KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

COLLEGE OF SCIENCE

DEPARTMENT OF CHEMISTRY

ASSESSMENT OF RADIONUCLIDES ACTIVITIES AND HEAVY METALS CONTAMINATION IN SEDIMENTS, WATER AND FISH IN LAKE BOSOMTWI AND BUI DAM

BY:

EUGENE ANSAH

JUNE, 2015

ASSESSMENT OF RADIONUCLIDES ACTIVITIES AND HEAVY METALS CONTAMINATION IN SEDIMENTS, WATER AND FISH IN LAKE BOSOMTWI AND BUI DAM

By:

Eugene Ansah

BSc. (Hons) (Dip Ed.) Chemistry

A Thesis submitted to the Department of Chemistry of the Kwame Nkrumah University of Science and Technology, in partial fulfilment of the requirements for the degree of Master of Philosophy (Analytical Chemistry)

JUNE, 2015

DECLARATION

I hereby declare that this thesis is the outcome of research work undertaken by the author towards the MPhil degree and to the best of my knowledge, contains no work previously published nor material accepted for another degree of the University except where due acknowledgment has been given in the text.

Signature…… DATE……

Eugene Ansah

PG 1036613

Signature…….. DATE……..…

Dr. Godfred Darko

(SUPERVISOR)

Signature…….. DATE……..…

Dr. Augustine Faanu

(SUPERVISOR)

Certified by:

Signature…… DATE…….

Dr. Godfred Darko

(HEAD OF DEPARTMENT)

DEDICATION

This work is dedicated to my father, Mr. Charles Degraft Quansah Esq. who has been a source of inspiration in my academic pursuit, my cheer leader and No. 1 financier and to the Blessed memory of Mr. Joseph Ansah and Sylvester Oscar Baah.

ACKNOWLEDGEMENT

This work has been made possible out of the amazing grace of the Lord God Almighty. I am therefore grateful to Him for the ideas, wisdom, travelling mercies and the sense of responsibility He filled me with. Special thanks go to my supervisors, Dr. Godfred Darko and Dr. Augustine Faanu for their immeasurable support, guidance, patience and love throughout this work. I say God bless you for all your loss.

I am grateful to all lecturers of the Department of Chemistry, KNUST and for the assistance of Mr. David Kpeglo, Mr. Charles Kansaana, Mrs. Rita Kpodzro, Mrs. Lillian Agyemang and all laboratory staff at Radiation Protection Institute, GAEC-Accra as well as my colleagues in the postgraduate class.

Lastly, I acknowledge the support, encouragement and financial assistance given to me by my mum, Mrs. Esther Ansah, and family viz: Mr. William Ansah, Mrs. Getrude Osei-Tutu, Mr. and Mrs. Kwaw Asare, Mr. Anthony Mensah and Miss Roberta Ansah, Andrew, Albert, Juliana, Paul and David Ansah, Fred Opoku Sarkodie, Grace Osaah Agyemang, Wilhemina Abena Acheampomaa Osei-Tutu, Joseph Ansah, Benjamin Osei-Tutu and John Amoah-Mensah (Lecturer, Sunyani Polytechnic).

ABSTRACT

Concentration of heavy metals and natural radioactivity were measured in water, sediment and fish samples from Lake Bosomtwi and Bui dam. The concentrations of the heavy metals in sediments were found to decrease in the sequence, Fe > Mn > Ni > Zn > Cr > Cu > Co > As > Hg for Lake Bosomtwi and Fe > Mn > Ni > As > Cr > Zn > Cd > Cu for Bui dam. Heavy metal concentration in water was in the order: Fe > Pb > Mn > Zn = As > Cd = Cr in Lake Bosomtwi and Fe > As > Pb > Mn > Cd = Zn > Cr for Bui dam whilst metal concentration in fish samples was in the order: Fe > Zn > Mn > Cu > Ni > Pb > Cr > Cd > Hg for Lake Bosomtwi and Fe > Mn > Zn > Cu > Ni > Pb > Cr > Cd > Hg for Bui dam. The study indicated a general absence of serious pollution in the two reservoirs with respect to heavy metals. The activity concentration due to ^{238}U, ^{232}Th and ^{40}K determined with the γ- spectrometer indicated that the surface water radioactivity concentration of ^{238}U, ^{232}Th and ^{40}K were ranging from 0.20±0.07 to 0.98±0.24, 0.03±0.08 to 0.82±0.13 and 0.02±0.67 to 3.32±0.77 Bq/L respectively for Lake Bosomtwi and from 0.13±0.08 to 0.42±0.01, 0.07±0.14 to 0.82±0.14 and 0.78±0.73 to 2.42±0.75 Bq/L respectively for Bui Dam. The average annual effective dose due to ingestion of radionuclide in water ranged from 20.5 to 156 and 26.5 to 162 μSv/year for Lake Bosomtwi and Bui Dam respectively. The average activity concentration of ^{238}U, ^{232}Th and ^{40}K in the sediment from the two reservoirs was 7.90, 7.83 and 169.73 Bq/kg respectively for Lake Bosomtwi and 7.56, 8.11 and 49.0 Bq/kg respectively for Bui Dam which is lower than world averages. The determined absorbed dose rate and annual effective dose for the sediments ranged from 12.41 to 18.74 nGy/year and 15.2 to 23.0 μS/year respectively for Lake Bosomtwi and 8.68 to 11.47 nGy/year and 10.6 to 14.1μS/year respectively for Bui Dam which are within worldwide recommended average of 59 nGy/year and 100 μS/year. None of the radioactivity is expected to cause

significant health problems to human beings through ingestion of water, consumption of fish or use of sediments for building purposes.

Keywords: Lake Bosomtwi; Bui dam; Heavy metals; Radioactivity; Hazard indices; Absorbed dose rate; Annual effective dose.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AFs	Accumulation factors
AVS	Acid Volatile sulphide
BSAF	Biota Sediment accumulation factor
CEQG	Canadian Environmental Quality Guideline
DTA	Differential Thermal Analyser
FAO	Food and Agricultural Organisation
FT-IR	Fourier transform Infra-red
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
NORMs	Naturally Occurring Radioactive Materials
OECD	Organisation for Economic Cooperation and Development
TGA	Thermogravimetric Analyser
UNSCEAR	United Nations Scientific Committee on the effects of Atomic Radiation
USEPA	United States Environmental Protection Agency
US-FDA	United States Food and Drugs Authority
WHO	World Health Organisation

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Environmental radioactivity of natural origin and the exposure associated with it externally as a result of gamma radiation hinges on the geographical and geological conditions of the area and are prominent at different concentrations in the World (UNSCEAR, 2000a). The rate of gamma dose distribution in the natural terrestrial environment is a major donor to the mean dose accepted by the populace (Tso & Leung, 2000). Estimating the doses of radiation circulating in the environment is key in examining the health exposure to a populace and provides a locus for recording variations in environmental radioactivity as a result of anthropogenic works (Obed et al., 2005). Human beings become exposed to radionuclides through pollution of the food chain which results from the direct deposit of radionuclides on sediment or water, leaves of plants, and from drinking of contaminated water and eating of contaminated fish (Avwiri et al., 2007).

Water sources from areas that are rich in naturally occurring radioactive materials exhibit high levels of radioactivity (Caroli et al., 2013). Natural water contains several α and β emitting isotopes in wide range of concentrations (Al-Amir et al., 2012). The predominant radionuclides found in water include ^{226}Ra, ^{232}Th, ^{137}Cs and ^{238}U and their decay products as well as ^{40}K (Khayet & Matsuura, 2013).

Ingested radionuclides are absorbed into the bloodstream and accumulate in specific tissues such as the kidneys, bones and flesh from where they exert both chemical- and radio- toxicities (Avwiri et al., 2007; Bonotto et al., 2009). Even small concentrations of a radioactive substance have the ability to produce a damaging biological effect (El-

Mageed et al., 2011). Alpha emitters are particularly of concern because of their high linear energy transfer. Measurements of gross α and β activities, therefore, serve as useful screening techniques that provide essential information about natural radionuclides in water used for drinking and help in examining the radiological impact on a population. As a result of the high radiotoxicity of the radionuclides (Khodashenas, 2012; Nriagu, 2012), their availability in water and the health risks associated with it require great attention. It is therefore essential to assess the levels of radioactivity in drinking water as their over exposure is injurious to human health. Low levels of exposure from radioactive materials are connected to cancers of certain organs, the prostate gland as well as with most forms of leukaemia (Degerlier & Karahan, 2010; El-Mageed et al., 2011). Data on radiation exposure to the population due to drinking water will inform decisions in maintaining drinking water standards (Al-Amir et al., 2012).

Many settlements have sprung up with no good sanitation and water supply services. For settlements where treated water is not available for domestic purposes, the inhabitants resort to the use of water in lakes for drinking, recreation and irrigation with no knowledge of the health risk associated with such water bodies (Adu et al., 2011). Water chemistry is influenced by a number of factors such as; rock weathering, evaporation, atmospheric precipitation and crystallization. The effect of sediment on the quality of water is very complex and can be attributed to the processes which control the exchange of chemicals between water and sediment (Bhatt et al., 2011).

1.2 Exposure to Radionuclides and their Determination

Although the contributions of water used for drinking to average radionuclide exposure is negligible, no set standards for the radionuclides in water are in place as compared to other samples. The method often used is to screen the water for gross beta and gross

alpha activity to know if their levels are above the accepted threshold or not. Levels above the threshold would not show any immediate health risk but would prompt additional investigation into knowing the radionuclides present and the risk they may pose considering local circumstances.

The approach taken in curtailing radiological hazards are:

- screening first for gross α and β activity to know if they are within the safe limits where no additional measure is needed and
- if the activities are above limits, individual radionuclide concentrations are then determined and compared to recommended standards (Gordon et al., 2008).

1.3 Environmental Behaviour of Radionuclides

Generally, released radionuclides into the environment which are in trace amounts are carried in the water or air media. The determinations of transfers of radionuclides from previous discharges are used to study and understand large-scale hydrological and atmospheric movements on the earth. Particular transfer and removal processes of the paths of exposures to radionuclides have been studied thoroughly. Models of methods for hydrological transports are developed and applied to water bodies such as rivers, lakes, estuaries, oceans and seas.

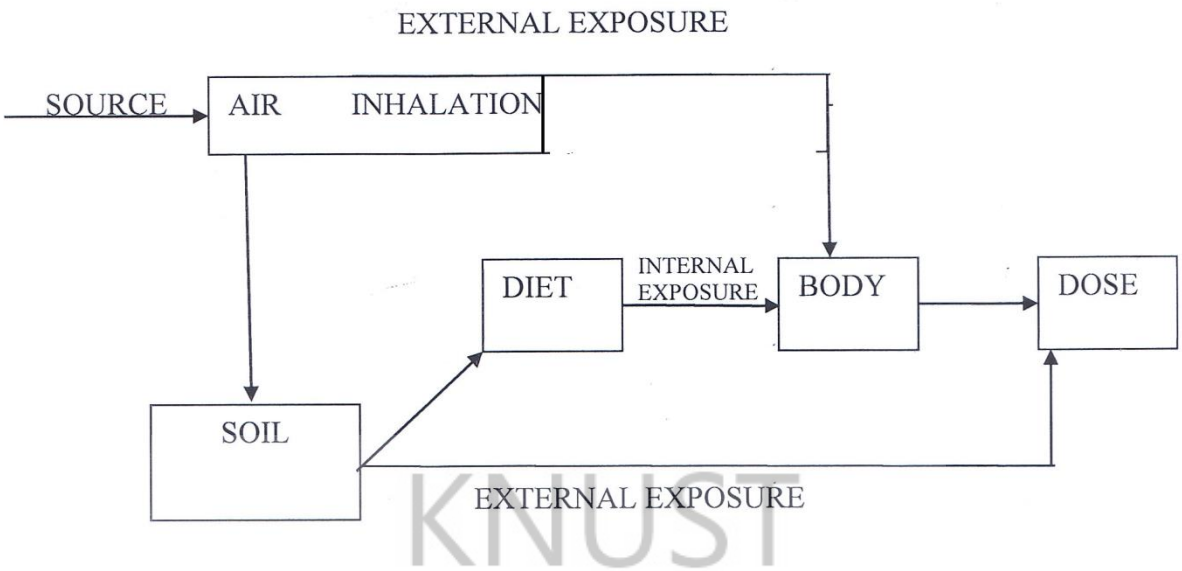


Figure 1.1: Terrestrial pathway of radionuclides and transfer of dose to humans (UNSCEAR, 2000b)

1.4 Health Effects of Radioactivity

Radionuclides cause many health related problems as a result of their exposure resulting in bio-accumulation and bio-toxicity. These health effects of exposure to radiation depend on factors such as; type of radiation, amount of energy delivered, exposure time, organs and tissues irradiated. Natural and artificial radionuclides release alpha, beta and gamma radiations. Of these radiations, gamma radiation has high penetration effect and can pose great risk due to both internal and external exposure. For instance, increased exposure to uranium by breathing has lots of effects on health, such as acute leucopoenia, lung disease, anaemia and mouth necrosis (Görür et al., 2012).

