persistence in the environment. OC pesticides are not desired in the environment due to the above reasons (Ntow, 2001).

The production and use of many forms of OC and OP compounds have been strictly limited and banned in many countries such as Ghana. Nonetheless, some of the OC and OP compounds are still being used without authorisation in many parts of Ghana and in other developing countries. This is due to their relatively low cost and effectiveness on pests and other organisms (Ntow *et al.*, 2006; Racke *et al.*, 1997).

The OP pesticides compared to the OC pesticides are relatively more degradable by microbial action. OC pesticides have a higher tendency to concentrate in lipid rich tissues of aquatic organisms and most mammals because they are hydrophobic and not easily degradable. The solubility of OP pesticides in water is variable but higher than that of OC pesticides. Some examples of OC pesticide residues are dieldrin, aldrin, p,p^{l}-dichlorodiphenyldichloroethene (p,p^{l}-DDE), p,p^{l}-dichlorodiphenyltrichloroethane (p,p^{l}-DDT), p,p^{l}-dichlorodiphenyldichloroethane (p,p^{l}-DDD), and heptachlor. Some examples of OP pesticide residues are fenitrothion, chlorpyrifos, diazinon, and dichlorvos (Werimo *et al.*, 2009).

2.6.1.1 Dichlorodiphenylethanes

All organochlorine pesticides that fall under this group have the dichlorodiphenylethane as a common unit structure. The well-known and widely used dichlorodiphenylethane is the dichlorodiphenyltrichloroethane (DDT). Figure 2.3 shows the structure of DDT.

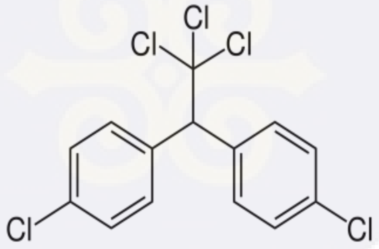
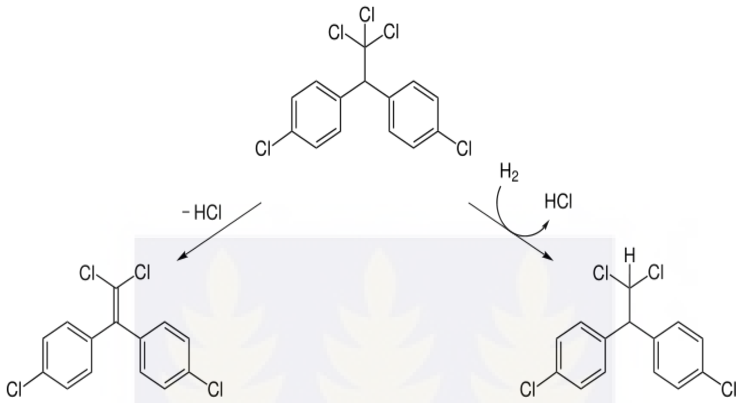


Figure 2.3: Molecular structure of dichlorodiphenyltrichloroethane (DDT)

DDT molecule contains two tetrahedral carbons in the ethane unit, and two benzene rings. Dichlorodiphenyldichloroethane (DDD) is an example of another molecule of DDT-like action. DDD is an environmental degradation product of DDT. The difference is the replacement of one chlorine atom from the $–CCl_3$ group in DDT by a hydrogen atom. Dichlorodiphenyldichloroethene (DDE) is another environmental degradation product of DDT. There is a planar C=C unit rather than a C–C linkage with tetrahedral group at each end in DDE.

DDE is therefore not an insecticide (Donkin, 1980). Figure 2.4 shows the environmental degradation pathway of DDT to DDD and DDE.

DDT



DDE DDD

Figure 2.4: Degradation pathway of DDT to form DDE and DDD

2.6.1.2 Chlorinated Cyclodienes

The derivatives of hexachlorocyclopentadiene are chlorinated cyclodienes. Most cyclodiene pesticides are persistent organic pollutants (POPs). They are used in the control of cockroaches, soil insects, termites, locusts and grasshoppers. Some examples of cyclodiene pesticides are aldrin, chlordane, dieldrin, endrin, endosulfan and heptachlor (Falandysz *et al.*, 2001).

Aldrin and dieldrin are chemicals applied in agriculture to control insects in soil. Aldrin and dieldrin are used in public health to control tsetse-flies and mosquitoes. Aldrin and dieldrin show similar chemical properties and toxicity because they have similar structures (Zitko, 2003). Aldrin degrades to the epoxide dieldrin which has strong insecticidal value when present in soils or in the digestive tracts of insects (Ferguson & Korte, 1977). Aldrin breaks down into dieldrin in living systems. Dieldrin resists bacterial and chemical breakdown processes in the environment. Aldrin and dieldrin have been known to cause health problems like Parkinson's disease (Fleming *et al.*, 1994), nervous system damage, reproductive failure and breast cancer (Orris *et al.*, 2000; Steinhart *et al.*, 1995). Figure 2.5 shows the molecular structure of aldrin and dieldrin. Figure 2.6 and Figure 2.7 show the synthesis of aldrin and dieldrin by Diels-Alder reaction respectively.

Aldrin

Dieldrin

Figure 2.5: Molecular structures of Aldrin and Dieldrin

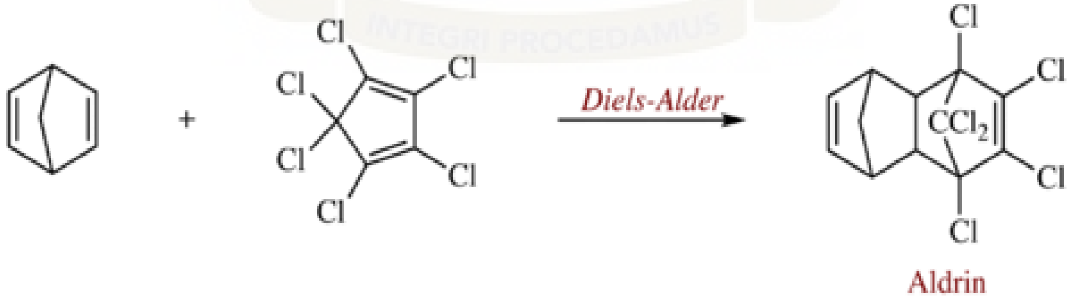


Figure 2.6: Synthesis of Aldrin by Diels-Alder reaction

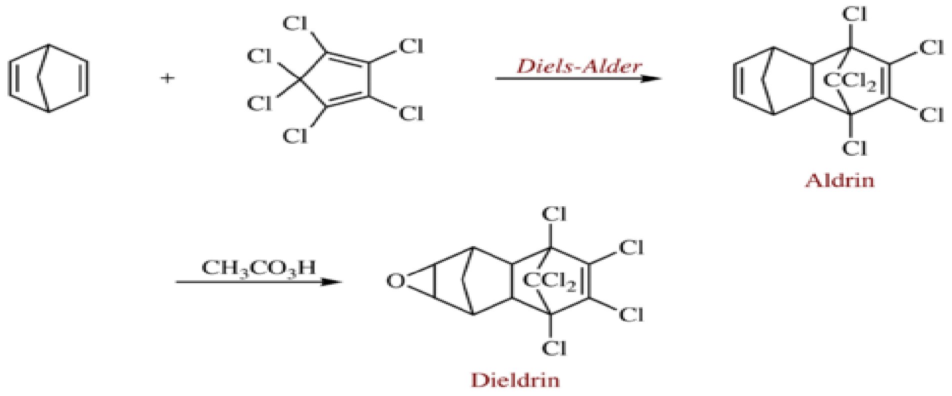


Figure 2.7: Synthesis of Dieldrin by Diels-Alder reaction

2.6.1.3 Fenitrothion

Fenitrothion is an organophosphate pesticide chemical with a half-life of about 12 to 28 hours. The compound is mobile intermediately in different soils ranging from sandy, loamy to clay soils (Radder *et al.*, 1989). Fenitrothion acts as a phytotoxic substance when high rates are applied to some fruit crops and Brassica crops. There is a high tendency of damage to fruit and cabbage if only the application dose of fenitrothion is exceeded (Hill, 2008). Fenitrothion is unstable in alkaline media and it undergoes a rapid mammalian metabolism and excretion. Dimethylfenitrooxon and 3-methyl-4-nitrophenol are the most important metabolites (Ray *et al.*, 1991; Hayes, 1982). Figure 2.8 shows the molecular structure of fenitrothion.

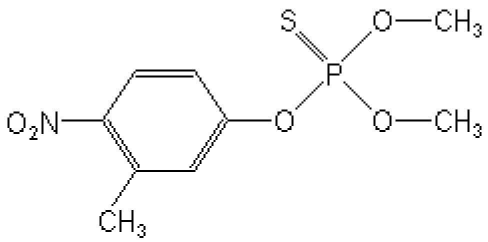


Figure 2.8: Molecular structure of fenitrothion

2.6.1.4 Chlorpyrifos

Chlorpyrifos is an organophosphate chemical that acts on the nervous system of insects by inhibiting acetylcholinesterase (Corbel *et al.*, 2009). To humans, it is moderately toxic to some extent. Exposure of chlorpyrifos has been linked to persistent developmental disorders, neurological effects, lung cancer and auto-immune disorders. When chlorpyrifos is exposed to pregnancy, it leads to the retardation of mental development of children (Carullo *et al.*, 2015; Rauh *et al.*, 2006). Chlorpyrifos has over the period of time been one of the most used insecticides in residential and commercial settings. It is used in agriculture to control insect pests (States & Protection, 2006). Figure 2.9 shows the molecular structure of chlorpyrifos.

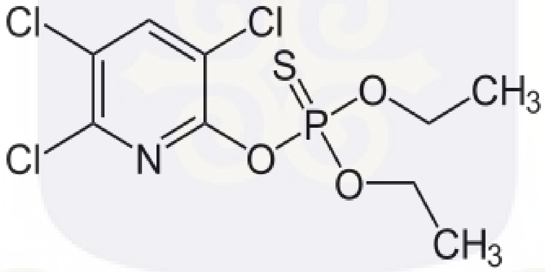


Figure 2.9: Molecular structure of chlorpyrifos

2.7.0 Pollution Indices

Pollution indices for the concentration of the heavy metals present in sediments are calculated by the use of contamination factor, geo-accumulation index and pollution load index. With the help of these indices, the quality of the environment can be quantified and simply understood by anybody (Tomlinson *et al.*, 1980).

2.7.1 Contamination Factor (C_f)

The outcomes of concentrations of heavy metals in sediment samples are contrasted with sediment standards that were set by Caspers, (1985). This is done to check the levels of contamination by heavy metals in the sediment samples. The level of contamination of sediment by heavy metal is expressed in terms of a contamination factor (C_f) (Salah *et al.*, 2012).

$$C_f = C_m \text{ Sample} / C_m \text{ Background}$$

Where: "C_m Sample" = concentration of the given metal in the sediment

"C_m Background" = the assessment of the metal represented mean shale concentration given by Martin and Meybeck (1979).

C_f is calculated in order to get a fair indication of the level of anthropogenic contamination and the build-up of heavy metals in sediments. C_f values for describing a particular level of contamination are indicated in Table 2.2.

Table 2.2: Contamination factor and Levels of contamination (Hakanson, 1980)

Contamination Factor (C_f)	**Levels of Contamination**
$C_f < 1$	Low concentration
$1 \leq C_f < 3$	Moderate concentration
$3 \leq C_f < 6$	Considerable concentration
$C_f > 6$	Very high concentration

2.7.2 Geo-Accumulation Index (I_{geo})

Müller's geochemical index (I_{geo}) is used to quantify the pollution intensities of heavy metals in sediments (Muller, 1979). In 1979, Müller proposed the I_{geo} and in 1981 he classified it. The I_{geo} evaluates the quantitative scale of pollution intensity. This happens as far as seven classes occur in view of the expansion in numerical estimations of the index. Table 2.3 gives a summary of Müller's characterisation for Geo-Accumulation (I_{geo}).

Table 2.3: Müller's characterisation for Geo-Accumulation (I_{geo})

(Uwah *et al.*, 2013)

Value Class	**Geo–Accumulation (I_{geo})**	**Sediment quality**
0	≤ 0	Unpolluted
1	0 – 1	Unpolluted to moderately polluted
2	1 – 2	Moderately polluted
3	2 – 3	Moderately polluted to strongly polluted
4	3 – 4	Strongly polluted
5	4 – 5	Strongly polluted to extremely polluted
6	> 6	Extremely polluted

The formula used to calculate I_{geo} is: $I_{geo} = \log_2 [(C_n) / (1.5 \text{ x } B_n)]$

Where: "C_n" is the measured concentration of the sediment for element or metal 'n' whereas "B_n" is the background concentration for element or metal 'n' (Turekian & Wedepohl, 1961).

The value 1.5 is the constant factor that considers regular changes of a given substance in the environment by natural fluctuations and additionally little anthropogenic impacts. It also represents conceivable variety in background data that might be as a result of terrigenous impacts.

2.7.3 Pollution Load Index (PLI)

Pollution Load Index (PLI) is generally used to define the contamination status of sediments.

The PLI for Sakumo, Chemu and Kpeshie lagoons was evaluated based on the equation below:

$$PLI = (C_f1 \text{ x } C_f2 \text{ x } C_f3 \text{ x } C_f4)^{1/n}$$

Where: “C_f” equals contamination factor and “n” stands for the number of metals.

PLI values > 1 indicates pollution whereas PLI < 1 shows no pollution (Seshan *et al.*, 2010).

CHAPTER THREE

3.0 MATERIALS AND METHODOLOGY

This chapter comprises research design, study area, chemicals and reagents, field study and sampling. Methods and other steps used for assessing elements or compounds under investigation are all stated in this chapter. Quality assurance and quality control measures taken to guarantee the consistency of analytical data are all described here.

3.1 Research Design

Heavy metals in water and sediment samples collected from Sakumo, Chemu and Kpeshie lagoons were determined by the use of atomic absorption spectrophotometer (AAS). Physicochemical parameters were determined in-situ with appropriate instruments. Pesticide residue contaminants suspected to be present were extracted by solid phase extraction (SPE) technique and analysed by gas chromatography (GC). Electron capture and pulse flame photometric detectors were used. Statistical analysis was done by the use of Statistical Package for Social Scientists (SPSS) v20.0 and Microsoft Excel 2013.

3.2 Study Area

The city of Accra exists 80 km west of the Volta River and is located within the coastal plains of Ghana. It engulfs a total land space of 2,054 km^2, covering the entire Accra Metropolitan Assembly (AMA) (1,520 km^2). The coastline of Ghana (550 km), which is part of the Gulf of Guinea, stretches from 3° W to 1^o 10' E and lies between 4^o 5' and 6^o 6' N. It is a low lying area; not more than 200 m above sea level and is subject to two wet seasons in a year - May to middle of June, which experiences heavy downpours and August to middle of November, where light downpours are experienced. Most of the coastline is fringed by coconut trees and also interspersed by lagoons and river estuaries (Mensah, 1979).

The Sakumo Ramsar site also called the Sakumo lagoon is a wetland of international significance. The Sakumo Ramsar wetland covers an area of 1,340 hectares (3,300 acres) and is located north of the coastal front street between the urban communities of Accra and Tema; around 3 km from Tema Township and due east of Accra, between Teshie-Nungua and Tema Township in the Greater Accra Region of Ghana. The lagoon is detached from the sea by a thin sand dune on which the Accra-Tema beach road is constructed. During the dry season (August to March), a bigger part of the lagoon dries up. The surge plain gets flooded occasionally. There are some areas covered with freshwater bog and coastal savanna grassland of different grass species. Monetary activities recognised along the lagoon include fishing, farming, industrial development and recreation (Koranteng, 2002; Marquette *et al.*, 2002). The area is infringed upon by cattle which graze in the dry season. The Sakumo wetland is the third most significant site for shorebirds on the coast of Ghana (Lawson, 2013).

The Kpeshie seepage bowl covers a moderately minor catchment area of roughly 110 km^2 and includes sand hill, open lagoon, damp grounds and scrublands. The Kpeshie lagoon is located at La peri-urban township just outside Accra. The Kpeshie lagoon lies on scope 5.566 with scope measurement of 5° 34' 0 N and longitude -0.133 with longitudinal measurement of 0° -8' 0 E. The lagoon is typically situated on a low lying plain i.e. between Whitller Baracks passageway, on the eastern side and the La-Trade Fair hall toward the west where it frames a damp zone. It is limited on the east by the Military Academy at Teshie, on the north by a line south of Madina and Adjiringanor. It covers the eastern part of Accra, Ridge, Cantonments, Osu, Labadi and Burma camp territories. The lagoon seems to be divided into two as a result of a bridge constructed across the lagoon with one portion mainly from the inner perimeter of the township and the other segment on the opposite side of the extension which joins the sea occasionally. There is another bit of the water body separated along the La Palm - Zenith College Street.

Due to late advancement, the wetland could be arranged into four areas. The first and second areas reach out from La Trade-Fair precinct to La Palm Royal Hotel and the third segment extends from Teshie town. The fourth section stretches out from Zenith College-Exopa path. Each of the four areas has different deltas leading into the lagoon. Sadly, the third and fourth segments have now become extinct because of contamination. In the past, the Kpeshie lagoon served as a remarkable fishing ground for the community of Kpeshie and other individuals outside the catchment territory (Ansah, 2006).

Chemu lagoon is a lagoon classified as class H (i.e. Hydrographic) in Ghana. It is located in Tema between coordinates 5° 37' 60" N and 0^{o} 1' 47.25" E in Degrees Minutes Seconds (DMS) or 5.63333 and 0.0166667 (in decimal degrees). It covers a territory of approximately 26 km^2 with various tributaries joining the main stream. The catchment zone has mangrove, fresh water channels, saltwater channels, and vegetation. Chemu lagoon which used to be a source of livelihood for the people of Tema and its surroundings, no longer serves that purpose due to the enormous level of pollution. As a result of industrial activities in the municipality, the lagoon has almost dried up. The once beautiful Chemu lagoon now has its banks engulfed with filth and industrial wastes. Aside the filth and industrial wastes, the banks of the lagoon have been taken over by slum dwellers (Ansah, 2006). Major industries such as Tema Oil Refinery (TOR), Unilever Ghana Limited (UNI), Kaysens Gaisie Ltd, and Frioghana Ltd are all located on the north of the lagoon (Doku, 2015; Ansah, 2006).

Maps showing sampling sites are represented in Figure 3.1 to Figure 3.3.

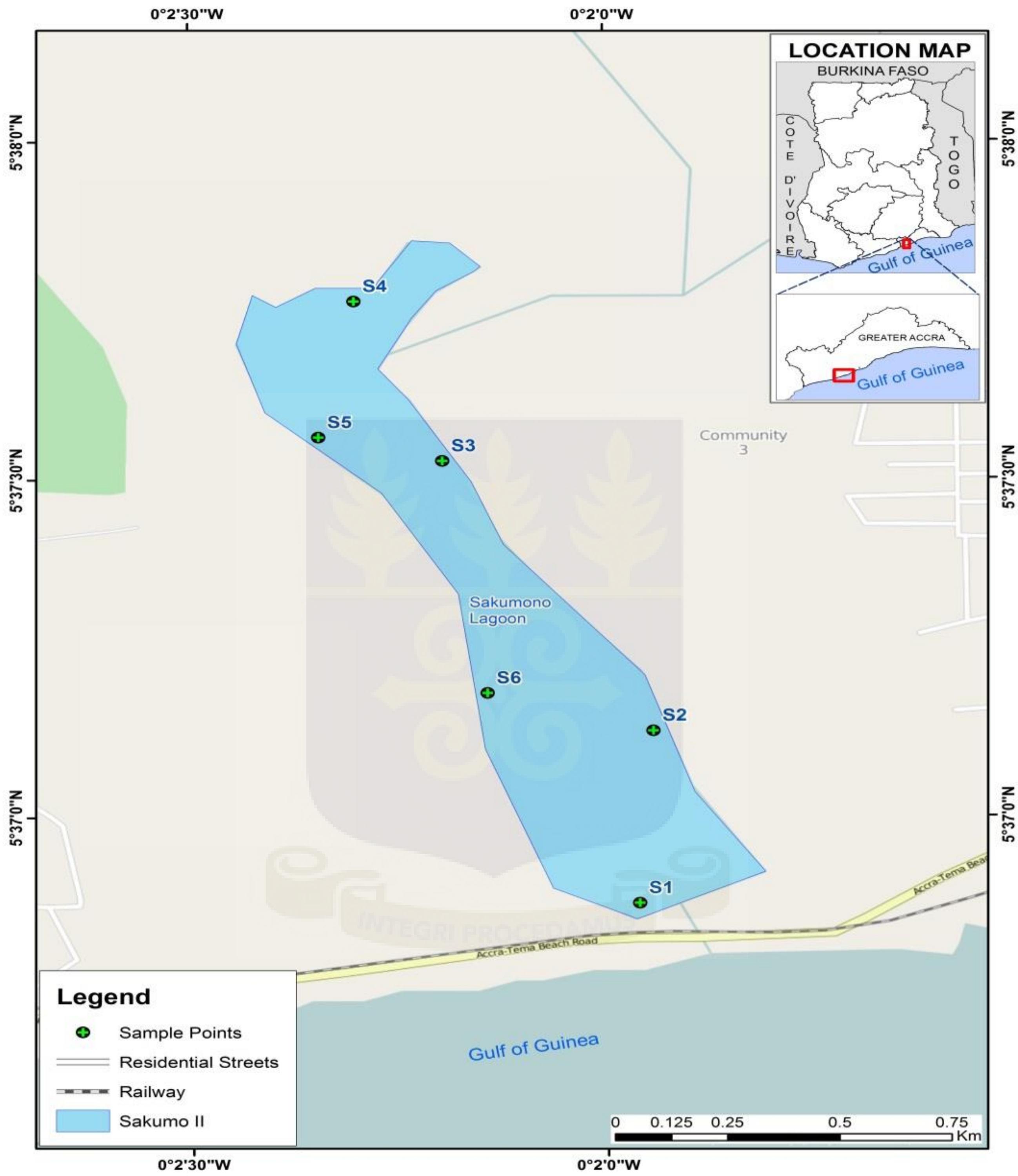


Figure 3.1: Map showing the catchment area of Sakumo lagoon

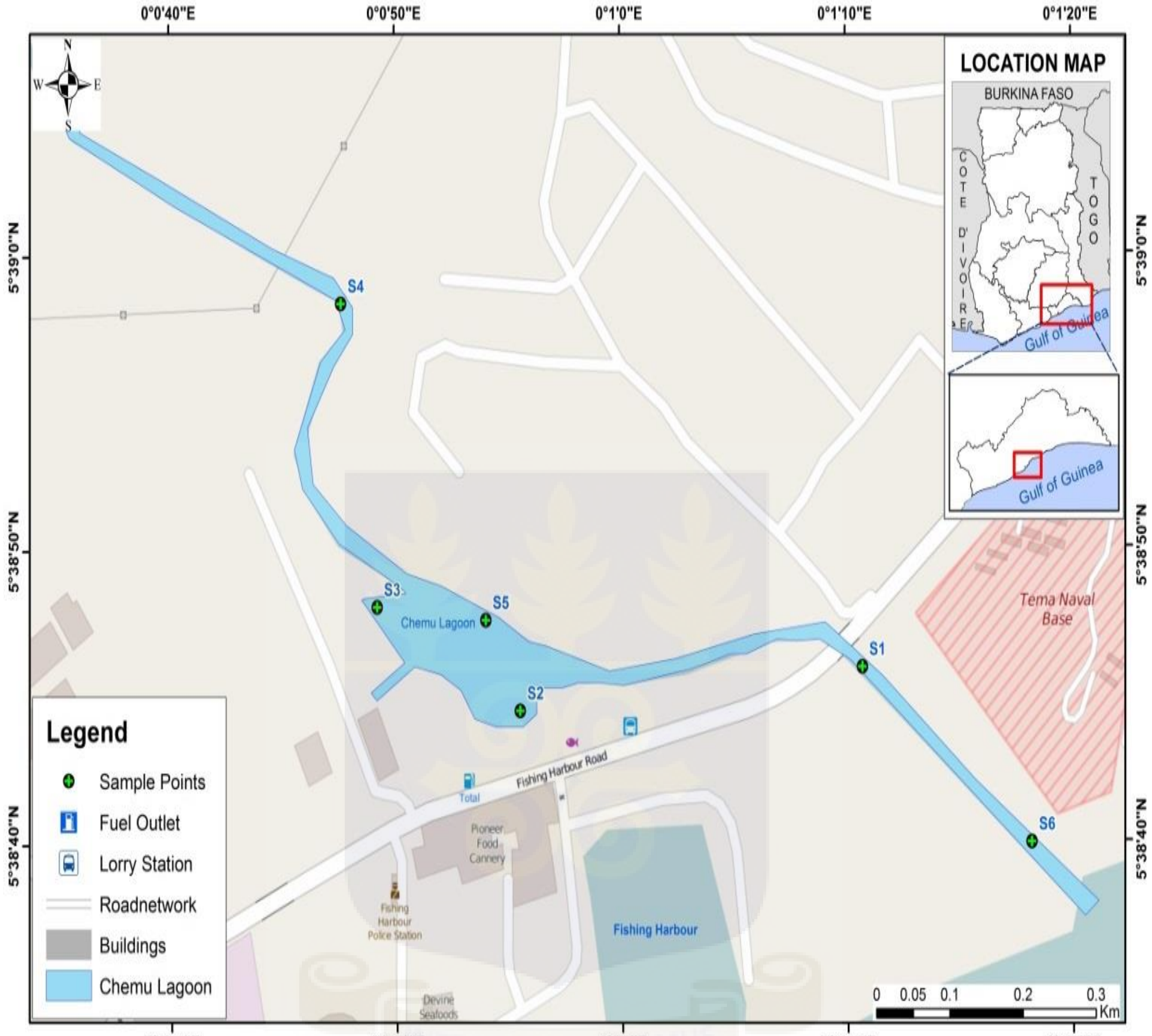


Figure 3.2: Map showing the catchment area of Chemu lagoon

Figure 3.3: Map showing the catchment area of Kpeshie lagoon

3.3 Chemicals and Reagents

The chemicals and reagents used were of analytical grade. The extraction solvents used were acetonitrile, dichloromethane and ethyl acetate. Acetonitrile was obtained from Van Waters and Rogers (VWR) International in the European Commission (EC). Dichloromethane was obtained from Merck KGaH in Germany. Ethyl acetate was obtained from Fisher Chemical in the United Kingdom. Polyethylene glycol, hydrochloric acid, sulfuric acid, vitamin C, hydrogen peroxide and nitric acid were obtained from British Drug Houses (BDH) Lab in England. Magnesium sulfate was obtained from Reagent Chemicals in Korea. Sodium sulfate and sodium chloride were obtained from Glassworld in South Africa. Reference standards used for trace metal analysis were from Fluka analytical, Sigma-Aldrich Chemie GmbH, in Switzerland. Pesticide residue standard mix used was from Dr. Ehrenstofer GmgH, Germany and it contained mixed organochlorine (OC), synthetic pyrethroid standard and mixed organophosphate (OP) standard. The silica used was from Agilent Band Elut, USA.

3.4.0 Field study and Sampling

3.4.1 Field study

A reconnaissance survey of the sites was conducted to assess the best possible areas for sampling. Six sampling sites were strategically chosen, taking into account their accessibility. During the survey, sampling schemes were mapped up for the study with the guide of a geographical positioning system (GPS) and Google maps.

Sakumo lagoon was picked as the control site since it is a Ramsar Site and thus a protected area. Designated sampling points were located and labeled strategically.

3.4.2 Sample containers and laboratory glass wares

High-density polyethylene (HDPE) bottles were used to take samples for physicochemical and heavy metal analysis. Amber glasses and plain glasses were used for taking samples for organic analysis. All the sampling containers and laboratory glass wares were pretreated by washing with warm water and detergent, after which they were rinsed with water followed by a second rinse with distilled water. They were then immersed in a 10% nitric acid solution for 48 hours and then thoroughly rinsed with distilled water before use (Carvalho *et al.*, 2007).

3.4.3 Sample collection

Sampling was performed wearing disposable nitrile gloves. Samples were taken from various points on the lagoons in order to get fairly representative specimens of each of the lagoons. Water and sediment specimens were collected simultaneously from Sakumo, Chemu and Kpeshie lagoons at six selected points. Sampling was done four times; once in every month from September, 2015 to October, 2015 and January, 2016 to February, 2016. Sampling was usually done during the first week of the selected sampling months. Samples collected between September, 2015 and October, 2015 were samples that represented the wet season and samples collected between January, 2016 and February, 2016 were samples that represented the dry season. Specimens were taken between the hours of 7:30 am and 11:30 am at the selected sampling sites.

With the aim of keeping the trace metals from being oxidised, one of the bottles was fixed with dilute nitric acid. Disposable nitrile gloves were used to prevent potential contamination from dermal contact, during the sampling operation. All samples were labeled and described on the field. After sampling, the samples were placed in a thermo-insulated container with some ice packs and then transported to the chemistry laboratory at Ghana Atomic Energy Commission (GAEC) and pesticide residue laboratory at Ghana Standards Authority (GSA) for processing and further analysis. At the laboratories, samples were stored at a temperature below 5 °C (APHA, 2005; APHA, 1992).

3.4.4.0 Sampling of water

3.4.4.1 Samples for physicochemical parameters, heavy metals and pesticide residues

Before sampling, the appropriate sampling bottles which were pretreated were rinsed three times with some of the respective lagoon water. The sampling bottles were then lowered under the water about 20 to 30 cm deep until they were filled completely with the lagoon water. They were then removed, capped and labeled immediately. Three replicate samples were collected at the same sampling point.

Physicochemical parameters such as pH, conductivity and TDS were determined in-situ.

pH

pH meter was used to measure the pH of the lagoon waters. The pH meter was first calibrated using pH buffer 4, 7 and 10, and the probe stored in 4M KCl saturated with AgCl for three hours prior to sampling. 100 mL of water was fetched into a beaker and the tip of the probe immersed into it. It was allowed to stabilise until stable pH readings nearest to 0.1 unit were recorded. The electrode was removed, rinsed with distilled water and wiped with a clean paper tissue before determining the pH of other lagoon water samples.

