ASSESSMENT OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS CONTAMINATION IN KORLE AND KPESHIE LAGOONS

By

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DECLARATION

This thesis is the original research work undertaken by Carolyne Alberta Clottey in the Institute for Environment and Sanitation Studies, University of Ghana, under the supervisions of Dr. Daniel Nukpezah, Dr. Samuel Koranteng and Dr. Daniel Amoako Darko

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I dedicate this work to the Almighty God for his Grace, guidance and protection and to my Pastor, Prophet John Adu, my husband Joseph Amoako Owiredu, my children and my father Mr. Albert Clottey for their support and encouragement throughout the studies.

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ABBREVIATIONS

μgl^{-1}	Microgram per Litre
μScm^{-1}	Micro Siemens per Centimetre
AAS	Atomic Absorption Spectrophotometry
ANOVA	Analysis of Variance
AMA	Accra Metropolitan Assembly
As	Arsenic
BDL	Below Detection Limit
CCME	Canadian Council of Ministers of the Environment
Cf	Contamination Factor
Cd	Cadmium
Cr	Chromium
Cu	Copper
DO	Dissolved Oxygen
Er	Potential Ecological Risk
EPA	Environmental Protection Agency
FAO	Food and Agricultural Organisation
$HClO_4$	Perchloric Acid
HNO_3	Nitric Acid

MCL	Maximum Contamination Limit
MDL	Minimum Detection Limit
$mgkg^{-1}$	Milligram per Kilogram
mgL^{-1}	Milligram per Litre
°C	Degrees Celsius
Pb	Lead
pH	Potential of Hydrogen
PLI	Pollution Load Index
RI	Potential Ecological Risk Index
SD	Standard Deviation
SPSS	Statistical Package for Social Sciences
SQG	Standard Quality Guideline
TDS	Total Dissolved Solids
TEMP	Temperature
THQ	Target Hazard Quotient
TTHQ	Total Target Hazard Quotient
Trf	Toxicity Response Factor
US EPA	United States Environmental Protection Agency
WHO	World Health Organization

Zn	Zinc

TABLE OF CONTENTS

TABLES

FIGURES

PLATES

ABSTRACT

Lagoons are highly productive coastal systems that provide natural services to the ecosystem, however, their pollutions cause adverse changes to the natural environment. Korle and Kpeshie Lagoons in Ghana, both receive wastes from industries and municipal sewage. Controlling and monitoring of contaminants in these systems is very important to environmental protection. The study examined the presence of heavy metals (arsenic, cadmium, chromium, copper, lead and zinc) in sediments, crabs (*Callinectes amnicola),* and in fish *(Sarotherodon melanotheron)* at Kpeshie and Korle Lagoons and compared the concentrations against the environmental standards set by international organisations such as WHO and US EPA. The sediments of Korle and Kpeshie lagoons showed traces of contamination in the order cadmium, lead, copper, zinc, chromium and arsenic, the following metal concentrations in *Sarotherodon melanotheron* in mgkg^{-1}: As, 0.397 ± 0.07; Cd, 1.10 ± 1.31; Cr, 5.895 ± 9.76; Cu, 3.494 ± 4.56; Pb, 1.227 ± 5.77; Zn, 23.225 ± 10.93, and in *Callinectes amnicola* : As, 0.288 ± 0.07 mgkg^{-1}; Cd, 4.60 ± 2.69 mgkg^{-1}; Cr, 39.521 ± 55.89 mgkg^{-1}; Cu, 31.085 ± 16.26 mgkg^{-1}; Pb, 10.902 ± 12.95 mgkg^{-1}; Zn, 36.042 ± 17.8 mgkg^{-1}. The pollution indices such as contamination factor (Cf), pollution load index (PLI) and potential ecological risk index (RI) calculated indicated that the sediments are highly polluted with Cd and Pb. Cadmium, chromium and lead concentrations in *Callinectes amnicola, and Sarotherodon melanotheron* exceeded the permissible limit by FAO/WHO. The estimated target hazard quotient (THQ) of Cd, Cr, and Pb of fishery examined in Kpeshie Lagoon resulted in less than 1, indicating that the daily consumption of *Callinectes amnicola and Sarotherodon melanotheron* do not pose potential non-carcinogenic health risk to individuals.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Waterbodies are useful to human and other living organisms. They include rivers, lakes, lagoons, sea and oceans. Their importance ranges from supporting aquatic life to human utilization for livelihood. Most economic and environmental activities depend on the availability and quality of these waterbodies.

The present study is focused on coastal lagoons; these are shallow coastal pools, which are fully or partially separated from the ocean either by sand bars (Isla, 2009) or embankments along the coast. They are among the most productive aquatic ecosystems in the world. They serve as nursery grounds, habitats for numerous species, toxins filters, flood control and recycle of nutrients to maintain the biological activities in their systems. Coastal lagoons are either opened or closed to the ocean entrance and are formed through the accumulation of marine sediments in low lying areas (Woodroffe, 2002). These coastal lagoons are under threat, they are being polluted through the persistent contamination of heavy metals and other pollutants such as poly aromantic hydrocarbons (PAH) by the surrounding communities of these water bodies (Bourgeoning, 1996) and industrial activities. The sediments of coastal lagoon serve as sinks for heavy metals (Sparks, 2005). Heavy metals are either adsorbed on or absorbed in suspended particulate matter of the water bodies. Most lagoons are losing their ecological and economic values due to environmental degradation by anthropogenic activities.

Heavy metals (HM) form part of the earth's crust and are defined as any metallic or metalloid chemical elements that have relatively high densities greater than 5gcm^{-3}, and are toxic even at low concentrations (Lenntech, 2010). Heavy metals are regarded as contaminants; however, some of these heavy metals are required in minute quantity for normal growth. These elements include iron, zinc, copper and manganese, and referred to as essential minerals. But the relevance of such elements is valid only at certain levels of concentration; otherwise they become toxicants at higher concentrations.

Heavy metals enter the environment through the disposal of wastewater and sewage sludge, runoff from agricultural fields, by-products from metal mining processes and atmospheric input. Heavy metals are considered as serious pollutants of the environment due to their persistence, toxicity and ability to be incorporated in food chain (Kadhum *et al.,* 2016). These metals are capable of binding to organic materials in the body, causing malfunctions of cells by hindering transport processes through the cell wall. Most metals when exposed to organisms and humans cause damage to the kidney, liver, may increase blood pressure and eventually lead to death. Many heavy metals are carcinogenic to man (Baird &.Cann, 2008).

Korle and Kpeshie lagoons are opened and closed lagoons respectively. Both lagoons are not designated as Ramsar Sites[1], and are among the most polluted coastal lagoons in the country. Korle is an outlet through which all major drainage channels in Accra empty their waters before it finally enters into the Gulf of Guinea. The lagoonal systems which could have been an attractive landscape and support socio-economic activities for local communities in the Metropolis, receives high volumes of domestic and industrial waste discharge (Karikari *et al*.,

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[1] Ramsar Sites are designated wetlands under the Convention on Wetlands of International Importance, which was adopted in 1971 in Ramsar, Iran for the conservation and wise use of wetlands and their resources.

2009). High levels of siltation in Korle lagoon have reduced its flow rate (Asumadu-Sarkodie *et al*., 2015) thus culminating in serious flooding during heavy downpours in the city of Accra.

Kpeshie, being a closed lagoon (Biney, 1984) experiences water level fluctuations depending on hydrologic inputs and outputs (Haines, 2009). The lagoon intermittently spills over into the ocean when the water level exceeds the sand barrier height or through a small inlet to the ocean. Living organisms in these lagoons are virtually extinct as a result of severe contaminations (Owusu Boadi & Kuitunen, 2002).

1.2 PROBLEM STATEMENT

Urbanization and rural-urban migration has largely contributed to the exponential population growth of the city of Accra. Inadequate planning of solid waste management coupled with the poor sanitation has resulted in the generation of waste in the excess of five hundred tonnes (500t) per day (AMA, 2011).

In the catchment areas of Korle and Kpeshie lagoons, slums and shanty towns have been set up close to or along the path of river channels that empty into these lagoons. As a result, solid wastes are dumped indiscriminately in gutters, river networks (Odaw River), and on any available space. Domestic wastewater is discharged directly into Kpeshie lagoon from establishments such as the La Palm Hotel, and large volumes of untreated industrial effluents and sewage are discharged directly into Korle lagoon (Owusu Boadi & Kuitunen, 2002) causing severe pollution thereby disrupting their natural ecology. Sewage, which is normally associated with high oxygen demand, induces favorable condition which increases heavy metal remobilization and solubility in these lagoons. This intensifies heavy metal toxicity to the aquatic system.

Previous studies on heavy metal loading in Kpeshie lagoon have been conducted on water quality (Apau *et al*., 2012); sediments (Addo *et al*., 2011); and fish (Laar *et al*., 2012), while that of Korle lagoon were focused on water quality (Karikari *et al.,* 2009); and urban waste pollution (Owusu Boadi & Kuitunen, 2002; Aglanu & Appiah, 2014). However, there is virtually no information on metal pollution in crustacean in Kpeshie and Korle lagoons.

The present study aims to assess and compare the concentrations of heavy metals in sediments, bigfisted swim crab *(Callinectes amnicola)* and tilapia (*Sarotherodon melanotheron)* in Korle and Kpeshie lagoons, and further estimate the target hazard quotient of heavy metals present in fishery with respect to human health effect associated with their consumptions.

1.3 JUSTIFICATION

Korle and Kpeshie lagoons and its environs are linked with extensive land usage and waste disposal (Karikari *et al*., 2009). These activities contribute substantially to the polluted nature of the lagoons, since they are depositional environments for chemicals and other pollutants. Among the chemical pollutants are heavy metals that are toxic at low concentrations, persistent and non-degradable and may continue to cause environmental health problems even after their major sources are controlled (Lacerda, 1994). These heavy metals (arsenic, cadmium, chromium, copper, lead and zinc) are greatly associated with municipal waste (household garbage) due to increase in industrialisation. For instance, arsenic, cadmium and chromium are used additives in paint and plastic manufacturing (Baird & Cann, 2008). Vehicular exhaust discharges lead and zinc into the environment as they ply the road (Lacerda, 1994). The recycling of e-waste along the banks of Korle and Kpeshie lagoons add to the constituents (cadmium and copper) of the lagoons.

Though zinc and copper are essential to the metabolic structure, the rest (arsenic, cadmium, chromium and lead) is toxic to the human immune system (Jakimska et al., 2011). Metals tend to accumulate on sediments in water and are released with changes in environmental conditions like pH, oxygen demand or temperature (Dang et al, 2015).

Fisheries are sources of protein and valuable to local communities (Okafor, 1988) around the coastal lagoon. Crab and tilapia inhabit the muddy bottom of mangrove areas in the coastal lagoons (Defelice et al., 2001) and feed on the organics and inorganics at the bottom sediment. In the process, they can accumulate heavy metals due to their metabolic activities. Accumulation of these metals in such organisms is often used as biomarkers to assess the heavy metal contaminants in lagoons. The study involved the use of crab and tilapia to assess some of these contaminants, hence it is necessary to understand the effects of heavy metals in aquatic systems to regularly update the knowledge of their contamination status in order to effectively control and monitor these coastal lagoons for environmental safety.

1.4 AIMS AND OBJECTIVES

The main objective of the study is to examine the presence of heavy metals, their concentrations in sediment, water, crab and fish in the Korle and Kpeshie Lagoons, compare their concentrations to the permissible limit set by International Standards such as Sediment Quality Guidelines (SQG) of the Canadian Council of Ministers of the Environment

(CCME), World Health Organization (WHO) and United States Environmental Protection Agency (US EPA). The study also sought to assess the pollution status in these lagoons:

1.4.1 Specific Objectives

The specific objectives of the study are to:

- Determine physical parameters such as total dissolved solids, pH, temperature, electrical conductivity and dissolved oxygen that influence metal concentration in water.
- Determine the pH of sediment cores.
- Determine the concentration of heavy metals (As, Cd, Cr, Cu, Pb, and Zn) in water, sediment core, crab and fish from the lagoons.
- Carry out a comparative analyses of metal concentrations in these lagoons
- Evaluate the contamination status of lagoons
- Estimate the target hazard quotient (THQ) of heavy metals in fish and crab.

CHAPTER TWO

LITERATURE REVIEW

2.1 LAGOON ECOSYSTEMS

Lagoons are brackish shallow coastal water bodies separated from the ocean either by a sand barrier or sand bank, connected at least intermittently to the open ocean by one or more restricted tidal inlets (Isla, 2009). The shallow, dynamic systems provide natural habitats for species of flora and fauna. Coastal ecosystems provide valuable services to the environment; flood prevention, retention of contaminant and groundwater recharging. Due to the nature of the coastal lagoon, they are extremely vulnerable to human impacts of increased activities in and around the catchment region.

2.1.1 Physical Characteristics of Lagoons

Lagoons occur in low-lying areas and can either be natural or man-made. Lagoons may be connected to the ocean by narrow streams. Geologically, coastal lagoons are young and dynamic (Kerfve, 1994). They were formed as a result of water levels rising mainly during the period of Holocene ((Kerfve, 1994).

There are three categories of coastal lagoons, based on their geomorphic and water exchange capacity with the coastal ocean (Kjerfve, 1994). These are choked, restricted, and leaky lagoons.

Choked lagoons occur along coasts where the tidal waves are much stronger, such that the rate of erosion surpasses that of deposition. They usually have a single narrow channel connection to the ocean. Water circulation in the choked lagoon is mainly due to wind patterns. They normally form in hot, dry climates and may be highly alkaline due to an increase in dissolved carbonates. Examples are Lagoa Dos Patos in Brasil, Fosu lagoon in Ghana and Coorong in Australia.

Restricted lagoons have one or more inlets, well defined water exchange with the ocean, and tend to show a net movement of water towards the sea (Hill, 2001). The circulation of water in this type of lagoons is mostly controlled by the tides and wind actions. Examples include Laguna de Terminos in Mexico, and Lake Pontchartrain in the USA.

A leaky lagoon has a wide tidal inlet, fast current and uninterrupted exchange of water with the ocean. They are elongated bodies of water parallel to the coast. These are formed in coastal areas where tidal flows are strong enough to prevent silting caused by waves and littoral drifts. The water in these lagoons tends to flow seawards. Wadden Zee in the Netherlands and Mississippi Sounds in the USA are some examples of this type of coastal lagoon.

In Ghana the classification of lagoons has been limited to two types: ‘open’ or ‘closed’ lagoons (Armah, 1991). Open lagoons are constantly open to the ocean and are fed by river flows throughout the year, whereas closed lagoons are separated from the ocean by sand barriers. They only open to the ocean in the rainy season via a narrow canal, when the barriers are broken by flood waters (Armah, 1991).

Globally, coastal lagoons form thirteen percent (13%) of coastal zones (Kerfve, 1994). Their surface areas range from less than 0.01 to more than 10,000 square kilometres, and are characteristically less than 5m deep (Bird, 1994). Coastal lagoons are created and maintained through the process of sedimentation and these processes can eventually fill in and reduce their depths (Nichols & Boon, 1994).

The rates at which lagoons lose or gain water from precipitation, evaporation, groundwater recharge and surface run-off strongly influence the quality and quantity of water (Allen *et al*., 1981). Lagoons have low flushing rates due to their restriction in water exchange capacity with the ocean, contributing to high primary productivity and contaminant concentrations (Spaulding, 1994). Coastal lagoons accumulate sediments from fluvial input (Lacerda, 1994). The factors basically affecting the flushing rate are the size, shape of lagoon and the number of inlets connected to the ocean (Phleger, 1981). Mangroves and marsh plants can expedite sedimentation in a lagoon, and some benthic organisms act as facilitators modifying the bottom sediments (UNESCO, 1981).

2.1.2 Biota Characteristics

As coastal lagoons are characterized by shallow depth, the photic zone extends to the lagoon floor with benthic organisms accounting for large portions of total primary production of the system. The high rate of activities of benthic primary producers facilitates nutrient recycling (McGlathery *et al*., 2007).

Though coastal floors lie within the photic zone, high levels of turbidity and phytoplankton growth in that zone impede light penetration to estuarine bottom. When sunlight penetrates to the basin floor, it facilitates the growth of benthic algae in the system. Therefore, benthic primary production in photic zone can outnumber that of phytoplankton production in the coastal systems. Because the ratio between lagoon volume of water and sediment surface area is small; this is of biogeochemical importance in nutrients recycling and other chemical reactions between sediments and water column.

The coastal lagoon experiences long water residence time; and available nutrient can be recycled several times before finding its way to the ocean (Lacerda, 1994). The hydrological, biological, geological and chemical processes of coastal lagoons support relatively high productivity rates of nutrient input and are a major factor in these systems, serving as excellent grounds for fishery nurseries. However, these same characteristics also create conditions favourable for nutrient over-enrichment, which lead to eutrophication (Paerl *et al.,* 2006).

Changes in physical and chemical characteristics of lagoon influence principal plant communities. For example, changes in turbidity or water residence time could play a determinant role in the composition of plant populations (Adolf *et al.,* 2006; Valdes-Weaver *et al.,* 2006). Furthermore, as feeding pressure changes, top down effects could speed up these biotic responses. For instance, salt marshes dominate in temperate lagoonal systems and mangroves in tropical systems. Benthic organisms such as microalgae, macro-algae, phytoplankton, and epiphytes, might account for more than half of the total production in some of these biotopes (Alongi, 1998). The habitats of these organisms are threatened in many aquatic ecosystems of the world as a result of climate change, storms or floods, sea-level rise, eutrophication, wastewater discharges, land reclamation, and other human activities (Adam *et al.,* 2008; Dodd and Ong, 2008).

Geographically, the most productive coastal systems are lagoons. Both the structure and activities within these systems vary greatly because of the number of physical and chemical disturbances (Gamito *et al.,* 2004). Coastal lagoons provide the ideal grounds for fishery nurseries and feeding habitats, even with the changes in environmental conditions. Several fauna make use of these environments seasonally, by entering and leaving the lagoon depending on situational signs. Considering the highly productive nature of coastal lagoons, few species remain existent, as permanent residents of these systems, and the dominated ones are the biotic communities (Colombo, 1977).

Many water birds move to the lagoons to nest (Kennish & Pearl, 2010), because of the primary production prevailing between the water column and sediments of lagoons (Barnes, 1994). Primary production in the benthic zone supports recreational and commercial fisheries activities. Due to the changes in physical, chemical and biotic features of coastal lagoons, as well as anthropogenic stressors, fishery activities must be resourcefully managed for long-term sustainability. Coastal lagoons provide good grounds for the application and development of fishery farming such as tilapia, milkfish and sea perch (Alongi, 1998). However, these systems are also highly prone to the accumulation of contaminants like heavy metals, nutrients, and pathogens, which can be hostile to viable fisheries, since these contaminants amass in the organisms can pose a health risk (Mactintosh, 1994).

2.1.3 Ecological and economic value

Features of coastal lagoons provide exceptional grounds for ecological and economic values. They provide diverse habitats which include; open waters, tidal flat, creeks and un-vegetated bottom sediments, for various species of birds and organisms. Most marine species of economic value spend a bit of their life span in lagoons. Apart from its ecological importance, coastal lagoons are good for aquaculture, generation of electric power, biotechnology, and transportation. Coastal lagoons also protect coastline watershed areas, such that it serves as a buffer against the effects of storms, floods, and erosion (Kennish & Pearl, 2010).

2.1.4 Human Impacts on Coastal Lagoons

Coastal lagoons are highly sensitive to anthropogenic stressors, besides several lagoons now rank amongst heavily polluted aquatic ecosystems on earth. Changes in land use, ground water withdrawal, usage of surface water, point and non-point source of water pollution, sedimentation, and over-exploitation of water resources are some of the examples of anthropogenic activities that have heavily impacted on coastal ecosystems (Khan 2007, Rodriguez *et al*., 2007). Though anthropogenic effects on coastal lagoons have attracted the most attention, there are some natural events such as coastal flooding also causing environmental degradation which can be more profound over both short and long periods of time (Kennish & Pearl, 2010).

2.2 PHYSICOCHEMICAL PROPERTIES

Dissolved oxygen, pH, water temperature, conductivity and total dissolved solids are some of the factors that influence quality of water and sediments in aquatic systems in terms of heavy metal contaminations.

