STUDIES OF TRACE METAL LEVELS IN FISH, SEDIMENT AND WATER FROM KPONG RESERVOIR

BY

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DECLARATION

I, Wisdom Kwasi Yikpo of the Chemistry Department of the University of Ghana, do hereby declare that this thesis ‘Studies of Trace Metal Levels in Fish, Sediment and Water from Kpong Reservoir’ is the outcome of research work undertaken by me under the supervision of Prof. V. K. Nartey and Dr. R. K. Klake and that it has neither in part nor in whole been presented for another degree in this University or elsewhere except for references to works of other researchers which have been duly acknowledged.

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Date

DEDICATION

This Thesis Is Dedicated To My Mother Avinyo Atafe, My Wife Attah Joyce And My Children Ransford, Louisa And Sedinam.

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“You can only see afar when you step on the shoulders of a giant” and “all professional can boast but the Teacher taught them all”. On this note my heartfelt gratitude goes to all the Lecturers of the Chemistry Department.

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LIST OF ABREVATIONS, SYMBOLS AND ACRONYMS

AAS	Atomic Absorption Spectrophotometer
AFS	Atomic Absorption Fluorescence Spectroscopy
GFAAS	Graphite Furnace Atomic Absorption spectroscopy
ICP - AES	Inductively coupled plasma - Atomic Emission spectroscopy
XRF	X - Ray Fluorescence
EM	Electron Microprobe
EPA	Environmental Protection Agency
FP	Flame Photometer
INAA	Instrumental Neutron Activation Analysis
PTFE	Polytetrafluoroethylene
EC	Electrical Conductivity
UNEP	United Nation Environmental Programme
HCL	Hollow Cathode Lamp
USPEA	United State Environmental Protection Agency
T. Hardness	Total Hardness
T-Hg	Total mercury
FAO	Food and Agricultural Organization
FDA	Food and Drug Administration
ECE	Economic Commission for Europe
AMAP	Artic Monitoring Assessment Programme
CoV	Co-efficient of Variation
WHO	World Health Organization
WRC	Water Resource Commission

WRI	World Resource Institute
%	Percentage
GSH	Glutathiones
UV	Ultraviolet
GAEC	Ghana Atomic Energy Commission
SRM	Standard Reference Material
STD	Standard deviation
BOD	Biological Oxy gen Demand
IAEA	International Atomic Energy Commission
PPb	Part Per billion
ppm	part per million
g	gram
mg/kg	milligram per kilogram
mg/L	milligram per Litre
ng/g	nanogram per gram
S-S	Sulfide bond
FAS	Ferrous Ammonium Sulphate
IUPAC	International Union of Pure and Applied Chemistry
FAHs	Polynuclear Aromatic hydrocabons
^oC	Degree Celsius
MeHg	Methymercury
HCl	Hydrochloric acid
H_2SO_4	Sulphuric acid
Se	Selenium

Hg	Mercury
Fe	Iron
Mn	Manganese
Pb	Lead
TM	Torgome
FU	Fodzoku
GC	Gacrom
GS	Gasikakofe
FN	Fremankofe
KP	Kpong
VK)	Vivorkofe
LN	Lorlornyokofe
AS	Agric Research Station
AU	Akrade

ABSTRACT

Water of good quality is indispensable to human survival on earth. The provision of potable water to both the rural and the urban populations is necessary to prevent health hazards. The aim of this research was to assess water quality with respect to physicochemical parameters and trace metals levels in the water, the sediment and the fish species from the Kpong Reservoir on the Lower Volta River. The water, the sediment and the fish samples were collected monthly for six (6) months from November 2011 to February 2012 (dry season) and from May to July 2012 (wet season). The water, the sediment and the fish samples were analyzed for Hg, Se, Fe, Mn and Pb using Atomic Absorption spectroscopy (AAS). Mercury was determined using a cold vapour technique with the AAS equipped with a hydride generator. Selenium was also determined by hydride generation. A mixture of nitric acid (HNO_3 65%), hydrochloric acid (HCl 35%) and hydrogen peroxide (H_2O_2 30%) was used for complete oxidation of the organic sample in a fume chamber. The samples were loaded on a Milestone microwave Labstation ETHOS 900, INSTR:MLS -1200 MEGA. The results of this study showed that there were significant differences in concentrations of the physicochemical parameters between the two seasons. Domestic, municipal and Agricultural waste might have contributed to the release of higher contaminants into the sediment in both seasons. Coefficients of variation for the physicochemical parameters were below 50%, while iron and lead in addition to phosphate and sulphate were more than 50%. The mean concentration of trace metals in the water were 0.008 mg/L for Hg, 0.0035 mg/L for Se, 0.255 mg/L for Fe, 0.087 mg/L for Mn and 0.135 mg/L for Pb. Levels of all trace metals were below the WHO guideline values, except Pb which exceeded at 0.05 mg/L. Levels of nutrients were also below the WHO guideline value except phosphate which recorded a standard deviation of ±0.02 for the WHO guideline value of 0.3 mg/ L. The concentration (mg/kg) of metals in the sediment were higher than that of water and fish species. Of all the five fish species, the mormyrops species which had the largest weight recorded the highest concentrations of T-Hg and Se. The occurrence of other metals are in the order of concentration: Fe > Mn > Se > Hg > Pb. The mean values of mercury in the fish samples were below the WHO guideline limit of 0.5 mg/kg. Based on these results, the fish species tilapia zilli, hermichromis fasciatus, claria laeviceps, mormyrops anguilode and mormyrops species from the Kpong Reservoir are suitable for human consumption.

CHAPTER ONE

INTRODUCTION

1.0 Background

The adage 'water is life' summarizes the importance of water in our day to day existence. Even though it is a resource, it is easily abused and polluted. Water contains a myriad of chemicals which are both beneficial and detrimental to humans. The quantity and quality of this renewable resource are closely related; contamination reduces the supply of water and increases the treatment cost for use. One source of contamination is Agricultural runoff to surface waters, and this is said to be the major source for the dissolution of nitrate and phosphate compounds (Correll et al., 1999; Chadwick and Chen, 2002; Ensign et al., 2006). It represents the greatest contamination risk to surface water systems (Jamieson et al., 2002). Diminishing water quality as a result of contamination has affected living resources through habitat degradation, thus reducing estuarine productivity and eliminating feeding and nursery habitats.

1.1 Statement of Problem

The river Volta Basin receives runoff water from the surroundings;- for settlers along the river are engaged in Agricultural activities which involve the use of agrochemicals and pesticides which could cause the deposition of trace metals in the sediment which contaminate the river, and this could be harmful to aquatic life. In light of this there is the need to regulate human activities that could have adverse effects on aquatic life. A large amount of sewage and other liquid and solid waste are discharged into the river, especially at Kpong.

Application of excessive nutrients results in the growth of algae and other plants resulting in eutrophication. The death of these undergrowth plants results in decay and depletion of oxygen which leads to anoxic conditions and subsequent destruction of the aquatic ecosystem. Along the river at Kpong, there used to be a washing bay and way side fitters who discharged gasoline products into the river, and this gradually entered the food chain. Many of the people living along the Volta Basin depend on fish species from the river as their only source of protein and the untreated raw water is the only source of drinking water, and it is not safe.

The contaminated state of the water also imposes a high treatment cost for the Ghana Water Company Limited (GWCL) to provide potable water to people at Kpong and its surroundings villages (Ayibotele et al., 1989).

Based on these, there is the need to carry out a comprehensive assessment of the water quality and the factors responsible for pollution and patterns of pollution to enable water managers make prompt decisions about how best to regulate the pollution level.

1.2 Justification

The commonest source of protein to humans is fish. It is very nutritious and a source of food for healthy growth and the development of the foetal brain. Considerable data exists on trace metal accumulation in fish. For example some studies showed that some fish had a high trace metal concentration specifically mercury as high as 3.6ppm.As a result of this elevated mercury level, fishing was banned in some lakes in Wisconsin and Alaska. (Koeman et al., 1975).

In Ghana, the River Volta is the main source of drinking water. It is used for most household chores as well as for irrigation purposes. There are a large number of settlements that do not have access to treated water along the Lower Volta basin. Even though the Kpong Water

Works supplies about 20% of pipe borne water, many inhabitants still depend solely on untreated water which might be contaminated and thus have an adverse health effect when used. (Amoah and Koranteng,2006). Along the bank of the river there are farming activities which involve the use of agrochemicals such as fertilizers and pesticides and these eventually drain into the river by means of erosion, runoffs and rain water which subsequently pollute the water. Kellogg *et al.*, (1972) reported that fertilizers and pesticides contain some levels of trace metals which accumulate in soils and water bodies with time. Trace metals are known to have adverse health effects on humans when consumed. For instance, Ogwuebu and Muhanga (2003) stated that lead toxicity causes reduction in haemoglobin synthesis, disturbance in the functioning of the kidneys and chronic damage to the central and peripheral nervous system. In light of this, there is the need to carry out this study on physicochemical parameters as well as trace metal concentration in the Kpong Hydroelectric Reservoir on the lower Volta River. Since fish species that serve as the source of protein for the population in the area are caught from this river, they must also be analyzed.

Studies completed by Hydro-Quebec have linked hydroelectric development in northern Quebec to an increased level of Hg in nearby ecosystems. Fish passing through into the downstream river showed significantly high levels of Hg due to hydro turbulence and run-off waters. Mercury concentration recorded in 230 fish samples from an Amazon hydroelectric reservoir recorded levels higher than 0.5mg/kg of Hg in fresh weights (Hall *et al.*, 1997). There is, therefore, the need to monitor levels of trace metals in fish species meant for consumption from hydroelectric reservoirs and compare levels with others around the world.
There is an extensive body of literature documenting a positive relationship between fish mercury concentration, size and length within individual water bodies. Due to inadequate data on trace metals of the aquatic ecosystem of the lower Volta, this research seeks to

determine the levels of mercury, selenium, iron, manganese and lead in the water, the sediments, and the fish from the Kpong Reservoir, along a 10 kilometer distance northwards towards Akosombo Hydro Electric Dam. The water, the sediment and the fish from the river may contain toxic elements which are detrimental to human health, hence it is relevant to investigate them. The results obtained will then serve as guidelines to assist regulatory bodies in making informed decisions and make recommendations on measures to improve on the drinking water and the fish.

1.3 Aims and Objectives

1.3.1 General Objective

The aim of this research is to study the levels of trace metals such as Hg, Se ,Fe, Mn and Pb in fish, sediments and water from the Kpong Reservoir.

1.3.2 The Specific Objectives

- Determine the levels of bioaccumulation of mercury, selenium, iron, manganese and lead in the water, the sediment and in some species of freshwater fish..
- Provide data for safe consumption of selected fish species such as tilapia zilli, hermichromis fasciatus, claria laeviceps,mormyrops anguiloides and mormyrops species
- Compare levels of trace metal contamination with those of the World Health organization standards.
- To identify the sediment as a trace metal sink in the river basin.
- Determine the correlation between total mercury and selenium in some fish species.

- Investigate physicochemical parameters such as pH, electrical conductivity, total dissolved solids, total hardness, phosphate, sulphate and nitrate levels of water from the Kpong Reservoir
- Make recommendations based on the outcome of the project.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

The geology of the underlying rock determines the surface water quality (Yidana et al, 2008) and the level at which mineral dissolves determines such materials' concentration in the water.

2.1 Water and Its Importance

The most available natural resource on earth is water, and it covers about 71% of the earth surface. The earth is covered by about 13% fresh water and 97% salt water. The climate of the earth is checked by fresh water and it also helps to lessen the strength of pollutants in the environment (Miller, 1988).

It is through water that all life processes occur because water plays an important role in our lives. Heavy metals such as manganese (Mn), lead (Pb), mercury (Hg)iron (Fe) and selenium are dissolved by water. These metals are harmful to aquatic life when they are high in concentrations. Water performs the following functions: removal of waste products, regulation of body temperature, distribution of cell nutrients and support of structure. Water makes up 60% of the human body (Cunningharm and Saigo, 1995).

50% - 97% of all plants weight is made up of water (Miller, 1988). Water is a key ingredient in our lives socially, economically, politically and culturally.

The location and activities of humans all over the world are determined by the availability of water, and it is present in great quantity worldwide. The average of water per person that enters stream and rivers every year is more than 7000m^3. However, this water is not sufficient to satisfy our needs (Cunningharm and Saigo, 1995).

Water, apart from its general use, plays a major role in crop production every year. In the dry season, irrigation systems are practiced where water is pumped all the time to maintain sufficient production of crops.

Moreover, water is key in aquaculture business. Apart from harvesting fishes from their natural habitat, they are reared artificially, especially, in rivers, lakes and ponds. The use of water in aquaculture business provides livelihood for farmers. It also provides food nutrients for them.

Water does not only provide food but also serves as a means of transport, generation of electricity, irrigation, recreation, industrial use, and drinking (Bartram and Balance, 2001).

2.2.1 Sources of Water Pollution

Aquatic ecosystem and quality of water can be steeply, significantly and adversely affected by water pollution. It is not easy to attribute pollution to its exact sources because of its variation through space and times. Consequently, voluntary incentives for abatement is depended on by minority of public policies implemented to address pollution except pesticides and animal waste (Brade and Shortle, 2013).

Water pollution has a lot of causes but they are put into two main categories namely direct (point) and indirect (non-point) contaminations. Effluent outfalls from refiners and factories fall under direct contaminants. Also, fluids of different quality emitted into water sources from waste treatment plants are direct contaminants. In many developed countries such as the United States of America, direct contaminants are regularized but their pollutant find their ways into the water bodies.

Pollutants from the atmosphere and soil system which find their way into water are examples of direct sources. Industrial wastes which are not properly disposed, and the residue of human Agricultural practices (fertilizers and pesticides) are contained in soil waters. Pollutants from the atmosphere are as a result of human practices such as gaseous emissions from automobiles, factories and bakeries.

2.2.1.1 Water Pollution through Agricultural Activities

Agriculture uses an average of 70% of all surface water bodies. Even though it uses freshwater resources in the largest quantity, it can be regarded as a cause of water pollution. Its emission of contaminants and sediment into both surface and or ground water makes it a cause of water pollution. Also, because of the salinization and water logging of irrigated land and the net loss of soil as a result of poor Agricultural practices, Agriculture is considered a cause. To use wastewater and polluted surface and groundwater is harmful to crops, consumers and farmers (FAO, 1996). Agriculture occurs in a symbiosis of water and land and it is evident in a statement made by the FAO (1996) which states "...appropriate steps must be taken to ensure that Agricultural activities do not adversely affect water quality so that subsequent uses of water for different purposes are not impaired".

Since the 1970's, increases in nitrate (NO_3^-), Phosphate (PO_4^{3-}) and pesticide residues in both surface and ground water have become a worrying situation in Europe. The French in 1980 were conclusive of the fact that Agriculture, at a significant rate, is an indirect source of pollution to both ground and surface water. This conclusion was drawn out of the intensive crop cultivation and factory livestock farming (Ignazi, 1993).

A report was made by Ansa-Asare (1996) on the growing Agricultural activities and high nitrate-nitrogen concentration in Weija. As a result of these activities, algal blooms became ubiquitous in the dry season. Another report was made by Asante (1999) concerning high BOD value of 8.16mg/L in Weija against background value of 3mg/L for fresh water. It was suggested that sewage, runoff from Agricultural activities and overland may be the causes of the high BOD. It was revealed by UNEP (1993) that Agriculture was the leading source of compounds in sediment containing phosphate.

2.2.1.2 Mining

Mining forms an integral part of the economies of many countries; however, its activities have significant adverse effect on health through water. The effect of mining on health in the first place, is through its method of extraction. For example, the health of children who pan off gold from dirty water is adversely affected. Also, the use of chemicals such as cyanide, in leaching gold; mercury, in coagulating gold and other metals, contribute to the effects on people's health. Furthermore, mining affects health through the pollution of local sources of water. This happens as a result of mine drainage. Finally, mining contributes to the production of toxic substances into the environment. For instance, erosion from some mining site has long term effects as its reduction in biodiversity of fish population.

Studies of methyl mercury poisoning far away in the Amazon demonstrated that mining may have a lesser effects on health (Harada et al. 1995). In the studies, mercury levels in hairs of the head residents of three fishing villages on the Japajos River were studied. The Japajos River is a tribute of the Amazon, far away from the gold mining areas. It was revealed that their head hairs had high mercury levels and other symptoms suggesting neuro-toxic disease.

In West Africa, Ghana is one of the countries that fall within the Precambrian Guinea shield. The main units of the Precambrian rock in Ghana are the metamorphosed and folded Tarkwaian and Birimian formations. These formations can be mainly found in the Eastern, Ashanti, Western, Central, Brong Ahafo and Northern region of Ghana (Kesse, 1985). The Ashanti and Western Belt are the location for most of the minerals in Ghana. In many ways, mining activities affect the environment. Most significantly, it affects water bodies as a result of poor management of effluents from processing plants, poor management of tailings, the use of mercury in small-scale mining, and the exposure of mined surfaces to acid mine drainage.

2.2.1.3 Pesticides as a source of water pollution

An unwanted organism can be killed directly by pesticides. In other words, pesticides control unwanted organisms. Ever since the introduction of pesticides, the synthetic ones are of major concern because they have the potential of causing harm to human health, when food contaminated with the chemicals are eaten (Baird, 2000). Pesticides have effects on the ecosystems and even beyond the ecosystems and individual organisms. A study conducted in Sweden revealed that pesticide application to a large extent affects biodiversity. It was reported that changes in land use and chemical weed control application were responsible for the downward growth of the population of partridges in Sweden (Jonsson et al, 1990). The use of chemical weed control is a cause for the decline in weed species, decline in habitat and moving the species balance in the plant habitat. Organisms which are considered micro, being agents of microbial degradation of plant matter and soil structure, are affected adversely by the use of pesticides.

In developing countries like Ghana, it is difficult to monitor data for pesticides effectively but in many developed countries like Japan, major pesticides form part of the monitoring schedule. Nevertheless, the cost of analysis and the necessity of sampling at crucial times (linked to periods of pesticides use) sometimes serve as a prelude to developing extensive data set. Lots of developed countries find it difficult to trace organic analysis, because it is capital intensive, has insufficient facilities and impure reagents. Immunoassay techniques are used to determine absence or presence of pesticide and to alleviate costs. Immunoassay technique are used for acid amides, 2, 4 - D/phenotype acid and triazines (Rickert, 1993).

2.2.1.4 Pollution by Sediments

Layers of organic matter particles and mineral are often fine in texture and are found beneath natural water bodies such as lakes, oceans and rivers. There is a substantial variation in the ratio of organic matter to minerals in sediment, which depends on time and space of sample collection. Environmentally, sediment plays a major role as they serve as sinks for chemicals, organic compounds and heavy metals such as Polynuclear Aromatic Hydrocarbons (PAHs). Pesticides have the potential of being transferred to the habitat of organisms.

Agriculture is not the only factor responsible for several problems related to water quality but also erosion and sedimentation is a world-wide concern that is primarily associated to Agriculture. In the absence of figures, it can be said that Agri culture, to a large extent, is responsible for the drifting of sediments into water bodies (FAO, 1996).

2.2.1.5 Heavy metals

Metallic elements of any kind that have a high relative density and are toxic or poisonous at low concentration can be termed as heavy metals. These metallic elements form the natural components of the crust of the earth. Heavy metals are not degradable or destroyable. Importantly, iron (Fe) and Selenium (Se) maintain the metabolism of the human body. On the contrary, they can lead to poisoning when they are at higher concentrations (IUPAC Technical Report, 2002). Heavy metals significantly pollute aquatic environment, as a result of its toxicity and accumulation in organisms. Also, it pollutes water bodies because of its persistence and its difficulty to be biodegraded (Emani et al, 2004). Physiological factors such as age and development status contributes to the variation in the distribution of metals among fish species (Kagi and Schaffer, 1998).

2.2.1.5.1 Mercury

The use of pesticides made from mercury leads to numerous poisoning accidents because mercury is regarded as an environmental contaminant (Koose and Longo, 1998). It has been estimated that anthropogenically, a range of 2,000 - 4,500 metric tons/year of mercury are released into the atmosphere through mining, and melting of mercury and other metal sulfide ores (IPCS, 1990; WHO, 1990).

The recuperation of metal price has been observed to be a cause in the upward growth in gold production. (DNPM, 2002, 2003). Sediments beneath the aquatic environment is considered to be the extreme sink where a highly insoluble mercuric sulfide is deposited (IPCS, 1990). Methylation in animals and precipitation in crops make mercury infiltrate into the food chain when crops and animals are consumed by people in the indigenous communities. The bio-accumulated methyl mercury in the trophical food chain forms the major source of protein for organisms along water bodies. This situation is dangerous because 73-98% of the total mercury represents methylated form (Barbosa et al, 1998; Maurice - Bourgoin et al, 2000).

2.2.1.5.2 Selenium

Selenium exposure can be considered to have both positive and negative effects. Selenium toxicity exposure commences when sulphur (S) in the ionic disulfide bonds (S-S) of tertiary protein formation is substituted by excess Selenium (Se) (Lemly, 2002). Selenotrisulfide linkages or triselenium linkages (Se-Se-Se) is produced by this substitution. Both linkages hinder the formation of disulfide bonds (Lemly, 2002).This results in the malformation of proteins and enzymes.

Skin lesions, fatigue, brittle hair and nails, irritability, depression, dental cavities, muscle tenderness, nausea, vomiting and nervousness are among the symptoms of Selenium poisoning in human beings (Wilber, 1980; Barceloux, 1999). However, it is still non-evidential that Selenium is a carcinogen (Barceloux, 1999; CCME, 2007). It cannot be proven to be a teratogen to humans either (Agency for Toxic substances and Disease control, 1997; CCME, 2007). Reverse relationship between Selenium exposure in humans and cancers have been revealed by many researchers (Coates, et al; 1988;Vant Veer et al; 1990; Hunter et al, 1990).

2.2.1.5.3 Selenium and Mercury interaction

It has been suggested by lots of studies that the chemical forms of Selenium and mercury are very essential in the toxicology of both mercury and Selenium. The interesting thing between the two metals depends on the chemical states in which they exist. It has been proven that the quantity of Selenium from food affects the quantity of mercury (Hg) taken up form food. About 5 - 11% of mercury accumulation is reduced by the upward adjustment of Selenium in food. On the contrary, if selenium and mercury (Hg) in the form of Hg (NO_3) and H_2SeO_3 were taken up from water, the concentrations of mercury (Hg) in the fishes from the various rivers were not affected by Selenium. This reveals that the dissimilarity between the assimilation of both Selenium and mercury (Hg) could have been caused by the probable transformation of both selenium and Hg into different forms prior to the consumption (Turner and Swide, 1983).

The abilities of selenite and selenium from tuna to support rats which are exposed to methyl mercury were compared and it had been found out that they both led to the improvement of the rats' mortality. However, selenite is better than Selenium from tuna in working against the manifestation of neurological mercury (Hg) toxicity. This makes selenite different from selenium. Another study conducted by Matsumoto and Miki (1981) revealed that Sodium selenate (vi) and Sodium Selenite(iv) prevented the neurotoxicity of methylmercury but the selenite was more effective than selenate five times. Selenium in different forms interacts with mercury in different forms differently. Research on Se and Hg bioaccumulation in the blue mussel conducted by Pelletier (1981) revealed that the muscles accumulated inorganic Hg at a slow rate in the absence of Hg. However, Organic selenium was not accumulated. Adding inorganic Hg to water, the rate of inorganic Selenium accumulation tripled when the exact quantity of methylmercury was added. There seemed not to be bioavailability of organic Selenium in the absence of methylmercury. On the contrary, regardless of the presence of the chemical form, concentration did not have any effect on the mercury accumulation rate. Cuvin-aralar and Ferness (1991) have discussed intensively the effects of other chemical forms (organic selenium) such as phenyl-selenium mercuric acetate.

2.2.1.5.4 Heavy metals as sources of water of pollution

Industrial and consumers waste, including acidic rain, make heavy metals enter water bodies both surface water and ground water, which breaks down soil particles (IUPAC Technical Report, 2002).

2.3 Environmental Effects of Water pollution

According to reports, heavy metals are stable and undegradable. Therefore, they become potential environmental pollutants to animals and plants. The pollutants tend to be accumulated in sediment and soil (Palmer et al, 1992).Even though metals are important to life, they can be toxic if their exposure exceeds estimated boundary then their adverse effects become pronounced. Many organisms have the ability to regulate the concentration of metals in their tissues (Palmer et al, 1992). Essential metals such as Zinc, Copper, and iron present in excess can be excreted by crustacean and Fish (Adamsson et al, 1984).

It has been revealed in research that aquatic plants and bivalves do not have the ability to regulate the accumulation of metal in contaminated environments successfully. Bivalves play the role of bio-monitor organism in areas of suspected pollution of heavy metals as part of estuarine systems (Kennish, 1992). Comparing aquatic plants, fresh water fish and invertebrates, aquatic plants are not more sensitive to metals like lead, zinc, mercury and copper. The organism in question makes metal uptake rates vary. Available metals are assimilated at a fast rate by zooplankton and phytoplankton due to their high surface area to volume ratio. The chemical and physical characteristics of the metals are largely responsible for the ability of the invertebrates and fish to absorb metals (Kennish, 1992; USEPA, 1987). It has been shown in studies that heavy metals get into the aquatic organism's systems via respiratory surfaces as free metal ion. This absorption is done through body surfaces readily diffused into the blood stream. Furthermore, food and absorbed metals particulate could be ingested including free ion in water (Adamsson et al; 1984).

The upward growth of Agricultural activities causes sediment loading of surface waters, which is a long term effect of pollution. To the extreme, navigable water has been destroyed. Bleaching effect, as a result of warmer temperature, affects coral reefs. The increasing temperature in water, as a result of pollution and global warming, is responsible for the destruction of ecosystems. Furthermore, indigenous water species are forced by the warm water to search for colder water in other areas. This has caused ecological damaging shifts in the affected areas.

Pathogenic microbes have made it evidential that a lot of microbes are borne out of the present day water bodies in the Quaternary for humans (Rich et al, 1996). Even during the cretaceous period times for other fauna (Pionar et al, 2008), it could be suggested that the microbial pathogenic infection rate gives rise to overcrowding and lacks the ability to supply fresh drinking water to a greater percentage of the human population. The likelihood of modern diseases to mutate rapidly has worsened these effects. Human adaptation finds it difficult to move at par with such disease mutation because of the abrupt non-induced alteration of the forms of the environment. As a result, it is likely that present day water-borne pathogenic diseases have a greater occurrence rate with global human population, with the exception of areas where medical care, prevention and water pollution control are enforced.

2.4 Previous Works

The effect of water pollution on human health has taken the interests of researchers onto the quality of water. Research is still ongoing on the causes, effects and control of water contamination.

Several studies have been conducted on the pollution status of numerous water bodies in the world. Mahmood *et al* (1997) reported high concentrations of nitrate in water sources in Karachi. Chandio (1999) also reported on the increasing rate of application of an N.P.K fertilizer in Pakistan over a few decades resulting in an excess of Nitrogen of about 2 million tonnes by 1990s. Lake Pichhola in Udaipur, India, which serves as the main drinking water supply reservoir for the township was reported by Premlata (2009) to have its water quality parameter polluted and this was ascribed to the development of human settlement along the banks of the lake. He observed an abnormally high level of sulphate concentration ranging from 405 to 742 mg/L. This high level of sulphate concentration was as a result of the indiscriminate dumping of sewage and garbage into the lake, with the results well above the WHO (2004) guide line limit.

In another development, Muhammad *et al* (2008) reported physicochemical parameters of water from Lake Manchar, such as pH, electrical conductivity, phosphate nitrate, sulphate, chloride, manganese, calcium, cadmiun, zinc, magnesiun, iron, nickel, lead and selenium and observed the following concentration in the respective trace metals as follows. Fe (2780) µg/L, Na (433.06 mg/L K (20.66) µg/L Mg (167) µg/L Cd (4.98) mg/L µg/L Pb (82.2) µg/L Se (42.5) and concluded that the concentrations were above the WHO (2004) permissible levelsof metal concentration in water. They also attributed the high level of these trace metals to anthropogenic sources such as discharge from industrial, Agri cultural and domestic wastes.