Electrical conductivity

Electrical conductivity was measured by the use of a conductivity meter model HACH (HI 8014) probe. It was first calibrated with a 0.1M KCl solution. The conductivity of the 0.1M KCl solution was set to 14.2 millisiemens/cm at 25 °C. The electrode was then removed and thoroughly rinsed with distilled water and wiped with a clean tissue paper before determining the conductivities of the lagoon water samples. Each reading was done three times (King *et al.*, 2002). The probe of the conductivity meter was all the time kept in distilled water.

Total Dissolved Solids

For the determination of total dissolved solids, an empty evaporating dish was cleaned and dried in an oven at a temperature of 103 to 105 °C. The dish was then weighed to a constant weight. 100 mL water sample was filtered through a 0.45 µm pore size filter paper. The filtrate was poured into the pretreated dish. The dish together with its content was heated at 103 to 105 °C until a constant weight was obtained. After heating, the dish was cooled in a desiccator. The difference in weight of the dish with its content and the empty dish was used to calculate for the total dissolved solids (APHA, 2005).

Total Suspended Solids

Total suspended solids were determined by first weighing a 0.45 µm pore size filter paper. Filtration apparatus together with the weighed filter paper was placed on a filter flask. 200 mL of lagoon water sample was mixed thoroughly and poured into a graduated cylinder. Suction was applied to the filter flask with the filter seated with a small amount of distilled water. 100 mL of the mixed sample was transferred into the filtration apparatus. The graduated cylinder was rinsed into the filtration apparatus with three successive 10 mL portions of distilled water. It was allowed to completely drain between each rinsing. After filtration of the final rinse was completed, suction was allowed to continue for three minutes. The filter together with the residue was dried in an oven at a temperature of 103 to 105 °C for about an hour. After drying, the filter paper was then cooled in a desiccator to room temperature. The filter together with the residue was then weighed and the total suspended solid recorded.

3.4.5 Sampling of Sediments

For the analyses of trace metals, sediments were collected by the use of a sterile 2 cm diameter polyvinylchloride (PVC) tube marked at 30 cm at one end. The length of the tube was supported with a metal rod and plunged into the sediments. Sediments were then collected into pretreated sampling bottles with the help of a pretreated and well washed spatula. Three samples were taken and consolidated to form a composite sample of roughly 150 g, and then labeled.

For the sediment samples used for the organic analyses, the PVC tube was wrapped with a pretreated aluminum foil before sampling. The sediment samples were placed in a thermo-insulated container with ice packs and afterward transported to the chemistry laboratory at GAEC and pesticide residue laboratory at GSA for processing and further analysis (APHA, 2005; APHA, 1992).

3.5.0 Research Facility, Statistical Procedures, Quality Control and Quality Assurance

Physicochemical parameters such as alkalinity, chloride, dissolved solids and total suspended solids were analysed for the water samples. The concentrations of copper (Cu), lead (Pb), iron (Fe), nickel (Ni), zinc (Zn), and manganese (Mn) in the water and sediment samples were determined by the use of Atomic Absorption Spectrophotometer (AAS).

The atomic absorption spectrophotometer used was VARIAN AA 240FS (Fast Sequential Atomic Absorption Spectrometer) fitted with a deuterium background corrector. Calibration of the atomic absorption spectrometer was done with the calibration standards for the elements being determined. Calibration curves for each of the elements were plotted with the absorbances obtained. Each element was determined by measuring the absorbances of the samples aspirated into the absorption cell after the calibration.

Plate 3.1 shows the AAS used and Table 3.1 gives the working conditions used.

Plate 3.1: VARIAN AA 240FS, AAS

Table 3.1: Working conditions for heavy metal analysis

ELEMENT	WAVELENGTH (nm)	LAMP CURRENT (mA)	SLIT WIDTH (nm)	FUEL	SUPPORT
Cu	327.4	4	0.5	Acetylene	Air
Fe	248.3	5	0.2	Acetylene	Air
Mn	279.5	5	0.2	Acetylene	Air
Ni	232.0	4	0.2	Acetylene	Air
Pb	217.0	5	1.0	Acetylene	Air
Zn	213.9	5	1.0	Acetylene	Air

Quality control and quality assurance

Quality control and quality assurance procedures were followed to ensure the accuracy of results. Reagents used were of analytical grade. Deionised and distilled water were also used in all the preparations of solution and cleaning of glass wares in the laboratory. The instrument setting and operational conditions were done as per the manufacturers' specifications. All analytical instruments used were calibrated fittingly, prior to measurement.

Sampling protocols were observed and followed to minimise and probably prevent contamination of samples. Triplicate analyses were done for every determination to minimise random error and ensure reproducibility. Each reported result was the average value of triplicate measurements. Standard Reference Materials (SRMs) used were treated as the samples themselves to check for efficiency of the equipment used and further validate the procedure.

Statistical Procedure

For the statistical procedure, calculations and statistical analyses were done using Microsoft Excel 2013 and Statistical Package for Social Scientists (SPSS) (v 20.0, SPSS Inc., Chicago, USA) softwares. These softwares were used to determine the mean, standard deviations and also plot graphs. A statistical model such as the Pearson correlation analysis was applied to the results to derive calibration curves and linearity of data. The paired sample t - test was used to determine whether there was any significant difference between the mean values obtained for the wet and dry seasons.

The results of the parameters obtained were compared with the WHO, USEPA and Ghana EPA standards for natural and effluent water.

Information relating to identity of instrument and apparatus used for multiresidue analysis are summarised in Table 3.2. Table 3.3 gives a summary of the chromatographic conditions used in the analysis of pesticide residues. Plate 3.2 shows images of the gas chromatograph used.

Table 3.2: Equipment and apparatus used for multiresidue analysis

Equipment	**Type**
Gas Chromatograph	Varian CP-3800 Gas Chromatograph with a Combi PAL Autosampler, Electron Capture Detector and Pulse Flame Photometric Detector
Analytical Column	30 m + 10 m EZ Guard x 0.25 mm internal diameter fused silica capillary coated with VF-5 ms (0.25 µm film) form Varian Inc. or equivalent 30 m x 0.25 mm internal diameter fused silica capillary coasted with VF-1701 ms (0.25 µm film) from Varian Inc. or equivalent
General Laboratory glassware	Separating flasks, Pear shape flasks, round bottom flasks and 10 mL bulb pipettes
Rotary film evaporator (RFE)	Bibby RE 200 and Buchi Rotavapor R-210
Horizontal Shaker	Ika-Werke HS 501 Digital
Ultrasonic baths	Clifton SW 3H and Grant XUB 18UK

Table 3.3: Chromatographic conditions for the analysis of pesticide residues

Apparatus:	
Instrument	**Description**
Gas Chromatograph	Varian CP-3800 GC-ECD with a Combi PAL Autosampler, Electron Capture Detector and Pulse Flame Photometric Detector
Analytical column	30 m + 10 m EZ Guard x 0.25 mm internal diameter fused silica capillary coated with VF -5 ms (0.25 µm film) from Varian Inc. or equivalent
Temperatures:	
Item	**Conditions**
Injector	Splitless mode, temperature 270 ^{o}C
Oven	70 ^{o}C / 2 min - 180 ^{o}C / 1 min - 300 ^{o}C
Detector – ECD	300 ^{o}C
Gases:	
Gas	**Flow rate**
Nitrogen (carrier)	1 mL/min constant flow
Make-up	29 mL/min

Plate 3.2: VARIAN CP-3800 GAS CHROMATOGRAPH

3.5.1.0 Preparation of Samples for Assaying through Atomic Absorption Spectrophotometry (AAS)

3.5.1.1 Water samples for heavy metal analyses

Digestion and analysis of heavy metals in water samples were done by the use of hot plate acid digestion method.

Water samples to be used for the determination of heavy metals were acidified by fixing with dilute sulfuric acid to a pH below 2.0 immediately after sampling (Eaton *et al.*, 2005).

In the laboratory, 40 mL of the water sample was poured in a 100 mL beaker. 5 mL of Aqua Regia in the ratio of 4.5 mL concentrated HCl to 0.5 mL concentrated HNO_3 was added to the water sample. This was done in a fume chamber. The beaker was covered with a cling film and placed on a hot plate and digested for 3 hours at 45 ^{o}C. After the acid digestion, the solution was allowed to cool to room temperature and filtered through a Whatman no. 42 filter paper into a 50 mL volumetric flask. It was then made up to the 50 mL mark with distilled water for the analysis of heavy metals (Cu, Pb, Fe, Ni, Zn and Mn). The solution was then transferred into a test tube for AAS analysis. Standard solutions ranging from 0.2 to 5.0 mg/L were prepared for the calibration curves of the various metals (APHA, 2005; APHA, 1992).

3.5.1.2 Sediment samples for heavy metal analyses

In the laboratory, organic debris and other unwanted materials were gloved-handpicked from the samples for heavy metal analysis. The sediment samples were air dried at room temperature in an open dust-free environment for twenty one days until consistent weights were observed. The air-dried sediment samples were ground in mortar and sieved using a 2 mm strainer to get rid of coarse particles. The fine powder sediment samples were stored in double-bagged polyethylene bags with hermetic seals. Aliquots of these samples were taken and then digested for the analysis while the rest of the samples were kept in refrigerators below 5 ^{o}C.

1.5 g of sediment sample was weighed in a beaker and acidified. 25 mL of Aqua Regia in the ratio of 1 mL concentrated HCl to 3 mL concentrated HNO_3 was added to the sediment sample. 0.25 mL of H_2O_2 was also added. This was done in a fume chamber. The beaker was covered with a cling film and placed on a hot plate and digested for 3 hours at 45 ^{o}C. After the acid digestion, similar steps were followed for the water digestion.

3.5.1.3 Calculation of concentration of AAS readings

The outcomes of atomic absorption spectrophotometer (AAS) readings are expressed in mg/kg dry weight for sediment samples and mg/L for water samples. The calibration curve for the analyte is used to compute the concentration of each analyte in the water and sediment samples. To get the rectified concentration, the value is multiplied by the dilution factor of the sample and divided by the underlying weight of the sample before digestion, to give the actual concentration of the analyte in the samples (Al-Weher, 2008).

For water samples: C_{sample} (mg/L) = $(C_{AAS} \text{ x } D_f \text{ x } V_N) / (W_S)$

For sediment samples: C_{sample} (mg/kg) = $(C_{AAS} \text{ x } D_f \text{ x } V_N) / (W_S)$

Where: C_{sample} = concentration of sample, C_{AAS} = concentration of analyte obtained from calibration regression line, D_f = dilution factor, V_N = nominal volume (mL) and W_S = weight of homogenised sample taken for digestion (g).

3.5.2.0 Preparation of Samples for Pesticide Residue Analysis through Gas Chromatography (GC)

3.5.2.1.0 Extraction of Pesticide Residue from Water Samples

After filtration of water sample through 0.45 µm Whatman filter paper, 1000 mL of water sample was poured into a 2 L capacity separatory funnel followed by the addition of 30 mL of saturated sodium chloride solution. The water sample was partitioned with 100 mL of dichloromethane (thrice) and at each time, the separatory funnel was vigorously shaken for three minutes and afterward, the pressure that built up was intermittently released. The layers were permitted to separate and the dichloromethane extract layer was drained.

The three extracts of dichloromethane layers were then combined and concentrated to about 2 mL by the use of a rotary vacuum evaporator for adsorption chromatography.

3.5.2.1.1 Purification of Extract using Silica Solid Phase Extraction (SPE) cartridge

A silica (1000 mg / 6 mL) cartridge which had 2 g layer of sodium sulfate on top was conditioned with 10 ± 0.2 mL of dichloromethane. 1 mL of the extract was loaded onto the cartridge. The elute was then collected into a 100 mL round-bottom flask. The column was eluted with 20 mL dichloromethane and the eluent concentrated. The concentrated eluent was dried by the use of a rotary evaporator below 40 ^{o}C. Care was taken not to make the concentrated eluent dry completely.

It was then re-dissolved by the addition of 1 mL ethyl acetate. The extract was then poured into a 2 mL standard opening vial for quantitation by GC. The concentrates were stored frozen until quantification was attained.

3.5.2.2.0 Sediment Samples for Pesticide Residue analysis

3.5.2.2.1 Specimen Preparation and Extraction

All stalks and stones that were in the sediment samples were removed after which the sample was homogenised. Appropriate representatives of sub-samples were taken for analysis.

10.0 ± 0.1 g of the homogenous sediment sample was weighed into a 100 mL separating flask. 10 mL of acetonitrile was added to it and the flask corked and sonicated for 5 min. After that, 10 mL acetonitrile was added again. The flask was then corked and set on a horizontal mechanical shaker. The shaker was adjusted to shake continuously for 45 minutes.

The mixture was made to stand for 10 min so that the layers separate. 10 mL which is equivalent to 5.0 g of the aliquot at the organic phase (top layer) was pipetted into a 50 mL round-bottom flask. It was then evaporated to about 2 mL at a temperature below 35 ^{o}C for extract purification. Care was taken not to make the extract dry.

3.5.2.2.2 Purification of Extract using Silica Solid Phase Extraction (SPE) cartridge

A silica (1000 mg / 6 mL) cartridge which had 1 cm thickness layer of anhydrous magnesium sulphate on top was conditioned with 10 ± 0.2 mL of acetonitrile. 2 mL of the extract was then loaded onto the cartridge and collected into a 50 mL pear-shaped flask.

The cartridge was eluted with 10 ± 0.2 mL of acetonitrile and the filtrate concentrated below 40 ^{o}C on a rotary evaporator just to dryness.

It was then re-dissolved by the addition of 1 mL ethyl acetate. The concentrate was then emptied into a 2 mL standard opening vial for quantitation by GC. The concentrates were stored frozen until quantification was completed.

3.5.2.2.3 Clean-up using Silica cartridge

A silica solid phase extraction cartridge, 1000 mg / 6 mL which had 2 g of $MgSO_4$ on top was conditioned with 6 ± 0.2 mL acetonitrile. A round-bottom flask was placed under the column to collect the elute. The extract was loaded onto the column and the column was eluted with 10 mL acetonitrile.

The filtrate was concentrated below 40 ^{o}C on a rotary evaporator just to dryness.

It was then re-dissolved by the addition of 1 mL ethyl acetate. The concentrate was then emptied into a 2 mL standard opening vial for quantitation by GC. The concentrates were stored frozen until quantification was done.

3.5.3 Analysis of Physicochemical Parameters

The lagoon water samples were first filtered through a 0.45 µm filter membrane, before any work was done for all physicochemical parameters.

Physicochemical parameters such as phosphate and nitrate determination were done by the use of UV/VIS Spectrophotometry and chloride determination was done by argentometric titration. Conductivity, total dissolved solids (TDS), total suspended solids (TSS), alkalinity concentrations were all determined by standard methods proposed by APHA, 2005; APHA, 1992; and H. Company, 1992.

Phosphate Determination

Approximately 0.0225 g of potassium-antimonyl tartrate and 1.875 g of ammonium molybdate were weighed into a 250 mL volumetric flask. 22 mL of concentrated sulfuric acid was then added. The volume was made up to the mark with distilled water. A 0.1M ascorbic acid was prepared by dissolving 1.76 g of the salt in 100 mL of distilled water. The molybdate antomonyl reagent and the ascorbic acid were added in the ratio 1:4. This mixture was referred to as the combined reagent.

About 0.6805 g of K_2HPO_4 was dissolved in 1 L (50 mg/L) volumetric flask. A series of standards in the range of 0.2, 0.4, 0.6, 0.8 and 1.0 mg/L were prepared from the K_2HPO_4 solution. 2 mL of the combined reagent was added to 20 mL of the sample and standards, and allowed to stand for about 10 to 15 minutes. The absorbance was then read at 880 nm using a 1 cm cell in a UV spectrophotometer. The concentration of phosphate in the sample was read from the calibration curve.

Nitrate Determination

For nitrate determination, a stock solution (100 mg/L NO_3-N) was prepared by dissolving approximately 0.7218 g of anhydrous potassium nitrate (KNO_3) in distilled water and diluted to 1 L in a volumetric flask. 2 mL chloroform was added to preserve the solution. An intermediate nitrate solution was prepared by diluting 10 mL of the stock solution in 1 L (10 mg/L) volumetric flask. From this solution, a series of NO_3-N calibration standards in the range 0.2, 0.4, 0.6, 0.8 and 1.0 mg/L were prepared.

20 mL of the water sample was pipetted into a test tube. 2 mL of 30 % (W/W) sodium chloride solution was then added to the water sample in the test tube. 10.0 mL of sulfuric acid solution was poured into each test tube and mixed thoroughly by swirling. The samples were allowed to come to thermal equilibrium in a cold bath. 0.5 mL brucine-sulfanilic acid reagent was then added to the sample in the test tube and carefully mixed by swirling. The solution was then heated in a water bath for exactly 25 minutes at 100 °C. The same procedure was followed for the standards and blanks except that, the brucine-sulfanilic reagent was not added to the blank. This is because the brucine-sulfanilic reagent gives a yellow colour as indication of the presence

of nitrate. The tubes were removed from the hot water bath and immersed in a cold water bath and allowed to reach thermal equilibrium (20 - 25 °C). The absorbance was read at 410 nm using a 1 cm cell in a UV spectrophotometer. The concentration of nitrate in the sample was then read from the calibration curve.

Chloride Determination

Chloride determination was done by the use of the Mohr Argentometric titration method. 20 mL of the water sample was measured into a 250 mL conical flask. 2 drops of 5 % potassium dichromate indicator was added to the contents of the flask. The content was then swirled to obtain a uniform mixture after which it was titrated against standardised silver nitrate solution. It was stirred constantly till a pinkish yellow colour end-point was obtained. The volume of the titre was recorded. Distilled water was used as the blank.

Calculation:

$$\text{Chloride (mg/L)} = [(A - B) \times M \times 35.45 \times 1000] / \text{Volume of sample (mL)}$$

Where; A = Volume of silver nitrate consumed by sample, B = Volume of silver nitrate consumed by blank, M = Molarity of silver nitrate and 35.45 = Atomic weight of chlorine

Alkalinity

20 mL of the water sample was pipetted into a round-bottom flask. Two drops of methyl orange was added as an indicator to the content in the round-bottom flask. The resulting solution was well-swirled and titrated with 0.01M HCl solution till a pale pink end-point was observed. The alkalinity of the water sample in mg $CaCO_3$/L was computed by the formula below:

$$\text{Alkalinity as mg } CaCO_3/L = [A \times M \times 50 \times 1000] / \text{Volume of water sample (mL)}$$

Where: A = volume of acid used (mL), M = Molarity of standard acid used and 50 = equivalence of $CaCO_3$.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

The results obtained from the field and laboratory analyses of water and sediment samples from Sakumo, Chemu and Kpeshie lagoons are shown in the form of tables and figures in this chapter. The parameters studied are categorised into the wet and dry seasons to ascertain the seasonal variations. The results are also compared with their respective World Health Organisation (WHO), Environmental Protection Agency (EPA), Ghana and United States Environmental Protection Agency (USEPA) recommended limits.

4.1.0 Paired Sample T-Test, Physicochemical Parameters and Nutrient Load of Water

4.1.1 Paired Sample T-Test

A paired sample t-test which is sometimes called the dependent sample t-test is a statistical procedure used to determine whether the mean difference between two sets of observations is set to zero.

A paired sample t-test was conducted on the data to compare the means of the parameters analysed in the wet and dry seasons. The mean values of the physicochemical parameters and concentration of heavy metals in water and sediment samples were set as paired variables with the confidence interval set at 95%.

From the results obtained in Tables 4.13 to 4.15, it was observed that the p values obtained from the various lagoons were all less than 0.050. The p values recorded were $0.000 \leq p \leq 0.033$ for Sakumo, $p = 0.000$ for Chemu, and $0.000 \leq p \leq 0.001$ for Kpeshie.

These results indicate that there are significant differences in the mean values obtained for the wet and dry seasons, hence the data has to be analysed separately for each season.

4.1.2.0 Physicochemical Parameters

The results obtained during the determination of physicochemical parameters of water from Sakumo, Chemu and Kpeshie lagoons are presented in Tables 4.1 to 4.3.

Table 4.1: Physicochemical parameters for water samples from Sakumo Lagoon (Wet & Dry Seasons)

Sakumo Lagoon

Parameters	Wet Season				Dry Season			
	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation
pH	8.65	9.08	8.84	0.18	7.32	7.74	7.48	0.18
Conductivity (µS/cm)	23637	25359	24265	610	27846	29199	28626	509
Total Dissolved Solids (mg/L)	15364	16483	15772	397	18099	18979	18607	331
Total Suspended Solids (mg/L)	59.03	60.33	59.47	0.52	40.60	42.19	41.55	0.56
Alkalinity (mg/L)	1007	1079	1038	29	739	756	745	7
Chloride (mg/L)	8924	9354	9156	158	7894	8631	8233	284
Phosphate (mg/L)	2.68	2.84	2.73	0.06	4.66	5.02	4.83	0.14
Nitrate (mg/L)	34.10	34.79	34.48	0.29	21.60	22.19	21.93	0.23

Table 4.2: Physicochemical parameters for water samples from Chemu Lagoon (Wet & Dry Seasons)

Chemu Lagoon

Parameters	Wet Season				Dry Season			
	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation
pH	9.17	10.64	9.91	0.49	8.11	8.78	8.43	0.24
Conductivity (µS/cm)	17645	19031	18510	482	20291	22053	20939	655
Total Dissolved Solids (mg/L)	11469	12370	12031	313	13189	14334	13610	426
Total Suspended Solids (mg/L)	159.59	162.33	161.07	0.90	129.87	131.61	130.77	0.78
Alkalinity (mg/L)	1473	1533	1502	21	1178	1278	1236	35
Chloride (mg/L)	5890	6086	5982	78	5414	5572	5485	61
Phosphate (mg/L)	5.87	6.11	6.00	0.08	9.97	10.19	10.11	0.09
Nitrate (mg/L)	102.89	103.94	103.30	0.39	77.00	78.09	77.51	0.38

Table 4.3: Physicochemical parameters for water samples from Kpeshie Lagoon (Wet & Dry Seasons)

Kpeshie Lagoon

Parameters	Wet Season				Dry Season			
	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation
pH	8.97	9.81	9.36	0.30	7.92	8.23	8.11	0.11
Conductivity (µS/cm)	21992	23001	22578	456	25310	27477	26696	850
Total Dissolved Solids (mg/L)	14295	14950	14676	297	16451	17860	17352	553
Total Suspended Solids (mg/L)	129.98	132.00	131.02	0.68	101.83	103.26	102.56	0.55
Alkalinity (mg/L)	1197	1222	1208	8	984	1071	1028	31
Chloride (mg/L)	6733	6983	6870	88	6311	6381	6353	29
Phosphate (mg/L)	5.85	6.08	5.98	0.08	7.98	8.19	8.08	0.09
Nitrate (mg/L)	86.87	88.16	87.59	0.48	46.19	47.23	46.64	0.35

4.1.2.1 pH

The pH of a solution is a measure of the concentration of hydrogen ions in the solution. It is also a measure of how acidic or basic a solution is. The pH range of natural water often falls between 4 and 9 (Amankona, 2010).

The results obtained from the pH analyses are shown in Table 4.1 to Table 4.3 and Figure 4.1.

The pH levels ranged from 8.65 to 9.08, 9.17 to 10.64 and 8.97 to 9.81 for Sakumo, Chemu and Kpeshie lagoons respectively in the wet season. In the dry season, the pH ranged between 7.32 and 7.74, 8.11 and 8.78, and 7.92 and 8.23 for Sakumo, Chemu and Kpeshie lagoons respectively.

It can be observed from Figure 4.1 that generally, the pH values were higher in the wet season compared with the pH values recorded during the dry season. This could be due to run-off from nearby industries and waste from human activities within the environs. The mean pH values recorded during the wet and dry seasons for Sakumo lagoon were within the WHO range of 6 to 9. The pH values recorded in the dry season for both Chemu and Kpeshie lagoons were within the WHO range except for their respective pH values recorded within the wet season.

During the wet season, the mean pH values of Chemu and Kpeshie lagoons were 9.91 ± 0.49 and 9.36 ± 0.30 respectively. The overall mean pH values of water samples from Sakumo, Chemu and Kpeshie lagoons were 8.16 ± 0.18, 9.17 ± 0.37 and 8.74 ± 0.21 respectively, indicating the order of pH to be Chemu > Kpeshie > Sakumo. pH for Sakumo, Chemu and Kpeshie lagoons were generally high. The results indicate that the lagoons were alkaline in nature. This agrees with the observation that most coastal lagoons in Ghana are slightly alkaline (Biney, 1990). The general alkalinity of Sakumo, Chemu and Kpeshie lagoons is partly due to the influence of the seawater (Karikari *et al.*, 2009).

4.1.2.2 Electrical Conductivity (EC)

The ability of a solution to carry electric current is defined as conductivity. Conductivity is normally dependent on the presence of dissolved ions. Inorganic compounds, bases, and salts are good conductors while organic compounds are poor conductors.

Table 4.1 to Table 4.3 and Figure 4.2 show the results of conductivity obtained from the analyses. The results show that, electrical conductivity in water samples was higher than the WHO limit of 2500 µS/cm. The conductivity values of water samples from Sakumo lagoon ranged from 23637 to 25359 µS/cm and 27846 to 29199 µS/cm for the wet and dry seasons respectively. Conductivity values of water sample from Chemu lagoon ranged between 17645 and 19031 µS/cm, and 20291 and 22053 µS/cm for the wet and dry seasons respectively while the conductivity values of water samples from Kpeshie lagoon during the wet and dry seasons varied from 20291 to 22053 µS/cm and 25310 to 27477 µS/cm respectively. The overall mean conductivity values of water samples from Sakumo, Chemu and Kpeshie lagoons were 26446 ± 560 µS/cm, 19725 ± 569 µS/cm and 24637 ± 653 µS/cm respectively. This observation corresponds with work done by Addo *et al.* (2011). High conductivity is also a reflection of high salinity of water in decreasing order of Sakumo lagoon, Kpeshie lagoon and Chemu lagoon (Sakumo lagoon > Kpeshie lagoon > Chemu lagoon).

Electrical conductivity in the lagoons was noted to be higher in the dry season than in the wet season (Figure 4.2). This could be due to the fact that there was a reduction in the volume of water in the lagoons during the dry season because of evaporation at the water surface. This may have resulted in the concentration of ions in the lagoons. Electrical conductivity values were generally high in all the lagoons. The cause of high electrical conductivity in the lagoons may be traced to the geology of the lagoons and run-off from land use activities (e.g. construction, dump sites, landfills) around the lagoons. The nature of Sakumo, Chemu and Kpeshie lagoons are such that they are close to the Gulf of Guinea, hence, the periodic mixture of the sea and lagoons might be the cause of the general increase in electrical conductivity of the lagoons. All the above factors could cause an increase in the concentration of ions in the lagoons, thus, leading to an exponential increase in electrical conductivity of the lagoons. The order of conductivity is indicated to be Sakumo > Kpeshie > Chemu. This shows the greater interaction Sakumo lagoon has with the sea compared with Kpeshie and Chemu lagoons.

4.1.2.3 Total Dissolved Solids (TDS) and Total Suspended Solids (TSS)

TDS is referred to as the sum of all the minerals dissolved in water. These materials include bicarbonates, carbonates, chlorides, phosphates, sulphates and possibly nitrates of sodium, calcium, potassium, and magnesium, which might be accompanied by traces of manganese and iron. TSS of water is the dry-weight of particles that have been trapped during filtration processes. TSS of water is determined by carefully pouring a measured volume of water through a pre-weighed filter paper, and weighing the filter paper again after drying, to remove all the water (Rhoades *et al.*, 1996).

The results obtained from the TDS and TSS analyses are shown in Table 4.1 to Table 4.3 and Figure 4.3 and Figure 4.4.

From Table 4.1 to 4.3, the TDS of water samples from Sakumo, Chemu and Kpeshie lagoons ranged from 15364 to 16483 mg/L, 11469 to 12370 mg/L and 14295 to 14950 mg/L respectively in the wet season and 18099 to 18979 mg/L, 13189 to 14334 mg/L and 16451 to 17860 mg/L respectively in the dry season. All the mean TDS values recorded were above the WHO limit of 5000 mg/L. It was observed that, the TDS of the water samples were higher in the dry season than in the wet season from Figure 4.3. Decrease in the volume of water due to evaporation on the surface of the water during the dry season could be the reason for the relatively high TDS values in the dry season compared with that of wet season.

Also, from Table 4.1 to 4.3, the TSS of water samples from Sakumo, Chemu and Kpeshie lagoons ranged between 59.03 and 60.33 mg/L, 159.59 and 162.23 mg/L, and 129.98 and 132.00 mg/L respectively in the wet season. TSS ranged from 40.60 to 42.19 mg/L, 129.87 to 131.61 mg/L and 101.83 to 103.26 mg/L for Sakumo, Chemu and Kpeshie lagoons respectively during the dry season. It can be observed from Figure 4.4 that the total suspended solids (TSS) of the water samples were higher in the wet season than in the dry season. Suspended solids in lagoons are often the result of sediments carried by water whose source include natural and anthropogenic activities in the water shed. Examples of such activities are natural or excessive soil erosion from agriculture, construction, urban run-off and industrial effluents (Kolawole *et al.*, 2011).

High levels of TSS are not suitable for aquatic life. This is because the suspended particles might prevent sunlight from reaching plants for photosynthesis resulting in the depletion of oxygen in the lagoons. High TSS in lagoons may result in the loss of fish biodiversity (Armah & Amlalo, 1998). The mean values of TSS for Chemu (145.92 ± 0.84 mg/L) and Kpeshie (116.79 ± 0.62 mg/L) lagoons were all above the EPA guideline value of 75 mg/L but the mean value of TSS of Sakumo lagoon (50.51 ± 0.54 mg/L) was below the EPA limit. The presence of TSS in lagoons, even in small amounts highlights the impact of industrial effluents in close proximity. This is made evident by the number of industries surrounding the Chemu lagoon.