2.2.1 pH

The measure of hydrogen ion (H^+) present in water is termed as pH. This is normally used to describe the acidity or alkalinity of water. A water pH of 7 is a neutral condition (pure water); while pH, less than 7 shows acidic and greater than 7, indicate alkaline conditions. Majority of aquatic organisms can strive within a pH range of 6.5-9.0. The solubility of metals and salt in water and sediments are influenced by pH (US EPA, 2012). Extreme water pH can dissolve certain minerals, release metals and other chemical compounds into the water column. pH can also regulate the chemical state of some chemical components, which in turn can affect the persistence, bioavailability and toxicity of metals (Hickin, 1995).

2.2.2 Dissolved Oxygen

Dissolved oxygen is the amount of free non-compound oxygen present in water. The levels of oxygen existing in water fluctuate daily, and depend on temperature and salinity (Wetzel, 2001). Ice-cold water can hold twice as much dissolved oxygen than warm water (Wetzel, 2001). Dissolved oxygen in water is derived either from the atmosphere or plant photosynthesis, which is utilized through respiration by aquatic organisms, chemical oxidations, and decomposition organic materials (Manahan, 2000).

Dissolved oxygen (DO) is noteworthy to the health of aquatic ecosystems. The dissolved oxygen needed in aquatic environments differs from one species to the other. Bottom dwellers: crabs, and oysters need a minimum amount of oxygen between 1 and 6 mgl^{-1} (APHA, 1999), while shallow water fish need higher levels of 4-15 mgl^{-1}.

2.2.3 Total Dissolved Solids

Total dissolved solid (TDS) is a measure of the total amount of all dissolved inorganic salt (calcium, potassium, magnesium bicarbonates) and organic matter in water (WHO, 2005). Coastal lagoon usually has TDS levels, which range from twenty thousand to two hundred thousand milligrams per litre (20,000 - 200,000 mgl^{-1}), contingent on the geology of terrain, climate, weather conditions, and other geographical features that affect the input of materials as well as the water movement system.

2.2.4 Water Temperature

Temperature is a measure of average kinetic energy of the particles in an object (Brown, 1999). Water temperature is amongst major determinant characteristics of an aquatic system, affecting dissolved oxygen, chemical and biological processes, water density and stratifications. Water temperature determines which organisms can thrive and which can diminish in numbers and size (Wetzel, 2001). Apart from the sun being the main source of heat, others, such as wastewater discharge, surface runoff, and heat exchange with the air contribute to water temperatures of lagoons.

A slight increase in temperature increases the rate of metabolism, respiration, and oxygen demand of fish and other aquatic organisms, to the extent of doubling the respiration rate. (Bennett & Santo, 2011). The solubility of many toxic substances is increased and intensified as the water temperature rises (US Ecology, 1991). Higher water temperatures influence the growth of sewage fungus.

2.2.5 Electrical Conductivity

Conductivity is a measure of water's capability to pass electrical flow. Conductivity of water is directly related to the concentration of dissolved solids in the water. Dissolved ions in water influence the ability of water to conduct an electrical current (Michaud, 1991). Conductivity is directly influenced by water temperature (Miller *et al.*, 1988). For every 1°C increase, conductivity can rise by 2-4 % (Miller *et al.*, 1988).

2.3 HEAVY METALS POLLUTION

Heavy metals have a relatively high density. The crust of the earth is naturally made of heavy metals. Heavy metals are toxic to all organisms and pose health risk to humans. Even at low concentrations they can neither be degraded nor destroyed, thus persisting in the environment. Heavy metals are transported via water, air, food, and adsorption or absorption on tiny particles. Heavy metals are stable and persistent environmental pollutants. Sediments serve as major sinks for these metals in aquatic ecosystem (Goodwin *et al.,* 2003). Exposures to heavy metals of a particular concentration are detrimental to the human immune systems.

2.3.1 Occurrence of Heavy Metals in Nature

Since the dawn of the industrial revolution, humans have explored the earth's geological components for infrastructural developments occasioning the distribution of these heavy metals in water, land and air as pollutants in the environments.

Exploration of minerals affects geological and ecological distribution of heavy metals through pollution of air, water, and soil. Human behaviour is also responsible for altering the chemical forms of heavy metals released to the environment affecting the toxicities of these metals. These are either through bioaccumulation in plants and animals or bio concentrating in the food chain, thereby attacking specific organs such as kidney and liver of the body. Even at low level exposure, heavy metals cause serious illnesses which can lead to neurological damage, particularly in young children. Excessive exposure to high levels of these metals could also lead to health disorders. For instance, high levels of copper in the human body could cause stomach upset, nausea, and headaches.

The earth is the natural source of all metals except those that enter the atmosphere from space in the form of meteorites and cosmic dust (Larcoque, 1998). In aquatic ecosystems, metals form soluble ions and complexes, colloids, and could be suspended on tiny particles. In the atmosphere, metals might be gaseous elements, particulates and aerosols (Nriagu, 1989).

Airborne and particulate materials are inhaled whilst solid and liquid metals may be ingested or absorbed, thus entering living things and man. In addition to being the main source of all metals, geosphere is an ultimate sink for metals. Nevertheless the atmosphere and hydrosphere also serve as sinks for metals; but are mostly considered as agents of transportation. The movements of metals from one point to another depend on their chemical properties.

2.3.2 Behaviour of Heavy Metals in the Environment

Microorganisms play roles in transforming metals such as mercury, selenium, tin, arsenic and chromium by enhancing their oxidation-reduction state, methylation mechanisms and dimethylation reactions. These processes affect the movements, solubility and toxicity of metals (Adriano 2001; Sparks 2005). For instance, Arsenic is a toxic metalloid with no known biological benefit. In the environment, arsenic compounds are absorbed, they are then converted into many different types of inorganic compounds, which are arsenite As(III), and arsenate As(V), and their organic species include dimethylarsinate (DMA), and monomethylarsonate (MMA). Organic arsenic species are generally considered harmless since they are poorly absorbed into cells (Akter *et al*., 2005) whilst inorganic arsenic species are highly reactive and affect a series of intracellular reactions (Drobná *et al*., 2010). Among the inorganic arsenic, arsenite [As(III)] is more toxic than arsenate [As(V)]; and trimethylarsine [$(CH_3)_3As$] and arsine (AsH_3) are extremely toxic, while tetramethylarsonium [$(CH_3)_4As^+X^-$] is not toxic.

Heavy metals can also be easily translated in the environment by the agents of erosion through which they are adsorbed or bound to tiny particles and re-deposited elsewhere. The transport, cycling, fate, bioavailability and toxicity of heavy metals, mainly depend on their physical or chemical forms in water and sediments.

2.4 BIOAVAILABILTY OF HEAVY METALS

Heavy metals carried on suspended tiny particles are more accessible than those in bottom sediments. Metals bioavailability depends on the type of metals, chemical forms or oxidation states, the nature of the suspended matter, the organisms taking up the metal and physicochemical conditions of the water.

Toxicity of heavy metals in sediments and their bioavailability to organisms is very important in determining the environmental effects of these metals in aquatic ecosystems and human health. Sediments in coastal lagoons are anaerobic (Baird & Cann, 2008). Sediments when exposed to air facilitate oxidation of sulfide to sulfate thereby releasing significant amounts of heavy metals. Several bio physicochemical factors can affect metal bioavailability in sediments. In aquatic systems, metal geochemistry plays an important role in determining the bioavailability and impacts of metals on sediments. Metals are partitioned amongst soluble phases, suspended particles, bottom sediments and biota in aquatic systems (Elder, 1988). The major pathways of metal partitioning based on environmental conditions include adsorption, complexation, precipitation (oxides or phosphates) and free ions. The soluble phase represents the principal source of bioavailable metals (Elder, 1988). The dissolved fraction is favoured under conditions of low pH, as the solubility of metal hydroxides increases as pH decreases.

2.4.1 Remobilization of Heavy Metals

Heavy metals are temporarily bound within sediment fractions, but are remobilized when changes happen within environmental conditions (Fergusson, 1990; Connell *et al*., 1999). The biogeochemical processes occurring at the water-sediment interface will keep heavy metals constantly cycling among the various lagoon sections, resulting in relatively higher concentrations of heavy metals in lagoon waters than the adjacent sea or river waters. Once in solution, heavy metals are transformed into other compounds that have more toxic effects. Iron (Fe) and manganese (Mn) are examples of heavy metals that rapidly re-precipitate and deposited as insoluble oxy-hydroxides where newly formed mobile traces of heavy metals can become adsorbed (Saulnier & Mucci, 2000). Adverse effect may occur when human beings are exposed to contaminated water, sediments and through the consumption of contaminated animals or plants (Jarup, 2003).

2.4.2 Anthropogenic Sources of Heavy Metals

A lot of researches have been conducted on heavy metal contamination in soil from various anthropogenic activities such as industrial wastes (Dipak, 2017), automobile emissions (Zhang *et al*., 2012; Garcia-Miragaya, 1984), mining activity (Ma *et al*., 2015; Parizanganeh *et al*., 2010) and agricultural practices (Colboum & Thornton, 1978). Heavy metals from anthropogenic stressors are believed to easily accumulate in the topsoil, causing potential complications such as toxicity to plants and animals, accumulation in food chain, perturbation of the ecosystem and adverse health effects.

2.4.3 Human Exposure and Health Hazards Associated with Heavy Metals

Ordinarily, humans are exposed to acceptable levels of heavy metals and the body is able to assimilate some of these metals to some degree. However, continuous exposure to a particular level could cause serious illness or death (Okonkwo & Mothida, 2005; Rollin *et al.*, 2005). An increase in exposure might occur via inhalation of aerosols, air particles, ingestion of contaminated soil by children and adults or by absorption through the skin (WHO, 1981).

Different heavy metals can cause different health hazards. Exposure to cadmium during human pregnancy could cause low birth weights and premature labour (Henson & Chedrese, 2004). Cadmium increases calcium excretion thus causes skeletal demineralisation. This might further lead to increase in bone fragility and risk of fractures (Wu *et al.*, 2001).

Zinc exposure is corrosive to skin, eye and mucous membrane. It causes distinct types of dermatitis known as "zinc pox" and Zn may also cause irritation to the digestive tract, resulting in nausea and vomiting (Patil & Ahmad, 2011).

High intake of copper can damage the liver and kidney or even cause death. Exposure to silver compounds can cause toxic effects ranging from liver and kidney damage through to irritation of the eye and skin, then to changes in blood cells (Drake & Hazelwood, 2005). Excessive amounts of iron can cause a rapid increase in pulse rate and clotting of blood, high blood pressure and drowsiness.

Fish species and human beings are generally exposed to lead either by consuming contaminated food or breathing. Lead naturally accumulates in muscles, bones, blood and fat (Elder & Collins, 1991). The adverse health effects from too much lead include critical damage to liver, kidneys, brain, nerves, reproductive disorders, increase in heart disease, high blood pressure, anaemia, behavioural disorders as well as learning defects (Afshan *et al.*, 2014). Children are most susceptible due to their body mass, Pb changes hormonal balance of metabolite of vitamin D and diminished intelligent quotient (IQ) (Siddiqui *et al*., 2004).

Mercury is considered as a global harmful pollutant because of its toxicity. Primarily, humans are exposed to methyl mercury via fish consumption. The effect of methyl mercury causes health problems; the aforementioned is listed as one of the most unsafe chemicals in the environment by the International Program of Chemical Safety (Gilbert & Grant-Webster, 1995).

The accumulation of chromium in human body depends on the metabolism (Karadede *et al*., 2004). Some hazardous effects of chromium to human include damaging immune system, various skin diseases, disruption to respiratory systems, mutation and thus cancer (Afshan *et al*., 2014). Arsenic has been known to be carcinogenic to humans and other organisms (Yoshida *et al*., 2004).

2.5 FISHERY

Organisms take up heavy metals particles released into the water body from sewage, industrial plants or runoff from municipal waste. Metals bioaccumulation in the organisms lead to metal related sicknesses. The process of bioaccumulation depends on the organism, the uptake, detoxification and the surrounding environment. Bioaccumulations in organisms indicate the contaminants level in a polluted environment (Bryan, 1973). These are few examples of studies using organisms to assess metal contamination:

A study was carried out to investigate the metal levels in fish (Black chin tilapia) in the Fosu Lagoon of Cape Coast, Ghana. The investigation assessed the metal pollution in the fish and compared the concentrations with the US Food and Nutrition Board Daily recommended Intake. The mean concentrations were iron (9.95 mgkg^{-1}); copper (0.20 mgkg^{-1}); manganese (27.90 mgkg^{-1}); nickel (1.15 mgkg^{-1}); lead (6.75 mgkg^{-1}); cadmium (2.25 mgkg^{-1}) and zinc (20.65 mgkg^{-1}). Chromium level was below detection limit in all the samples whilst iron, manganese, lead and zinc were detected in high concentrations. However, the concentrations of all the metals in the fish did not exceed the limit of US Food and Nutrition Board Daily recommended Intake, but the presence of lead and cadmium is a health threat since they have the tendency to bioaccumulate and biomagnified along the food chain (Eshun, 2011).

A research by Adu (2010), to determine the heavy metal concentrations (manganese, zinc, iron and mercury) in sediment and tissues of the clam *Galatea paradoxa* in Ada and Aveglo at Volta Estuary, Ghana. Thirty clam samples were obtained from various locations for analysis. Mean concentrations of metals in the tissue of the clams from the Ada sampling station were: Mn: 152.9 µgg^{-1}; Fe: 174.9 µgg^{-1}, Zn: 34.6 µgg^{-1} and Hg: 0.043 µgg^{-1} and mean metal concentrations in the Aveglo clams were: Mn: 130.0 µgg^{-1}, Fe: 187.0 µgg^{-1}, Zn: 37.1 µgg^{-1} and Hg: 0.046 µgg^{-1}. The sediments recorded mean concentrations of Mn: 186.0 µgg^{-1}, Fe: 1770.4 µgg^{-1}, Zn: 3.2 µgg^{-1} and Hg: 0.0086 µgg^{-1} for the Ada sampling station and those of Aveglo sediments were as follows: Mn: 171.9 µgg^{-1}, Fe: 1758.5 µgg^{-1}, Zn: 3.7 µgg^{-1} and Hg: 0.0115 µgg^{-1}. Risk analyzes associated with the consumption of clams by humans revealed that the concentration of the Mn, Zn, Fe and Hg found in the clam tissues were within permissible limits using WHO Safety Reference Standards for Bivalves and other indicators such as the Tolerable daily Intake (TDI), Rate of shellfish consumption (RSC), Risk Quotients (RQs) and levels of concerns (LOCs) Based on geoaccumulation calculations, the sediments from the two sampling stations are unpolluted in terms of the heavy metals investigated (Adu, 2010).

Viswanathan *et al.* (2013) assessed the concentrations of cadmium (Cd), copper (Cu), chromium (Cr), lead (Pb) and zinc (Zn) in gill, muscle and hepatopancreas of *Portunus pelagicus* (Blue swimming crab) at Ennore Estuary, from January to June 2009 in order to monitor the industrial discharges from the surrounding factories into the estuary. Thirty six (36) samples were collected and analyzed using Inductively Coupled plasma Atomic Emission Spectrometer (ICP AES). The measured mean concentrations of Cd, Cu, Cr, Pb and Zn in the gill of P. pelagicus were 0.08 ± 0.01 μgg^{-1}, 0.02 ± 0.01 μgg^{-1}, 4.26 ± 0.11 μgg^{-1}, 0.04 ± 0.00 μgg^{-1}, respectively and those of the muscles were Cd (0.02 ± 0.01 μgg^{-1}), Cu (0.03 ± 0.01 μgg^{-1}), Cr (2.63 ± 0.19 μgg^{-1}), Pb (0.03 ± 0.00 μgg^{-1}) and Zn (2.34 ± 0.18 μgg^{-1}). The mean concentration of Cd, Cu, Cr, Pb and Zn was 0.02 ± 0.00 μgg^{-1}, 0.04 ± 0.00 μgg^{-1}, 0.89 ± 0.29 μgg^{-1}, 0.03 ± 0.00 μgg^{-1} and 2.82 ± 0.60 μgg^{-1}, respectively. Pattern of accumulation of heavy metals in the gill, muscle and hepatopancreas follow the sequence: Cu>Zn>Cd>Pb>Cr, Cu>Zn>Cr>Pb>Cd and Zn>Cu>Cr>Pb>Cd, respectively. The results indicated, metal concentrations in the gill, muscle and hepatopancreas of the examined crabs were in the safety permissible levels given by Franklin (1987) for human consumption.

2.5.1 Selection of Bio Indicators

Plants and organisms pick up contaminants from immediate environments and their compositions are used as to assess the effect of pollution on aquatic and terrestrial ecosystem. The study employed various criteria in selecting the organisms used for bio markers.

- Organisms were widely distributed in the system
- Ecosystem integration, could interact with the component of the community
- The organisms are indigenous and structurally stable in the ecosystem
- A lot of information were available on these organisms

- One of the organisms have not been used in ecological assessment in order to minimised information overlap (Ryder & Edwards, 1985)
- The organisms were easy to collect and monitor
- The organisms were suitable for laboratory experiment
- The organisms have social value, especially of economic importance to humans (Podowski & Angus, 1990)

2.5.2 Crab and Tilapia as Bio Indicators

Crab and tilapia were the only organisms within the criteria used. Contaminants are generally more concentrated in sediments than water column in the aquatic system, and crabs like other invertebrates in the benthic zone feed on sediments and are exposed to greater levels of metal pollutants. Crabs exhibit a steady, predictable response to heavy metal.

On the other hand tilapias are pelagic filter feeders, large biomass for chemical sensitivity and high tolerant to contaminants. They are relatively easily to identify.

2.5.3 Bigfisted Swimming Crabs: (*Callinectes amnicola*)

Crabs are crustacean, have a hard exoskeleton and two claws. The bigfisted swim crab (*Callinectes amnicola)* belongs to Portunidae family. Crabs are the most common seafood, rich in nutrients and minerals that are essential for human health. The most common ones in Ghana are African ghost crab (*Ocpode Africana*), lagoonland crab (*Cardiosoma armatum*) and bigfisted swim crab (*Callinectes amnicola*) (Oduro *et al.,* 2001).

Crab meat contains high quantity of phosphorus (Oduro *et al*., 2001), a mineral next to calcium in providing strong and healthy bones and teeth; vitamin B2, selenium, copper and omega-3 fatty acid. Crab meat protects the immune system and the heart. The consumption of crabs promotes anti-inflammatory activities in the body besides reducing blood pressure. The meat contains anti-oxidant that protects the body from chronic disease.

Crabs are benthic invertebrate that feed on organic matter within the sediments and mostly dwell in marine environment. Ecologically, crabs play diverse roles in aquatic food chain: as detritivores (the composers) at bottom sediments, herbivores, predators and also prey for some birds (Guillory, 2001). Crustaceans particularly crabs can serve as good bio indicators in determining heavy metal concentration in sediments, due to their mode of feeding (Ololade *et al*., 2011).

2.5.4 Black Chin Tilapia (*Sarotherodon melanotheron*)

Tilapias are a group of tropical, hardy, fast-growing fresh and brackish water fish in the family of Cichlida (Hoover, 2006). Tilapias can mostly be found in Africa and Southeastern Middle East. Tilapias were initially used to control aquatic weeds and insects in reservoirs and aquaria. Recently, they have been promoted as an important source of protein to provide food security for developing countries.

Black chin tilapia (*Sarotherodon melanotheron*) acquired its name from the patches of black or melanic colour that usually occur on the neck and throat. The coloration of these patches depends on their geographical location. Black chin tilapias are normally found in brackish or freshwater lagoons between the depth of 0-3m (Teugels & Thys van den Audenaerde, 2003). Tilapias feed on aufwuchs, detritus (Trewavas, 1983), bivalves and zooplankton (Diouf, 1996) and can tolerate a wide range of environmental conditions to the extent of breeding in pure seawater (Canonico *et al*., 2005).

2.6 REVIEW OF HISTORICAL DEPOSITION AND SPATIAL DISTRIBUTION OF HEAVY METAL

Distribution of trace metals in marine and estuarine environment has features that make them appropriate for historical analysis (Heim & Schwarzbens, 2013). Globally, environmental metal pollution increased during the industrial evolution. According to Valette-Silver (1993), the accumulation of pollution continued and reached its peak between 1960 and 1970. There was a downward trend of pollution in the mid-1980s in certain heavy metals as a result of environmental laws and regulations that were implemented. Apart from lagoons, freshwater environment can also be used to highlight pollution history using core sediment analysis.