In Ghana, Armah *et al* (2010) worked on heavy metals pollution in the aquatic ecosystem in Tarkwa and reported a natural and anthropogenic origin of contaminants in surface waters in the Tarkwa municipality.

Kwaansah - Ansah *et al* (2012) researched on trace metal contamination of water, sediment and some fish species from lake Volta and reported the total mercury concentration in water to be within the range of 0.0027 to 0.862 mg/kg and sediment within 0.0096 to 0.7005 mg/kg while that of fish was found to be0.00 211mg/kg to 0.3556 mg/kg . The concentration of total mercury in sediment was lower than that of the International Atomic Energy Agency (IAEA) threshold of 0.810 mg/kg while the concentration in water and fish samples were below the WHO guideline limit. They, therefore recommended the water and the fish species as fit for human consumption.

2.5 Analytical Methods for Metal Analysis

Elements can be determined in the laboratory using the following fixed techniques: Atomic Absorption Spectroscopy (AAS), Atomic Fluorescence Spectroscopy (AFS), Graphite Furnace Atomic Absorption Spectroscopy (GFAAS), Hydride Generation Atomic Absorption Spectroscopy (ICP-AES), Inductive Coupled Plasma-Mass Spectroscopy (ICP-MS), X-ray fluorescence (XRF), Electron Microprobe (EM), Flame Photometer (FP) and Instrumental Neutron Activation Analysis (INAA). These instruments accurately measure elements in environmental samples to parts per billion (ppb) concentration i.e. µg L^{-1} and µg Kg^{-1} liquids and solid samples respectively (Melamed, 2005). Though inductively coupled plasma is a sensitive multi-elemental technique, it is expensive, therefore we adhere to the use of AAS since it is less expensive.

The use of Atomic Absorption Spectroscopy (AAS) is a common technique in environmental samples. AAS is a technique in which the absorption of light by free gaseous atoms in a flame or furnace is used to measure the concentration of the atom. AAS is based on the absorption of monochromatic light by a cloud of atoms of the analyte metal. In AAS, a liquid sample is aspirated into a nebulizer system. The sample then mixes with an oxidant gas which is drawn under pressure into a burner to form an aerosol. The flame which uses either air-acetylene or nitrous –oxide acetylene operates at a temperature of 2400°C and 2800°C respectively.

Within the flame, the aerosol undergoes processes such as evaporation of the solvent and excitation of gaseous metallic element. To determine the concentration of the analyte, a light beam from a lamp usually a Hollow Cathode Lamp (HCL) whose cathode is made of the element being determined is passed through the flame. A photomultiplier tube attached to the AAS can detect the amount of reduction of the light intensity due to absorption (absorbance) by the analyte. The absorption is proportional to the concentration of the metal ions following the Beer-Lambert Law (Skoog et al., 1989). The advantages of AAS include greater sensitivity and detection limits, direct analysis of some types of liquid samples, low spectral interference and it requires a very small sample size. Generally, the reducing agents that are normally made use of during cold vapour analysis are tin (II) chloride ($SnCl_2$) and sodium borohydride ($NaBH_4$). These chemical are common and less expensive hence the Open cast system is employed for sodium borohydride since it produces hydrogen a nontoxic gas.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

This chapter describes the study area, sampling procedures, various analytical methods and the supplementary materials used in this work .

3.1 Study Area

This Study was undertaken from November, 2011 to July 2012 in the Lower Volta Basin specifically on the Kpong Reservoir. Ten sampling sites within a stretch of 10 km sited along the Kpong Reservoir were selected. These towns are Torgome - (TM), Fodzoku - (FU), Gacrom - (GC), Gasikakope - (GS), Fremankope - (FN), Kpong - (KP), Vivorkope - (VK), Lorlonyokope - (LN), Agric Research station - (AS) and Akrade - (AU).

3.2 Description of Study Area

One of the major river basins in West Africa is the Volta basin. This basin drains an area of 407,000 km^2 into the Gulf of Guinea. The Volta basin is located in the sub-humid to semi-and West Africa Savanna Zone and the District North-South gradients are shown. Acidity in the Volta basin goes up because of its further distance from the coast. White Volta, Black Volta and the Red Volta are the three tributaries joining River Volta. This study is based on the lower Volta Basin which lies latitudes 5^0 30'S and 14^0 30'N and longitudes 2^0 00'E and 5^0 30'W. The six countries being part of the lower Volta Basin and being the beneficiaries are (1) Togo (6%,), (2) Mali (4%), (3) Cote D'Ivoire (3%), (4)Ghana (40%), (5)Benin (4%), and (6) Burkina Faso (43%). River Volta is the largest one in Ghana. It has a distance of 1,600km away from the source in Burkina Faso and it enters the ocean in Ada, a southeastern town in Ghana. The River Volta runs through sandstone, quartzite and other hard rocks in Togo structural unit by narrow, step and deep gorges. Ghana is located at the downstream of the Basin.

The Volta River is dammed at Akosombo and Kpong to generate electricity, which resulted in the creation of the Lake Volta.

The study area stretches from Akrade to Torgorme a distance of 10 km apart and located on the Kpong reservoir. There are two rainfall peaks in this area and fall between May to July as the major season and September to October as the minor season. The dry season is the Harmattan season which is characterized by north east trade winds blowing over the Sahara desert bringing along dry conditions. This period normally spans from November to February.

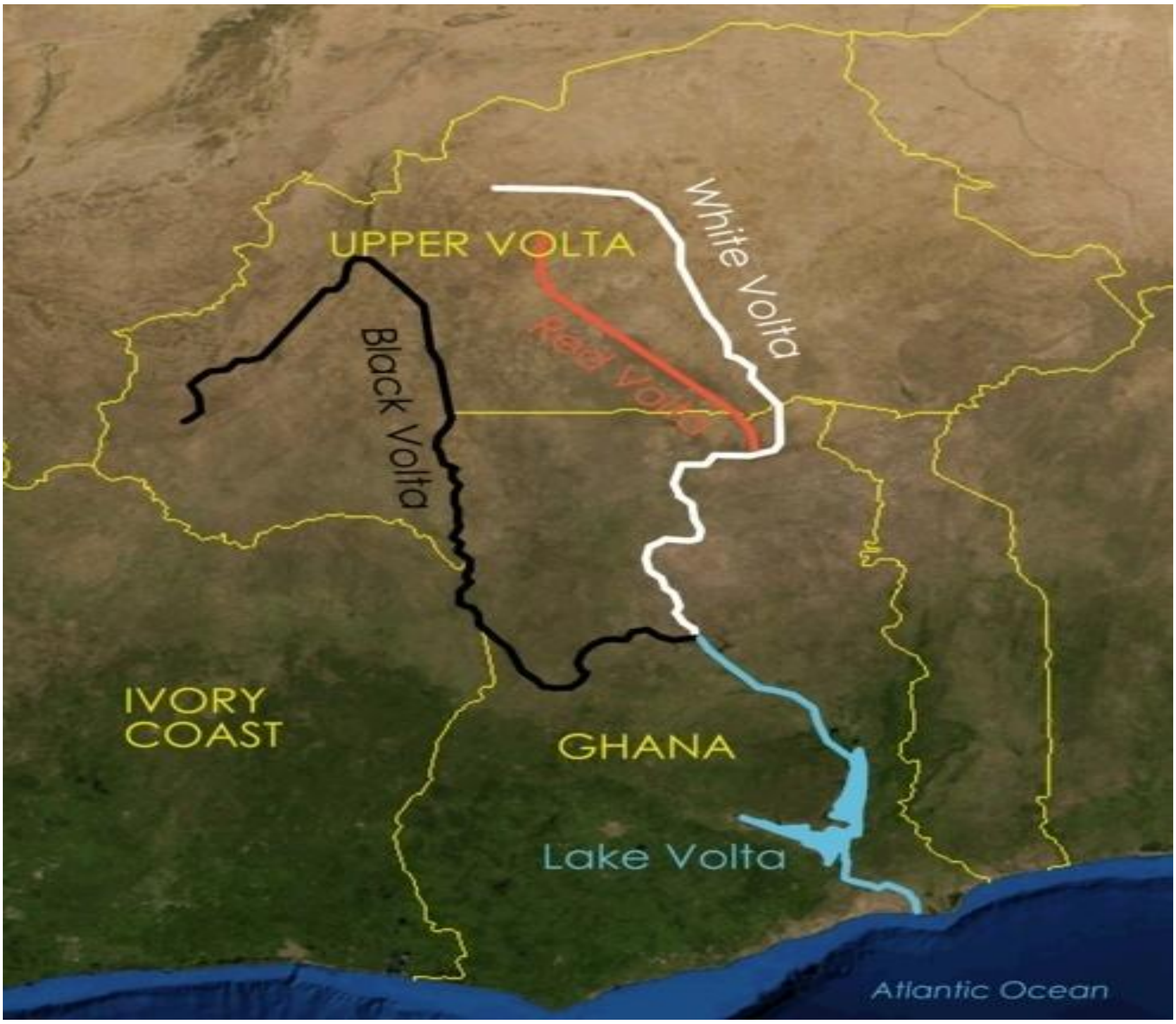


Figure 1.1 Map of Ghana showing the Volta River Basin

3.3 Importance of the Volta Lake

River Volta serves several economic purposes of which the most prominent ones are; Irrigation for farming, generation of hydroelectric power, fishing, transportation as well as a tourist attraction (Bartram and Balance,2001).

Figure 1.1 :Map the study area indicating the sampling sites

3.4 Treatment of Sample Containers

In order to maintain purity of the samples, the glassware and high density plastic containers were soaked in a detergent solution for two days and thoroughly washed and rinsed with distilled water and later soaked in 10% (v/v) analytical grade HCl for 3 days and rinsed with distilled water.

3.5 Reagents

All the reagents used were of analytical grade (BDH chemical Ltd Poole, England) unless otherwise stated. Distilled water was consistently used in the preparation of all solutions.

3.6 Samples and Sampling Procedure

Sampling was done between November 20011 and February 2012 for the dry season and May to July 2012 for the wet season. The samples taken included three samples of water at each site, three sample of sediment and five samples (5) fish species. Sampling points were on the average a distance of 1.0 km apart. Thirty samples of sediment and thirty samples of water were taken each month as the true representation of the sites, including three samples of each fish species. This procedure was repeated for 6 months. Sediment and Water samples were taken from 10 sites and stored in an ice chest on the field. The sediment samples were collected with pre-cleaned polyethylene shovel from each site. The shovel was thoroughly cleaned after every scoop to prevent cross contamination. The sediment samples were stored in polythene bags and sealed with duct tape. The water samples were collected directly into acid pre-cleaned Teflon-bottles using ultra-clean free metal sampling protocol (Gill and Fitzgerald, 1985, 1987). For the water sample collection, each water bottle was immersed at about 10 cm below the water surface at each sampling point and filled to the brim to avoid any air space that contain CO_2. Three sets of samples were taken; one for the measurement of pH, electrical conductivity and the other two were acidified with 0.5% HNO_3 to pH less than 2. The acidification is to maintain the metal ions in a dissolved state so that they would not be lost by absorption on the walls of the containing vessel. The fish and other samples were kept in an ice chest at all times, but the fish samples were transported to the Department of

Oceanography for identification and classification and later sent to the Chemistry Laboratory of the Ghana Atomic Energy Commission (GAEC) for analysis. The samples were stored in a refrigerator at 4°C. There were five fish species bought from canoe fishermen at sales points at Kpong and Torgome.

In all one hundred and eighty (180) water samples, one hundred and eighty (180) sediment samples and ninety (90) fish samples were obtained.

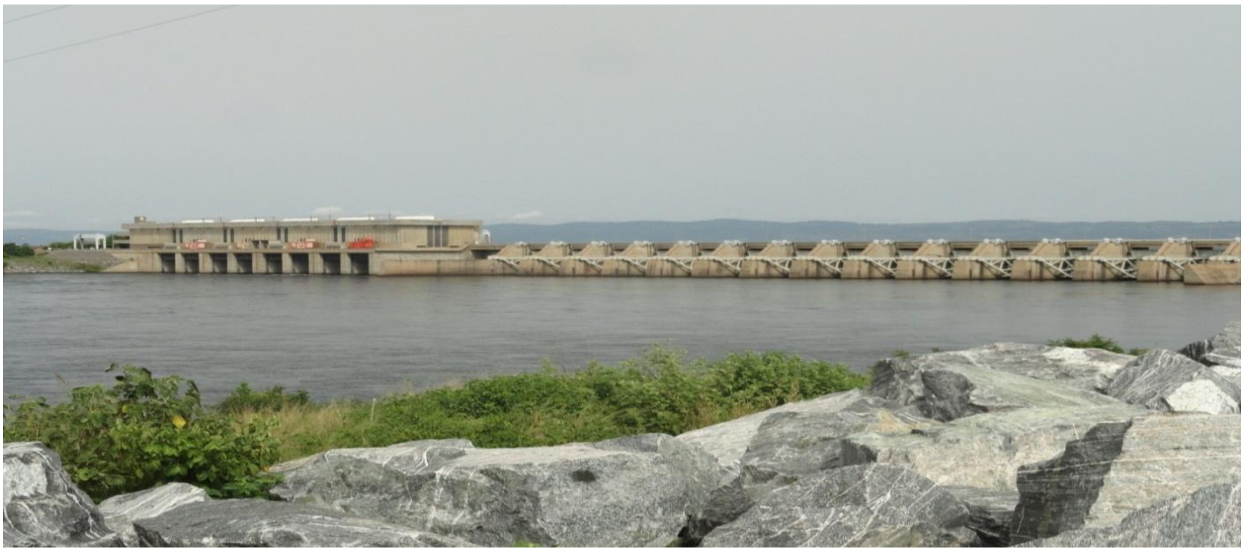


Plate 1 A cross section of the Kpong dam showing a section of the Reservoir

Plate 2 A sewage draining into the Kpong reservoir

Plate 3 Tilapia zilli caught from the Kpong Reservoir

Plate 4 Hermichromis fasciatus caught from the Kpong reservoir

Plate 5 Clarias laeviceps caught from the Kpong reservoir

Plate 6 Mormyrops anguiloides caught from the Kpong reservoir

Plate 7 Mormyrops species caught from the Kpong reservoir

3.7 Sample Preparation and Analysis

3.7.1 Determination of physico-chemical parameters

The physico-chemical parameters of the water samples determined on site are: Temperature, pH, Conductivity and Total dissolved Solids.

3.7.1.1 pH

The pH meter for the determination was first calibrated using a pH 4,7and 9 buffer; and the probe stored in 4M KCl saturated with AgCl three hours prior to the sampling. A volume of 50 ml of water was fetched in a beaker and the tip of the probe was dipped into it. The stable pH readings were recorded to the nearest 0.1 unit. The electrode was removed and rinsed with distilled water and wiped with a clean tissue paper before other samples were determined.

3.7.1.2 Temperature

The temperature of the various water samples were measured on the field using a thermometer.

3.7.1.3 Conductivity

The conductivity meter model Phywe 13701.93 was used for conductivity determination. The conductivity meter was calibrated using a 0.01 M KCl solution with corresponding conductivity of 1413 µs/cm at 25 °C. The sample to be measured was thoroughly mixed and the electrode was gently dipped into it and a stable reading recorded. The probe of the conductivity meter was always kept in distilled water.

3.7.1.4 Total dissolved solids (TDS)

Total dissolved solids were obtained using the gravimetric method. An empty beaker was cleaned and dried in an oven at the temperature of (103-105) °C and weighed to a constant weight. 100 ml water sample was filtered through 0.45 µm pore size filter paper into a weighed beaker and heated and evaporated at the temperature of 105°C to dryness. The beaker and its contents were cooled in a desiccators and heated again at 105°C to a constant weight. The difference in weight between the empty container and the beaker with its content Total dissolved solid (mg/L) is computed asgivesthe total dissolved .solids.

$$\text{TDS mg/L} = \frac{\text{weight of dry residue mg} \times 1000}{\text{Volume sample ml}}$$

3.7.1.5 Alkalinity

A volume 50 ml of water sample was pipetted into an erlenmeyer flask and 2 drops of methyl orange was added to it. The resulting solution was titrated with 0.01 M HCl standard solution to a pale pink end point. Total alkalinity of the water sample in mg/$CaCO_3$ was computed as below;

$$\text{Alkanity mg/CaCO}_3 = \frac{A\times M\times 50\times 100}{\text{Volume sample ml}},$$

where A = titre value

M = molarity of HCl used

50 = equivalent of $CaCO_3$

3.7.1.6 Sodium and Potassium

Instrument Calibration

A volume of 5 ml of distilled water was measured into a test-tube and 2 ml of cesium chloride solution (100 mg/L) added. The sodium was then shaken well to mix. It was then aspirated into the flame photometer and the zero knob pressed. Aspiration was continued till the instrument registered zero on the read out.

Sample Analysis

A volume of 5 ml of filtered sample was measured into a previously washed test-tube and 2 ml cesium solution (100 mg/L) added and shaken to mix well. The cesium chloride solution acts as an ionization suppressant. The solution was then aspirated into a Sheerwood model 420 flame photometer and the aspiration continued till the final reading was displayed on the instrument's read out. The readings were given in concentration.

Standard Calibration:

A volume 5 ml of combined standard Na^+/K^+ (100mg/L) was measured and 2 ml cesium chloride solution (100 mg/L) added and mixed well. The solution was then aspirated after pressing the CAL knob. Aspiration was continued till the instrument registered 100mg/L for both Na^+ (on channel 1) and 100 mg/L for K^+ (on channel 2). Total volume of aspirated solution should not be less than 5 ml.

3.7.1.7 Chloride

The chloride was determined using the Mohr Argentometric titration method. A volume of 25 ml of water sample was measured into a conical flask to which 1 ml of H_2O_2 was added and stirred for 1 minute to prevent sulphide and thio- sulphate from interfering.

A few drops of 0.1M NaOH were added to move the pH to the range of 7 – 10. A volume of 1 ml of 5% $K_2Cr_2O_4$ indicator solution was added. The sample was later titrated with standard

0.01M $AgNO_3$ to a pinkish yellow end point. Distilled water was used as the blank and the chloride content of sample in mg/L was computed as

$$\text{Chloride mg/L} = \frac{(A - B) \times M \times 35.45 \times 1000}{\text{Volume sample (ml)}},$$

where A = Volume of silver nitrate consumed by the sample

B = Volume of silver nitrate consumed by the blank

M = molarity of $AgNO_3$ (aq)

35.45 = Atomic weight of chlorine

3.7.1.8 Fluoride

Fluoride content was determined using DR/890 colorimeter by HACTH. Standard solution of concentration 100 mg/L was prepared by dissolving 0.022 g of anhydrous sodium fluoride (NaF) in distilled water and diluted to 100 ml. A SPANDS reagent was also prepared by dissolving 0.958 g of 4,5-dihydroxy-3- (parasulfophenylazo) - 2,7- naphthalenedisulfonic acid trisodium salt, in distilled water and diluted to 500 ml. The blank and the standard were placed in the cell and the readout knob was pressed to read the values. To 10 ml of the filtered sample, 2 ml of the combined reagent were added and mixed well. The combined reagent was a mixture of zirconyl-acid and SPANDS and was allowed to stand for one minute. The sample cells were placed in the samples holder and the readout knob was pressed to record the fluoride concentrations in mg/L.

$$\text{mgF}^- / \text{L} = \frac{A_0 - A_x}{A_0 - A_1},$$

where A_o= Absorbance of the prepared 0 mg F^-/L

A_1 = Absorbance of the prepared 1.0 mg F^-/L

A_X = Absorbance of the prepared sample

3.7.1.9 Total Hardness

Using EDTA Titrimetric method, 25 ml of water sample were pipetted into a 250 ml conical flask and 2 ml of NH_4Cl- NH_4OH buffer solution were added to maintain the pH around 10.0. Two drops of Eriochrome Black T indicator were added to form a wine- red solution which was later titrated against a 0.01M standard EDTA titrant with continuous swirling till the colour changed through purple to pure blue at the end point. Titration reaction equation:

$M^{2+}_{(aq)} + 2[H_3C\text{-}(CH_2)_{10}\text{-}COO^-]_{(aq)} \rightarrow [H_3C\text{-}(CH_2)_{10}\text{-}COO^-]_2\, M^{+2} + 2H^+$

Calculation

$$\text{Hardness EDTA as mg CaCO}_3\,/\,\text{L} = \frac{A \times B \times 100}{\text{ml of sample}},$$

where A = ml titration for sample

B = mg $CaCO_3$ equivalent to 1.00 ml EDTA titrant

3.7.1.10 Calcium

A volume of 2 ml of 1 M NaOH solution wereadded to 25 ml of water sample which were pipetted into a 250 ml conical flask. 0.2 g of murexide indicator was added to give a pink colour. The EDTA titrant was gently added alongside continuous swirling till a purple colour showed at the end point.

Calculation

$$\text{mg Ca}\,/\,\text{L} = \frac{A \times B \times 400.8}{\text{ml of sample}},$$

where A = ml titrant for sample

B = mg $CaCO_3$, equivalent to 1.00ml EDTA at the calcium indicator end point.

3.7.1.11 Magnesium Hardness

The numerical difference between Total Hardness and the calcium hardness represents Magnesium Hardness

3.7.1.12 Nitrate

For nitrate determination, a stock solution (100 mg/L NO_3-N) was prepared by dissolving 0.7218 g KNO_3 into 1000ml distilled water preserved with 2 ml $CHCl_3$. An intermediate nitrate solution was prepared by diluting 5 ml of the stock nitrate solution to 500 ml in a volumetric flask (10 mg/L). A series of NO_3 –N calibration standards in the range 0.20 – 1.0 mg/L were prepared from the intermediate nitrate solution and made up to 10 ml each. A volume of 5 ml of filtered sample was measured into test tube and 1 ml of 30 % (W/W) NaCl added. 5 ml of 6.5M H_2SO_4 was then added with swirling after which a 0.25 ml brucine reagent was added. The solution was then heated in a water bath for 25 minutes at 95 °C. The same was done for the blanks and standards except brucine which was not added to the blank since it gives a yellow colour as indication of nitrate in the sample. The heated solution was allowed to cool to room temperature and absorbance read on a uv-spectrophotometer at 410 nm wavelength. The standards were treated just like the sample. A calibration curve of absorbance against concentration was plotted. Concentration of the sample was then read from the curve

Calculation

$$\text{mg NO}_3^- / \text{L} = \frac{\text{Absorbance of sample taken} \times \text{Conc of Std} \times 1000}{\text{Absorbance of Std} - \text{Sample taken}}$$

3.7.1.13 Sulphate

For sulphate, 10 ml of the filtered sample was fetched in a test tube and 1 ml of an acid salt (60 g of NaCl dissolved in 250 ml of water plus 20 ml of conc HCl) was added followed by the addition of 0.5 ml of glycerol and 0.5 g barium chloride. The resulting solution was shaken for 1 minute. The mixture was allowed to stand for 10 minutes. From the stock solution of 100 mg/L (sodium sulphate), five standards with concentration in the range 15-35 mg/L were prepared. The standards and the blank were treated just as the sample. Concentrations of the samples were calculated from the calibration curve.

Calculation

$$\left[\mathrm{SO_4}^{2-}\right]\mathrm{mg/L} = \frac{\left[\mathrm{SO_4}^{2-}\right]\times 1000}{\text{ml of sample}}$$

3.7.1.14 Phosphate

For phosphate, 1.875 g of ammonium molybdate and 0.0225 g of potassium- antimonyl Tatrate were taken and transferred to a 250 ml volumetric flask and 22.0 ml of concentrated H_2SO_4 added and made up with distilled water to the mark. A concentration of 0.1M ascorbic acid was prepared by dissolving 1.76 g of the salt in 100 ml distilled water. The molybdate-antimony reagent and the ascorbic acid were added in the ratio of 1:4 and this is referred to as the combined reagent. To 10 ml of the filtered sample, 2 ml of the combined reagent were added and mixed well and allowed to stand for 10 minutes. Absorbance of each sample and the blank (reference) were measured on UV spectrophotometer at 880 nm. The same was done for the standard of 50 mg/L prepared from anhydrous KH_2PO_4 in the range of 0.2-10 mg/L. Concentration of the samples were calculated from the calibration curve.

3.8 Sediment Preparation

The sediment samples were air dried for 21 days. The dried samples were milled using an agate mortar and pestle and sieved to produce a gritty powder using a laboratory sieve of mesh of 120 µm pore size and a 125 µm diameter

3.8.1 Mercury and Selenium determination

Concentrations of total mercury and selenium of unfiltered water were determined using AAS equipped with a cold vapour facility and a hydride generator. The reducing agent used was sodiumborohydride ($NaBH_4$).A volume of 5 ml of a mixture of 0.3 % $NaBH_4$ and 0.5 % NaOH, 5 ml of 5 M HCl and 5 ml of the sample were aspirated into the vapour generation accessory for which the reaction takes place in the reductant cell. The resultant is then separated into the gaseous and liquid phase by the liquid/ gas separator. The gas then enters the AAS through a fluorinated tube. Selenium and mercury were determined at the wavelengths of 253.7 nm and lamp current of 10 mA, with a slit width of 0.1 nm and acetylene gas as the fuel gas and argon as support gas were used The same procedure applies to the blank and the standards which ranged from 0.02 - 0.10 mg/L. In the case of selenium determination, the same condition applied except the concentrations of the reagents were changed to a mixture of 0.6 % $NaBH_4$ and 0.5 % NaOH and 6 M HCl. with standards ranging from 0.02-0.10 mg/L.

3.9 Preparation of Fish Samples

The fish samples were sorted and transported to the Oceanography Department for identification and later sent to Ghana Atomic Energy Commission laboratory and kept in the refrigerator at the temperature of -2 °C. The various samples were washed with distilled water and dried in a clean tissue paper free from heavy metal contamination. The weights and lengths of the various samples were recorded after defrosting. The tissue of each sample was removed, homogenized and stored in a properly washed glass vial and kept in a refrigerator for analysis. The Digestion Protocol for fresh fish samples using Milestone Acid Digestion Microwave Ethos 900 was used. Samples were freeze dried for two days using CHRIST BETA 1- 16 freeze drying machine. The samples were then milled into powder.

3.10 Digestion procedures

3.10.1 Digestion of fish

For digestion of fish, 0.5 g of the sample was weighed into a previously acid washed labeled 100ml polytetraflouroethylene (PTFE) Teflon bombs.

A volume of 6 ml of concentrated nitric acid (HNO_3, 65 %) and 1.0 ml of hydrogen peroxide (H_2O_2, 30 %) were added to each sample in a fume chamber using a wrench. The complete assembly was microwave irradiated for 22 minutes using a milestone microwave labstation ETHOS 900, INSTR: MLS-1200 MEGA microwave programme as shown (Appendix D)

3.10.2 Digestion of sediment

Digestion Protocol for sediment Sample Using Milestone Acid Digestion Microwave Ethos 900 were followed.

For digestion of sediment, 1.5 g of the sample was weighed into a previously acid washed labeled 100 ml polytetrafluoroethylene (PTFE) Teflon bomb.

A volume of 6 ml of concentrated nitric acid (HNO_3, 65 %), 3 ml of concentrated hydrochloric acid (HCl, 35 %) and 0.25 ml of hydrogen peroxide (H_2O_2,30 %) were added to each sample in a fume chamber. The samples were then loaded on the microwave carousel. The vessel caps were secured tightly using a wrench. The complete assembly was microwave irradiated for 26 minutes using the milestone microwave labstation ETHOS 900, INSTR: MLS-1200 MEGA using the microwaveprogramme as outlined in at Appendix D

3.10.3 Digestion of water

Digestion Protocol For water Sample Using Milestone Acid Digestion Microwave ETHBOS 900 was followed. A weight of 5.0 g of water sample was weighed into a previously acid washed labeled 100 ml polytetraflouroethylene (PTFE) Teflon bombs. A volume of 6ml of concentrated nitric acid (HNO_3, 65 %), 3ml of concentrated hydrochloric acid (HCl, 35 %) and 0.25 ml of hydrogen peroxide (H_2O_2, 30 %) was added to each sample in a fume chamber.