These health related problems make radionuclides as a parameter for determination in drinking water important, so that if radionuclides are present they would be monitored in order not to exceed the acceptable threshold and would make local authorities to be on alert on ways of controlling the levels or their possible elimination.

1.5 Heavy Metals

Besides radionuclides which are considered potentially injurious to health due to their radiotoxicity, there are growing concerns about impact of heavy metals on the environment which results in destruction of the aquatic ecosystem. Aquatic environmental pollution by metals has recently become a global problem since the metals are indestructible, persistent in the environment, having toxic effects on organisms and also bio-accumulate in the environment (Censi et al., 2006). Concentrations of heavy metal in the aquatic environment are watched by determining their levels in sediments, biota and water which usually are present in low levels in water and increased amounts in biota and sediments (Camusso, 1995).

The rate of bio-accumulation of heavy metals in aquatic organisms is not independent of the capacity of the organisms to metabolize the metals and the levels of the metals in the water as well as the feeding behaviour of the organisms present (Begum et al., 2009). Fish has been seen as a good accumulator of all kinds of pollutants. Modes of feeding, lipid content in the tissue as well as age of fish are important factors that affect how fishes accumulate heavy metals (Newman & Doubetm 1989). The incidence of high concentrations of trace metals in the surrounding sediments of the water bodies can be a good pointer of pollution caused by man rather than geological weathering enriching the sediments (Chang et al., 1998).

1.5.2 Incidence and Recovery of Heavy Metals

Heavy metals occur in the earth crust naturally and are bad environmental contaminants because they are not degradable. They are ingested into the human system through food, water and air and bio-accumulate over long periods. These metals are primary obtained from rocks as ores in various forms; sulphides and oxides. Mineral ores may occur in families where metals that exist naturally as sulphides would occur together. Therefore,

sulphides of lead, arsenic, cadmium, and mercury would be found in nature occurring together with sulphides of copper (chalcopyrite, $CuFeS_2$) and iron (pyrite, FeS_2) which are obtained as by-products of various processes or as part of exhaust fumes in pyro-metallurgical process and other processes that follow after mining to recover them. During mining, some metals are left behind as mine tailings scattered in both partially covered and open pits; others are transported through the air and flood, creating all kinds of environmental problems (Duruibe et al., 2007).

1.6 Health Effects of Heavy Metals

Natural environment is usually polluted with large quantities of heavy metals which are discharged into it causing a myriad of environmental problems as a result of their persistence and non-biodegradability; they then accumulate in the food chain and pose a significant danger to human health. In the current study embarked on to determine heavy metals concentrations and radionuclides activities in water, fish and sediment, no known correlation has been found in the literature for aquatic environments (Ozmen et al., 2004). Therefore, the knowledge of concentrations and distributions of the heavy metals and radionuclides in water, sediment and fish samples are of interest in this work since it offers useful data in the evaluation of environmental quality and monitoring of environmental contaminations and their effects on living organisms especially man (Uosif et al., 2014; Zorer et al., 2008).

1.7 Statement of Problem

Lakes in Ghana serve many useful purposes to both indigenes and foreigners, by providing food (fish) for them, being a source of drinking water (in some cases), water for irrigation purposes, for transportation and for recreation to holiday makers. In the wake of all these uses, there is the need to regularly monitor the concentration of

radionuclide and heavy metals present in these lakes so as to know whether they pose health risk to patrons of produce from these areas or not, as high concentrations are injurious to humans, identify the pollution source and use the results obtained to predict levels of contamination in similar areas.

1.8 Justification

Water is an essential component of living organisms and forms about 90% of the body fluid. Water from lakes is used extensively for irrigation and domestic purposes. Activities around the banks of the lake as well as agricultural and municipal runoffs are likely to deposit heavy metals and radionuclides into the lake, hence the need for this present study to assess the pollution of the lakes which results in contamination of the water and biota.

This study is also justified on the basis that safety of food is a key global issue and in recent times, the high demand for it has sparked research on the health risk connected with consuming food and water polluted by heavy metals, pesticides and/or toxins as well as eating of food polluted with radionuclides which represent the important routes for long-term health considerations. Amongst scholarly works done in these fields, none has looked at these two problems viz. heavy metals and radionuclides simultaneously for both water and biota hence the pressing need to embark on this present study.

1.9 Aims and Objectives

The aim of this study is to determine the level of radioactivity and concentration of heavy metals in sediments, water and fish in lakes (Bui dam and Bosomtwi) in Ghana.

Specific objectives of the study are:

- To determine the activities of ^{40}K, ^{232}Th and ^{238}U in water, sediments and fish from the lakes using a γ- spectrometer coupled with a HPGe detector.

- To determine heavy metal concentrations in water, fish and sediments using AAS.
- To deduce source of pollution.
- To calculate the health risk associated with the ingestion of water and fish from the lakes.

CHAPTER TWO

LITERATURE REVIEW

2.0 Background

This chapter takes a look at works undertaken on heavy metals and radionuclides which are relevant to this study to know how the current study relates to previous scholarly works done elsewhere to enable comparison.

2.1 Heavy Metals

At their right concentrations, some heavy metals are important to the health and well-being of living organisms on this planet, including human beings. Heavy metals as a term, generally applies to the general contaminants of inland and freshwater ecosystems which occur naturally. They are mostly found naturally in rocks and soils with a resultant natural background levels in sediments, water and living organisms. Anthropogenic releases can result in increased concentrations of the metals as against the normal background values. The most important anthropogenic releases of heavy metals to the environment come from metalliferous mining, agricultural materials (pesticides and fertilisers), application of sewage water and sludge, fossil fuel combustion and metallurgical industries (Kiekens, 1995).

However, if excess amounts of heavy metals are allowed to accumulate in our natural environment, the result can lead to a number of problems including soil contamination, surface and groundwater contamination, loss of aquatic life, and even severe human health effects. The contamination of sediments, soils, water resources and biota by heavy metals is of utmost worry because of their persistence, bio-accumulative nature and toxicity, (Ikem et al., 2003). Metal toxicity may alter many biochemical parameters and, physiological processes in aquatic animals (Barlas, 2005).The concentrations of heavy

metals in aquatic and terrestrial organisms are measured by the size of the source whether anthropogenic or natural and adsorption and/or precipitation in sediments or soils. The degree of adsorption depends on the chemical and physical properties of the environment, the type of metal, concentrations of other metal-complexes in the soil or water. Heavy metals again accrue in organisms as a result of direct uptake from food, water, respiration or from the surroundings across the body wall. Uptake through food is very important in terrestrial organisms and it may be also important in the aquatic environment. Dietary intake can include heavy metals adsorbed on particles present on the surface of leaves, which have not been absorbed by the plant (Redondo-Gómez, 2013).

2.2 Sources of heavy metals

Heavy metals are released into the environment from a variety of anthropogenic sources added to the natural, background geochemical sources. The heavy metal levels deposited on the earth's surface are much greater than depositions from natural background sources. Other sources include municipal wastewater and industrial effluents (Dankwah, 2011).

2.3 Distribution Routes and Fate of Heavy Metals in Aquatic Environment

In the distribution of metals, permanent or temporary storage of metals takes place in the sediments of both marine and freshwater environments. Redox processes and microbial activities may change the sediments' properties and affect the composition of interstitial water. As a result of this, magnesium and iron oxides may be converted to sulphides or carbonates, leading to a decreased absorption capacity of the sediments. Re-working of the sediments by organisms will also bring bottom sediments to the surface, where a high fraction of the metal will be released (Bala et al., 2008).

2.4 Pollution of the Aquatic Ecosystem with Heavy Metals

Water quality is the key component considered to control disease and health of animals and man in the aquatic environment. When heavy metals enter the aquatic environment, the metal ions can react with constituents of the water or settle to the bottom and react with the sediments. Heavy metals have a greater chance of remaining in solution when complexed to chelating agents such as specific anions whose concentrations are described by the pH of the surrounding environment. Metals precipitate as oxides or hydroxides at different pH regions and the amphoteric elements return to solution at higher pH. The pH of the environment therefore is of great importance for the mobility of metals likewise other factors such as redox conditions and the presence of adsorbent sediments (Alloway & Ayres, 1998).

Water pollution is mostly associated with the release of effluents from factories, sewers or sewage treatment plants and drains into water bodies of streams, rivers, lakes, reservoirs and seas. The accumulation and pollution of aquatic environment by metals has direct impact on man and the ecosystem.

2.5 Bioavailability of Heavy Metals

Bioavailability is the degree to which a contaminant from a source is free for uptake and brings about site of action effect (Ownby et al., 2002). Exposure of an organism to contaminant concentration depends on whether the organism comes into close contact with the contaminant containing media. The organism must be in appropriate contact in order to absorb, imbibe, ingest, or inhale the contaminated material. Whether this contact results in a realized dose in the organism or not will depend on a range of factors that combine to determine their bioavailability (Newman & Evans, 2008).

2.6 Bio-monitoring of Ecosystem Pollutants

Earlier, the programs available for monitoring contaminants in the environment were dependent on the chemical analysis until the inherent problems became prominent. Most researchers have discovered that it is not possible to merge the conditions of the environment and its effects on aquatic life and as well quantify concentrations of contaminants which are very low in the natural waters, therefore by only monitoring the contaminants is not enough. (Amiard et al., 2000; Philips, 1994).

Monitoring chemical contamination in an ecosystem does not enable us to assess its impact on the organisms, populations and communities. In terms of sub lethal levels the response of organisms to contamination can only be evaluated by measurement of biological, physiological and biochemical parameters according to an approach similar to that used in medical diagnostics in human or veterinary clinical toxicology (Amiard et al., 2000). Bio-monitoring is the use of living organisms (bio-indicators) systematically to evaluate changes in water or environmental quality in field or laboratory conditions, by determining either biological effect, bioaccumulation, health (occurrence of disease) and/or ecosystem integrity. It is thus a process in which the animal and plant organisms or their fragments used, provide constant reel-time analytical information (Van der Oost et al., 2003).

Bio-indicators are biological indicators of environmental quality that characterize environmental conditions and reflect changes in the condition of an organism resulting from exposure to a toxicant (Chambers et al., 2002). Their tolerance is usually limited, so their absence or presence, and health state enable the determination of some chemical and physical components of the environment without complicated laboratory analyses

and measurements (Gadzała-Kopciuch et al., 2004) and they are indicators of normal status or changes in individuals of a study population.

There are various advantages of bio-indicators in pollution monitoring. They are useful as "early warning" tools of potentially adverse effects. Furthermore, responses may provide a temporally and spatially integrated measure of bioavailable pollutants. For example bio-indicators can detect intermittent pollution events that routine monitoring may miss. Specific responses can be used to attribute exposure to pollutants; bio-indicators can provide information on the relative toxicities of specific chemicals; and they are applicable in both the laboratory and the field (Amiard et al., 2000).

2.7 Limitations of Bio-monitoring

Amiard et al. (2000), states that the major handicap in the use of bio-indicators in field conditions is the interference from natural abiotic and biotic factors, as it is almost impossible to distinguish between signals of disturbance caused by pollutants and the "background noise" due to natural fluctuations. Another disadvantage is that chemicals may interact within their environment and therefore the combined action of these chemicals can complicate the interpretation of bio-indicator's responses (Amiard et al., 2000). However because it cannot be replicated, bio- monitoring studies gives results which are equivocal.

2.8 Aquatic Sediment Contamination

Sediment contamination in aquatic environment is of global concern. This is because contaminants may stay on for long in the sediments, having the capacity to impact on the environment and human health adversely. Chemicals are continuously been released into water bodies from municipal and industrial sources as well as run-offs from agricultural

practices which accumulate to dangerous amounts of contaminants in sediments (Mackevièienë, 2002).

The analysis of sediment is a good method of assessing pollution of the aquatic ecosystem with heavy metals since they accumulate much of the metals. The incidence of high levels of metals in bottom sediments may be a good pointer of anthropogenic pollution other than pollution from natural sources (Chang et al., 1998).

Metals may be present in the water system in varying ways as free ions, dissolved species, organic complexes with humic and fulvic acids. Also, most metals may readily associate with particles and become adsorbed or co-precipitated with oxy-hydroxides, carbonates, sulphides and clay minerals. Subsequently, these metal contaminants are accumulated in the sediments which act as long-term reservoirs for the metals in the environment (Spencer & MacLeod, 2002) and thus leads to exposure of organisms dwelling in sediment through ingestion and consumption of food, sediment particles and interstitial waters (Luoma & Bryan, 1982).