The significantly high TSS of the water samples from Sakumo, Chemu and Kpeshie lagoons are indicative of pollution in the order Chemu > Kpeshie > Sakumo.

4.1.2.4 Alkalinity

Alkalinity is the measure of the buffering capacity of water – its ability to resist changes in pH. The main species accountable for alkalinity are carbonates, bicarbonates, ammonia, hydroxide ions, and organic acids (Meybeck *et al.*, 1992). Borates, phosphates and silicates also contribute to alkalinity. Limestone is also rich in carbonates, thus, water that flows through limestone bedrocks or regions usually have high alkalinity.

The results obtained from the alkalinity analyses are shown in Tables 4.1 to 4.3 and Figure 4.5.

From Tables 4.1 to 4.3, the levels of alkalinity ranged between 1007 and 1079 mg/L, 1473 and 1533 mg/L, and 1197 and 1222 mg/L for Sakumo, Chemu and Kpeshie lagoons respectively in the wet season. In the dry season, the alkalinity ranged from 739 to 756 mg/L, 1178 to 1278 mg/L and 984 to 1071 mg/L for Sakumo, Chemu and Kpeshie lagoons respectively.

It can be observed from Figure 4.5 that generally, alkalinity was high in the wet season compared with alkalinity during the dry season. High alkalinity levels in the water might have been influenced by the processes of weathering of the underlying rocks and run-off which could have picked up contaminants such as pesticides, fertilisers or petroleum (Fianko *et al.*, 2013). High alkalinity values above 500 mg/L are often associated with high pH values, hardness and increasing dissolved solids.

The mean alkalinity values recorded from all the sampling sites were above the WHO limit of 500 mg/L, that is, Sakumo (891.50 ± 18.00 mg/L), Chemu (1369 ± 28.00 mg/L) and Kpeshie (1118 ± 19.50 mg/L). These results correspond with work done by Addo *et al.* (2011).

4.1.2.5 Chloride (Cl^-)

Chloride is present in all ground water and natural surface water. Chlorides mainly come from inorganic salts such as $CaCl_2$, KCl, and NaCl. (Murhekar, 2011; Meybeck *et al.*, 1992). Chlorides are harmless to humans but at some high levels, they become harmful to life (Abulude *et al.*, 2006). High concentrations of chloride increase the corrosive property of water.

The chloride content of the water sampled from Sakumo, Chemu and Kpeshie lagoons were analysed using the Mohr Argentometric titration method and the mean results are summarised in Table 4.1 to Table 4.3 and Figure 4.6.

The Cl^- values of water samples from Sakumo lagoon ranged from 8924 to 9354 mg/L and 7894 to 8631 mg/L for the wet and dry seasons respectively. Cl^- values of water sample from Chemu lagoon varied from 5890 to 6086 mg/L and 5414 to 5572 mg/L for the wet and dry seasons respectively while the Cl^- values of water samples from Kpeshie lagoon during the wet and dry seasons were between 6733 and 6983 mg/L, and 6311 and 6381 mg/L respectively.

It can be observed from Figure 4.6 that the Cl^- contents were generally higher than the EPA limit of 5000 mg/L. This might be due to sea water intrusion as a result of the proximity of the lagoons to the sea. Cl^- values recorded in Sakumo lagoon was the highest, followed by Kpeshie lagoon and then Chemu lagoon. The wet season recorded the highest Cl^- values in order of Sakumo > Kpeshie > Chemu. The high Cl^- values recorded for Sakumo lagoon compared with that of Kpeshie and Chemu lagoons could be due to the free flow that occurs between the lagoon and the sea. This is mainly because of the relatively low amount of pollutants and the larger area mass occupied by the Sakumo lagoon. The high chloride content in Sakumo lagoon is evident in the corrosion caused by the lagoon on the rail-way built along the Sakumono high way.

Too much waste has been dumped into the Chemu lagoon causing the gradual siltation of the lagoon and reduction in the area mass of the lagoon. As a result, the interaction that occurs between Chemu lagoon and the sea is very minimal.

4.1.3.0 Nutrient load of water

Nitrates and phosphates are the nutrients measured in the water samples.

4.1.3.1 Nitrate (NO_3^-)

Nitrates are vital indications of biological pollution in natural water. The main nutrient that accelerates the growth of algae and hydrophytes in water is the inorganic nitrogen present in water as Nitrate (NO_3^-). Nitrate occurs in water from various natural sources and is also the result of human activities. Some of the human activities are agricultural practices, disposal of domestic and industrial sewage and dumping of refuse (Kuzelka & Ennenga, 2013; Murhekar, 2011). Nitrate stimulates growth of phytoplankton and hydrophytes that consequently increase the nutrient in a water body leading to eutrophication.

Table 4.1 to Table 4.3 indicate that NO_3^- values of water samples from Sakumo lagoon ranged from 34.10 to 34.79 mg/L and 21.60 to 22.19 mg/L for the wet and dry seasons respectively. NO_3^- values of water samples from Chemu lagoon varied from 102.89 to 103.94 mg/L and 77.00 to 78.09 mg/L for the wet and dry seasons respectively while the NO_3^- values of water samples from Kpeshie lagoon during the wet and dry seasons were between 86.87 and 88.16 mg/L, and 46.19 and 47.23 mg/L respectively (Table 4.1 to Table 4.3). This corresponds to work done by Ansa-Asare *et al.* (2009). From Figure 4.7, NO_3^- levels in Chemu lagoon were higher compared with those of Kpeshie and Sakumo lagoons. It was also observed that the nitrate values were higher in the wet season than the dry season. This conforms to work done by Nartey *et al.* (2012). The relatively higher nitrate values recorded in the wet season could be due to the fact that there was rapid mixture of sub-surface and surface water during the rainy season. This might have favoured the nitrate replenishment mechanism and the rapid replenishment of nitrate from the surficial biogenic sediments as a consequence of microbial activities (Nayak & Behera, 2004).

Again, arable farming is a vigorous enterprise in the catchment areas of the lagoons. It is very likely that the use of fertilisers and pesticides in farming activities could leave left residues that were transported by run-off into the lagoons during the rainy season.

4.1.3.2 Phosphate (PO_4^{3-})

Phosphorous is a limiting nutrient for algal growth and thus controls the primary productivity of a water body (Karikari *et al.*, 2007). Phosphorous is an essential nutrient and an indicator of anthropogenic biological pollution (Addo *et al.*, 2011). Phosphate may occur in surface water as a result of domestic wastes, detergent and agricultural run-off containing fertiliser (Kolawole *et al.*, 2011; Murhekar, 2011).

As represented in Tables 4.1 to 4.3, the PO_4^{3-} values of water samples from Sakumo lagoon ranged from 2.68 to 2.84 mg/L and 4.66 to 5.02 mg/L for the wet and dry seasons respectively. PO_4^{3-} values of water sample from Chemu lagoon ranged between 5.87 and 6.11 mg/L, and 9.97 and 10.19 mg/L for the wet and dry seasons respectively while the PO_4^{3-} of water samples from Kpeshie lagoon during the wet and dry seasons ranged from 5.85 to 6.08 mg/L and 7.98 to 8.19 mg/L respectively (Tables 4.1 to 4.3). The mean phosphate values of Sakumo, Chemu and Kpeshie lagoons exceeded the EPA maximum guideline value of 2.0 mg/L for total phosphorus. This indicates that, the three lagoons were all polluted with phosphate and it is clearly seen in Figure

4.8. During the dry season, high phosphate values were recorded in the study period compared with the wet season. This situation may possibly be due to the lower volume of water in the lagoons during the dry season, resulting in increased concentration of the nutrients and ions in water. This is comparable to work done by Nartey *et al.* (2012). The high levels of phosphate in Sakumo lagoon might be caused by the wide green vegetation found in some sections of the Ramsar site while the high levels of phosphate in Chemu and Kpeshie lagoons may be due to run-off from domestic wastes, detergents and agricultural fertiliser. The high concentrations of phosphate in Sakumo, Chemu and Kpeshie lagoons may have the potential of causing eutrophication thereby reducing the level of oxygen in the lagoons needed by aquatic organisms, especially fish, for respiration (Fianko *et al.*, 2013).

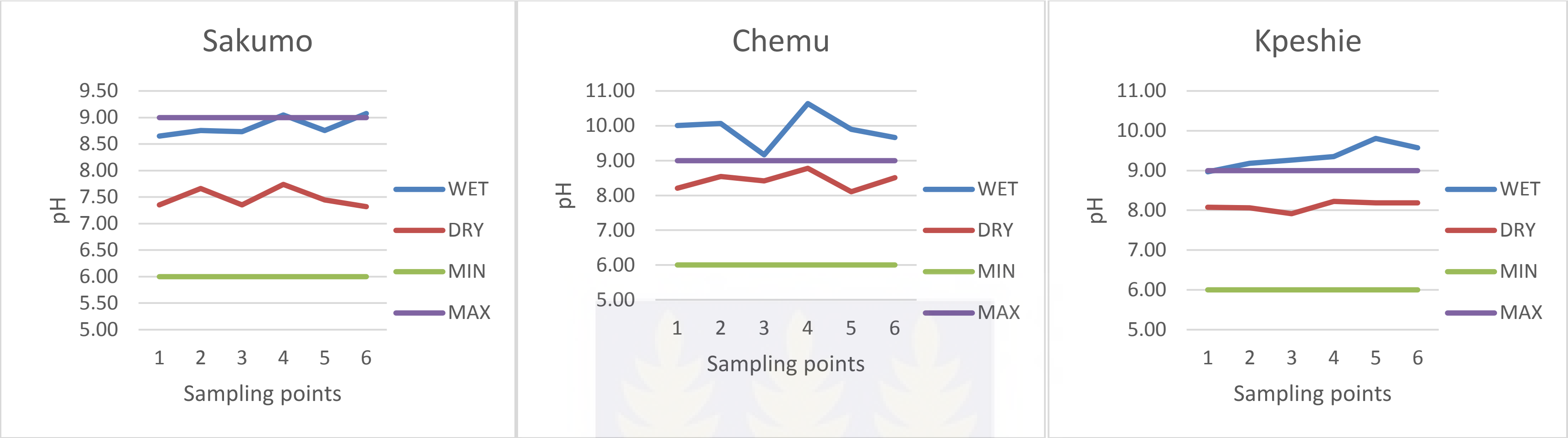


Figure 4.1: Seasonal variations of pH in water samples from Sakumo, Chemu and Kpeshie lagoons

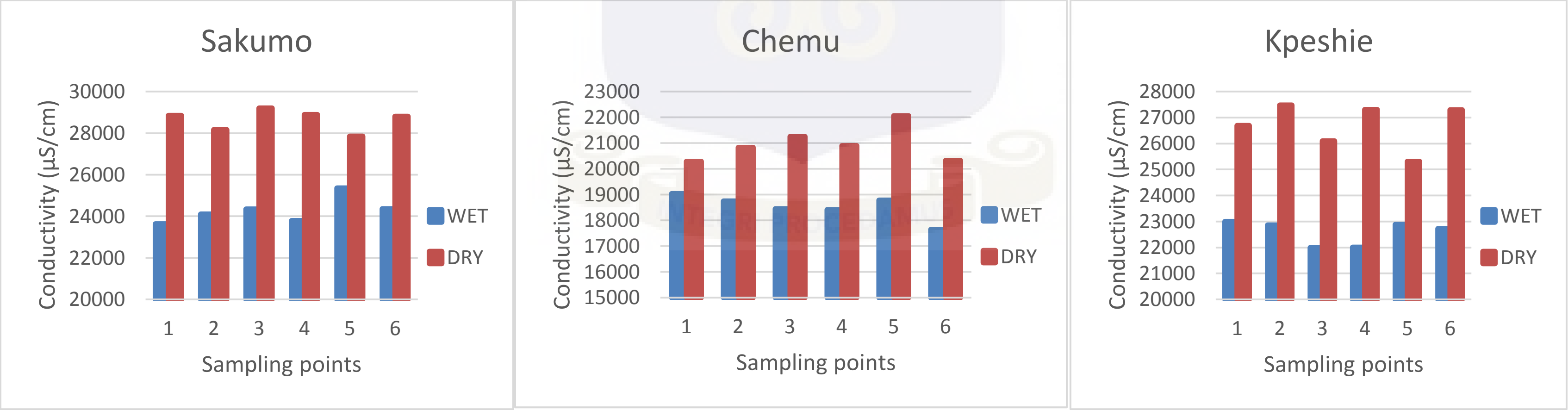


Figure 4.2: Seasonal variations of conductivity in water samples from Sakumo, Chemu and Kpeshie lagoons

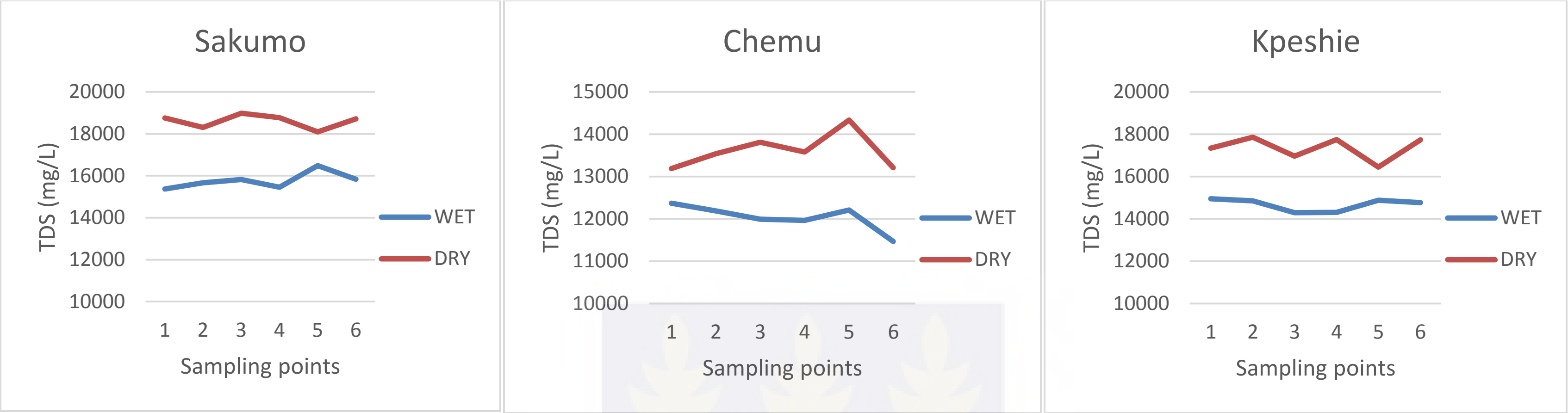


Figure 4.3: Seasonal variations of TDS in water samples from Sakumo, Chemu and Kpeshie lagoons

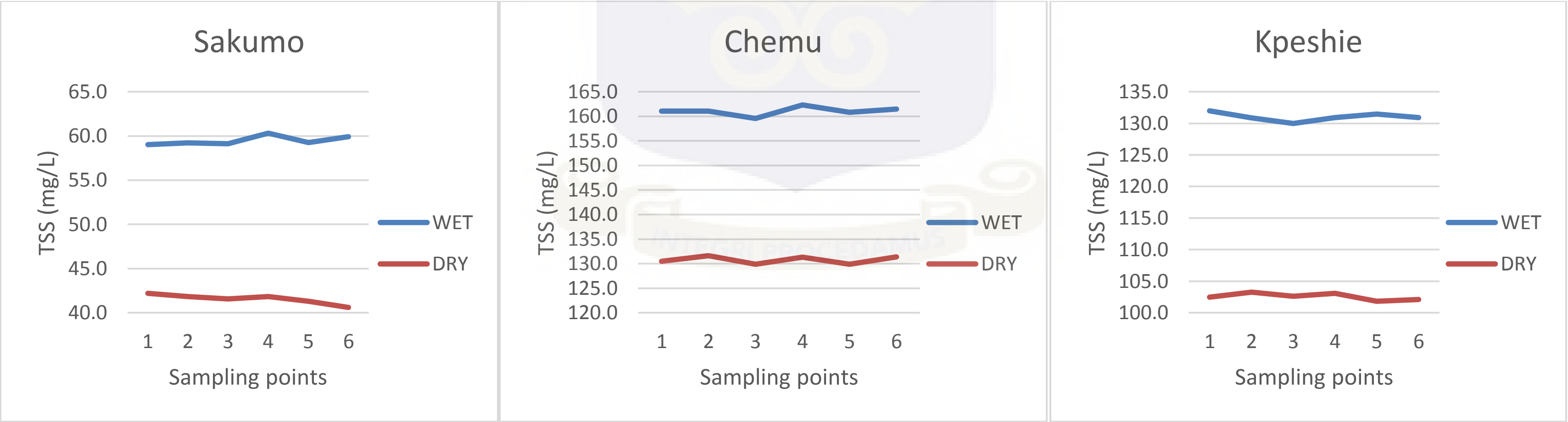


Figure 4.4: Seasonal variations of TSS in water samples from Sakumo, Chemu and Kpeshie lagoons

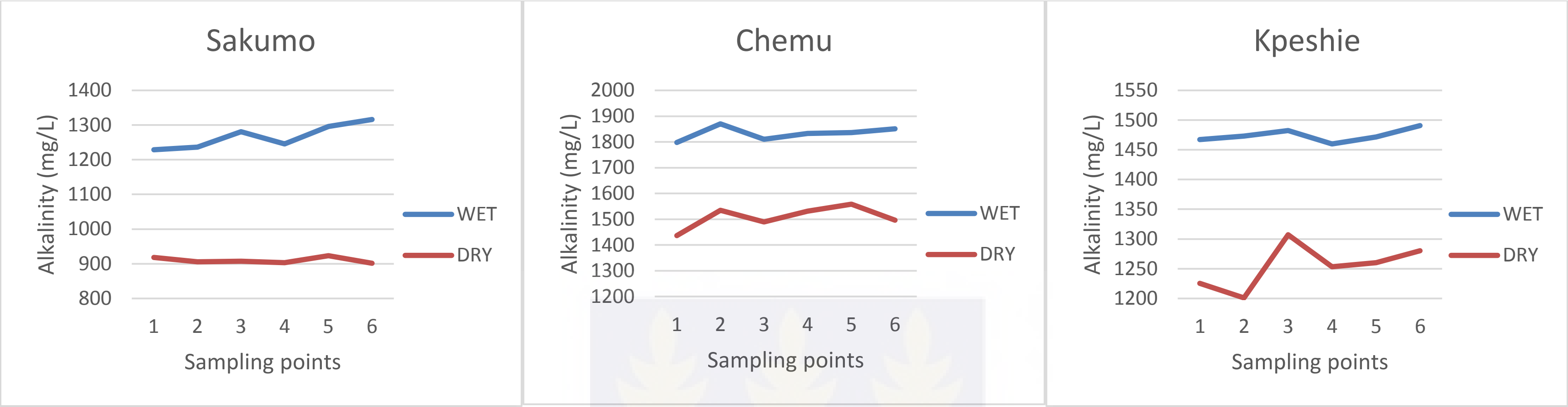


Figure 4.5: Seasonal variations of alkalinity in water samples from Sakumo, Chemu and Kpeshie lagoons

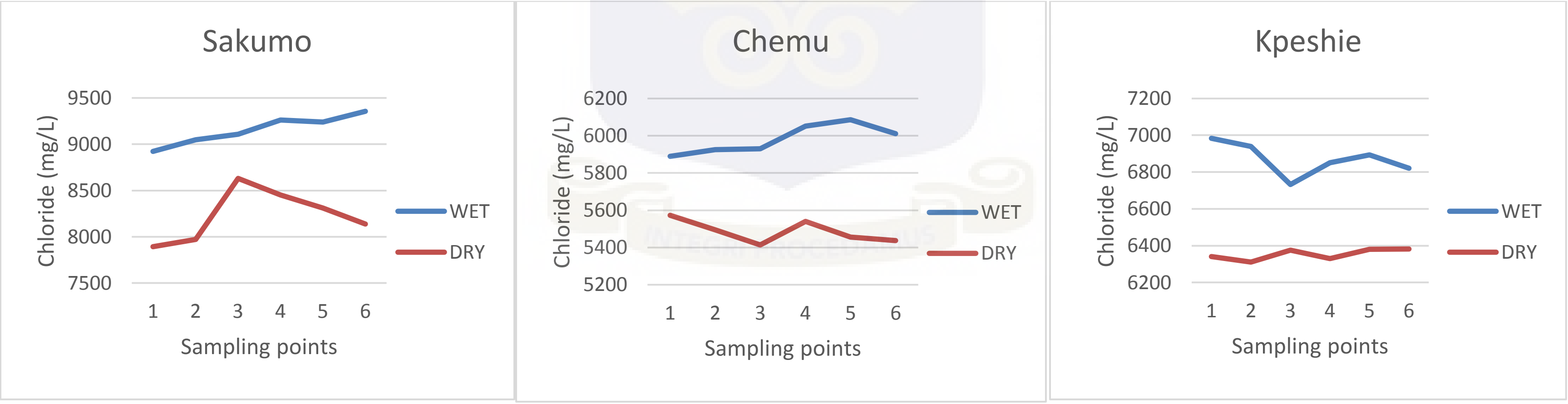


Figure 4.6: Seasonal variations of chloride in water samples from Sakumo, Chemu and Kpeshie lagoons

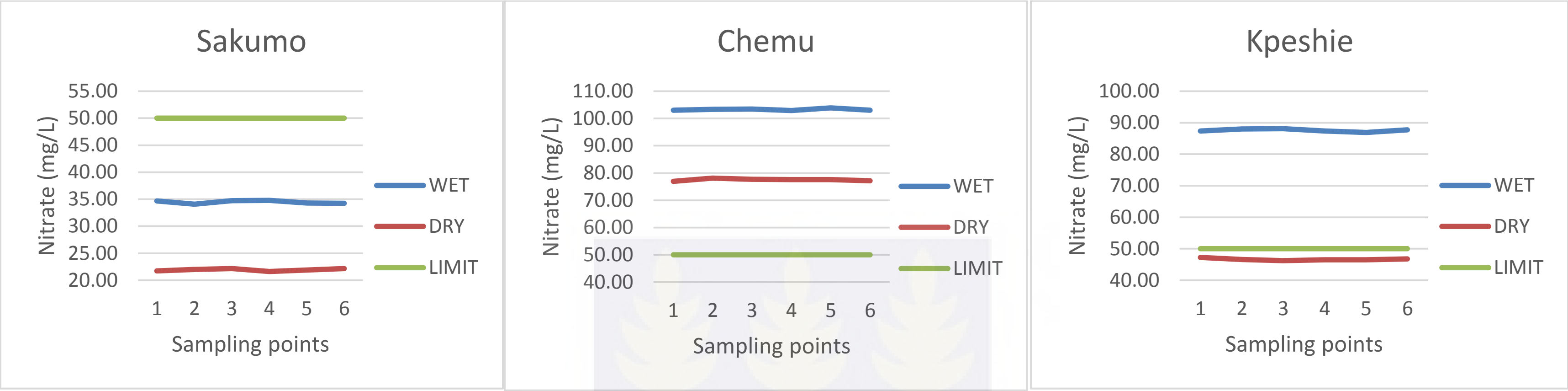


Figure 4.7: Seasonal variations of nitrate in water samples from Sakumo, Chemu and Kpeshie lagoons

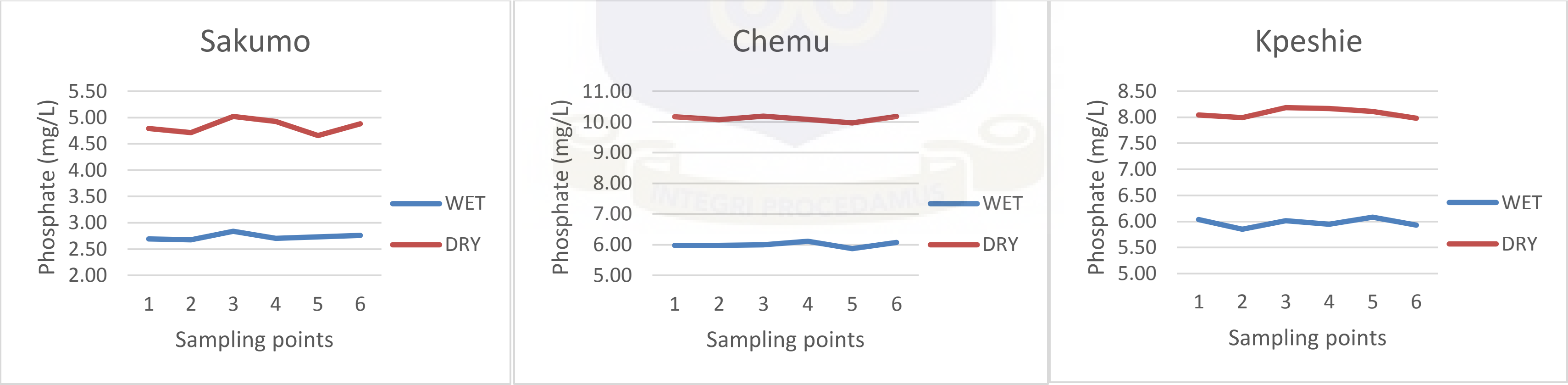


Figure 4.8: Seasonal variations of phosphate in water samples from Sakumo, Chemu and Kpeshie lagoons

4.2.0 Heavy Metals

In all, six metals including Copper (Cu), Lead (Pb), Iron (Fe), Nickel (Ni), Zinc (Zn) and Manganese (Mn) were determined. Below are the results and discussion for the six metals that were determined in the water and sediment samples taken from Sakumo, Chemu and Kpeshie lagoons.

Table 4.4: Total elemental concentration (mg/L) of heavy metals in water samples from Sakumo Lagoon during the wet and dry seasons

Sakumo Lagoon

Metals	Wet Season				Dry Season			
	Min	Max	Mean	Standard deviation	Min	Max	Mean	Standard deviation
Copper (mg/L)	2.87	3.95	3.48	0.40	5.03	6.03	5.39	0.42
Lead (mg/L)	0.13	0.55	0.32	0.15	0.12	0.15	0.14	0.01
Iron (mg/L)	4.61	5.32	5.06	0.27	5.75	6.76	6.40	0.37
Nickel (mg/L)	1.75	2.01	1.89	0.11	2.15	2.70	2.45	0.24
Zinc (mg/L)	3.53	4.01	3.74	0.17	5.04	5.27	5.14	0.11
Manganese (mg/L)	0.01	0.09	0.05	0.03	0.23	0.29	0.26	0.02

Table 4.5: Total elemental concentration (mg/L) of heavy metals in water samples from Chemu Lagoon during the wet and dry seasons

Chemu Lagoon

Metals	Wet Season				Dry Season			
	Min	Max	Mean	Standard deviation	Min	Max	Mean	Standard deviation
Copper (mg/L)	8.32	9.39	8.65	0.41	11.23	12.03	11.69	0.30
Lead (mg/L)	0.52	0.59	0.55	0.03	0.65	0.70	0.68	0.02
Iron (mg/L)	22.26	23.51	22.86	0.49	27.26	27.89	27.48	0.25
Nickel (mg/L)	8.06	8.58	8.33	0.24	9.41	9.93	9.70	0.22
Zinc (mg/L)	17.44	18.35	17.83	0.41	23.80	24.34	24.09	0.24
Manganese (mg/L)	0.68	0.75	0.71	0.02	1.40	1.49	1.45	0.03

Table 4.6: Total elemental concentration (mg/L) of heavy metals in water samples from Kpeshie Lagoon during the wet and dry seasons

Kpeshie Lagoon

Metals	Wet Season				Dry Season			
	Min	Max	Mean	Standard deviation	Min	Max	Mean	Standard deviation
Copper (mg/L)	6.10	6.84	6.51	0.30	8.12	8.67	8.41	0.24
Lead (mg/L)	0.31	0.37	0.34	0.02	0.47	0.50	0.48	0.01
Iron (mg/L)	17.57	18.25	17.84	0.27	20.98	22.32	21.76	0.46
Nickel (mg/L)	4.74	4.97	4.88	0.09	7.40	7.67	7.56	0.10
Zinc (mg/L)	13.10	13.48	13.19	0.14	18.58	19.11	18.87	0.18
Manganese (mg/L)	0.48	0.53	0.50	0.02	1.02	1.10	1.06	0.03

Table 4.7: Total elemental concentration (mg/kg) of heavy metals in sediment samples from Sakumo Lagoon during the wet and dry seasons

Sakumo Lagoon

Parameters	Wet Season				Dry Season			
	Min	Max	Mean	Standard deviation	Min	Max	Mean	Standard deviation
Copper (mg/kg)	28.29	31.50	29.62	1.23	45.08	48.11	47.09	1.06
Lead (mg/kg)	15.20	24.93	20.27	3.53	46.43	50.87	49.13	1.74
Iron (mg/kg)	51.31	52.69	51.65	0.52	51.33	55.92	53.50	1.67
Nickel (mg/kg)	1.93	2.68	2.25	0.29	2.95	3.32	3.11	0.15
Zinc (mg/kg)	53.72	58.44	56.74	1.74	72.03	76.85	74.26	1.94
Manganese (mg/kg)	91.43	96.28	94.36	1.75	102.18	123.34	114.60	8.28

Table 4.8: Total elemental concentration (mg/kg) of heavy metals in sediment samples from Chemu Lagoon during the wet and dry seasons

Chemu Lagoon

Parameters	Wet Season				Dry Season			
	Min	Max	Mean	Standard deviation	Min	Max	Mean	Standard deviation
Copper (mg/kg)	76.32	83.77	80.28	2.96	95.37	101.27	98.56	2.13
Lead (mg/kg)	30.73	33.77	31.72	1.12	62.95	67.55	64.94	1.83
Iron (mg/kg)	91.21	99.47	95.11	3.35	123.33	130.42	127.89	2.57
Nickel (mg/kg)	4.74	5.73	5.21	0.39	8.06	9.10	8.71	0.39
Zinc (mg/kg)	78.26	84.19	80.40	2.12	97.27	106.55	102.44	3.35
Manganese (mg/kg)	837.56	852.97	845.79	5.91	912.83	920.18	916.08	3.29

Table 4.9: Total elemental concentration (mg/kg) of heavy metals in sediment samples from Kpeshie Lagoon during the wet and dry seasons

Kpeshie Lagoon

Parameters	Wet Season				Dry Season			
	Min	Max	Mean	Standard deviation	Min	Max	Mean	Standard deviation
Copper (mg/kg)	53.98	56.33	55.18	0.81	74.98	80.06	77.79	1.85
Lead (mg/kg)	16.19	19.53	18.30	1.28	43.03	45.90	44.63	1.10
Iron (mg/kg)	64.56	69.05	66.87	1.59	78.37	82.95	79.95	1.77
Nickel (mg/kg)	2.89	3.34	3.05	0.16	4.45	4.83	4.63	0.15
Zinc (mg/kg)	43.88	50.56	47.01	2.14	75.22	78.63	77.56	1.33
Manganese (mg/kg)	330.86	360.03	344.80	12.24	529.22	568.56	550.48	14.98

4.2.1.0 Heavy Metals in water and sediment samples from Sakumo, Chemu and Kpeshie lagoons

4.2.1.1 Copper (Cu)

Copper (Cu) is a very common element that occurs naturally in the environment and it is essential to life. Cu is rapidly accumulated by plants and animals. Cu even at very low concentrations in water, can be toxic. Cu is known to cause brain damage in mammals (Fatoki *et al.*, 2002; DWAF, 1996).