The samples were then loaded on the microwave carousel. The vessel caps were secured tightly using a wrench. The complete assembly was microwave irradiated for 26 minutes using milestone microwave labstation ETHOS 900, INSTR: MLS-1200 MEGA using the microwave programme as outlined in Appendix D.

After digestion, the Teflon bombs mounted on the microwave carousel were cooled in a water bath to reduce internal pressure and allow volatilized material to re- stabilize. This procedure applied to water, sediment and fish samples.

The digestate was made up to 20 ml with distilled water and assayed for the presence of Mercury (Hg), Selenium (Se), Lead (Pb), Iron (Fe) and Manganese (Mn) using VARIAN AAS 240FS- Atomic Absorption Spectrometer in an acetylene- air flame equipped with a Hydride Generator .

Standard Reference Material used for the elements of interest, blanks and duplicates of samples were digested using the same conditions as the samples. These served as internal positive controls.

3.10.4 Quality Control and Quality Assurance

Quality control and quality assurance techniques were used during the analysis. For reagent blanks, equal volumes of the reagents added to the sample for digestion were taken and digested under the same condition as the sample were done (were prepared) to account for interferences by the traces of analyte found in the reagents used for sample preparation and analysis. They were also analyzed the same way the samples were done. They were used to correct the absorbance by reagents and impurities. To ensure reproducibility of results, duplicates of each sample was prepared. Standard reference materials were also used to check the efficiency of the equipment used. For further validation of the procedure, Standard Reference Materials (SRM) used were treated as the samples for analysis. The SRM used are 1643e Trace Elements in water by National Institute of Standard Technology (NIST), IAEA –SRM 1646a (Estuarine sediment) and IAEA-350 for fish sample.

3.10.5 Atomic Absorption Spectrometry Method for Metals

Mercury was determined using the cold vapour technique with the AAS equipped with a hydride generator. Selenium was also determined by hydride generation. Fe, Mn and Pb were determined at wavelengths of 248.3, 279.5 and 217.0 nm respectively, lamp current of 5 mA, slit width of 0.2for Fe and Mn and 0.1 for Pb, the fuel gas was Acetylene and air as the support gas. The digested samples were aspirated into the spectrometer (Varian AA240 Fast Sequential Atomic Absorption Spectrometer) based on the manufacturer's guideline for each element in the cook book of AAS.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

This chapter gives the interpretation of results of both field and laboratory analyses in both tables and figures. The parameters discussed were considered whether they are below or above pollution level using different criteria most importantly the WHO guideline limits for the assessment. The results and discussions were categorized into two seasons which covers the wet and dry seasons. Generally, seasonal variation was observed in the concentration of physico-chemical parameters. The dry season recorded higher levels of most physico-chemical parameters .compared to that of the wet season. This general trend could be attributed to runoffs, discharge of waste chemicals into the river, dissolved minerals and excessive evaporation of water from the surface which resulted in an increase in concentration of ions. Based on the objectives of the study, the results are discussed under their respective headings. Correlation studies and coefficient of variation were used. The results of this study is also compared with other studies carried out elsewhere on water, sediments and fish samples.

4.1 Coefficient of variation

Coefficient of variation is a statistical tool used for the measure of dispersion of a probability or frequency distribution. It is mathematically stated as the ratio of standard deviation to the mean. When then the coefficient of variation is less than 50%, the sample is said to be uniformly, closely or narrowly distributed. However when the coefficient of variation is 50% and above, then sample is considered to be scattered, widely distributed or highly dispersed (Affum, et al., 2008)

$$\text{Coefficient of variation} \quad \text{CoV } \% = \frac{\text{Standard Deviation } \times 100\%}{\text{Mean}}$$

Table 4.1a: Mean, standard deviation and coefficient of variation of Physico chemical parameters of water samples between (May - July) wet season 2012 from Kpong reservoir on the Lower Volta River.

Parameters	**Mean**	**St. D**	**Co. V/%**
Temp ^{o}C	25.98	0.51	1.96
pH	7.12	0.24	3.41
Cond (µs/cm)	61.78	14.29	23.13
TDS (mg/L)	31.33	7.26	23.16
Alkalinty (mg/L)	34.10	4.74	13.91
T.Hardness (mg/L)	27.81	4.95	17.81
Sodium (mg/L)	8.98	1.82	20.25
Potassium (mg/L)	4.77	0.33	6.82
Chloride (mg/L)	5.66	1.49	26.22
Fluoride (mg/L)	0.05	0.01	27.97
Calcium (mg/L)	16.04	1.84	11.48
Magnesium (mg/L)	10.09	3.24	32.10
Nitrate (mg/L)	0.42	0.05	12.16
Phosphate (mg/L)	0.13	0.14	108.07
Sulphate (mg/L)	4.12	2.43	59.14
Mercury (mg/L)	0.00	0.00	15.75
Selenium (mg/L)	0.00	0.00	41.47
Iron (mg/L)	0.47	0.34	72.83
Lead (mg/L)	0.18	0.10	57.00
Manganese (mg/L)	0.46	0.14	30.93

BDL =Below Detection Limit, Total Dissolved Solids = TDS

Table 4.1b: Mean, standard deviation and coefficient of variation of Physico- chemical parameters of water samples between (Nov-Feb) dry season 2011- 2012 from Kpong reservoir on the Lower Volta River.

Parameter	mean	std	CoV%
Temp ^{o}C	26.78	0.85	3.19
pH	6.88	0.14	2.01
Cond (µs/cm)	68.23	6.75	9.89
TDS (mg/L)	71.00	29.58	41.66
Alkalinty (mg/L)	39.40	2.20	5.58
T.Hardness (mg/L)	43.46	5.86	13.49
Sodium (mg/L)	8.462	0.41	4.92
Potassium (mg/L)	4.851	0.93	19.30
Chloride (mg/L)	6.718	1.64	24.54
Fluoride (mg/L)	0.091	0.02	27.14
Calcium (mg/L)	17.604	2.58	14.68
Magnesium (mg/L)	26.226	8.61	32.84
Nitrate (mg/L)	0.302	0.12	40.27
Phosphate (mg/L)	0.329	0.058	17.92
Sulphate (mg/L)	3.557	1.86	52.42
Mercury (mg/L)	0.002	0.0015	76.37
Selenium (mg/L)	0.005	0.0006	13.33
Iron (mg/L)	0.062	0.03	55.65
Lead (mg/L)	0.089	0.04	49.24
Manganese (mg/L)	0.691	0.39	50.41

T. Hardness = Total Hardness.

Table 4.2: Mean values of physico-chemical parameters of water between May-Jul (wet) season 2012 from Kpong reservoir on the Lower Volta River.

Parameter	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
Temp°C	26.57	26.05	25.28	25.07	26.23	25.6	26.15	26.4	26.47	25.93
pH	7.13	6.88	7.78	7.1	7.06	7.08	7.08	6.96	7.09	7.06
Cond (µs/cm)	94.02	53.98	46.48	50.78	46.85	57.43	62.73	69.12	67.03	69.35
TDS (mg/L)	46.95	27.02	23.15	26.07	23.5	28.75	32.96	34.41	33.52	36.99
Alkalinty(mg/L)	37.08	36.08	32.17	38	43.17	31.65	29.35	33.33	26.4	33.73
T.Hardness(mgL/)	35.75	37.22	26.91	28.15	26.17	23.21	23.77	23.92	28.66	24.31

Sampling sites: Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU)

Table4.3: Mean values of physico-chemical parameters of water between Nov-Feb (dry) season 2011- 2012 from Kpong reservoir on the Lower Volta River

Parameter	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
Temp °C	26.88	27	27.05	27.35	27.13	27.12	26.52	26.28	26.13	26.33
pH	6.66	6.85	6.96	6.98	6.97	7.02	6.69	6.73	6.88	7.02
Cond (µs/cm)	81.52	64.52	62.38	68.62	60.72	73.4	76.42	64.92	63.97	65.78
TDS (mg/L)	33.37	20.07	66.53	85.4	73.42	81.67	81.62	70.82	72.02	80.05
Alkalinty (mg/L)	35.67	41	38.83	37.83	37.5	38	41.67	41.83	39.5	42.17
T.Hardness (mg/L)	48.67	48	48.67	43.3	53.33	40	38	39.33	35.33	40

Sampling sites:Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU)

Table4.4: Anions, trace metals and nutrient concentrations from Kpong reservoir on the Lower Volta River between May-July (Wet season) (mg/L) 2012.

Parameter	**TM**	**FU**	**GC**	**GS**	**FN**	**KP**	**VK**	**LN**	**AS**	**AU**
Sodium	7.98	9.08	7.13	13.68	9.7	9.14	8.6	7.85	8.78	7.87
Potassium	4.68	5.22	4.6	5.27	4.85	4.83	4.43	4.2	4.87	4.73
Chloride	4.17	7.7	4.04	4.4	4.7	7.83	6.07	4.57	6.04	7.12
Fluoride	0.04	0.05	0.04	0.07	0.03	0.06	0.04	0.05	0.07	0.04
Calcium	14.4	15.05	13.24	14.98	18.55	15.64	17.29	16.04	16.03	19.18
Magnesium	13.85	17.32	10.85	8.96	8.6	8.88	7.93	9.73	8.61	6.16
Nitrate	0.41	0.48	0.4	0.37	0.42	0.49	0.48	0.39	0.36	0.36
Phosphate	0.02	0.15	0.23	0.08	0.47	0.22	0.03	0.04	0.03	0.05
Sulphate	0.99	4.44	7.87	5.36	7.02	1.61	2.3	6.16	1.8	3.61
Mercury	BDL	0.0015	BDL	BDL	BDL	BDL	BDL	0.002	BDL	0.002
Selenium	0.003	BDL	0.001	0.003	0.002	0.001	0.003	0.002	0.003	0.004
Iron	0.77	0.41	0.83	0.84	0.24	0.13	0.94	0.33	0.04	0.16
Lead	0.18	0.1	0.25	0.21	0.07	0.06	0.09	0.17	0.36	0.3
Manganese	0.42	0.62	0.55	0.34	0.57	0.43	0.51	0.51	0.13	0.55

Sampling sites: Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU)

Table 4.5: Anions, trace metals and nutrient concentrations from Kpong reservoir of the River Volta Basin between Nov-Feb (Dry) season (mg/L) 2011- 2012

Parameter	**TM**	**FU**	**GC**	**GS**	**FN**	**KP**	**VK**	**LN**	**AS**	**AU**
Sodium	8.5	8.85	9	8.65	8.38	8.08	8.67	8.38	8.58	7.53
Potassium	5.18	5.37	5.12	4.87	5	4.92	2.25	5.45	5.38	4.97
Chloride	7.09	3.83	6.64	7.04	6.05	9.55	7.04	4.73	6.66	8.55
Fluoride	0.05	0.09	0.11	0.11	0.07	0.06	0.08	0.12	0.11	0.11
Calcium	21.89	19.9	15.39	19.19	17.58	14.33	15.85	14.24	19.52	18.15
Magnesium	34.67	32.95	35.27	28.35	34.78	24.36	20.71	22.93	19.31	8.93
Nitrate	0.49	0.41	0.45	0.27	0.37	0.19	0.2	0.19	0.3	0.15
Phosphate	0.33	0.38	0.39	0.23	0.34	0.42	0.28	0.35	0.28	0.29
Sulphate	1.65	4.32	3.76	4.82	6.29	0.75	3.29	5.68	1.22	3.79
Mercury	0.001	0.001	BDL	0.003	0.002	BDL	0.001	BDL	0.001	0.005
Selenium	0.005	0.005	0.004	0.006	0.006	0.005	0.005	0.005	0.004	0.005
Iron	BDL	0.05	0.01	0.08	BDL	0.06	0.04	0.12	0.08	BDL
Lead	0.14	0.14	0.14	0.09	0.11	0.05	0.1	0.03	0.05	0.04
Manganese	0.35	0.72	0.83	0.52	0.95	0.91	1.31	0.53	0.27	0.32

Sampling sites: Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU)

BDL = Below Detection Limit

Table 4.6: Mean values of parameters of water for both wet and dry seasons over the entire sampling period compared with WHO guidelines.

Parameter	Wet season	Dry season	Mean	WHO
Temp °C	25.98	26.78	26.38	25
pH	7.12	6.88	7	6.5-8.5
Cond (µs/cm)	61.78	68.23	65	1000
TDS (mg/L)	31.33	70.99	51.16	1000
Alkalinty (mg/L)	34.1	39.4	36.75	400
T. Hardness (mg/L)	27.81	43.46	35.64	500
Sodium (mg/L)	8.98	8.46	8.72	200
Potassium (mg/L)	4.77	4.85	4.81	30
Chloride (mg/L)	5.66	6.72	6.19	250
Fluoride (mg/L)	0.049	0.09	0.07	1.5
Nitrate (mg/L)	0.416	0.3	0.36	10
Phosphate (mg/L)	0.132	0.33	0.23	0.3
Sulphate (mg/L)	4.12	3.56	3.84	250
Calcium (mg/L)	16.04	17.6	16.82	200
Magnesium (mg/L)	10.09	26.23	18.16	150
Mercury (mg/L)	0.0006	0.001	0.0008	0.001
Selenium (mg/L)	0.002	0.005	0.0035	
Iron (mg/L)	0.47	0.04	0.255	0.3
Lead (mg/L) (mg/L)	0.179	0.089	0.135	0.05
Manganese (mg/L)	0.463	0.71	0.087	0.5

T. Hardness = Total Hardness, Total Dissolved Solids = TDS

Table 4.7a: Mean, standard deviation and coefficient of variation of Trace metals in sediment samples from various sampling points between May -July (wet)season(mg/kg)2011- 2012

Parameter	Mean	Std	CoV%
Mercury	0.02	0.008	37.12
Selenium	0.12	0.02	21.88
Iron	185.12	17.49	09.45
Manganese	0.46	0.14	30.93
Lead	BDL	BDL	BDL

Table 4.7b: Mean ,standard deviation and coefficient of variation of Trace metals in sediment samples from various sampling points between Nov -Feb (dry)season(mg/kg) 2011- 2012

Parameter	Mean	Std	CoV%
Mercury	0.10	0.12	119.08
Selenium	0.41	0.05	11.24
Iron	152.00	1.48	0.97
Manganese	0.69	0.33	50.13
Lead	BDL	BDL	BDL

Table4.8: Mean values of Trace metal concentrations in sediments between May-July(wet) season (mg/kg) 2011- 2012

Parameter	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
Mercury	0.02	0.03	0.03	0.01	0.03	0.03	0.02	0.01	BDL	0.03
Selenium	0.16	0.15	0.14	0.09	0.1	0.1	0.12	0.17	0.12	0.11
Iron	198.35	198.41	190.64	197.38	191.95	184.65	177.6	188.36	139.21	184.66
Manganese	0.42	0.62	0.55	0.34	0.57	0.43	0.51	0.51	0.13	0.55
Lead	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Sampling sites: Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU)

Table4.9: Mean values of Trace metal concentrations in sediments between Nov-Feb (Dry season (mg/kg) 2011- 2012

Parameter	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
Mercury	0.04	0.15	0.38	0.08	0.26	0.04	0.02	0.02	0.02	0.03
Selenium	0.35	0.4	0.34	0.41	0.49	0.44	0.45	0.38	0.39	0.4
Iron	151.81	153.53	154.9	151.6	152.64	152.8	151.19	150.1	150.79	150.6
Manganese	0.35	0.72	0.83	0.52	0.95	0.91	1.31	0.53	0.27	0.32
Lead	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Table 4.10: Mean values of sediments for both wet and dry seasons over the entire period compared with WHO threshold.

Parameter	Wet season	dry season	Mean
Mercury	0.021	0.1	0.061
Selenium	0.126	0.4	0.263
Iron	185.12	151.99	168.55
Manganese	0.46	0.67	0.568
Lead	BDL	BDL	BDL

4.2 Temperature

Tables 4.1a and 4.1b show the mean, standard deviation and coefficient of variation values of temperature during the wet and dry seasons. The coefficient of variation are 1.96 % and 3.19% in both wet and dry seasons indicating uniform and very close temperature distribution at each sampling point within the study area.. Tables 4.2, 4.3 and Figure 4.1 compare the mean values of the wet and dry seasons. The mean temperature ranged from

25.07 °C at Gasikakofe(GS) in the wet season to 26.57 °C and ranged from 26.13 °C at Agric research station to 27.35 °C at Gacrom in the dry season with their respective means of 25.98 °C and 26.78 °C. The dry season temperature values were a little higher than that of the wet season. This variation might be as a result of the hot weather that existed in the dry season of the year even though there were canopies of trees on some parts of the reservoir. The low temperature values in the wet season could also be attributed to the cold weather of the wet season. The temperature ranges during the entire sampling period were not a threat to human and aquatic life, since it favourably compared with that (27-30) °C of Amoah and Koranteng (2006) and also that(26.1-29.1) of Antwi (1990) for surface water of the Lower Volta Basin from Akuse through Sogakofe to Ada.

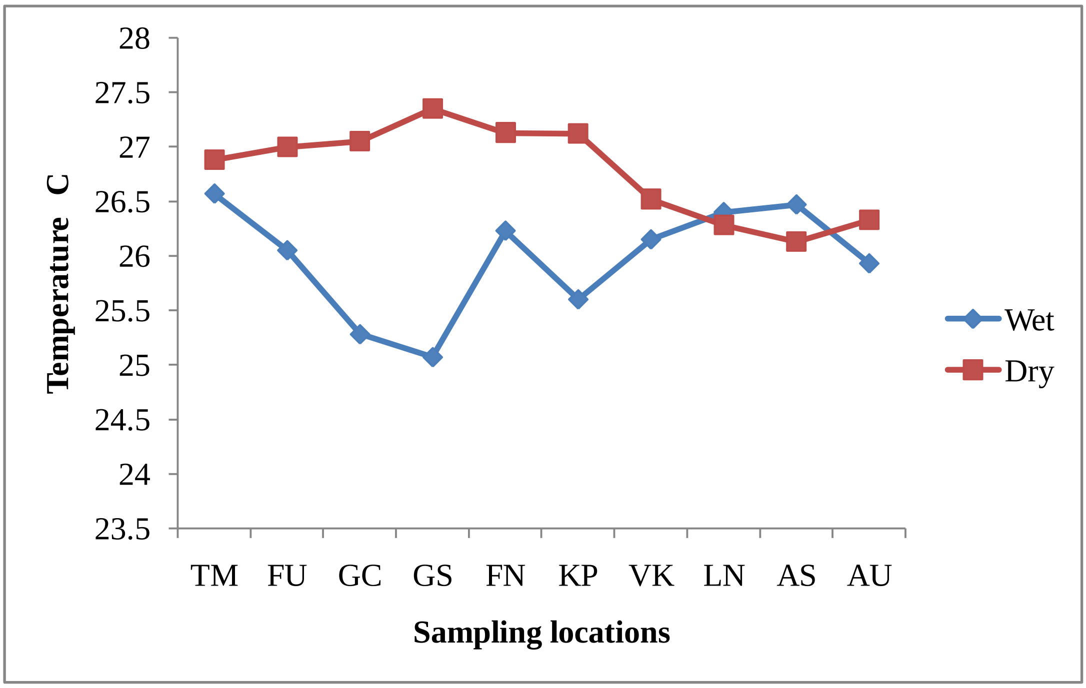


Figure 4.1: Mean Temperature distribution of water in both November-February (dry) 1and May-July (wet) season for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.3 pH

The pH measures the negative logarithm to base 10 ($\log_{10}$) of hydrogen ion concentration of water. This indicates the relative acidic or basic nature of the water. The pH of the water provides information about solubility and biological availability and chemical processes within water bodies (Chapman, 1992). Tables 4.1a and 4.1b describe the mean and coefficient of variation of both wet and dry season pH. The coefficient of variation values were 3.41 % for the wet season while 2.01 % was recorded in the dry season from the Kpong Reservoir at the various sampling sites for the whole sampling periods. The coefficient of variation values were far less than 50 %indicating closeness and uniformity distribution of pH values within the sampling sites. Tables 4.2, 4.3 and figure 4.2 also compare well with the mean pH values of wet season to the mean pH values of the dry season. The pH values ranged from 6.66at Torgorme (TM) in the dry season to 7.02 and ranged from 6.88 to 7.78 at Gacrom (GC) in the wet season with their seasonal means values of 6.88 and 7.12 as shown in (Table 4.6).

The mean pH value of 7.12 in the wet season was higher than that of the dry season of 6.88. The high mean pH value recorded during the wet season is as a result of the presence of $CaCO_3$which releases OH^- in a two-step equation as shown below:

$CO_3^{2-} + H_2O \rightarrow HCO_3^- + OH^-$ ①

$HCO_3^- + H_2O \rightarrow H_2CO_3 + OH$ ②

All the pH values were within the WHO (2006) guideline range of 6.5-8.5, hence the results were considered good enough to support aquatic life ,

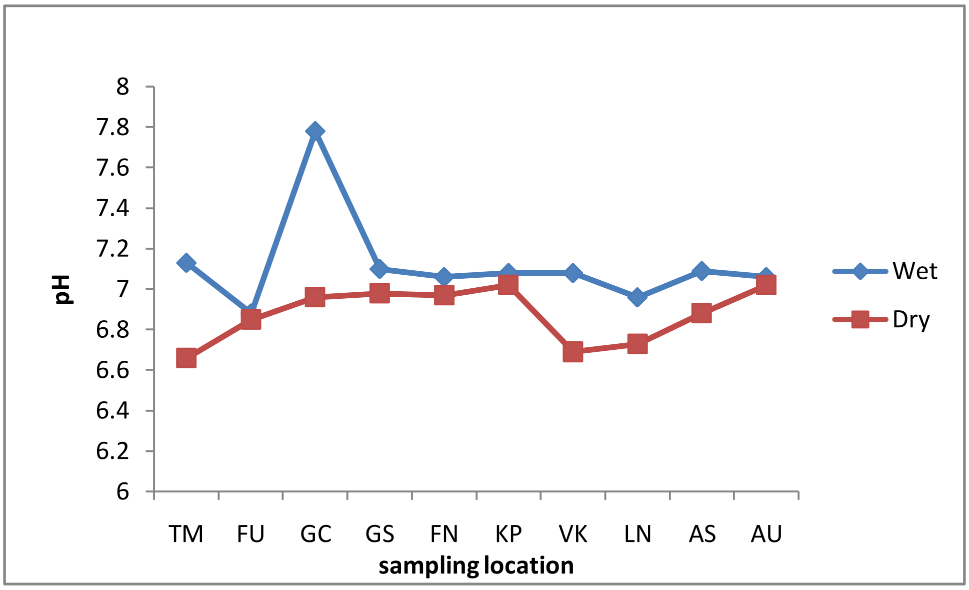


Figure 4.2: Mean pH distribution of water in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.4 Electrical conductivity

Electrical conductivity gives information about the level of mineralization of the water under study. It also shows the ability of dissolved substances to conduct an electric current which mostly depends on the ionic strength of the water sample (APHA, 1995). Chapman (1992) reported that conductivity is related to the concentration of total dissolved solids and major ions.

Table 4.1a and 4.1b show the coefficient of variation of both wet and dry seasons of electrical conductivity values of water samples from the Kpong Reservoir. The coefficients of variation values were relatively low in the two seasons. The wet season recorded 23.1 % while the dry season recorded 9.89 %. These low values show that the mean conductivity values are relatively narrowly distributed. Tables 4.2, 4.3 and Figure 4.3 compare the mean electrical conductivities of both wet and dry seasons. There were seasonal variations in electrical conductivity (EC) with the highest mean electrical conductivity(EC) values of 94.02 µs/cm recorded at Torgorme (TM) in the wet season while the lowest electrical conductivity (EC) value of 46.48 µs/cm was recorded at Gacrom (GC) in the same season and ranged from 60.72 µs/cm at Fremankofe (FN) in the dry season to 81.52 µs/cm at Torgorme (TM) and again ranged from 46.48 µs/cm to 94.02 µs/cm at Torgorme in the wet season. The respective means for wet and dry seasons were 61.78 µs/cm and 68.23 µs/cm (Table 4.6). With reference to the WHO threshold value of 1500 µs/cm, all the electrical conductivity(EC) values in both seasons in this research were far below the threshold value.

The high mean values of EC in the dry season could be attributed to dissolved organic matter (Coke, 2001) which was washed into the reservoir by the rainfall, and also a decrease in the river volume as a result of evaporation at the water surface leading to the concentration of ions. The geology of the area could also contribute to the high mean Electrical conductivity

(EC) values. It could also be ascribed to farming activities along the river bank which involves application of inorganic materials as well as agrochemicals (like fertilizers) on crops. On the other hand, the low Electrical conductivity (EC) in the wet season might be due to high rainfall which lowers the concentration of dissolved solids through dilution of water in the river volume through runoffs and erosions which resulted in the increase in the water volumes (FAO,1993). Conductivity increases downstream and this may be due to the conservation of water in the reservoir as a result of damming. The mean value for this work falls within the guideline limit of Ghana Environmental Protection Agency (GEPA) and WHO (2004) standard of 1000 µs /cm for most fresh water which compares well with other reported values elsewhere. Based on these guidelines, the water could be said to be safe for human consumption.

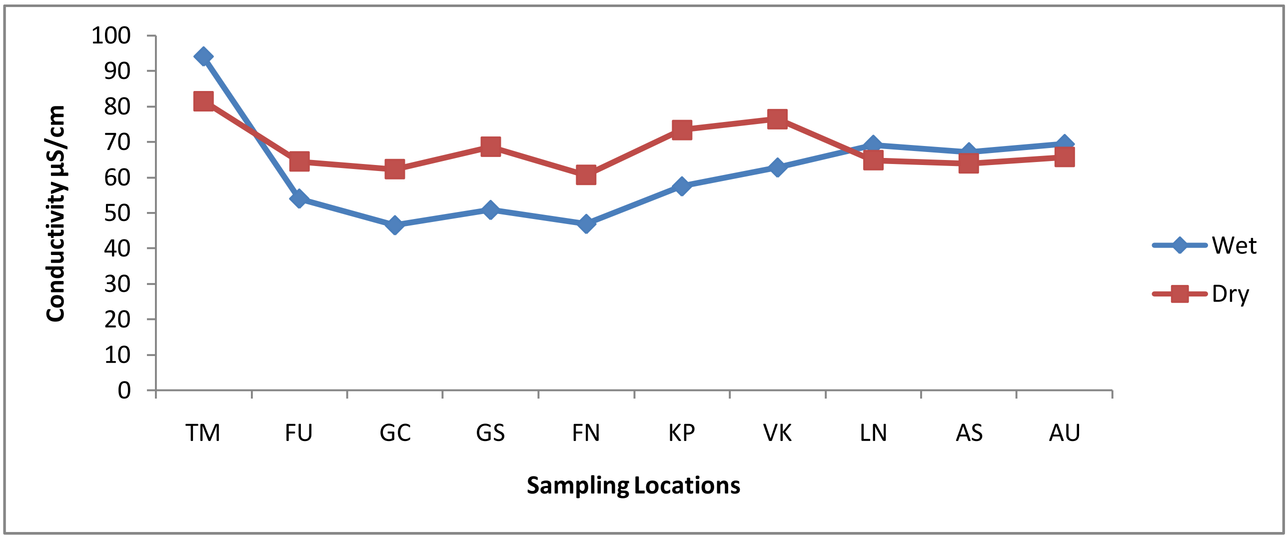


Figure 4.3: Mean Conductivity distribution of water in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.5 Total dissolved solids

Substances that dissolved in water and have the ability to pass through a filter of pore size of 0.45cm is referred to as Total Dissolved Solids (TDS). The TDS in natural waters occur because of weathering and dissolution of minerals got form soils and bed rock including cation and anions necessary for proper aquatic life functioning (Freeze and Cherry, 1979, Athur and Brades, 2007). To be more specific, inorganic salts such as calcium, Sulphate and potassium are the total dissolved substances. The TDS's consist of a very little amount of organic matter.