To evaluate toxicity of contaminants in the sediment and the transfer of bioavailable metal contaminants from sediments in a food chain the concentrations of the contaminants are considered. The bioavailable part can be assessed by estimation or by directly sampling and analysing benthic invertebrates. Direct measurement is usually preferred to the estimation because of the certainty involved and the accurate information it provides on contaminant loads in the biota. However, in some cases this may not be plausible because of inadequate personnel, funding or time in sampling and measurements thus the alternative taken is by doing estimation of the contaminants in the biota (United States Department of Energy, 1998).

Concentrations of contaminants in biota may be calculated by the use of varying methods; which ranges from complex mechanistic process models to simple accumulation factors. While the mechanistic process models used in estimating concentrations of contaminant in biota may give a good estimate, the information required is not readily available for a risk assessment. To estimate the loads of contaminants in biota, accumulation factors are used as the simplest method. Accumulation factors which include biota sediment accumulation factor (BSAF) deals with the ratio of contaminant concentration in the biota and an abiotic media. The index of geoaccumulation (Igeo) is a measure of bottom sediment contamination. It assesses contamination by making comparison between present metal levels and pre-industrial levels (Agyarko et al., 2014). The content taken as background is always multiplied by the constant 1.5 so as to take into consideration natural fluctuations of the substance in the environment as well as very small anthropogenic influences (Sabo et al., 2013). The value of the geoaccumulation index is described by the following equation:

$$I_{geo} = \log_2\left[\frac{C_m \text{ Sample}}{(1.5 \times C_m \text{ Background})}\right]$$

Where Cm = Concentration of metal.

2.9 Water Pollution

Water pollution is a key environmental issue next to air pollution. Changes in biological chemical and physical properties of water that can harm living organisms are considered as water pollution. Polluted water is a problem to global water sources and its effect is felt by man and animals as a result of the health implications involved in the consumption of it. It is known to cause typhoid, diarrhea and dysentery whose causative organisms are microbes which prefer such habitats. Because of water pollution, the

general ecosystem becomes disturbed and this is thought to be the highest cause of death and diseases globally, recording more than 14,000 deaths daily. (Kamble, 2014).

2.10 Heavy metals in aquatic environment

Ozmen et al., (2004), reported on Hazar Lake that the heavy metals (Cu, Fe, Mn, Ni, Pb and Zn) and major elements (Ca, K, Mg, Na) concentrations in water did not exceed World Health Organisation, European Community, Environment Protection Agency and Turkish Standard-266 guidelines. Generally, concentrations of major elements and heavy metals in the sediments were found to decrease in the order: Fe > Mg > Ca > Mn > Zn > Ni > Cr > Cu > Co > Pb. Generally, the results of the study indicated an absence of serious pollution in the Hazar Lake (Ozmen et al., 2004).

The sequential extraction used in the study of heavy metals in Lake Uluabat was helpful to determine the potential mobility of heavy metals in the sediment indirectly. In the study, concentrations of Cd, Cr, Cu, Ni, Pb and Zn were higher in the Lake, especially in plankton samples. The magnitude of heavy metal concentrations in water and plankton samples were in the order: B > Zn > As > Cd > Pb > Ni > Cr and Zn > Ni > Cu > Cr > Cd > Pb, respectively. The mobility of metals in sediment samples were sequenced as: Pb > Cu > Cr > Ni > Cd > Zn, whereas the magnitude of easily mobilizable metal concentration was determined as: Pb > Ni > Cr > Cu > Cd > Zn (Elmaci et al., 2007).

Zorer et al.,(2008) determined the heavy metals levels in the River basin of Bendimahi by statistical analysis and comparing it to natural gross radioactivity concentration. Fifteen water samples were collected from Bendimahi River and Van Lake for two seasons in 2005. Eight elements were analysed using AAS to determine their concentrations in the water samples. The concentrations of all metals except for Zn and Cu were found to be higher than World Health Organisation, European Community,

USEPA and Institution of Turkish Standards (TSE-266) guidelines for drinking water. Concentrations of heavy metals in the water samples for the two seasons were generally found to be in the following order: Cd < Co < Mn < Cu < Cr < Pb < Zn < Fe and Cd < Co < Mn < Cr < Pb < Cu < Zn < Fe (Zorer et al., 2008).

El-Sayed & El-Ayyat (2011) presented findings of an investigation into the factors affecting live fish at different sources of water (agriculture drainage, industrial drainage and sewage wastewater). Heavy metal residues (Zn, Cu, Pb, Cd, Cr, Al, Mn, Ni and Co) were determined in water, sediment and fish organs (muscles, gills, kidney and liver tissues) of three fishes (*Oreochromis niloticus, Clarias gariepinus* and *Bagrus bayad*). The industrial drainage and sewage water revealed the highest concentrations of heavy metals followed by agriculture drainage water. The muscles, gills, kidney and liver tissues of fish samples collected from industrial drainage and sewage canals had the highest levels of heavy metal residues followed by agriculture drainage canals. The heavy metal studies revealed that there is a public health hazard associated with industrial drainage, sewage wastewater and agriculture drainage as the quality of fish did not comply with the standard levels recommended by WHO, USEPA and Australian and New Zealand Environmental Conservation Council. Potential adverse health effects in such applications could be avoided if the wastewater is sufficiently treated (El-Sayed et al., 2011).

Uosif et al., (2013) reported on heavy metal pollution in Assiut zone, central Egypt that, heavy metal levels in the sediments were in a descending order as: Fe > Mg > Pb > Zn > Cr > Cu > Ni > Cd. In some locations, the levels determined exceeded the permissible limits recommended by the Canadian Environmental Quality Guidelines. The highest concentration of most heavy metals was found in Arab Al-Madabegh region; the sewage

irrigated zone. Whereas, the lowest was found in the non-irrigated lands, which was considered as a reference point of analyses (Uosif et al., 2013).

Pakzadtoochaei (2013) determined metal concentrations in the sediment and different tissues of *Avicenia marina* (root, leaf, steam and flower) from different stations along the natural and artificial mangrove forests after acid digestion by using atomic absorption spectrophotometer. The results showed sediments accumulated high concentration of metals and high concentration of Cd was also obtained in the leaves. This pattern may be due to plant strategies for Cd removal from tissues with leaf falling. After sediment the high levels of Ni and Cu were determined in the root. The accumulation of these elements in the sediment can increase the concentration of Ni and Cu in root. The high concentration of Zn in flower may be due to the need of this part of plant to Zn for growth. The Gwatr has high level of metals in comparison with Kharchang bay which can be due to upstream agricultural runoff and other activities done in its surrounding. The relationship between the sediment and different tissues of *A. marina* was indicated, the kinds of mangrove tree in these areas can be useful tools for bio-monitoring of Ni; furthermore, the leaves and flower only can be used for Cu and Zn bio-monitoring respectively in these areas (Pakzadtoochaei, 2013a).

2.11 Radioactivity

Living organisms are being exposed continuously to naturally occurring ionizing radiation. These radiations which we are exposed to usually are cosmic rays which are sourced from outer space, the sun's surface, radionuclides which occur in the earth's crust, in building materials, water, air foods and the human body. Some of these exposures are constant and uniformly distributed for all individuals globally, for example, ingestion of ^{40}K in foods. Other exposures vary greatly depending on location.

Cosmic rays, for example, are stronger at high altitudes, and concentrations of thorium and uranium in soils are elevated in localized areas. Exposures may also change as a result of human practices and activities. Mostly, building materials and design of houses and their ventilation systems strongly influence indoor concentrations of radon gas and its decay products, which contribute greatly to inhalation doses. Therefore, it is necessary to study the naturally occurring radiation levels in the different components of the environment. Such investigations could be useful for both assessment of public dose rates and the performance of epidemiological studies as well as keeping reference-data records to ascertain possible changes in the environmental radioactivity due to nuclear, industrial, and other human activities (UNSCEAR, 2000a).

2.11.2 Radioactivity in lakes and aquatic ecosystem

Adu et al., (2011) determined the concentrations of ^{238}U, ^{232}Th, and ^{40}K in water from Lake Bosomtwi basin and bore-holes in selected towns around the Lake Bosomtwi basin of the Ashanti region of Ghana. The water samples from the lake were found to contain acceptable levels of radionuclides with mean activity concentrations of 7.9, 89.7 and 0.6 mBq/L for ^{238}U, ^{40}K, and ^{232}Th, respectively. The water samples from the bore-holes recorded mean activity concentrations of 7.7, 85.5, and 3.3 mBq/L for ^{238}U, ^{40}K and ^{232}Th, respectively. The annual effective dose calculated for the lake varied from 0.244 to 1.121 µSv with an average of 0.763 µSv and that calculated for the boreholes varied from 0.296 to 2.173 µSv with an average of 1.166 µSv. The radionuclides concentrations in water from the bore-holes and that of the lake, which serve as sources of water supply to the surrounding communities were negligible and posed no radiological hazards to the public (Adu et al., 2011).

The radiochemical analysis of the content of natural radionuclides ^{238}U, ^{232}Th and ^{226}Ra in soils near Issyk-Kul lake (Kyrgyzstan) studied by Jovanovic et al., (2012) showed that the concentrations of ^{232}Th fluctuate in the range of 11.7 $\times 10^{-4}$ % to 84.1 $\times 10^{-4}$ % in the soils. The highest concentration of ^{232}Th was found in the light chestnut soils. The content of ^{238}U in the soils near Issyk-Kul Lake fluctuates in the range of 2.8 $\times 10^{-4}$ % to 12.7 $\times 10^{-4}$ %. The concentrations of ^{226}Ra also fluctuate in the range of 9.4 $\times 10^{-11}$ % to 43.0 $\times 10^{-11}$ %. The highest concentration of ^{226}Ra was determined in the light chestnut soil (Jovanovic et al., 2012).

2.11.3 Radioactivity in water, sand, sediment and soil

Agbalagba et al. (2012) carried out an assessment of naturally occurring radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in soil samples collected from oil and gas field environment of Delta state, Nigeria. The activity concentration of the samples ranged from 19.2±5.6 to 94.2±7.7 Bq/kg for ^{226}Ra, 17.1±3.0 to 47.5±5.3 Bq/kg for ^{232}Th and 107.0±10.2 to 712.4±38.9 Bq/kg for ^{40}K. The activity values obtained were in good agreement with the world range and values reported elsewhere in other countries. The study also examined some radiation hazard indices. The mean values obtained were; 98.5±12.3 Bq/kg for radium equivalent activity, 0.8 Bq/kg for representative level index, 54.6 nGy/h for absorbed dose rates, 0.07 μSv/y for annual effective dose rates, 0.3 for external hazard index and 0.4 for internal hazard index. These calculated hazard indices were well below their permissible limit (Agbalagba et al., 2012).

Again, Agbalagba and Onoja (2011) presented the observations of a study taken to evaluate the baseline levels of the natural radioactivity in water, sediment and soil samples in 4 flood plain lakes of the Niger Delta using a hyper pure germanium detector. The activity concentrations of the species determined showed low activity within the

study area. The average activity concentration of the radionuclides ^{226}Ra, ^{232}Th and ^{40}K is 20±3, 20±3 and 180±50 Bq/kg, respectively. These values were well within values reported elsewhere in the country and in other countries with similar environments. The study also examined some radiation hazard indices. The average values obtained were: 30±5.5 ηGy/h, 76±14 Bq/kg, 37±6.8 mSv/y, 0.23 and 0.17 for absorbed dose rates, radium equivalent activity, annual effective dose rates, internal hazard index and external hazard index respectively. All the health hazard indices were well below their acceptable limits. The sediments and soil from the study provided no excess exposures for the indigenes and could be used as material for construction any great radiological threat being posed to the population. The water was safe radiologically to be used for industrial and domestic use (Agbalagba & Onoja, 2011).

El-Aydarous, (2007) determined the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil samples from El Taif, in Saudi Arabia. The soil activity ranges from 13±1.2 to 33±3.4 Bq/kg for ^{226}Ra, 11±1 to 27±4.2 Bq/kg for ^{232}Th and 129±5.7 to 230±11 Bq/kg for ^{40}K with mean values of 23.8±2.4 Bq/kg, 18.6±1.7 Bq/kg and 162.8±7.6 Bq/kg, respectively. The measured activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil were lower than the world average. All the soil samples had radium equivalent activities lower than the 370 Bq/kg limit set in the OECD report (OECD, 1979). The overall mean outdoor terrestrial gamma dose rate was 28.98 nGy/h and the corresponding outdoor annual effective dose was 0.04 mSv/y (El-Aydarous, 2007).

Diab et al., (2010) in studying activity concentration in soil samples from a cultivated area found that the average activity concentration ranged from 6.0±1.2 to 87.5±4.5 Bq/kg for ^{226}Ra. The activity concentration of ^{232}Th varied from 3.8±1.2 to 14.2±3.3 Bq/kg whilst ^{40}K registered activity concentration ranging from 71.8±24 to 543.2±26.5 Bq/kg.