Cu is introduced into the aquatic environment through minerals in soil and weathered rocks that form the sediments and suspended particles in water. Biological particles which include living and dead organic matter also contribute to the release of Cu into the aquatic environment. Run-off from industries, landfills and waste deposits also contribute to the release of copper into water bodies.

The results obtained from the copper analyses in water samples from Sakumo, Chemu and Kpeshie lagoons are shown in Table 4.4 to Table 4.6 and Figure 4.9. Also, results for Cu in sediment samples are shown in Table 4.7 to Table 4.9 and Figure 4.15.

In the water of Sakumo lagoon, Cu concentrations varied from 2.87 to 3.95 mg/L and 5.03 to 6.03 mg/L in the wet and dry seasons respectively (Table 4.4). The mean Cu values of Sakumo, Chemu and Kpeshie lagoons were 4.44 ± 0.41 mg/L, 10.17 ± 0.36 mg/L and 7.46 ± 0.27 mg/L respectively (Figure 4.9). The relatively high Cu levels in Sakumo lagoon could be attributed to the presence of organic matter as a result of run-off and relatively high oxygen concentration. As such, aerobic degradation of organic matter is enhanced and this process (i.e degradation of organic matter) is usually associated with the deposition of Cu (Das & Notling, 1993).

In the case of Chemu and Kpeshie lagoons, Cu concentrations in the lagoons' water ranged between 8.32 and 9.39 mg/L, and 6.10 and 6.84 mg/L, respectively in the wet season.

In the dry season, the levels of Cu ranged from 11.23 to 12.03 mg/L and 8.12 to 8.67 mg/L for Chemu and Kpeshie lagoons respectively (Table 4.5 and Table 4.6). The results indicated that the levels of Cu detected in waters from Chemu and Kpeshie lagoons were relatively higher than the Cu detected in water from the Sakumo lagoon (Figure 4.9). This suggests that, the Chemu lagoon may have a relatively high amount of organic matter as such a relatively high level of biological oxygen demand and relatively low dissolved oxygen. Run-off from farm lands around Kpeshie lagoon and the feeder streams can be said to be potential sources of Cu contamination to the Kpeshie lagoon (Das & Notling, 1993). Cu levels in water from Chemu lagoon were relatively higher (Table 4.5) than those detected in Kpeshie (Table 4.6) and Sakumo (Table 4.4) lagoons. This indicates the intense domestic and industrial influence on the Chemu lagoon as a result of urbanisation (i.e. residential facilities) and industrialisation (i.e. the presence of manufacturing industries such as Printex, Coca Cola Bottling Company, Kasapreko Company Ltd, etc.) in the catchments of Chemu lagoon.

4.2.1.2 Lead (Pb)

Lead (Pb) has been classified by the United States Environmental Protection Agency (USEPA) as potentially hazardous to most forms of life. Pb is considered poisonous and relatively accessible to aquatic organisms (USEPA, 1986). Pb is bioaccumulated by fish, invertebrates, freshwater plants, and benthic bacteria (DWAF, 1996). The chronic effect of Pb on man includes neurological disorders especially in foetus and children. This can lead to behavioural changes and impaired performance in IQ tests (Lansdown, 1986; Needleman, 1987).

Tables 4.4 to 4.6 and Figure 4.10 show the results obtained from Pb analysis in water samples from Sakumo, Chemu and Kpeshie lagoons. The results of Pb in sediment samples are shown in Table 4.7 to Table 4.9 and Figure 4.16.

In the Sakumo lagoon, Pb concentrations detected in water ranged between 0.13 and 0.55 mg/L in the wet season and 0.12 and 0.15 mg/L in the dry season (Table 4.4). The water of Chemu and Kpeshie lagoons recorded Pb concentrations varying from 0.52 to 0.59 mg/L and 0.31 to 0.37 mg/L in the wet season respectively and 0.65 to 0.70 mg/L and 0.47 to 0.50 mg/L in the dry season respectively (Table 4.5 and Table 4.6). The mean Pb values of water samples from Sakumo, Chemu and Kpeshie lagoons were 0.23 ± 0.08 mg/L, 0.61 ± 0.03 mg/L and 0.41 ± 0.02 mg/L respectively. The probable source of Pb could be its persistence in the environment due to run-off from used dry-cell batteries, used containers, gasoline and engine oils from refuse dumped around the lagoons. From this study, it can be seen that Chemu lagoon had higher Pb levels compared with Kpeshie and Sakumo lagoons (Figure 4.10).

Results from the study show that the water of Sakumo, Chemu and Kpeshie lagoons, may be harmful to foetuses and children. This might lead to the possible development of neurological problems since Pb levels in these water bodies were greater than 0.1 mg/L as per USEPA limit.

The study also shows that Pb concentrations in the sediments from Chemu lagoon were relatively higher than Kpeshie and Sakumo lagoons (Table 4.7 to Table 4.9). The overall mean Pb values of sediment samples from Sakumo, Chemu and Kpeshie lagoons were 34.70 ± 2.64 mg/kg, 48.33 ± 1.46 mg/kg and 31.47 ± 1.19 mg/kg respectively (Figure 4.16). The relatively high detection and presence of Pb in the sediments of Sakumo, Chemu and Kpeshie lagoons may be due to atmospheric deposition resulting from the persistence of Pb in the environment. The high Pb levels in sediments of the lagoons could be as a result of flocculation of lead-laden effluents discharged into watercourses that eventually wash down into the lagoons. This results in the sedimentation of particulate Pb. The use of lead in industrial processes and consumer products such as gasoline additives, batteries, paints, cable sheathing alloys and pigments may also account for the presence of Pb. Mostly, a percentage of Pb ingested in fishes can be taken up by man through the food chain. The seemingly increasing levels of lead in the lagoons suggest pollution of the lagoons by lead. Results from the study show that the levels of Pb detected in water and sediments from Chemu lagoon were relatively higher than those from Kpeshie and Sakumo lagoons. This demonstrates the possible impact of the discharge of domestic wastewater, industrial and sewage effluents into the Chemu lagoon.

4.2.1.3 Iron (Fe)

Iron (Fe) is one of the most abundant metals on Earth and it is essential to most forms of life (Institute of Medicine, 2001). Fe is found in natural fresh and groundwater. In humans, Fe is an essential component of proteins involved in oxygen transport (Dallman, 1986). Deficiency of Fe can limit delivery of oxygen to cells. This may result in decreased immunity, poor work performance and fatigue (Institute of Medicine, 2001, Bhaskaram, 2001). On the other hand, excess amounts of iron in man can result in toxicity and even death (Corbett, 1995).

Fe concentrations in water from Sakumo, Chemu and Kpeshie lagoons ranged between 4.61 and 5.32 mg/L, 22.26 and 23.51 mg/L, and 17.57 and 18.25 mg/L, respectively in the wet season. In the dry season, the iron values ranged from 5.75 to 6.76 mg/L, 27.26 to 27.89 mg/L and 20.98 to 22.32 mg/L for Sakumo, Chemu and Kpeshie lagoons respectively (Table 4.4 to Table 4.6). The mean of Fe concentrations in water samples from Sakumo, Chemu and Kpeshie lagoons were 5.73 ± 0.32 mg/L, 25.17 ± 0.37 mg/L and 19.80 ± 0.37 mg/L respectively (Figure 4.11). This may be due to natural occurrences within the lagoons, since the lagoons undergo certain geochemical and biochemical processes which take place within them, facilitating the release of Fe (WHO, 2004). Results from Tables 4.4 to 4.6 show that Fe values in water from Sakumo, Chemu and Kpeshie lagoons were all above the EPA limit of 5.00 mg/L.

In the case of sediment samples, the mean concentrations of Fe from Sakumo, Chemu and Kpeshie lagoons were 52.58 ± 1.10 mg/kg, 111.50 ± 2.96 mg/kg and 73.41 ± 1.68 mg/kg respectively (Tables 4.7 to 4.9 and Figure 4.17). This indicates the order of Fe to be Chemu > Kpeshie > Sakumo. Results from Table 4.7 to Table 4.9 also evince that Fe levels in sediments from the lagoons were all above the EPA limit of 48.00 mg/kg.

Probable sources of Fe in the sediments of the Sakumo, Chemu and Kpeshie lagoons could be the result of natural phenomena considering that natural geochemical and biochemical processes occur within the lagoons. Also, the high levels of Fe in sediment samples of the study areas could be due to the discharge of iron-laden waste and effluent replete of corroded iron pipes, scraps and containers into lagoons. However, Fe levels in sediments from Chemu (Table 4.8) and Kpeshie (Table 4.9) lagoons were relatively higher than those from Sakumo (Table 4.7).

From these results, it can be suggested that run-off from industrial sites (since they use heavy metal equipment), landfills and damp sites near the lagoons could be the main sources of Fe in the lagoons. Also run-off from the waste generated by the numerous number of scrap dealers along the lagoons could be a contributing factor to the elevated levels of Fe in the lagoons.

4.2.1.4 Nickel (Ni)

Nickel (Ni) is a naturally occurring element. Nickel can be found ubiquitously in the air, soil, sediments and water as a result of natural and man-made processes such as improper disposal of waste, chemicals and agricultural drainage. Excessive amounts of nickel in any of the environmental compartments (e.g. air, soil, sediment and water) can result in reduction in the quality of the environment for flora and fauna.

The results from Table 4.4 to Table 4.6 indicate that the concentrations of Ni from Sakumo, Chemu and Kpeshie lagoons ranged from 1.75 to 2.01 mg/L, 8.06 to 8.58 mg/L and 4.74 to 4.97 respectively in the wet season and 2.15 to 2.70 mg/L, 9.41 to 9.93 mg/L and 7.40 to 7.69 in the dry season respectively. The mean values for Ni in water samples from Sakumo, Chemu and Kpeshie lagoons were 2.17 ± 0.18 mg/L, 9.05 ± 0.23 mg/L and 6.22 ± 0.10 mg/L respectively (Tables 4.4 to 4.6). It was observed that the Ni values of the water samples were generally higher in the dry season than in the wet season (Figure 4.12). These observations made could be attributed to the cleansing effect of rainfall (Ajani & Island, 2015) during the rainy season and also, the accumulation of heavy metals as a result of human activities during the dry season. Run-off from industrial waste, lime, fertiliser and sewage sludge constitute the major sources of Ni in the aquatic environment.

Ni concentrations in the sediments from Sakumo, Chemu and Kpeshie lagoons are represented in Table 4.7 to Table 4.9. The mean values for nickel of sediment samples from Sakumo, Chemu and Kpeshie lagoons were 2.68 ± 0.22 mg/kg, 6.96 ± 0.39 mg/kg and 3.84 ± 0.16 mg/kg respectively. The mean Ni concentrations recorded from the sampling sites were all above the EPA limit of 2.00 mg/kg. It can be observed from Figure 4.18 that generally, Ni values were higher in the dry season compared to the Ni values recorded during the wet season. Ni is a metal that has been classified as very toxic to aquatic life and is relatively accessible to aquatic organisms through run-off from waste petroleum products. Chronic discharge of waste petroleum products into aquatic ecosystems could result in the accumulation of Ni in the aquatic environment.

4.2.1.5 Zinc (Zn)

Zinc (Zn) is one of the earliest known heavy metals. It is a common environmental pollutant and is widely distributed in the aquatic environment (Lawson, 2011). Zinc is mainly used in modern societies to coat or galvanise iron in order to prevent corrosion. Particles released from vehicle tyres and brake linings are a major source of zinc (WHO, 2001). Zinc is an essential element for the human body. It acts as a catalytic or structural component in many enzymes that are involved in energy metabolism, and in transcription and translation of RNA (Moolenaar, 1998). High doses of Zn can result in health complications such as fatigue, dizziness and neutropenia (Hess & Schmidt, 2002).

From Table 4.4, the Zn concentrations of Sakumo lagoon ranged between 3.53 and 4.01 mg/L in the wet season and 5.04 and 5.27 mg/L in the dry season. Zn concentrations for Chemu lagoon were 17.44 to 18.35 mg/L in the wet season and 23.80 to 24.34 mg/L in the dry season (Tables 4.5) while Zn concentrations in Kpeshie lagoon ranged from 13.10 to 13.48 mg/L in the wet season and 18.58 to 19.11 mg/L in the dry season (Tables 4.6).

The mean Zn values of Sakumo, Chemu and Kpeshie lagoons were 4.44 ± 0.14 mg/L, 20.96 ± 0.33 mg/L and 16.03 ± 0.16 mg/L respectively (Figure 4.13). Zn is a pollutant especially in areas that are close to industrial plants and are engaged in the processing of petroleum. Zn is directly added to drilling fluids as zinc carbonate and acts as a corrosion inhibitor (Ize-Iyamu & Bernard, 2007).

Due to the location of various industries around the Chemu lagoon (e. g. Tema Oil Refinery) and human activities such as operating fuel stations around Kpeshie lagoon, the study's results indicate the level of pollution on the various lagoons with respect to Zn (Asami, 1974). The order of pollution in the lagoons is therefore indicated as Chemu > Kpeshie > Sakumo. The Chemu lagoon may be acting as a ready sink, receiving metal loads including Zn from the feeder streams. Natural sources of pollution resulting from the weathering of minerals and soils (Merian, 1991) as well as atmospheric deposition could be attributed to the Zn in Sakumo lagoon.

Table 4.7 to Table 4.9 show the results of sediment samples from Sakumo, Chemu and Kpeshie lagoons. The mean Zn concentration from Sakumo lagoon was 65.50 ± 1.84 mg/kg. Chemu and Kpeshie lagoons recorded mean Zn concentrations of 91.42 ± 2.74 mg/kg and 62.29 ± 1.74 mg/kg respectively (Figure 4.19). The relatively high Zn values recorded in sediment from Sakumo, Chemu and Kpeshie lagoons might be due to the weathering of minerals and soils. The concentrations of zinc in the sediment samples of Sakumo, Chemu and Kpeshie lagoons were generally low compared with that of the EPA limit of 150.00 mg/kg.

4.2.1.6 Manganese (Mn)

Manganese (Mn) is one of the abundant elements in the Earth's crust and is widely distributed in soils, sediments, rocks, water, and biological materials (NAS/NRC, 1973). Mn is one of the most biogeochemical and active transition metals in aquatic environment (Evans *et al.*, 1977). Mn occurs in surface water that is low in oxygen and often does so with Fe. Mn accumulates in certain species of fish (Uthe & Blish, 1971). The major sources of man-made environmental pollution by manganese arise in the manufacture of alloys, steel, and iron products. Some sources of manganese include mining operations, production and use of fertilisers and fungicides, and the production of synthetic manganese oxide and dry-cell batteries (WHO, 1981).

Table 4.4 to Table 4.6 and Figure 4.14 show the results obtained from the analysis of Mn in water samples from Sakumo, Chemu and Kpeshie lagoons. The results of Mn in sediment samples are shown in Table 4.7 to Table 4.9 and Figure 4.20.

Mn concentrations in water samples from Sakumo, Chemu and Kpeshie lagoons varied from 0.01 to 0.09 mg/L, 0.68 to 0.75 mg/L and 0.48 to 0.53 mg/L respectively in the wet season and 0.23 to 0.29 mg/L, 1.40 to 1.49 mg/L and 1.02 to 1.10 mg/L in the dry season respectively (Tables 4.4 to 4.6). The mean Mn concentrations were 0.16 ± 0.03 mg/L, 1.08 ± 0.03 mg/L and 0.78 ± 0.03 mg/L for Sakumo, Chemu and Kpeshie lagoons respectively (Figure 4.14**)**. A probable source of air-borne inorganic manganese pollutant is the combustion of methylcyclopentadienyl manganese tricarbonyl (MMT) (Sierra *et al.*, 1998). MMT is an anti-knocking agent present in petroleum products which has Mn as an active component. MMT has a neutral charge and contains organic groups, which make it highly lipophilic and soluble in petrol. Weak bonds between the central metals and the organic groups readily break down in hot car engine environment during vehicle combustion. Combustion of MMT leads to the emission of manganese sulfate, manganese phosphates and manganese oxides. The manganese oxides include manganese tetroxide as a minor component (Zayed, 2001; WHO, 2004). The relative Mn levels in Sakumo, Chemu and Kpeshie lagoons could, therefore be due to deposits from MMT.

Sediment samples from Sakumo, Chemu and Kpeshie lagoons had mean Mn concentrations of 104.48 ± 5.02 mg/kg, 880.94 ± 4.6 mg/kg and 447.64 ± 27.22 mg/kg respectively (Figure 4.20). This may be owing to flocculation resulting in the sedimentation of Mn in lagoons. Sediment samples from Chemu lagoon had higher Mn levels relative to Sakumo and Kpeshie lagoons. This could be attributed to the relatively high impact of human activities in the catchment areas of Chemu lagoon as compared with the relatively less impact of human activities in the environs of Sakumo lagoon. The major anthropogenic sources of environmental manganese are municipal wastewater discharges, sewage sludge, emissions from alloy, and steel and iron production. Combustion of fossil fuels can also be a major factor that influences the release of manganese into the environment.

In general, heavy metals (Cu, Pb, Fe, Ni, Zn and Mn) in sediment samples were relatively higher than heavy metals in water samples. This confirms the ability of sediments to serve as ready sinks or reservoirs for pollutants including heavy metals (Onyari *et al*., 2003).

Generally, it can be observed from Figure 4.9 to Figure 4.20 that the levels of heavy metals (Cu, Pb, Fe, Ni, Zn and Mn) studied in this research were relatively high in the dry season compared with the wet season. This could be due to the fact that there was reduction in the volume of water in the lagoons during the dry season because of evaporation on the water surface. When this happens, the metals which get into the lagoons through run-off from nearby dump sites, industries and slums get concentrated, resulting in the higher heavy metal levels.

This research identifies the intense anthropogenic influence of industrialisation and urbanisation within the catchments of Chemu lagoon as the cause of the high levels of heavy metals within the lagoon as against the absence of industries and low population (rural setting) within the environs of Sakumo lagoon, hence relatively low concentration of heavy metals. The general order of pollution with respect to the heavy metals of the three lagoons under study is Chemu > Kpeshie > Sakumo lagoons.

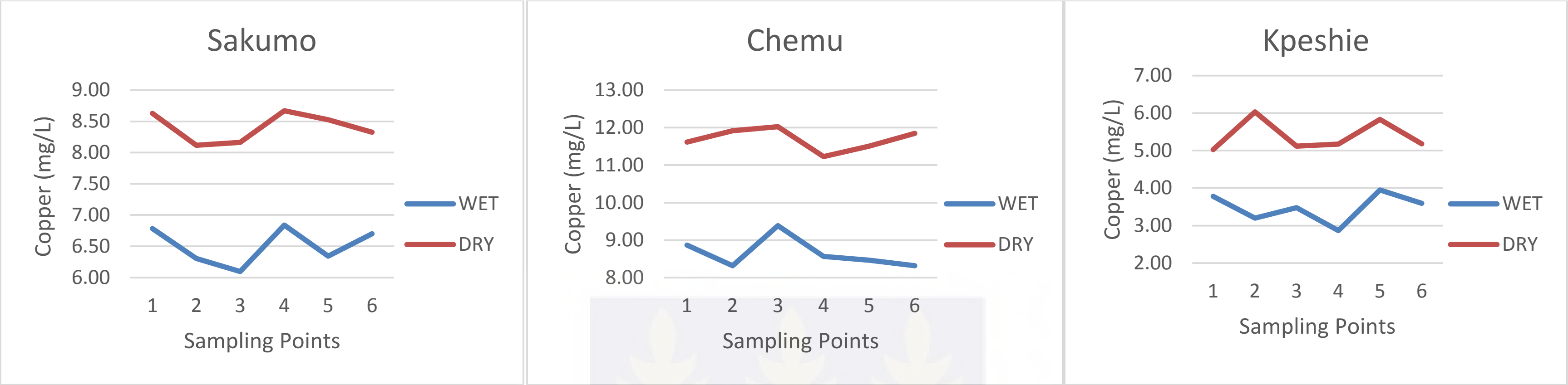


Figure 4.9: Seasonal variations of Copper in water samples from Sakumo, Chemu and Kpeshie lagoons

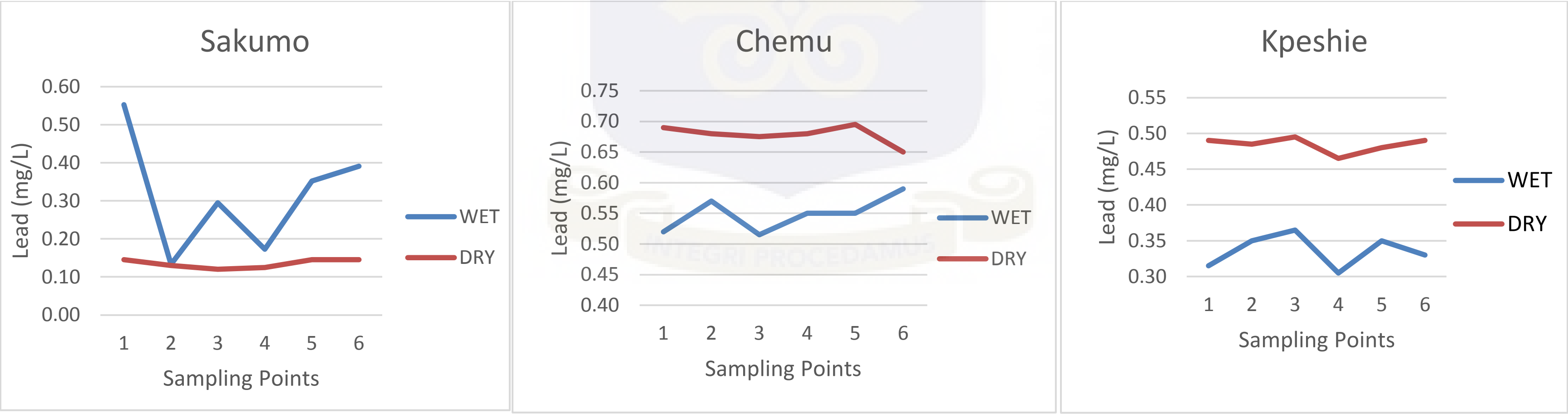


Figure 4.10: Seasonal variations of Lead in water samples from Sakumo, Chemu and Kpeshie lagoons

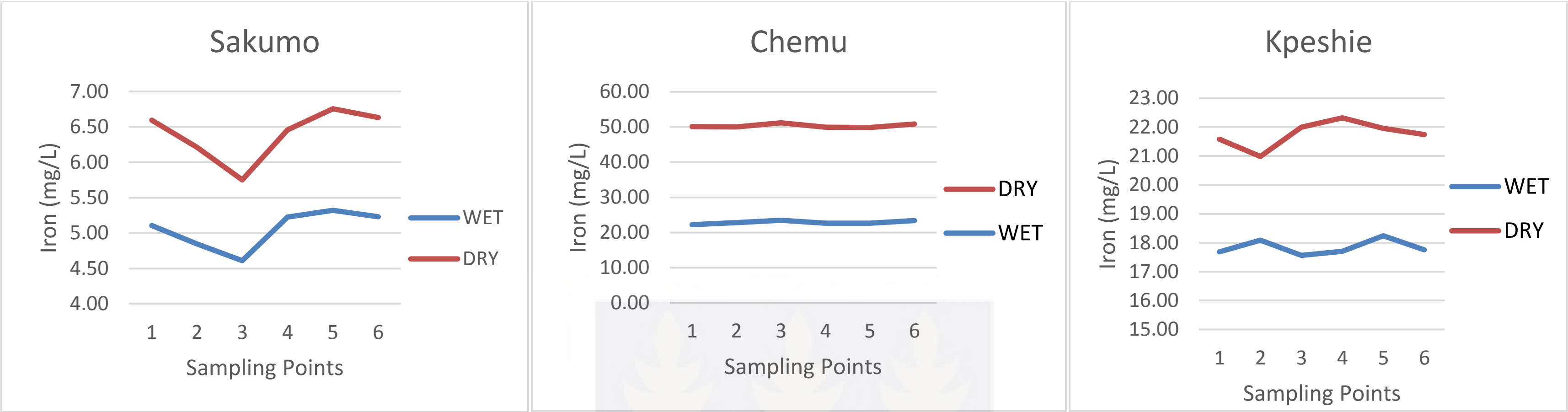


Figure 4.11: Seasonal variations of Iron in water samples from Sakumo, Chemu and Kpeshie lagoons

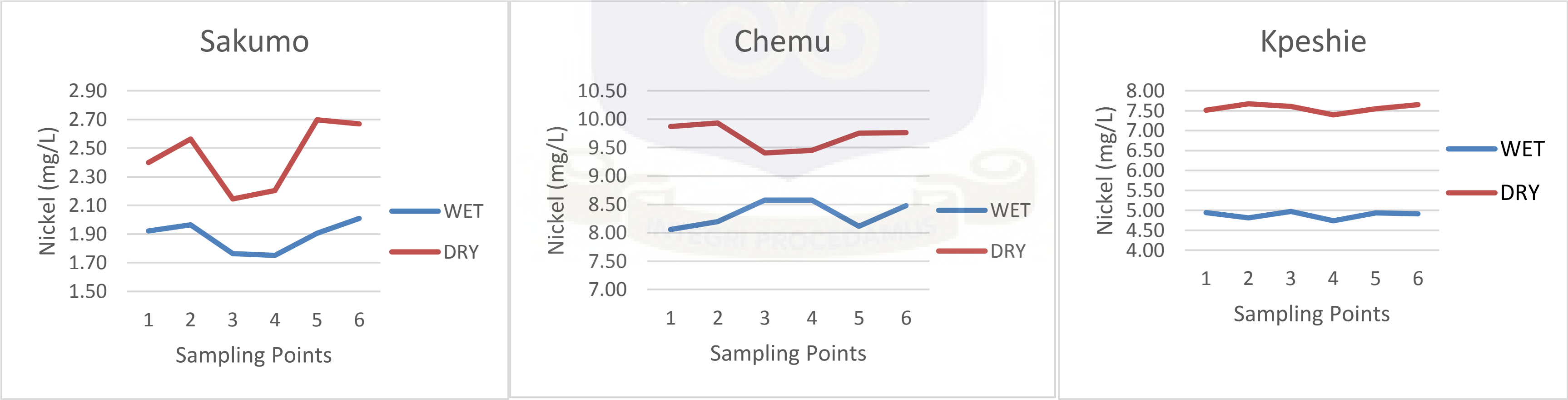


Figure 4.12: Seasonal variations of Nickel in water samples from Sakumo, Chemu and Kpeshie lagoons

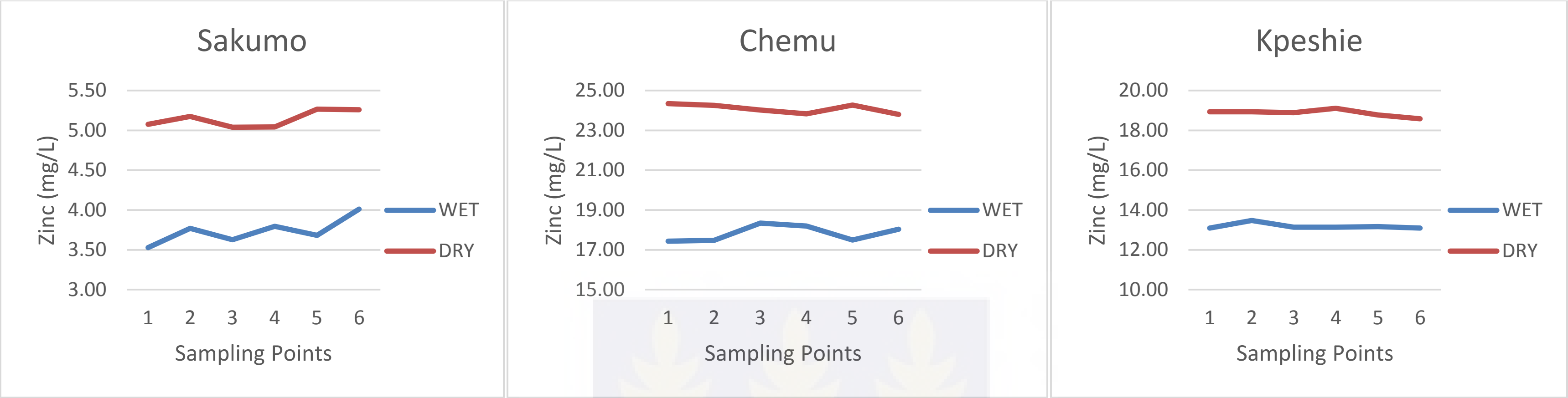


Figure 4.13: Seasonal variations of Zinc in water samples from Sakumo, Chemu and Kpeshie lagoons