From tables 4.1a and 4.1b,the coefficients of variation are 23.16 % in the wet season and 41.66 % in the dry season. Though the dry season values are higher than those of the wet season, they were both narrowly distributed.

Tables 4.2, 4.3 and Figure 4.4 show the comparison of the wet season to the dry season. The mean TDS values ranged from 23.15 mg/L at Gacrom (GC) to 46.95 mg/L in the wet season and ranged from 20.07 mg/L to 130.40 mg/L in the dry seasons at Fodzoku (FU) and Gasika kope (GS) respectively. The mean values for dry and wet are 70.99 mg/L and31.33 mg/L respectively. The mean values of the dry season are generally higher than those of the wet season (Table 4.6). The higher TDS values in the dry season might be due to the reduction in the volume of water as a result of evaporation that has occurred at the surface of the water.

Another source of the high level of TDS may be associated with the rocks through which the river flows over the years, this longer contact time with the soils and rocks might have led to the dissolution of substances which finally resulted in the elevated level of the concentration of the dissolved ions. Evaporation from the surface of the water body might also lead to the concentration of the TDS. The observed temperatures were almost always high during the dry season; this was in agreement of observation made by Ayibotele and Nerquaye-Tetteh (1989). In general, the main sources of TDS at the study area could be attributed to

Agricultural runoff and leaching of soil contaminants in the study area. All the values were lower than the WHO threshold value of 1000 mg/L.

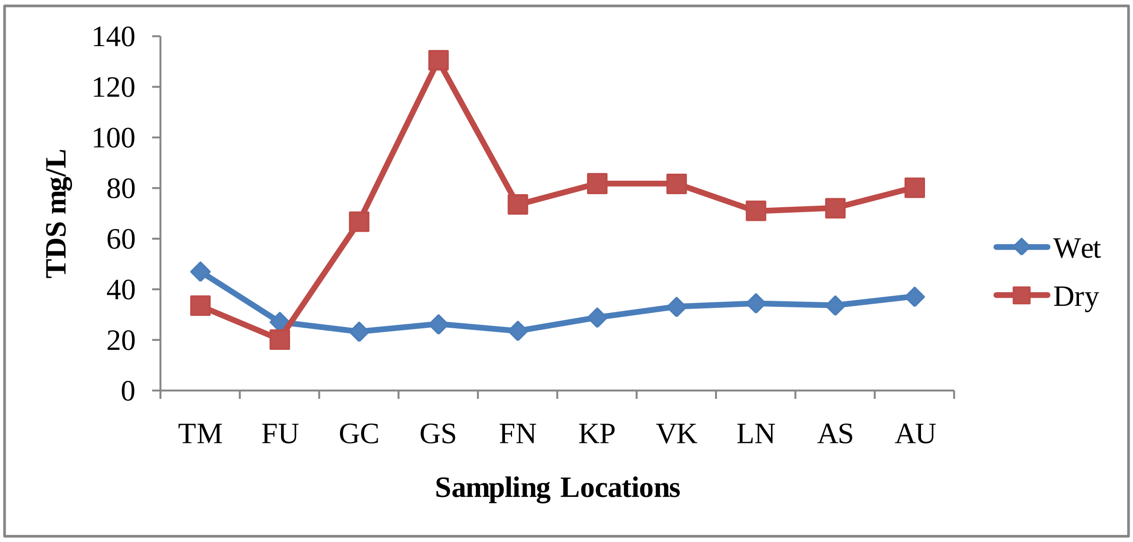


Figure 4.4: Mean TDS distribution of water in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.6 Total alkalinity

Alkalinity of water is the ability of water to neutralize an acid. Carbonates, bicarbonates and hydroxides content constitute the alkalinity (ALPHA1995). Tables 4.1a and 4.1b show the Coefficients of variation of total alkalinity in both the wet and the dry seasons. The wet season and the dry season recorded 13.91 % and 5.58 % indicating a closer dispersion of the total alkalinity values. Tables 4.2, 4.3 and figure 4.5 show the comparison of the wet to the dry seasons. Alkalinity was slightly uniform within the period, since no clear trend of variation was observed. The dry season recorded the highest mean value of 39.4 mg/L and ranged from 35.67 mg/L at Torgorme (TM) to 42.17 mg/L at Akrade (AU) while the wet season recorded the lowest mean value of 34.1 mg/L and ranged from 26.4 mg/L to 43.17

mg/L at the Agric Research Station(AS) and Fremankofe (FN) respectively. The pre-concentration of ion during the dry season due to evaporation led to a decrease in the water volume hence an increase in concentration of the constituents of the alkalinity. The other sources of high alkalinity could be attributed to the activities of cabbage farmers along the bank of the river that drains from Kpong and Akrade into the river. The low levels of buffering indicated by the mean alkalinity value were in agreement with the water quality assessment report (2003). All the values obtained from this work were far below WHO threshold value of 400mg/l.

Based on this (and other water quality parameters), the water is therefore fit for drinking and for any domestic use with respect to Total Alkalinity.

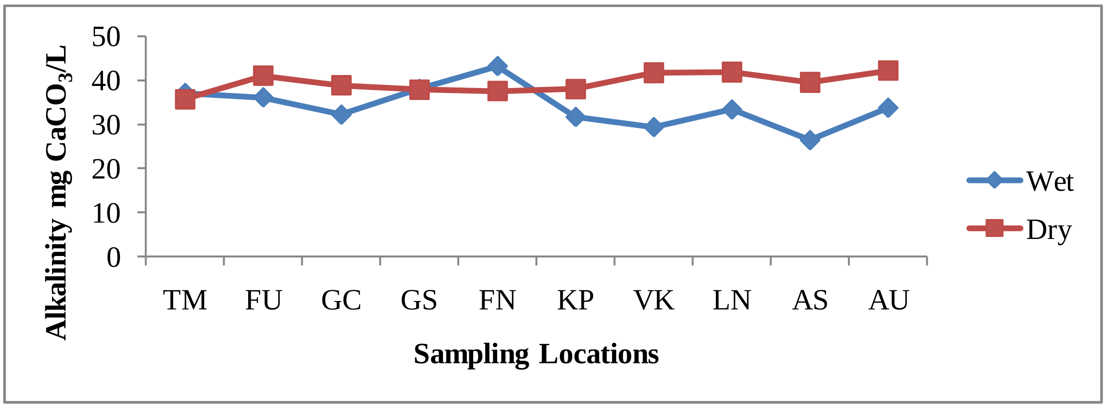


Figure 4.5: Mean Alkalinity distribution of water in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.7 Sodium and Potassium

Sodium usually occurs in low concentrations in water, since rocks that contain it tend to be hard and resistant to weathering. Potassium, on the other hand, is used in industries and in fertilizers for Agricultural land. It is also incorporated into mineral structures and accumulated by aquatic biota as an essential nutritional element.

Tables 4.1a and 4.1a show the coefficients of variation of wet and dry seasons of sodium and potassium. The coefficients of variation of sodium recorded in both the wet and the dry seasons are 25.25 % and 4.92 % while 6.82 % and 19.30 % for potassium in wet and dry seasons. These values are less than 50 %, the distributions were almost uniform. Tables 4.2,4.3 and Figure 4.6 describe the variation and the trend of concentration of sodium and potassium in both wet and dry seasons. The dry season registered the mean value of 8.46 mg/L of sodium and the wet season also registered the mean value of 8.98 mg/L and ranged from 7.13 mg/L to 13.68 mg/L at Gacrom and Gasikakofe respectively in the wet season while the mean for the dry season ranged from 7.53 to 9.0 mg/L at Akrade (AU)and Gacrom (GC) in the wet season. Potassium also recorded means of 4.77 mg/L and 4.85 mg/L for both wet dry seasons and ranged from 4.2 mg/L at Lorlornyo to 5.27 mg/L in the wet season and 2.25 to 5.37 mg/L in the dry season. There was a gradual decrease in sodium concentration in the dry season at Akrade and it suddenly increased through the rest of the sites. This could be attributed to dilution from a larger volume of water from the runoffs into the river bodies in the early part of the dry season. The high sodium value could also be attributed to washing and discharge of soapy solutions into the river due to several settlements at the area. There is the possibility that some sodium may be contained in the runoff as well. The value of potassium decreases gradually from the dry season to the wet season basically due to the dilution as a result of runoff. The mean values of both sodium and potassium were lower than the WHO threshold values of 200 mg/L and 30 mg/L respectively.

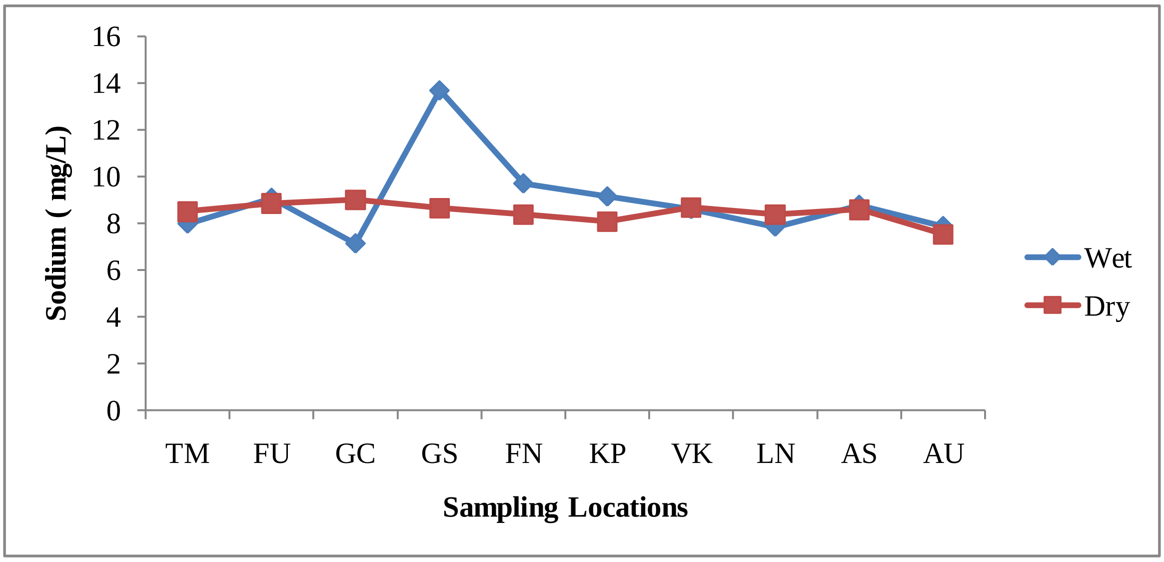


Figure 4.6: Mean sodium distribution of water in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

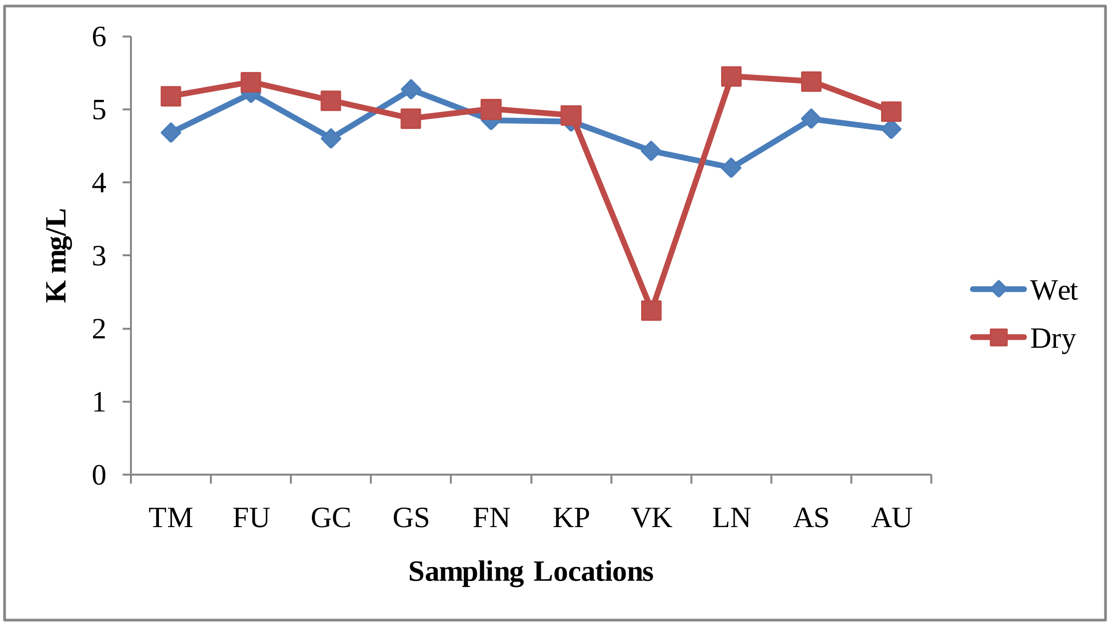


Figure 4.7 Mean potassium distribution of water in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.8 Chloride

Chloride is normally associated with sewage (which) and gives an indication of faecal contamination (chapman, 1992). It can also be derived from brine, rock salts, animal waste or fertilizers. Tables 4.1a and 4.1b give the coefficients of variation of mean chloride concentrations through the whole survey periods. The mean chloride concentration recorded 26.22 % and 24.54 % coefficients of variation respectively, in both the wet and the dry seasons. The recorded values were below 50%,which indicates narrowly dispersed chloride concentration. Tables 4.4 - 4.6 and Figure 4.8 show the range and the mean values of chloride concentrations in both wet and dry seasons. The mean value of 6.72 mg/L for the dry season is slightly higher than 5.66 mg/L of the wet season. The mean chloride concentration ranged from 3.83 mg/L at Fodzoku to 9.55 mg/L at Kpong in the dry season, while the mean concentration in the wet ranged from 4.04 mg/L at Gacrom (GC) to 7.83 mg/L at Kpong. There was a general decrease in chloride concentration from upstream to downstream. All the values were below the WHO threshold of 250 mg/L. This variation in the chloride values could be attributed to slight evaporation of the water from the river volume which led to high values and that of the low value could be attributed to dilution as a result of runoff and leakage of water bodies into the mainstream.

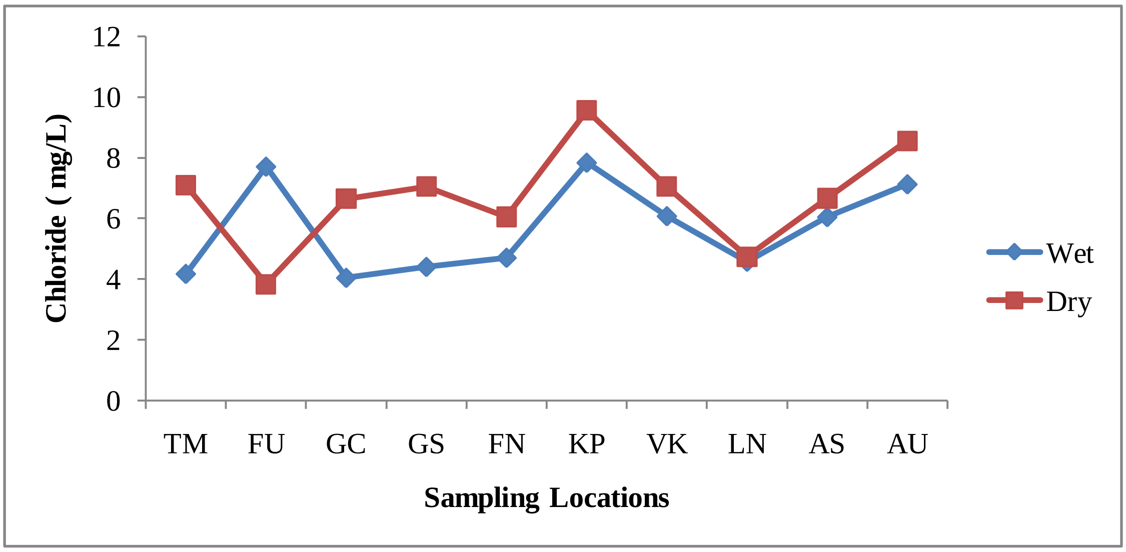


Figure 4.8: Mean Chloride distribution of water in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.9 Fluorides

Flouride is got when mineral ores containing flouride are weathered. Flouride emerges to the surface through runoff, Greater concentration of flouride is harmful to humans and animals which consequently becomes source of bone disease. Beneficially, increasing the concentration a little helps to prevent dental carries (Chapman, 1992).

Tables 4.1a, 4.1b presented coefficients of variation of both wet and dry seasons. The coefficients of variation of fluoride for the wet season was 27.97 % and 27.14 % indicating a close dispersal of fluoride. Tables 4.4 - 4.5and Figure 4.9 compare the mean values of fluoride concentration in both the dry and the wet seasons. There was a remarkable variation between the wet season and the dry seasons but both the dry and the wet seasons recorded the same concentrations of fluoride at Kpong while the rest of the sampling sites recorded values lower than that of the dry season. The wet season registered a lower mean value of 0.049 mg/L than the 0.09 mg/L of the dry season and the concentration of fluoride in the wet season ranged from 0.03 mg/L at Fremankofe to 0.007 mg/L at both Gasikakofe and the Agric Research Station. The mean of the dry season ranged from 0.05 to 0.12 mg/L at Torgorme (TM) and Lorlornyokofe (LN) in the dry season. The fluoride concentration decreases from upstream to downstream. Values recorded within the two seasons were below the WHO guideline of 1.5 mg/L. High level of fluoride could be attributed to the composition of the bedrocks within the area. Report by the WHO (2003) indicated that low concentrations of fluoride are medically good for healthy teeth but a high concentration results in a disease Known as skeletal fluorosis.

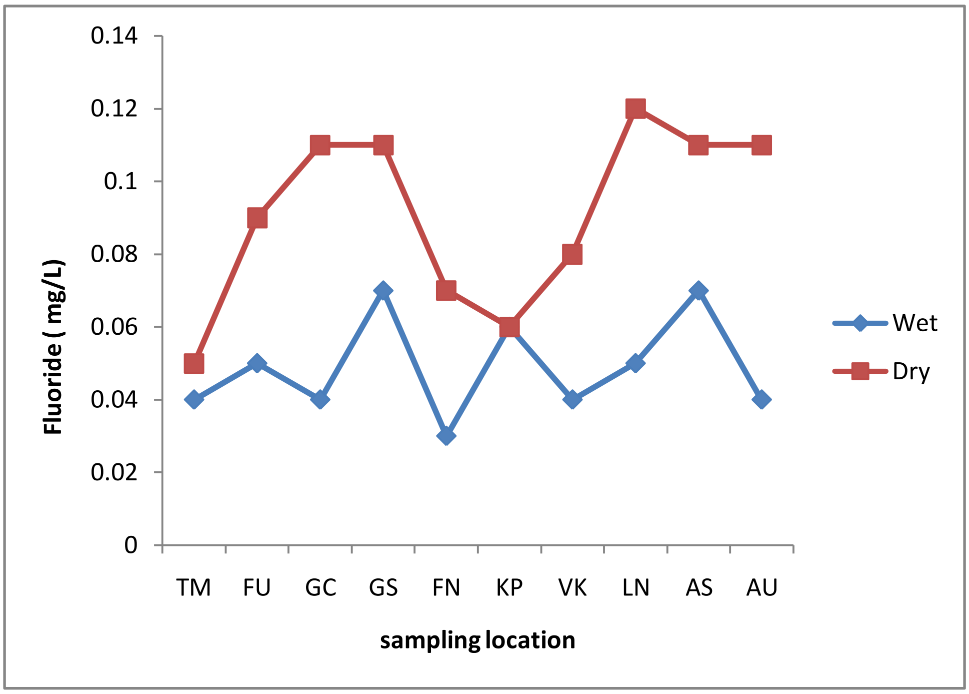


Figure 4.9: Mean Fluoride distribution of water in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

Nutrients are chemicals needed by plants and animals for growth and development. Unfavourable life conditions are met when excessive nutrients have drained into rivers and streams. The nutrient analyzed were nitrate, phosphate and sulphate.

4.10 Nitrate

The most common form of nitrate ion is when nitrogen is mixed with neural waters. On the other hand, intensive cultivation of Agricultural land without the use fertilizers or manure helps facilitate the oxidation of nitrite to nitrate in the soil (Baird, 2013).

Igneous rocks are examples of natural sources of nitrate in surface water. The risk of anaemia in pregnant women and infants is promoted by nitrate toxicity. Nitrate toxicity is also associated with the carcinogenic nitrosamine formation (Much and Meyer, 1982). The presence of domestic waste matters and nitrate fertilizer from Agricultural waste in the area under study is indicated by nitrate-nitrogen.

Natural sources of nitrate in surface water include igneous rocks, land drainage and plant and animal debris. Nitrate toxicity enhances the risk of anaemia in infants and pregnant women and also the formation of carcinogenic nitrosamine (Mush and Meyer, 1982). Nitrate-nitrogen indicates the presence of sewage generated from domestic activities and nitrate fertilizer from Agricultural waste in the area under study. Tables 4.1a and 4.1b present the coefficients of variation of both the wet and the dry season for the period of survey. Nitrate concentrations were narrowly dispersed since Coefficients of variation 12.16 % and 40.42 % for both the wet and the dry seasons were observed. There was a general increase in the mean value from upstream to downstream. The mean concentration of the wet season is 0.416 mg/L and the dry seasons registered the mean of 0.3 mg/L. Tables 4.4, 4.5 and Figure 4.10 describe the seasonal trend of nitrate concentrations. The nitrate concentration ranged from 0.15 mg/L at Akrade in the dry season to 0.49 mg/L at both Torgorme and Kpong. The nitrate concentration ranged from 0.36 mg/L at Akrade and Agric research station (AS) to 0.49 mg/L at Kpong in the wet season. In general, the nitrate values were far below the WHO threshold value of 10mg/L The mean values obtained in this study compared favourably with the mean values of 0.038 mg/L recorded by the water Quality assessment of south western and coastal river systems by CSIR/WRI for water the Resources Commission (WRC 2003). The mean value of 0.49 mg/L of nitrate obtained during the wet season is higher than the 0.36 mg/L of the dry season. This could be associated with runoffs from the farmlands, where agrochemicals such as fertilizers were used on the soil and then finally drained into the river.

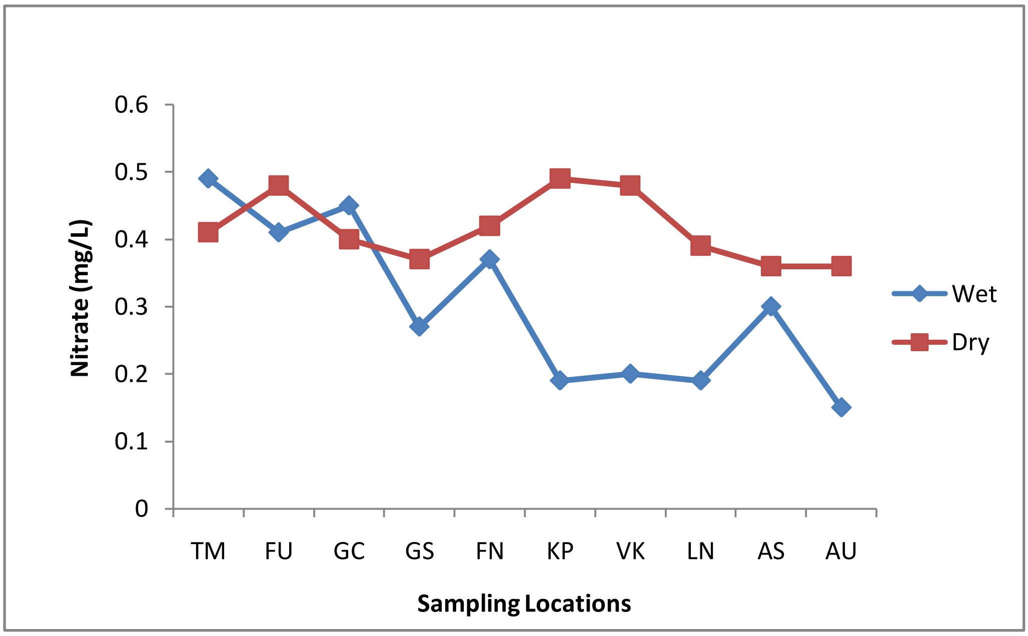


Figure 4.10: Mean Nitrate distribution of water in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.11 Phosphate

.Phosphate plays a very essential role in providing nutrients for living organisms. It can exist in water bodies in dissolved and particulate, which naturally occurs in rocks and other mineral deposits. Phosphorus or soluble phosphate ion is released naturally during the process of weathering. Metaphosphate (polyphosphate), organically bound phosphate and orthophosphate are the three forms of phosphate. These three forms usually occur in decaying and living plants and animal in the form of free ions or loosely chemically held in aqueous system. They are chemically bound to sediment and soils or mineral compounds in rock and sediments. Orthophosphate forms are produced naturally. However, man-made influence is the main source. Runoffs from Agricultural lands and sewage which is not treated or incompletely treated are examples of man-made influence. Furthermore, when lawn phosphate fertilizers are applied, it results into stimulating plants growth and even aqueous plants. Thus, it serves as food for a great number of organisms which include fish, zooplankton, human and other organisms. Concentration at its highest level indicates the presence of pollution thereby resulting in eutrophication (Chapman, 1992).The range of phosphate concentration in natural waters is from 0.005 to 0.02 mg/L (UNESCO/WHO/UNEP, 1997). The presence of pollution is indicated by the high level of phosphate concentrations and it is responsible for the depletion of dissolve oxygen which affects the life of fish adversely.

In general, phosphate concentration in natural waters normally ranged from 0.005 to 0.02 mg/L (UNESCO/WHO/UNEP 1997). High concentrations indicate the presence of pollution which is responsible for the depletion of dissolved oxygen which has an adverse effect on fish life. Coefficients of variation recorded are shown in tables 4.1a and 4.1b. The coefficients of variation of phosphate was 108 % in the wet season which gives an indication that the mean phosphate concentration are highly dispersed since the recoded value was greater than 50 % during the whole survey period. The mean phosphate values of 0.132 mg/L and 0.33 mg/L were recorded in the wet and dry seasons respectively and ranged from 0.02 mg/L at Torgorme to 0.47 mg/L at Fremankofe in the wet season. The phosphate concentration in the dry season also ranged from 0.23 mg/L to 0.42 mg/L at Gasikakofe and Kpong as shown in Tables 4.4, 4.5 and Figure 4.11. The concentration of the phosphate values in the seasons was prominent. No defined trend was observed but there was a sudden rise in the mean concentration at Fodzoku and Kpong respectively. Mean value at Kpong exceeded the WHO value by 0.02 mg/L. The wet season recorded the highest values of 0.47 mg/L of phosphate which also exceeded the WHO value by 0.12 mg/L at Fremankope, while the dry season values were low. The high values of the phosphate could be attributed to the runoffs from Agricultural lands on which fertilizers were applied and that drained during the wet season into the Reservoir. Also, since there are many settlements along the river, the high phosphate values could be as a result of drainage of waste water, and of both treated and untreated sewage into the river through gutters.