Al-Mur *et al*. (2017) conducted a study on distribution of heavy metals in sediments core in the Red Sea, Saudi Arabia. Four core sediment samples were obtained in close proximity to Jeddah from depth of 0-50 cm. The result indicated utmost concentrations of Mn, Cu and Pb on the top 15 cm of the core profile compared to the lower depth sub-samples. These metal concentrations were likely to relate to an increase in anthropogenic pollutants inputs from rapid urbanization and industrialization.

Raulinaitis *et al*. (2012), emphasized that having knowledge on pollutant distribution is important for effective management of the environment in spatial distribution of heavy metals in sediments. Continuous increase in concentrations of heavy metals in aquatic environment presents a risk to biota and human health (Jarup, 2003).

Shanbehzadeh *et al.* (2014) examined heavy metal concentrations in water and sediment of upstream and downstream of sewage entrance on Tembi River in Iran. Heavy metals (Cd, Cr, Cu, Ni, Fe, Pb, Mn and Zn) were analysed using AAS. The analysed samples indicated that average levels of metals in water and sediment in downstream sites were much more than that of the upstream sites. The research compared the mean concentrations of these metals in the River Tembi with standard levels in drinking water, irrigation water for agriculture and for aquatic life. It revealed that mean Cu (0.52 mgL^{-1}) level was within the range of standard drinking water, Mn (0.70 mgL^{-1}) and Cd (0.21 mgL^{-1}) were within the range of irrigation water, and mean value of Zn (0.28 mgL^{-1}) was within the limits of drinking, irrigation and aquatic life. In conclusion, the River Tembi was contaminated with heavy metals and not suitable for recreational, fishing or washing purposes.

2.7 EMPIRICAL STUDIES OF HEAVY METALS CONTAMINATION OF LAGOON

Sivanantha *et al*. (2016) researched on the presence of five heavy metals (As, Cd, Cr, Pb and Hg) in biotic and abiotic components of Negombo lagoon, in Sri Lanka using ICP-OES. The investigation in water recorded no detection for all metal examined, except Cr (0.09 mgL^{-1}) which read low level of concentration. Heavy metal levels in sediment and soil were higher than those recorded in water. The levels of As, Cd, Cr, Hg and Pb in sediment ranged ND[*]-8.65 $mgkg^{-1}$, ND-1.67 $mgkg^{-1}$, 7.64-34.34 $mgkg^{-1}$, ND and 2.53-19.61 $mgkg^{-1}$ respectively, and those of soil ranged ND-9.89 $mgkg^{-1}$, ND-2.63 $mgkg^{-1}$, 2.4-49.70 $mgkg^{-1}$, ND and ND-20.6 $mgkg^{-1}$ respectively. The overall trend of heavy metals in the study were in the order of water < leaves < bark < snail < crab < sediment < soil. The study concluded that the sediment in the lagoon was highly polluted.

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[*] ND refers to No Detection

Heavy metals (chromium, nickel, copper, zinc, arsenic and lead) contamination in commercial fish and crustaceans were examined from coastal area (Cox Bazar) of Bangladesh. The study revealed considerably high concentration of As (13 $mgkg^{-1}$) and Zn (138 $mgkg^{-1}$) in fish. The study also observed remarkably high concentrations of As (53 $mgkg^{-1}$), Cu (400 $mgkg^{-1}$) and Zn (1480 $mgkg^{-1}$). The level of heavy metal loading was attributed to the hatcheries and industrial activities in the studied area (Raknuzzaman *et al*., 2016).

Lawal-Are *et al*. (2017) investigated the concentrations of Cr, Cu, Ni, Pb and Zn in *Callinectes amnicola* and *Farfantepenaeus notialis* in Igbese River, Makoko and Lekki Lagoon in Nigeria, for eight months using AAS. The study revealed the mean levels of heavy metals in the tissues of crab as Cr (0.14, 0.71, 0.19 mgL^{-1}), Cu (2.17, 1.27, 1.51 mgL^{-1}), Ni (0.33, 0.30, 0.19 mgL^{-1}), Pb (0.47, 0.26, 0.15 mgL^{-1}), Zn (0.04, 1.05, 0.63 mgL^{-1}) in Igbese River, Makoko site and Lekki Lagoon respectively. While the heavy metal concentrations in the tissues of shrimps reported: Cr (0.28, 0.18, 0.14 mgL^{-1}), Cu (1.21, 0.19, 0.53 mgL^{-1}), Ni (0.28, 0.27, 0.15 mgL^{-1}), Pb (0.26, 0.19, 0.13 mgL^{-1}), Zn (0.74, 1.11, 0.36 mgL^{-1}) in Igbese River, Makoko site and Lekki Lagoon respectively. The concentrations showed that the heavy metal levels in crabs and shrimps were within the permissible regulatory limit.

Laar *et al, (*2011) researched on levels of heavy metals pollution and distribution in the Sakumo wetlands, which is being contaminated with industrial, domestic and sewage discharge. Sampling analyses showed the presence of heavy metals such as As, Cd, Cr, Cu, Fe, Hg and Zn in water column, sediments and fish. The results revealed high levels of manganese and copper in all three types of samples: fish, water and sediments. Cadmium and mercury were relatively low in fish, but iron, zinc and manganese levels were high in fish when compared with WHO/FAO recommendation values. It concluded that these concentrations would not pose immediate threat to human health.

Addo *et al.* (2012) studied heavy metals in Mokwe lagoon and used geoaccumulation index, enrichment factor, contamination factor and pollution load factor to assess concentrations of heavy metals and their distribution in the sediments. The analysis showed high metals enrichment in the bottom sediments, especially for Ni (1-504 $mgkg^{-1}$) and Cr (1-243.11 $mgkg^{-1}$). The water column was less contaminated, thus falling within the range of international guideline limits of natural water (US EPA). The study reflected human activities were the causative factor of contamination.

The water quality of Keta Lagoon was studied by Lamptey *et al*. (2013). The study revealed that the water is contaminated with agro-chemicals used for farming within the catchment areas. The quality of water was compared to that of WHO standards and it was established that it was not suitable for human consumption per its quality (Lamptey *et al*., 2013).

Sackey (2014) determined heavy Metal Pollution in Sediments at 12 different stations within the Brenya Lagoon in Komenda Edina Eguafo Abrem Municipality (KEEA) in the central region of Ghana. It revealed sediments are highly polluted with Cd, As, Pb and Hg when compared with the criteria of US EPA and SQG of CCME. Correlation of As-Cd and Zn-Pb using Pearson's coefficient showed similar source of pollution. Further assessment with geo-accumulation and contamination factor also showed the degree of pollution in the order of Cd > Pb > As > Hg > Cu > Cr > Zn.

Aboagye (2012) carried out a study in the Korle Lagoon Estuary and indicated that the levels of metal in the tissues of *Seriola dumerili* and *Pteroscion peli* were low in terms of copper (4.43;5.11 μgg^{-1}) and zinc (13.90;16.41 μgg^{-1}), but higher for lead (2.54;2.73 μgg^{-1}) and cadmium (1.75;2.17 μgg^{-1}) as compared to the World Health Organization (2005) standard. Heavy metals concentrations in the flesh of *Seriola dumerili* and *Pteroscion peli* in relation to size discovered that, both sizes accumulated higher lead and cadmium concentrations and lower zinc and copper concentrations. The study revealed that consumption of fish from the Korle lagoon estuary should be prohibited and be discouraged because of the high levels of Pb and Cd in the tissue of *Seriola dumerili* and *Pteroscion peli* in both small and large sizes.

The outcome of study from Kpeshie showed that Cd, Cr and Ni were extremely enriched in the sediments. Their concentrations ranged: Cd (0.20-2.80 mgkg^{-1}); Cr (150-1350 mgkg^{-1}); Ni (50-1568 mgkg^{-1}). The enrichment were as a result of farming activities upstream, solid waste dumping close to the lagoon and discharge of effluent from the hotels situated in close proximity to the lagoon. Amongst all the metals, levels of zinc (0.001-0002 mgkg^{-1}) were within the background limit set by US EPA (Addo *et al*., 2011).

2.8 POLLUTION INDICES

Pollution indices are standard calculations used to evaluate the likelihood ecological adverse effect that may occur as a result of heavy metals contaminants in sediments. They are diagnostic tool for controlling environmental pollution. Several procedures such as contamination factor, enrichment factor and geo accumulation index have been used in studies (e.g. Samir *et al*., 2006; Abdullah *et al*., 2015) to establish the pollutants distribution of the ecosystem, since these heavy metals are released naturally and from anthropogenic activities and accumulate on sediments. The study employed a few to determine the ratio between the natural and artificial components of sediments.

2.8.1 Contamination Factor

The contamination factor (Cf) evaluates the enrichment in heavy metals in relation to the background concentrations of each heavy metal in sediments. The contamination factor (Cf) is defined by Hàkanson (1980) as the ratio obtained by dividing each element concentration to its corresponding background value. Limits have been denoted to describe the contamination factor:

$Cf < 1$ indicates a low contamination factor; $1 \leq Cf < 3$ implies a moderate contamination factor: $3 \leq Cf < 6$ is a considerable contamination factor; $Cf > 6$ is a high contamination factor

2.8.2 Pollution Load Index

Pollution load index (PLI) assesses the pollution status of heavy metals in a site (Tomlinson *et al*., 1980). PLI is a comparative means of evaluating sampling sites in relation to sediment pollution. A value of zero (0) indicates perfection; a value of one (1) indicates the baseline level of pollution; values less or greater than one (1) are considered either as unpolluted or polluted.

2.8.3 Potential Ecological Risk Index

The potential ecological risk index (RI) assesses the adverse effect of heavy metal contamination in sediment samples on living organisms and man (U.S. EPA, 1992). RI is defined as the sum of all potential ecological risk factors (Er) of heavy metals of a site. Er is determined by the product of toxic response factor of a metal (Trf) and contamination factor (Cf) (Hàkanson, 1980). The following limits of RI categorize its toxicity:

RI < 95 indicates low potential; 95 ≤ RI < 190 implies moderate potential: 190 ≤ RI < 380 is considerable potential; RI > 380 is very high potential.

2.8.4 Target Hazard Quotient

Though seafood is an important source of protein and minerals, its consumption has been reported to be one of the routes of human exposure to certain chemical contaminants (Llobet *et al*., 2003). Target hazard quotient (THQ) signifies the non-carcinogenic health risk posed by exposure to respective toxic element (Antoine *et al*., 2017). If THQ is less than one (< 1), then non-carcinogenic health effects are not likely to occur, on the other hand, if THQ is greater than one (>1), then there is the likelihood of non-carcinogenic health effect to occur

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CHAPTER THREE

MATERIALS AND METHODS

3.1 STUDY AREA

Korle and Kpeshie lagoons where the study took place are located in the Greater Accra Region of Ghana. These lagoons are shallow water bodies, found in coastal low lying areas that were once a sight of beauty depicting beautiful sand dunes, open mangroves, marshes and scrubs, providing extensive and suitable feeding, roosting and nesting grounds for various species of water bird (Owusu Boadi & Kuitinen, 2003).

Korle lagoon has a surface area of approximately 0.127 square kilometres, and it is located within the south-western part of the Accra Metropolis, with an elevation of about 7m above sea level. The Korle Lagoon is connected to Odaw River, which flows from Abokobi and Adjankote hills through Ashongman, Atomic Energy, West Legon, Achimota, Alajo, Avenor and Agbogbloshie and finally empties into the lagoon, and two other major drainage channels (Biney, 1982). The Korle lagoon (figure 3.1), which is located between the geographical coordinates of 0° 13' 07.72"W; 5° 31' 48.32"N and 0° 13' 20.60"W; 5° 31' 47.46"N could support fin and shellfish in the mid twentieth century. The lagoon, a major basin receives discharges of industrial, municipal sewage and flood water from a catchment area of 400 square kilometres. The discharge water collects silt and debris as they are transported into the lagoon (Mensah, 1976), which often blocks the main outlet to the sea. The flow rate is gradually reduced as a result of the blockage, depriving the lagoon water of oxygen. The water quality changes towards the sea, where the tides help in making this part of the lagoon less polluted (Amuzu, 1976).

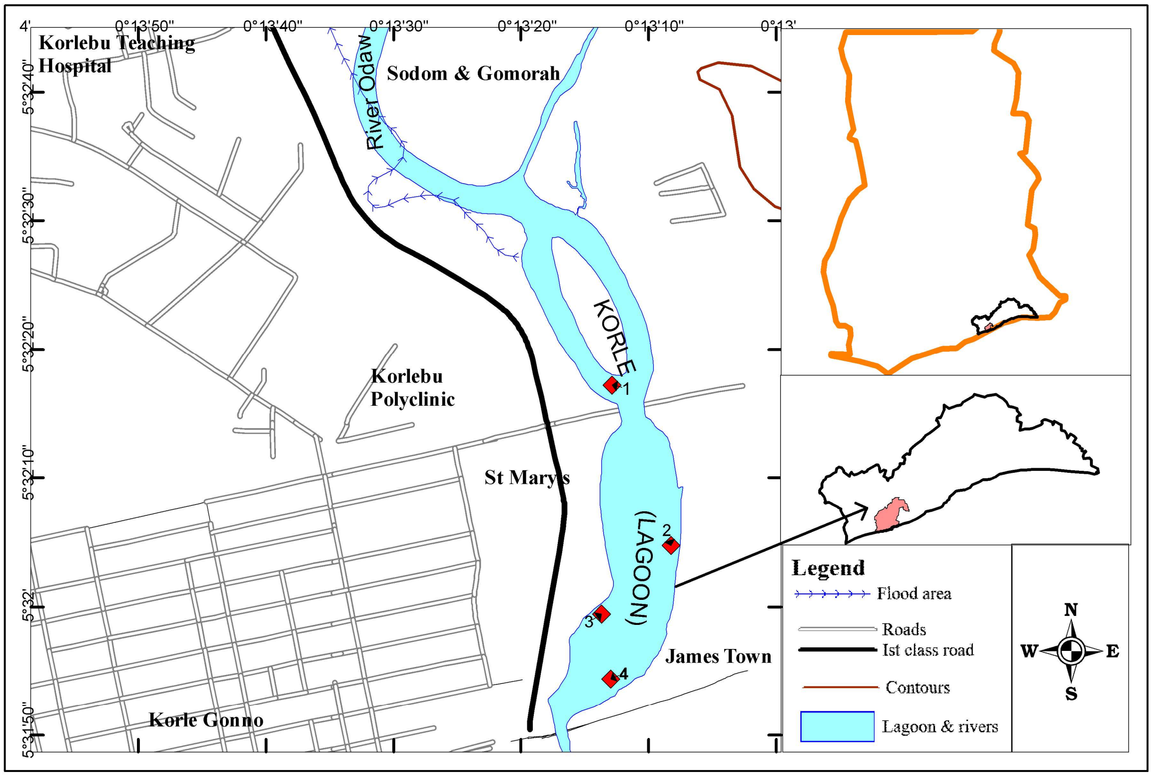

Figure 3.1: Map of Korle Lagoon

Kpeshie lagoon shown in figure 3.2 is sited along the main La-Teshie road with a surface area of 0.326 square kilometres in the La-Dade Kotopon district of Greater Accra Region. The lagoon is close to the sea and overflows its barriers during periods of floods into the Gulf of Guinea. Directly southwest of the lagoon are hospitality industries, and then to the east is the Whitler Barracks and La community is to the west. There are no major manufacturing industries located in the catchment area but a number of vehicle repair workshops and schools are scattered along the lagoonal stretch that empties their waste water into the lagoon. The local community uses the bank of the lagoon as a refuse dump and defecation spots. The Kpeshie Lagoon is bounded between the coordinates 0° 08' 40.52"W; 5° 33' 46.37"N and 0° 08' 20.90"W; 5° 33' 54.72"N.

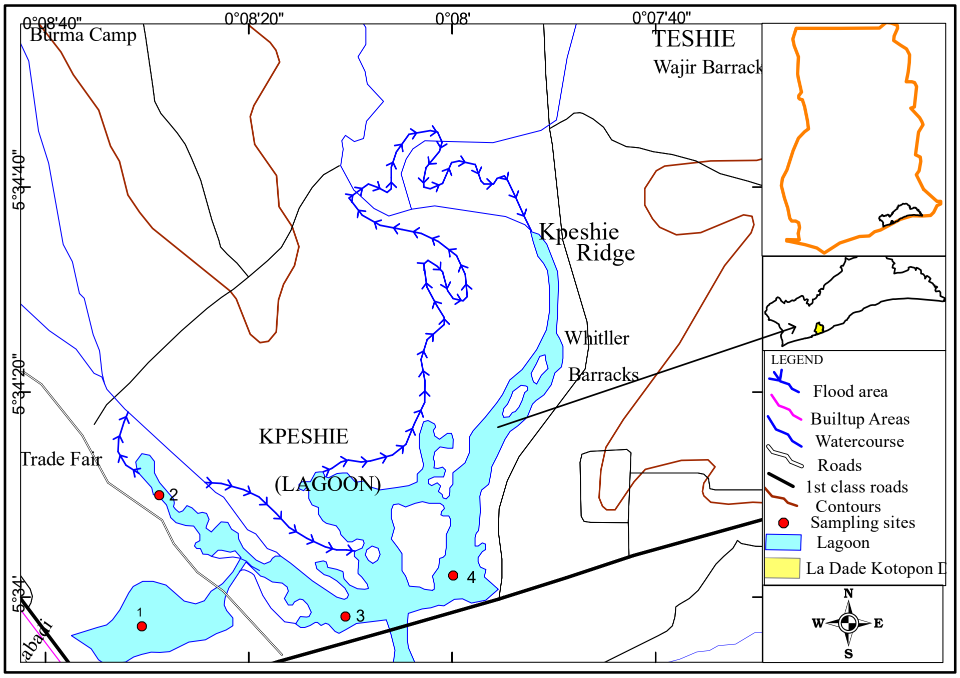

Figure 3.2: Map of Kpeshie Lagoon

3.1.1 Climate, Geology and Vegetation

Climate

The climate of the study areas is the tropical savanna type. The areas have two rainfall seasons with an annual average of about 730 mm; the main rainy season starts in April and ends in late July, and the minor one which is less strong, begins in early October. Rainfall is usually not prolonged, but is short with intensive storms and causes flooding, especially in low lying areas blocking the drainage channels (Amoako & Boamah, 2014).

The variation in temperature that occurs within the year is minimal, ranging from mean monthly temperature of 25.9 °C in August to 29.6 °C in March with an average of 27.6 °C for the year. The cooler months tend to be more humid than the warmer months. As a result, during the warmer months, particularly the windy Harmattan season, the city experiences a breezy dry heat.

As the study areas are in the coastal city, they respond to changes to climate such as a rise in sea level and increase in temperature, which are driven by population growth and infrastructural developments. Drainage channels are threatened with silt, debris and waste materials having profound implications for people's health.

Geology

The coastal shore lines of the lagoons are made up of sand that is regularly watered by the Ocean. The rocks of Korle Lagoon fall within the Devonian era between the ages of 354-417 million years. The rock types are of Sekondian and Accraian unit, and are generally sandstone and shale. The rocks weather into yellowish brown clay and silt depending on the parent rock, and are slightly permeable (Goudie & Viles, 2008).

The rocks of Kpeshie Lagoon on the other hand, are different from that of Korle Lagoon. The formation is of Early Proterozoic, between 2.2 to 1.8 million years old. These fall under the Dahomeyan unit and compose of felsic and mafic gneiss, schist and magmatite rocks (Holm, 1973).

Relief and Vegetation

The relief pattern at Korle and Kpeshie Lagoons are of coastal savanna, a low lying flat land interconnected by numerous streams and rivers. The lagoons gradually empty themselves into the Gulf of Guinea from an average height of 7 m.

The vegetation of the study areas is basically coastal grassland that comprises of different grass species (that is *Panicum maximum* and *Imperata cylindrical*), and scrubs. Coconut trees are well scattered in the study areas with patches of grasses. The banks of Kpeshie lagoon are covered with mangrove trees.

3.2 DATA COLLECTION

3.2.1 Field reconnaissance study

Prior to data collected from the study area, a three-day reconnaissance study was embarked upon on 20th to 22nd October 2017 in order to observe the extent of anthropogenic activities such as waste disposal, e-waste recovering and various vehicle repair workshops sited along the lagoons. The reconnaissance survey gave ideas of the tools and the approach necessary for sampling.