The absorbed dose in air was found to be 31 nGy/h which is within the world average value (57 nGy/h). The the external hazard index, radium equivalent activity and the annual dose equivalent were also estimated and found to be within the international level (Diab et al., 2010).

Harb et al., (2008) measured the specific activities of ^{238}U series (^{226}Ra), ^{232}Th series (^{228}Ra, ^{228}Th and ^{232}Th), as well as ^{40}K, in soil and phosphate samples obtained from the El-Sabaea phosphate factory. The activity of ^{226}Ra values was between 59.7±6.7 to 638.3±31.0 Bq/kg and ranged from 9.4±1.4 to 38.3±4.0 Bq/kg for ^{232}Th series while it was ranged from 308.9±13.2 to 699.3±29.4 Bq/kg for ^{40}K. The mean activity concentrations values of ^{238}U series (^{226}Ra), ^{232}Th-series (^{228}Ra , ^{228}Th and ^{232}Th) and ^{40}K activity concentrations in Bq/kg for soil samples from the area around El-Sabaea phosphate factory ranged from 65.5±7.1 to 528.4±25.1 Bq/kg, 19.2±3.2 to 40.6±6.3 Bq/kg and 213.1±9.5 to 798.9±30.6 Bq/kg respectively (Harb et al., 2008).

Concentration of natural radionuclides in the bottom sediments of Karachi Harbour/Manora channel area (Akram et al., 2006). Samples from Layari River were also analyzed to account for background contribution from terrestrial sources. The activity in sea sediment samples from these areas were found to vary from 18.5±4.3 to 29.1±3.8 Bq/kg for ^{226}R, 11.7±1.2 to 27.7±4.2 Bq/kg for ^{228}Ra, and 332.2±19.3 to 729.2±36.7 Bq/kg for ^{40}K. The activity in Layari River ranged from 14.9±2.6 to 29.7±2.9 Bq/kg for ^{226}Ra, 8.6 ± 0.9 to 31.6±1.3 Bq/kg for ^{228}Ra and 197.3±11.6 to 643.7±25.9 Bq/kg for ^{40}K. The mean values of radium equivalent activity, absorbed dose rate and annual effective dose were 89 Bq/kg, 44 nGy/h and 0.055 mSv/y respectively. The value of effective dose was much less than level of 1.0 mSv/y, recommended by International commission on radiological protection (ICRP, 1990).

Kabir et al., (2009) found that the radioactivity levels of ^{226}Ra, ^{232}Th and ^{40}K in sediment samples collected from water-bodies of the district of Jessore Bangladesh ranged from 23.10±1.53 to 61.76±2.18, 19.71±5 to 85.36±6.8 and 254.46±43.38 to 986.48±42.86 Bq/kg with the average value of 42.90±11.05, 47.85±14.26 and 502.73±146.36 Bq/kg respectively. Calculated radium equivalent activity and absorbed rate were found to be 155.85±30.96 and 71.71±18.48 Bq/kg, respectively. The results were compared with those of different countries of the world and Bangladesh (Kabir et al., 2009).

Kessaratikoon et al., (2007) determined the specific activities of ^{40}K, ^{226}Ra and ^{232}Th, in 80 sand samples collected along the Chalatat and the Samila beaches in Songkhla province. The beach sand specific activity ranged from 89 to 963 Bq/kg for ^{40}K, 0 to 120 Bq/kg for ^{226}Ra and 0 to 319 Bq/kg for ^{232}Th with mean values: 248±44 Bq/kg, 41±5 Bq/kg and 64±7 Bq/kg for ^{40}K, ^{226}Ra and ^{232}Th respectively. All the beach sand samples have mean values of radium equivalent activities lower than the limit set in the Organization for Economic Co-operation and Development report (Kessaratikoon et al., 2007).

Radenković et al., (2009) determined the activity concentrations for the radionuclides ^{232}Th, ^{226}Ra and ^{40}K in the determined sand samples. Results of the random sand samples taken from both river and sea beach areas of tourist zone, showed low activities of ^{232}Th and ^{226}Ra, which originate from the natural radioactive series, as well as naturally occurring ^{40}K. The minimum activity concentration of ^{226}Ra recorded as 2.24 Bq/kg was found in sand samples taken from the Copacabana Beach (Brazil), whilst the highest value of 15.9 Bq/kg was found in the sand samples from the Great Beach of Ulcinj (Montenegro). The activities of ^{232}Th were in the range 2.6 to 17.3 Bq/kg, with the

lowest value for the Patara Beach (Turkey) and the highest value for the Manhattan Beach (Radenkovic et al., 2009).

Beach sands of some well-known tourist resorts in the Greater Accra region of Ghana were investigated by Lawluvi et al., (2011) to identify the levels and hazards associated with the ^{238}U, ^{232}Th and ^{40}K present. The annual effective doses and the total absorbed dose rate were calculated. The specific activities ranged from 11.0 to 31.8 Bq/kg for ^{238}U, 0.5 to 1.5 Bq/kg for ^{235}U, 10.9 to 103.7 Bq/kg for ^{226}Ra, 16.8 to 231.2 Bq/kg for ^{232}Th and 68.3 to 183.9 Bq/kg for ^{40}K. Average values of the annual external effective dose, absorbed dose rate, radium equivalent activity, internal and external hazard indices and the radiation level index were; 0.066 mSv/y, 54.08 nGy/h, 101.0 Bq/kg, 0.36, 0.27 and 0.71, respectively. The results showed that the natural radio activities in the sand samples from the beach pose no major risk to tourists and other patrons of the area. Beach sand samples were shown to be safe to be used in construction, indicating the importance of the radiological quality of the beaches from environmental and human viewpoints

Activity concentration of ^{238}U, ^{232}Th and ^{40}K measured in sediment and water samples from Suez Canal gave the average activity concentrations of ^{238}U, ^{232}Th and ^{40}K in sediment samples as 10.69±0.25, 13.71±0.28 and 194.58±0.81 Bq/kg dry weight respectively. The average activity concentration of ^{40}K in water samples was 15.92±0.41 Bq/L (El-Tahawy et al., 1994).

Ashnani et al., (2010) measured the average activity concentration of ^{226}Ra, ^{40}K and ^{232}Th in water, soil and sediment samples from Aras River and south west of Caspian Sea. In water, soil and sediment samples the average activity concentrations of ^{40}K and ^{226}Ra were 263.75±6.18 Bq/kg and 4.42±0.46 Bq/kg respectively and in soil and

sediment samples the average concentrations of activity of ^{232}Th was 20.24±1.18 Bq/kg results showed that in one third samples the activity of ^{40}K is more than allowable limitations and other natural activities are in range of background (Ashnani, Yavari, & Hassani, 2010).

Ramasamy et al., (2010) determined the activity concentration of natural radionuclides (^{238}U, ^{232}Th and ^{40}K) for all samples. It varies from site to site, because river bottoms can exhibit large variation in chemical and mineralogical properties. The mean activity concentration ranges for ^{238}U, ^{232}Th and ^{40}K are below detectable limit to 11.60±6.13 Bq/kg, BDL to 106.11±9.20Bq/kg and 201.23±19.90 to 467.71±34.34 Bq/kg with an average 384.03±26.82 Bq/kg respectively (Ramasmy, Govindasamy, & Ponnusamy, 2010).

Levels of natural radioactivity in soils of some selected towns around Lake Bosomtwi of Ashanti region of Ghana have been studied (Darko et al., 2011). Thirteen samples from different locations close to the catchment area of the lake were collected for determination of NORM activity concentrations using high-purity germanium gamma spectrometer. Activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K ranged from 2.9±0.14 Bq/kg to 168.2±0.6 Bq/kg, 0.4±0.1 Bq/kg to 108.4±9 Bq/kg and 20.4±3 Bq/kg to 340.8±12 Bq/kg respectively. The results obtained were also in good agreement with studies from other countries in the region and therefore could be used to enhance present radioactivity database. The calculated external hazard values ranged from 0.02 Bq/kg to 0.56 Bq/kg with the mean of 0.15 (less than unity) showed no risk of external hazard to the inhabitants and tourist visiting the catchment area.

El-Sayed (2014) studied natural radioactivity related to the radionuclides of ^{238}U series, ^{232}Th series and ^{40}K radionuclide in Qarun Lake located in the deepest part of El-Fayoum

depression at the western desert, 70 km South of Cairo-Egypt in environmental samples. In the collected samples, the specific activities of ^{238}U series, ^{232}Th series and ^{40}K were measured using gamma ray spectrometer based on HPGe detector. For soil, bottom sediment and shore sediment samples thermal analysis was measured using differential thermal analyser and thermogravimetry. X-ray diffraction was measured using X-ray diffractometer. FT-IR analysis was measured using fourier transform infrared spectroscopy. X-ray fluorescence was measured using X-ray florescence spectrometry. Total organic matter, particle size distribution, density and porosity were measured.

The mean specific activities of ^{238}U series, ^{232}Th series and ^{40}K in the bottom sediment samples ranged from 7.06±0.28 to 30.15±1.8 Bq/kg for ^{238}U and it ranged from 5.9±0.14 to 20.35±1.01 Bq/kg for ^{232}Th and for ^{40}K, it ranged from 68.06±2.01 to 351.88±4.82 Bq/kg. The activity concentrations for water samples ranged from 0.18±0.03 to 3.53±0.21 Bq/L for ^{232}Th. The activity ranged from 0.95±0.01 to 6.57±0.26 Bq/L for ^{238}U and ranged from 1.03±0.04 to 43.74±2.74 for ^{40}K. The activity concentrations of shore sediment samples ranged from 1.43±0.07 to 10.02±1.61 for ^{232}Th, also the activity ranged from 2.32±0.84 to 13.08±1.74 for ^{238}U and ranged from 12.39 ± 3.62 to 80.75±7.35 for ^{40}K.

The activity concentrations for the cultivated agriculture soil samples ranged from 3.29±0.90 to 18.52±2.67 Bq/kg for ^{232}Th, while activity values ranged from 3.51±0.79 to 18.65±5.1 Bq/kg for ^{238}U, and the activity ranged from 45.85±2.60 to 350.35±1.09 Bq/kg for ^{40}K. For dose assessment the radiological hazard indices were measured for the soil samples collected from the cultivated land. The Hex was less than one and the Raeq was from 11.74 to 70.39 Bq/kg with an annual effective dose ranging from 6.82 to 44.27 μSv/y for the studied area (El-Sayed, 2014).

2.11.4 Radioactivity in vegetation, drinking water and food

Hosseini, (2007) determined the natural radioactivity concentration in soil, drinking water and certain food samples of Zahedan city in Iran. Also the absorbed dose was calculated across nearby 5 Sistan cities in Iran. Results showed that the concentrations of ^{40}K, ^{238}U and ^{232}Th in the samples of the city varied from 396±38.4 to 576±57.4 Bq/kg with a mean of 473.3±40.7 Bq/kg for ^{40}K, whereas for ^{238}U and ^{232}Th values varied from 20.6±2.3 to 24.7±3.6 Bq/kg with a mean of 21.9±2.8 Bq/kg and from 28.9±3.3 to 36.5±3.6 Bq/kg with a mean of 33±3.7 Bq/kg, respectively. It can be concluded that there is no risk threat to the residents in and around Zahedan city (Hosseini, 2007).

Studies conducted on samples of groundwater from some wells in University of Cape Coast and its surroundings in the Central region of Ghana to determine the annual effective dose from intake of naturally occurring radionuclides by gamma spectrometry has been reported by (Faanu, et al., 2011). The average annual effective doses obtained in this study were 0.15±0.04 mSv for Apewosika, 0.17±0.03 mSv for Amamoma, 0.14±0.01 mSv for Kokoado and 0.17±0.03 mSv for Kwaprow respectively. The values calculated were about 1.7 times higher than WHO guidance levels of 0.1 mSv/y from intake of radionuclides in water. ^{232}Th and ^{40}K levels were lower than the world average values whilst ^{238} U levels were slightly higher. The total annual effective dose in the studied areas were lower than the ICRP recommended public dose limit of 1 mSv per year.

Darko et al., (2014) studied the gross α - β activities of ^{226}Ra, ^{232}Th and ^{40}K as well as ɣ spectroscopy in underground water samples. The gross α-β concentrations were measured using a low background gasless automatic α-β counting system calibrated with ^{241}Am and ^{90}Sr standards for α and β, respectively, while c analyses were carried out

using ɣ spectrometry system coupled to a NaI (TI) detector and measuring assembly. Gross α activity in the water samples varied from 15.7 to 142.7 mBq/L, registering an average value of 40.7±12 mBq/L, whereas gross β activities ranged from 89.3 to 400 mBq/L. The activities of ^{226}Ra, ^{232}Th and ^{40}K were 22.41±6.07, 114.62±13.01 and 227.38±12.16 mBq/L, respectively. The mean annual effective dose due to water consumption was determined to be 7.00±0.86l Sv/y per inhabitant. The gross α - β levels, the activities obtained for the three radionuclides and the annual effective dose were all within the WHO safe limits. The study indicated that underground water in the areas sampled is radiologically safe for consumption (Darko et al., 2014).