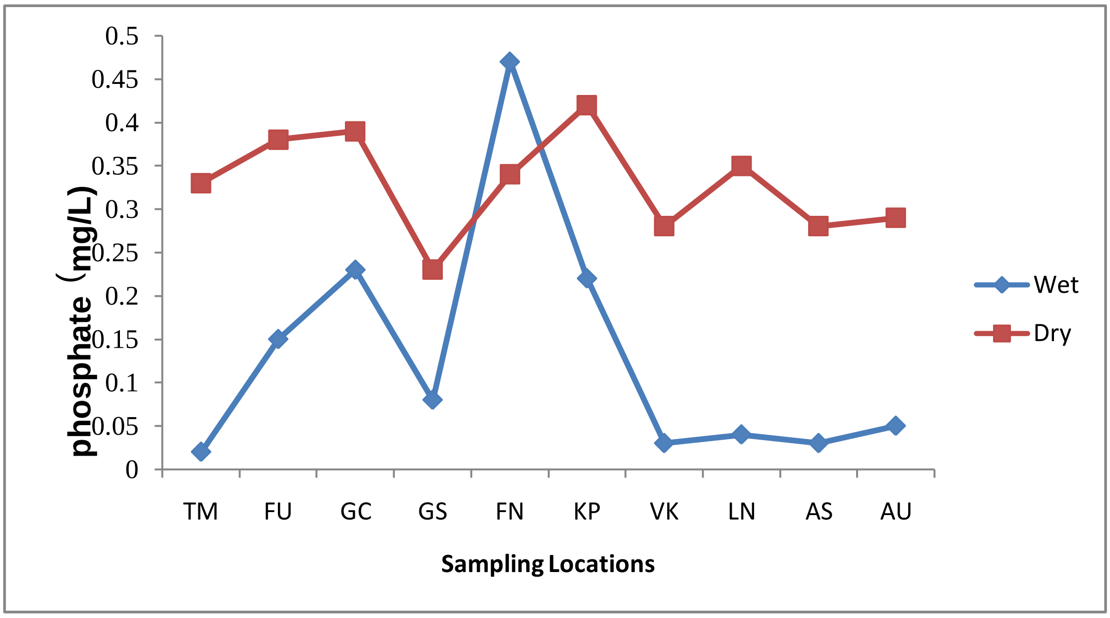


Figure 4.11: Mean Phosphate distribution of water in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.12 Sulphate

Naturally, sulphur exists in minerals including Epsomite (mgSO_4, 7H_2O, Barite ($BaSO_4$) and Cypsum ($CaSO_4.2HD_2O$) Volcanoes, sea salt over the oceans and decomposition and combustion of organic matter are some of the natural sources of sulphur. Sulphur from different sources is transported by the atmosphere (Kellogg et al, 1972). Sulphate pollute the aquatic environment in the form of waste form mining, melting operation and industries that use of sulphate and sulphuric acid (Kellegg et al, 1972). A source of exposing sulphur to the atmosphere t is through fossil fuels combustion. A major recognized source sulphate in water is a sulphate fertilizer (Kellog et al, 1972). The geology of the area greatly influences sulphate distribution to a large extent. It is likely that waste drainage contributes to the presence of sulphate in water bodies (APHA, 1995).

On the other hand, Lester and Birkett (1999) indicated that sulphate concentration in most river water is 11.2 mg/L. Sulphate concentration shows a scattered dispersion of coefficient of variation which is 59.14 % and 52.42 % as shown in Tables 4.1a and 4.1b respectively. The highest mean value of sulphate occurred at Fremankope and this could be due to farming activities where fertilizers are applied. Generally the mean values of sulphate in both the wet and the dry seasons were far below the WHO threshold value of 250 mg/L. Tables 4.4, 4.5 and Figure 4.12 show the comparison of the mean sulphate concentrations in the wet to the dry seasons of which the mean for the wet season, 4.12 mg/L was higher than 3.56 mg/L the mean for the dry season. The mean concentration of sulphate ranged from 0.99 mg/L to 7.87 mg/L at Torgorme (TM) and Gackom (GC) respectively in the wet season, and 0.75 mg/L to 6.29 mg/L at Kpong (KP) and Fremankofe (FN) in the dry season respectively. There was variation in the seasons where the highest sulphate value was recorded during the dry season at Fremankofe, while the lowest value occurred during the wet season at Torgorme. Generally, the sulphate concentration decreases from upstream to downstream. This variation in season could be due to dilution of the sulphate concentration in the water through runoffs.

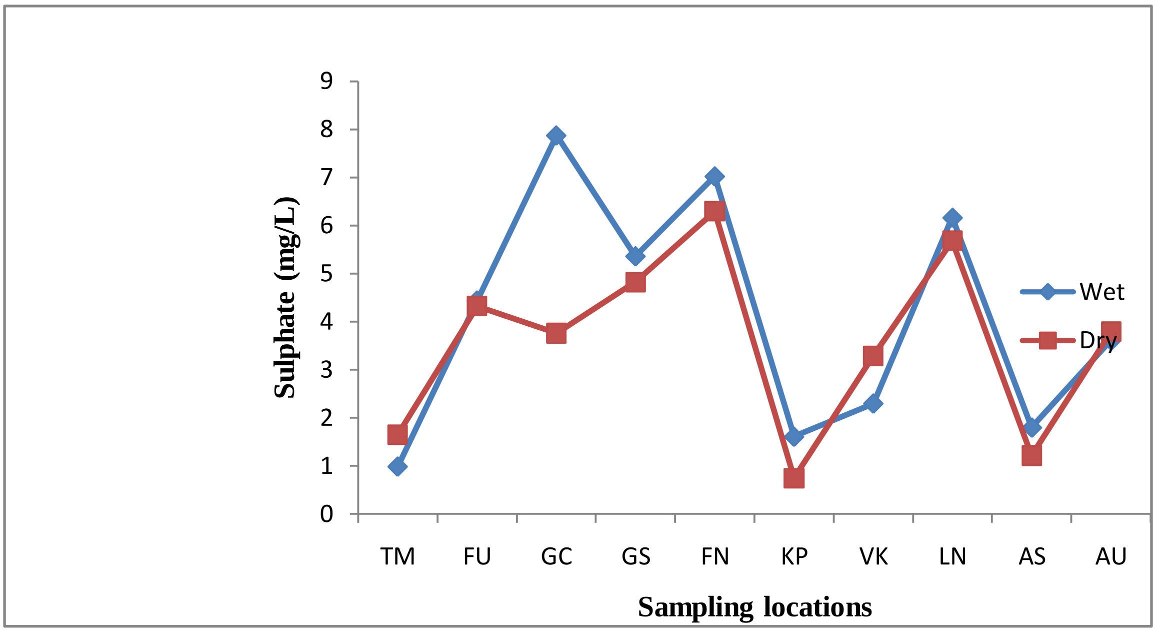


Figure 4.12: Mean sulphate distribution of water in both November-February (dry) and May-July(wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.13 Total hardness

Hardness, a measure of the ability of water to form lather with soap, is influenced by the presence of calcium and magnesium salts. Table 4.1a and 4.1b show coefficient of variation which describe the nature of total hardness of water of the sampling sites over the whole survey period. The coefficient of variation was 17.81 % in the wet season while that of the dry season was 13.49 %. Both values were uniformly distributed in the catchment area of the study during the wet and the dry seasons. The mean total hardness of 43.46 mg/L is higher in the dry season than 27.81 mg/L in the wet season as shown in table 4.6 and Figure 4.13. Total hardness value ranged from 23.21 mg/L at Kpong in the wet season to 37.22 mg/L at Fodzoku and also ranged from 35.33 mg/L at Agric Research Station to 53.33 mg/L at Fremankofe (FN) in the dry season. There was a gradual increase in concentration of total hardness from upstream to downstream. The higher value in the dry season might be as a result of evaporation of the water at the surface. This led to a decrease in the volume of the water and an increase in the concentration of the chemical constituent of the water. The low values in the wet season could be attributed to run offs which dilute the concentration of the chemicals in the water. Although all the values were far below the WHO threshold value of 500 mg/L, the increasing level of the hardness in the dry season is a major concern to the Ghana Water Company (limited) (GWCL) as they may have to utilize more chemicals to soften the water for both domestic and industrial use.

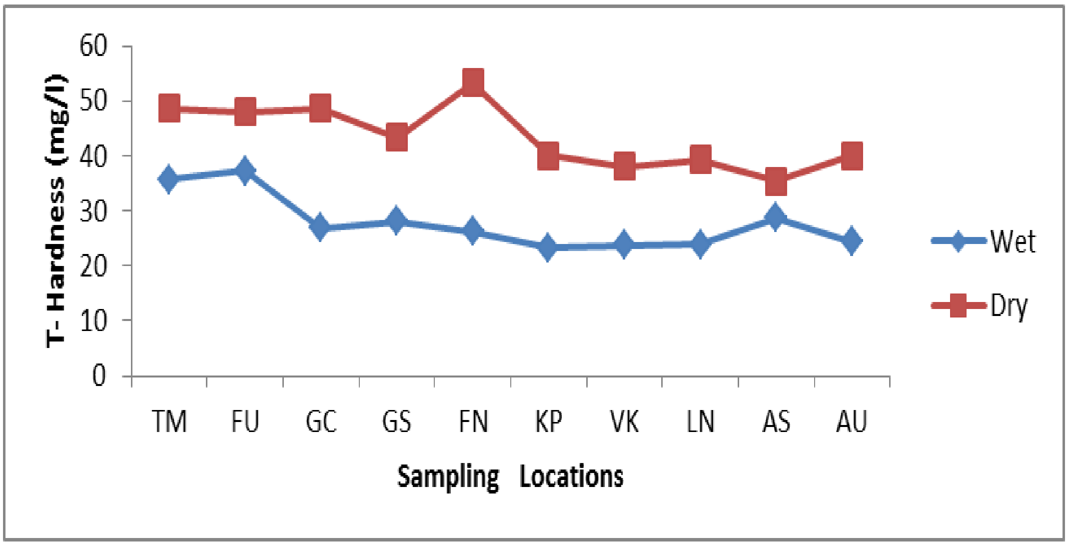


Figure 4.13: Mean Total Hardness distribution of water in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.14 Calcium

Almost all rocks are weathered by calcium and it is finally detected in water. Lime stone areas serve as sources of many waters. Those lime stone areas associated with gypsiferous shade contain more amount of calcium contributing immensely to total harden of water (APHA, 1995).

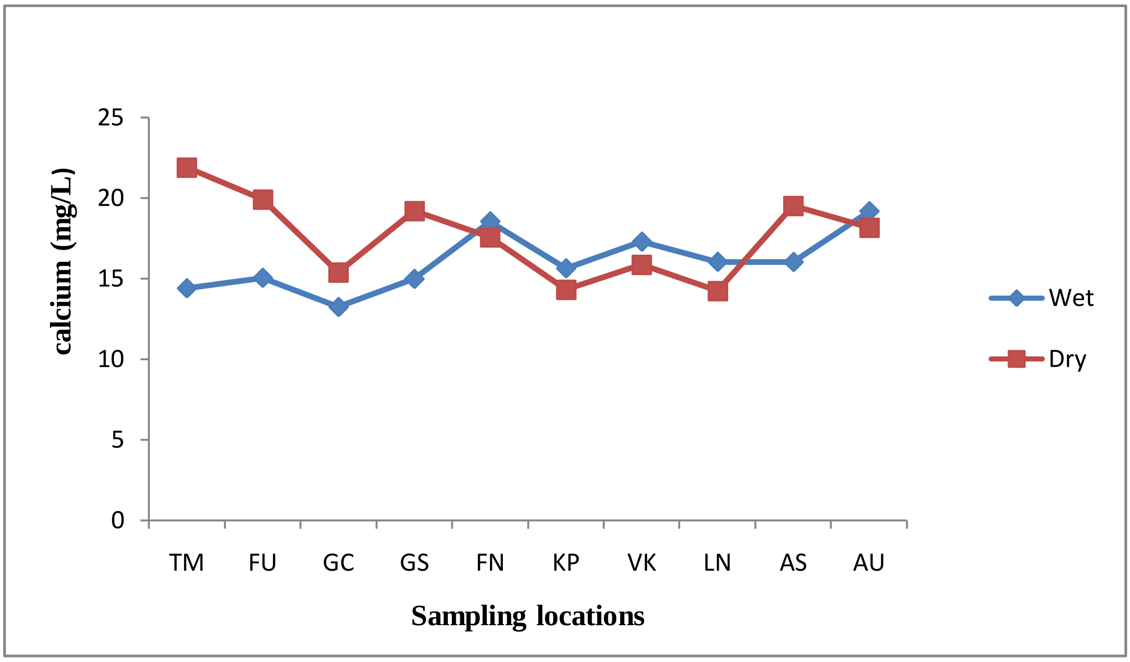


Figure 4.14: Mean Calcium Hardness distribution of water in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.15 Magnesium and calcium

Table 4.1a and 4.1b show Coefficients of variation of both calcium and magnesium concentration at the various sampling sites over the entire survey period. Coefficients of variation indicated that the distribution of calcium was uniform since it recorded coefficients of variation of 11.48 mg/L and14.68 mg/L in both the wet and the dry seasons. Figure 4.15.shows a gradual decrease in the mean concentration of magnesium from 24.06 mg/L at Torgorme to 13.49 mg/L at Akrade. There was a gradual decrease in magnesium concentration from 13.85 mg/L at Torgorme to 6.16 mg/L at Akrade during the wet and the dry seasons. The mean Calcium and magnesium values ranged from 14.32 to 18.67 mg/L at

Gakrom and Akrade respectively. The mean calcium value in the dry season was higher than that of the wet season as indicated in Table 4.6. The mean calcium concentration ranged from 14.24 mg/L to 21.89 mg/L at Lorlornyo (LN) and Torgorme (TM) respectively in the dry season while the mean calcium concentration in the wet season ranged from 13.24 mg/L to 19.18 mg/L at Torgorme (TM) and Akrade (AU) respectively. The high mean value of calcium is as a result of the underlying rock over which the water flows which might have a high composition of calcium than other components. Such rocks include anorbite ($CaAl_2Si_2O_8$) and other silicate minerals that could contribute to the dissolution of calcium by interaction of water (Dallas, 1992). The mean value of calcium is lower than the WHO values of 200mg/L respectively. The low concentration of calcium is due to the fact that the decomposition of most igneous rocks is very slow. Though the natural abundance of calcium is generally higher than that of magnesium, the magnesium concentration in this study was found to be higher. This high concentration of magnesium could be as a result of domestic waste and dissolution of Dolomite in the study area (Jalali, 2006).

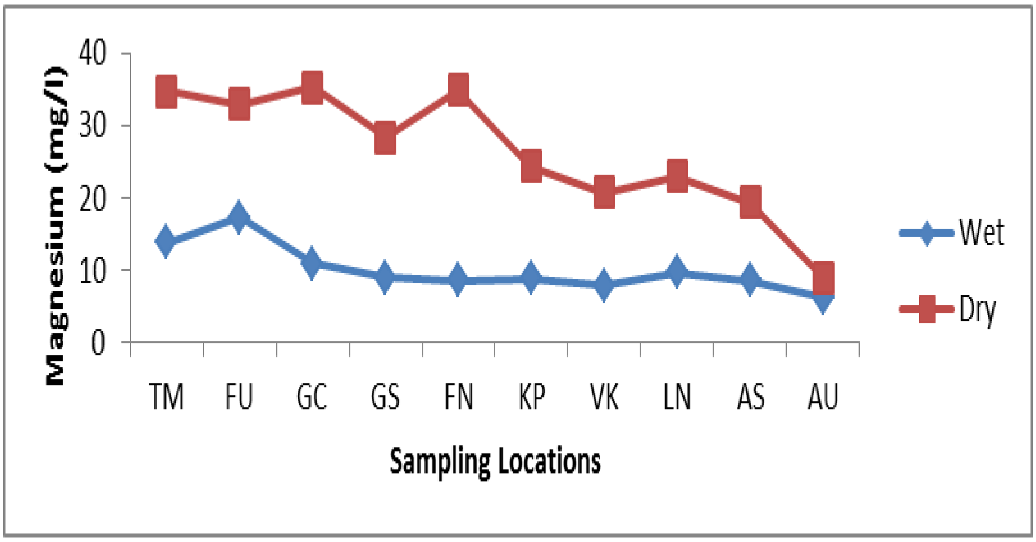
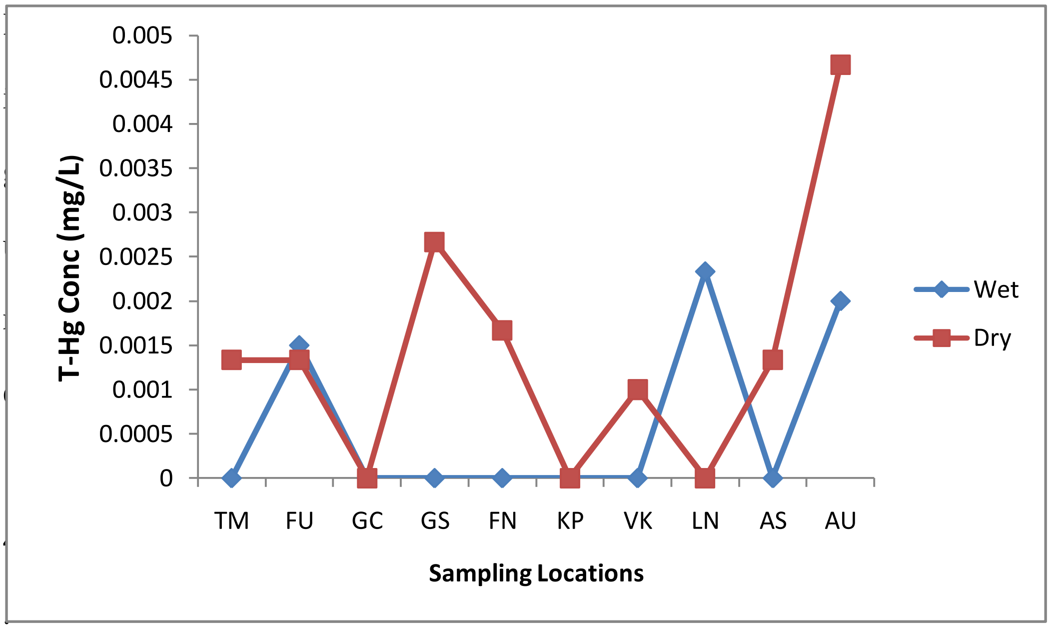


Figure 4.15: Mean magnesium Hardness distribution of water in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.16 Mercury in water

Tables 4.1a and 4.1b show the coefficient of variation for distribution of concentration of total mercury at various sampling sites for the whole survey periods. Total mercury gave 15.75 % of coefficient of variation which was widely scattered in the wet season . Coefficient of variation of 72 % was also recorded for mercury distribution in the dry season. A trend of mercury concentration was observed along the river from Torgorme to Akrade. Tables 4.4 - 4.6 and Figure 4.16 also shows the comparison of mercury in the wet to dry seasons of the survey period. Though some samples below had levels below the detection limit of the AAS, there was a slight variation in the seasons of both the wet and the dry. The values recorded in the dry season were higher than those of the wet season with respective means of 0.0006 mg/L for the wet season and 0.001 mg/L for the dry season and ranged from 0.001 mg/L to 0.005 mg/L in the dry season, and 0.0012 mg/L at Fodzoku to 0.002 mg/L at Akrade in the wet season . The values recorded were below the WHO guideline of 0.001 mg/L as shown in figure 18. The low values of 0.001 mg/L of the mercury concentration could be as a result of environmental transport since Hg disperses faster.

Soil erosion is also a means of transport of mercury from anthropogenic sources associated with a particulate matter into the aquatic system as observed in the Amazon Roulet *et al.* (1998). The hydroelectric Dam could also be a factor even though there is no known artisanal mining close to the study site.



16: mean T-Hg distribution of water in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.17 Selenium in water.

Tables 4.1a and 4.1b show the coefficient of variation and the trend of selenium distribution in water at various sampling locations during entire survey period. The selenium recorded coefficient of variation of 41.47 % and 13.33 % indicating a close and uniform distribution of selenium concentration in both the wet and the dry seasons. Tables 4,4 -4.6 and Figure 4.17 compare the mean concentrations of selenium in the wet to the dry season. The mean concentrations of selenium ranged from 0.001 at Kpong in the wet season to 0.004 mg/L at Akrade. The mean selenium concentration in the dry season also ranged from 0.004 mg/L at Gacrom and Agric research station to 0.006 mg/L at Gasikakofe (GS) and Fremankofe (FN) with their respective means of 0.002 mg/L and 0.005 mg/L. The highest mean concentrations of selenium were recorded in the dry season, while the lowest were recorded in the wet season. Though the general level of selenium in water is low, it is relatively higher than the levels of mercury concentration. This result is in agreement with similar research conducted by (Chen *et al*., 2001; Belzile *et al* 2006b) where Hg and CH_3Hg^+ concentration decreases with total Se concentration increasing in lake waters and tissues of studied biota.

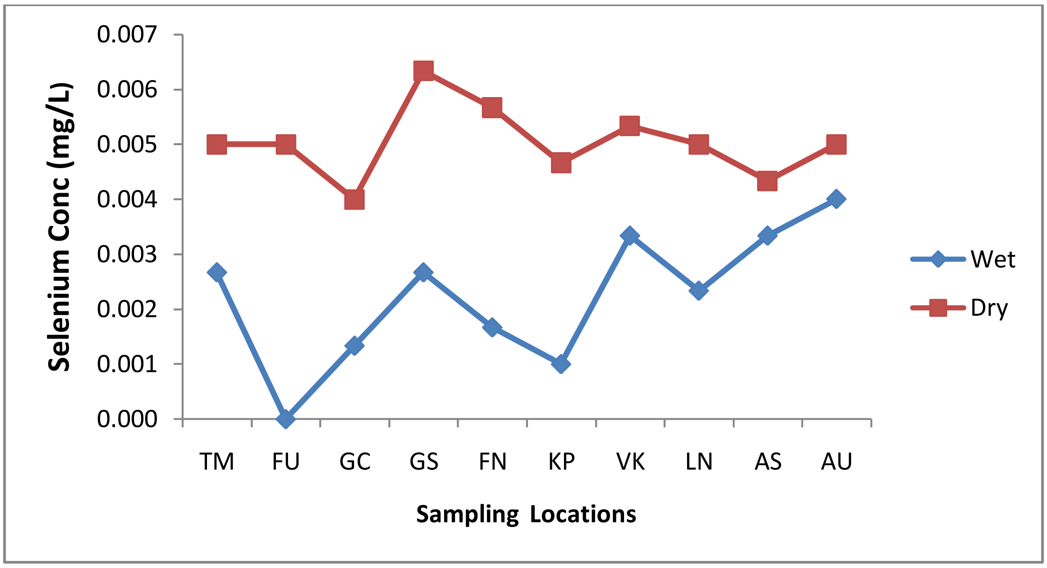


Figure 4. 17: Mean Se distribution of water in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.18 Iron in water

From tables 4.1a and 4.1b description of coefficient of variation and the distribution pattern of iron throughout the whole sampling season was observed, iron recorded 72.83 % in the wet season and 55.68 % in the dry season, all of which are highly dispersed. Iron concentrations were high at Torgorme and Fodzoku but low at the other sampling locations, thus the concentration decreases from upstream to downstream. The concentration of the iron level in water depends on external factors such as environmental conditions particularly, oxidation and reduction potential (Chapman 1992) as well as the pH. The mean value of 0.47

mg/L for the wet season was higher than the mean of 0.04 mg/L for the dry season. The mean ranged from 0.01 mg/L at Gacrom (GC) in the dry season to 0.08 mg/L at the Agric. Research Station, while the iron concentration in the wet season ranged from 0.04 mg/L at the Agric Research Station to 0.94 mg/L where some concentrations were below the detection limit of the AAS as shown in (tables 4.4 - 4.6). Some of the values recorded were above the WHO values (2006) guideline limit of 0.3mg/L. There was a general variation in the concentrations of iron, the highest value was recorded in the wet season as shown in fig 4.18 . The highest value was recorded at Vivorkofe and the lowest at the Agric Research Station. Despite the fact that iron is essentially required in nutrition, only a concentration of 0.3 mg/L in water is the acceptable value (Badojevic and Bashkin, 1999). Iron concentrations above 0.3 mg/L results in a disease condition known as haemochromatosis. The levels of iron concentration in this study could be attributed to the geology of the area which is commonly made up of granitoid complex and a Birimian rocks system. (Kesse 1995) suggests that in addition to the atmospheric transport, the iron smelter situated at Tema could also be a contributing factor since it is not far from the sampling sites. Another source of high concentrations of iron could be ascribed to runoff from domestic activities as well as discharge of waste water from the Akosombo and the Juapong Textile factories upstream. Iron levels in rivers and lakes could generally be influenced by the vegetation of the aquatic environment which include both rooted and free floating forms (Osborn and Hem, 1962).

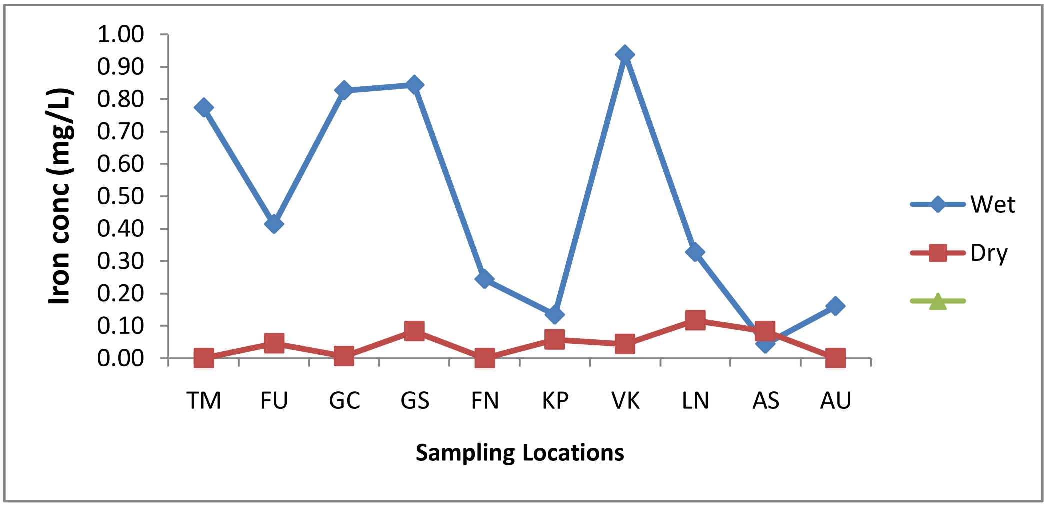


Figure 4.18: mean Fe distribution of water in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.19 Lead in water.

Nature and anthropogenic activities are the sources through which lead enters water in the ecosystem. Naturally, erosion, volcanic eruption and weathering cause lead pollution of the ecosystem. However, several times, lead concentration in the environment is as a result of anthropogenic means involving the burning of lead in the gasoline by vehicles engines. The high level of lead concentration is dangerous to organisms in the aquatic environment. This is because when lead containing substances are consumed, about one percent of lead which may enter the human body through food chain will be retained (Yown and Blevins, 1981). Lead is carcinogenic and it has the ability to damage the kidney and the nervous system (Radojevic and Bashkin, 1999) The coefficients of variation of lead were recorded in tables 4.1a and 4.1b The wet season recorded 57 % which was widely dispersed, while 49.24 % was found in the wet season. The highest means value was observed at the Agric. Research Station (AS). Tables 4.4 - 4.5 and Figure 4.19 also show the comparison of mean lead concentration in the dry to the wet seasons. There were seasonal variation in both the wet and the dry seasons.

The wet season recorded the highest mean of 0.179 mg/L and this ranged from 0.06 at Kpong in the wet season to 0.36 mg/L at the Agric. research station in the same season. The dry season also ranged from 0.03 mg/L at Lorlornyo (LN) to 0.14 mg/L at Torgorme (TM), Fodzoku (FU) and Gacrom (GC). The high level of lead in the wet season could be attributed to some wayside fitters and also car washing bay from which water runs into the river. Lead, which is used in the manufacture of paints, car batteries and pesticides could be introduced into the water body by anthropogenic means which may in the long run cause serious damage to the kidneys, the brain, the nervous system as well as cause high blood pressure to people who have excess of lead in their body system. In this work almost all the values recorded at the sites were above WHO guideline limit of 0.05 mg/L There is therefore the need for treatment of the water to meet the safe standard (to be safe) for drinking and domestic use.