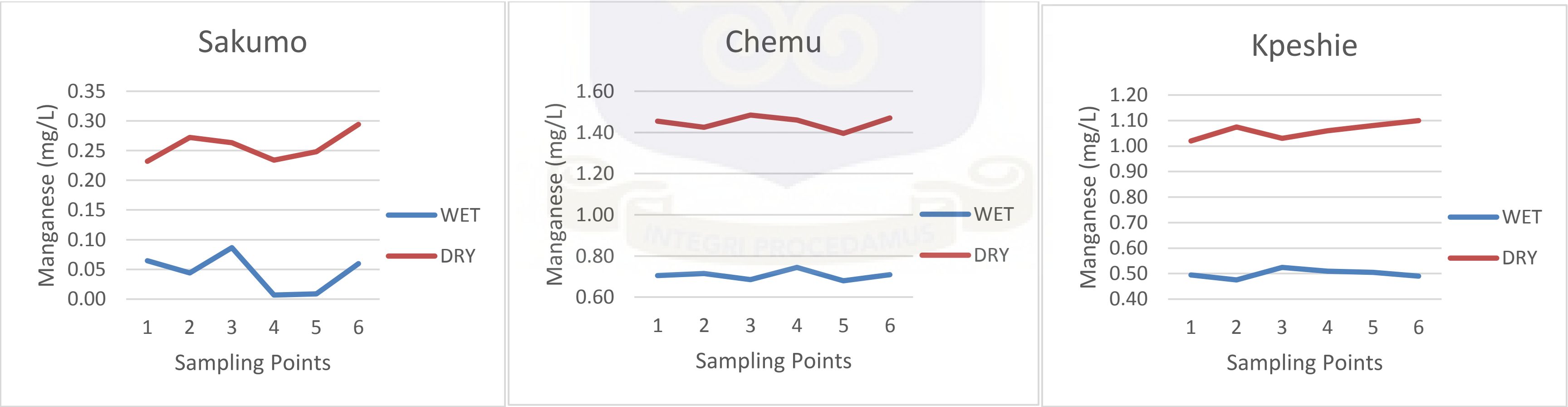


Figure 4.14: Seasonal variations of Manganese in water samples from Sakumo, Chemu and Kpeshie lagoons

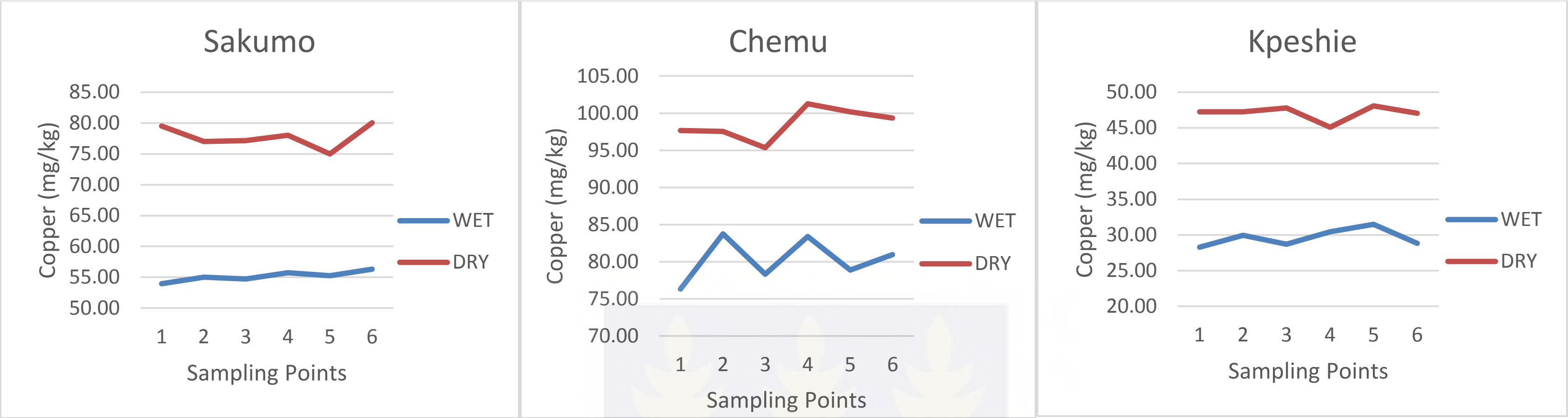


Figure 4.15: Seasonal variations of Copper in sediment samples from Sakumo, Chemu and Kpeshie lagoons

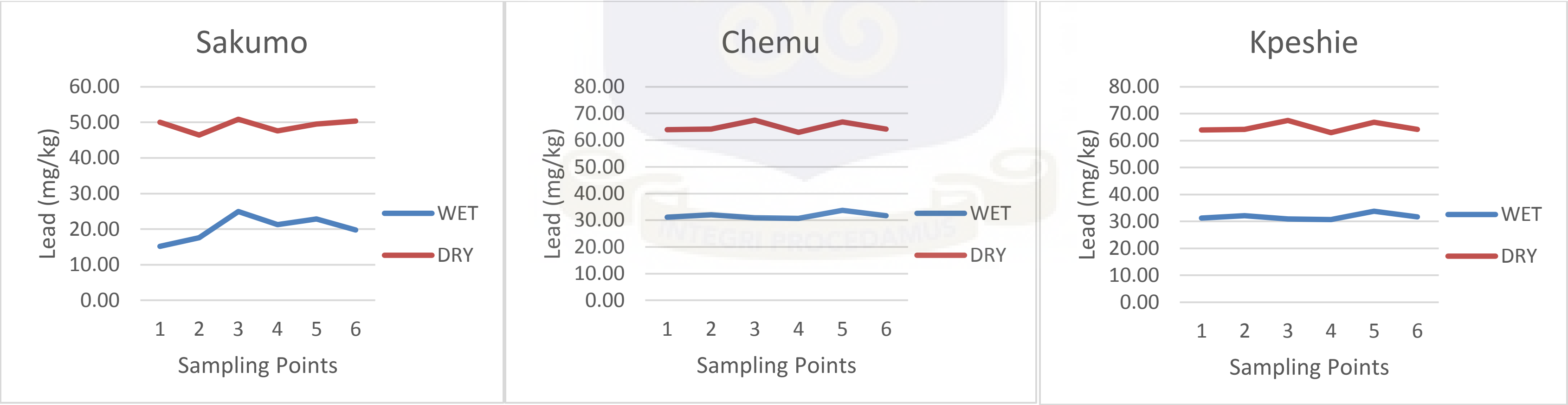


Figure 4.16: Seasonal variations of Lead in sediment samples from Sakumo, Chemu and Kpeshie lagoons

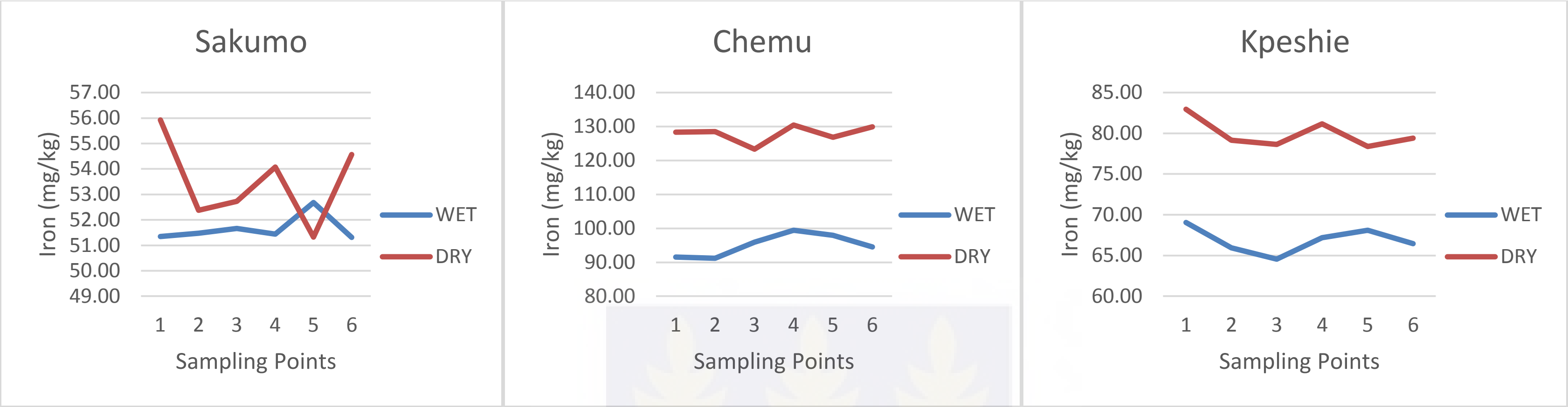


Figure 4.17: Seasonal variations of Iron in sediment samples from Sakumo, Chemu and Kpeshie lagoons

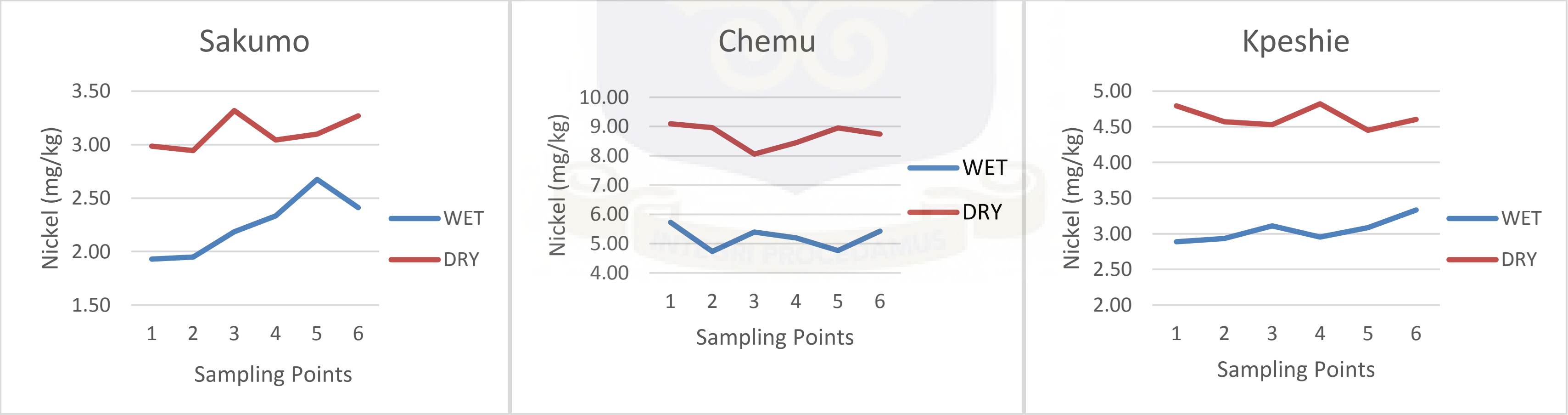


Figure 4.18: Seasonal variations of Nickel in sediment samples from Sakumo, Chemu and Kpeshie lagoons

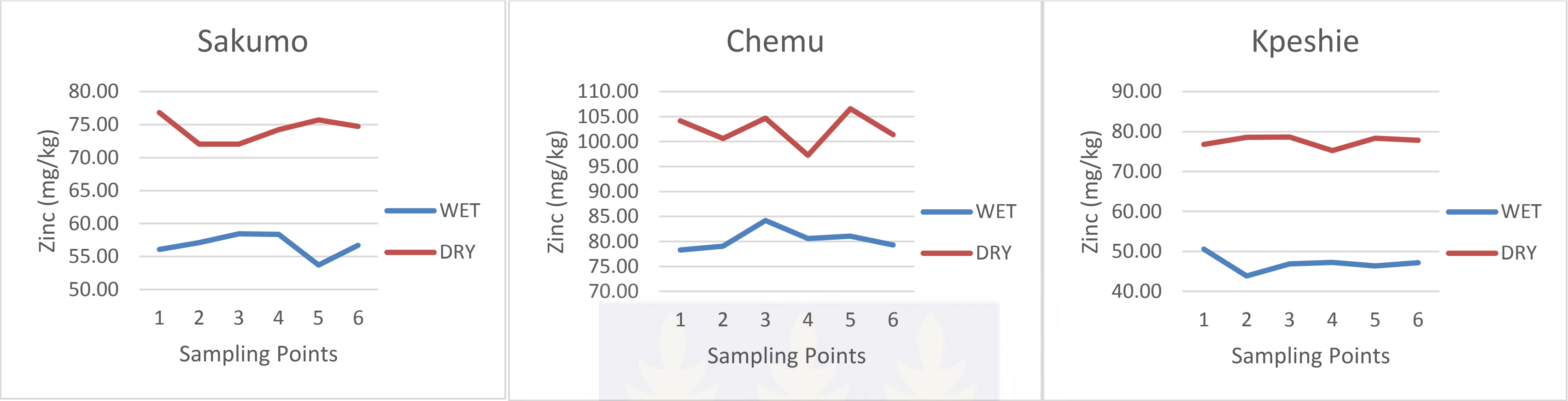


Figure 4.19: Seasonal variations of Zinc in sediment samples from Sakumo, Chemu and Kpeshie lagoons

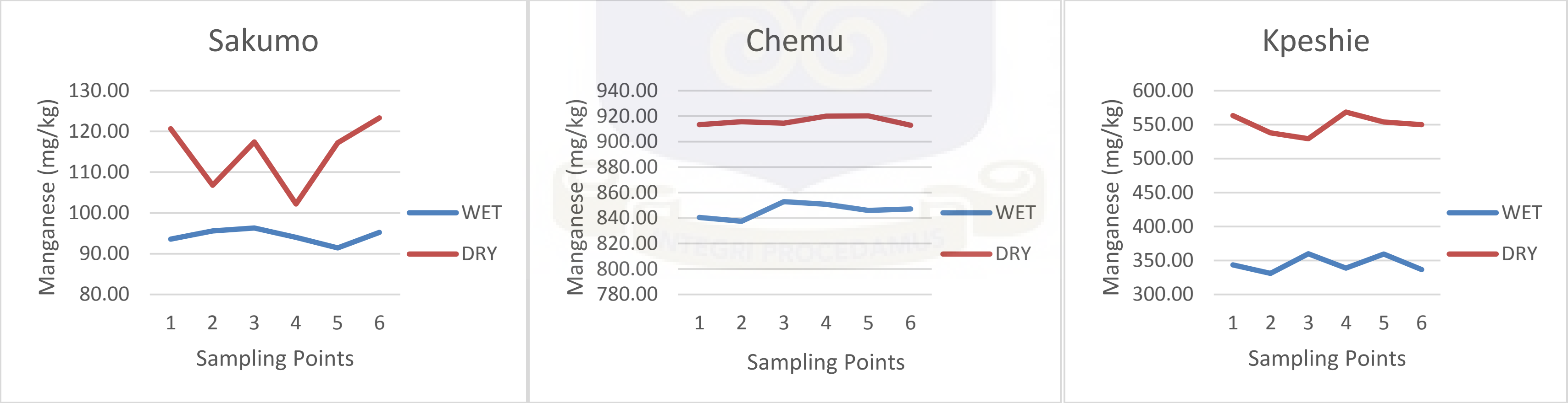


Figure 4.20: Seasonal variations of Manganese in sediment samples from Sakumo, Chemu and Kpeshie lagoons

4.2.3 Contamination status of bottom sediment samples

The pollution indices that were used to assess levels of heavy metal contamination of the sediments sampled from Sakumo, Chemu and Kpeshie lagoons include contamination factor (C_f), geo-accumulation index (I_{geo}), and pollution load index (PLI). The results obtained are represented in Table 4.10 to Table 4.12.

From Table 4.10, it can be realised that, the sediment samples from Sakumo lagoon during the wet season all had mean C_f values below 1 with the exception of Pb which had a mean C_f value of 1.621 indicating a moderate concentration of Pb in sediments (Table 2.2) (Hakanson, 1980). During the dry season, sediment samples taken from Sakumo lagoon had mean C_f values of Pb, Cu and Zn to be 3.931, 1.414 and 1.061 (Table 4.10) respectively. The mean C_f of Pb indicates considerable concentration of Pb in sediments while the mean C_f of Cu and Zn indicate moderate concentrations of Cu and Zn in the sediments (Table 2.2) (Hakanson, 1980).

Looking at Table 4.11, during the wet season, sediment samples from Chemu lagoon recorded mean C_f values for Cu, Pb and Zn as 1.460, 2.538 and 1.149 respectively, which show moderate concentrations of Cu, Pb and Zn in sediments (Table 2.2). Mean C_f values recorded during the dry season for Cu, Pb and Zn were 1.792, 5.195 and 1.463 respectively. The mean C_f values for Cu and Zn indicate moderate concentrations of Cu and Zn in sediments while the mean C_f value for Pb shows considerable concentration of Pb in sediments (Table 2.2) (Hakanson, 1980).

From Table 4.12, it can be observed that sediment samples from Kpeshie lagoon recorded a mean C_f value of 1.464 for Pb during the wet season; indicating moderate concentration of Pb in sediments (Table 2.2). In the dry season, mean C_f values for Pb and Zn were recorded to be 3.570 and 1.108 respectively. The mean C_f value for Pb showcases considerable concentration of Pb in sediments while the mean C_f value for Zn indicates moderate concentration of Zn in sediments (Table 2.2) (Hakanson, 1980).

According to Müller's characterisation for geo-accumulation; I-geo ≤ 0 represents unpolluted sediments, I-geo 0 – 1 represents unpolluted to moderately polluted sediments and I-geo 1 – 2 represents moderately polluted sediments with respect to the particular metal under investigation (Table 2.3) (Uwah *et al.*, 2013).

From Table 4.10, the sediment samples collected from Sakumo lagoon were unpolluted with Cu, Fe, Ni, Zn and Mn in both the wet and dry seasons. However, pollution as a result of Pb occurred for both the wet and dry seasons. This is seen in the mean values recorded; mean I-geo values of 0.093 (indicating unpolluted to moderately polluted sediments with respect to Pb) in the wet season and 1.389 (indicating moderately polluted sediments with respect to Pb) in the dry season respectively.

Table 4.11 shows that sediment samples collected from Chemu lagoon were polluted with Pb in both the wet and dry seasons. Also, sediments were polluted with Cu only in the dry season. The mean I-geo value recorded for Pb in the wet season was 0.758 (indicating unpolluted to moderately polluted sediments with respect to Pb). The mean I-geo values recorded for Pb and Cu during the dry season were 1.792 (indicating moderately polluted sediments with respect to Pb) and 0.256 (indicating unpolluted to moderately polluted sediments with respect to Cu) respectively.

It is observed from Table 4.12 that sediment samples collected from Kpeshie lagoon were polluted with Pb only in the dry season, with a mean I-geo value of 1.251. This indicates that, the sediments are moderately polluted with respect to Pb.

It can be concluded that Pb is the major heavy metal pollutant in all the lagoons studied in this research. This could be due to its persistence in the environment as a result of run-off from used dry-cell and wet-cell batteries, used containers, gasoline and engine oils from refuse dumped around the lagoons.

Table 4.10: Contamination factor, Geoaccumulation factor and Pollution Load Index for heavy metal concentrations in sediments of Sakumo lagoon in both wet and dry seasons (mg/kg)

		Sakumo Lagoon (Wet Season)							Sakumo Lagoon (Dry Season)						
PARA-METERS	**Metals**	**Point 1**	**Point 2**	**Point 3**	**Point 4**	**Point 5**	**Point 6**	**Mean**	**Point 1**	**Point 2**	**Point 3**	**Point 4**	**Point 5**	**Point 6**	**Mean**
Concentration (mg/kg)	Cu	53.98	55.03	54.75	55.74	55.25	56.33	55.18	79.51	77.02	77.18	78.03	74.98	80.06	77.79
	Pb	15.2	17.61	24.93	21.25	22.83	19.79	20.27	50.00	46.43	50.87	47.59	49.57	50.34	49.13
	Fe	51.35	51.47	51.66	51.44	52.69	51.31	51.65	55.92	52.38	52.73	54.08	51.33	54.57	53.5
	Ni	1.93	1.95	2.19	2.34	2.68	2.41	2.25	2.99	2.95	3.32	3.05	3.10	3.27	3.11
	Zn	56.08	57.12	58.44	58.36	53.72	56.71	56.74	76.85	72.05	72.03	74.24	75.71	74.71	74.26
	Mn	343.44	330.86	360.03	338.66	359.41	336.44	344.8	563.57	537.83	529.22	568.56	553.83	549.87	550.48
Contamination factor (Cf)	Cu	0.981	1.001	0.995	1.013	1.005	1.024	1.003	1.446	1.400	1.403	1.419	1.363	1.456	1.414
	Pb	1.216	1.408	1.994	1.7	1.826	1.583	1.621	4.000	3.714	4.070	3.807	3.966	4.027	3.931
	Fe	0.000912	0.000914	0.000918	0.000914	0.000936	0.000911	0.000917	0.00099	0.00093	0.00094	0.00096	0.00091	0.00097	0.00095
	Ni	0.026	0.026	0.029	0.031	0.036	0.032	0.03	0.04	0.039	0.044	0.041	0.041	0.044	0.041
	Zn	0.801	0.816	0.835	0.834	0.767	0.81	0.811	1.098	1.029	1.029	1.061	1.082	1.067	1.061
	Mn	0.362	0.348	0.379	0.356	0.378	0.354	0.363	0.593	0.566	0.557	0.598	0.583	0.579	0.579
Geoaccumulation Index (Geo-I)	Cu	-0.612	-0.584	-0.592	-0.566	-0.578	-0.55	-0.58	-0.053	-0.099	-0.096	-0.081	-0.138	-0.043	-0.085
	Pb	-0.303	-0.091	0.411	0.181	0.284	0.078	0.093	1.415	1.308	1.44	1.344	1.403	1.425	1.389
	Fe	-10.684	-10.680	-10.675	-10.681	-10.646	-10.685	-10.675	-10.561	-10.655	-10.645	-10.609	-10.684	-10.596	-10.625
	Ni	-5.865	-5.85	-5.686	-5.59	-5.394	-5.545	-5.655	-5.236	-5.256	-5.083	-5.207	-5.182	-5.104	-5.178
	Zn	-0.905	-0.878	-0.845	-0.847	-0.967	-0.889	-0.889	-0.45	-0.543	-0.544	-0.5	-0.472	-0.491	-0.5
	Mn	-2.053	-2.107	-1.985	-2.073	-1.987	-2.083	-2.048	-1.338	-1.406	-1.429	-1.326	-1.363	-1.374	-1.373
Pollution Load Index (PLI)		0.142	0.146	0.16	0.156	0.162	0.155	0.154	0.23	0.219	0.227	0.226	0.225	0.231	0.226

Table 4.11: Contamination factor, Geoaccumulation factor and Pollution Load Index for heavy metal concentrations in sediments of Chemu lagoon in both wet and dry seasons (mg/kg)

		Chemu Lagoon (Wet Season)							Chemu Lagoon (Dry Season)						
PARA-METERS	**Metals**	**Point 1**	**Point 2**	**Point 3**	**Point 4**	**Point 5**	**Point 6**	**Mean**	**Point 1**	**Point 2**	**Point 3**	**Point 4**	**Point 5**	**Point 6**	**Mean**
Concentration (mg/kg)	Cu	76.32	83.77	78.34	83.39	78.89	80.98	80.28	97.68	97.55	95.37	101.27	100.18	99.33	98.56
	Pb	31.20	32.07	30.88	30.73	33.77	31.71	31.72	63.92	64.18	67.55	62.95	66.87	64.20	64.94
	Fe	91.58	91.21	95.90	99.47	98.00	94.51	95.11	128.29	128.53	123.33	130.42	126.83	129.94	127.89
	Ni	5.73	4.74	5.40	5.19	4.77	5.42	5.21	9.10	8.97	8.06	8.45	8.96	8.74	8.71
	Zn	78.26	79.04	84.19	80.57	81.08	79.29	80.40	104.17	100.60	104.69	97.27	106.55	101.38	102.44
	Mn	840.44	837.56	852.97	850.76	845.88	847.12	845.79	913.30	915.64	914.43	920.10	920.18	912.83	916.08
Contamination factor (Cf)	Cu	1.388	1.523	1.424	1.516	1.434	1.472	1.460	1.776	1.774	1.734	1.841	1.821	1.806	1.792
	Pb	2.496	2.566	2.470	2.458	2.701	2.536	2.538	5.113	5.134	5.404	5.036	5.349	5.136	5.195
	Fe	0.00163	0.00162	0.00170	0.00177	0.00174	0.00168	0.00169	0.00228	0.00228	0.00219	0.00232	0.00225	0.00231	0.00227
	Ni	0.076	0.063	0.072	0.069	0.064	0.072	0.069	0.121	0.120	0.107	0.113	0.119	0.116	0.116
	Zn	1.118	1.129	1.203	1.151	1.158	1.133	1.149	1.488	1.437	1.496	1.390	1.522	1.448	1.463
	Mn	0.885	0.882	0.898	0.896	0.890	0.892	0.890	0.961	0.964	0.963	0.969	0.969	0.961	0.964
Geoaccumulation Index (Geo-I)	Cu	-0.112	0.022	-0.075	0.015	-0.065	-0.027	-0.040	0.244	0.242	0.209	0.296	0.280	0.268	0.256
	Pb	0.735	0.774	0.720	0.713	0.849	0.758	0.758	1.769	1.775	1.849	1.747	1.834	1.776	1.792
	Fe	-9.849	-9.855	-9.782	-9.730	-9.751	-9.803	-9.795	-9.363	-9.360	-9.419	-9.339	-9.379	-9.344	-9.367
	Ni	-4.295	-4.570	-4.382	-4.438	-4.561	-4.375	-4.437	-3.629	-3.649	-3.803	-3.736	-3.651	-3.687	-3.692
	Zn	-0.424	-0.410	-0.319	-0.382	-0.373	-0.405	-0.385	-0.012	-0.062	-0.004	-0.110	0.021	-0.051	-0.036
	Mn	-0.762	-0.767	-0.740	-0.744	-0.752	-0.750	-0.753	-0.642	-0.638	-0.640	-0.631	-0.631	-0.643	-0.637
Pollution Load Index (PLI)		0.274	0.271	0.278	0.279	0.276	0.278	0.276	0.391	0.389	0.383	0.385	0.396	0.389	0.389

Table 4.12: Contamination factor, Geoaccumulation factor and Pollution Load Index for heavy metal concentrations in sediments of Kpeshie lagoon in both wet and dry seasons (mg/kg)

		Kpeshie Lagoon (Wet Season)							Kpeshie Lagoon (Dry Season)						
SAMPLING POINTS	**Metals**	**Point 1**	**Point 2**	**Point 3**	**Point 4**	**Point 5**	**Point 6**	**Mean**	**Point 1**	**Point 2**	**Point 3**	**Point 4**	**Point 5**	**Point 6**	**Mean**
Concentration (mg/kg)	Cu	28.29	29.93	28.70	30.47	31.50	28.82	29.62	47.24	47.28	47.80	45.08	48.11	47.05	47.09
	Pb	18.00	19.41	19.03	16.19	19.53	17.67	18.30	45.15	45.57	45.90	43.90	43.03	44.22	44.63
	Fe	69.05	65.94	64.56	67.18	68.09	66.45	66.87	82.95	79.16	78.62	81.17	78.37	79.42	79.95
	Ni	2.89	2.94	3.11	2.96	3.09	3.34	3.05	4.80	4.57	4.53	4.83	4.45	4.61	4.63
	Zn	50.56	43.88	46.89	47.26	46.35	47.16	47.01	76.78	78.54	78.63	75.22	78.36	77.81	77.56
	Mn	93.59	95.58	96.28	94.04	91.43	95.27	94.36	120.67	106.83	117.42	102.18	117.19	123.34	114.60
Contamination factor (Cf)	Cu	0.514	0.544	0.522	0.554	0.573	0.524	0.538	0.859	0.860	0.869	0.820	0.875	0.855	0.856
	Pb	1.440	1.552	1.522	1.295	1.562	1.414	1.464	3.612	3.645	3.672	3.512	3.442	3.538	3.570
	Fe	0.00123	0.00117	0.00115	0.00119	0.00121	0.00118	0.00119	0.00147	0.00141	0.00140	0.00144	0.00139	0.00141	0.00142
	Ni	0.039	0.039	0.041	0.039	0.041	0.044	0.041	0.064	0.061	0.060	0.064	0.059	0.061	0.062
	Zn	0.722	0.627	0.670	0.675	0.662	0.674	0.672	1.097	1.122	1.123	1.075	1.119	1.112	1.108
	Mn	0.099	0.101	0.101	0.099	0.096	0.100	0.099	0.127	0.112	0.124	0.108	0.123	0.130	0.121
Geoaccumulation Index (Geo-I)	Cu	-1.544	-1.463	-1.523	-1.437	-1.389	-1.517	-1.479	-0.804	-0.803	-0.787	-0.872	-0.778	-0.810	-0.809
	Pb	-0.059	0.050	0.021	-0.212	0.059	-0.086	-0.038	1.268	1.281	1.292	1.227	1.198	1.238	1.251
	Fe	-10.256	-10.323	-10.353	-10.296	-10.277	-10.312	-10.303	-9.992	-10.059	-10.069	-10.023	-10.074	-10.054	-10.045
	Ni	-5.283	-5.260	-5.177	-5.251	-5.189	-5.076	-5.206	-4.552	-4.622	-4.634	-4.543	-4.660	-4.611	-4.604
	Zn	-1.054	-1.259	-1.163	-1.152	-1.180	-1.155	-1.160	-0.452	-0.419	-0.417	-0.481	-0.422	-0.432	-0.437
	Mn	-3.929	-3.898	-3.888	-3.922	-3.962	-3.903	-3.917	-3.562	-3.738	-3.601	-3.802	-3.604	-3.530	-3.639
Pollution Load Index (PLI)		0.116	0.116	0.117	0.114	0.119	0.117	0.117	0.185	0.180	0.183	0.177	0.180	0.183	0.182

4.3.0 Pearson Correlation of sediment samples

A two-tailed test is a statistical test in which the critical area of a distribution is two-sided. It is used to test whether a sample is greater than or less than a certain range of values. If the sample being tested falls into either of the critical areas, the alternative hypothesis is accepted instead of the null hypothesis. For instance, suppose the null hypothesis states that the mean is equal to 10, the alternative hypothesis would be that the mean is less than 10 or greater than 10 (Massey & Miller, n.d.).