In a related study in Ghana, Darko et al., (2015) investigated the activity concentrations of radionuclides in water, soil and tuber crops of a major food-producing area in Ghana. The average annual effective dose due to ingestion of radionuclide in water ranges from 20.08 to 53.45 μSv/year. The activity concentration of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in cassava ranged from 0.38 to 6.73, 1.82 to 10.32, 17.65 to 41.01 and 0.38 to 1.02 Bq/kg respectively. Additionally, the activity concentration of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in yam also ranged from 0.47 to 4.89, 0.93 to 5.03, 14.19 to 35.07 and 0.34 to 0.89 Bq/kg, respectively. The average concentration ratio for ^{238}U, ^{232}Th and ^{40}K in yam were 0.12, 0.11 and 0.17, respectively, and in cassava was 0.11, 0.12 and 0.2 respectively. None of the radioactivity determined was expected to cause significant health problems to human beings.

2.11.5 Radioactivity in other environmental samples

Atmospheric ^{3}H concentration in 1993- 2005 at two monitoring sites around Qinshan Nuclear Power Plant was (78.9±96.3) and (64.2±40.2) mBq/m^3 respectively, with an increasing trend after 2003. Atmospheric ^{I4}C concentrations at the two sites were in the

same levels as the background and data of the reference site (Hu et al., 2010). Detection of a given amount of radionuclide in a particular environment does not suggest that the levels in a given locality are the same at all places. However, it encourages determination of activity concentrations and their distributions in other areas to have a database for comparison and make predictions.

CHAPTER THREE

3.0 METHODOLOGY

The description of the study area, materials and methods used in this study are presented in this chapter. The instrument setup for the determinations, sampling, sample preparation and analysis are all presented.

3.1 Study area

Lake Bosomtwi is a natural lake found in the Ashanti Region of Ghana which is located about 30 km south-east of Kumasi. The lake lies between longitudes 01° 25′ W and latitudes 06° 32′ N and covers an area of about 52 km^2 (Turner et al., 1996).

The lake is closed hydrologically, without any connection to the water aquifer underground, river or stream inflow originating outside of the crater, and surface water outflow except when the lake reaches its spillway located 110 m above the present level of the lake. According to Turner et al. (1996), the level of the lake is very sensitive to minor variations in rainfall and other climatic conditions which include evaporation from the Lake Surface and annual average temperature. The 24 towns surrounding the lake depend largely on the fishes caught for their food (protein) and income as a source of livelihood. Besides fishing, the lake water is used for drinking purposes and also for irrigation of agricultural farmlands. The lake is also noted for its socio-economic benefit of serving as a tourist destination and for transportation. The Bosomtwi Forest Reserve which spans an area of 140 km^2, is a legally protected area consisting of semi-deciduous tropical rainforest and provides an attractive eco-tourism environmet (Adu et al., 2011).

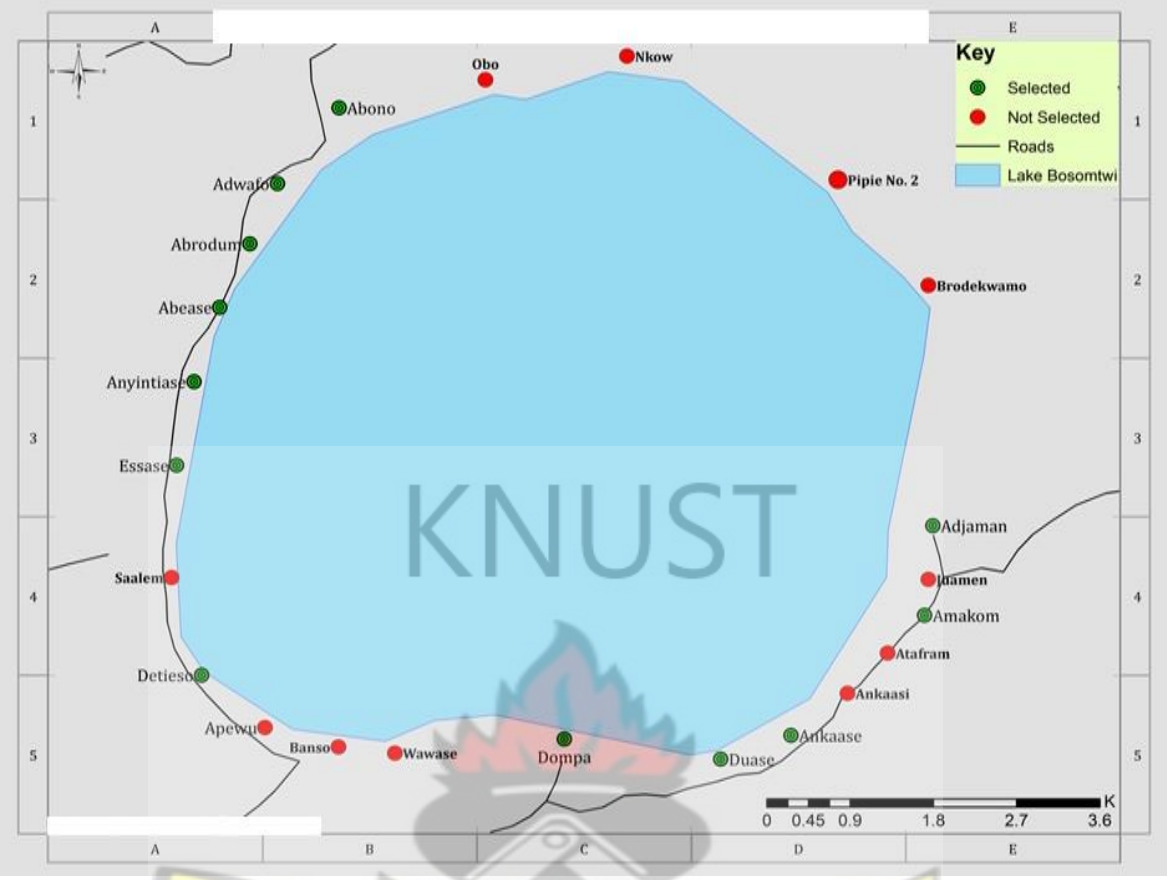


Figure 3.1: Map of Lake Bosomtwi showing sampling sites

BUI DAM

Bui dam another location studied in the work is constructed on the Black Volta river at the Bui Gorge, at the southern end of Bui National Park to provide continuous water supply to drive turbines at the hydroelectric power station. The reservoir floods about one-fifth of the National Park and affects the habitats of the scarce black hippopotamus as well as other wildlife species. The lake being formed by this dam is also being used by the indigenes who were displaced from the construction of the dam as a source of water for drinking, water for irrigation and for transportation which connect the various settlements viz: Bator Akanyakrom, Donkokyina, Jama, Mtn, Oldsoldier, Akomekope, Tanakope, Agohome and Agodeke along the lake.

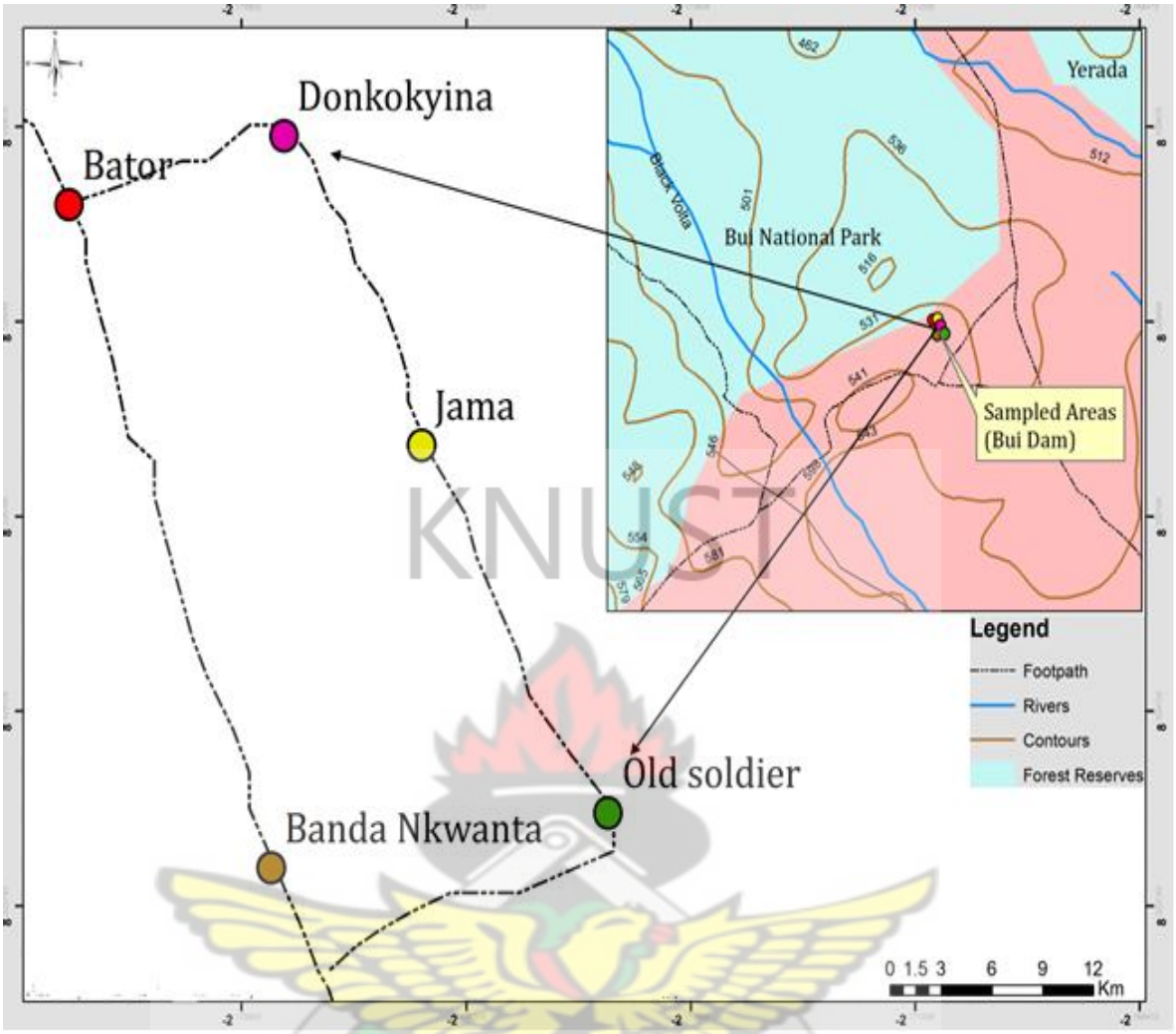


Figure 3.2: Map of Bui dam showing sampling sites

3.2 Apparatus

Volumetric flasks, reagent bottles, measuring cylinders, spatula, stainless steel knife, clean plastic bags, clean polyethylene bottles, wash bottle, wash brush, beakers, micropipette, plastic shovel, thermometer, pH/Conductivity/TDS meter coupled to an HI98129 glass electrode (Hanna, USA), and High Purity Germanium Detector (Canberra).

3.3 Sample Collection and Preparation

Sampling from the two locations were conducted in May-June, 2014 (1st batch) and October-November, 2014 (replicate).

3.3.1 Water

Water samples were collected in cleaned one and half liter (1.5 L) polyethylene sample bottles previously soaked in 10% HNO_3 overnight, washed with tap water, rinsed with doubled distilled water and dried to avoid contamination or adsorption of the analyte present in the samples. A few drops of HCl were added to the samples to keep the analyte dissolved in solution and also prevent the radionuclides from adhering to the walls of the containers. The bottles were filled to the brim without any headspace to prevent trapping of gas. The bottles were covered tightly with their lids, labelled appropriately and transported to the laboratory.

In the laboratory, the water samples were filled into 1 L Marinelli beakers with no special treatment. The samples in the Marinelli bakers were sealed hermetically to maintain a radioactive equilibrium between ^{226}Ra and its short-lived daughters, weighed and stored for a 1 month period. The radionuclides in the samples were counted using a high purity germanium detector.

3.3.2 Sediment

About 1 kg of the sediment samples were taken up to a depth of about 10–20 cm in the lake bed with pre-cleaned plastic shovel and sediment auger. The sediment samples were collected and transferred into pre-cleaned zip-lock polyethylene bags with labels and transported to the laboratory. Sediment samples were air dried at room temperature for 7 days then oven-dried at 105 °C to constant weight. A ball mill was used to ground the samples into fine powder and sieved with a 2 μm mesh size and then transferred into 1 L Marinelli beakers. The Marinelli beakers filled with the samples were sealed completely and stored for 1 month to allow the short-lived daughters of ^{238}U and ^{232}Th decay series to reach equilibrium with their long-lived parent radionuclides (Adukpo et al., 2014).