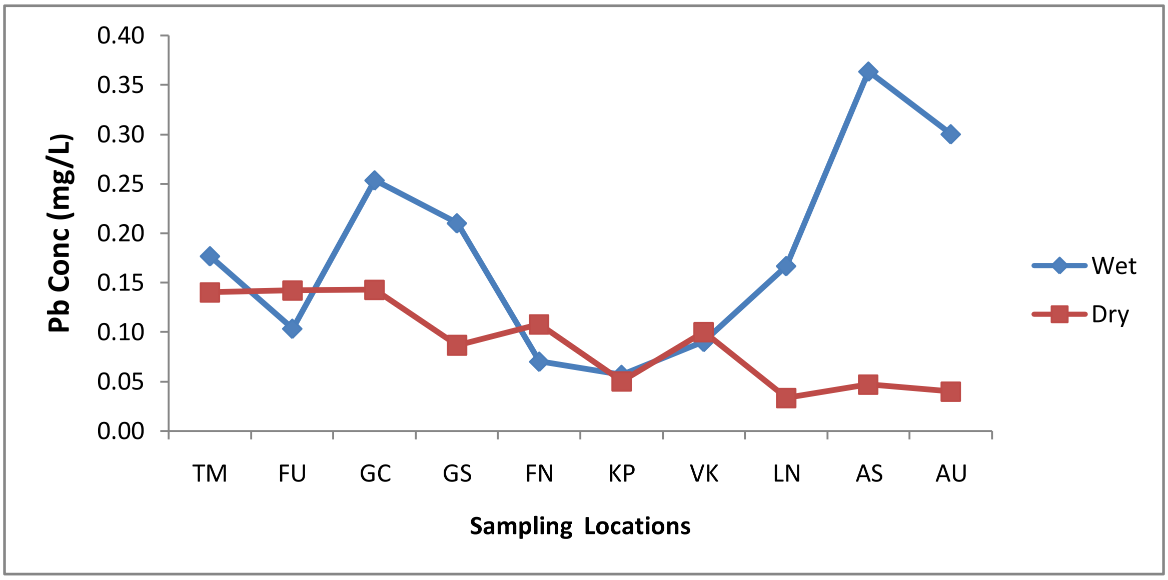


Figure 4.19: Pb distribution of water in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agri research station (AS) and Akrade (AU).

4.20 Manganese in water

Manganese occurs naturally in rocks and soils and may have low concentrations in waters. Manganese in excess affects the taste and the colour of water. Table 4.1a and b show the mean concentration and the distribution of manganese at various sampling sites throughout the entire season of survey. The coefficients of variation of manganese shown in tables 4.1a and 4.1b gave a narrow distribution, which constitutes 30.93 % in the wet season while the dry season gave a scattered distribution which constitutes 50.41 %. There was a general variation in both the wet and the dry seasons. Table 4.4 - 4.6 and Figure 4.20 show the mean concentration of manganese in the wet and the dry seasons. The dry season recorded the highest mean concentration of 0.71 mg/L and the mean concentrations of manganese ranged from 0.27 mg/L at the Agric. Research Station in the dry season to 1.31 mg/L at Vivorkofe, while the manganese concentration of the wet season ranged from 0.34 mg/L at Gasikakofe to 0.62 mg/L at Fodzoku with the mean value of 0.463 mg/L recorded. In general, the values recorded were lower than the WHO guidelines limit of 0.5 mg/L, except the 0.62 mg/ at Fodzoku recorded in the wet season, and 0.72 mg/L,0.83 mg/L, 0.95 mg/L and 0.91 mg/L at Fodzoku, Gacrom, Fremankofe and Kpong in the dry season. These high values of manganese in the dry season could be attributed to the geological constitution of the area under study. It could also be attributed to the release of waste water which might contain manganese from the Akosombo and the Juapong Textile factories that are located upstream.

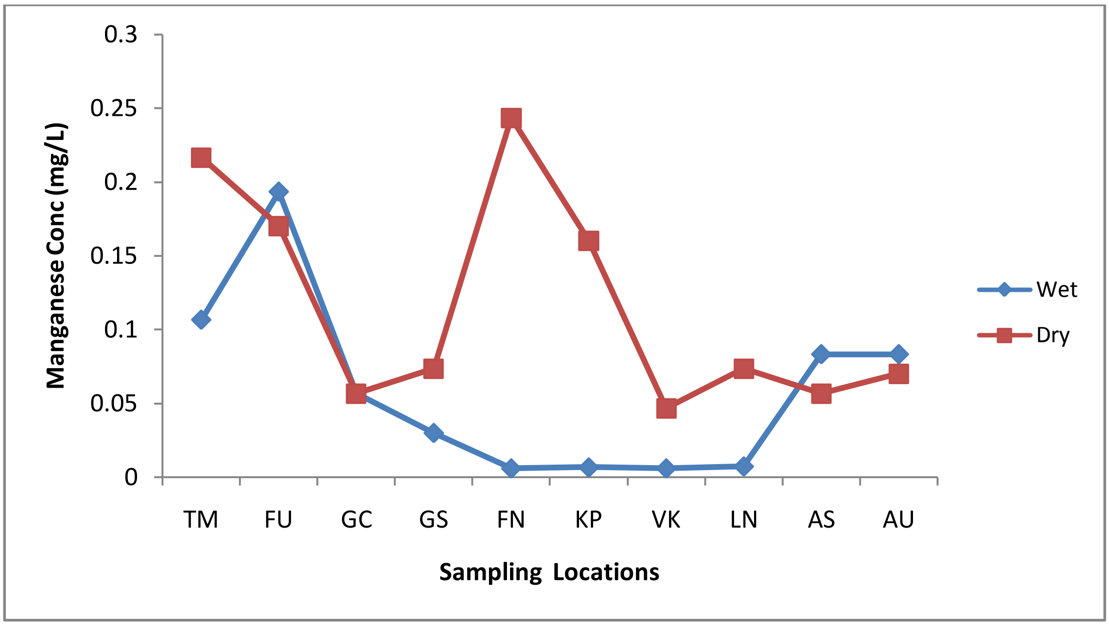


Figure 4.20: Mean Mn distribution of water in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.21 Mercury in sediment

In general, concentrations of heavy metals are higher in sediments than in water and tissue of organism since the metal concentration accumulates with time. Table 47a and 4.7b.show uniformly and evenly mercury concentration distribution at the various sampling sites throughout the entire season of survey with coefficients of variation of 37.12 % in the wet season and highly scattered in the dry season with 119 % coefficients of variation. Tables 4.8 - 4.10 and Figure 4.21 also show the comparison of mercury in wet to dry seasons. Mercury concentrations were high from Torgorme to Fremankope and came from Kpong to Akrade, thus it decreases upwards in both seasons. There exists a remarkable difference between the dry season and the wet season. The dry season recorded a higher mean value of 0.1 mg/kg while the wet season registered 0.021 mg/kg and ranged from 0.01 mg/kg at Lorlornyokofe to 0.03 mg/kg at Fodzoku, Gacrom, Fremankofe, Kpong and Akrade in the wet season. The mercury concentrations ranged from 0.02 to 0.38 mg/kg at the Agric Research Station and Gacrom in the dry season. Through Anthropogenic means, mercury could also enter the sediment as a result of atmospheric depositions, discharge of industrial waste products, application of pesticides to Agricultural land which later undergoes erosion and results in the elevated level of mercury which continuously deposits on the sediment. Values obtained are also less than USEPA limit of 0.2 mg/kg except the site at Gacrom which recorded 0.38 mg/kg and this result indicated that the sediment is not polluted.

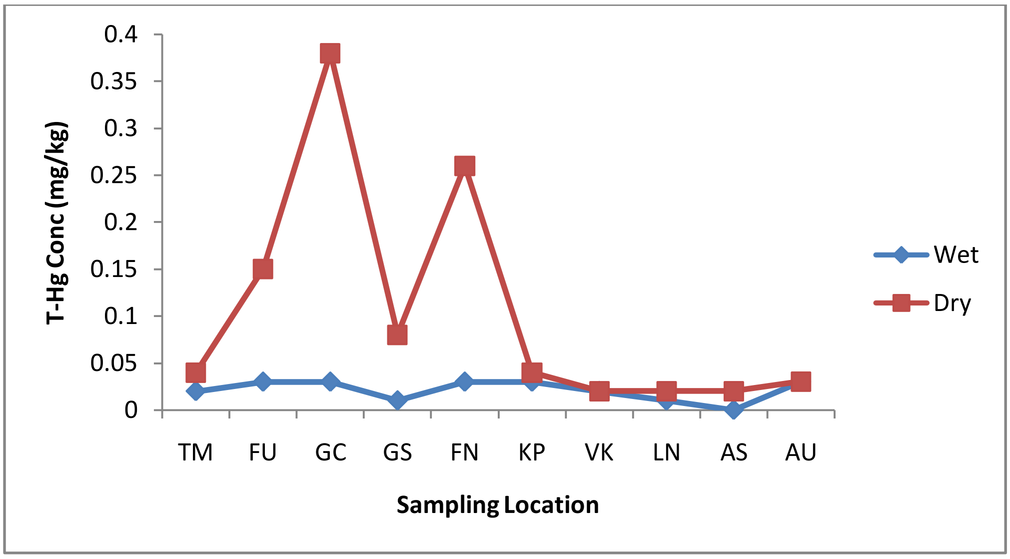


Figure 4.21: Mean Hg distribution of sediment in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.22 Selenium in sediment

Tables 4.7a and 4.1b show the coefficient of variation, mean concentrations and distributions of selenium at the sampling sites over the entire survey period. Selenium recorded a coefficient of variation of 31.88 % and 11.24 % in both the wet and the dry season. A uniform distribution was observed along the Kpong reservoir. Tables 4.8 - 4.10 describe and compare the wet to the dry season. The mean concentration of Se recorded in the dry season was 0.4 mg/kg and that of the wet season registered 0.126 mg/kg and ranged from 0.09 at the Agric. Research Station in the wet season (and also ranged from 0.34 mg/kg) to 0.44 mg/kg at Kpong in the dry season. The higher values recorded in the dry season could be attributed to atmospheric deposition and a decrease in the volume of the water body which leads to pre-concentration of the selenium. The lower value in the wet season may be associated with the drainage and runoffs into the river which diluted the concentration of the metal ion.

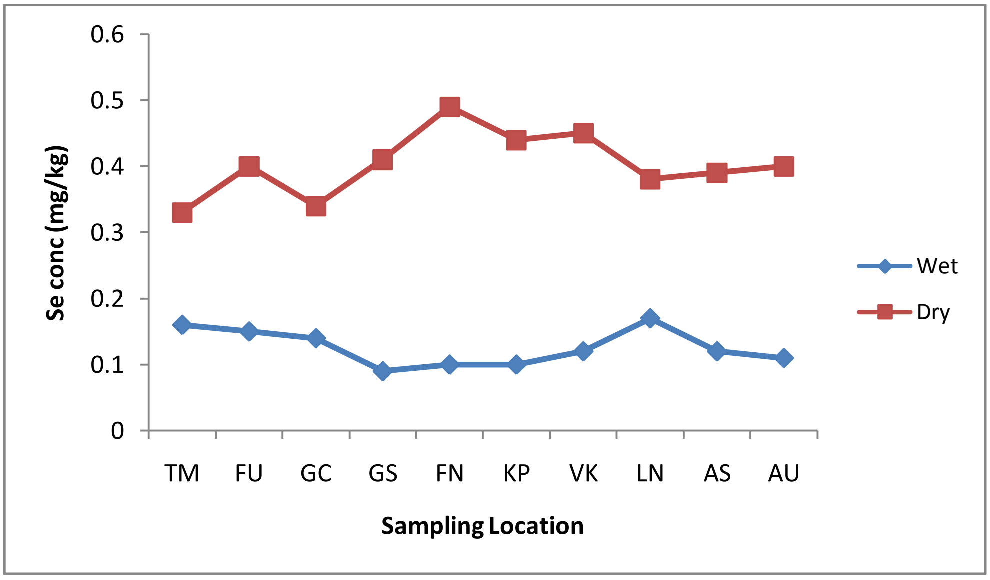


Figure 4.22: Mean Se distribution of sediment in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.23 Iron in sediment

Tables 4.7a and 4.7b show coefficients of variation, mean concentration and distributions of iron in the sediment throughout the survey period. The coefficients of variation recorded in both the wet and the dry seasons were 9.45 % and 0.97 %. These low values indicate a narrow distribution of iron. Tables 4.8- 4,10 and Figure 4.23 also compare the iron concentrations in the wet to the dry seasons; there was a trend of decrease from Torgorme to Akrade. The highest concentration occurred in the wet season with the mean value of 185.12 mg/kg while 151.99 mg/kg occurred in the dry season, and ranged from 139.21 mg/kg at the Agric Research Station in the wet season to 198.41 mg/kg at Fodzoku in the wet season. The iron concentration in the dry season ranged from 150.1 to 154.90 mg/kg at Lorlornyo and Gacrom respectively. High levels of iron may be due to the activities of farmers such through the use of Agricultural inputs found in the several towns and villages that are sited along the banks of the river, also combustion of fossil fuel, incineration of domestic wastes that contain dye paints, cement and rusty zinc cans which are disposed upstream that finally find their way into the river by runoffs.

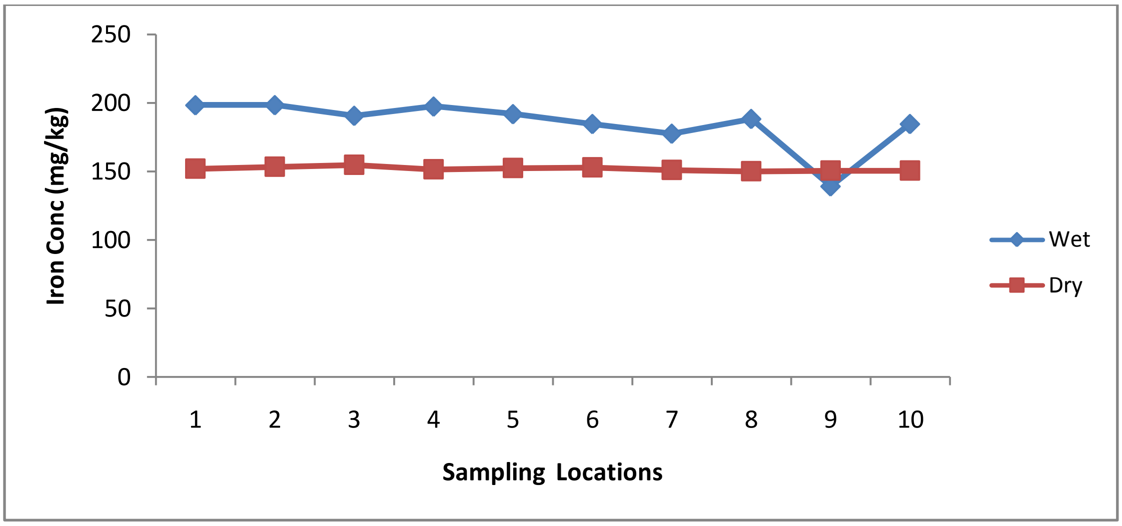


Figure 4.23: Mean Fe distribution of sediment in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.24 Manganese in sediment

In the wet season, manganese gave 30.93 % coefficients of variation indicating a uniform distribution while 50.13 % was in the dry season indicating a scattered distribution as shown in Tables 4.7a and 4.7b respectively. Table 4.8 - 4.10 and Figure 4.24 compare the mean concentrations in the wet to the dry seasons. The seasonal variation recorded a higher mean value of 0.67 mg/kg in the dry season while 0.46 mg/kg occurred in the wet season and ranged from 0.27 mg/kg at the Agric Research Station to 1.31 mg/kg at Vivorkofe, all in the dry season, and these also ranged from 0.13 to 0.57 mg/kg at the Agric Research Station and Fremankofe respectively in the wet season.. The high concentration of the Mn may be due to the atmospheric deposition and transport of mineral by runoff into the river which finally settled at the bottom, since sediment acts as the sink for heavy metals. The concentration of manganese was found to be very high, which is in agreement with the report that the mobility and transport of metals in aquatic media made them bioavailable (Rubio and Rauret 1996). Sin *et al*. (2001) reported that the sediment contained metals ingested by the suspended filter feeder, P. viridis, which then became bioavailable.

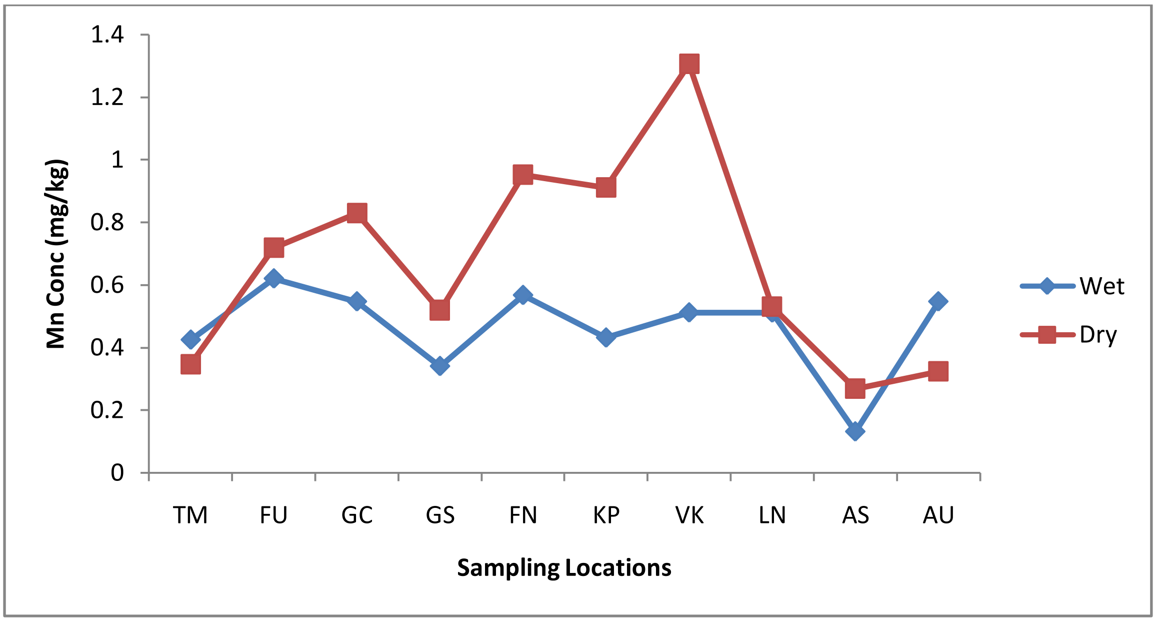


Figure 24: Mean Mn distribution of sediment in both November-February (dry) and May-July (wet) seasons for sampling sites Torgome (TM), Fodzoku (FU), Gacrom (GC,) Gasikakofe (GS), Fremankofe (FN), Kpong (KP), Vivorkofe (VK), Lorlornyokofe (LN), Agric research station (AS) and Akrade (AU).

4.25 Correlation studies of mercury and selenium in fish versus physico-chemical parameters of water

4.26 pH versus Mercury

The correlation studies of this analysis determine whether the presence of selenium and mercury are dependent on the physico-chemical parameters. Tables 4.11 and 4.14 show that mercury and pH recorded a negative correlation coefficients of $r = -0.412$ in tilapia zilli in the dry season. This means that as the pH increases, the total mercury concentration decreases. The same trend was observed in Table 4.13 b which has a weak negative correlation coefficient $r = -0.138$ in the wet season. Though there was a negative correlation, it was not significant at $p < 0.05$.

On the contrary, a weak positive correlation coefficient ($r = 0.353$) at ($p > 0.05$) was observed in tilapia zilli in the wet season while mormyrops species also recorded a weak positive correlation coefficient $r = 0.187$ in the dry season as shown in table 4.13a;

Mormyropsanguilloid recorded r = 0.416 in the wet season (table 4.15). Tables 4.17 show the correlation between T-Hg and pH where hermichromis fasciatus recorded a weak positive correlation coefficient of r = 0.073, and there was a significant correlation at 0.05 level (2-tailed) as shown in Table 4.17 .

Clarias laeviceps showed a weak positive correlation coefficient r = 0.157 at $p > 0.05$ insignificant in the dry season. The correlation at ($P< 0.05$) between T-Hg and pH was more convincing and significant in clarias laevicep, in the wet season with correlation coefficient r = 0.073. In general, total mercury concentration in clarias laeviceps increases as the pH increases.

Table 4.11: Correlations between Hg and Total weight, Length , Se,Temp, pH and Conductivity inTilapia zilli (dry season)

Dry season		**Total weight (g)**	**Length (cm)**	**Se (mg/kg)**	**Temp (^{o}C)**	**pH**	**Conductivity (µS/cm)**
Hg (mg/kg)	Pearson Correlation	-0.274	0.029	0.462	0.064	-0.412	0.660
	Sig. (2-tailed)	0.511	0.947	0.250	0.880	0.311	0.075
	N	9	9	9	9	9	9

Table 4.12: Correlations between Hg and Total weight, Length , Se,Temp, pH and Conductivity inTilapia zilli (wet season)

Wet Season		**Total weight (g)**	**Length (cm)**	**Se (mg/kg)**	**Temp (°C)**	**pH**	**Conductivity (µS/cm)**
Hg (mg/kg)	Pearson Correlation	0.464	0.373	0.168	0.288	0.353	-0.126
	Sig. (2-tailed)	0.354	0.466	0.750	0.581	0.493	0.811
	N	9	9	9	9	9	9

Table 4.13a: Correlations between Hg and Total weight, Length , Se,Temp, pH and Conductivity in mormyrops *species* (dry season)

Dry Season		**Total weight (g)**	**Length (cm)**	**Se (mg/kg)**	**Temp (°C)**	**pH**	**Conductivity (µS/cm)**
Hg (mg/kg)	Pearson Correlation	-0.015	0.034	0.316	-0.608	0.187	0.023
	Sig. (2-tailed)	0.969	0.930	0.407	0.082	0.629	0.954
	N	9	9	9	9	9	9

Table 4.13b: Correlations between Hg and Total weight, Length , Se,Temp, pH and Conductivity in mormyrops *species* (Wet Season)

Wet Season		**Total weight (g)**	**Length (cm)**	**Se (mg/kg)**	**Temp (°C)**	**pH**	**Conductivity (µS/cm)**
Hg (mg/kg)	Pearson Correlation	-0.077	0.033	-0.109	0.121	-0.138	-0.116
	Sig. (2-tailed)	0.843	0.932	0.780	0.757	0.723	0.767
	N	9	9	9	9	9	9

Table 4.14: Correlations between Hg and Total weight, Length , Se,Temp, pH and Conductivity in mormyrops anguilloides (dry season)

Dry Season		**Total weight (g)**	**Length (cm)**	**Se (mg/kg)**	**Temp (°C)**	**pH**	**Conductivity (µS/cm)**
Hg (mg/kg)	Pearson Correlation	0.113	0.129	-0.104	-0.296	0.370	-0.609
	Sig. (2-tailed)	0.773	0.741	0.790	0.440	0.326	0.082
	N	9	9	9	9	9	9

Table 4.15: Correlations between Hg and Total weight, Length , Se,Temp, pH and Conductivity in mormyrops anguilloides (wet season)

Wet Season		**Total weight (g)**	**Length (cm)**	**Se (mg/kg)**	**Temp (°C)**	**pH**	**Conductivity (µS/cm)**
Hg (mg/kg)	Pearson Correlation	0.332	-0.197	0.347	-0.612	0.416	0.030
	Sig. (2-tailed)	0.383	0.612	0.361	0.080	0.266	0.938
	N	9	9	9	9	9	9

Table 4.16: Correlations between Hg and Total weight, Length , Se,Temp, pH and Conductivity in hermichromis fasciatus (dry season)

Dry Season		**Total weight (g)**	**Length (cm)**	**Se (mg/kg)**	**Temp (°C)**	**pH**	**Conductivity**
Hg (mg/kg)	Pearson Correlation	-0.249	-0.129	-0.274	0.426	0.451	-0.448
	Sig. (2-tailed)	0.519	0.742	0.475	0.253	0.224	0.226
	N	9	9	9	9	9	9

Table 4.17: Correlations between Hg and Total weight, Length , Se,Temp, pH and Conductivity in hermichromis fasciatus (wet season)

Wet Season		**Total weight (g)**	**Length (cm)**	**Se (mg/kg)**	**Temp (^oC)**	**pH**	**Conductivity (µS/cm)**
Hg (mg/kg)	Pearson Correlation	0.352	0.229	0.044	0.352	0.073	0.833*
	Sig. (2-tailed)	0.353	0.553	0.911	0.352	0.852	0.005
	N	9	9	9	9	9	9

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

Table 4.18: Correlations between Hg and Total weight, Length , Se,Temp, pH and Conductivity in clarias *laeviceps* (dry season)

Dry Season		**Total weight (g)**	**Length (cm)**	**Se (mg/kg)**	**Temp (^oC)**	**pH**	**Conductivity**
Hg (mg/kg)	Pearson Correlation	0.449	0.538	-0.576	0.59	0.157	-0.397
	Sig. (2-tailed)	0.225	0.135	0.105	0.094	0.687	0.29
	N	9	9	9	9	9	9

Table 4.19: Correlations between Hg and Total weight, Length , Se,Temp, pH and Conductivity in clarias *laeviceps* (wet season)

Wet Season		Total weight (g)	Length (cm)	Se (mg/kg)	Temp (^oC)	pH	Conductivity
Hg (mg/kg)	Pearson Correlation	-0.632	-0.724*	0.060	-0.406	0.073	-0.305
	Sig. (2-tailed)	0.068	0.027	0.879	0.278	0.852	0.425
	N	9	9	9	9	9	9

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

4.27 Conductivity versus Mercury

Table 4.11 gave a strong positive correlation coefficient of r = 0.660 (p< 0.05) but not significant in Tilapia zilli in the dry season. This means conductivity increases with increasing mercury concentration. A negative correlation coefficient r = - 0.126 indicates that as the conductivity increases, Total Mercury concentration decreases in the wet season. This correlation is not significant at $p < 0.05$ (Tables 4.11 and 4.12).

Mormyrops species (Table 4.13a) showed a weak positive correlation coefficient r = 0.023 between T- Hg and conductivity in the dry season which means conductivity increases with increasing T-Hg concentration. A weak negative correlation coefficient r = - 0.116 was observed in mormyrops species in Table 4.14 in the wet season and this also indicates that as the T- Hg concentration decreases, conductivity increases, but none of the above correlations are significant at $p < 0.05$.

Mormyrops anguiloides showed a strong negative correlation between T-Hg and conductivity with the r = 0.609 as shown in (Table 4.15) but not significant at $p < 0.05$.

The correlation coefficient r = 0.030 was also observed in the wet season between T-Hg concentration and conductivity. This positive correlation showed that conductivity increases as total mercury concentration increases.

Table 4.17 also recorded slight negative correlation coefficient of r = -0.448 which is a insignificant correlation at $p < 0.05$ in hermichromis fasciatus.

A strong positive correlation was observed between T-Hg and conductivity in hercmichromis fasciatus in the wet season. The correlation co-efficient r = 0.833 gave a strong correlation at a 0.01 significant level. This indicates that mercury concentration has a direct bearing on conductivity. The strong correlation may be due to the presence of other ions which are promoting the mercury transformation. Claria laeviceps gave a negative correlation in both the dry and the wet seasons, but the correlation is not significant at $p < 0.05$

4.28 Temperature versus Mercury

Tables 4.13a and 4.14 describe the correlation between T-Hg concentration and temperature in mormyrops species and mormyrops anguilloides. There existed a strong negative correlation with temperature, the correlation co-efficient r = - 0.608, but not significant at $p < 0.05$ in the dry season but the reverse in which r = 0.121 was observed in the wet season but still not significant at $p < 0.05$ in the normyrops species. Tilapia Zilli gave a weak positive correlation but not significant at $p < 0.05$ in both seasons. In the mormyrops species T-Hg concentration increases as the temperature increases.