3.2.2 Sampling

The collection of samples was between November 2017 and April 2018. Core sediment samples were collected once from four different points in both Korle and Kpeshie Lagoons. The selected sites were based on activities along the lagoons and vantage points, taking into consideration the morphometry. The Etrex global positioning system (GPS) was used to locate these sample points (Table 3.1) and these are shown on figures 3.1a and 3.2a.

Table 3.1: Sampling points locations and descriptions

Points	Lagoon	Longitude	Latitude	Location descriptions
1	Korle	0° 13' 12.864"W	5° 32' 16.836"N	Sewage waste discharge point
2	Korle	0° 13' 08.259"W	5° 32' 04.736"N	South eastern side
3	Korle	0° 13' 13.565"W	5° 31' 59.412"N	South western side
4	Korle	0° 13' 12.975"W	5° 31' 54.379"N	Close to the estuary
1	Kpeshie	0° 08' 30.501"W	5° 33' 57.124"N	Africa, fishing point
2	Kpeshie	0° 08' 28.781"W	5° 34' 09.742"N	close to the vehicle garage
3	Kpeshie	0° 08' 10.496"W	5° 33' 58.107"N	Behind the washing bay
4	Kpeshie	0° 07' 56.901"W	5° 34' 02.110"N	Close to the barracks, fishing point

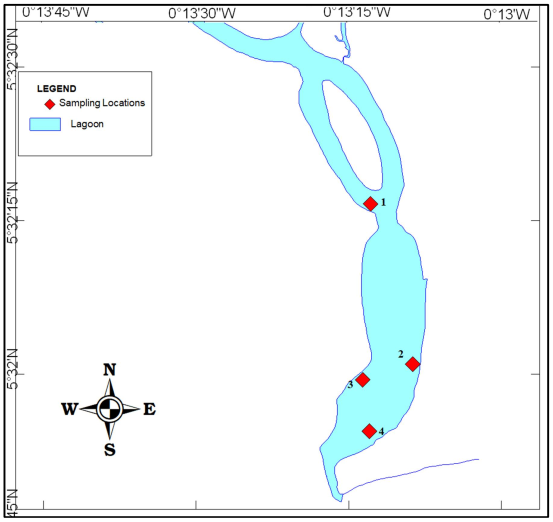

Figure 3.1a: Sampling points at Korle Lagoon

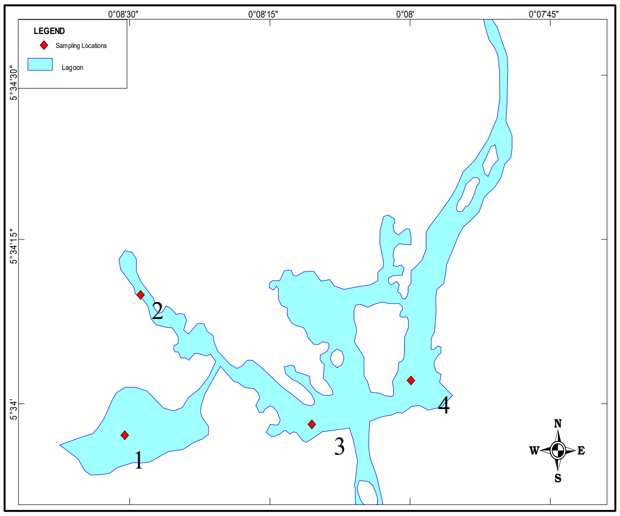

Figure3.2a: Sampling at Kpeshie Lagoon

Sediment core samples were taken from the lagoons using homemade PVC corer of 1m long and 2cm diameter to a depth of 30cm (Plate 2). The PVC Corer was washed with distilled and lagoon water before sampling. The recovered cores were measured with a tape measure, sliced at 5cm intervals, bagged and clearly labelled. The samples were secured in a zip-locked plastic bag, placed on ice and transferred to the laboratory.

Samples were air-dried between 24 and 36 hours with each sample mixed homogeneously, re-labelled and stored in polyethylene bags for analysis (US EPA, 2000).

3.2.3 Water Sampling

Samples of water were collected at all selected points chosen for sediment core drilling with plastic bottles (Plate 1), which were washed with distilled water as set out by the United Nations Environment Programme and the World Health Organization (UNEP/WHO, 1996). At each sampling site, the bottles were rinsed with lagoonal water before collecting the sample. Two drops of nitric acid were added to bottled samples before capped. Water samples were appropriately labelled, kept on ice and transferred into a refrigerator for analysis in the laboratory.

The parameters: pH, temperature, dissolved oxygen (DO), electrical conductivity (EC) and total dissolved solids (TDS) were measured in-situ using handheld griffin pH meter, thermometer, DO sensor, EC meter and TDS meter respectively. This approach was employed, particularly for DO to avoid changes in water due to either loss of gases or absorption of gases from the atmosphere (Manahan, 2000).

3.2.4 Heavy Metal Determination in *Callinectes amnicola*

Crabs (*Callinectes amnicola*) were bought from fishermen fishing in the Kpeshie lagoon shown on plates 3 and 4. The lengths were measured in the field using measuring tape and the weight taken with weighing scale at the laboratory. The samples were bagged in sealable polyethylene, clearly labelled and kept frozen on ice in an ice chest and carried to the laboratory for total heavy metal analysis using Atomic Absorption Spectrophotometry (AAS).

3.2.5 Heavy Metal determination in *Sarotherodon melanotheron*

Tilapias (*Sarotherodon melanotheron*) were bought from the fishermen at Kpeshie lagoon (Plate 5). The lengths of the samples were measured with a tape measure, labelled and stored in polyethylene bags on ice. The samples were carried to the Ecological laboratory, University of Ghana, for analysis.

3.3 SAMPLE PREPARATIONS AND ANALYSIS AT THE LABORATORY

3.3.1 Sediment Core Samples

At the laboratory, the dried sediment samples were grounded using mortar and pestle, and sieved with 2 mm mesh. One gram (1 g) of sediment was weighed into Folin-Wu digestive tubes and digested in 5 ml of ternary mixture of 1:1 nitric acid (HNO_3) and Perchloric acid ($HClO_4$). The mixture was heated using a block digester under fume hood for 1 hour at 80°C till the solution turned colourless. It was allowed to cool, filtered into 100 ml volumetric flasks using Whatman No. 0.45 filter paper. The volume was then made to the mark with distilled water. Atomic Absorption Spectrophotometry (AAS) was calibrated with standard solutions of the respective metals and de-ionized water before it was used to measure the levels of heavy metals in the digested samples. A total of 48 sediment core samples were analysed.

pH of the sediment samples was determined by measuring 10 g of the sediment into a beaker. Twenty (20) ml of distilled water was added and stirred for 30 minutes. It was then allowed to settle for 30 minutes, after which measurements were made with the pH meter.

3.3.2 Water samples

Heavy metal concentrations were determined by measuring 1.5 ml water samples into digestion tubes. A 5 ml of ternary mixture (1:1 of concentrated HNO_3 and $HCLO_4$) were added. The mixtures were digested for I hour at 80 °C, allowed to cool and filtered into100 ml volumetric flask. The solutions were topped with distilled water to the 100 ml mark. The metal contents were measured with the Analyst 400 Perkin-Elmer atomic absorption spectrophotometer according to the method prescribed by (Bentum *et al.,* 2011). AAS was calibrated with standard solutions of the respective metals and de-ionized water before it was used to measure the levels of heavy metals in the digested samples. A total of 24 samples of water were analysed.

Plate 1: Water and Sediment Core samples

Plate 2: Sediment Core samples

3.3.3 Bigfisted Swim Crab (*Callinectes amnicola*) Samples

The big fisted swim crab samples were oven-dried at 55°C for 24 hours and grounded in a stainless steel mill to a fine powder to pass through 1 mm screening. One gram (1g) of each powdered sample was weighed and digested in a 5 ml ternary mixture of 1:1 concentrated nitric acid and perchloric acid for one hour to obtain a clear solution. The samples were allowed to cool, filtered and diluted with distilled water into a 100 ml volumetric flask. AAS was calibrated with standard solutions of the respective metals and de-ionized water before it was used to measure the levels of heavy metals in the digested samples. Twenty four (24) crab samples were analysed.

Plates 3 and 4: crustacean samples collected from field

3.3.4 Tilapia (*Sarotherodon melanotheron*) Samples

The fish samples were washed with distilled water and oven-dried at 55°C for 24 hours. The dried tilapia tissue was ground into powder. One gram (1g) of these samples was digested with 5 ml of ternary mixture of 1:1 concentrated nitric acid and perchloric acid in digestion tubes inside a fume chamber. The sample mixtures were then filtered into 100 ml volumetric flask. Distilled water was added to the 100 ml mark. The filtrates were analysed for heavy metals using AAS. The AAS was calibrated with standard solutions and de-ionised water before measurements were made. A total of 24 samples was analysed.

Plate 5 *Sarotherodon melanotheron* caught in Kpeshie lagoon

3.3.5 Quality Control

Before analysis of the samples, standards and blanks were run to check the calibration of the instrument. Laboratory blanks and standards were primarily used to check contaminations and precisions, respectively, of the analytes. The quality assurance measures also included strict cleansing of laboratory glassware. (US EPA 1987).

3.4 DATA ANALYSIS

Data were presented in tables as mean ± SD. Data obtained in this study for the concentrations of heavy metals in sediments, water, crab and fish were analysed with ANOVA statistical tools of SPSS. In all cases, 95% confidence level was applied to compare the means. All descriptive statistics and graphs were executed using the Microsoft excel version 10.

3.4.1 Contamination Factor (Cf)

Contamination factor (Cf) is defined as the ratio of a metal concentration in the study to the background value of that metal in equation 1 (Hákanson, 1980). This gives the factor of contamination in the sediments.

$$Cf = C_{metal} / C_{background} \quad \text{----------------------------------} (1)$$

Where $C_{background}$ (see appendices 8 and 9) is the average concentration of a metal in a background level (Taylor, 1964);

C_{metal} is the concentration of heavy metal in the sediment of this study.

3.4.2 Pollution Load Index (PLI)

The pollution load index assessed the environmental quality of sediments. Pollution load index is determined as the nth root of the product of total number of contamination factor (Cf) (Tomlinson *et al*., 1980). It is defined as:

$$PLI = {}^{m}\sqrt{(Cf_1 \text{ x } Cf_2 \text{ x } Cf_3 \text{ x} \ldots\ldots\ldots \text{ x } Cf_m)} \quad \text{--------------------------} (2)$$

Where m is the number of analysed heavy metals

3.4.3 Potential Ecological Risk Index (RI)

Hákanson (1980) suggested a work out procedure (equation 3) to derive the potential ecological risk index (RI) to assess the characteristics and behaviour of heavy metal contaminants in environmental samples, especially sediment. The potential ecological risk index (RI) is defined by:

$$RI = \sum_{i=1}^{i=m} Er^{i} \quad \text{------------------------------------} (3)$$

Where Er^i is the single potential ecological risk factor, defined in equation 4 as the product of contamination factor (Cf) and the toxic response factor for a given heavy metal (Trf^i) (see appendices 10 and 11); and

m is the number of analysed heavy metal

$$Er^i = Cf \times Trf^i \quad \text{-------------------------------------} \ (4)$$

According to Hákanson (1980), the standardized toxic response factor (Trf^i)* accepted globally for As, Cd, Cr, Cu, Pb and Zn are 10, 30, 2, 5, 5 and 1 respectively.

3.4.4 Target Hazard Quotient (THQ)

THQ evaluates the non-carcinogenic health effect of heavy metals. THQ is defined in equation 5 by (US EPA, 2011) as:

$$THQ = \frac{EFr \times Ed \times FIR \times C}{Rfd \times BWa \times ATn} \quad \text{---------------------------} \ (5)$$

Where

EFr is the exposure frequency (days per year) (365)

Ed is the exposure duration equivalent to average lifetime (64 years for a Ghanaian adult) (WHO, 2016)

FIR is the daily average intake rate of fish and crustacean (fish: 36g/person/day; crustacean: 5.42g/person/day) (FAO, 2005)

C is the mean heavy metal concentration in fish and crab in the study (in $mgkg^{-1}$)

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* Trf^i of a particular metal was derived by Hákanson (1980) from (a) "abundance principle" (b) the "sink-effect" and (c) the "dimension-problem".

Rfd is the oral reference dose of the trace element (Cd: 0.001mgkg^{-1}/day; Pb: 0.004mgkg^{-1}/da; Cr: 0.003mgkg^{-1}/day) (US EPA, 1991)

BWa is the average body weight (considered to be 70 Kg for adult)

ATn is the averaged exposure time to the heavy metal (365 days per year x Ed)

CHAPTER FOUR

RESULTS

4.1 PHYSICOCHEMICAL PARAMETERS OF THE WATER

The mean values of physicochemical parameters of the study areas are presented below in (Table 4.1).

4.1.1 Korle Lagoon

The pH values of Korle lagoon in water and sediments ranged from 4.31 - 8.62 and 7.5 - 8.4 respectively. The mean pH were 6.61 ± 1.11 (water) and 7.81 ± 0.28 (sediment). The lagoon had a mean temperature of 29.41°C ranging from 28.9 – 30.1°C. Electrical conductivity values also varied between 35200 and 56300 µScm^{-1} and that of total dissolved solids (TDS) ranged from 21400 to 36700 mgL^{-1}. Figure 4.1a illustrates scatter plot of electrical conductivity verses the TDS of Korle Lagoons respectively Dissolved oxygen varied from 0.87 - 3.12mgL^{-1} averaging at 1.86 ± 0.74 mgL^{-1} as indicated in (Table 4.1).

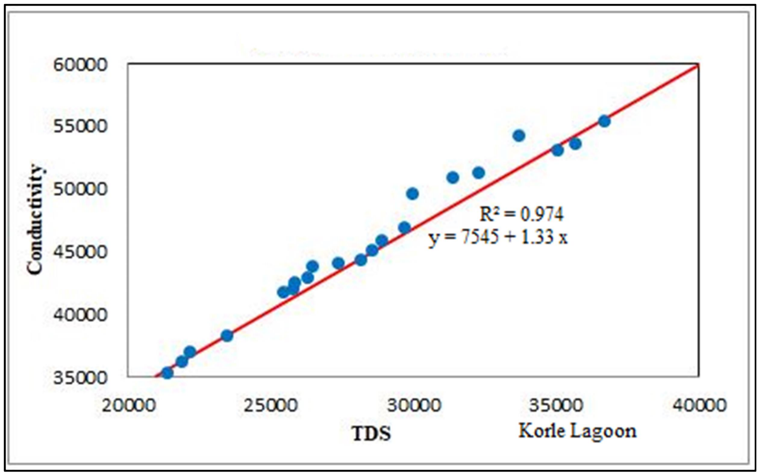

Figure 4.1a: A plot of electrical conductivity against TDS of Korle Lagoon

4.1.2 Kpeshie Lagoon

pH values ranged from 3.69 – 8.48 in water and that of sediments were 7.1– 7.6, and their mean values recorded 7.52 ± 1.22 and 7.36 ± 0.15 respectively. Water temperatures of Kpeshie lagoon varied from 30.1 – 31.4 °C with an average value of 30.73 ± 0.41 °C. The electrical conductivity and TDS were fairly unstable with values ranging from 9600 – 44800 μScm^{-1} and 6050 – 27300 mgL^{-1}, respectively. The scatter plots (figure 4.1b) of electrical conductivity verses the TDS of Kpeshie Lagoon. Dissolved oxygen values fluctuated between 3.15 – 6.42 mgL^{-1}; averaging at 4.58 ± 0.98 mgL^{-1} as indicated in (Table 4.1).

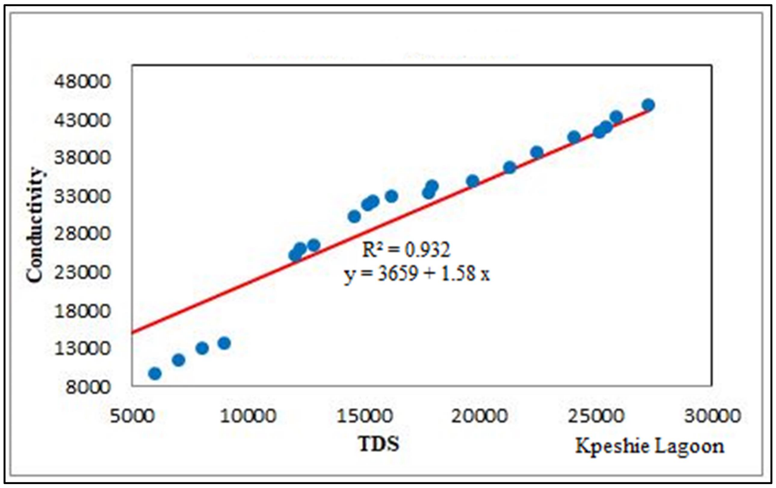

Figure 4.1b: A plot of electrical conductivity against TDS of Kpeshie Lagoon

Table 4.1: Mean physio-chemical parameters of water and sediments in Korle and Kpeshie lagoon

	Korle Lagoon	Kpeshie Lagoon	WHO 2005	US EPA 2004
PH_water	6.61 ± 1.11	7.52 ± 1.22	6.5_8.5	6_9
PH_sediment	7.81 ± 0.28	7.36 ± 0.15	6.5_8.5	6_9
Temp (°C)	29.41 ± 0.26	30.73 ± 0.41	25_30	25_32
DO (mg/L)	1.86 ± 0.74	4.58 ± 0.98	> 5	> 5
TDS (mg/L)	28390 ± 4633	16516 ± 6430	1000	1000
Conductivity (µS/cm)	45355 ± 6251	29860 ± 10633	1500	1500

4.2 MEAN HEAVY METAL CONCENTRATION IN WATER

4.2.1 Heavy metal concentrations in Korle Lagoon water

Mean arsenic[2] concentration of Korle lagoon was 5.410 ± 0.08 ugL^{-1}; site 1, the highest level in the water. Site 2, 3 and 4 were 4.968 ± 0.03 ugL^{-1}; 5.400 ± 0.05 ugL^{-1} and 5.086 ± 0.03 ugL^{-1} respectively. The highest mean value of cadmium in water was 0.071±0.02 mgL^{-1} at site 1, followed by site 2 with a mean concentration of 0.046 ± 0.01 mgL^{-1}, then site 3 with a mean level of 0.031± 0.02 mgL^{-1}. Site 4 was the lowest with a mean of 0.017±0.01 mgL^{-1}.

The average values of chromium of Korle lagoon were 0.065 ± 0.01 mgL^{-1} at site 1; 0.045 ± 0.02 mgL^{-1} at site 2; 0.037 ± 0.03 mgL^{-1} at site 3, and 0.014 ± 0.01 mgL^{-1} at site 4. Mean values of copper and lead, followed a similar trend with cadmium. Site 1 was the highest: 0.397 ± 0.06 mgL^{-1} for Cu; 1.216 ± 0.48 mgL^{-1} for Pb. The lowest value of copper was at site 4 which recorded 0.166 ± 0.05 mgL^{-1} and at site 2 for lead, which recorded 0.254 ± 0.14 mgL^{-1}. The mean concentrations of zinc for site 1, 2, 3 and 4 were 0.101 ± 0.02 mgL^{-1}, 0.053 ± 0.02 mgL^{-1}, 0.050 ± 0.03 mgL^{-1} and 0.074 ± 0.01 mgL^{-1} respectively as indicated in (Table 4.2).

4.2.2 Heavy Metals Concentration Kpeshie Lagoon Water

In Kpeshie lagoon, the average lowest arsenic concentration was 4.867 ± 0.05 μgL^{-1} at site 2. The highest was at site 4 with a mean concentration of 5.316 ± 0.27 ugL^{-1}. Site 3 was the second mean highest level with 5.116 ± 0.02 ugL^{-1}, followed by site 1 with the mean value of 4.968 ± 0.08 ugL^{-1}. Cadmium had the lowest mean value of 0.035 ± 0.02 mgL^{-1} at site 1. It was followed by site 3 with 0.037 ± 0.03 mgL^{-1}, then site 4 with 0.054 ± 0.01 mgL^{-1} and

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[2] All heavy metals in water were analysed in mgl^{-1} except arsenic in μgl^{-1} due to their low concentrations

finally site 2 with 0.068 ± 0.01 mgL^{-1}. The mean levels of chromium were moderately low with site 2 recording the highest of 0.075 ± 0.01 mgL^{-1}. Sites 3, 1, and 4 recorded mean concentrations of 0.073 ± 0.00mgL^{-1}, 0.060 ± 0.03 mgL^{-1} and 0.025 ± 0.00 mgL^{-1} respectively in descending order.