In order to ascertain the sources that affect the distribution of heavy metals in wetland sediments, inter-elemental associations were evaluated using the Pearson correlation coefficient and the results are presented in Table 4.13 to Table 4.15. Elemental associations may signify that each paired element has an identical source or common sink in the stream sediments (Cynthia *et al.*, 2011; Nyangabo *et al.*, 2005; Sing *et al.*, 2002).

Table 4.13 to Table 4.15 show that there was a strong positive correlation of the heavy metals (Cu and Pb, Cu and Fe, Cu and Ni, Cu and Zn, Cu and Mn, Pb and Fe, Pb and Ni, Pb and Zn, Pb and Mn, Fe and Ni, Fe and Zn, Fe and Mn, Ni and Zn, Ni and Mn, and Mn and Zn) in sediment samples of Sakumo, Chemu and Kpeshie lagoons respectively. The correlations were above 0.5.

The results emphasise that the heavy metals in the sediments of Chemu lagoon might be coming from a particular pollution source, which is likely to be the consequence of anthropogenic activities such as effluents from industries, surface run-off and domestic wastes. The high correlation in sediments of Sakumo lagoon could be accounted for by the geology of the area. There are no industries along the banks of Kpeshie lagoon. Domestic waste and surface run-off from agricultural fields are likely to be the main factors responsible for heavy metals in the

Kpeshie lagoon. The correlation between the heavy metals is significant at 0.05 or 95% confidence level (2-tailed).

Table 4.13: Pearson correlation of heavy metal contents (mg/kg) in sediment samples from Sakumo lagoon

Correlations							
		Cu	Pb	Fe	Ni	Zn	Mn
Cu	Pearson Correlation	1	**0.983****	0.700*	**0.907****	**0.980****	**0.988****
	Sig. (2-tailed)		0.000	**0.011**	0.000	0.000	0.000
	N	12	12	12	12	12	12
Pb	Pearson Correlation	**0.983****	1	0.655*	**0.936****	**0.973****	**0.985****
	Sig. (2-tailed)	0.000		**0.021**	0.000	0.000	0.000
	N	12	12	12	12	12	12
Fe	Pearson Correlation	0.700*	0.655*	1	0.617*	0.651*	0.677*
	Sig. (2-tailed)	**0.011**	**0.021**		**0.033**	**0.022**	**0.016**
	N	12	12	12	12	12	12
Ni	Pearson Correlation	**0.907****	**0.936****	0.617*	1	**0.854****	**0.898****
	Sig. (2-tailed)	0.000	0.000	**0.033**		0.000	0.000
	N	12	12	12	12	12	12
Zn	Pearson Correlation	**0.980****	**0.973****	0.651*	**0.854****	1	**0.982****
	Sig. (2-tailed)	0.000	0.000	**0.022**	0.000		0.000
	N	12	12	12	12	12	12
Mn	Pearson Correlation	**0.988****	**0.985****	0.677*	**0.898****	**0.982****	1
	Sig. (2-tailed)	0.000	0.000	**0.016**	0.000	0.000	
	N	12	12	12	12	12	12
**: Correlation is significant at the 0.01 level (2-tailed).							
*: Correlation is significant at the 0.05 level (2-tailed).							

Table 4.44: Pearson correlation of heavy metal contents (mg/kg) in sediment samples from Chemu lagoon

Correlations							
		Cu	Pb	Fe	Ni	Zn	Mn
Cu	Pearson Correlation	1	$\mathbf{0.960}^{**}$	$\mathbf{0.970}^{**}$	$\mathbf{0.938}^{**}$	$\mathbf{0.928}^{**}$	$\mathbf{0.966}^{**}$
	Sig. (2-tailed)		0.000	0.000	0.000	0.000	0.000
	N	12	12	12	12	12	12
Pb	Pearson Correlation	$\mathbf{0.960}^{**}$	1	$\mathbf{0.977}^{**}$	$\mathbf{0.969}^{**}$	$\mathbf{0.981}^{**}$	$\mathbf{0.988}^{**}$
	Sig. (2-tailed)	0.000		0.000	0.000	0.000	0.000
	N	12	12	12	12	12	12
Fe	Pearson Correlation	$\mathbf{0.970}^{**}$	$\mathbf{0.977}^{**}$	1	$\mathbf{0.969}^{**}$	$\mathbf{0.956}^{**}$	$\mathbf{0.991}^{**}$
	Sig. (2-tailed)	0.000	0.000		0.000	0.000	0.000
	N	12	12	12	12	12	12
Ni	Pearson Correlation	$\mathbf{0.938}^{**}$	$\mathbf{0.969}^{**}$	$\mathbf{0.969}^{**}$	1	$\mathbf{0.957}^{**}$	$\mathbf{0.975}^{**}$
	Sig. (2-tailed)	0.000	0.000	0.000		0.000	0.000
	N	12	12	12	12	12	12
Zn	Pearson Correlation	$\mathbf{0.928}^{**}$	$\mathbf{0.981}^{**}$	$\mathbf{0.956}^{**}$	$\mathbf{0.957}^{**}$	1	$\mathbf{0.975}^{**}$
	Sig. (2-tailed)	0.000	0.000	0.000	0.000		0.000
	N	12	12	12	12	12	12
Mn	Pearson Correlation	$\mathbf{0.966}^{**}$	$\mathbf{0.988}^{**}$	$\mathbf{0.991}^{**}$	$\mathbf{0\ .975}^{**}$	$\mathbf{0.975}^{**}$	1
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	
	N	12	12	12	12	12	12
**: Correlation is significant at the 0.01 level (2-tailed).							

Table 4.15: Pearson correlation of heavy metal contents (mg/kg) in sediment samples from Kpeshie lagoon

Correlations

		Cu	Pb	Fe	Ni	Zn	Mn
Cu	Pearson Correlation	1	**0.991****	**0.962****	**0.968****	**0.987****	**0.892****
	Sig. (2-tailed)		0.000	0.000	0.000	0.000	0.000
	N	12	12	12	12	12	12
Pb	Pearson Correlation	**0.991****	1	**0.969****	**0.981****	**0.989****	**0.877****
	Sig. (2-tailed)	0.000		0.000	0.000	0.000	0.000
	N	12	12	12	12	12	12
Fe	Pearson Correlation	**0.962****	**0.969****	1	**0.969****	**0.969****	**0.841****
	Sig. (2-tailed)	0.000	0.000		0.000	0.000	**0.001**
	N	12	12	12	12	12	12
Ni	Pearson Correlation	**0.968****	**0.981****	**0.969****	1	**0.971****	**0.851****
	Sig. (2-tailed)	0.000	0.000	0.000		0.000	0.000
	N	12	12	12	12	12	12
Zn	Pearson Correlation	**0.987****	**0.989****	**0.969****	**0.971****	1	**0.884****
	Sig. (2-tailed)	0.000	0.000	0.000	0.000		0.000
	N	12	12	12	12	12	12
Mn	Pearson Correlation	**0.892****	**0.877****	**0.841****	**0.851****	**0.884****	1
	Sig. (2-tailed)	0.000	0.000	0.001	0.000	0.000	
	N	12	12	12	12	12	12

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

4.4.0 Concentration of pesticide residues and metabolites in water and sediment samples from Sakumo, Chemu and Kpeshie lagoons

Arable crop farming is the dominant occupation of residents in Sakumono Village, Klagon and Tema Community 3. Inorganic fertilisers and pesticides are used by the arable crop farmers to enhance their yield or produce. Fertilisers such as NPK (15-15-15, 20-10-10), urea and ammonia are used in their farming activities. Some of the pesticides that were found with the farmers on the farm lands were DDT, Pawa 2.5EC, Furadan, Atellic, Dursban 4E, Karate, Confidor, Gamelin-20, Run-up, Supermaster-20-20-20, Pyrinex 48EC and More Harvest (Adamus *et al.* 2001; Harris *et al.* 1998; Wren *et al.* 1997). Similar chemicals are used in some habitats around the environs of Kpeshie and Chemu lagoons for farming. Some residents of La, Teshie, Sakumono and their environs expressed suspicions about the use of the aforementioned chemicals by some individuals in illegal fishing activities at the Sakumo and Kpeshie lagoons.

Due to the run-off from farm lands, nearby industries and the usage of dangerous chemicals for fishing in lagoons, pesticide residues were analysed in the water and sediment samples from Sakumo, Chemu and Kpeshie lagoons. The pesticide residues analysed included DDT, DDD, DDE, aldrin, dieldrin, fenitrothion and chlorpyrifos.

The results obtained are represented in Table 4.16 and Table 4.17.

The specifications of DDT, DDD, DDE, aldrin, dieldrin, fenitrothion and chlorpyrifos in water samples according to US/WHO/EU default maximum residue limits (MRLs) are 2.00 ug/L (Max), 2.00 ug/L (Max), 2.00 ug/L (Max), 0.03 ug/L (Max), 0.03 ug/L (Max), 30.00 ug/L (Max) and 0.05 ug/L (LOD) respectively. The specifications of DDT, DDD, DDE, aldrin, dieldrin, fenitrothion and chlorpyrifos in sediment samples according to US/EU default MRLs are 0.05 mg/kg (Max), 0.04 mg/kg (Max), 0.04 mg/kg (Max), 0.04 mg/kg (Max), 0.03 mg/kg (Max), 0.05 mg/kg (Max) and 0.03 mg/kg (Max) respectively.

Essumang *et al.*, in 2009, assessed DDT, DDD, DDE and propiconazol in water samples from Chemu lagoon. The concentrations of DDT, DDD, DDE and propiconazol they recorded were 0.0360 ± 0.0009 mg/L, 0.0369 ± 0.0007 mg/L, 0.0718 ± 0.0009 mg/L and 0.5164 ± 0.0100 mg/L respectively but results obtained from the current study (Table 4.16 and Table 4.17) show that all the pesticide residues studied were below detection limit. This could possibly imply that, individuals in possession of some of the harmful chemicals used them on a very moderate scale. Also, the chemicals have relatively short half-life after being used, hence they biodegrade into other forms. Most of these chemicals are readily deactivated and degraded by microbial activities. Moreover, the coastal lagoons observed are made up of flowing water; hence there is a possibility of chemicals being transported from one point to another. By so doing, they may disintegrate into other forms. The fact that pesticide residues were not detected does not mean they are absent. The results give a general indication that Sakumo, Chemu and Kpeshie lagoons were unpolluted with respect to the pesticide residues studied, and thus, there could be a possibility of pollution by other pesticide residues beyond the scope of this study.

Table 4.16: Mean concentrations of pesticide residues (ug/L) in water samples from Sakumo, Chemu and Kpeshie lagoons

Water samples from various lagoons (both wet and dry seasons)	Mean concentration in ug/L						
	p,p'-DDT (Limit - 2.00)	p,p'-DDD (Limit - 2.00)	p,p'-DDE (Limit - 2.00)	Aldrin (Limit - 0.03)	Dieldrin (Limit - 0.03)	Fenitrothion (Limit - 30.00)	Chlorpyrifos (Limit - 0.05)
Sakumo lagoon	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Chemu lagoon	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Kpeshie lagoon	BDL	BDL	BDL	BDL	BDL	BDL	BDL

*BDL – below detection limit

Table 4.17: Mean concentrations of pesticide residues (mg/kg) in sediment samples from Sakumo, Chemu and Kpeshie lagoons

Sediment samples from various lagoons (both wet and dry seasons)	Mean concentration in mg/kg						
	p,p'-DDT (Limit - 0.05)	p,p'-DDD (Limit - 0.04)	p,p'-DDE (Limit - 0.04)	Aldrin (Limit - 0.04)	Dieldrin (Limit - 0.03)	Fenitrothion (Limit - 0.05)	Chlorpyrifos (Limit - 0.03)
Sakumo lagoon	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Chemu lagoon	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Kpeshie lagoon	BDL	BDL	BDL	BDL	BDL	BDL	BDL

* BDL – below detection limit

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Physicochemical parameters (such as pH, total suspended solids, alkalinity, electrical conductivity, total dissolved solids, chloride, nitrate and phosphate), heavy metals (like copper, lead, iron, nickel, zinc and manganese) and pesticide residues (DT, DDD, DDE, aldrin, dieldrin, fenitrothion and chlorpyrifos) were analysed in water and sediment samples from Sakumo, Chemu and Kpeshie lagoons in this research. Sampling was done for both the wet and dry seasons. The results obtained were compared with EPA, Ghana; WHO and USEPA recommended limits. Most of the results obtained from the analyses were higher than the recommended limits of the agencies mentioned above. The water and sediment samples were of poor quality and this poses a threat to humans and animals that depend on these lagoons for their livelihood and survival.

The results obtained from the physicochemical analyses (pH, total suspended solids, alkalinity, chloride and nitrate) of the wet season water samples were generally higher than those obtained for the dry season water samples except for electrical conductivity, total dissolved solids and phosphate. This may be because during the wet season, the down-pour of rains and the increase in run-off from industrial waste, domestic waste, dump sites and farm lands might have caused the amount of ions and suspended particles present in the lagoons to increase. Also, there could be percolation of nutrients and ions into the lagoons during the wet season. Therefore within the period of this study, the pH and total suspended solids may have increased. A frequent flow and mixture of the lagoons with the sea took place. This could be the reason why there was a relative increase in alkalinity and chloride in the lagoons. The relatively higher nitrate values in the wet season could be due to the rapid mixture of surface water during the rainy season and the quick replenishment of nitrate from the surficial biogenic sediment as a consequence of microbial activities (Nayak & Behera, 2004).

Physicochemical parameters such as electrical conductivity, total dissolved solids and phosphate were relatively higher in the dry season. This could be ascribed to the reduction in the volume of water in the lagoons during the dry season because of evaporation at the water surface, which resulted in the concentration of ions and dissolved solids in the lagoons.

All the heavy metals determined [copper (Cu), lead (Pb), iron (Fe), nickel (Ni), zinc (Zn) and manganese (Mn)] generally had higher values in the dry season compared with the wet season. This may be because, during the dry season a larger volume of the water evaporated leading to the concentration of metals in the lagoons. Values of heavy metals obtained from the sediment analyses also observed a similar trend as above and this is comparable to work done by Klake *et al.* (2012) on the sediments in Sakumo and Kpeshie lagoons, Ghana.

The results obtained from the analyses of pesticide residues in the water and sediment samples from Sakumo, Chemu and Kpeshie lagoons were all below detection limits. In other words, pesticide residues were not detected (ND) in this study (Tables 4.16 and 4.17). This could be an indication that the ban on the use of some toxic chemicals like dichlorodiphenyltrichloroethane (DDT) amongst others is going down well. Information gathered in the course of this study showed that some individuals still use these toxic chemicals but do so on a micro scale.

Strong positive correlation exists between Cu and Pb, Cu and Fe, Cu and Ni, Cu and Zn, Cu and Mn, Pb and Fe, Pb and Ni, Pb and Zn, Pb and Mn, Fe and Ni, Fe and Zn, Fe and Mn, Ni and Zn, Ni and Mn, and Mn and Zn in sediment samples of Sakumo, Chemu and Kpeshie lagoons. This suggests that the metals came from a particular source such as industries, dump sites, construction sites, agricultural lands and possible geology of the lagoon.

Due to the increase in population at the coastal zone of Ghana, there is a heavy burden on coastal lagoons which poses a threat to these natural resources.

5.2 Recommendations

Based on the results of the study, it is recommended that the coastal lagoons should be regularly monitored and assessed by appropriate agencies like the EPA, Ghana; Tema Metropolitan Assembly (TMA) and the Wildlife department so that the indiscriminate release of effluents into the lagoons and other significant water bodies can be monitored and controlled.

The effluents that are released from surrounding industries should be monitored strictly in order to safe-guard the coastal lagoons. Also, regulatory mechanisms should be put in place and enforced to ensure that current deteriorations of the lagoons are not aggravated.

In addition, further investigations should be conducted to find out more about the presence of other inorganic and organic pollutants.

Lastly, there should be sustainable public education on natural resource management in Ghana.

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APPENDICES

APPENDIX A

TABLES OF PHYSICOCHEMICAL PARAMETERS OF WATER SAMPLES FROM SAKUMO LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF pH AND CONDUCTIVITY

SAMPLING POINTS	pH								CONDUCTIVITY							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	8.87	8.43	8.65	0.31	7.43	7.27	7.35	0.11	21843.00	25432.00	23637.50	2537.81	28324.00	29382.00	28853.00	748.12
Point 2	8.58	8.93	8.76	0.25	7.84	7.48	7.66	0.25	21765.00	26437.00	24101.00	3303.60	27482.00	28854.00	28168.00	970.15
Point 3	9.32	8.14	8.73	0.83	7.48	7.22	7.35	0.18	22743.00	25949.00	24346.00	2266.98	28904.00	29494.00	29199.00	417.19
Point 4	9.27	8.83	9.05	0.31	7.92	7.56	7.74	0.25	20594.00	26976.00	23785.00	4512.76	28455.00	29325.00	28890.00	615.18
Point 5	8.49	9.02	8.76	0.37	7.51	7.38	7.45	0.09	23868.00	26851.00	25359.50	2109.30	26849.00	28843.00	27846.00	1409.97
Point 6	9.18	8.97	9.08	0.15	7.38	7.26	7.32	0.08	22832.00	25895.00	24363.50	2165.87	27843.00	29764.00	28803.50	1358.35
MIN	8.49	8.14	8.65	0.15	7.38	7.22	7.32	0.08	20594.00	25432.00	23637.50	2109.30	26849.00	28843.00	27846.00	417.19
MAX	9.32	9.02	9.08	0.83	7.92	7.56	7.74	0.25	23868.00	26976.00	25359.50	4512.76	28904.00	29764.00	29199.00	1409.97
AVE	8.95	8.72	8.84	0.37	7.59	7.36	7.48	0.16	22274.17	26256.67	24265.42	2816.05	27976.17	29277.00	28626.58	919.83
STD	0.36	0.35	0.18	0.24	0.23	0.14	0.18	0.08	1126.00	601.45	610.78	939.96	740.75	364.66	509.75	402.49

TABLES OF PHYSICOCHEMICAL PARAMETERS OF WATER SAMPLES FROM SAKUMO LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF TDS AND TSS

SAMPLING POINTS	TDS								TSS							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	14197.95	16530.80	15364.38	1649.57	18410.60	19098.30	18754.45	486.28	60.72	57.33	59.03	2.40	48.74	35.63	42.19	9.27
Point 2	14147.25	17184.05	15665.65	2147.34	17863.30	18755.10	18309.20	630.60	60.32	58.13	59.23	1.55	47.87	35.83	41.85	8.51
Point 3	14782.95	16866.85	15824.90	1473.54	18787.60	19171.10	18979.35	271.18	61.63	56.62	59.13	3.54	48.35	34.76	41.56	9.61
Point 4	13386.10	17534.40	15460.25	2933.29	18495.75	19061.25	18778.50	399.87	62.82	57.83	60.33	3.53	48.28	35.42	41.85	9.09
Point 5	15514.20	17453.15	16483.68	1371.04	17451.85	18747.95	18099.90	916.48	62.14	56.34	59.24	4.10	47.63	34.95	41.29	8.97
Point 6	14840.80	16831.75	15836.28	1407.81	18097.95	19346.60	18722.28	882.93	61.76	58.05	59.91	2.62	46.98	34.21	40.60	9.03
MIN	13386.10	16530.80	15364.38	1371.04	17451.85	18747.95	18099.90	271.18	60.32	56.34	59.03	1.55	46.98	34.21	40.60	8.51
MAX	15514.20	17534.40	16483.68	2933.29	18787.60	19346.60	18979.35	916.48	62.82	58.13	60.33	4.10	48.74	35.83	42.19	9.61
AVE	14478.21	17066.83	15772.52	1830.43	18184.51	19030.05	18607.28	597.89	61.57	57.38	59.47	2.96	47.98	35.13	41.55	9.08
STD	731.90	390.94	397.01	610.98	481.49	237.03	331.34	261.62	0.92	0.76	0.52	0.94	0.62	0.61	0.56	0.36

TABLES OF PHYSICOCHEMICAL PARAMETERS OF WATER SAMPLES FROM SAKUMO LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF ALKALINITY AND CHLORIDE

SAMPLING POINTS	ALKALINITY								CHLORIDE							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	1023.00	992.00	1007.50	21.92	782.00	723.00	752.50	41.72	7850.93	7938.00	7894.47	61.57	8702.54	9146.00	8924.27	313.57
Point 2	1044.00	983.00	1013.50	43.13	753.00	732.00	742.50	14.85	7924.35	8021.00	7972.68	68.34	8823.65	9273.00	9048.33	317.74
Point 3	1153.00	947.00	1050.00	145.66	769.00	719.00	744.00	35.36	8530.23	8732.00	8631.12	142.67	8900.32	9318.00	9109.16	295.34
Point 4	1054.00	988.00	1021.00	46.67	742.00	738.00	740.00	2.83	8323.65	8581.00	8452.33	181.97	9102.18	9421.00	9261.59	225.44
Point 5	1173.00	952.00	1062.50	156.27	786.00	727.00	756.50	41.72	8186.88	8436.00	8311.44	176.15	9098.32	9382.00	9240.16	200.59
Point 6	1193.00	965.00	1079.00	161.22	735.00	743.00	739.00	5.66	8003.85	8273.00	8138.43	190.32	9238.77	9471.00	9354.89	164.21
MIN	1023.00	947.00	1007.50	21.92	735.00	719.00	739.00	2.83	7850.93	7938.00	7894.47	61.57	8702.54	9146.00	8924.27	164.21
MAX	1193.00	992.00	1079.00	161.22	786.00	743.00	756.50	41.72	8530.23	8732.00	8631.12	190.32	9238.77	9471.00	9354.89	317.74
AVE	1106.67	971.17	1038.92	95.81	761.17	730.33	745.75	23.69	8136.65	8330.17	8233.41	136.84	8977.63	9335.17	9156.40	252.82
STD	74.43	19.22	29.12	64.91	21.12	9.11	7.12	18.03	259.52	312.49	284.28	58.02	201.81	116.58	158.29	64.87

TABLES OF PHYSICOCHEMICAL PARAMETERS OF WATER SAMPLES FROM SAKUMO LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF PHOSPHATE AND NITRATE

SAMPLING POINTS	PHOSPHATE								NITRATE							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	3.21	2.18	2.70	0.73	5.23	4.35	4.79	0.62	35.84	33.54	34.69	1.63	20.76	22.72	21.74	1.39
Point 2	3.32	2.03	2.68	0.91	5.17	4.26	4.72	0.64	35.53	32.67	34.10	2.02	21.73	22.28	22.01	0.39
Point 3	3.47	2.21	2.84	0.89	5.42	4.62	5.02	0.57	35.72	33.76	34.74	1.39	21.85	22.45	22.15	0.42
Point 4	3.28	2.13	2.71	0.81	5.32	4.53	4.93	0.56	35.61	33.97	34.79	1.16	20.57	22.63	21.60	1.46
Point 5	3.39	2.07	2.73	0.93	5.11	4.21	4.66	0.64	35.74	32.83	34.29	2.06	21.33	22.41	21.87	0.76
Point 6	3.27	2.25	2.76	0.72	5.28	4.48	4.88	0.57	35.63	32.92	34.28	1.92	21.77	22.60	22.19	0.59
MIN	3.21	2.03	2.68	0.72	5.11	4.21	4.66	0.56	35.53	32.67	34.10	1.16	20.57	22.28	21.60	0.39
MAX	3.47	2.25	2.84	0.93	5.42	4.62	5.02	0.64	35.84	33.97	34.79	2.06	21.85	22.72	22.19	1.46
AVE	3.32	2.15	2.73	0.83	5.26	4.41	4.83	0.60	35.68	33.28	34.48	1.69	21.34	22.52	21.93	0.83
STD	0.09	0.08	0.06	0.09	0.11	0.16	0.14	0.04	0.11	0.54	0.29	0.37	0.55	0.16	0.23	0.47

TABLES OF PHYSICOCHEMICAL PARAMETERS OF WATER SAMPLES FROM CHEMU LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF pH AND CONDUCTIVITY

SAMPLING	pH								CONDUCTIVITY							
POINTS	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	10.76	9.26	10.01	1.06	8.37	8.05	8.21	0.23	18462.00	19601.00	19031.50	805.39	19271.00	21312.00	20291.50	1443.20
Point 2	10.35	9.79	10.07	0.40	8.82	8.26	8.54	0.40	17535.00	19956.00	18745.50	1711.91	20837.00	20821.00	20829.00	11.31
Point 3	9.86	8.47	9.17	0.98	8.65	8.18	8.42	0.33	18679.00	18221.00	18450.00	323.85	20874.00	21622.00	21248.00	528.92
Point 4	11.06	10.21	10.64	0.60	8.92	8.63	8.78	0.21	18566.00	18254.00	18410.00	220.62	20351.00	21432.00	20891.50	764.38
Point 5	10.42	9.38	9.90	0.74	8.36	7.85	8.11	0.36	18941.00	18621.00	18781.00	226.27	21463.00	22643.00	22053.00	834.39
Point 6	10.38	8.95	9.67	1.01	8.73	8.29	8.51	0.31	17353.00	17938.00	17645.50	413.66	19682.00	20967.00	20324.50	908.63
MIN	9.86	8.47	9.17	0.40	8.36	7.85	8.11	0.21	17353.00	17938.00	17645.50	220.62	19271.00	20821.00	20291.50	11.31
MAX	11.06	10.21	10.64	1.06	8.92	8.63	8.78	0.40	18941.00	19956.00	19031.50	1711.91	21463.00	22643.00	22053.00	1443.20
AVE	10.47	9.34	9.91	0.80	8.64	8.21	8.43	0.31	18256.00	18765.17	18510.58	616.95	20413.00	21466.17	20939.58	748.47
STD	0.41	0.61	0.49	0.27	0.23	0.26	0.24	0.08	651.45	822.08	482.04	578.17	816.97	648.01	655.39	470.65

TABLES OF PHYSICOCHEMICAL PARAMETERS OF WATER SAMPLES FROM CHEMU LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF TDS AND TSS

SAMPLING POINTS	TDS								TSS							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	12000.30	12740.65	12370.48	523.51	12526.15	13852.80	13189.48	938.08	165.83	156.32	161.08	6.72	137.98	122.97	130.48	10.61
Point 2	11397.75	12971.40	12184.58	1112.74	13544.05	13533.65	13538.85	7.35	164.92	157.25	161.09	5.42	141.73	121.48	131.61	14.32
Point 3	12141.35	11843.65	11992.50	210.51	13568.10	14054.30	13811.20	343.80	164.45	154.72	159.59	6.88	138.27	121.54	129.91	11.83
Point 4	12067.90	11865.10	11966.50	143.40	13228.15	13930.80	13579.48	496.85	167.53	157.12	162.33	7.36	140.64	122.03	131.34	13.16
Point 5	12311.65	12103.65	12207.65	147.08	13950.95	14717.95	14334.45	542.35	166.82	154.84	160.83	8.47	138.82	120.92	129.87	12.66
Point 6	11279.45	11659.70	11469.58	268.88	12793.30	13628.55	13210.93	590.61	167.07	155.93	161.50	7.88	141.02	121.79	131.41	13.60
MIN	11279.45	11659.70	11469.58	143.40	12526.15	13533.65	13189.48	7.35	164.45	154.72	159.59	5.42	137.98	120.92	129.87	10.61
MAX	12311.65	12971.40	12370.48	1112.74	13950.95	14717.95	14334.45	938.08	167.53	157.25	162.33	8.47	141.73	122.97	131.61	14.32
AVE	11866.40	12197.36	12031.88	401.02	13268.45	13953.01	13610.73	486.51	166.10	156.03	161.07	7.12	139.74	121.79	130.77	12.70
STD	423.44	534.35	313.33	375.81	531.03	421.20	426.01	305.92	1.24	1.09	0.90	1.05	1.58	0.69	0.78	1.32

TABLES OF PHYSICOCHEMICAL PARAMETERS OF WATER SAMPLES FROM CHEMU LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF ALKALINITY AND CHLORIDE

SAMPLING POINTS	ALKALINITY								CHLORIDE							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	1526.00	1421.00	1473.50	74.25	1224.00	1132.00	1178.00	1526.00	140.32	132.87	136.60	5.27	5460.43	5684.00	5572.22	158.09
Point 2	1584.00	1483.00	1533.50	71.42	1243.00	1274.00	1258.50	1584.00	138.64	131.72	135.18	4.89	5409.37	5579.00	5494.19	119.95
Point 3	1529.00	1439.00	1484.00	63.64	1258.00	1184.00	1221.00	1529.00	141.92	131.37	136.65	7.46	5360.23	5468.00	5414.12	76.20
Point 4	1533.00	1472.00	1502.50	43.13	1353.00	1158.00	1255.50	1533.00	139.28	132.74	136.01	4.62	5450.91	5629.00	5539.96	125.93
Point 5	1547.00	1464.00	1505.50	58.69	1321.00	1235.00	1278.00	1547.00	140.83	132.65	136.74	5.78	5330.28	5581.00	5455.64	177.29
Point 6	1581.00	1453.00	1517.00	90.51	1282.00	1172.00	1227.00	1581.00	139.22	131.32	135.27	5.59	5378.32	5497.00	5437.66	83.92
MIN	1526.00	1421.00	1473.50	43.13	1224.00	1132.00	1178.00	1526.00	138.64	131.32	135.18	4.62	5330.28	5468.00	5414.12	76.20
MAX	1584.00	1483.00	1533.50	90.51	1353.00	1274.00	1278.00	1584.00	141.92	132.87	136.74	7.46	5460.43	5684.00	5572.22	177.29
AVE	1550.00	1455.33	1502.67	66.94	1280.17	1192.50	1236.33	1550.00	140.04	132.11	136.07	5.60	5398.26	5573.00	5485.63	123.56
STD	26.20	22.67	21.74	15.97	49.00	52.52	35.55	26.20	1.22	0.72	0.71	1.01	51.43	80.45	61.38	39.78