In mormyrops anguilloides the two season recorded an inverse relationship of r = - 0.296 and a strong r = - 0.612 but not significant at $p < 0.05$ significant level.

In herrmichromis fasciatus in the two seasons a weak positive correlation was observed. The correlation coefficients r = 0.426 and 0.352 were observed but insignificant at $p < 0.05$. claria laeviceps also gave moderate positive correlation in the dry season at r = 0.59. An inverse relationship exists in the wet season at r = - 0.406. Table 4.19 and 4.20. The but none of the correlations are significant at $p < 0.05$

4.29 Correlation between T-Hg and Selenium.

Tables 4.11 -4.20 showed the inverse relationship between mercury and selenium in some fish species from the Kpong Reservoir. Various fish species, which include hermichromis fasciatus, mormyrops anguiloides and claria laeviceps recorded negative correlations between T-Hg and selenium during the dry season.The correlation co-efficient of hermichromis fasciatus recorded r = - 0.274 while claria laeviceps has r = - 0.576, but this correlation is not significant at $p < 0.05$ level. Some positive correlations between T-Hg and selenium in the dry season were also observed in the mormyrops species where the selenium concentration increases with increasing total mercury concentration. There exists an inverse relationship between selenium and T-Hg mercury in which an increase in the selenium concentration results in the decrease in the T-Hg concentration.

4.30 Correlation between T-Hg and Physical Parameters.

From Table 4.1 it can be observed that the pH of the water samples ranged from 6.6 to 7.02 in the dry season and from 6.88 to 7.78 in the wet season. This indicates that the water samples were acidic, neutral and slightly alkaline at some places. The highest negative correlation co-efficient of r = - 0.138 and lowest r = -.0.412 was observed in mormyrops species and tilapia zilli. This negative correlation shows that the pH of the water increases with decreasing concentration of total mercury during the dry and the wet seasons respectively, as shown in tables 4.11 and 4.13b

The positive correlation occurred in the clarias laeviceps during both seasons. This means that an increase in the pH led to the corresponding increase in the T-Hg concentration but this relationship is not significant at the significant level of $p < 0.05$. The correlation between T-Hg and conductivity recorded positive correlation in tilapia zilli. This also indicated the fact that the concentration of the total mercury also increases in tilapia zilli with increasing conductivity as shown in tables 4.11 and 4.12 in the two seasons but this correlation is significant at $p < 0.05$ level. The strong positive correlation of $r = 0.833$ occurred in hermichromis fasciatus during the wet season and this is highly significant (95%) significant level of $p = 0.05$. This could be attributed to the inflow or runoff over farmland on which chemicals such as weedicides were applied. This increases the ionic level of the water and this high ionic level constituted the mercury transformation factor. However, the negative correlation during the dry season shown in tables 4.17 and 4.19 indicates that as the conductivity increases, the T-Hg concentration decreases. This could also be attributed to the increase of ionic strength within the organism. This means that as more ions are in the water, the water will tend to move into the organism which leads to a decrease in the concentration of the T-Hg. There is no defined trend in the seasons since some fish samples recorded both a positive and a negative correlation co-efficient in both seasons.

The temperature values are all above 20°C which indicates that the water samples were considered to have a high temperature. At any given temperature, the pH portrays the acidic or basic character of a solution which is governed by the dissolved compounds and bio-geo chemical processes that have taken place. A change in pH may indicate the availability of some discharged effluent specifically if regularly recorded and monitored in addition to the conductivity of the water.

4.31 Correlation between T-Hg and Weight and Length in various Fish species

Tables 4.11-4.20 show the correlation between mercury concentrations and weight and length in various fish species. Total mercury concentrations were determined in some fish species in both the dry and the wet season from the Kpong Reservoir. In all about 90 samples of fish which consisted of 5 species were sampled. Of the species were tilapia zilli (n = 9). mormyrops species (n = 9) mormyrops anguiloides n = 9 hermichromis fasciatus (n = 9) and clarias laeviceps (n = 9) all of which are consumable (edible) by human. The mean T-Hg concentration in the fish species ranged from 0.04 to 0.04 mg/kg in the tilpia zilli, 0.02 to 0.06 mg/kg in the mormyrops species 0.04 to 0.28 mg/kg in mormyrops anguiloides, 0.04 to 0.12 mg/kg in hermichromis fasciatus and 0.04to 0.16 mg/kg in claria laeviceps with respective means of 0.03 mg/kg, 0.03 mg/kg , 0.08 mg/kg, 0.07 mg/kg and 0.1 mg/kg of the tilpia zilli, mormyrops species, mormyrops anguiloides, hermichromis fasciatus and claria laeviceps.

The range and the means of the weight and the length are recorded in Appendix C. All the samples showed that T-Hg concentration were below the WHO value of 0.5mgk/g in both the dry and the wet season (Appendix C). These values could be influenced by such factors as the age of the fish, organic matter and seasonal variation. The low levels of the trace metal, specifically mercury conservation obtained, fall within the range of levels of mercury reported by Bodaly *et al*, (1999).

Some of the five species of fish showed both positive and negative correlations between total mercury concentration and weight respectively. There exists a weak positive correlation with correlation co-efficients of r = 0.113 and 0.332 but this correlation is not significant at $p< 0.05$ level in mormyrops anguiloide in both the dry and the wet seasons. Mormyrops anguiloide recorded the highest value 0.090 mg/kg of T-Hg concentration in the dry season and the lowest of 0.06 mg/kg in the wet season. Since seasonal change is a factor, this low value could also be attributed to the dilution of the water in the river through runoff. On the other hand, the Kpong dam is periodically opened to decrease the water level. Since these fish samples were collected at the time that the water was conserved, this could be the cause of the dilution leading to an increase in the volume of water, hence low levels of the T-Hg during the wet season. The positive correlation of the T-Hg with weight also indicates that as the weight of the fish increases the concentration of the T-Hg increases as a result of bioaccumulation which normally occurs in large fish species.

Hermichrosmis fasciatus which recorded 0.05 mg/kg and 0.07 mg/kg during the two seasons could also be associated with the above factors. The relatively high levels could be due to the high trophic level in the food chain. The negative correlation co-efficient between mercury and length in the wet season showed that the increase in length of the fish resulted in the decrease in the concentration of the T-Hg in the fish; only in few cases could it be argued that the length influenced the total mercury concentration. With this, the age of the fish species, seasonal changes and regional variation could be responsible. The generally low levels of T-Hg concentration in the lake could be as a result of no or very little mercury contamination activities. Other factors of methylation which include organic matter and pH may also be responsible for the low level of mercury concentration. Action of microbial activities could reduce the level of metal mercury in the ecosystem. The poor correlations were in conformity of what had been reported by Castilhos *et al* 1998 for non-carnivorous Species.

Another reason for the weak and poor correlation could be the fish species are not representative of their diet. Even though no data is available to ascertain a general T-Hg trend, since the construction of Kpong Hydroelectric dam and no known artisanal mining along the lake, we can conclude, that the galamsey work on the Black Volta, which is one of the tributaries of the River Volta and which involves the use of mercury in addition to other natural and anthropogenic sources could be the cause. The low levels of T-Hg for this study could again be attributed to several factors. The hydrological condition is essential in increasing the mercury concentration in a hydroelectric reservoir. Generally, elevated levels of Hg in the fresh water fish as a result of construction of hydroelectric dams have been reported by (Ramsey, et al 1990). Since levels of mercury in this study were below the WHO threshold, the fish species from the Kpong Reservoir are fit for human consumption.

4.32 Levels of Trace Metals in Fish Species

In general, two - third of the earth's surface is covered by water, the rest is made up of land. The soil and water contain several organic and inorganic particles and gaseous liquid constituents which act as a sink and therefore bind the organic and inorganic pollutant to the surface of the soil colloid in the form of Fe-M-oxyhydrates, clay minerals and organic or biological systems (Evang, 1989). In this work a summary of the mean values of the metal, weight and length of the fish during both the dry and the wet seasons are shown in tables 4.21 and 4.22 respectively. The five (5) metals that were determined in this study were ranked on mg/kg basis in the order of Fe > Mn > Se > Hg where Hg was present in the lowest concentration while Pb was below the detection limit in tilapia zilli but in mormyrops anguiloides, hermichromis fasciatus and claris laeviceps , Fe and Mn were high while Se and Hg recorded the lowest concentration and ranked as Fe > Mn >Se > Hg during the dry season.

In another development, metal concentration could be ranked in order of Fe > Mn > Se >Hg in all the fish species except in clarias laeviceps in which Mn recorded the highest level followed by Fe, Se and Hg, that were lowest in the wet-season. There was no clear trend in the metal concentration with respect to the two seasons since different fish species were caught during both seasons. Since the fish species are in the water and they also feed based on their level in the food chain, the levels of these metals in the water are assimilated by the organism hence the result of the determination reflects the ability of the fish species to assimilate the metal ions. The increasing rate of the elements was in accordance with Chaisemartin (1983) who reported that fertilizers containing heavy metals could cause pollution to the water body, sediment and fish. In his report, Fe was present in the highest concentration of 6.45 mg/kg whereas other elements, which in accordance with this experimentwere Mn and Fe, recorded the highest concentration in all the five fish species.

In water, sediment and fish, application of fertilizers and other food substances to the river for fish farming could be a contributing factor to these high levels of some trace metals in addition to deposition of metals by runoff as well as atmospheric deposition.

Table 4.20: Mean metal concentration in some species of fresh water fish from Kpong Reservoir from Nov-Feb (Dry season)

Fish species	Se (mg/kg)	Hg (mg/kg)	Mn (mg/kg)	Pb (mg/kg)	Fe (mg/kg)	Weight (g)	Length (cm)
Tilapia zilli	0.98	0.02	27.42	BDL	27.92	218.17	21.19
Mormyrops species	0.04	0.02	38.12	BDL	38.73	865.40	62.06
Mormyrops anguilloides	1.09	0.09	27.94	BDL	27.76	723.17	52.72
Hermichromis	1.13	0.07	33.21	BDL	9.89	179.97	16.60
Claria laeviceps	2.5	0.10	16.68	BDL	15.47	180.67	22.67

Table 4.21 Mean metal concentration in some species of fresh water fish from Kpong Reservoir from May-July (Wet season)

Fish species	Se (mg/kg)	Hg (mg/kg)	Mn (mg/kg)	Pb (mg/kg)	Fe (mg/kg)	Weight (g)	Length (cm)
Tilapia	0.39	0.02	2.14	BDL	2.78	158.01	17.76
Mormyrop species	0.54	0.02	29.45	BDL	30.94	638.31	53.74
Mormyrop anguiloides	1.07	0.06	8.82	BDL	9.12	745.50	43.30s
Hermichromis	1.29	0.05	1.60	BDL	6.42	205.92	17.38
Clarialaeviceps	1.28	0.10	16.68	BDL	15.47	223.69	27.78

BDL = Below Detection Limit

4.33 Interaction between Selenium and Mercury

In this research, tables 4.11- 4.20 show the relationship that exists between mercury and selenium concentrations, tables 4.15, 4.17 and others show a negative correlation The mean concentrations of T-Hg and selenium in tilapia zilli were 0.02 mg/kg and 0.98 mg/kg in the dry season. The dry season recorded the highest mean values while the lowest values recorded in the wet season were 0.012 mg/kg for T-Hg and 0.39 mg/kg for selenium. Almost all the fish species recorded a similar trend of T-Hg and selenium concentration within the two seasons as shown in appendix C.

In both seasons the selenium concentrations in all the species were higher than the T- Hg concentration. The high levels of selenium concentration in this study were as a result of both bioaccummulatiom and biomagnifications which normally occur in large fish samples, specifically mormyrops anguiloides. This was also evident in studies, namely that selenium can be bioaccumulated and biomagnified in the food chain (Lemly, 1999; Muscatell *et al*, 2002) and cause adverse effect in the aquatic system. Lemly(1999) proposed a threshold value of 8, 12 and 10 µgg-^{1} for fish muscles, ovaries and eggs respectively. However our results were far below the proposed values indicating that the fish species caught are safe for human consumption. The high level of selenium tends to lower the concentration of T-Hg. And this leads to the detoxification of mercury in the presence of selenium thus demonstrating its antagonistic effect (Parizek and Ostadalova 1967). In this work, concentrations of T-Hg are lower than the concentrations of selenium, which is in agreement with the report that high levels of selenium is responsible for the detoxification of Hg due to the formation of equimolar Hg – Se complex which is biologically inert (Suzuki *et al*., 1998).

The Tema smelter which is less than 65km from the study site could be a contributory factor to the higher levels of Se than Hg. This slightly high level of selenium could limit the solubility, methylation and bioavailability of Hg. From other studies a threshold level of selenium must be attained before antagonistic or detoxification can take place (Hansen, 1988) within the organisms.

Redistribution and excretion of the correspondingly high level of Hg in the presence of Se might have occurred since low levels of Hg were recorded in this study. Results obtained could also be conclusively compared with the study reported by Shanker *et al* (1996a) using the Green House experiment in which plants accumulated less Hg (irrigated as mercuric chloride) when a selenite or a selenate solution (0.5 – 6.0 mg/kg) was applied to the soil or sand where they grew. In this, the authors assume that the in situ formation of HgSe was the cause of the reduction of Hg accumulation. Since there is no previous work done on selenium and mercury interaction in this reservoir to compare this work with, these results confirm the important role played by selenium in limiting the assimilation and toxicity of Hg and MeHg.

Further studies are expected to investigate the possible use of Se as a remediation agent against Hg contamination in the natural system.

4.34 Comparison with Previous Studies

The extent of concentration of trace metals and some physico-chemical parameters of water must be compared with previous studies to give a distinguishable level of the parameters analyzed. Table 4.23 compares the results of this study with previous results of research reported along the Lower Volta Basin by Amoah and Koranteng (2006) and elsewhere. The results of this study showed clearly that Parameters such as temperature, pH conductivity, total hardness, iron, chloride, fluoride and nitrate, gave lower values than those recorded in 2006, except nitrate which recorded the highest value. This high value could be ascribed to run offs from farmland on which agrochemicals such as fertilizers(N.P.K) were used on the soil.

The results of this study are also lower than the results of the studies carried by Kwaansa-Ansah *et al*. (2012). According to their results, sediment recorded the highest level of total mercury which ranged from 0.0096 to 0.7005 mg/kg followed by the fish of 0.00 21 to 0. 3556 mg/kg while water recorded the lowest ranging from 0.0027 to 0.086 mg/L.

The same trend was observed in this study. Though the values were comparatively low, the concentrations of total mercury recorded in the sediment ranged from 0.01 to 0.2 mg/kg, followed by the fish of 0.02 to 0. mg/kg while that of water ranged from 0.001 to 0.003mg/L. The high level of Hg in the sediment holds since the primary sink for mercury is the bottom sediment where an inorganic form of mercury undergoes methylation to form an organic form which could enter the food chain or could be released into the atmosphere by volatilization due to biogeochemical factors in the sediment (Chen et al, 2008).

Physico-chemical parameters greatly contribute to the transformation of inorganic mercury to methylmercury that in turn determines its potential for bioaccumulation and biomagnification in the food web (Chen et *al*, 2008).

Carolina *et al* (2011) observed an inverse relationship between selenium and mercury and found that concentrations below 0.040 mg/kg gave a negative correlation between mercury and selenium while those concentration above 40 mg/kg had a positive correlation. This observation was in agreement with the present study.

As shown in this study, the low level of T- Hg in fish species analyzed indicates a comparatively clean aquatic environment which has not yet been contaminated by anthropogenic means.

Table 4.22: Range of some physico-chemical parameters of previous research compared this study

Parameter	Temp (°C)	pH	Cond (µS/cm)	Nitrate (mg/L)	Chloride (mg/L)	Total Hardness	Iron (mg/L)	Fluoride (mg/L)
Reported	27-30	6.9-7.9	99-287	0.1-0.5	13-276	61-175	0.02-.05	0.2-1.2
This study	26-26.73	6.29-7.78	53.78-87.77	0.25-0.45	5.34-8.69	30-42.61	0.06-0.49	0.05-0.09

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The analyses of surface water quality, trace metal levels in sediments and fish from the Kpong Reservoir suggest the following conclusions:

The mean values of all the physicochemical parameters of water from the Kpong Reservoir on the Lower Volta river were below the WHO threshold values except for phosphate which recorded a standard deviation of ±0.02 for the WHO guideline value of 0.3 mg/ L and manganese which recorded 0.71 mg/L instead of 0.5 mg/L.

The physicochemical parameters were generally higher in the dry season compared with the wet season. This physicochemical parameter of the water in the dry season should be monitored over a period of time because of a possible threat to an elevated concentration after a prolonged and continuous intake of the water.

All the trace metal levels in water were below the WHO guideline limit except lead which was higher than the WHO threshold limit of 0.05 mg/L, but the levels of the trace metals were generally higher in the dry season compared to the wet season.

Trace metal levels in the sediment were higher in the dry season than in the wet season except for iron which was higher in the wet season than in the dry season.

Levels of the trace metals recorded in both the wet and the dry season were below the WHO threshold value.

Levels of trace metals in fish species were generally higher in the dry season than in the wet season and ranked in order of Fe > Mn > Se > Hg > Pb but were lower in the wet season and ranked as Mn > Fe > se > Hg > Pb where lead levels are below the detection limit of the AAS used.

In case of the influence or the effect of physical parameters, a weak negative correlation was observed in tilapia zilli and mormyrops species with correlation coefficients of r = - 0.412 in the dry season and (r = -0.138) in the wet season which indicates an increase in PH with a decrease in mercury concentration, which means that mercury transformation is likely to occur in an acidic medium,

Conductivity increases with an increasing mercury concentration in the tilapia zilli and the mormyrops species in the dry season showed a strong correlation coefficient of r = 0.660 in tilapia zilli and a weak correlation coefficient of r =0.023 in the mormyrops species in the wet season but increases with decreasing mercury concentration in the wet season with a weak negative correlation coefficient of r = - 0.126.

Temperature increases with decreasing mercury concentration in mormyrops anguilloides at correlation coefficient of r = 0.121. This means total mercury transformation occurs at a low temperature.

Negative correlations were observed in some fish species, and this indicates an inverse relation in the fish samples between selenium and mercury. In this relationship, as selenium concentration increases, Hg concentration decreases.

In general, metal concentrations are higher in sediment followed by water and fish

5.2 Recommendations

The following recommendations are as a result of this research.

More research should be carried out on the same fish species, since bioaccumulation makes fish species toxic for human consumption.

It will be beneficial to establish long-term monitoring stations in the basin to regulate anthropogenic activities that lead to unwholesomeness of the water, sediments and fish species.

Determination of other trace metals such as Zn, Cd, Cr, As, other species of Hg, etc. in aquatic sources in the fish species under consideration should be carried out since trace metals, especially mercury, bioaccumulate in living organisms rendering them toxic for human consumption.

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APPENDICES

APPENDIX A

TABLES OF PHYSICO - CHEMICAL PARAMETERS OF WATER SHOWING THE MEAN AND STANDARD DEVIATIONS

Temperature °C

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	28.2	28.65	28.3	28.75	28.85	28.25	27	26.4	25.35	25.55
January	25.55	25.9	26.45	26.2	25.75	26.7	26.35	26.7	26.6	26.9
February	26.9	26.45	26.4	27.1	26.8	26.4	26.2	26.05	26.45	26.55
Mean	26.88	27.00	27.05	27.35	27.13	27.12	26.52	26.38	26.13	26.33
std	±1.33	±1.46	±1.08	±1.29	±1.58	±0.99	±0.43	±0.33	±0.68	±0.70
May	23.85	22.8	24.2	23.35	23.85	25.2	25.05	24.75	23.95	23
June	27.35	26.7	25.85	25	26	26.05	24.7	25.95	26.7	26.2
July	28.5	28.65	25.8	28.75	28.85	25.55	28.7	28.5	28.75	28.6
mean	26.88	27	27.05	27.35	27.13	27.12	26.52	26.28	26.13	26.33
Std	±2.42	±2.98	±0.94	±2.77	±2.51	±0.43	±2.22	±1.92	±2.41	±2.81

pH

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	6.94	6.95	7.1	7.03	6.91	7.11	7.02	7.03	7.08	6.87
January	6.41	6.81	6.9	6.98	7.08	7.12	6.29	6.76	6.79	7.17
February	6.63	6.79	6.87	6.92	6.92	6.84	6.75	6.4	6.76	7.01
mean	6.66	6.85	6.96	6.98	6.97	7.02	6.69	6.73	6.88	7.02
std	±0.27	±0.09	±0.13	±0.06	±0.10	±0.16	±0.37	±0.32	±0.18	±0.15
May	6.78	6.79	6.87	7.17	7.12	7.1	7.15	6.94	7.13	7.1
June	6.82	6.95	6.47	7.11	7.05	7.1	7.03	6.94	7.12	7.06
July	7.78	6.9	7	7.01	7.01	7.03	7.05	7	7.01	7.01
mean	7.13	6.88	6.78	7.10	7.06	7.08	7.08	6.96	7.09	7.06
std	±0.27	±0.09	±0.13	±0.06	±0.10	±0.16	±0.37	±0.32	±0.18	±0.15

CONDUCTIVITY µs/cm

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	66.7	64.2	65.9	65.05	65	63.05	66.1	63.55	63.7	68.95
January	88.5	62.8	57.35	68.35	54.65	78.7	77.1	65.65	64.1	62.7
February	89.35	66.55	63.9	72.45	62.5	78.45	86.05	65.55	64.1	65.7
mean	89.35	66.55	63.9	72.45	62.5	78.45	86.05	65.55	64.1	65.7
std	±12.84	±1.89	±4.47	±3.71	±5.40	±8.96	±9.99	±1.18	±0.23	±3.13
May	94.15	53.3	46.25	51.4	46.75	57.7	66.3	69.35	66.9	69.55
June	94.2	54.55	46.9	50.5	47.4	57.6	65.85	69.25	67.4	69.55
July	93.7	54.1	46.3	50.45	46.4	57	65.05	68.45	66.8	68.95
mean	94.02	53.98	46.48	50.78	46.85	57.43	65.73	69.02	67.03	69.35
std	±0.28	±0.63	±0.36	±0.53	±0.51	±0.38	±0.63	±0.49	±0.32	±0.35

TDS mg/L

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	28	17.5	69.5	160	70.5	44	91	75.5	75	101
January	27.5	17	59.5	207	81	52.5	94	71	74	89
February	44.6	25.7	70.6	24.1	68.75	148.5	59.85	66.05	67.2	52.85
mean	33.37	20.07	66.53	130.37	73.42	81.67	81.62	70.85	72.07	80.95
std	±9.73	±4.89	±6.12	±94.98	±6.63	±58.04	±18.91	±4.73	±4.24	±25.06
May	47.3	26.7	22.8	27.75	23.45	28.88	33.15	34.68	33.45	36.51
June	47.1	27.3	23.5	25.2	23.85	28.88	33.2	34.33	33.7	37.57
July	46.45	27.05	23.15	25.25	23.2	28.5	32.53	34.23	33.4	36.9
mean	46.95	27.02	23.15	26.07	23.50	28.75	32.96	34.41	33.52	36.99
std	±0.44	±0.30	±0.35	±1.46	±0.33	±0.22	±0.37	±0.24	±0.16	±0.54

ALKALINITY mg/L

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	32.5	38	34	36	33	34	38	41	41	40.5
January	37.5	42.5	40	38	40	41	42.5	41	37.5	43
February	37	42.5	42.5	39.5	39.5	39	44.5	43.5	40	43
mean	35.67	41.00	38.83	37.83	37.50	38.00	41.67	41.83	39.50	42.17
std	±2.75	±2.60	±4.37	±1.76	±3.91	±3.61	±3.33	±1.44	±1.80	±1.44
May	38	38	33	39	35	32.5	30	33.5	27	38
June	36.95	36.6	32.1	38.05	33.85	31.4	29.4	33.65	26.4	32.1
July	36.3	35.8	31.4	36.95	33.65	31.05	28.65	32.85	25.8	31.1
mean	37.08	36.80	32.17	38.00	34.17	31.65	29.35	33.33	26.40	33.73
std	±0.86	±1.11	±0.80	±1.03	±0.73	±0.76	±0.68	±0.43	±0.60	±3.73

Na^+ mg/L

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	8.6	8.45	8.5	8.55	8.05	8.35	9.05	8.25	8.15	7.08
January	8.7	8.75	9.1	8.65	8.45	8.1	8.55	8.2	8.75	7.55
February	8.2	9.35	9.4	8.75	8.65	7.8	8.4	8.7	8.85	7.95
mean	8.50	8.85	9.00	8.65	8.38	8.08	8.67	8.38	8.58	7.53
std	±0.26	±0.46	±0.46	±0.10	±0.31	±0.28	±0.34	±0.28	±0.38	±0.44
May	8.55	10.05	7.9	8.95	9.9	1±0.9	9.05	8.2	9.2	8.3
June	8	10.15	7.4	8.55	9.85	6.71	8.55	7.9	8.85	7.95
July	7.4	7.05	6.08	23.55	9.35	9.8	8.2	7.45	8.3	7.35
mean	4.68	9.08	7.13	13.68	9.70	9.14	8.60	7.85	8.78	7.87
std	±1.05	±1.76	±0.94	±8.55	±0.30	±2.17	±0.43	±0.38	±0.45	±0.48

K^+ mg/L

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	5.4	5.1	4.85	5	4.7	4.95	5.05	5.3	5.05	4.65
January	5.1	5.3	5.25	4.95	5.15	5.05	5.05	5.55	5.35	5.25
February	5.05	5.7	5.25	4.65	5.15	4.75	5.65	5.5	5.75	5
mean	5.18	5.37	5.12	4.87	5.00	4.92	5.25	5.45	5.38	4.97
std	±0.19	±0.31	±0.23	±0.19	±0.26	±0.15	±0.35	±0.13	±0.35	±0.30
May	4.95	5.1	4.95	5.5	5.45	5.1	4.95	4.75	5.15	5
June	4.65	5.65	4.85	5.4	4.9	5.05	4.3	4.15	4.95	4.85
July	4.45	4.9	4	4.9	4.2	4.5	4.05	3.7	4.5	4.35
mean	4.68	5.22	4.60	5.27	4.85	4.88	4.43	4.20	4.87	4.73
std	±0.25	±0.39	±0.52	±0.32	±0.63	±0.33	±0.46	±0.53	±0.33	±0.34

Cl^- mg/L

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	6.38	3.76	6.38	6.74	5.67	9.93	6.38	4.75	6.38	8.15
January	7.88	3.47	6.38	7.37	6.31	9.36	7.66	4.89	6.52	8.86
February	7.02	4.25	7.16	7.02	6.17	9.36	7.09	4.54	7.09	8.65
mean	7.09	3.83	6.64	7.04	6.05	9.55	7.04	4.73	6.66	8.55
std	±0.75	±0.39	±0.45	±0.32	±0.34	±0.33	±0.64	±0.18	±0.38	±0.36
May	5	11.99	4.99	4.44	4.99	8.99	6.45	4.99	6.44	7.99
June	4.99	7.51	3.94	5.21	4.91	6.84	6.13	4.54	6.15	6.98
July	4.19	3.6	3.18	3.55	4.21	7.66	5.64	4.19	5.54	6.39
mean	5.00	9.75	4.47	4.83	4.95	7.92	6.29	4.77	6.30	7.49
std	±0.46	±4.20	±0.91	±0.83	±0.43	±1.09	±0.41	±0.40	±0.46	±0.81