Copper values ranged from 0.033 – 0.566 mgL^{-1}. Mean concentration at site 1 recorded 0.266± 0.15 mgL^{-1} (second highest); site 2 recorded 0.241 ± 0.07 mgL^{-1} (second lowest); site 3 recorded 0.485 ± 0.21 mgL^{-1} (highest), and site 4 recorded 0.038 ± 0.01 mgl^{-1} (lowest). Lead concentrations varied between 0.006 – 2.035 mgL^{-1} with the lowest mean concentrations of 0.216 ± 0.34 mgL^{-1} for site 3 and the highest was 1.056 ± 0.85mgL^{-1} at site 4. Table 4.2 illustrates these mean values. Zinc concentrations recorded varied values from 0.008 – 0.254 mgL^{-1}. Site 4 measured the highest concentration of zinc with a value of 0.240 ± 0.01 mgL^{-1}.

Table 4.2: Mean heavy metal concentrations of water samples in Korle and Kpeshie Lagoons

Lagoon	*As (µg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Pb (mg/L)	Zn (mg/L)
Standard (WHO)	10.00	0.003	0.05	2.00	0.01	3.00
Korle						
Site 1	5.410± 0.08	0.071 ± 0.02	0.065 ± 0.01	0.397 ± 0.06	1.216 ± 0.48	0.101 ± 0.02
Site 2	4.968 ± 0.03	0.046 ± 0.01	0.045 ± 0.02	0.509 ± 0.23	0.254 ± 0.14	0.053 ± 0.02
Site 3	5.400 ± 0.05	0.031 ± 0.02	0.037 ± 0.03	0.182 ± 0.14	0.478 ± 0.34	0.050± 0.03
Site 4	5.086 ± 0.03	0.017 ± 0.01	0.014 ± 0.01	0.166 ± 0.05	0.482 ± 0.07	0.074 ± 0.01
Kpeshie						
Site 1	4.968 ± 0.08	0.035 ± 0.02	0.060± 0.03	0.266 ± 0.15	0.301 ± 0.04	0.037 ± 0.02
Site 2	4.867 ± 0.05	0.068 ± 0.01	0.075 ± 0.01	0.241 ± 0.07	0.448 ± 0.34	0.027 ± 0.02
Site 3	5.116 ± 0.02	0.037 ± 0.03	0.073 ± 0.00	0.485 ± 0.08	0.216 ± 0.34	0.063 ± 0.04
Site 4	5.316 ± 0.27	0.054 ± 0.01	0.025 ± 0.00	0.038 ± 0.00	1.056 ± 0.85	0.240 ± 0.01

∗As (µg/L) was analysed in microgram per litre due to their low concentrations.

4.3 HEAVY MEAN METAL CONCENTRATION IN SEDIMENT CORE

4.3.1 Korle Lagoon Sediments

Arsenic concentrations were very low in the Korle lagoon. Site 2 recorded the lowest mean of 0.4728 ± 0.04 mgkg^{-1} with values ranging from 0.4252 – 0.5143 mgkg^{-1}. Figure 4.2 showed low heavy metal concentrations of sediments in Korle and Kpeshie lagoons, with the red line denoting SQG limit of arsenic in sediment. The highest mean concentration was site 1, 0.5089 ± 0.02 mgkg^{-1}, with varied values from 0.4825 – 0.5369 mgkg^{-1}. Concentrations of sites 3 and 4 varied between 0.3014 – 0.5417 mgkg^{-1} and 0.4359 – 0.5141 mgkg^{-1} respectively. There were no significant variations (p-value = 0.85; $p > 0.05$) in the mean concentrations.

Figure 4.3 illustrates cadmium concentrations in both lagoons with recommended limit of 0.7 mgkg^{-1} set by CCME (2001). Cadmium concentrations in Korle lagoon ranged from 1.10 – 54.50 mgkg^{-1}. Site 1 recorded the highest mean cadmium of 19.067 ± 26.28 mgkg^{-1} and site 3 measured the lowest mean of 5.034 ± 3.92 mgkg^{-1} as depicted in table 4.3. The average concentrations of site 2 and 4 were 7.950 ± 1.05 mgkg^{-1} and 6.250 ± 1.75 mgkg^{-1} respectively. There was no significant variation (p-value = 0.45; $p > 0.05$) in the mean concentrations.

The values of chromium were between 0.3 and 50.6 mgkg^{-1}. It was observed that site 1 recorded the highest mean of 30.467 ± 16.02 mgkg^{-1} with values ranging from 15.7 – 50.6 mgkg^{-1}. Site 2 averaged 14.617 ± 10.47 mgkg^{-1} ranging from 0.5 to 24.5 mgkg^{-1}, site 3 averaged 9.933 ± 7.29 mgkg^{-1} ranging between 1.3 – 20.4 mgkg^{-1} and site 4 recorded the lowest mean of 6.450 ± 6.11 mgkg^{-1} with values between 0.3 to 14.7 mgkg^{-1} of Cr as shown in (Table 4.3) below. Figure 4.4 illustrates average level of chromium in sediments with SQG (CCME, 2001) limit indicated as red line. There was no significant variation (p-value = 0.64; $p > 0.05$) in the mean concentrations.

Mean copper concentrations of site 1, 2, 3 and 4 were 29.383 ± 37.35 $mgkg^{-1}$; 11.467 ± 9.02 $mgkg^{-1}$; 33.001 ± 0.69 $mgkg^{-1}$; and 5.150 ± 4.04 $mgkg^{-1}$ respectively. Site 3 recorded the highest mean while site 4 recorded the lowest. Their concentrations ranged from 4.7 to 78.0 $mgkg^{-1}$ at site 1, 5.1– 23.5 $mgkg^{-1}$ at site 2, 32.1 – 34.1 $mgkg^{-1}$ at site 3 and from <0.001 to 9.7 $mgkg^{-1}$ at site 4. The values of site 4 were fairly constant. There were no significant differences (p-value = 0.84; $p > 0.05$) in their mean concentrations.

Lead concentrations in sediments at Korle Lagoon sampling sites were very high compared to other studied metals; with site 1 recording the highest mean value of 112.45 ± 48 $mgkg^{-1}$, ranging from 76.8 – 174.6 $mgkg^{-1}$. Site 2 measured the lowest value with mean concentrations of 42.917 ± 26.23 $mgkg^{-1}$ with values between 25.1 – 78.1 $mgkg^{-1}$, while site 3 and site 4 averagely measured 59.167 ± 5.92 $mgkg^{-1}$ and 29.700 ± 12.34 $mgkg^{-1}$ respectively as shown in (Table 4.3). The concentrations of site 3 varied between 51.1 – 63.5$mgkg^{-1}$ and those of site 4 were 11.0 – 41.4 $mgkg^{-1}$. One way ANOVA showed no significant variations (p-value = 0.93; $p > 0.05$) in the mean concentrations.

Zinc concentrations of sediments in Korle Lagoon were consistently high at site 3 as compared to the other sites, ranging from 189.9 - 241.7 $mgkg^{-1}$ with averaged value of 209.001 ± 22.42 $mgkg^{-1}$. The mean values of zinc concentrations at sites 1 and 2 were 100.583 ± 93.39 $mgkg^{-1}$ and 126.783 ± 112.54 $mgkg^{-1}$ respectively. The values of site 1 varied between 39.5 – 221.9 $mgkg^{-1}$ and site 2 ranged from 86 – 205.8 $mgkg^{-1}$. The average zinc level of site 4 was 13.817 ± 5.85 mgkg^{-1} with concentrations varying from 3.4 – 82.9 mgkg^{-1}. Mean concentrations of zinc in sediments core ranked the following order: site 3 > site 2 > site 1 > site 4. There were however no significant variations (p-value = 0.96; $p > 0.05$) in their concentrations.

4.3.2 Kpeshie Lagoon Sediment

Arsenic concentrations in sediments at Kpeshie lagoon had a similar trend with Korle lagoon (figure 4.2). The mean values of arsenic at site 1, 2, 3 and 4 were 0.5063 ± 0.03 mgkg^{-1}, 0.5065 ± 0.05 mgkg^{-1}, 0.5551 ± 0.03 mgkg^{-1} and 0.4502 ± 0.03 mgkg^{-1}, respectively. One way ANOVA showed no significant variations (p-value = 0.79; $p > 0.05$) in the levels of arsenic measured at the sampling sites. Site 4 recorded the lowest mean value while site 2 recorded the highest mean concentration (Table 4.3).

Table 4.3: Mean eavy metal concentrations in sediment sample in Korle and Kpeshie lagoon

Lagoon	As (mg/kg)	Cd (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
Standard (CCME)	7.24	0.70	52.30	18.70	30.20	124.00
Korle						
Site 1	0.5089 ± 0.02	19.067 ± 26.28	30.467 ± 16.02	29.383 ± 37.35	112.450 ± 48.00	100.583 ± 93.39
Site 2	0.4728 ± 0.04	7.950 ± 1.05	14.617 ± 10.47	11.467 ± 9.02	42.917 ± 26.23	126.783 ± 112.54
Site 3	0.4956 ± 0.10	5.034 ± 3.92	9.933 ± 7.29	33.001 ± 0.69	59.167 ± 5.92	209.0 1 ± 22.42
Site 4	0.4852 ± 0.03	6.250 ± 1.75	6.450 ± 6.11	5.150 ± 4.04	29.750 ± 12.34	13.817 ± 5.85
Kpeshie						
Site 1	0.5063 ± 0.03	13.667 ± 6.13	28.517 ± 4.15	15.733 ± 16.20	44.333 ± 24.37	114.650 ± 107.22
Site 2	0.5065 ± 0.05	7.550 ± 5.95	31.400 ± 12.36	42.617 ± 2.91	42.283 ± 24.36	69.200 ± 58.28
Site 3	0.5551 ± 0.03	5.350 ± 1.51	50.833 ± 6.27	41.517 ± 40.79	188.433 ±139.77	70.367 ± 10.31
Site 4	0.4502 ± 0.03	5.750 ± 1.41	18.033 ± 13.70	2.408 ± 4.23	56.850 ± 17.05	18.400 ± 4.91

The concentrations of cadmium in sediments at Kpeshie lagoon were fairly comparable at the four sampling sites. In general, cadmium concentrations vary with depth and far greater than the limit set by CCME (figure 4.3) Site 1 recorded the highest mean level for cadmium of

13.867 ± 6.13 mgkg^{-1} with values ranging from 1.7 – 18.1 mgkg^{-1}, site 3 recorded the lowest mean concentration of 5.350 ± 1.51 mgkg^{-1} with values ranging from 3.8 – 7.3 mgkg^{-1}. The mean cadmium level at site 2 and site 4 were 7.550 ± 5.95 mgkg^{-1} and 5.750 ± 1.41 mgkg^{-1} respectively as shown on (Table 4.3). The single factor ANOVA showed no significant variations (p-value = 0.93; $p > 0.05$) in the levels of cadmium between sampling sites.

The concentrations of chromium in the sediments at the four sampling sites were highly measurable, with site 4 recording the lowest mean of 18.033 ± 13.70 mgkg^{-1}, with values ranging from 5.0 – 37.1 mgkg$^{-1.}$ It was followed by site 1 with 28.517 ± 4.15 mgkg^{-1} for average values of chromium. Site 3 measured concentrations from 41.5 – 58.7 mgkg^{-1} and had the highest mean of 50.833 ± 6.27 mgkg^{-1} and site 2 recorded average chromium of 31.400 ± 12.36 mgkg^{-1} with concentrations varied from 18.9 – 45.9 mgkg^{-1}. Chromium concentrations measured with depth (figure 4.4) fell within the SQG limit of 52.3 mgkg^{-1}. Their mean concentrations showed no significant variations (p-value = 0.99; $p > 0.05$) at all sampling sites.

Copper concentrations in sediments of Kpeshie lagoon were generally moderate. Individual copper values ranged from <0.001 – 94.3 mgkg^{-1}. The levels of copper measured vary considerably with depth (Figure 4.5). There were no significant variations (p-value = 0.55; $p > 0.05$) in the copper concentrations recorded at the four sampling sites. The mean levels were, site 1 (15.733 ± 16.20 mgkg^{-1}), site 2 (42.667 ± 2.91 mgkg^{-1}), site 3 (41.517 ± 40.79 mgkg^{-1}) and site 4 (2.408 ± 4.23 mgkg^{-1}) as shown in (Table 4.3).

Lead concentrations at the four sampling sites of Kpeshie Lagoon were moderately high, ranging from 7.9 – 281.1 mgkg^{-1}. Mean concentrations of lead of site 1, 2, 3 and 4 were

44.333 ± 24.37 $mgkg^{-1}$, 42.283 ± 24.36 $mgkg^{-1}$, 188.433 ± 139.77 $mgkg^{-1}$ and 56.850 ± 17.05 $mgkg^{-1}$ respectively (Table 4.3). Site 3 had the highest mean, while site 2 recorded the lowest mean concentrations. Single factor ANOVA indicated no significant differences (p-value = 0.67; $p > 0.05$) in the mean concentrations at all sampling sites.

Zinc concentrations in sediments of Kpeshie lagoon were moderately low at site 2 and site 3. The sediment at site 1 recorded zinc levels ranging from 11.7 – 237.3 $mgkg^{-1}$ and averaged at 114.650 ± 107.22 $mgkg^{-1}$, the highest mean concentration. The average values of sites 2, 3 and 4 were 69.200 ± 58.28 $mgkg^{-1}$, 70.367 ± 10.31 $mgkg^{-1}$ and 18.400 ± 4.91 $mgkg^{-1}$ respectively as shown in (Table 4.3). There were no significant differences ($p = 0.73$; $p > 0.05$) in the average levels of zinc at the sampling stations.