3.3.3 Fish

Fish (tilapia) samples were bought from random commercial catches available around the lake for sale. A total of 56 samples were collected during the period, stored on ice in an ice chest and transported to the laboratory where they were oven-dried at about 100°C to constant weight and then ground into powder using mortar and pestle and stored in paper envelopes for further processing.

3.4 Analysis of Samples

The samples for radionuclides determination were analyzed with a Canberra high resolution gamma-spectrometry system equipped with HPGE detector coupled to a computer based processor. Identification and quantitative analysis of radionuclides was performed using gamma ray spectrum analysis software, Genie 2000. The detector was connected to an Uninterrupted Power Supply cooled with liquid nitrogen provided in a 25 L Dewar flask at a temperature of 77 K. The ambient temperature around the detector was 16^{o}C during the period of measurement. The background distribution in the detector's environment, its correction and least detectable activities was determined by cleaning thoroughly 10 Marinelli beakers and filling them with distilled water to be counted for 36,000 seconds and adjustments made. Table 3.1 gives the radiological characteristics of the radionuclides used as standards for the efficiency calibration.

Table 3.1: Radiological characteristics of standard nuclides used for calibrations

Source	Energy (keV)	Channel number	Half-life(year)	Initial activity (x 10^3)	Final activity (x 10^3)	Net counts	Abundance (γ)	Efficiency (ε)
^{241}Am	60	64	432.2	2.97	2.937	118,798	0.3590	0.0313
^{137}Cs	662	690	30	2.78	2.365	924,485	0.8500	0.0128
^{57}Co	1,173	1224	5.27	3.40	1.354	375,803	0.9985	0.0077
^{60}Co	1,332	1390	5.27	3.40	1.354	343,046	0.9999	0.0070

3.4.2 High Purity Germanium Detector

High purity germanium detectors having high-resolution gamma-ray spectrometry has been widely used in qualitative and quantitative determination of gamma-ray emitting radionuclides in environmental samples. This is a non- destructive technique which does not require any rigorous sample preparation. It works on the principle that gamma ray photons have discrete energies which are characteristic of the emitting source. Therefore by measuring the energies of gamma ray photons in samples, the source of radiation can be accurately determined.

However, often times some radiations which do not originate from the samples are detected in the gamma spectrometry. These radiations are called background radiation and are subtracted from the sample measurement during data processing. ^{40}K, ^{232}Th, ^{238}U and ^{235}U which are radioisotopes of high-energy gamma ray of sufficient intensity are used for gamma ray mapping. High purity germanium detector is highly preferred to the other detectors because of its high resolution and sensitivity which is unmatched by any of the other detectors including NaI(Tl) detector (Hosseini, 2007).

3.5 Calculation of activity concentration and estimation of doses

The activities of ^{238}U in the samples were determined using the energy peak of 609.31 keV of ^{214}Bi. Similarly, the activity of ^{232}Th was determined using 911.21 keV peak of ^{228}Ac. The activity of ^{40}K was determined from the energy of 1460.83 keV. The analytical model used in the calculating the activity in Bq/kg for sediment and Bq/L for water samples is shown in equation (1).

$$A_{sp} = \frac{N_D e^{\lambda_P t_d}}{p.T_c.\eta(E).m} \qquad (1)$$

where; P is the probability of gamma ray emission (yield of gamma ray), N_D is the net counts of the samples' radionuclides, t_d is the time delayed between sampling and counting, $\eta(E)$ is the absolute counting efficiency of the detector system, T_c is the time taken to count sample, m is the weight of the sample (kg) or volume (l), $\exp(\lambda_p t_d)$ is the factor of decay correction for delay between time of sampling and counting and λ_p is the decay constant of the parent radionuclide

The external gamma dose rate (D_γ) at 1.0 m above ground for the sediment samples was calculated from the activity concentrations using equation (2) (Uosif et al., 2014).

$$D_\gamma\left(nGyh^{-1}\right) = DCF_K * A_K + DCF_U * A_U + DCF_{Th} * A_{Th} \qquad (2)$$

Where; $DCF_{Th,}$ $DCF_{U,}$ DCF_K are the absorbed dose rate conversion factors for ^{232}Th, ^{238}U and ^{40}K in nGy/h/Bq/kg and $A_{Th,}$ A_K and A_U are the activity concentrations for ^{232}Th, ^{40}K and ^{238}U respectively.

DCF_K = 0.0417 nGy/h/Bq/kg; DCF_U = 0.462 nGy/h/Bq/kg; DCF_{Th} = 0.604 nGy/h/Bq/kg

The mean yearly effective dose was calculated from the absorbed dose rate by using an outdoor occupancy factor of 0.2 and dose conversion factor of 0.7 Sv/Gy (UNSCEAR, 2000) represented by equation (3).

$$E_y = D_y \times 0.7 \times 8760 \times 0.2 \quad (3)$$

Where; E_γ is the average yearly effective dose and D_γ is the absorbed dose rate in air.

The committed effective doses for water samples were estimated from the activity concentrations of the individual radionuclide and applying the annual water consumption rate for adults of 730 L/year (Gordon et al., 2008). The dose conversion factors of ^{238}U, ^{232}Th and ^{40}K were taken from the Basic Safety Standards (IAEA, 1996) and equation (4) used to calculate the committed effective dose.

$$S_{ing}(w) = I_w \sum_{j=1}^{3} DCF_{ing}(U, Th, K) A_{sp}(w) \quad (4)$$

Where, A_{sp} (w) is the activity of radionuclides in water sample in Bq/L, I_w is the intake of water and DCF_{ing} is the coefficient of ingestion dose in Sv/Bq/L.

3.6 Calculation of total annual effective dose

The total annual effective dose (E_T) to members of the public was calculated using International Commission for Radiological Protection dose calculation method (ICRP, 2007). The analytical model for the determination is given in equation (5).

$$E_T = E_\gamma(U, Th, K) + E_{ing}(W) \quad (5)$$

where; E_γ (U, Th, K) is the external gamma effective dose from the sediment samples, E_T is the total effective dose in Sievert (Sv), E_{ing} (W) is the effective dose from water consumption (Faanu et al., 2006).

3.7 Determination of radium equivalent activity and hazard indices

The radiological risk of NORM in sediments in the study areas which may be used as building material was assessed by calculating the radium equivalent activity (Ra_{eq}) and the internal hazard and external hazard indices.

The Ra_{eq} is a widely used hazard index and it was determined using equation (6) (Agbalagba & Onoja, 2011):

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (6)$$

Where; C_{Th}, C_{Ra} and C_K are the activity concentrations of ^{232}Th, ^{226}Ra and ^{40}K respectively. In the definition of Ra_{eq}, The maximum recommended value of Ra_{eq} in raw building materials and products must be less than 370 Bq/kg for safe use. This means that the external gamma dose must be less than 1.5 mSv/year.

External hazard index is also a factor for consideration in using sediments for construction material and it is shown in equation (7).

$$H_{ex} = \frac{A_{RA}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (7)$$

Where C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively. The value of the external hazard index must be less than one for the external gamma radiation hazard to be considered negligible. The radiation exposure due to the radioactivity from construction materials is limited to 1.5 mSv/y.

Also internal hazard index (H_{in}) due to radon and its daughters was calculated from equation (8). This is based on the fact that, radon and its short-lived products are also hazardous to the respiratory organs.

$$H_{in} = \frac{A_{RA}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \qquad (8)$$

Where C_{Th}, C_{Ra} and C_K are the activity concentrations of ^{232}Th, ^{226}Ra, and ^{40}K respectively. For construction materials to be considered safe for construction of dwellings, the Hin should be less than one (Agbalagba & Onoja, 2011).

3.8 Metal Concentration Determination

Digestion of samples

40 mL of water sample was measured and digested with 5 mL of a mixture of acids (4.5 mL HCl and 0.5 mL of HNO_3) and 0.25 mL of H_2O_2. The mixture was digested on a hot plate for 3 hours at 45°C under reflux. Upon cooling, the digested sample was transferred into a 30 mL volumetric flask and made up to the graduated mark using distilled water.

Two grams of sediment sample was digested with 50 mL aqua regia (conc. HNO_3 and conc. HCl in the ratio 1:3) and 1 mL of H_2O_2. The mixture was put on a hot plate for 3 hours at 45°C under reflux. Upon cooling, the digested sample was filtered into a 30 mL volumetric flask and made up to the graduated mark using distilled water and 2g of the powdered fish samples were digested using 9 mL of HNO_3 and 2.5 mL of H_2O_2. The mixture was put on a hot plate for 3 hours at 45°C under reflux. Upon cooling, the digested sample was filtered into a 30 mL volumetric flask and made up to the graduated mark using distilled water.

After digestion of the samples, the concentration of metals was then determined using AAS analysis with AAS model: Varian AA240FS at the National Nuclear Research Institute (GAEC) and subsequently the final concentration calculated for the samples using equations 9-10.

3.8.2 Calibration of Instrument

Working standards of concentrations 1, 2, 5 and 10 mg/L of lead, copper, zinc, cadmium, cobalt, manganese, iron, nickel, arsenic, mercury and chromium were prepared by diluting stock solutions and determined using the AAS.

3.8.3 Calculation of Concentration of Metals

Water sample

$$\text{Final concentration (mg/L)} = \frac{\textit{Concentration read on AAS x Nominal volume}}{\textit{Sample volume}} \quad (9)$$

Sediment and fish sample

$$\text{Final concentration (mg/kg)} = \frac{\textit{Concentration read on AAS x Nominal volume}}{\textit{Sample weight}} \quad (10)$$

Where Nominal volume = 30 mL, Sample weight = 2 g and Sample volume = 40 mL

Concentrations of Fe and Mn of the sediment samples were found to be above the instrument's detection limit therefore, standards calibration curve was plotted for the metals and the concentration of the samples determined from the equation of the line. The line of best fit shows positive correlation with $R^2 = 1$

3.9 Sediment Pollution Analysis

The concentrations of the eleven metals in the sediment samples were subjected to various calculations to find out the level of metal pollution at the studied area as far as sediments are concerned.

3.9.1 Biota-Sediment Accumulation Factor

Biota Sediment Accumulation Factors were assessed for the studied areas for sediment and fish samples to verify the efficiency of metal bioaccumulation in the tissues of the organisms. BSAFs were calculated for each metal using equation (11):

$$\text{BSAF} = \frac{concentration\ of\ heavy\ metal\ in\ the\ organism}{concentration\ of\ heavy\ metal\ in\ sediment} \qquad (11)$$

This method was to help in the risk assessments of the ecology since ambient media concentrations were readily available; ambient media data were required for the characterization of the site and health assessments of humans typically conducted in conjunction with ecological assessments.

3.9.2 Index of Geo-accumulation and Contamination Factor

Heavy metal concentrations found in the sediments were compared to GESAMP (1982) sediment standards to know the level of metal pollution of the sediments at the studied areas. Müller's geochemical index (Igeo) was also used to measure the pollution intensities of the studied sediments. The Igeo is a qualitative measure of pollution intensity of the samples and is classified as unpolluted (<0), unpolluted to moderately polluted ($0 \leq$ Igeo ≤ 1), moderately polluted ($1 \leq$ Igeo ≤ 2), moderately to strongly polluted ($2 \leq$ Igeo ≤ 3), strongly polluted ($3 \leq$ Igeo ≤ 4), strongly to extremely polluted ($4 \leq$ Igeo ≤ 5) and extremely polluted (Igeo ≥ 5).

The Igeo formula used for the calculation is given in equation (12):

$$I_{geo} = \log_2\left[\frac{C_S}{1.5 \times C_B}\right] \qquad (12)$$

Cm sample is the calculated concentration of element "m" and Cm standard concentration of the element in "average shale" (background concentration). The geoaccumulation index (Igeo) was earlier defined to measure quantitatively the pollution of aquatic sediments with metals. The concentration used as background is multiplied by a factor of 1.5 which takes care of natural fluctuations of the metal in the environment as well as other influences. The calculated Igeo values would then be compared with Igeo classification for sediment quality to know the extent of pollution of the sampled areas. The average shale values used were; Cr = 240 mg/kg; Fe = 4.67 mg/kg; Mn = 850 mg/kg; Cu = 70 mg/kg; Zn = 95 mg/kg; Co = 15 mg/kg; As = 18 mg/kg; Hg = 0.2 mg/kg; Ni = 30 mg/kg (Boszke et al., 2004).

3.9.3 Contamination Factor

The level of contamination of soil by metal is expressed in terms of a contamination factor which is the ratio of concentration of metal in sediment to that in shale.

This calculation was done to get a fair idea of the extent of anthropogenic pollution and accumulation of heavy metals in the sediments at the sampling locations. The CF classification was classified as follows: if CF < 1 there is low contamination, $1 \leq CF < 3$ moderate contamination, $3 \leq CF \leq 6$ considerable contamination and CF > 6 high contamination (Banu et al., 2013).