F^- mg/L

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	0.06	0.13	0.11	0.1	0.05	0.05	0.08	0.14	0.07	0.11
January	0.07	0.07	0.12	0.11	0.06	0.06	0.08	0.11	0.13	0.11
February	0.03	0.06	0.09	0.13	0.11	0.06	0.08	0.1	0.12	0.11
mean	0.05	0.09	0.11	0.11	0.07	0.06	0.08	0.12	0.11	0.11
std	±0.02	±0.04	±0.02	±0.02	±0.03	±0.01	±0.00	±0.02	±0.03	±0.00
May	0.04	0.07	0.04	0.1	0.04	0.09	0.05	0.07	0.1	0.05
June	0.05	0.05	0.04	0.07	0.03	0.06	0.05	0.04	0.07	0.04
July	0.04	0.04	0.03	0.04	0.02	0.03	0.03	0.03	0.04	0.03
mean	0.043	0.053	0.037	0.070	0.030	0.060	0.043	0.047	0.070	0.040
std	±0.006	±0.015	±0.006	±0.030	±0.010	±0.030	±0.012	±0.021	±0.030	±0.010

Nitrate mg/L

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	0.35	0.36	0.27	**0.31**	0.39	0.29	0.22	0.22	0.26	0.2
January	0.51	0.7	0.48	**0.5**	0.47	0.7	0.73	0.38	0.45	0.48
February	0.38	0.37	0.45	**0.3**	0.39	0.5	0.48	0.59	0.38	0.38
mean	0.41	0.48	0.40	**0.37**	0.42	0.50	0.48	0.40	0.36	0.35
std	±0.09	±0.19	±0.11	**±0.11**	±0.05	±0.21	±0.26	±0.19	±0.10	±0.14
May	0.78	0.45	0.29	**0.29**	0.4	0.21	0.22	0.21	0.26	0.16
June	0.35	0.39	0.25	**0.27**	0.36	0.19	0.2	0.19	0.42	0.15
July	0.33	0.38	0.81	**0.26**	0.34	0.16	0.19	0.18	0.23	0.13
mean	0.49	0.41	0.45	0.27	0.37	0.19	0.20	0.19	0.30	0.15
std	±0.25	±0.04	±0.31	±0.02	±0.03	±0.03	±0.02	±0.02	±0.10	±0.02

Sulphate mg/L

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	3.84	4.71	5.52	5.39	6.62	1.54	2.65	6.08	1.16	4.28
January	0.34	3.59	5.04	4.82	6.18	0.36	2.25	5.83	1.19	3.64
February	0.76	4.67	0.72	4.25	6.08	0.35	1.96	5.14	1.3	3.45
mean	1.65	4.32	3.76	4.82	6.29	0.75	2.29	5.68	1.22	3.79
std	±0.91	±0.64	±2.64	±0.57	±0.29	±0.68	±0.35	±0.49	±0.07	±0.43
May	BDL	5.667	5.67	5.5	6.62	0.167	2.25	6.08	1.5	4.17
June	0.992	2.33	6.1	5.58	8.1	4.49	1.9	6.08	2.66	2.16
July	BDL	5.33	11.83	5	6.33	0.17	2.92	6.33	1.25	4.5
mean	0.33	4.44	7.87	5.36	7.02	1.61	2.36	6.16	1.80	3.61
std	±0.17	±1.84	±3.44	±0.31	±0.95	±0.50	±0.52	±0.14	±0.75	±0.27

Phosphate mg/L

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	0.03	0.04	0.04	0.003	0.07	0.25	0.07	0.05	0.06	0.06
January	0.57	0.57	0.49	0.36	0.43	0.61	0.3	0.46	0.38	0.37
February	0.38	0.53	0.63	0.32	0.53	0.39	0.48	0.53	0.4	0.45
mean	0.33	0.38	0.39	0.23	0.34	0.42	0.28	0.35	0.28	0.29
std	±0.27	±0.30	±0.11	±0.20	±0.24	±0.18	±0.21	±0.26	±0.19	±0.21
May	0.01	0.39	0.02	0.01	0.05	0.23	0.05	0.04	0.04	0.06
June	0.01	0.03	0.03	0.19	0.05	0.22	0.02	0.04	0.03	0.05
July	0.04	0.03	0.02	0.04	0.04	0.21	0.01	0.03	0.02	0.04
mean	0.02	0.15	0.02	0.08	0.05	0.22	0.03	0.04	0.03	0.05
std	±0.02	±0.07	±0.02	±0.10	±0.05	±0.22	±0.02	±0.04	±0.03	±0.05

Total Hardness mg/L

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	52	48	42	24	50	32	22	24	24	48
January	50	54	54	58	56	38	38	42	32	34
February	44	42	50	48	54	50	54	52	50	38
mean	48.67	48.00	48.67	43.33	53.33	40.00	38.00	39.33	35.33	40.00
std	±4.16	±6.00	±6.11	±17.47	±3.06	±9.17	±16.00	±14.19	±13.32	±7.21
May	36.3	41.54	27.76	29.72	26.78	23.98	24.36	24.96	29.44	25.4
June	353.89	38.34	24.08	27.89	26.16	22.99	23.89	23.79	28.29	24.16
July	5.05	31.78	28.9	26.84	25.57	22.65	23.07	23	28.24	23.36
mean	32.41	37.22	26.91	28.15	26.17	23.21	23.77	23.92	28.66	24.31
std	±6.38	±4.98	±2.52	±1.46	±0.61	±0.69	±0.65	±0.99	±0.68	±1.03

Ca Hardness mg/L

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	15	14.34	13.32	14.34	24.66	15.32	15.66	14	16.68	21.34
January	14.4	15.2	12.4	16	15	13.6	20	19.2	16.2	18.4
February	13.8	15.6	14	14.6	16	18	16.2	16	15.2	17.8
mean	14.40	15.05	13.24	14.98	18.55	15.64	17.29	16.40	16.03	19.18
std	±0.60	±0.64	±0.80	±0.89	±5.31	±2.22	±2.37	±2.62	±0.76	±1.89
May	22.2	21.62	14.58	20	18.03	14.74	16.1	14.75	19.72	18.6
June	21.94	20.68	13.55	19.05	17.56	14.18	15.89	14.34	19.53	18.2
July	21.55	17.4	18.05	18.53	17.14	14.06	15.55	13.64	19.31	17.65
mean	21.90	19.90	15.39	19.19	17.58	14.33	15.85	14.24	19.52	18.15
std	±0.33	±2.22	±2.36	±0.75	±0.45	±0.36	±0.28	±0.56	±0.21	±0.48

Magnesium Hardness mg/L

Sites	**TM**	**FU**	**GC**	**GS**	**FN**	**KP**	**VK**	**LN**	**AS**	**AU**
November	37	33.66	28.68	9.66	25.34	16.68	6.34	10	7.32	26.66
January	35.6	38.8	41.6	42	41	24.4	18	22.8	15.8	15.6
February	30.2	26.4	36	33.4	38	32	37.8	36	34.8	20.2
mean	34.26	35.43	28.35	34.78	24.36	20.71	22.93	19.31	20.82	20.82
std	±6.23	±6.48	±16.75	±8.31	±7.66	±15.90	±13.00	±14.07	±5.56	±2.15
May	14.1	19.93	11.18	9.72	8.75	9.24	8.26	10.21	7.72	6.8
June	13.96	17.66	10.53	8.84	8.6	8.82	8.01	9.63	9.17	5.96
July	13.5	14.38	10.85	8.31	8.44	8.59	7.52	9.36	8.93	5.71
mean	13.85	17.32	10.85	8.96	8.60	8.88	7.93	9.73	8.61	6.16
std	±0.31	±2.79	±0.33	±0.71	±0.16	±0.33	±0.38	±0.43	±0.78	±0.57

APPENDIX B

Total Mercury (THg) levels in sediment mg/kg

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	0.03	0.03	0.03	0.04	0.03	0.04	0.05	0.04	0.04	0.03
January	0.03	0.05	0.04	0.05	0.05	0.05	0	0.02	0.01	0.02
February	0.07	0.38	1.06	0.14	0.7	0.03	0.01	0.01	0.01	0.03
May	0.03	0.05	0.05	0	0.04	0.05	0.01	0.02	0.01	0.04
June	0.02	0.02	0.03	0.01	0.03	0.02	0.01	0.01	BDL	0.01
July	0.01	0.02	0.01	0.02	0.02	0.02	0.03	0.01	BDL	0.03

Selenium (Se) levels in sediment mg/kg

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	0.35	0.47	0.34	0.29	0.47	0.36	0.45	0.34	0.43	0.44
January	0.42	0.55	0.35	0.51	0.44	0.43	0.41	0.43	0.25	0.27
February	0.28	0.2	0.35	0.44	0.56	0.55	0.49	0.35	0.48	0.48
May	0.11	0.21	0.17	0.1	0.17	0.13	0.14	0.26	0.06	0.12
June	0.2	0.13	0.15	0	0.07	0.15	0.05	0.15	0.17	0.16
July	0.17	0.1	0.11	0.18	0.05	0.03	0.15	0.11	0.14	0.04

Iron (Fe) levels in sediment mg/kg

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	132	131	132	131	132	133	132	133	133	134
January	161	163	164	162	163	161	160	158	159	159
February	163	166	168	162	163	165	162	160	161	158
May	205	201	193	200	196	190	185	191	172	189
June	197	197	190	197	191	182	175	187	82	183
July	193	196	189	195	189	182	174	187	163	182

Pb in levels in sediment mg/kg

Sites	TM	FU	GC	GS	FN	KP	VK	LN		AU
November	2.786	2.773	3.359	3.999	3.266	2.266	2.666	2.493	2.839	2.986
January	2.447	3.318	1.623	2.208	2.567	2.673	2.283	3.89	3.192	2.474
February	2.288	3.112	0.865	2.347	2.54	2.687	3.192	1.41	1.181	1.556
May	0.087	BDL	0.153	BDL	0.407	0.153	3.546	0.113	BDL	0.227
June	0.067	BDL	0.12	BDL	0.313	0.1	3.426	0.08	BDL	0.167
July	0.053	BDL	0.107	BDL	0.28	0.073	3.266	0.04		BDL

Manganese (Mn) levels in sediment mg/kg

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	0.293	0.227	1.106	0.36	1.293	0.6	0.44	1.04	0.413	0.293
January	0.326	0.818	0.685	0.512	0.705	1.702	1.682	0.333	0.166	0.18
February	0.432	1.111	0.698	0.685	0.858	0.432	1.796	0.219	0.226	0.499
May	0.58	0.72	0.7	0.66	0.607	0.48	0.5	0.62	0.227	0.573
June	0.373	0.507	0.52	0.2	0.507	0.42	0.567	0.54	0.033	0.54
July	0.32	0.633	0.42	0.16	0.587	0.393	0.467	0.373	0.133	0.527

Mercury (THg) levels in water mg/L

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	0.004	0.004	BDL	BDL	BDL	BDL	0.003	BDL	BDL	0.004
January	BDL	BDL	BDL	0.004	0.005	BDL	BDL	BDL	0.004	0.006
February	BDL	BDL	BDL	0.004	BDL	BDL	BDL	BDL	BDL	0.004
May	BDL	0.004	BDL	BDL	BDL	BDL	BDL	0.004	BDL	BDL
June	BDL	0.003	BDL	BDL	BDL	BDL	BDL	0.003	BDL	0.003
July	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.003

Selenium (Se) levels in water mg/L

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	0.003	0.004	0.004	0.006	0.006	0.004	0.006	0.005	0.004	0.006
January	0.006	0.005	0.004	0.007	0.005	0.006	0.005	0.005	0.004	0.004
February	0.006	0.006	0.004	0.006	0.006	0.004	0.005	0.005	0.005	0.005
May	0.005	BDL	0.004	0.005	0.005	0.003	0.006	0.004	0.004	0.005
June	0.003	BDL	BDL	0.003	BDL	BDL	0.004	BDL	0.003	0.004
July	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.003	0.003	0.003

Iron (Fe) levels in water mg/L

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	BDL	0.04	0.02	0.08	BDL	0.04	0.04	0.11	BDL	BDL
January	BDL	0.056	BDL	0.07	BDL	0.07	0.05	0.13	0.02	BDL
February	BDL	0.04	BDL	0.1	BDL	0.06	0.04	0.11	0.23	BDL
May	0.78	0.43	0.94	0.84	0.25	0.15	0.95	0.35	0.06	0.36
June	0.78	0.42	0.92	0.85	0.24	0.13	0.94	0.32	0.04	0.07
July	0.76	0.39	0.62	0.84	0.24	0.12	0.92	0.31	0.03	0.05

Lead (Pb) levels in water mg/L

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	0.42	0.4	0.41	0.26	0.31	0.14	0.3	0.09	0.14	0.12
January	BDL	0.02	0.01	BDL	0.01	0.01	BDL	0.01	BDL	BDL
February	BDL	0.006	0.008	BDL	0.004	BDL	BDL	BDL	BDL	BDL
May	BDL	BDL	0.33	0.24	0.09	0.06	0.10	0.19	0.39	0.25
June	0.28	0.17	0.25	0.19	0.07	0.04	0.05	0.17	0.37	0.35
July	0.25	0.14	0.18	0.20	0.05	0.07	0.12	0.14	0.33	0.3

Manganese (Mn) levels in water mg/L

Sites	TM	FU	GC	GS	FN	KP	VK	LN	AS	AU
November	0.22	0.32	0.08	0.12	0.25	0.11	0.06	0.05	0.04	0.08
January	0.21	0.08	0.04	0.06	0.26	0.19	0.03	0.07	0.06	0.06
February	0.22	0.11	0.05	0.04	0.22	0.18	0.05	0.10	0.07	0.07
May	0.13	0.21	0.08	0.04	0.01	0.01	0.01	0.01	0.1	0.1
June	0.10	0.19	0.06	0.03	0.004	0.006	0.004	0.006	0.08	0.08
July	0.09	0.18	0.03	0.02	0.004	0.004	0.004	0.006	0.07	0.07

APPENDIX C

Heavy metals concentrations in tilapia zilli

SEASON	sample ID	total weight (g)	length (cm)	Se (mg/kg)	Hg (mg/kg)	Mn (mg/kg)	Pb (mg/kg)	Fe (mg/kg)
DRY	DTZ1	291.42	24.70	0.72	0.04	7.92	BDL	24.00
	DTZ2	290.04	23.80	1.00	0.04	30.64	BDL	24.16
	DTZ3	288.63	21.90	1.00	0.00	35.48	BDL	19.52
	DTZ4	282.74	21.60	0.72	0.00	26.04	BDL	23.20
	DTZ5	175.30	20.80	0.60	0.00	12.72	BDL	25.32
	DTZ6	170.42	20.40	0.76	0.04	24.44	BDL	35.44
	DTZ7	163.32	19.50	1.28	0.04	34.32	BDL	35.56
	DTZ8	155.47	19.30	1.52	0.04	32.88	BDL	16.56
	DTZ9	146.21	18.70	1.20	BDL	42.32	BDL	47.48
MEAN		218.17	21.19	0.98	0.02	27.42	BDL	27.92

Heavy metals concentrations in *tilapia zilli*

SEASON	sample ID	total weight (g)	length (cm)	Se (mg/kg)	Hg (mg/kg)	Mn (mg/kg)	Pb (mg/kg)	Fe (mg/kg)
WET	WTZ1	321.34	26.50	1.08	BDL	2.64	BDL	12.00
	WTZ2	300.57	24.40	0.92	BDL	1.20	BDL	10.00
	WTZ3	142.43	18.00	0.72	BDL	2.32	BDL	6.80
	WTZ4	136.78	17.80	0.07	0.01	3.52	BDL	12.44
	WTZ5	130.59	16.90	0.17	0.03	1.76	BDL	10.20
	WTZ6	116.29	15.70	0.13	0.03	2.76	BDL	6.76
	WTZ7	111.48	14.40	0.09	0.03	1.24	BDL	5.32
	WTZ8	92.24	13.30	0.12	0.00	1.64	BDL	5.72
	WTZ9	70.39	12.80	0.16	0.01	2.20	BDL	6.16
MEAN		158.01	17.76	0.39	0.012	2.14	BDL	8.38

Heavy metals concentrations in mormyrops *species*

SEASON	sample ID	total weight (g)	length (cm)	Se (mg/kg)	Hg (mg/kg)	Mn (mg/kg)	Pb (mg/kg)	Fe (mg/kg)
	DMS1	1312.13	77.00	0.05	0.02	59.48	BDL	68.04
	DMS2	1136.34	75.00	0.05	0.02	41.40	BDL	35.40
	DMS3	945.26	68.00	0.04	0.02	39.28	BDL	45.20
	DMS4	852.70	62.70	0.05	0.02	31.72	BDL	24.04
	DMS5	830.45	65.30	0.05	0.02	40.72	BDL	37.40
DRY	DMS6	801.96	61.90	0.04	0.02	33.60	BDL	30.08
	DMS7	784.57	54.60	0.04	0.02	34.92	BDL	25.84
	DMS8	722.34	30.70	0.04	0.02	27.52	BDL	13.24
	DMS9	914.71	63.30	0.05	0.06	34.44	BDL	69.32
MEAN		922.27	62.06	0.04	0.03	38.12		38.73

Heavy metals concentrations in mormyrops *species*

SEASON	sample ID	total weight (g)	length (cm)	Se (mg/kg)	Hg (mg/kg)	Mn (mg/kg)	Pb (mg/kg)	Fe (mg/kg)
	WMS1	1543.41	85.50	1.24	0.02	8.84	BDL	.
	WMS2	1628.75	83.80	1.52	0.01	32.12	BDL	24.20
	WMS3	1162.57	73.70	0.88	0.03	36.72	BDL	19.52
	WMS4	875.21	58.60	0.32	0.01	25.84	BDL	23.68
WET	WMS5	620.61	48.40	0.21	0.04	36.24	BDL	47.60
	WMS6	515.78	42.70	0.20	0.01	34.64	BDL	36.30
	WMS7	394.89	37.90	0.19	0.04	33.24	BDL	35.92
	WMS8	250.74	28.60	0.17	0.01	31.84	BDL	35.52
	WMS9	347.66	24.50	0.09	0.01	25.60	BDL	24.80
MEAN		815.51	53.74	0.54	0.02	29.45	BDL	30.94

SEASON	sample ID	total weight (g)	length (cm)	Se (mg/kg)	Hg (mg/kg)	Mn (mg/kg)	Pb (mg/kg)	Fe (mg/kg)
DRY	DMA 1	748.21	46.97	1.24	0.00	8.84	BDL	24.12
	DMA 2	840.67	58.97	1.52	0.12	32.12	BDL	24.20
	DMA 3	753.46	51.56	0.88	0.28	36.72	BDL	19.52
	DMA 4	457.46	45.25	0.32	0.08	25.84	BDL	23.68
	DMA 5	568.23	42.52	0.36	0.08	13.28	BDL	24.44
	DMA 6	489.00	47.23	0.68	0.04	24.20	BDL	35.44
	DMA7	896.53	63.75	1.68	0.08	35.20	BDL	35.28
	DMA 8	975.31	65.74	1.84	0.08	33.60	BDL	16.44
	DMA 9	779.63	52.46	1.32	0.00	41.64	BDL	46.76
MEAN		723.17	52.72	1.09	0.08	27.94	!	27.76

Heavy metals concentrations in mormyrops anguilloides *species*

SEASON	sample ID	total weight (g)	length (cm)	Se (mg/kg)	Hg (mg/kg)	Mn (mg/kg)	Pb (mg/kg)	Fe (mg/kg)
WET	WMA1	875	48.42	0.8	0.04	3.52	BDL	12.44
	WMA2	742.2	53.28	0.44	0.04	1.76	BDL	10.2
	WMA3	914.35	541.75	0.6	0.04	2.76	BDL	6.76
	WMA4	543.1	56.83	1.67	0.04	1.24	BDL	5.32
	WMA5	538.12	28.96	1.45	0.04	1.64	BDL	5.72
	WMA6	674.76	28.54	1.72	0.08	2.2	BDL	6.16
	WMA7	729.47	34.71	0.92	0.04	31.28	BDL	12.4
	WMA8	678.42	43.587	0.84	0.04	33.8	BDL	20.12
	WMA9	893	38.49	1.2	0.12	1.2	BDL!	2.92

Heavy metals concentrations in hermichromis fasciatus *species*

SEASON	sample ID	total weight (g)	length (cm)	Se (mg/kg)	Hg (mg/kg)	Mn (mg/kg)	Pb (mg/kg)	Fe (mg/kg)
DRY	DHF1	106.46	16.68	1.20	0.04	31.84	BDL	24.64
	DHF2	110.01	17.50	1.12	0.12	36.24	BDL	19.64
	DHF3	34.57	12.68	0.52	0.04	25.60	BDL	23.96
	DHF4	64.25	13.76	0.68	0.12	13.12	BDL	24.80
	DHF5	84.35	14.52	0.92	0.08	24.00	BDL	35.52
	DHF6	352.81	20.00	1.48	0.08	34.64	BDL	35.92
	DHF7	510.23	21.20	1.76	0.04	33.24	BDL	16.80
	DHF8	200.42	18.30	1.52	0.04	40.88	BDL	47.60
	DHF9	120.61	14.80	0.96	0.04	59.36	BDL	36.00
MEAN		175.97	16.60	1.13	0.07	33.21	BDL	29.43

Heavy metals concentrations in hermichromis fasciatus *species*

SEASON	sample ID	total weight (g)	length (cm)	Se (mg/kg)	Hg (mg/kg)	Mn (mg/kg)	Pb (mg/kg)	Fe (mg/kg)
WET	WHF1	342.73	19.97	1.48	0.16	1.44	BDL	7.72
	WHF2	310.62	19.75	2.44	0.04	2.32	BDL	10.60
	WHF3	263.40	18.91	1.40	0.00	1.16	BDL	3.92
	WHF4	210.83	18.52	0.88	0.04	0.72	BDL	4.40
	WHF5	193.62	17.96	1.56	0.00	0.76	BDL	5.80
	WHF6	184.48	17.46	1.32	0.12	1.56	BDL	6.48
	WHF7	142.56	16.10	0.72	0.04	1.52	BDL	8.20
	WHF8	123.47	15.20	0.64	0.04	3.18	BDL	4.74
	WHF9	81.53	12.56	1.16	0.04	5.78	BDL	5.93
MEAN		205.92	17.38	1.29	0.05	2.05	BDL	6.42

Heavy metals concentrations in clarias *laeviceps species*

SEASON	sample ID	total weight (g)	length (cm)	Se (mg/kg)	Hg (mg/kg)	Mn (mg/kg)	Pb (mg/kg)	Fe (mg/kg)
DRY	DCL1	260.00	31.00	2.08	0.08	15.20	BDL	5.92
	DCL2	245.00	30.00	1.60	0.16	2.00	BDL	6.36
	DCL3	217.00	27.00	1.04	0.08	31.08	BDL	12.68
	DCL4	182.00	24.00	1.04	0.16	33.56	BDL	20.44
	DCL5	170.00	22.00	1.12	0.12	1.20	BDL	3.20
	DCL6	156.00	20.00	1.08	0.08	1.52	BDL	8.48
	DCL7	142.00	18.00	2.32	0.08	28.04	BDL	44.52
	DCL8	134.00	18.00	1.84	0.08	36.20	BDL	29.56
	DCL9	120.00	14.00	10.40	0.04	1.28	BDL	8.04
MEAN		180.67	22.67	2.50	0.10	16.68	BDL	15.47

Heavy metals concentrations in clarias *laeviceps species*

SEASON	sample ID	total weight (g)	length (cm)	Se (mg/kg)	Hg (mg/kg)	Mn (mg/kg)	Pb (mg/kg)	Fe (mg/kg)
WET	WCL1	273.54	38.00	0.80	#VALUE!	0.52	BDL	5.60
	WCL2	268.52	35.00	1.08	#VALUE!	2.00	BDL	6.28
	WCL3	262.91	33.00	1.00	0.04	1.40	BDL	8.32
	WCL4	258.32	31.00	1.26	0.04	3.52	BDL	12.44
	WCL5	243.53	28.00	1.68	0.04	1.76	BDL	10.20
	WCL6	220.80	26.00	1.84	0.04	2.76	BDL	6.76
	WCL7	180.57	23.00	1.32	0.04	1.24	BDL	5.32
	WCL8	166.35	20.00	0.72	0.08	1.64	BDL	5.72
	WCL9	138.63	16.00	1.84	0.04	2.20	BDL	6.16
MEAN		223.69	27.78	1.28	#VALUE!	1.89	BDL	7.42

SEDIMENT

APPENDIX D

microwave programme for digestion of fish.

Step	Time	Power	Pressure	Temp °C 1	Temp °C 2
1	00:01:00	250	100	400	500
2	00:01:00	0	100	400	500
3	00:05:00	250	100	400	500
4	00:05:00	400	100	400	500
5	00:05:00	650	100	400	500
Vent:00:05:00		Rotorctrl on		Twist on	

Ref: Milestone Acid Digestion Cookbook update 1st January 1996

Microwave programme.of digestion of sediment

Step	Time	Power	Pressure	Temp °C 1	Temp °C 2
1	00:05:00	250	100	400	500
2	00:01:00	0	100	400	500
3	00:10:00	250	100	400	500
4	00:05:00	450	100	400	500
Vent:00:05:00		Rotorctrl on		Twist on	

Ref: Milestone Acid Digestion Cookbook update 1st January 1996

Microwave program of digestion of water.

Step	Time	Power	Pressure	Temp ^{o}C 1	Temp ^{o}C 2
1	00:05:00	250	100	400	500
2	00:01:00	0	100	400	500
3	00:10:00	250	100	400	500
4	00:05:00	450	100	400	500
Vent:00:05:00		Rotorctrl on		Twist on	

Ref: Milestone Acid Digestion Cookbook update 1st January 1996

WORKING CONDITION FOR DIGESTION OF FISH.

ELEMENT	WAVELENGTH nm	LAMP CURRENT nA	SLIT WIDTH nm	FUEL	SUPPORT
Zn	213.9	5	1.0	ACETYLENE	AIR
Pb	217.0	5	1.0	ACETYLENE	AIR
Cu	324.7	4	0.5	ACETYLENE	AIR
Fe	248.3	5	0.2	ACETYLENE	AIR
Mn	279.5	5	0.2	ACETYLENE	AIR
Cr	357.9	7	0.2	ACETYLENE	AIR
Hg(BY HYDRIDE)	253.7	4	0.5	ARGON	AIR

Ref: VARIAN. Publication No 85- 100009-00 Revised March 1989.

WORKING CONDITIONS FOR DIGESTION OF SEDIMENT

ELEMENT	WAVELENGTH nm	LAMP CURRENT nA	SLIT WIDTH nm	FUEL	SUPPORT
Zn	213.9	5	1.0	ACETYLENE	AIR
Pb	217.0	5	1.0	ACETYLENE	AIR
Cu	324.7	4	0.5	ACETYLENE	AIR
Fe	248.3	5	0.2	ACETYLENE	AIR
Mn	279.5	5	0.2	ACETYLENE	AIR
Cr	357.9	7	0.2	ACETYLENE	AIR
Hg(BY HYDRIDE)	253.7	4	0.5	ARGON	AIR

Ref: VARIAN. Publication No 85- 100009-00 Revised March 1989.

WORKING CONDITIONS FOR DIGESTION OF WATER .

ELEMENT	WAVELENGTH nm	LAMP CURRENT nA	SLIT WIDTH nm	FUEL	SUPPORT
Zn	213.9	5	1.0	ACETYLENE	AIR
Pb	217.0	5	1.0	ACETYLENE	AIR
Se(by hydride)	196.0	10	1.0	ACETYLENE	ARGON
Fe	248.3	5	0.2	ACETYLENE	AIR
Mn	279.5	5	0.2	ACETYLENE	AIR
Cr	357.9	7	0.2	ACETYLENE	AIR
Hg(BY	253.7	4	0.5	ACETYLENE	ARGON

APPENDIX E

RESULTS OF STANDARD REFERENCE MATERIALS (NIST) SHOWING REPORTED AND LOCAL LABORATORY VALUES

Parameters	Reported (mg/L)	measured (mg/L)
Na	100	99.8
K	100	100
Hg	0.04	0.038
Se	0.04	0.036
Fe	5	5.004
Mn	10	10.2
Pb	5	4.993