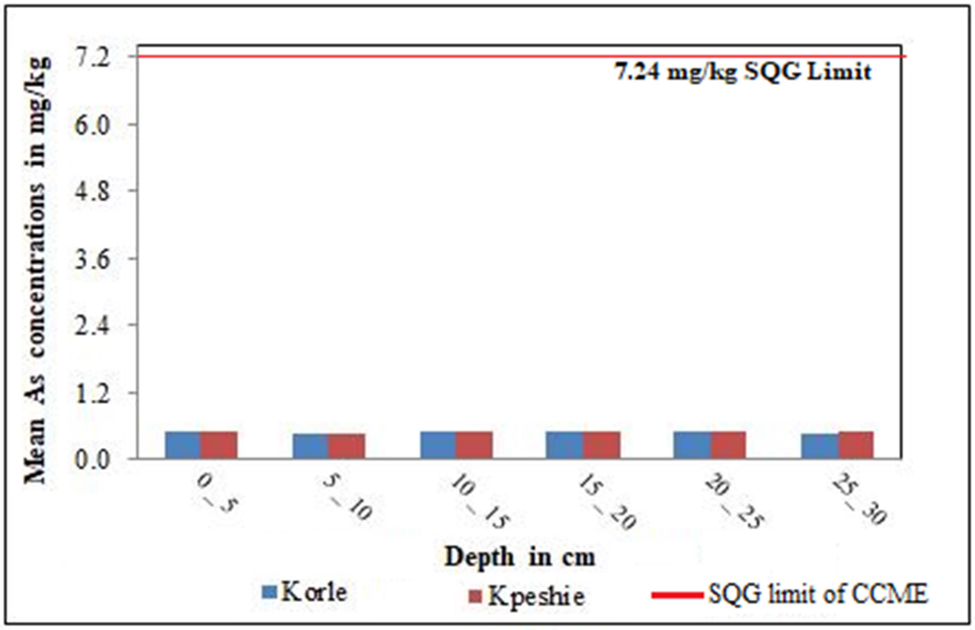

Figure 4.2: Arsenic concentrations in Korle-Kpeshie Lagoons

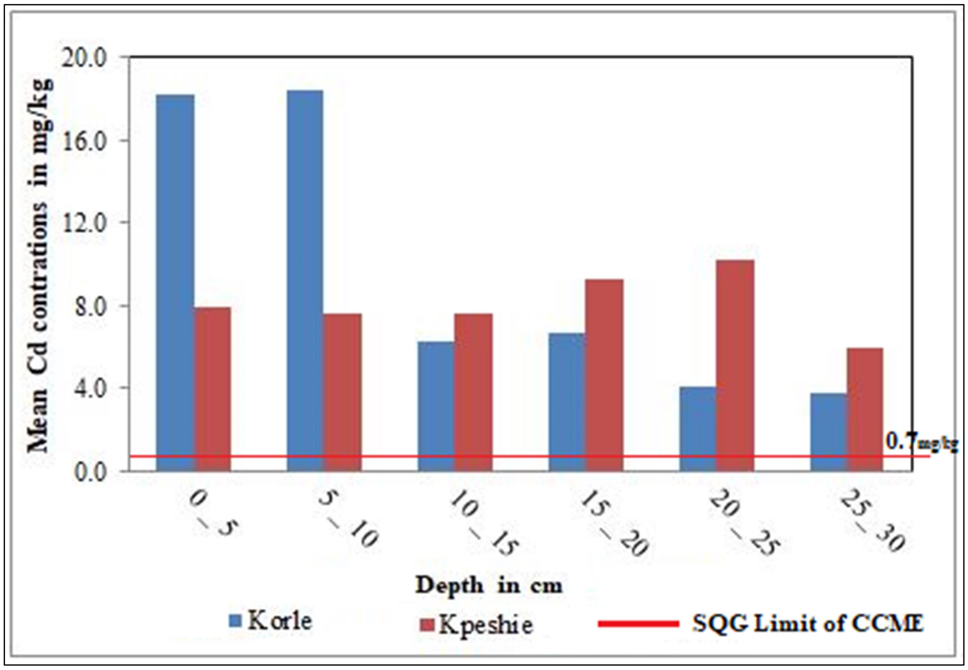

Figure 4.3: Cadmium concentrations in Korle-Kpeshie Lagoons

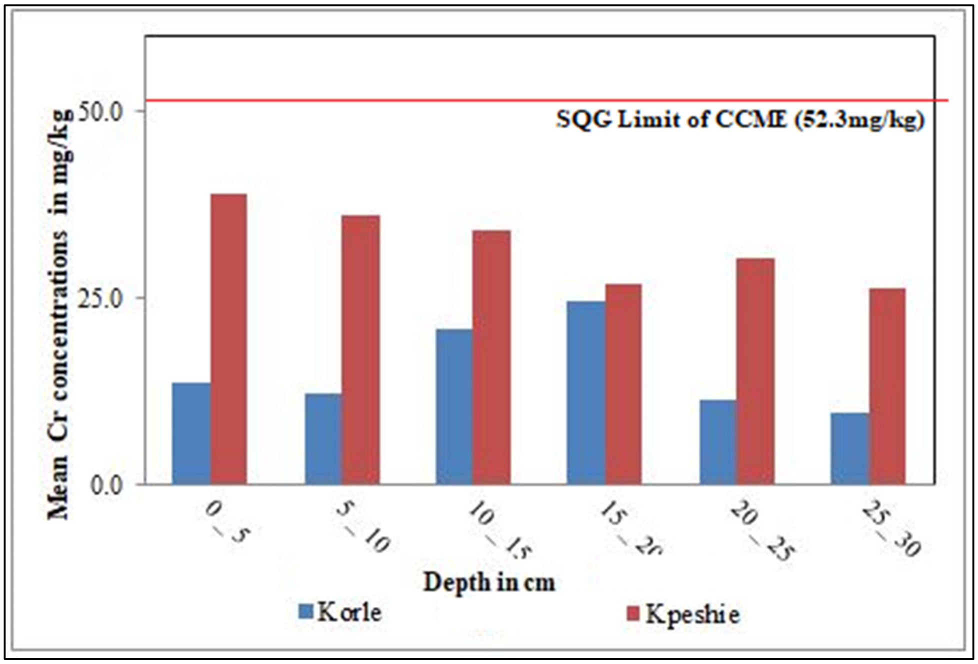

Figure 4.4: Chromium concentrations in Korle-Kpeshie Lagoons

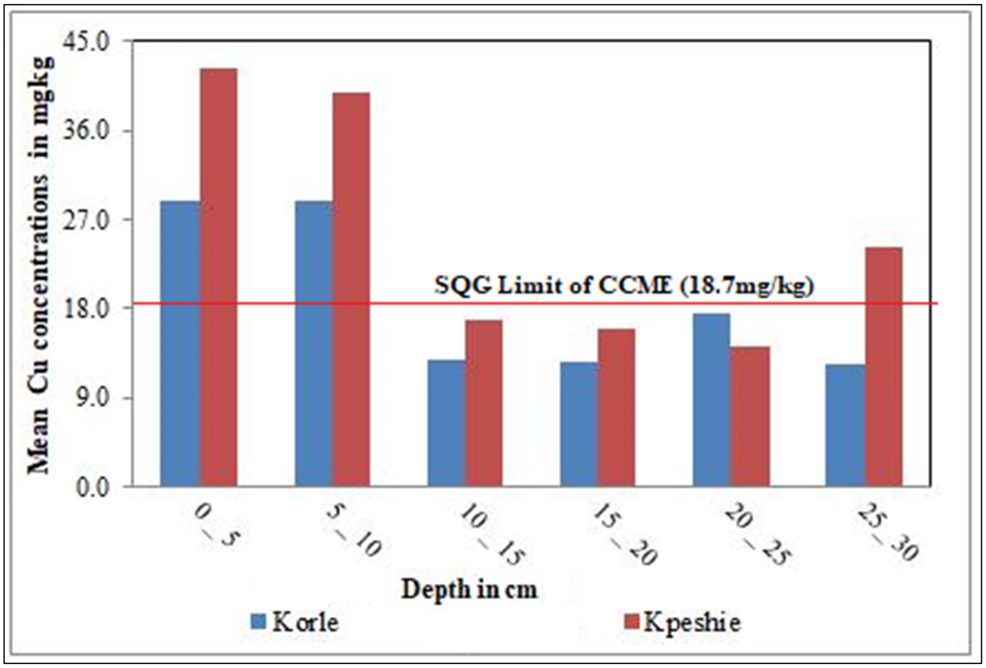

Figure 4.5: Copper concentrations in Korle-Kpeshie Lagoons

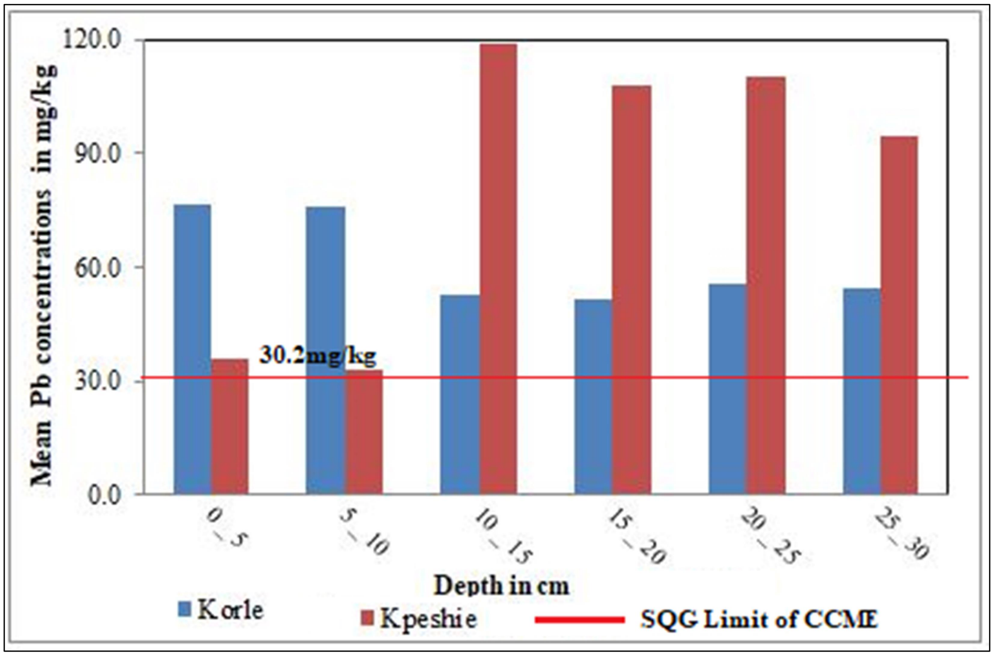

Figure 4.6: Lead concentrations in Korle-Kpeshie Lagoons

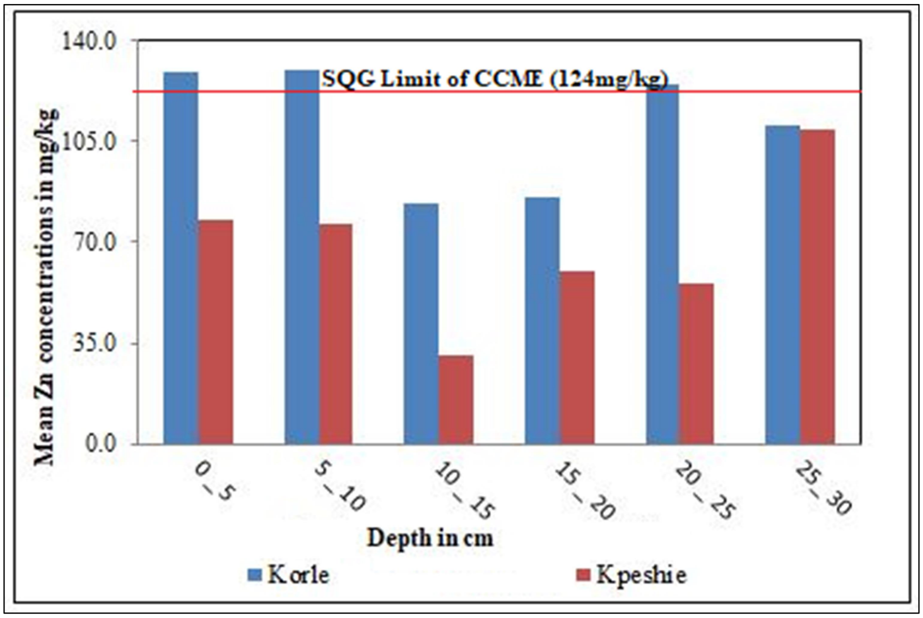

Figure 4.7: Zinc concentrations in Korle-Kpeshie Lagoons

4.4 HEAVY METAL CONCENTRATION IN CRAB (*Callinectes amnicola)*

Callinectes amnicola were harvested only at Site 1 and 4 of Kpeshie Lagoon as Sites 2 and 3 could not support any life. The mean concentrations of arsenic, cadmium, chromium, copper, lead and zinc in C*allinectes amnicola* of site 1 were 0.303 ± 0.05 mgkg^{-1}; 5.483 ± 2.88 mgkg^{-1}, 71.908 ± 64.80 mgkg^{-1}; 26.812 ± 19.72 mgkg^{-1}; 13.667 ± 17.40 mgkg^{-1} and 45.183 ± 20.70 mgkg^{-1}, respectively. For site 4 their mean concentrations were: arsenic, 0.273 ± 0.08 mgkg^{-1}; cadmium, 3.713 ± 2.26 mgkg^{-1}; chromium, 7.133 ± 6.64 mgkg^{-1}; copper, 35.358 ± 11.11 mgkg^{-1}; lead, 8.138 ± 5.61 mgkg^{-1}; and zinc, 26.900 ± 7.40 mgkg^{-1}, as indicated in (Table 4.4). One way ANOVA analysis showed no significant variations ($p > 0.05$) in the mean concentrations of the sites except chromium and zinc (Table 4.4).

Table 4.4: Mean heavy metals concentrations in *Callinectes amnicola*

Sampling Sites (crustacean) at Kpeshie Lagoon				
Elements	S1 (mg/kg)	S4 (mg/kg)	US EPA 2010	p-value
As	0.303 ± 0.05	0.273 ± 0.08	0.50	0.29
Cd	5.483 ± 2.88	3.713 ± 2.26	0.50	0.11
Cr	71.908 ± 64.80	7.133 ± 6.64	0.50	0.002
Cu	26.812 ± 19.72	35.358 ± 11.11	70.00	0.20
Pb	13.667 ± 17.40	8.137 ± 5.61	0.50	0.31
Zn	45.183 ± 20.70	26.900 ± 7.40	80.00	0.008

4.5 HEAVY METAL CONCENTRATION IN FISH (*Sarotherodon melanotheron)*

Fish samples were available only at Kpeshie Lagoon at sites 1 and 4 as site 2 and 3 did not have any. Mean concentrations of metals investigated in *Sarotherodon melanotheron* samples at sites 1 and 4 disclosed similar trend in values for arsenic and cadmium. Average arsenic concentrations in fish recorded were 0.3714 ± 0.07 mgkg^{-1} and 0.423 ± 0.07 mgkg^{-1} for site 1 and 4, respectively. Mean levels of cadmium recorded 1.517 ± 1.65 mgkg^{-1} at site 1, and 0.683 ± 0.70 mgkg^{-1} at site 4. The mean concentrations of chromium, copper and zinc in fish were (site 1) 2.454 ± 4.58 mgkg^{-1}; (site 4) 9.321 ± 12.34 mgkg^{-1}, (site 1) 2.929 ± 2.2 mgkg^{-1}; (site 4) 4.058 ± 6.15 mgkg^{-1}, and (site 1) 28.642 ± 11.33 mgkg^{-1}; (site 4) 17.81 ± 7.58 mgkg^{-1}, respectively, as tabulated in table 4.5. The concentrations of lead in *Sarotherodon melanotheron* measured below detection limit (BDL) with the exception of site 4 that recorded 28.3 mgkg^{-1}. There were no significant differences ($p > 0.05$) in the mean concentrations with the exception of zinc (Table 4.5).

Table 4.5: Mean heavy metal concentrations in *Sarotherodon melanotheron*

Sampling Sites (Fish) at Kpeshie Lagoon				
Elements	S1 (mg/kg)	S4 (mg/kg)	FAO/WHO 2011	p-value
As	0.371 ± 0.07	0.423 ± 0.07	0.26	0.85
Cd	1.517 ± 1.65	0.683 ± 0.70	0.20	0.12
Cr	2.454 ± 4.58	9.321 ± 12.34	0.50	0.08
Cu	2.929 ± 2.20	4.058 ± 6.15	20	0.56
Pb	0.05 ± 0.00	2.404 ± 8.16	1.00	0.32
Zn	28.642 ± 11.33	17.81 ± 7.58	40.00	0.02

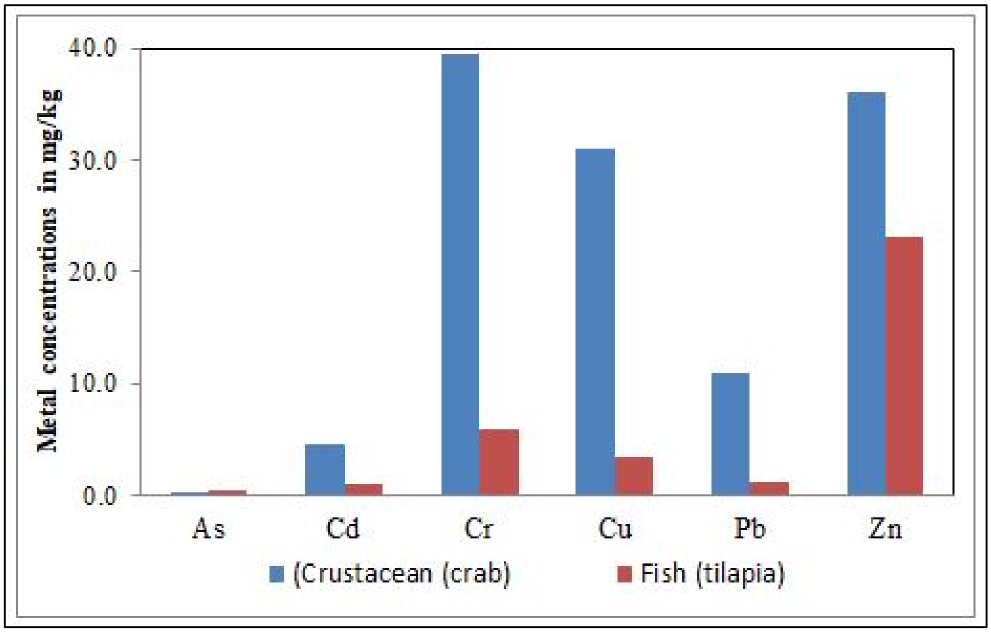

Figure 4.8: Heavy Metal Concentrations in Crustacean and Tilapia

4.6 CORRELATION STUDIES OF THE KORLE AND KPESHIE LAGOONS

The inter-metal correlation between pairs of heavy metals in water, sediment, crab and fish of the Korle and Kpeshie Lagoons were determined using Pearson Correlation Coefficient and presented in Tables 4.61, 4.6.2 and 4.6.3. There were a couple of significant positive relationships of metals in water column of Korle Lagoon: Pb-As ($r = 0.589$, $p < 0.05$) and Cu-Cd ($r = 0.525$, $p < 0.05$), whilst metals in Kpeshie lagoonal water showed both negative and positive significant correlations between Cr-As ($r = -0.615$, $p < 0.05$), Pb-Cr ($r = -0.578$) and Pb-As ($r = 0.691$, $p < 0.05$).

The Pearson's correlation of sediments in Korle showed few significant links between Cu-Cd ($r = 0.812$, $p < 0.05$), Pb-Cd ($r = 0.789$, $p < 0.05$), Pb-Cd ($r = 0.793$, $p < 0.05$) and Zn-Cu ($r = 0.795$, $p < 0.05$). On the other hand sediment in Kpeshie did not show any significant relationships except Pb-Cr ($r = 0.603$, $p < 0.05$).

The big fisted swim crab showed positive significant metal correlations between Pb-Cr ($r = 0.754$; $p < 0.05$) and Zn-Cr ($r = 0.528$; $p < 0.05$), and significant trends existed in Cu-Cr ($r = -0.762$; $p < 0.05$) and Pb-Cu ($r = - 0.598$; $p < 0.05$). The correlation analysis in tilapia revealed the following. A negative significant down trend between Cd-As ($r = - 0.562$, $p < 0.05$) but positive significant correlations existed between Pb-Cu ($r = 0.454$, $p < 0.05$) and Zn-Cd ($r= 0.450$, $p < 0.05$).

Table 4.6.1: Correlations between Metals in Water Column of the Lagoons

Korle Lagoon

	As	Cd	Cr	Cu	Pb	Zn
As	1					
Cd	0.340	1				
Cr	0.361	0.464	1			
Cu	-0.189	0.525	0.420	1		
Pb	0.589	0.481	0.316	-0.027	1	
Zn	0.306	0.360	0.235	-0.203	0.824	1

Kpeshie Lagoon

	As	Cd	Cr	Cu	Pb
As	1				
Cd	-0.141	1			
Cr	-0.615	0.215	1		
Cu	-0.301	-0.391	0.473	1	
Pb	0.691	-0.045	-0.578	-0.462	1

Table 4.6.2: Correlations between Metals of Sediment in the Lagoons

Korle Lagoon

	As	Cd	Cr	Cu	Pb	Zn
As	1					
Cd	0.061	1				
Cr	0.246	-0.024	1			
Cu	0.075	0.812	-0.167	1		
Pb	0.183	0.789	0.196	0.793	1	
Zn	-0.037	0.379	-0.284	0.795	0.495	1

Kpeshie Lagoon

	As	Cd	Cr	Cu	Pb	Zn
As	1					
Cd	0.217	1				
Cr	0.444	-0.262	1			
Cu	0.305	-0.176	0.316	1		
Pb	0.431	-0.337	0.603	-0.318	1	
Zn	0.281	0.203	-0.070	0.306	-0.190	1

Table 4.6.3: Heavy Metals Relationship in Organisms from Kpeshie Lagoon

Crustecean

	As	Cd	Cr	Cu	Pb	Zn
As	1					
Cd	0.316	1				
Cr	0.051	0.074	1			
Cu	-0.023	0.131	-0.762	1		
Pb	0.044	0.260	0.754	-0.598	1	
Zn	-0.092	0.207	0.528	-0.348	0.420	1

Tilapia

	As	Cd	Cr	Cu	Pb	Zn
As	1					
Cd	-0.562	1				
Cr	0.125	-0.026	1			
Cu	0.333	-0.112	-0.189	1		
Pb	0.353	-0.016	-0.067	0.454	1	
Zn	-0.347	0.450	-0.369	-0.184	-0.151	1

4.7 POLLUTION INDICES OF SEDIMENTS

Pollution indices were used to check for the level of heavy metal contamination of the sediment samples of Korle and Kpeshie Lagoons. Table 4.6 shows the calculated values of pollution indices of sediments in the study.

4.7.1 Contamination Factor

From Table 4.6, Cf values varied from 0.06 – 97.83. It was observed that Cd and Pb had the highest Cf values, and this trend was observed at all the sampling sites of Korle and Kpeshie Lagoons. Site 1 recorded the highest Cf with respect to Cd and Pb at Korle lagoon. while site 3 recorded the lowest value of Cf in Cd and site 4 the lowest in Pb in the same lagoon.

The Cfs at Kpeshie Lagoon were different from those of Korle Lagoon. Cadmium recorded the highest Cf values in Kpeshie lagoon. In terms of the sites, site 1 recorded the highest in Cd (69.33) while site 3 recorded the lowest (26.75). Comparatively, site 3 recorded the highest Cf in Pb (15.07) while site 2 (3.38) recorded the lowest.

4.7.2 Pollution Load Index

As shown in table 4.6, pollution load index (PLI) ranged from 0.54 – 1.97, with a mean value of 1.24 in sediments at Korle lagoon. PLI values of all sampling sites were more than one except site 4, located close to the estuary. PLI values of Kpeshie lagoon varied from 0.64 – 1.91 with a mean value of 1.36. Sites 1, 2, 3 recorded more than one (PLI > 1) with the exception of site 4, located near the Whitler Barracks.

4.7.3 Potential Ecological Risk Index (RI)

Potential ecological risk indices of As, Cd, Cr, Cu, Pb, and Zn at all sampling sites were also shown (in table 4.6) based on Hákanason (1980). The sediments in Korle Lagoon recorded values ranging from 1.23 to 5822.50 while those of Kpeshie lagoon varied from 2.58 to 2877.50.

Table 4.7: Average Contamination Factor (Cf), Pollution Load Index (PLI) and Potential Ecological Risk Index (RI) of Sediments

Korle	**Element**	**n***	**As**	**Cd**	**Cr**	**Cu**	**Pb**	**Zn**	**PLI**
	Site 1: Cf	6	0.28	97.83	0.30	0.53	9.00	1.44	**1.97**
	Site 2: Cf	6	0.26	39.75	0.15	0.21	3.43	1.81	**1.12**
	Site 3: Cf	6	0.28	25.25	0.10	0.60	4.73	2.99	**1.34**
	Site 4: Cf	6	0.27	31.25	0.06	0.09	2.38	0.20	**0.54**
	background values		1.8	0.2	100	55	12.5	70	
	RI		**10.90**	**5822.50**	**1.23**	**7.18**	**97.71**	**6.43**	
Kpeshie	Site 1: Cf	6	0.28	69.33	0.29	0.29	3.55	1.64	**1.45**
	Site 2: Cf	6	0.28	37.75	0.31	0.78	3.38	0.99	**1.43**
	Site 3: Cf	6	0.31	26.75	0.51	0.75	15.07	1.01	**1.91**
	Site 4: Cf	6	0.25	28.75	0.18	0.04	4.55	0.26	**0.64**
	RI		**11.21**	**2877.50**	**2.58**	**9.30**	**132.80**	**3.89**	

n* number of samples per site; background values was estimated by Taylor (1964

*n is the number of samples collected at each site;

Table 4.7.1: Heavy Metals Ranking for Contamination Factor of Sediment in Lagoons

	Korle	Kpeshie
Cf > 6 high contamination factor	Cd	Cd, Pb
3 ≤ Cf ≤ 6, considerable factor	Pb	
1 ≤ Cf ≤ 3, moderate factor	Zn	Zn
Cf < 1, low contamination factor	As, Cr, Cu	As, Cr, Cu

Table 4.7.2: Heavy Metals Ranking in Potential Ecological Risk Index (RI) of Sediment

	Korle	Kpeshie
RI > 380, very high ecological. risk	Cd, Pb	Cd, Pb
190 ≤ RI ≤ 380, considerable ecological Risk		
95 ≤ RI ≤ 190, Moderate ecological Risk		
RI < 95, low ecological risk	As, Cr, Cu, Zn	As, Cr, Cu, Zn

4.7.4 Target Hazard Quotient (THQ)

Three elements (Cd, Cr, Pb) were selected for the evaluation of THQ of *Callinectes amnicola* and *Sarotherodon melanotheron.* Cadmium and lead were based on the values of the potential ecological risk index, while chromium was based on its concentrations in the studied organisms (*Callinectes amnicola* and *Sarotherodon melanotheron*). The values of THQ of the respective elements recorded less than one in both organisms.