3.9.4 Pollution Load Index

Pollution load index (PLI) for the soil profile was evaluated using the model proposed by Tomilson et al. (1980). The PLI is used to assess site quality to know of the pollution intensity.

PLI is expressed as in equation (13):

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots \times CF_n)^{\frac{1}{n}} \qquad (13)$$

Where, n is the number of metals studied and CF is the contamination factor of each metal on the site.

The PLI range and pollution intensity are classified as; Perfection (<1), pollutants present but only baseline levels (=1) and (>1) deterioration of site quality (Banu et al., 2013).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Physical Parameters

Results of the physical parameters of water samples from the studied areas presented in Table 4.1 shows variations of the physical parameters in the studied areas. Generally, the pH of the samples were almost the same for the water samples from Lake Bosomtwi, pH recorded was in the range of 8.79 to 8.90 with a mean of 8.86±0.04 whilst that of Bui dam had a range of 6.73 to 6.83 and a mean of 6.78±0.05. These indicate that the water samples from Lake Bosomtwi are generally alkaline. The alkaline nature of the lake water can be attributed to chemical weathering of rocks and human activities in the lake notably bathing, swimming and washing of clothes along the banks of the lake. The people use soap in these activities which may hydrolyze to produce OH^- ions to make the water basic.

The Bui dam samples were acidic (6.73-6.83) which can be attributed to chemicals leached into the water from agricultural practices near-by and chemical weathering of the rocks. World Health Organization accepted range of pH for water meant for drinking is 6.5 to 8.5 (Gordon et al., 2008). Bui dam water samples were within the WHO limits but Lake Bosomtwi samples were outside the recommended limit. It is known that the pH of water generally influences the concentration of heavy metals and radionuclides by altering their bio-availability and toxicity (Faanu, 2011). High temperature and low pH may result in increased metal and radionuclides toxicity in water. The chemical and biogeochemical processes that result in lowering of pH encourage the dissolution of radionuclides and heavy metals into the water system in very high concentrations. This could thus lead to the water becoming unsafe for human consumption (Faanu, 2011),

also increased water temperature promotes the growth of microbes and may give rise to taste, odor and color problems (Gordon et al., 2008).

Electrical conductivity which is a measure of the conductance of the aqueous solution and also estimates the total ions and total ionic salinity in a water sample was determined for the water samples from the studied areas. Lake Bosomtwi samples ranged from 1240 to 1252 µS/cm with an average of 1245±3.45 µS/cm whilst Bui dam samples were in the range of 80.8 to 83.5 µS/cm with an average of 81.8±1.09 µS/cm. The recommended value of electrical conductivity in drinking water samples according to WHO is 700 µS/cm (Gordon et al., 2008). A comparison of the results from the present study to recommended limits shows that samples from Bui dam were within limits but those of Lake Bosomtwi were above limits.

Electrical conductivity also is a useful indicator of minerals in water bodies and shows relationship with total dissolved solids (TDS) in water as both measures the ionic strength of water (Faanu, 2011), bicarbonate alkalinity, and the pH of lake waters (Akyil et al., 2009). TDS values recorded for Lake Bosomtwi samples were in the range of 841 to 853 mg/L with a mean of 846 mg/L while that of Bui dam varied in the range of 51 to 53 mg/L with a mean of 52 mg/L. The WHO recommended value of TDS in drinking water ranges from 600 to 1000 mg/L (Gordon et al., 2008). The results were in good agreement with the recommended value.

Table 4.1: Physical parameters of water samples from the lakes

Location	pH	Temperature (°C)	TDS (mg/L)	Conductivity (µS/cm)
Lake Bosomtwe				
Abono	8.85	27.00	847	1243
Adwafo	8.83	27.10	842	1243
Abrodum	8.88	27.10	844	1247
Anyinatiase	8.79	27.10	844	1245
Esaase	8.84	27.20	853	1252
Detieso	8.80	27.20	850	1243
Dompa	8.90	27.00	841	1240
Duase	8.88	27.10	843	1245
Ankaase	8.89	27.20	843	1241
Amakom	8.88	27.20	850	1248
Adjamam	8.88	27.10	844	1247
Average	**8.86**	**27.12**	**846**	**1245**
Bui Dam				
Banda Nkwanta	6.76	28.00	52	82.2
Bator	6.73	28.10	52	81.6
Donkokyina	6.83	28.20	51	80.8
Jama	6.83	28.30	52	81.0
Old soldier	6.76	28.30	53	83.5
Average	**6.80**	**28.20**	**52**	**81.8**

4.2 Activity concentration of naturally occurring radionuclides

Three naturally occurring radionuclides (^{238}U, ^{232}Th and ^{40}K) were determined in the sediment and water samples. Table 4.2 gives activity concentration of the radionuclides, absorbed dose rate at 1 meter above sampling point, annual effective dose as well as the percentage contribution of individual radionuclides to the absorbed dose rate.

Activity concentration of ^{238}U Lake Bosomtwi ranged from 5.27±0.43 Bq/kg in Abono to 10.40±0.58 Bq/kg in Detieso with an average value of 7.90±1.61 Bq/kg, while ^{232}Th ranged from 5.38±0.75 Bq/kg in Abrodum to 13.80±1.87 Bq/kg also in Duase with an average value of 7.83±2.34 Bq/kg.

Table 4.2: Activity concentration, absorbed dose rate, percentage contribution of radionuclide to absorbed dose rate and annual effective dose in sediment samples of Lake Bosomtwi.

Lake Bosomtwi	Mean activity concentration ± SD Bq/kg			Absorbed dose rate (nGy/h)	Annual effective dose (μSv)	Percentage contribution of radionuclide to absorbed dose rate (%)		
	^{40}K	^{232}Th	^{238}U			^{238}U	^{232}Th	^{40}K
Abono	187±4.05	5.39±0.75	5.27±0.43	13.48	16.5	18.06	24.15	57.79
Adwafo	189±4.05	6.95±0.96	7.65±0.54	15.61	19.1	22.65	26.89	50.46
Abrodum	161±3.60	5.38±0.75	6.39±0.48	12.92	15.8	22.84	25.15	52.01
Anyinatiase	189±4.05	6.95±0.96	7.65±0.54	15.61	19.1	22.65	26.89	50.46
Essase	197±4.19	7.02±0.97	10.40±0.58	17.24	21.1	27.81	24.61	47.58
Detieso	197±4.19	7.02±0.97	10.4±0.58	17.24	21.1	27.81	24.61	47.58
Dompa	162±3.63	7.94±1.09	6.97±0.61	14.78	18.1	21.78	32.47	45.75
Duase	145±3.33	13.80±1.87	9.44±0.58	18.74	23.0	23.28	44.53	32.19
Ankaase	126±3.01	9.80±1.34	8.02±0.53	14.89	18.3	24.89	39.75	35.36
Amakom	109±2.69	7.60±1.05	7.10±0.53	12.41	15.2	26.41	36.98	36.61
Adjamam	205±4.71	8.25±1.13	7.66±0.54	17.05	20.9	20.75	29.20	50.04
Average	**169.73**	**7.83**	**7.90**	**15.45**	**18.9**	**23.54**	**30.48**	**45.98**
Standard deviation	**31.81**	**2.34**	**1.61**	**2.00**	**2.5**	**2.99**	**7.03**	**7.93**
Range	**109 - 205**	**5.38 – 13.80**	**5.27 – 10.40**	**12.41-18.74**	**15.2 – 23.0**	**18.06 -27.81**	**24.15 - 44.53**	**32.19 – 57.79**

The activity of ^{40}K was identified to be higher than the activities of both ^{238}U and ^{232}Th in all the sediments samples studied for Lake Bosomtwi. Its value ranged from 109±2.69 Bq/kg in Amakom to 205±4.71 Bq/kg in Adjamam with an average value of 169.73±31.81 Bq/kg. The very high activity concentration of ^{40}K could be because the rocks in the study area contain high levels of potassium and other metals as a result of the crystalline nature of the rock.

ui dam sediment samples as shown in Table 4.2b, also recorded activity concentration of ^{238}U in the range of 6.31±0.49 Bq/kg in Jama to 8.97±0.55 Bq/kg in Old soldier with a mean value of 7.56±1.05 Bq/kg, ^{232}Th recorded a range of 6.12±0.85 Bq/kg in Jama to 9.89±1.35 Bq/kg in Dokokyina with a mean value of 8.11±1.45 Bq/kg and ^{40}K having a range of 35.1±1.39 Bq/kg in Banda nkwanta to 62.0±1.87 Bq/kg in Bator and a mean value of 49.0±10.19 Bq/kg. The average activity concentration of the 3 radionuclides in the sediments from this study were found to be lower than that reported in similar environment for soil and sediments (Adukpo et al., 2014; Agbalagba, 2013; Darko, 2014; Fahmi, 2010) as well as soil samples from Lake Bosomtwi one of the studied areas (Darko et al., 2011) but higher than those reported for Assiut zone in Egypt (Uosif et al., 2013).

Table 4.2b: Activity concentration, absorbed dose rate, percentage contribution of radionuclide to absorbed dose rate and annual effective dose in sediment samples of Bui dam

Bui dam	Mean activity concentration ± SD Bq/kg			Absorbed dose rate (nGy/h)	Annual effective dose (μSv)	Percentage contribution of radionuclide to absorbed dose rate (%)		
	^{40}K	^{232}Th	^{238}U			^{238}U	^{232}Th	^{40}K
Banda Nkwanta	35.1±1.39	8.85±1.21	8.23±0.54	10.61	13.0	35.81	50.38	13.81
Bator	62.0±1.87	7.32±1.01	7.32±0.54	10.39	12.7	32.54	42.57	24.89
Donkokyina	44.0±1.58	9.89±1.35	6.99±0.50	11.04	13.5	29.26	54.11	16.64
Jama	49.6±1.55	6.12±0.85	6.31±0.49	8.68	10.6	33.57	42.60	23.83
Old soldier	54.3±1.65	8.37±1.15	8.97±0.55	11.47	14.1	36.14	44.10	19.76
Average	**49.0**	**8.11**	**7.56**	**10.44**	**12.8**	**33.46**	**46.75**	**19.79**
Standard deviation	**10.9**	**1.45**	**1.05**	**4.1**	**5.0**	**2.79**	**5.22**	**4.69**
Range	**35.1-62.0**	**6.12 – 9.89**	**6.31-8.97**	**8.68–11.47**	**10.6–14.1**	**29.26–36.14**	**42.57–54.11**	**13.81–24.89**
World average	**400**	**30.0**	**35.0**	**59**	**100**			

In the case of the absorbed dose rate and annual effective dose, the absorbed dose rate varied in a range of 12.41 to 18.74 nGy/h with an average of 15.45 nGy/h for Lake Bosomtwi and varied in a range of 8.68 to 11.47 nGy/h with an average of 10.44 nGy/h for Bui dam which are lower as compared with the acceptable International value of 59 nGy/h in sediment (UNSCEAR, 2000a). The absorbed dose rate and annual effective dose calculated were lower than those reported earlier for Lake Bosomtwi (Darko et al., 2011) and that reported in Egypt (Fahmi et al., 2010).

Generally, the activity concentration of the samples from the studied areas were found to be below world average values (UNSCEAR, 2000a) and Figure 4.1 shows the variation of results from the studied area with the UNSCEAR average activity concentration.

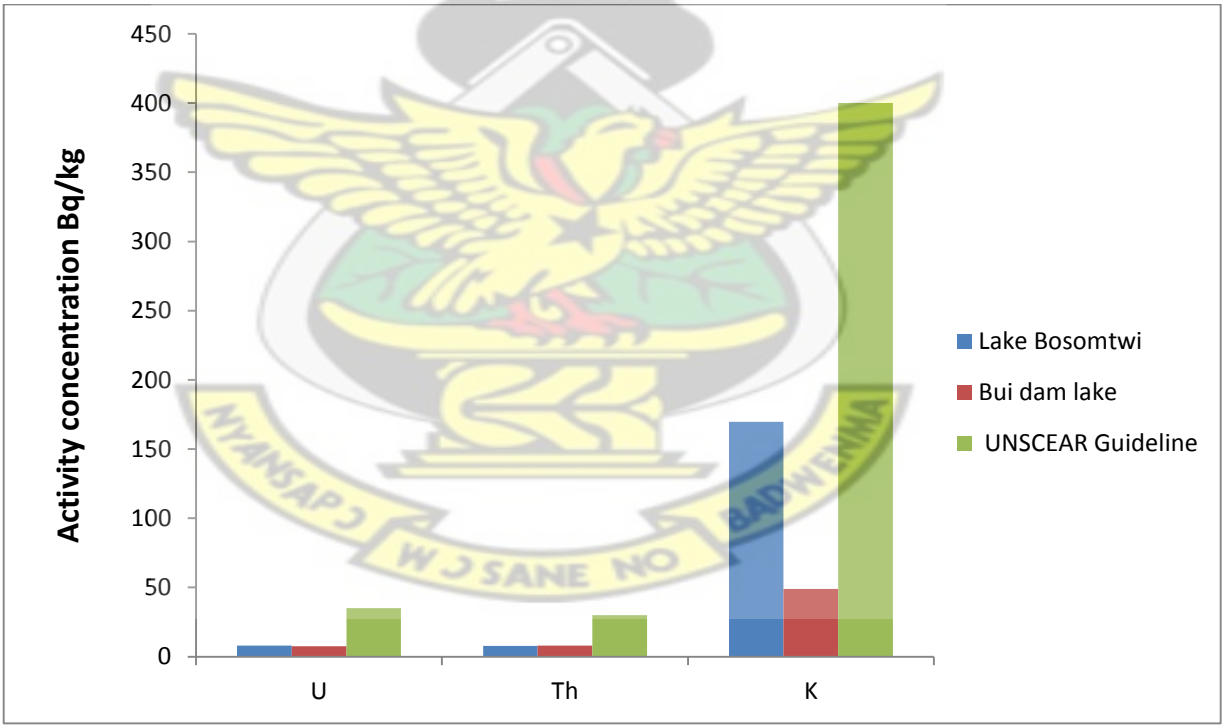


Figure 4.1: Activity Concentration Bq/kg for sediment samples.