TABLES OF PHYSICOCHEMICAL PARAMETERS OF WATER SAMPLES FROM CHEMU LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF PHOSPHATE AND NITRATE

SAMPLING POINTS	PHOSPHATE								NITRATE							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	6.32	5.63	5.98	0.49	10.71	9.63	10.17	0.76	107.24	98.84	103.04	5.94	78.35	75.65	77.00	1.91
Point 2	6.57	5.39	5.98	0.83	10.65	9.49	10.07	0.82	108.32	98.43	103.38	6.99	79.83	76.34	78.09	2.47
Point 3	6.42	5.58	6.00	0.59	10.76	9.61	10.19	0.81	107.89	99.12	103.51	6.20	79.45	75.85	77.65	2.55
Point 4	6.63	5.59	6.11	0.74	10.59	9.58	10.09	0.71	107.46	98.31	102.89	6.47	79.72	75.37	77.55	3.08
Point 5	6.38	5.36	5.87	0.72	10.51	9.42	9.97	0.77	108.34	99.54	103.94	6.22	78.93	76.25	77.59	1.90
Point 6	6.67	5.48	6.08	0.84	10.67	9.68	10.18	0.70	107.55	98.59	103.07	6.34	78.12	76.21	77.17	1.35
MIN	6.32	5.36	5.87	0.49	10.51	9.42	9.97	0.70	107.24	98.31	102.89	5.94	78.12	75.37	77.00	1.35
MAX	6.67	5.63	6.11	0.84	10.76	9.68	10.19	0.82	108.34	99.54	103.94	6.99	79.83	76.34	78.09	3.08
AVE	6.50	5.51	6.00	0.70	10.65	9.57	10.11	0.76	107.80	98.81	103.30	6.36	79.07	75.95	77.51	2.21
STD	0.14	0.11	0.08	0.14	0.09	0.10	0.09	0.05	0.46	0.46	0.39	0.36	0.72	0.39	0.38	0.61

TABLES OF PHYSICOCHEMICAL PARAMETERS OF WATER SAMPLES FROM KPESHIE LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF pH AND CONDUCTIVITY

SAMPLING POINTS	pH								CONDUCTIVITY							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	9.36	8.57	8.97	0.56	8.32	7.83	8.08	0.35	21281.00	24721.00	23001.00	2432.45	25549.00	27826.00	26687.50	1610.08
Point 2	10.08	8.28	9.18	1.27	8.21	7.92	8.07	0.21	21854.00	23865.00	22859.50	1421.99	26473.00	28481.00	27477.00	1419.87
Point 3	9.89	8.64	9.27	0.88	8.19	7.64	7.92	0.39	20182.00	23803.00	21992.50	2560.43	24902.00	27297.00	26099.50	1693.52
Point 4	9.78	8.92	9.35	0.61	8.38	8.07	8.23	0.22	20593.00	23421.00	22007.00	1999.70	26821.00	27801.00	27311.00	692.96
Point 5	10.13	9.48	9.81	0.46	8.41	7.96	8.19	0.32	21393.00	24382.00	22887.50	2113.54	23371.00	27249.00	25310.00	2742.16
Point 6	9.82	9.33	9.58	0.35	8.25	8.12	8.19	0.09	21238.00	24210.00	22724.00	2101.52	25743.00	28842.00	27292.50	2191.32
MIN	9.36	8.28	8.97	0.35	8.19	7.64	7.92	0.09	20182.00	23421.00	21992.50	1421.99	23371.00	27249.00	25310.00	692.96
MAX	10.13	9.48	9.81	1.27	8.41	8.12	8.23	0.39	21854.00	24721.00	23001.00	2560.43	26821.00	28842.00	27477.00	2742.16
AVE	9.84	8.87	9.36	0.69	8.29	7.92	8.11	0.26	21090.17	24067.00	22578.58	2104.94	25476.50	27916.00	26696.25	1724.99
STD	0.28	0.46	0.30	0.34	0.09	0.17	0.11	0.11	600.89	463.73	456.97	398.07	1236.14	636.57	850.99	696.34

TABLES OF PHYSICOCHEMICAL PARAMETERS OF WATER SAMPLES FROM KPESHIE LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF TDS AND TSS

SAMPLING POINTS	TDS								TSS							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	13832.65	16068.65	14950.65	1581.09	16606.85	18086.90	17346.88	1046.55	136.79	127.21	132.00	6.77	112.21	92.76	102.49	13.75
Point 2	14205.10	15512.25	14858.68	924.29	17207.45	18512.65	17860.05	922.92	135.86	125.82	130.84	7.10	114.62	91.89	103.26	16.07
Point 3	13118.30	15471.95	14295.13	1664.28	16186.30	17743.05	16964.68	1100.79	135.94	124.01	129.98	8.44	114.04	91.21	102.63	16.14
Point 4	13385.45	15223.65	14304.55	1299.80	17433.65	18070.65	17752.15	450.43	136.53	125.26	130.90	7.97	113.87	92.27	103.07	15.27
Point 5	13905.45	15848.30	14876.88	1373.80	15191.15	17711.85	16451.50	1782.40	136.05	126.92	131.49	6.46	112.73	90.92	101.83	15.42
Point 6	13804.70	15736.50	14770.60	1365.99	16732.95	18747.30	17740.13	1424.36	135.78	126.03	130.91	6.89	113.57	90.61	102.09	16.24
MIN	13118.30	15223.65	14295.13	924.29	15191.15	17711.85	16451.50	450.43	135.78	124.01	129.98	6.46	112.21	90.61	101.83	13.75
MAX	14205.10	16068.65	14950.65	1664.28	17433.65	18747.30	17860.05	1782.40	136.79	127.21	132.00	8.44	114.62	92.76	103.26	16.24
AVE	13708.61	15643.55	14676.08	1368.21	16559.73	18145.40	17352.56	1121.24	136.16	125.88	131.02	7.27	113.51	91.61	102.56	15.48
STD	390.58	301.42	297.03	258.75	803.49	413.77	553.14	452.62	0.41	1.16	0.68	0.77	0.89	0.83	0.55	0.94

TABLES OF PHYSICOCHEMICAL PARAMETERS OF WATER SAMPLES FROM KPESHIE LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF ALKALINITY AND CHLORIDE

SAMPLING POINTS	ALKALINITY								CHLORIDE							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	1264.00	1142.00	1203.00	86.27	1038.00	971.00	1004.50	47.38	6254.93	6426.43	6340.68	121.27	6865.02	7102.00	6983.51	167.57
Point 2	1252.00	1163.00	1207.50	62.93	1027.00	942.00	984.50	60.10	6132.04	6491.00	6311.52	253.82	6790.00	7087.00	6938.50	210.01
Point 3	1273.00	1158.00	1215.50	81.32	1131.00	1012.00	1071.50	84.15	6210.06	6542.00	6376.03	234.72	6370.24	7096.00	6733.12	513.19
Point 4	1245.00	1149.00	1197.00	67.88	1121.00	934.00	1027.50	132.23	6223.29	6437.00	6330.15	151.12	6589.65	7113.00	6851.33	370.06
Point 5	1261.00	1152.00	1206.50	77.07	1083.00	983.00	1033.00	70.71	6289.56	6471.00	6380.28	128.30	6678.82	7108.00	6893.41	303.48
Point 6	1273.00	1171.00	1222.00	72.12	1092.00	1007.00	1049.50	60.10	6231.74	6531.00	6381.37	211.61	6568.24	7074.00	6821.12	357.63
MIN	1245.00	1142.00	1197.00	62.93	1027.00	934.00	984.50	47.38	6132.04	6426.43	6311.52	121.27	6370.24	7074.00	6733.12	167.57
MAX	1273.00	1171.00	1222.00	86.27	1131.00	1012.00	1071.50	132.23	6289.56	6542.00	6381.37	253.82	6865.02	7113.00	6983.51	513.19
AVE	1261.33	1155.83	1208.58	74.60	1082.00	974.83	1028.42	75.78	6223.60	6483.07	6353.34	183.47	6643.66	7096.67	6870.16	320.32
STD	11.25	10.38	8.93	8.66	42.39	32.38	31.06	30.27	52.85	47.56	29.91	57.14	176.08	14.36	88.99	123.98

TABLES OF PHYSICOCHEMICAL PARAMETERS OF WATER SAMPLES FROM KPESHIE LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF PHOSPHATE AND NITRATE

SAMPLING POINTS	PHOSPHATE								NITRATE							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	6.86	5.21	6.04	1.17	8.84	7.25	8.05	1.12	88.56	86.24	87.40	1.64	48.83	45.62	47.23	2.27
Point 2	6.57	5.13	5.85	1.02	8.63	7.36	8.00	0.90	88.32	87.78	88.05	0.38	48.75	44.43	46.59	3.05
Point 3	6.75	5.28	6.02	1.04	8.73	7.64	8.19	0.77	88.87	87.44	88.16	1.01	47.39	44.98	46.19	1.70
Point 4	6.74	5.15	5.95	1.12	8.81	7.53	8.17	0.91	87.91	86.83	87.37	0.76	47.73	45.35	46.54	1.68
Point 5	6.84	5.32	6.08	1.07	8.79	7.43	8.11	0.96	87.67	86.06	86.87	1.14	48.32	44.72	46.52	2.55
Point 6	6.68	5.18	5.93	1.06	8.68	7.28	7.98	0.99	88.13	87.27	87.70	0.61	47.75	45.82	46.79	1.36
MIN	6.57	5.13	5.85	1.02	8.63	7.25	7.98	0.77	87.67	86.06	86.87	0.38	47.39	44.43	46.19	1.36
MAX	6.86	5.32	6.08	1.17	8.84	7.64	8.19	1.12	88.87	87.78	88.16	1.64	48.83	45.82	47.23	3.05
AVE	6.74	5.21	5.98	1.08	8.75	7.42	8.08	0.94	88.24	86.94	87.59	0.92	48.13	45.15	46.64	2.10
STD	0.11	0.07	0.08	0.06	0.08	0.15	0.09	0.12	0.44	0.68	0.48	0.44	0.59	0.54	0.35	0.63

APPENDIX B

TABLES OF HEAVY METALS OF WATER SAMPLES FROM SAKUMO LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF Cu AND Pb

SAMPLING POINTS	Cu								Pb							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	3.43	4.12	3.78	0.49	4.43	5.62	5.03	0.84	0.06	0.12	0.55	0.04	0.13	0.16	0.15	0.02
Point 2	2.85	3.54	3.20	0.49	5.84	6.22	6.03	0.27	0.08	0.11	0.13	0.02	0.14	0.12	0.13	0.01
Point 3	3.13	3.83	3.48	0.49	4.79	5.45	5.12	0.47	0.05	0.07	0.29	0.01	0.09	0.15	0.12	0.04
Point 4	2.48	3.25	2.87	0.54	4.96	5.39	5.18	0.30	0.06	0.07	0.17	0.01	0.11	0.14	0.13	0.02
Point 5	3.87	4.03	3.95	0.11	5.45	6.21	5.83	0.54	0.04	0.09	0.35	0.04	0.15	0.14	0.15	0.01
Point 6	3.53	3.66	3.60	0.09	4.74	5.62	5.18	0.62	0.07	0.11	0.39	0.03	0.13	0.16	0.15	0.02
MIN	2.48	3.25	2.87	0.09	4.43	5.39	5.03	0.27	0.04	0.07	0.13	0.01	0.09	0.12	0.12	0.01
MAX	3.87	4.12	3.95	0.54	5.84	6.22	6.03	0.84	0.08	0.12	0.55	0.04	0.15	0.16	0.15	0.04
AVE	3.22	3.74	3.48	0.37	5.04	5.75	5.39	0.51	0.06	0.10	0.32	0.02	0.13	0.15	0.14	0.02
STD	0.50	0.32	0.40	0.21	0.52	0.37	0.42	0.21	0.01	0.02	0.15	0.01	0.02	0.02	0.01	0.01

TABLES OF HEAVY METALS OF WATER SAMPLES FROM SAKUMO LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF Fe AND Ni

SAMPLING POINTS	Fe								Ni							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	7.24	7.88	5.10	0.45	9.78	9.94	6.60	0.11	2.83	3.32	1.92	0.35	3.74	4.21	2.40	0.33
Point 2	6.87	8.62	4.85	1.24	10.02	10.25	6.21	0.16	2.94	3.26	1.96	0.23	3.85	4.02	2.56	0.12
Point 3	6.56	8.45	4.61	1.34	9.47	10.03	5.75	0.40	2.89	3.52	1.76	0.45	3.48	4.17	2.15	0.49
Point 4	7.41	8.24	5.22	0.59	9.72	9.95	6.46	0.16	2.64	3.21	1.75	0.40	3.52	3.95	2.20	0.30
Point 5	7.53	7.96	5.32	0.30	9.86	10.32	6.76	0.33	3.02	2.94	1.91	0.06	3.87	4.13	2.70	0.18
Point 6	7.42	7.83	5.23	0.29	9.67	9.84	6.63	0.12	2.96	3.25	2.01	0.21	3.98	3.93	2.67	0.04
MIN	6.56	7.83	4.61	0.29	9.47	9.84	5.75	0.11	2.64	2.94	1.75	0.06	3.48	3.93	2.15	0.04
MAX	7.53	8.62	5.32	1.34	10.02	10.32	6.76	0.40	3.02	3.52	2.01	0.45	3.98	4.21	2.70	0.49
AVE	7.17	8.16	5.06	0.70	9.75	10.06	6.40	0.21	2.88	3.25	1.89	0.28	3.74	4.07	2.45	0.24
STD	0.38	0.33	0.27	0.47	0.19	0.19	0.37	0.12	0.13	0.19	0.11	0.15	0.20	0.12	0.24	0.16

TABLES OF HEAVY METALS OF WATER SAMPLES FROM SAKUMO LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF Zn AND Mn

SAMPLING POINTS	Zn								Mn							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	5.32	6.37	3.53	0.74	7.92	8.13	5.08	0.15	0.24	0.37	0.06	0.09	0.42	0.51	0.23	0.06
Point 2	5.45	5.89	3.77	0.31	7.63	7.91	5.18	0.20	0.26	0.38	0.04	0.08	0.47	0.45	0.27	0.01
Point 3	5.62	6.25	3.63	0.45	7.57	8.04	5.04	0.33	0.21	0.32	0.09	0.08	0.45	0.48	0.26	0.02
Point 4	5.67	6.18	3.79	0.36	7.49	7.83	5.04	0.24	0.25	0.39	0.01	0.10	0.43	0.53	0.23	0.07
Point 5	5.39	5.93	3.68	0.38	7.83	8.11	5.27	0.20	0.21	0.35	0.01	0.10	0.45	0.49	0.25	0.03
Point 6	5.71	6.11	4.01	0.28	7.72	7.94	5.26	0.16	0.24	0.33	0.06	0.06	0.48	0.47	0.29	0.01
MIN	5.32	5.89	3.53	0.28	7.49	7.83	5.04	0.15	0.21	0.32	0.01	0.06	0.42	0.45	0.23	0.01
MAX	5.71	6.37	4.01	0.74	7.92	8.13	5.27	0.33	0.26	0.39	0.09	0.10	0.48	0.53	0.29	0.07
AVE	5.53	6.12	3.74	0.42	7.69	7.99	5.14	0.21	0.24	0.36	0.05	0.09	0.45	0.49	0.26	0.03
STD	0.16	0.19	0.17	0.17	0.16	0.12	0.11	0.07	0.02	0.03	0.03	0.01	0.02	0.03	0.02	0.03

TABLES OF HEAVY METALS OF WATER SAMPLES FROM CHEMU LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF Cu AND Pb

SAMPLING POINTS	Cu								Pb							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	8.33	9.41	8.87	0.76	10.81	12.42	11.62	1.14	0.47	0.57	0.52	0.07	0.64	0.74	0.69	0.07
Point 2	7.81	8.82	8.32	0.71	11.32	12.51	11.92	0.84	0.53	0.61	0.57	0.06	0.67	0.69	0.68	0.01
Point 3	9.64	9.13	9.39	0.36	11.72	12.33	12.03	0.43	0.49	0.54	0.52	0.04	0.63	0.72	0.68	0.06
Point 4	7.52	9.61	8.57	1.48	10.91	11.55	11.23	0.45	0.46	0.64	0.55	0.13	0.71	0.65	0.68	0.04
Point 5	8.21	8.72	8.47	0.36	11.14	11.87	11.51	0.52	0.52	0.58	0.55	0.04	0.68	0.71	0.70	0.02
Point 6	7.71	9.22	8.32	1.07	11.38	12.32	11.85	0.66	0.58	0.60	0.59	0.01	0.62	0.68	0.65	0.04
MIN	7.52	8.72	8.32	0.36	10.81	11.55	11.23	0.43	0.46	0.54	0.52	0.01	0.62	0.65	0.65	0.01
MAX	9.64	9.61	9.39	1.48	11.72	12.51	12.03	1.14	0.58	0.64	0.59	0.13	0.71	0.74	0.70	0.07
AVE	8.20	9.15	8.65	0.79	11.21	12.17	11.69	0.67	0.51	0.59	0.55	0.06	0.66	0.70	0.68	0.04
STD	0.77	0.34	0.41	0.43	0.33	0.37	0.30	0.27	0.04	0.03	0.03	0.04	0.03	0.03	0.02	0.02

TABLES OF HEAVY METALS OF WATER SAMPLES FROM CHEMU LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF Fe AND Ni

SAMPLING POINTS	Fe								Ni							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	20.78	23.73	22.26	2.09	27.54	28.23	27.89	0.49	7.55	8.56	8.06	0.71	9.53	10.21	9.87	0.48
Point 2	21.36	24.22	22.79	2.02	26.84	27.67	27.26	0.59	7.64	8.75	8.20	0.78	9.72	10.14	9.93	0.30
Point 3	21.64	25.37	23.51	2.64	27.21	28.18	27.70	0.69	8.23	8.92	8.58	0.49	8.98	9.83	9.41	0.60
Point 4	20.96	24.27	22.62	2.34	26.43	28.26	27.35	1.29	8.17	8.98	8.58	0.57	8.73	10.17	9.45	1.02
Point 5	21.23	23.96	22.60	1.93	27.31	27.28	27.30	0.02	7.89	8.34	8.12	0.32	9.42	10.09	9.76	0.47
Point 6	21.28	25.53	23.41	3.01	26.95	27.89	27.42	0.66	8.41	8.54	8.48	0.09	9.58	9.95	9.77	0.26
MIN	20.78	23.73	22.26	1.93	26.43	27.28	27.26	0.02	7.55	8.34	8.06	0.09	8.73	9.83	9.41	0.26
MAX	21.64	25.53	23.51	3.01	27.54	28.26	27.89	1.29	8.41	8.98	8.58	0.78	9.72	10.21	9.93	1.02
AVE	21.21	24.51	22.86	2.34	27.05	27.92	27.48	0.62	7.98	8.68	8.33	0.49	9.33	10.07	9.70	0.52
STD	0.30	0.75	0.49	0.42	0.39	0.39	0.25	0.41	0.34	0.25	0.24	0.26	0.39	0.15	0.22	0.27

TABLES OF HEAVY METALS OF WATER SAMPLES FROM CHEMU LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF Zn AND Mn

SAMPLING POINTS	Zn								Mn							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	16.32	18.56	17.44	1.58	23.56	25.12	24.34	1.10	0.63	0.78	0.71	0.11	1.39	1.52	1.46	0.09
Point 2	16.74	18.22	17.48	1.05	23.87	24.65	24.26	0.55	0.61	0.82	0.72	0.15	1.36	1.49	1.43	0.09
Point 3	17.23	19.46	18.35	1.58	22.98	25.05	24.02	1.46	0.58	0.79	0.69	0.15	1.41	1.56	1.49	0.11
Point 4	17.18	19.20	18.19	1.43	22.78	24.89	23.84	1.49	0.65	0.84	0.75	0.13	1.45	1.47	1.46	0.01
Point 5	16.86	18.12	17.49	0.89	23.32	25.23	24.28	1.35	0.55	0.81	0.68	0.18	1.35	1.44	1.40	0.06
Point 6	17.21	18.87	18.04	1.17	22.84	24.75	23.80	1.35	0.61	0.81	0.71	0.14	1.44	1.50	1.47	0.04
MIN	16.32	18.12	17.44	0.89	22.78	24.65	23.80	0.55	0.55	0.78	0.68	0.11	1.35	1.44	1.40	0.01
MAX	17.23	19.46	18.35	1.58	23.87	25.23	24.34	1.49	0.65	0.84	0.75	0.18	1.45	1.56	1.49	0.11
AVE	16.92	18.74	17.83	1.28	23.23	24.95	24.09	1.22	0.61	0.81	0.71	0.14	1.40	1.50	1.45	0.07
STD	0.36	0.54	0.41	0.29	0.43	0.22	0.24	0.35	0.04	0.02	0.02	0.03	0.04	0.04	0.03	0.04

TABLES OF HEAVY METALS OF WATER SAMPLES FROM KPESHIE LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF Cu AND Pb

SAMPLING POINTS	Cu								Pb							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	6.32	7.25	6.79	0.66	8.43	8.83	8.63	0.28	0.27	0.36	0.32	0.06	0.46	0.52	0.49	0.04
Point 2	5.78	6.83	6.31	0.74	7.82	8.41	8.12	0.42	0.31	0.39	0.35	0.06	0.48	0.49	0.49	0.01
Point 3	5.74	6.45	6.10	0.50	7.58	8.75	8.17	0.83	0.35	0.38	0.37	0.02	0.51	0.48	0.50	0.02
Point 4	6.56	7.12	6.84	0.40	8.31	9.03	8.67	0.51	0.29	0.32	0.31	0.02	0.42	0.51	0.47	0.06
Point 5	6.41	6.27	6.34	0.10	8.43	8.62	8.53	0.13	0.34	0.36	0.35	0.01	0.45	0.51	0.48	0.04
Point 6	5.94	7.46	6.70	1.07	8.38	8.27	8.33	0.08	0.28	0.38	0.33	0.07	0.51	0.47	0.49	0.03
MIN	5.74	6.27	6.10	0.10	7.58	8.27	8.12	0.08	0.27	0.32	0.31	0.01	0.42	0.47	0.47	0.01
MAX	6.56	7.46	6.84	1.07	8.43	9.03	8.67	0.83	0.35	0.39	0.37	0.07	0.51	0.52	0.50	0.06
AVE	6.13	6.90	6.51	0.58	8.16	8.65	8.41	0.37	0.31	0.37	0.34	0.04	0.47	0.50	0.48	0.03
STD	0.35	0.47	0.30	0.33	0.37	0.28	0.24	0.28	0.03	0.03	0.02	0.03	0.04	0.02	0.01	0.02

TABLES OF HEAVY METALS OF WATER SAMPLES FROM KPESHIE LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF Fe AND Ni

SAMPLING POINTS	Fe								Ni							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	15.63	19.73	17.68	2.90	20.63	22.52	21.58	1.34	4.03	5.86	4.95	1.29	6.84	8.19	7.52	0.95
Point 2	17.23	18.95	18.09	1.22	20.10	21.86	20.98	1.24	4.15	5.47	4.81	0.93	7.31	8.03	7.67	0.51
Point 3	16.38	18.75	17.57	1.68	21.72	22.27	22.00	0.39	4.21	5.73	4.97	1.07	7.24	7.98	7.61	0.52
Point 4	15.89	19.52	17.71	2.57	22.01	22.63	22.32	0.44	4.08	5.39	4.74	0.93	6.93	7.86	7.40	0.66
Point 5	17.14	19.35	18.25	1.56	21.98	21.92	21.95	0.04	4.19	5.68	4.94	1.05	7.08	8.01	7.55	0.66
Point 6	16.59	18.92	17.76	1.65	21.70	21.79	21.75	0.06	4.05	5.77	4.91	1.22	7.17	8.13	7.65	0.68
MIN	15.63	18.75	17.57	1.22	20.10	21.79	20.98	0.04	4.03	5.39	4.74	0.93	6.84	7.86	7.40	0.51
MAX	17.23	19.73	18.25	2.90	22.01	22.63	22.32	1.34	4.21	5.86	4.97	1.29	7.31	8.19	7.67	0.95
AVE	16.48	19.20	17.84	1.93	21.36	22.17	21.76	0.59	4.12	5.65	4.88	1.08	7.10	8.03	7.56	0.66
STD	0.65	0.39	0.27	0.65	0.80	0.36	0.46	0.57	0.08	0.18	0.09	0.15	0.18	0.12	0.10	0.16

TABLES OF HEAVY METALS OF WATER SAMPLES FROM KPESHIE LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF Zn AND Mn

SAMPLING POINTS	Zn								Mn							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	12.32	13.87	13.10	1.10	18.34	19.54	18.94	0.85	0.41	0.58	0.50	0.12	0.92	1.12	1.02	0.14
Point 2	12.21	14.74	13.48	1.79	18.84	19.03	18.94	0.13	0.43	0.52	0.48	0.06	1.12	1.03	1.08	0.06
Point 3	12.07	14.22	13.15	1.52	18.46	19.32	18.89	0.61	0.48	0.57	0.53	0.06	0.97	1.09	1.03	0.08
Point 4	12.30	13.97	13.14	1.18	18.73	19.48	19.11	0.53	0.51	0.51	0.51	0.00	0.95	1.17	1.06	0.16
Point 5	12.41	13.93	13.17	1.07	18.29	19.26	18.78	0.69	0.49	0.52	0.51	0.02	1.02	1.14	1.08	0.08
Point 6	12.04	14.15	13.10	1.49	18.08	19.08	18.58	0.71	0.42	0.56	0.49	0.10	1.15	1.05	1.10	0.07
MIN	12.04	13.87	13.10	1.07	18.08	19.03	18.58	0.13	0.41	0.51	0.48	0.00	0.92	1.03	1.02	0.06
MAX	12.41	14.74	13.48	1.79	18.84	19.54	19.11	0.85	0.51	0.58	0.53	0.12	1.15	1.17	1.10	0.16
AVE	12.23	14.15	13.19	1.36	18.46	19.29	18.87	0.59	0.46	0.54	0.50	0.06	1.02	1.10	1.06	0.10
STD	0.15	0.32	0.14	0.29	0.28	0.21	0.18	0.25	0.04	0.03	0.02	0.05	0.09	0.05	0.03	0.04

APPENDIX C

TABLES OF HEAVY METALS OF SEDIMENT SAMPLES FROM SAKUMO LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF Cu AND Pb

SAMPLING POINTS	Cu								Pb							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	43.64	64.32	53.98	14.62	74.65	84.36	79.51	6.87	8.66	21.73	15.20	9.24	46.28	53.72	50.00	5.26
Point 2	48.22	61.84	55.03	9.63	78.21	75.82	77.02	1.69	8.39	26.82	17.61	13.03	43.72	49.13	46.43	3.83
Point 3	46.29	63.21	54.75	11.96	70.87	83.48	77.18	8.92	17.63	32.23	24.93	10.32	50.38	51.36	50.87	0.69
Point 4	51.75	59.72	55.74	5.64	72.08	83.97	78.03	8.41	13.17	29.33	21.25	11.43	48.01	47.17	47.59	0.59
Point 5	47.93	62.57	55.25	10.35	70.23	79.72	74.98	6.71	14.77	30.88	22.83	11.39	47.11	52.03	49.57	3.48
Point 6	53.84	58.82	56.33	3.52	76.54	83.57	80.06	4.97	15.30	24.27	19.79	6.34	49.84	50.83	50.34	0.70
MIN	43.64	58.82	53.98	3.52	70.23	75.82	74.98	1.69	8.39	21.73	15.20	6.34	43.72	47.17	46.43	0.59
MAX	53.84	64.32	56.33	14.62	78.21	84.36	80.06	8.92	17.63	32.23	24.93	13.03	50.38	53.72	50.87	5.26
AVE	48.61	61.75	55.18	9.29	73.76	81.82	77.79	6.26	12.99	27.54	20.27	10.29	47.56	50.71	49.13	2.43
STD	3.69	2.10	0.81	4.09	3.22	3.39	1.85	2.64	3.74	4.03	3.53	2.31	2.45	2.29	1.74	2.02

TABLES OF HEAVY METALS OF SEDIMENT SAMPLES FROM SAKUMO LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF Fe AND Ni

SAMPLING POINTS	Fe								Ni							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	48.72	53.98	51.35	3.72	55.03	56.81	55.92	1.26	1.43	2.43	1.93	0.71	2.22	3.75	2.99	1.08
Point 2	50.62	52.32	51.47	1.20	50.82	53.93	52.38	2.20	1.78	2.12	1.95	0.24	2.67	3.22	2.95	0.39
Point 3	49.27	54.05	51.66	3.38	51.44	54.02	52.73	1.82	2.01	2.36	2.19	0.25	3.21	3.43	3.32	0.16
Point 4	51.33	51.54	51.44	0.15	52.21	55.95	54.08	2.64	1.89	2.78	2.34	0.63	3.11	2.98	3.05	0.09
Point 5	52.02	53.35	52.69	0.94	50.33	52.32	51.33	1.41	2.14	3.21	2.68	0.76	2.49	3.71	3.10	0.86
Point 6	49.68	52.94	51.31	2.31	54.84	54.29	54.57	0.39	1.94	2.88	2.41	0.66	2.87	3.67	3.27	0.57
MIN	48.72	51.54	51.31	0.15	50.33	52.32	51.33	0.39	1.43	2.12	1.93	0.24	2.22	2.98	2.95	0.09
MAX	52.02	54.05	52.69	3.72	55.03	56.81	55.92	2.64	2.14	3.21	2.68	0.76	3.21	3.75	3.32	1.08
AVE	50.27	53.03	51.65	1.95	52.45	54.55	53.50	1.62	1.87	2.63	2.25	0.54	2.76	3.46	3.11	0.52
STD	1.27	0.98	0.52	1.42	2.03	1.60	1.67	0.79	0.24	0.40	0.29	0.23	0.38	0.31	0.15	0.39