Table 4.8: THQ Estimation of Fishery

Element	**Cd**	**Pb**	**Cr**	**TTHQ**
Callinectes amnicola	0.33	0.19	0.93	1.45
Sarotherodon melanotheron	0.52	0.34	0.92	1.78

CHAPTER FIVE

DISCUSSION

5.1 PHYSIOCHEMICAL PARAMETERS

Mean pH of water samples of Korle lagoon measured 6.61 while that of Kpeshie was 7.55. These indicated that, Korle lagoon was slightly acidic while Kpeshie lagoon on the other hand was neutral to basic. The pH of water for both lagoons fell within the range of acceptable limits of 6.5 to 8.5 (US EPA, 2004; WHO, 2005). A similar study conducted by Addo *et al*. (2011) reported a mean pH of water in Kpeshie lagoon as 7.8, which was comparable to this study. The pH of sediment in Korle and Kpeshie lagoons recorded were within US EPA limits of 6 to 9.

Water temperature at Korle lagoon ranged from 28.9 to 30.1°C while Kpeshie varied from 30.1 to 31.4°C. These are typical of tropical shallow coastal lagoon, where ambient temperatures remain within a narrow range of 25–35°C (Biney, 1990). The mean dissolved oxygen in the lagoon water of Korle measured 1.86 mgL^{-1} while that of Kpeshie lagoon measured 4.58 mgL^{-1}. It was an indication that DO level in Korle lagoon was too low to possibly support any aquatic organisms. A research on water quality characteristics at the estuary of Korle Lagoon by Karikari *et al*. (2009) revealed DO level as 1.93 mgL^{-1}, similar to the present study. Kpeshie lagoon on the other hand was very close to the required limit of 5 mgL^{-1}. This might explain the existence of fisheries in the lagoon. Also Kpeshie lagoon is engulfed with mangroves which also contribute to the oxygenation of its waters. A similar study carried out by Addo *et al*. (2011) revealed DO as 2.42 mgL^{-1} which is contrary to the present study. This could probably be the result of low phosphorus inflow to the Kpeshie Lagoon in recent times.

The lagoons recorded very high mean figures of TDS; 28415 mgL^{-1} and 16963mgl^{-1} at Korle and Kpeshie lagoons respectively, which were twenty times more than the recommended level set by (US EPA, 2004) of 1000 mgL^{-1}. These implied high concentration of ions in the lagoons and could inhibit the growth of aquatic animals. The sources of these ions could be from the organic and inorganic substances present in industrial wastewater, sewage discharge or runoff from urban and waste dumps sited in proximity of the lagoons. High levels of ions could be corrosive and would render the lagoonal water unsuitable for any domestic, industrial and agricultural use (Oram, 2014). A research by Apau *et al*. (2012) at Kpeshie lagoon revealed varied values of TDS and conductivity as 24.1–45.4 gL^{-1} and 54.8– 101.8 μSm^{-1} respectively. These values are comparable to the current study.

It was observed that conductivity increases with TDS. The coefficient of regression, R^2 indicated most point fell on the regression line. Conductivity reflects the dissolved salts and metals present in surface water. The conductivity level of water samples from Kpeshie Lagoon were lower than that of Korle Lagoon in the current study. This could probably be due to the absence of major waste dump site and industrial discharge plant in the vicinity of the Kpeshie lagoon. The mean conductivity values of both lagoons exceeded the US EPA guideline of secondary surface water. Aglanu & Appiah (2014) revealed a mean conductivity of 47040 μScm^{-1} in Korle Lagoon and Addo *et al*. (2011) also discovered conductivities at Kpeshie lagoon to range from 19370 to 28500 μScm^{-1}. The mean conductivity values fall in line with the present study.

5.2 HEAVY METAL CONCENTRATIONS IN WATER, SEDIMENTS, CRAB AND FISH

The heavy metal concentrations measured in water samples were lower than those measured in sediments in both lagoons. This might probably be the result of sediments being considered as a temporary sink for heavy metals (Sparks, 2005). Low heavy metal concentrations recorded in samples of water from both Korle and Kpeshie water could be attributed to long residence time and low flushing rate of lagoons. The fish species (*Callinectes amnicola,* and *Sarotherodon melanotheron)* were only harvested at Kpeshie lagoon and their metal concentrations recorded higher value than those of the water column.

5.2.1 Arsenic

Arsenic concentrations recorded the lowest values at all sampling sites compared to any other metals investigated in the study lagoons. In the water column, mean arsenic levels of Korle and Kpeshie were below the recommended values of 10 μgL^{-1} set by (WHO, 2005).

Korle lagoon sediments measured averagely 0.4906 $mgkg^{-1}$ of As concentration and those of Kpeshie recorded 0.5045 $mgkg^{-1}$. The mean values did not exceed the Sediment Quality Guideline (SQG) limit of 7.24 $mgkg^{-1}$ set by the Canadian Council of Ministers of the Environment (CCME, 2001). The values of As concentrations in sediments showed similar trend in both lagoons. These values were indicative of no direct anthropogenic input of arsenic into both lagoons. The current level of As in both lagoons could however be attributed to recycling and burning of electronic waste at the banks of the lagoons.

The mean levels of arsenic in *Callinectes amnicola,* and *Sarotherodon melanotheron* were 0.2879 $mgkg^{-1}$ and 0.3971 $mgkg^{-1}$ respectively. The mean value of arsenic in *Callinectes* *amnicola* was below the recommended limit of 0.50 $mgkg^{-1}$ (US EPA, 2010), while *Sarotherodon melanotheron* exceeded the permissible value of 0.26 $mgkg^{-1}$ (FAO/WHO 2011). Though arsenic concentrations in sediments of Kpeshie lagoon were low, their level in *Sarotherodon melanotheron* exceeded the threshold value. This could probably be attributed to the accumulative behaviour of heavy metals from one species of organism to another.

5.3.2 Cadmium

Cadmium is one of the most toxic heavy metals that can pose health complications in humans Manahan (2000). The study revealed a mean Cd concentration in water column of Korle lagoon as 0.036 mgL^{-1} while Kpeshie lagoon measured 0.048 mgL^{-1}. The mean heavy metal concentrations compared to WHO 2005 exceeded the recommended limit of 0.003 mgL^{-1} of surface water. Aglanu & Appiah (2014) recorded 0.001 mgL^{-1} of Cd in Korle lagoon water, which is lower, compared to the present study. This could reflect an increase in Cd contamination within the catchment area.

Cadmium concentrations in sediment core at Korle lagoon decreased progressively from 0-5cm. The first 10cm recorded very high levels of Cd in Korle lagoon sediment, and last 20cm showed a moderately stable trend. The trend in concentrations could be suggested that the anthropogenic input of cadmium into Korle Lagoon quadrupled in recent years due to an increase in industrial and municipal wastewater discharge (Boadi Owusu & Kuitunen, 2002).

Kpeshie lagoon on the other hand was fairly stable with varied Cd concentrations from 7.63 $mgkg^{-1}$ to 10.28 $mgkg^{-1}$. As Kpeshie lagoon has no manufacturing facility sited within its locality, the source of cadmium might solely be of urban waste or runoffs.

Callinectes amnicola, and *Sarotherodon melanotheron* measured mean Cd concentration of 4.60 mgkg^{-1} and 1.10 mgkg^{-1} respectively. These mean values exceeded the permissible limit of 0.5 mgkg^{-1} by US EPA (2010) and 0.05 mgkg^{-1} set by FAO/WHO (2011) for both crustaceans and fish. A previous study by Fianko *et al.* (2013) at Kpeshie lagoon revealed below detection limit (BDL) for cadmium concentration in tilapia. This is comparable to the present study as some of the fish samples read below detection limit.

5.3.3 Chromium

Chromium has no known beneficial role for humans and animal diet (USGS, 1996). Chromium in hexavalent form is toxic and a danger to human health. Concentrations of chromium are known to decrease with increase in pH and water hardness (Codex, 1995). The mean concentration of chromium in surface water of Korle lagoon recorded below the permissible limit of 0.05 mgL^{-1} (WHO, 2005), while that of Kpeshie lagoon recorded slightly above the WHO limit. The concentration of chromium measured in water column of Kpeshie is comparable to the study carried out by Apau *et al*. (2012).

Chromium levels in sediments of Korle and Kpeshie lagoons averagely recorded within the SQG recommended limit of 52.3 mgkg^{-1} (CCME, 2001). Chromium concentrations in sediment at Kpeshie lagoon are higher and relatively stable as compared to the concentrations of sediment in Korle lagoon. The source of chromium could probably be the wastewater that drains from hospitality industries into Kpeshie lagoon, whilst those of Korle lagoon could be the runoff from the Agbogbloshie market.

Callinectes amnicola recorded a higher value of 39.52 mgkg^{-1} for chromium than *Sarotherodon melanotheron* (5.88 mgkg^{-1}). As a crustacean benthos bottom feeder it is more exposed to higher levels of heavy metals in the benthos as compared to the tilapias which are pelagic and filter feeders (Signor & Vermeij, 1994). Though, the concentrations of metals in sediments were within the standard limits, their levels in *Callinectes amnicola,* and *Sarotherodon melanotheron* were above standard limits of 0.5 mgkg^{-1} (US EPA, 2010).

5.3.4 Copper

Copper is an essential element and is required for metabolic activities. Copper levels measured in water column of Korle and Kpeshie lagoons were below the recommended limit of 2.0 mgL^{-1} set by (WHO, 2005). A similar study conducted by Aglanu & Appiah (2014) recorded 0.049 mgL^{-1} in the lagoonal water of Korle.

Unlike the sediments, copper concentrations recorded above the SQG recommended limit of 18.7 mgkg^{-1}. The sediments of both lagoons showed an increase in copper levels in recent years. These could probably be the result of e-waste or vehicle tires burning at the banks of both lagoons. A research by Klark *et al*. (2012) at Kpeshie revealed varying levels of copper from 21.8 -51.98 mgkg^{-1} which is similar to the trend of the present study.

Callinectes amnicola measured higher concentrations of copper with an average of 31.09mgkg^{-1} than *Sarotherodon melanotheron,* which averaged 3.49 mgkg^{-1}. Both average concentrations measured were within their permissible limit of 70 mgkg^{-1} (US EPA, 2010) and 20 mgkg^{-1} (FAO/WHO, 2011) for crustaceans and tilapias respectively. Copper levels in *Callinectes amnicola, and Sarotherodon melanotheron* were within the permissible limit because the element is essential to the health of organisms and needed for normal metabolic processes (USGS, 1996).

5.3.5 Lead

Lead concentrations in water column of both lagoons averagely recorded 0.62 mgL^{-1}, above the permissible limit of 0.01mgL^{-1} set by WHO (2005). Mean concentrations of lead in lagoonal water recorded lower concentrations than the sediments.

The sediments of Korle and Kpeshie lagoons followed a reverse trend. In Korle lagoon, lead levels in sediment were fairly stable but increased in recent years. Kpeshie lagoon on the other hand, recorded lower concentration in recent years. The values of lead were above the SQG recommended limit set by the CCME. These could probably be revealing an increase in e-waste recovery within the catchment areas of Korle lagoon as well as atmospheric input from vehicular activities.

Lead concentrations in *Callinectes amnicola* averaged 10.9 $mgkg^{-1}$ and *Sarotherodon melanotheron* averaged 1.23 $mgkg^{-1}$. These concentrations of lead recorded in crustacean and tilapia were above the recommended limit of 1 $mgkg^{-1}$ (FAO/WHO, 2011). Crustacea recorded higher metal concentrations than those of the tilapias. This observation may be as a result of major physiological differences in their body functions. Also the variation is an indication of the degree to which particular species pick up particulate matter from surrounding water, especially in sediments while feeding (Olowu *et al.*, 2010).

5.3.6 Zinc

Zinc is essential and beneficial to metabolic process, seems to have no ill effect even at fairly high concentrations of 20,000-40,000 mgL^{-1}. Zinc levels in water column of Korle and Kpeshie lagoons recorded low values of 0.07 mgL^{-1} and 0.09 mgL^{-1} respectively. The concentrations were within the permissible limit of 3 mgL^{-1} (WHO, 2005). A study by Addo *et al*. (2011) conducted in the Kpeshie lagoon water revealed a similar trend of zinc concentrations.

Concentrations of zinc in sediments recorded higher values than those levels in water column of both lagoons. Though the zinc levels were high, most of the concentrations recorded were within the recommended SQG limit of 124 $mgkg^{-1}$ (CCME, 2001). The measured concentrations could be associated to urban runoff from the adjacent shanty towns, such as Sodom and Gomorrah, burning of vehicle tires at the banks of the lagoons, and continued use of dry cells and building materials.

Zinc concentrations in *Callinectes amnicola* averaged 36.04 $mgkg^{-1}$ and *Sarotherodon melanotheron* averaged 23.23 $mgkg^{-1}$. These concentrations recorded in crustacean and tilapias were within the recommended limit of 80 $mgkg^{-1}$ and 40 $mgkg^{-1}$ respectively (FAO/WHO, 2011). This indicated no contamination with respect to zinc. Zinc, an essential element has probably been utilized via the metabolic processes of these organisms.

5.4 POLLUTION INDICES

Most of the Cf values estimated in the studied heavy metals (As, Cr, Cu) were less than one, which indicated low contamination factor. The values (Cf) of zinc showed moderate contamination factor and that of Cd and Pb revealed high factor.

Also the degrees of contamination (CD) in Korle and Kpeshie indicated a similar trend to the contamination factor, with As, Cr, Cu recording low degree of contamination. The values of PLI were found to be generally high (>1) in most of the sites selected in this study. Indication from the data sets was that the sediments of both lagoons are highly polluted with respect to Cd and Pb.

5.5 TARGET HAZARD QUOTIENT

THQ calculated in relation to Cd, Cr and Pb in *Callinectes amnicola,* and *Sarotherodon melanotheron* were less than one. A THQ (<1) is an indication that heavy metals would possibly not pose any non-carcinogenic health effect to consumers. However, the THQs of chromium were very close to one for both *Callinectes amnicola* and *Sarotherodon melanotheron.* Chromium might perhaps not have any non-carcinogenic health effect to daily consumers of crab and tilapia for now, but care should be exercised in the rate of consumption.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The present research revealed that Korle and Kpeshie Lagoon are polluted. The Kpeshie lagoon has just enough dissolved oxygen and therefore supports fishery resources.

From the analysis, it can be concluded that both lagoon waters are contaminated with cadmium and lead. This is indicative of an increase in industrial, municipal and domestic wastes emptying into these lagoons with fewer environmental regulations. Among the heavy metals investigated, levels of arsenic, copper, and zinc were low (WHO, 2005; US EPA, 2004).

The sediments of both lagoons are highly polluted with cadmium, copper and lead at varying degrees, and to a lesser extent chromium. Degree of contamination in the sediments ranked cadmium and lead to be high contaminants. The ecological potential risk index calculated on the levels of heavy metals in the sediments, also confirmed that both lagoons are extremely contaminated with respect to cadmium and lead.

The result of analyses of fish in Kpeshie lagoon showed high metal concentrations of cadmium, chromium and lead in the tissues of tilapia and crustacean. The present study also discovered that metals concentrations (Cd, Cr, Cu, Pb, Zn) in *Callinectes amnicola* were higher than those of *Sarotherodon melanotheron* except for arsenic.

Based on the values of heavy metal concentrations in *Callinectes amnicola*, *Sarotherodon melanotheron* and the rank of the ecological potential risk index (RI), THQ computed on the levels of metals of fishery resources were less than one (1). This signified that, individuals that consume tilapia and crab on daily basis from Kpeshie lagoon are safe from any non-carcinogenic health effect. However, it is advisable to control the rate of intake since the levels of cadmium, chromium and lead, which are of no nutritional value have the tendency to bio accumulate.

6.2 RECOMMENDATIONS

The waste generated at the Agbogbloshie market could be converted to organic fertilizers for the farmers.

The communities around the Lagoons should be educated to desist from burning e-waste at the banks, dumping of solid waste into open drains and channels. These cause aesthetic nuisances, and also affect the quality of the effluent.

The mangroves and other plants around Lagoons should not be uprooted, these oxygenate the Lagoons.

The laws should be enforced by Metropolitan Authorities to sanction perpetrators who abuse and misuse the Lagoon by cutting trees and should not encourage the development of slums in proximity to surface water.

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APPENDICES

Appendix 1: Physio-chemical Parameters Korle Lagoon

Site	pH water	pH sediment	Temperature(°C)	DO(mgL^{-1})	TDS(mgI^{-1})	EC (µScm^{-1})
1	6.45	7.6	29.8	0.90	32300	51200
1	6.98	7.6	29.2	2.60	25500	41700
1	8.62	7.6	29.5	2.01	30010	49600
1	5.41	7.6	29.1	1.04	25900	42500
1	6.45	7.5	28.9	1.24	21400	35200
2	5.21	7.8	29.2	0.89	22200	36900
2	7.69	8.3	29.3	1.09	35100	53000
2	7.58	8.2	29.4	2.09	27400	44000
2	6.22	8.4	29.5	2.41	21900	36100
2	8.01	7.9	29.2	1.22	23500	38200
3	8.05	7.5	30.1	1.58	26300	42900
3	6.55	7.7	29.6	1.67	26500	43800
3	6.27	7.9	29.4	2.47	28200	44300
3	7.19	7.6	29.5	2.51	29700	46900
3	7.28	7.7	29.3	2.67	28600	45100
4	4.31	7.8	29.6	3.12	25800	41900
4	6.05	7.5	29.5	3.05	33700	54200
4	6.49	7.9	29.4	0.87	31400	50800
4	4.91	7.8	29.4	2.11	35700	53500
4	6.54	8.3	29.2	1.58	36700	55300

Appendix 2: Physio-chemical Parameters of Kpeshie Lagoon

Site	pH water	pH sediment	Temperature(°C)	DO(mgL^{-1})	TDS(mgL^{-1})	EC (µScm^{-1})
1	8.42	7.2	30.4	6.42	25200	41200
1	5.59	7.3	30.6	4.22	27300	44800
1	8.07	7.3	30.5	3.28	7070	11400
1	8.48	7.5	30.4	4.24	6050	9600
1	7.36	7.4	30.4	4.92	12100	25000
2	8.23	7.5	30.5	4.55	8070	12800
2	6.57	7.4	30.6	4.68	9040	13600
2	8.33	7.3	30.5	4.07	14600	30100
2	7.98	7.2	30.6	4.03	15200	31700
2	8.02	7.1	31.4	4.32	21300	36500
3	3.69	7.5	31.2	4.19	22500	38600
3	8.45	7.1	31.2	4.88	24100	40500
3	8.03	7.5	31.3	6.25	12300	25900
3	8.02	7.5	30.1	6.31	18000	34100
3	8.01	7.6	30.5	5.87	15400	32100
4	7.88	7.2	30.4	5.04	12900	26400
4	6.65	7.5	31.1	3.45	17800	33200
4	8.26	7.4	31.3	3.95	16200	32900
4	8.18	7.3	31.2	3.85	19700	34900
4	6.26	7.3	30.3	3.15	25500	41900

Appendix 3: Heavy Metals of Water Column at Korle Lagoon

Element	Site	As(μgl^{-1})	Cd(mgl^{-1})	Cr(mgl^{-1})	Cu(mgl^{-1})	Pb(mgl^{-1})	Zn(mgl^{-1})
KLW01	1	5.412	0.054	0.066	0.454	1.727	0.113
KLW02	1	5.479	0.078	0.075	0.393	1.137	0.112
KLW03	1	5.312	0.082	0.055	0.343	0.784	0.077
KLW04	2	5.036	0.051	0.056	0.596	0.131	0.054
KLW05	2	4.924	0.032	0.054	0.250	0.408	0.077
KLW06	2	4.943	0.055	0.024	0.680	0.223	0.028
KLW07	3	5.441	0.050	0.005	0.067	0.868	0.082
KLW08	3	5.411	0.023	0.045	0.335	0.221	0.022
KLW09	3	5.349	0.019	0.061	0.143	0.346	0.045
KLW10	4	5.126	0.012	0.023	0.182	0.441	0.085
KLW11	4	4.936	0.015	0.005	0.115	0.437	0.072
KLW12	4	5.195	0.025	0.015	0.201	0.568	0.065

Appendix 4: Heavy Metals of Water Column at Kpeshie Lagoon

Element	Site	As(μgL^{-1})	Cd(mgL^{-1})	Cr(mgL^{-1})	Cu(mgL^{-1})	Pb(mgL^{-1})	Zn(mgL^{-1})
KPW01	1	4.998	0.048	0.087	0.096	0.276	0.050
KPW02	1	4.880	0.049	0.058	0.356	0.275	0.017
KPW03	1	5.029	0.009	0.034	0.346	0.352	0.045
KPW04	2	4.816	0.068	0.085	0.165	0.488	0.018
KPW05	2	4.910	0.082	0.077	0.253	0.089	0.055
KPW06	2	4.873	0.055	0.062	0.304	0.767	0.008
KPW07	3	5.123	0.068	0.077	0.485	0.032	0.022
KPW08	3	5.099	0.017	0.073	0.566	0.610	0.072
KPW09	3	5.127	0.026	0.069	0.404	0.006	0.095
KPW10	4	5.616	0.049	0.021	0.033	2.035	0.229
KPW11	4	5.079	0.046	0.025	0.038	0.559	0.254
KPW12	4	5.252	0.068	0.029	0.042	0.573	0.236

Appendix 5: Heavy Metals in Sediments at Korle and Kpeshie Lagoons (mgkg^{-1})

SampleID	Site	Lagoon	from	To	As	Cd	Cr	Cu	Pb	Zn
KL001	1	Korle	0.0	5.0	0.4993	54.4	16.4	78.0	174.6	220.4
KL002	1	Korle	5.0	10.0	0.4825	54.5	15.7	77.2	173.8	221.9
KL003	1	Korle	10.0	15.0	0.5226	3.9	49.9	5.8	86.2	40.0
KL004	1	Korle	15.0	20.0	0.4996	2.0	50.6	5.5	85.9	41.6
KL005	1	Korle	20.0	25.0	0.5126	1.5	28.8	5.1	77.4	40.1
KL006	1	Korle	25.0	30.0	0.5369	1.1	21.4	4.7	76.8	39.5
KL007	2	Korle	0.0	5.0	0.4841	8.8	24.8	5.9	26.8	86.0
KL008	2	Korle	5.0	10.0	0.4785	7.0	21.6	5.1	25.1	86.7
KL009	2	Korle	10.0	15.0	0.4356	6.4	15.4	5.5	25.7	90.1
KL010	2	Korle	15.0	20.0	0.4257	8.0	22.4	6.1	26.4	88.8
KL011	2	Korle	20.0	25.0	0.5143	8.4	0.5	22.7	75.4	203.3
KL012	2	Korle	25.0	30.0	0.4987	9.1	3.0	23.5	78.1	205.8
KL013	3	Korle	0.0	5.0	0.5285	7.2	12.3	32.1	62.9	195.4
KL014	3	Korle	5.0	10.0	0.5428	7.8	11.8	32.5	63.5	196.1
KL015	3	Korle	10.0	15.0	0.5426	7.1	12.1	34.1	63.1	189.9
KL016	3	Korle	15.0	20.0	0.5471	8.1	20.4	33.3	62.4	197.4
KL017	3	Korle	20.0	25.0	0.5112	BDL	1.3	32.9	52.0	234.0
KL018	3	Korle	25.0	30.0	0.3014	BDL	1.7	33.1	51.1	241.2
KL043	4	Korle	0.0	5.0	0.4462	4.9	0.7	BDL	41.4	14.3
KL044	4	Korle	5.0	10.0	0.4359	4.4	0.3	0.5	40.4	14.1
KL045	4	Korle	10.0	15.0	0.5049	7.7	5.5	6.4	35.1	14.9
KL046	4	Korle	15.0	20.0	0.5141	8.8	4.5	5.9	32.1	14.6
KL047	4	Korle	20.0	25.0	0.5074	6.6	14.7	9.7	18.5	21.6
KL048	4	Korle	25.0	30.0	0.5024	5.1	13.0	8.4	11.0	3.4
KP019	1	Kpeshie	0.0	5.0	0.5378	14.9	30.4	18.6	27.0	199.5
KP020	1	Kpeshie	5.0	10.0	0.4805	14.7	25.9	17.9	25.8	198.1
KP021	1	Kpeshie	10.0	15.0	0.4994	17.8	35.1	4.3	66.4	11.7
KP022	1	Kpeshie	15.0	20.0	0.5196	16.0	24.7	4.5	65.9	21.2
KP023	1	Kpeshie	20.0	25.0	0.5278	18.1	30.3	3.5	66.7	20.1
KP024	1	Kpeshie	25.0	30.0	0.4724	1.7	24.7	45.6	14.8	237.3
KP025	2	Kpeshie	0.0	5.0	0.4204	1.8	45.9	45.2	67.6	15.9
KP026	2	Kpeshie	5.0	10.0	0.5021	2.1	41.1	45.9	65.7	15.7
KP027	2	Kpeshie	10.0	15.0	0.5100	2.5	40.6	44.8	59.9	16.4
KP028	2	Kpeshie	15.0	20.0	0.5592	12.2	21.2	40.3	20.7	121.7
KP029	2	Kpeshie	20.0	25.0	0.5269	13.5	20.7	40.1	20.1	122.1
KP030	2	Kpeshie	25.0	30.0	0.5201	13.2	18.9	39.7	19.7	123.4
KP031	3	Kpeshie	0.0	5.0	0.5824	7.3	46.3	94.3	8.1	80.7
KP032	3	Kpeshie	5.0	10.0	0.5078	7.1	41.5	93.8	7.9	80.1
KP033	3	Kpeshie	10.0	15.0	0.5889	4.0	55.6	18.5	276.0	73.2

KP034	3	Kpeshie	15.0	20.0	0.5535	3.8	52.8	18.1	281.1	72.3
KP035	3	Kpeshie	20.0	25.0	0.5556	5.0	58.7	12.9	279.4	60.2
KP036	3	Kpeshie	25.0	30.0	0.5426	4.9	50.1	11.5	278.1	55.7
KP037	4	Kpeshie	0.0	5.0	0.4414	7.9	33.6	10.9	40.3	14.3
KP038	4	Kpeshie	5.0	10.0	0.4147	6.6	37.1	2.0	31.4	10.7
KP039	4	Kpeshie	10.0	15.0	0.4656	6.2	5.0	0.1	64.7	21.5
KP040	4	Kpeshie	15.0	20.0	0.4521	5.1	8.7	1.2	63.4	23.8
KP041	4	Kpeshie	20.0	25.0	0.469	4.5	12.0	BDL	75.5	20.4
KP042	4	Kpeshie	25.0	30.0	0.4583	4.2	11.8	0.2	65.8	19.7

BDL is Below Detection Limit was halved to (0.05 mgkg^{-1}) for the purpose calculations

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Appendix 6: Heavy Metals in Crustacean at Kpeshie Lagoon (mgkg^{-1})

SampleID	Site	As	Cd	Cr	Cu	Pb	Zn
KPC01	1	0.3301	6.30	124.90	7.80	40.8	12.00
KPC02	1	0.3214	7.30	131.30	BDL	32.4	75.20
KPC03	1	0.2893	5.70	155.80	10.3	41.9	72.50
KPC04	1	0.2784	7.40	113.60	26.6	27.2	57.80
KPC05	1	0.2545	BDL	143.20	8.1	18.8	58.10
KPC06	1	0.2775	3.10	128.30	10.1	2.60	28.50
KPC07	1	0.2925	8.10	26.40	34.7	BDL	37.40
KPC08	1	0.2512	7.40	11.00	28.7	BDL	39.50
KPC09	1	0.2705	BDL	18.10	34.3	BDL	57.30
KPC10	1	0.2841	7.50	BDL	55.9	BDL	57.30
KPC11	1	0.3444	7.6	BDL	53.8	BDL	20.4
KPC12	1	0.439	5.3	10.2	51.4	BDL	26.2
KPC13	4	0.4086	7.3	6.5	18.7	12.8	35.5
KPC14	4	0.1832	4.8	5.3	28.6	11.7	33.4
KPC15	4	0.2334	3.1	6.2	31.9	8.2	36.2
KPC16	4	0.254	6.0	8.5	55.9	8.9	24.5
KPC17	4	0.2523	2.7	BDL	31.6	10.9	27.3
KPC18	4	0.364	3.2	18.7	19.8	4.5	20.4
KPC19	4	0.2892	2.9	16.6	39.5	14.8	21.8
KPC20	4	0.222	6.1	9.5	45.3	14.5	38.5
KPC21	4	0.3215	5.6	14.1	49.8	11.2	28.1
KPC22	4	0.3538	0.7	BDL	31.5	BDL	17.7
KPC23	4	0.1209	BDL	BDL	34.2	BDL	20.3
KPC24	4	0.2757	2.10	BDL	37.50	BDL	19.1

BDL is Below Detection Limit were halved to (0.05 mgkg^{-1}) for the purpose calculations

Appendix 7: Heavy Metals in Tilapia at Kpeshie Lagoon (mgkg^{-1})

ELEMENTS	Site	As	Cd	Cr	Cu	Pb	Zn
KPF01	1	0.3495	3.30	BDL	3.40	BDL	31.80
KPF02	1	0.2986	2.90	6.40	3.10	BDL	31.70
KPF03	1	0.3821	2.10	BDL	5.90	BDL	32.80
KPF04	1	0.3482	2.50	BDL	5.80	BDL	47.40
KPF05	1	0.2779	4.60	BDL	1.80	BDL	42.90
KPF06	1	0.4404	BDL	BDL	BDL	BDL	42.40
KPF07	1	0.4656	BDL	BDL	2.80	BDL	18.50
KPF08	1	0.2902	2.50	BDL	2.20	BDL	15.20
KPF09	1	0.4077	BDL	BDL	4.50	BDL	14.20
KPF10	1	0.4516	BDL	9.50	BDL	BDL	24.50
KPF11	1	0.4264	BDL	13.10	BDL	BDL	23.40
KPF12	1	0.3187	BDL	BDL	5.50	BDL	18.90
KPF13	4	0.3805	0.90	BDL	BDL	BDL	18.90
KPF14	4	0.3159	BDL	1.30	7.30	BDL	20.20
KPF15	4	0.3314	1.20	36.70	BDL	BDL	21.20
KPF16	4	0.4245	1.50	BDL	BDL	BDL	27.00
KPF17	4	0.404	BDL	2.00	BDL	BDL	30.20
KPF18	4	0.4278	BDL	BDL	BDL	BDL	27.20
KPF19	4	0.4215	1.70	24.90	BDL	BDL	10.60
KPF20	4	0.4271	1.60	23.10	BDL	BDL	7.60
KPF21	4	0.4063	BDL	4.30	BDL	BDL	8.80
KPF22	4	0.5184	1.00	2.80	13.20	28.30	15.50
KPF23	4	0.5875	BDL	13.20	13.50	BDL	14.40
KPF24	4	0.4287	BDL	3.40	14.30	BDL	12.10

BDL is Below Detection Limit were halved to (0.05 mgkg^{-1}) for the purpose calculations

Appendix 8: Contamination Factor (Cf) and Pollution Load Index (PLI) of Sediments at Korle Lagoon

SampleID	Site	As	Cd	Cr	Cu	Pb	Zn	PLI
KL01	1	0.28	257.00	0.16	1.42	13.97	3.15	3.00
KL02	1	0.27	272.50	0.16	1.40	13.90	3.17	2.99
KL03	1	0.29	19.50	0.50	0.11	6.90	0.57	1.03
KL04	1	0.28	10.00	0.51	0.10	6.87	0.59	0.91
KL05	1	0.28	7.50	0.29	0.09	6.19	0.57	0.77
KL06	1	0.30	5.50	0.21	0.09	6.14	0.56	0.69
KL07	2	0.27	44.00	0.25	0.11	2.14	1.23	0.97
KL08	2	0.27	35.00	0.22	0.09	2.01	1.24	0.88
KL09	2	0.24	32.00	0.15	0.10	2.06	1.29	0.83
KL10	2	0.24	40.00	0.22	0.11	2.11	1.27	0.93
KL11	2	0.29	42.00	0.01	0.41	6.03	2.90	0.87
KL12	2	0.28	45.50	0.03	0.43	6.25	2.94	1.20
KL13	3	0.29	36.00	0.12	0.58	5.03	2.79	1.48
KL14	3	0.30	39.00	0.12	0.59	5.08	2.80	1.51
KL15	3	0.30	35.50	0.12	0.62	5.05	2.71	1.49
KL16	3	0.30	40.50	0.20	0.61	4.99	2.82	1.67
KL17	3	0.28	0.00	0.01	0.60	4.16	3.34	0.21
KL18	3	0.17	0.00	0.02	0.60	4.09	3.45	0.20
KL19	4	0.25	24.50	0.01	0.00	3.31	0.20	0.17
KL20	4	0.24	22.00	0.00	0.01	3.23	0.20	0.21
KL21	4	0.28	38.50	0.06	0.12	2.81	0.21	0.59
KL22	4	0.29	44.00	0.05	0.11	2.57	0.21	0.56
KL23	4	0.28	33.00	0.15	0.18	1.48	0.31	0.69
KL24	4	0.25	25.50	0.13	0.15	0.88	0.05	0.42
Background values		1.8	0.2	100	55	12.5	70	3.00

Appendix 9: Contamination Factor (Cf) and Pollution Load Index (PLI) of Sediments at Kpeshie Lagoon

SampleID	Site	As	Cd	Cr	Cu	Pb	Zn	PLI
KP01	1	0.30	74.50	0.30	0.37	1.35	2.00	1.38
KP02	1	0.27	73.50	0.26	0.36	1.29	1.98	1.29
KP03	1	0.28	89.00	0.35	0.09	3.32	0.12	0.81
KP04	1	0.29	80.00	0.25	0.09	3.30	0.21	0.84
KP05	1	0.29	90.50	0.30	0.07	3.34	0.20	0.85
KP06	1	0.26	8.50	0.25	0.91	0.74	2.37	0.98
KP07	2	0.23	9.00	0.46	0.90	3.38	0.16	0.88
KP08	2	0.28	10.50	0.41	0.92	3.29	0.16	0.91
KP09	2	0.28	12.50	0.41	0.90	3.00	0.16	0.93
KP10	2	0.31	61.00	0.21	0.81	1.04	1.22	1.26
KP11	2	0.29	67.50	0.21	0.80	1.01	1.22	1.26
KP12	2	0.29	66.00	0.19	0.79	0.99	1.23	1.23
KP13	3	0.32	36.50	0.46	1.89	0.41	0.81	1.22
KP14	3	0.28	35.50	0.42	1.88	0.40	0.80	1.16
KP15	3	0.33	20.00	0.56	0.37	13.80	0.73	1.54
KP16	3	0.31	19.00	0.53	0.36	14.06	0.72	1.50
KP17	3	0.31	25.00	0.59	0.26	13.97	0.60	1.46
KP18	3	0.30	24.50	0.50	0.23	13.91	0.56	1.37
KP19	4	0.25	39.50	0.34	0.22	2.02	0.14	0.77
KP20	4	0.23	33.00	0.37	0.04	1.57	0.11	0.52
KP21	4	0.26	31.00	0.05	0.00	3.24	0.22	0.29
KP22	4	0.25	25.50	0.09	0.02	3.17	0.24	0.46
KP23	4	0.26	22.50	0.12	0.00	3.78	0.20	0.29
KP24	4	0.25	21.00	0.12	0.00	3.29	0.20	0.34
Background values		1.8	0.2	100	55	12.5	70	

Appendix 10: Potential Ecological risk (Er) factor and Potential Ecological Risk Index (RI) Values of Heavy Metals in Sediments at Korle Lagoon

SampleID	**Site**	**As**	**Cd**	**Cr**	**Cu**	**Pb**	**Zn**
KL01	1	2.77	7710.00	0.33	7.09	69.84	3.15
KL02	1	2.68	8175.00	0.31	7.02	69.52	3.17
KL03	1	2.90	585.00	1.00	0.53	34.48	0.57
KL04	1	2.78	300.00	1.01	0.50	34.36	0.59
KL05	1	2.85	225.00	0.58	0.46	30.96	0.57
KL06	1	2.98	165.00	0.43	0.43	30.72	0.56
KL07	2	2.69	1320.00	0.50	0.54	10.72	1.23
KL08	2	2.66	1050.00	0.43	0.46	10.04	1.24
KL09	2	2.42	960.00	0.31	0.50	10.28	1.29
KL10	2	2.37	1200.00	0.45	0.55	10.56	1.27
KL11	2	2.86	1260.00	0.01	2.06	30.16	2.90
KL12	2	2.77	1365.00	0.06	2.14	31.24	2.94
KL13	3	2.94	1080.00	0.25	2.92	25.16	2.79
KL14	3	3.02	1170.00	0.24	2.95	25.4	2.80
KL15	3	3.01	1065.00	0.24	3.10	25.24	2.71
KL16	3	3.04	1215.00	0.41	3.03	24.96	2.82
KL17	3	2.84	0.08	0.03	2.99	20.8	3.34
KL18	3	1.67	0.08	0.03	3.01	20.44	3.45
KL19	4	2.48	735.00	0.01	0.00	16.56	0.20
KL20	4	2.42	660.00	0.01	0.05	16.16	0.20
KL21	4	2.81	1155.00	0.11	0.58	14.04	0.21
KL22	4	2.86	1320.00	0.09	0.54	12.84	0.21
KL23	4	2.82	990.00	0.29	0.88	7.4	0.31
KL24	4	2.55	765.00	0.26	0.76	4.4	0.05
Toxicity factor		10	30	2	5	5	1
RI		**65.17**	**34470.15**	**7.38**	**43.09**	**586.28**	**38.59**

Appendix 11: Potential Ecological Risk (Er) factor and Potential Ecological Risk Index (RI) Values of Heavy Metals in Sediments at Kpeshie Lagoon

SampleID	Site	As	Cd	Cr	Cu	Pb	Zn
KP01	1	2.99	2235.00	0.61	1.86	6.75	2.00
KP02	1	2.67	2205.00	0.52	1.79	6.45	1.98
KP03	1	2.77	2670.00	0.70	0.43	16.60	0.12
KP04	1	2.89	2400.00	0.49	0.45	16.48	0.21
KP05	1	2.93	2715.00	0.61	0.35	16.68	0.20
KP06	1	2.62	255.00	0.49	4.56	3.70	2.37
KP07	2	2.34	270.00	0.92	4.52	16.90	0.16
KP08	2	2.79	315.00	0.82	4.59	16.43	0.16
KP09	2	2.83	375.00	0.81	4.48	14.98	0.16
KP10	2	3.11	1830.00	0.42	4.03	5.18	1.22
KP11	2	2.93	2025.00	0.41	4.01	5.03	1.22
KP12	2	2.89	1980.00	0.38	3.97	4.93	1.23
KP13	3	3.24	1095.00	0.93	9.43	2.03	0.81
KP14	3	2.82	1065.00	0.83	9.38	1.98	0.80
KP15	3	3.27	600.00	1.11	1.85	69.00	0.73
KP16	3	3.08	570.00	1.06	1.81	70.28	0.72
KP17	3	3.09	750.00	1.17	1.29	69.85	0.60
KP18	3	3.01	735.00	1.00	1.15	69.53	0.56
KP19	4	2.45	1185.00	0.67	1.09	10.08	0.14
KP20	4	2.30	990.00	0.74	0.20	7.85	0.11
KP21	4	2.59	930.00	0.10	0.01	16.18	0.22
KP22	4	2.51	765.00	0.17	0.12	15.85	0.24
KP23	4	2.61	675.00	0.24	0.01	18.88	0.20
KP24	4	2.55	630.00	0.24	0.02	16.45	0.20
Toxicity factor		10	30	2	5	5	1
RI		**67.27**	**29265.00**	**15.45**	**61.40**	**498.00**	**16.36**

Plate 6: Kpeshie Lagoon

Plate 7: Kpeshie Lagoon entering the Sea

Plate 8: Korle Lagoon