TABLES OF HEAVY METALS OF SEDIMENT SAMPLES FROM SAKUMO LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF Zn AND Mn

SAMPLING POINTS	Zn								Mn							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	47.82	64.33	56.08	11.67	72.48	81.21	76.85	6.17	254.45	432.42	343.44	125.84	483.32	643.82	563.57	113.49
Point 2	52.73	61.50	57.12	6.20	65.83	78.27	72.05	8.80	273.86	387.85	330.86	80.60	421.54	654.11	537.83	164.45
Point 3	49.65	67.23	58.44	12.43	70.04	74.02	72.03	2.81	293.33	426.73	360.03	94.33	469.05	589.39	529.22	85.09
Point 4	51.04	65.67	58.36	10.34	68.22	80.25	74.24	8.51	284.73	392.58	338.66	76.26	523.58	613.54	568.56	63.61
Point 5	48.99	58.45	53.72	6.69	71.78	79.63	75.71	5.55	301.43	417.39	359.41	82.00	514.43	593.22	553.83	55.71
Point 6	50.65	62.77	56.71	8.57	70.71	78.71	74.71	5.66	267.22	405.65	336.44	97.88	495.38	604.35	549.87	77.05
MIN	47.82	58.45	53.72	6.20	65.83	74.02	72.03	2.81	254.45	387.85	330.86	76.26	421.54	589.39	529.22	55.71
MAX	52.73	67.23	58.44	12.43	72.48	81.21	76.85	8.80	301.43	432.42	360.03	125.84	523.58	654.11	568.56	164.45
AVE	50.15	63.33	56.74	9.32	69.84	78.68	74.26	6.25	279.17	410.44	344.80	92.82	484.55	616.41	550.48	93.24
STD	1.72	3.14	1.74	2.59	2.46	2.52	1.94	2.20	17.37	18.16	12.24	18.22	36.73	26.81	14.98	40.24

TABLES OF HEAVY METALS OF SEDIMENT SAMPLES FROM CHEMU LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF Cu AND Pb

SAMPLING POINTS	Cu								Pb							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	70.81	81.82	76.32	7.79	93.92	101.43	97.68	5.31	18.67	43.73	31.20	17.72	53.38	74.45	63.92	14.90
Point 2	82.33	85.21	83.77	2.04	97.71	97.38	97.55	0.23	25.52	38.62	32.07	9.26	58.23	70.12	64.18	8.41
Point 3	74.72	81.95	78.34	5.11	94.82	95.91	95.37	0.77	22.71	39.04	30.88	11.55	62.18	72.91	67.55	7.59
Point 4	78.69	88.09	83.39	6.65	99.72	102.82	101.27	2.19	19.63	41.83	30.73	15.70	57.17	68.72	62.95	8.17
Point 5	71.77	86.01	78.89	10.07	102.13	98.23	100.18	2.76	24.81	42.72	33.77	12.66	61.91	71.82	66.87	7.01
Point 6	77.21	84.74	80.98	5.32	100.72	97.94	99.33	1.97	23.03	40.38	31.71	12.27	59.16	69.24	64.20	7.13
MIN	70.81	81.82	76.32	2.04	93.92	95.91	95.37	0.23	18.67	38.62	30.73	9.26	53.38	68.72	62.95	7.01
MAX	82.33	88.09	83.77	10.07	102.13	102.82	101.27	5.31	25.52	43.73	33.77	17.72	62.18	74.45	67.55	14.90
AVE	75.92	84.64	80.28	6.16	98.17	98.95	98.56	2.20	22.40	41.05	31.72	13.19	58.67	71.21	64.94	8.87
STD	4.36	2.42	2.96	2.72	3.29	2.62	2.13	1.79	2.74	2.05	1.12	3.04	3.27	2.24	1.83	3.01

TABLES OF HEAVY METALS OF SEDIMENT SAMPLES FROM CHEMU LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF Fe AND Ni

SAMPLING POINTS	Fe								Ni							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	82.53	100.62	91.58	12.79	117.36	139.22	128.29	15.46	4.93	6.53	5.73	1.13	8.32	9.87	9.10	1.10
Point 2	85.20	97.21	91.21	8.49	125.23	131.83	128.53	4.67	4.25	5.22	4.74	0.69	8.72	9.21	8.97	0.35
Point 3	88.32	103.47	95.90	10.71	119.27	127.39	123.33	5.74	4.17	6.62	5.40	1.73	7.34	8.78	8.06	1.02
Point 4	92.62	106.32	99.47	9.69	123.67	137.17	130.42	9.55	4.56	5.82	5.19	0.89	7.87	9.02	8.45	0.81
Point 5	91.43	104.56	98.00	9.28	124.38	129.27	126.83	3.46	4.33	5.20	4.77	0.62	8.18	9.73	8.96	1.10
Point 6	89.65	99.36	94.51	6.87	121.11	138.77	129.94	12.49	4.65	6.19	5.42	1.09	8.54	8.93	8.74	0.28
MIN	82.53	97.21	91.21	6.87	117.36	127.39	123.33	3.46	4.17	5.20	4.74	0.62	7.34	8.78	8.06	0.28
MAX	92.62	106.32	99.47	12.79	125.23	139.22	130.42	15.46	4.93	6.62	5.73	1.73	8.72	9.87	9.10	1.10
AVE	88.29	101.92	95.11	9.64	121.84	133.94	127.89	8.56	4.48	5.93	5.21	1.02	8.16	9.26	8.71	0.77
STD	3.83	3.44	3.35	2.01	3.11	5.11	2.57	4.76	0.29	0.62	0.39	0.40	0.50	0.45	0.39	0.37

TABLES OF HEAVY METALS OF SEDIMENT SAMPLES FROM CHEMU LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF Zn AND Mn

SAMPLING POINTS	Zn								Mn							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	71.43	85.09	78.26	9.66	92.79	115.54	104.17	16.09	813.65	867.22	840.44	37.88	903.71	922.88	913.30	13.56
Point 2	75.31	82.77	79.04	5.28	97.76	103.43	100.60	4.01	821.08	854.04	837.56	23.31	912.36	918.92	915.64	4.64
Point 3	80.74	87.63	84.19	4.87	95.82	113.56	104.69	12.54	843.12	862.82	852.97	13.93	907.22	921.63	914.43	10.19
Point 4	73.91	87.23	80.57	9.42	91.71	102.82	97.27	7.86	830.23	871.29	850.76	29.03	921.38	918.81	920.10	1.82
Point 5	78.23	83.92	81.08	4.02	100.37	112.73	106.55	8.74	821.87	869.88	845.88	33.95	920.24	920.12	920.18	0.08
Point 6	72.76	85.81	79.29	9.23	94.83	107.92	101.38	9.26	837.03	857.21	847.12	14.27	906.33	919.32	912.83	9.19
MIN	71.43	82.77	78.26	4.02	91.71	102.82	97.27	4.01	813.65	854.04	837.56	13.93	903.71	918.81	912.83	0.08
MAX	80.74	87.63	84.19	9.66	100.37	115.54	106.55	16.09	843.12	871.29	852.97	37.88	921.38	922.88	920.18	13.56
AVE	75.40	85.41	80.40	7.08	95.55	109.33	102.44	9.75	827.83	863.74	845.79	25.39	911.87	920.28	916.08	6.58
STD	3.51	1.88	2.12	2.62	3.20	5.43	3.35	4.14	11.01	6.99	5.91	10.02	7.48	1.65	3.29	5.24

TABLES OF HEAVY METALS OF SEDIMENT SAMPLES FROM KPESHIE LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF Cu AND Pb

SAMPLING POINTS	Cu								Pb							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	21.96	34.62	28.29	8.95	42.72	51.76	47.24	6.39	9.65	26.35	18.00	11.81	36.08	54.22	45.15	12.83
Point 2	28.02	31.84	29.93	2.70	46.21	48.34	47.28	1.51	16.33	22.48	19.41	4.35	40.32	50.81	45.57	7.42
Point 3	24.33	33.07	28.70	6.18	44.87	50.73	47.80	4.14	12.74	25.32	19.03	8.90	38.76	53.04	45.90	10.10
Point 4	22.71	38.22	30.47	10.97	43.08	47.08	45.08	2.83	10.44	21.93	16.19	8.12	41.38	46.42	43.90	3.56
Point 5	27.29	35.70	31.50	5.95	45.93	50.28	48.11	3.08	15.02	24.04	19.53	6.38	37.44	48.61	43.03	7.90
Point 6	25.31	32.33	28.82	4.96	44.43	49.66	47.05	3.70	11.57	23.77	17.67	8.63	39.21	49.23	44.22	7.09
MIN	21.96	31.84	28.29	2.70	42.72	47.08	45.08	1.51	9.65	21.93	16.19	4.35	36.08	46.42	43.03	3.56
MAX	28.02	38.22	31.50	10.97	46.21	51.76	48.11	6.39	16.33	26.35	19.53	11.81	41.38	54.22	45.90	12.83
AVE	24.94	34.30	29.62	6.62	44.54	49.64	47.09	3.61	12.63	23.98	18.30	8.03	38.87	50.39	44.63	8.15
STD	2.42	2.40	1.23	2.94	1.43	1.69	1.06	1.63	2.62	1.67	1.28	2.52	1.92	2.90	1.10	3.11

TABLES OF HEAVY METALS OF SEDIMENT SAMPLES FROM KPESHIE LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF Fe AND Ni

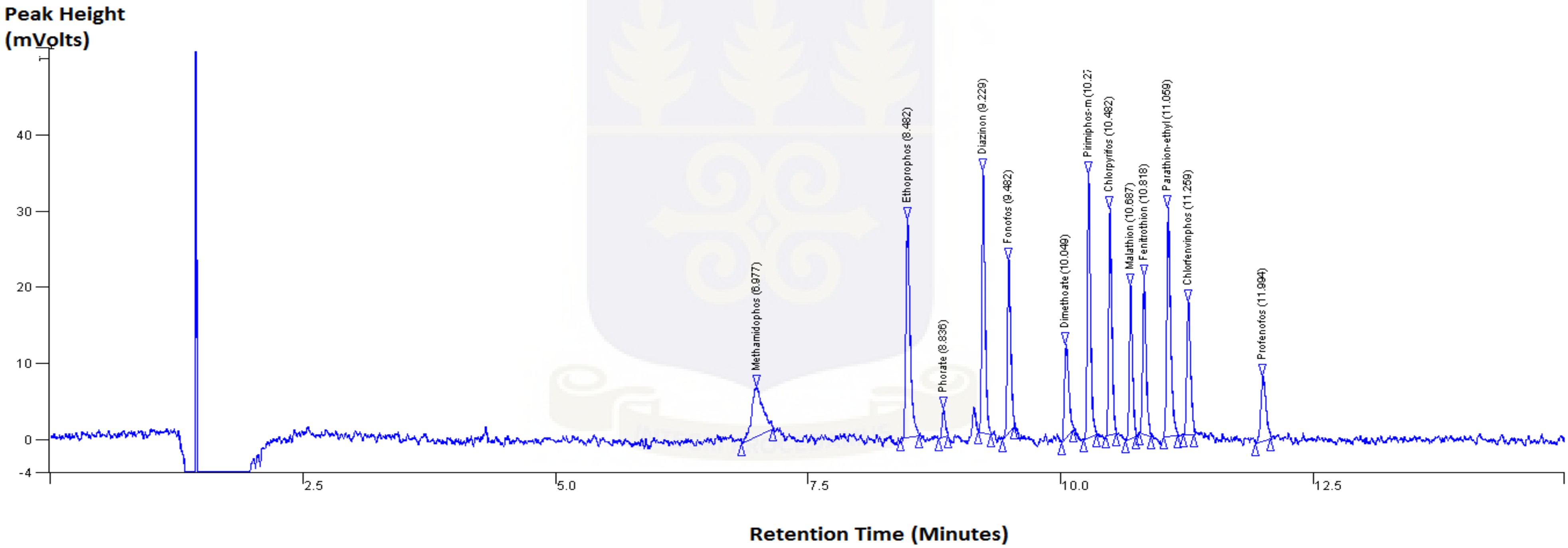
SAMPLING POINTS	Fe								Ni							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	63.46	74.63	69.05	7.90	78.55	87.35	82.95	6.22	2.54	3.24	2.89	0.49	4.38	5.21	4.80	0.59
Point 2	59.32	72.56	65.94	9.36	75.09	83.23	79.16	5.76	2.15	3.72	2.94	1.11	4.11	5.03	4.57	0.65
Point 3	61.06	68.05	64.56	4.94	77.57	79.67	78.62	1.48	3.20	3.02	3.11	0.13	3.87	5.19	4.53	0.93
Point 4	64.93	69.42	67.18	3.17	76.35	85.98	81.17	6.81	2.78	3.13	2.96	0.25	4.23	5.42	4.83	0.84
Point 5	62.22	73.95	68.09	8.29	78.31	78.43	78.37	0.08	2.24	3.93	3.09	1.20	3.92	4.98	4.45	0.75
Point 6	63.14	69.75	66.45	4.67	75.98	82.85	79.42	4.86	3.03	3.64	3.34	0.43	4.08	5.13	4.61	0.74
MIN	59.32	68.05	64.56	3.17	75.09	78.43	78.37	0.08	2.15	3.02	2.89	0.13	3.87	4.98	4.45	0.59
MAX	64.93	74.63	69.05	9.36	78.55	87.35	82.95	6.81	3.20	3.93	3.34	1.20	4.38	5.42	4.83	0.93
AVE	62.36	71.39	66.87	6.39	76.98	82.92	79.95	4.20	2.66	3.45	3.05	0.60	4.10	5.16	4.63	0.75
STD	1.97	2.69	1.59	2.45	1.38	3.46	1.77	2.76	0.42	0.37	0.16	0.45	0.19	0.16	0.15	0.13

TABLES OF HEAVY METALS OF SEDIMENT SAMPLES FROM KPESHIE LAGOON SHOWING THE MEAN AND STANDARD DEVIATIONS OF Zn AND Mn

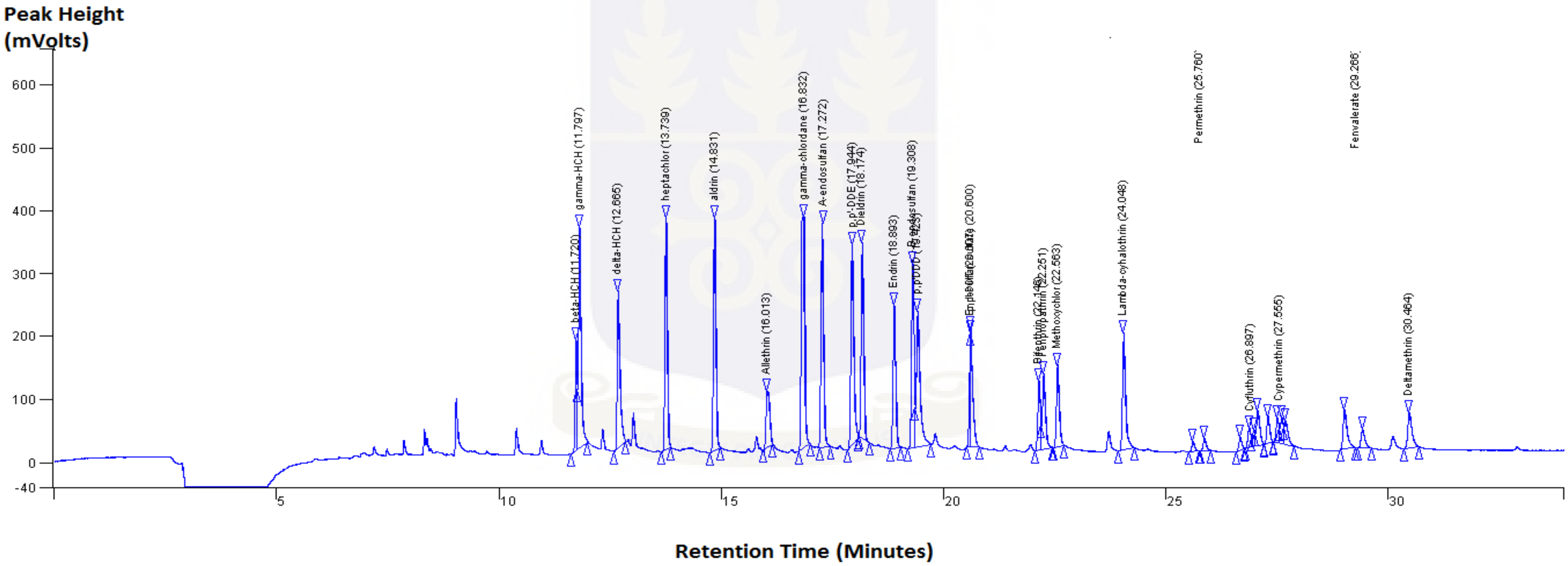
SAMPLING POINTS	Zn								Mn							
	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD	SEPT	OCT	MEAN	STD	JAN	FEB	MEAN	STD
Point 1	43.29	57.83	50.56	10.28	68.33	85.23	76.78	11.95	84.32	102.85	93.59	13.10	117.91	123.43	120.67	3.90
Point 2	38.98	48.77	43.88	6.92	74.21	82.87	78.54	6.12	92.93	98.23	95.58	3.75	100.82	112.83	106.83	8.49
Point 3	41.74	52.03	46.89	7.28	77.93	79.32	78.63	0.98	91.25	101.30	96.28	7.11	102.72	132.11	117.42	20.78
Point 4	39.08	55.43	47.26	11.56	69.12	81.31	75.22	8.62	88.73	99.35	94.04	7.51	101.63	102.73	102.18	0.78
Point 5	42.88	49.82	46.35	4.91	72.88	83.84	78.36	7.75	86.04	96.82	91.43	7.62	113.29	121.08	117.19	5.51
Point 6	38.22	56.09	47.16	12.64	71.49	84.13	77.81	8.94	90.31	100.22	95.27	7.01	115.45	131.22	123.34	11.15
MIN	38.22	48.77	43.88	4.91	68.33	79.32	75.22	0.98	84.32	96.82	91.43	3.75	100.82	102.73	102.18	0.78
MAX	43.29	57.83	50.56	12.64	77.93	85.23	78.63	11.95	92.93	102.85	96.28	13.10	117.91	132.11	123.34	20.78
AVE	40.70	53.33	47.01	8.93	72.33	82.78	77.56	7.39	88.93	99.80	94.36	7.68	108.64	120.57	114.60	8.44
STD	2.20	3.66	2.14	3.01	3.53	2.15	1.33	3.67	3.25	2.16	1.75	3.02	7.74	11.25	8.28	7.04

APPENDIX D

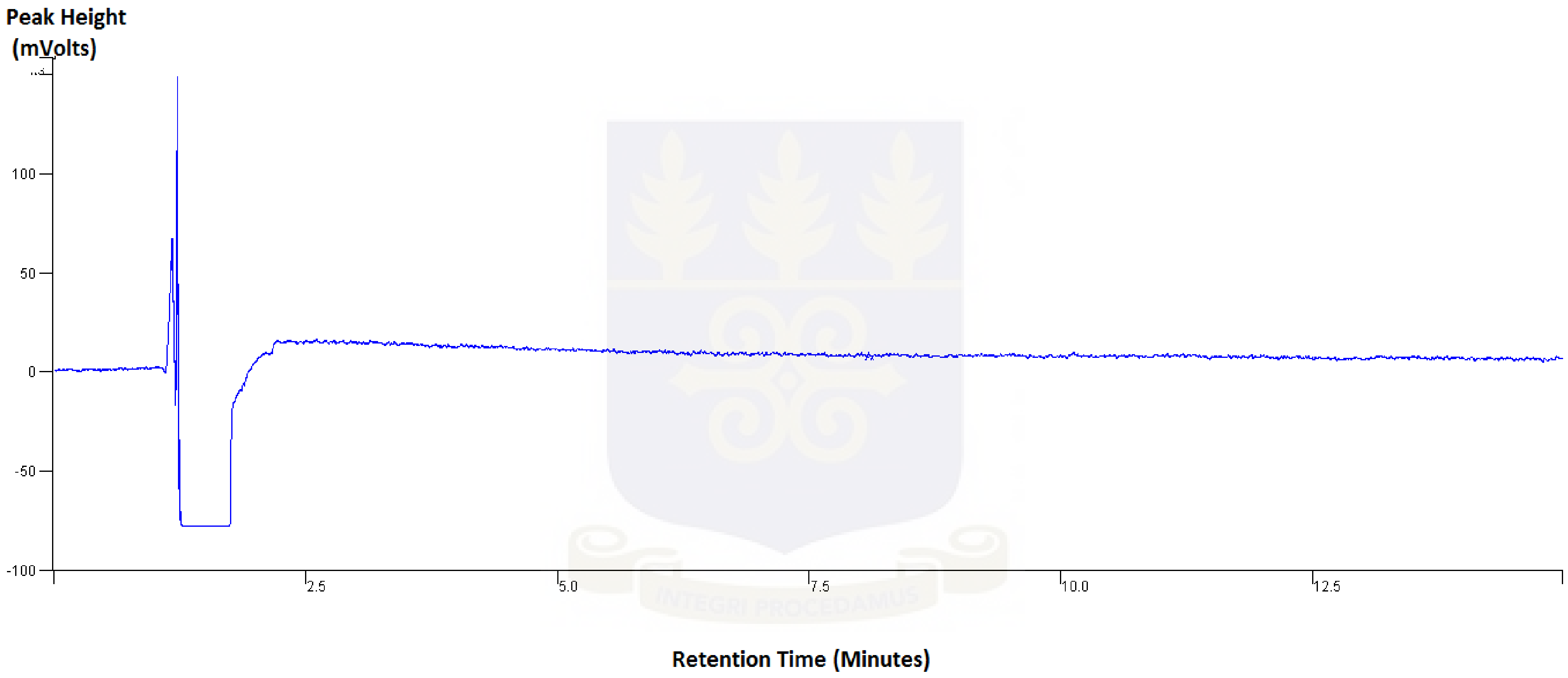
GRAPH OF STANDARD PESTICIDE RESIDUE STANDARD MIX (0.5 PPM ORGANOPHOSPHATE STANDARD)



GRAPH OF STANDARD PESTICIDE RESIDUE STANDARD MIX (0.10 PPM ORGANOCHLORINE STANDARD)

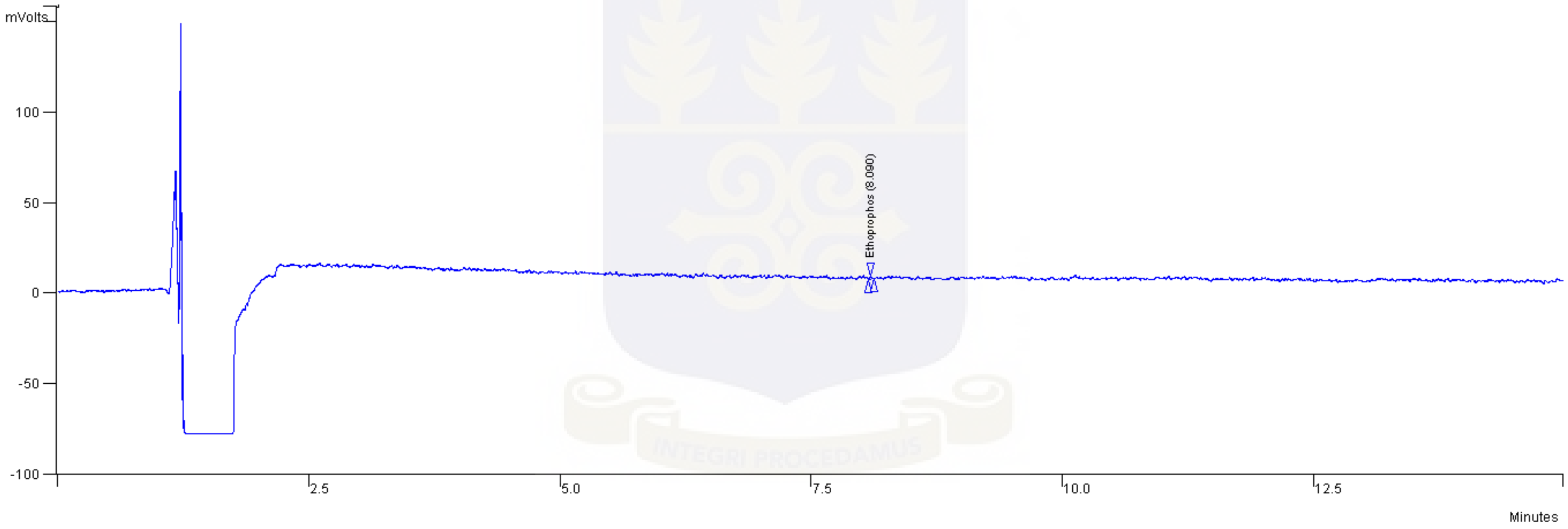


GRAPH OF ORGANOPHOSPHATE COMPOUND IN SAKUMO LAGOON



GRAPH OF ORGANOCHLORINE COMPOUND IN CHEMU LAGOON

Peak Height



Retention Time

GRAPH OF ORGANOPHOSPHATE COMPOUND IN KPESHIE LAGOON

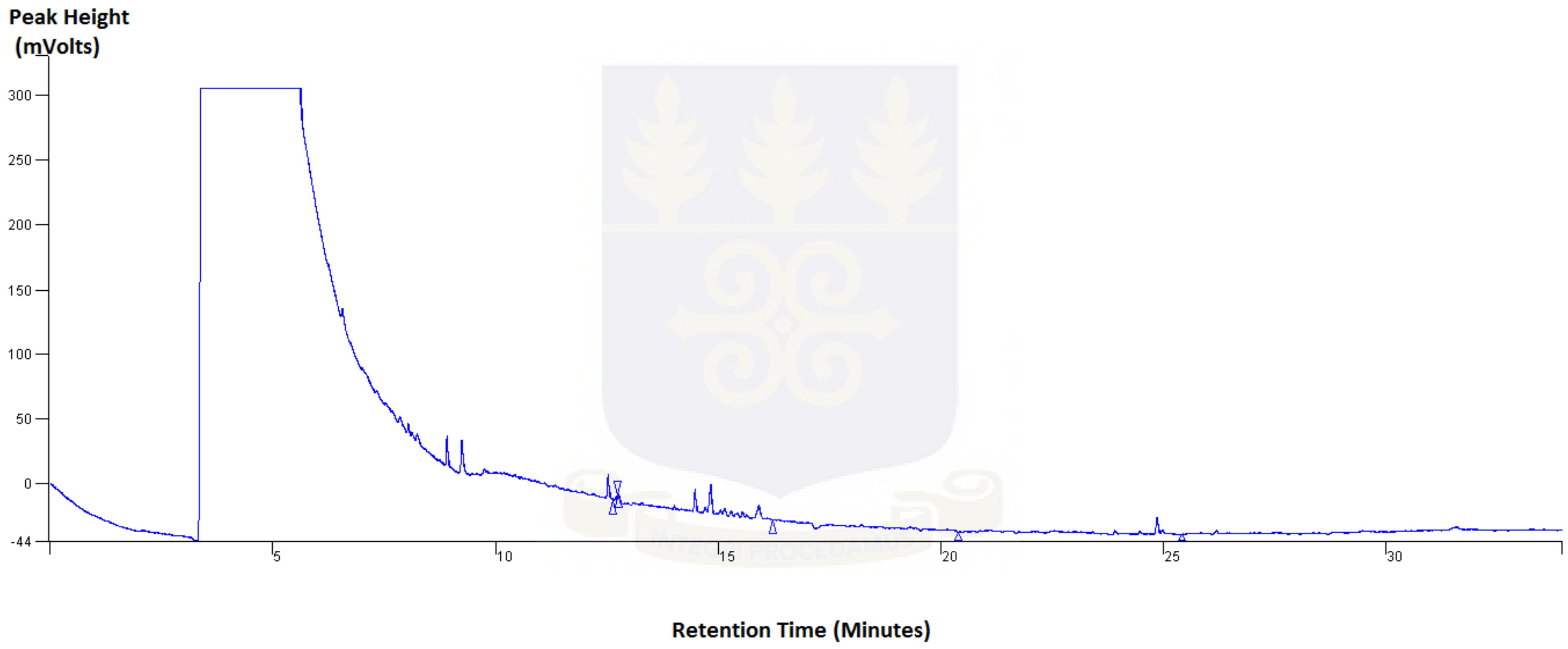


TABLE OF MEAN CONCENTRATION (ug/L) OF PESTICIDE RESIDUES OF WATER SAMPLES FROM SAKUMO, CHEMU AND KPESHIE LAGOONS

Water samples from various lagoons (both wet and dry seasons)	Mean concentration in ug/L						
	p,p'-DDT (Limit - 2.00)	p,p'-DDD (Limit - 2.00)	p,p'-DDE (Limit - 2.00)	Aldrin (Limit - 0.03)	Dieldrin (Limit - 0.03)	Fenitrothion (Limit - 30.00)	Chlorpyrifos (Limit - 0.05)
Sakumo lagoon	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Chemu lagoon	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Kpeshie lagoon	BDL	BDL	BDL	BDL	BDL	BDL	BDL

*BDL – below detection limit

TABLE OF MEAN CONCENTRATION (mg/kg) OF PESTICIDE RESIDUES OF SEDIMENT SAMPLES FROM SAKUMO, CHEMU AND KPESHIE LAGOONS

Sediment samples from various lagoons (both wet and dry seasons)	Mean concentration in mg/kg						
	p,p'-DDT (Limit - 0.05)	p,p'-DDD (Limit - 0.04)	p,p'-DDE (Limit - 0.04)	Aldrin (Limit - 0.04)	Dieldrin (Limit - 0.03)	Fenitrothion (Limit - 0.05)	Chlorpyrifos (Limit - 0.03)
Sakumo lagoon	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Chemu lagoon	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Kpeshie lagoon	BDL	BDL	BDL	BDL	BDL	BDL	BDL

* BDL – below detection limit