Figure 4.2 and 4.3 give percentages contributed by the radionuclides to the absorbed dose rate from the studied areas. In Lake Bosomtwi, the average percentage contribution of ^{40}K was found to be higher than the other two radionuclides contributing 46% whilst ^{238}U contributed 24% and ^{232}Th 30% to the absorbed dose rate but Bui dam had ^{232}Th contributing the highest average percentage of 47% followed by ^{238}U with 33% and ^{40}K with 20%. The high percentage of ^{232}Th in the area could be due to the mineralogical and geochemical composition of the soil and rock.

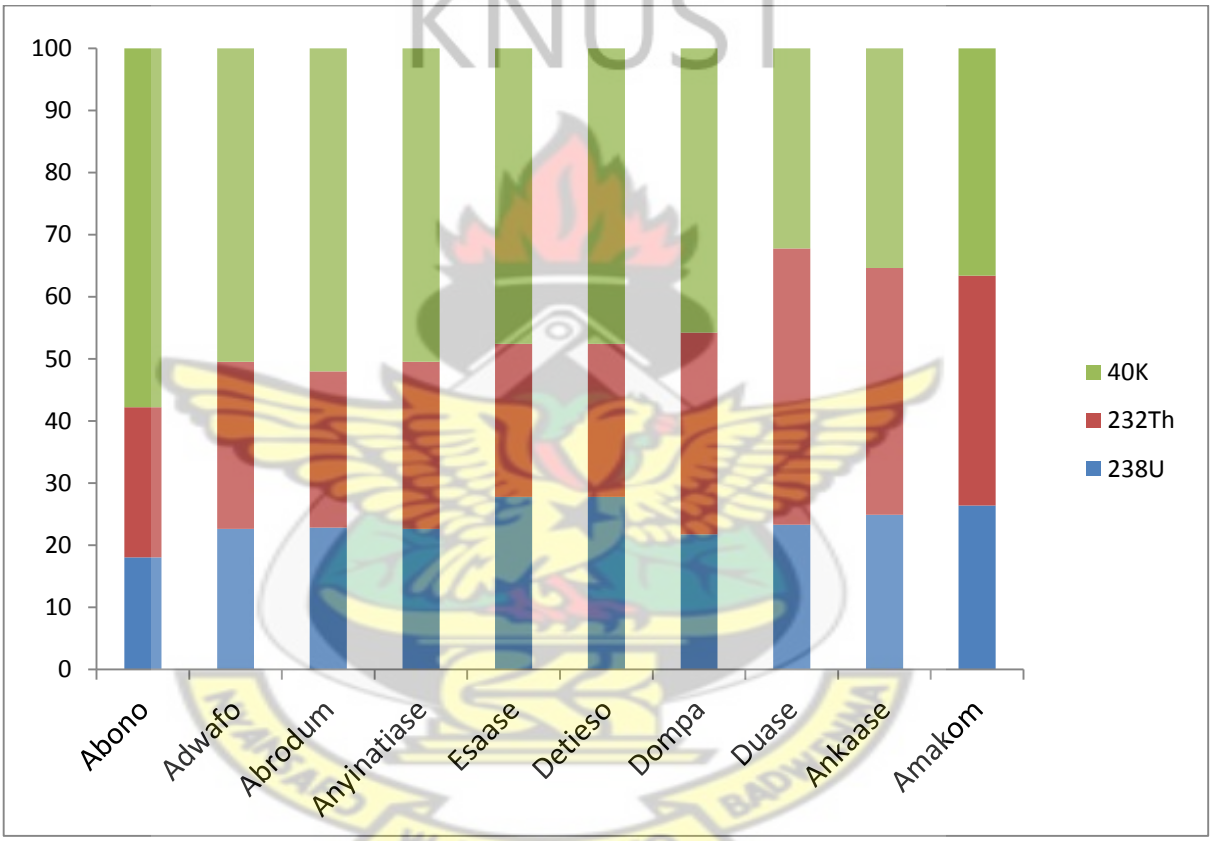


Figure 4.2: Percentage contributed by radionuclides to the absorbed dose rate in sediment for Lake Bosomtwi

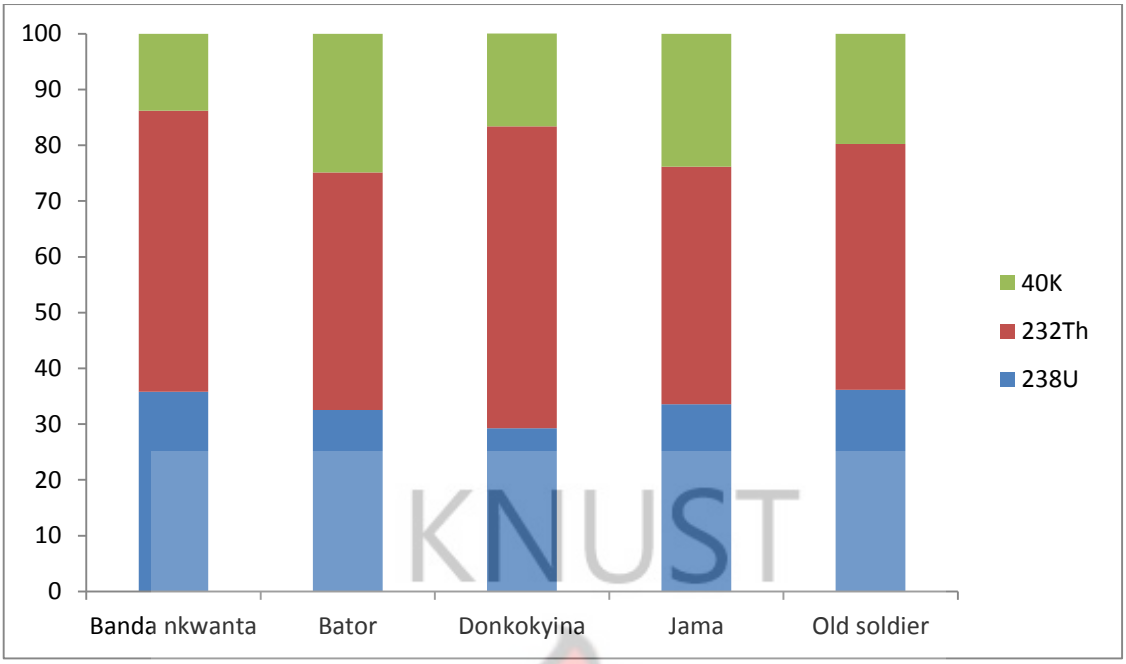


Figure 4.3: Percentage contributed by radionuclides to the absorbed dose rate in sediment for Bui dam.

Table 4.3 presents the activity concentration in water samples from Lake Bosomtwi. They had a range of 0.20±0.07 Bq/L in Essase to 0.98±0.24 Bq/ L with a mean of 0.42±0.20 Bq/L for ^{238}U. Activity concentrations for ^{232}Th ranged from 0.03±0.08 Bq/L in Adwafo to 0.82±0.13 Bq/L in Dompa with a mean of 0.33±0.31 Bq/L, while ^{40}K activity concentrations ranged from 0.02±0.67 Bq/L in Adjamam to 3.32±0.77 Bq/L in Abrodum with a mean of 1.59±1.07 Bq/L.

Activity concentration of ^{238}U in water samples from Bui dam was in the range of 0.13±0.08 Bq/L in Banda nkwanta to 0.42±0.01 Bq/L in Jama and an average value of 0.26±0.14 Bq/L, ^{232}Th ranged from 0.07±0.14 Bq/L in Dokokyina to 0.82±0.14 Bq/L in Bator and an average of 0.67±0.34 Bq/L with ^{40}K being in the range of 0.78±0.73 Bq/L in Old soldier to 2.42±0.75 Bq/L in Jama and an average value of 1.47±0.62 Bq/L. These results were found to be lower than that from other locations like the river Pra in Ghana due to gold

Table 4.3: Average activity concentrations and annual effective doses due to ^{238}U, ^{232}Th and ^{40}K in water samples in the study areas.

Lake Bosomtwi	Activity concentration, Bq/L			Committed effective dose, μSv/year
	^{238}U	^{232}Th	^{40}K	
Abono	0.98±0.24	0.54±0.13	2.51±0.75	134
Adwafo	0.41±0.01	0.03±0.08	0.42±0.68	20.5
Abrodum	0.43±0.01	0.17±0.12	3.32±0.77	57.9
Anyinatiase	0.41±0.01	0.82±0.13	0.94±0.70	155
Essase	0.20±0.07	0.15±0.15	0.31±0.76	46.5
Detieso	0.30±0.08	0.16±0.14	2.34±0.68	47.5
Dompa	0.40±0.01	0.82±0.13	1.30±0.70	156
Duase	0.42±0.01	0.14±0.14	2.58±0.78	48.6
Ankaase	0.27±0.08	0.10±0.14	1.92±0.72	33.8
Amakom	0.36±0.08	0.61±0.14	1.80±0.73	122
Adjamam	0.44±0.01	0.07±0.14	0.02±0.67	26.9
Average	**0.42**	**0.33**	**1.59**	**77.20**
Standard deviation	**0.20**	**0.31**	**1.07**	**53.05**
Range	**0.20 – 0.98**	**0.03 – 0.82**	**0.02 – 3.32**	**20.5 – 156**
Bui dam				
Banda Nkwanta	0.13±0.08	0.82±0.14	1.15±0.69	146
Bator	0.41±0.01	0.82±0.14	1.36±0.70	156
Donkokyina	0.21±0.07	0.07±0.14	1.63±0.73	26.5
Jama	0.42±0.01	0.82±0.14	2.42±0.75	162
Old soldier	0.14±0.06	0.82±0.14	0.78±0.73	145
Average	**0.26**	**0.67**	**1.47**	**127.10**
Standard deviation	**0.14**	**0.34**	**0.62**	**56.68**
Range	**0.13 – 0.42**	**0.07 – 0.82**	**0.78 – 2.42**	**26.5 – 162**
Guideline levels (WHO, 2008)	**10.0**	**1.0**	**N/A**	**100**

mining (Adukpo et al., 2015), from Chirano gold mine in Ghana (Faanu et al., 2013) drinking waters from oil mill communities in Nigeria due to mining and oil prospecting (Agbalagba et al., 2013), in flood plain lakes in Nigeria which are frequently polluted by oil and gas exploration activities (Agbalagba & Onoja, 2011) as well as some lakes in Turkey (Akyil et al., 2009). The activity concentration in water was however greater than the activity concentration determined in drinking water from boreholes in Kumasi (Darko et al., 2014) and food producing communities in the Tano district of Brong Ahafo (Darko et al., 2015).

The activity concentration from the studied areas were found to be below WHO guidelines of 10 Bq/L for ^{238}U and 1 Bq/L for ^{232}Th. The World Health Organisation recommended level of ^{40}K in water meant for drinking is unavailable. This is as a result of the maintenance at a constant amount of potassium in the human body at a fixed body mass. The consumed annual effective dose from drinking water also varied in a range of 15.2 to 23.0 μSv with an average value of 18.9 μSv for Lake Bosomtwi while Bui dam samples varied in a range of 10.6 to 14.1 μSv with an average value of 12.8 μSv which is within the International Commission for Radiological Protection requirement. The ICRP requirement with respect to drinking water quality estimates that the consumed annual effective dose from all radionuclides except for ^{3}H and Rn should not exceed 100 μSv per year for public exposure (ICRP, 1990). Figure 4.4 compares average activity concentration of ^{238}U and ^{232}Th from the studied areas with World Health Organisation, 2008 standards.

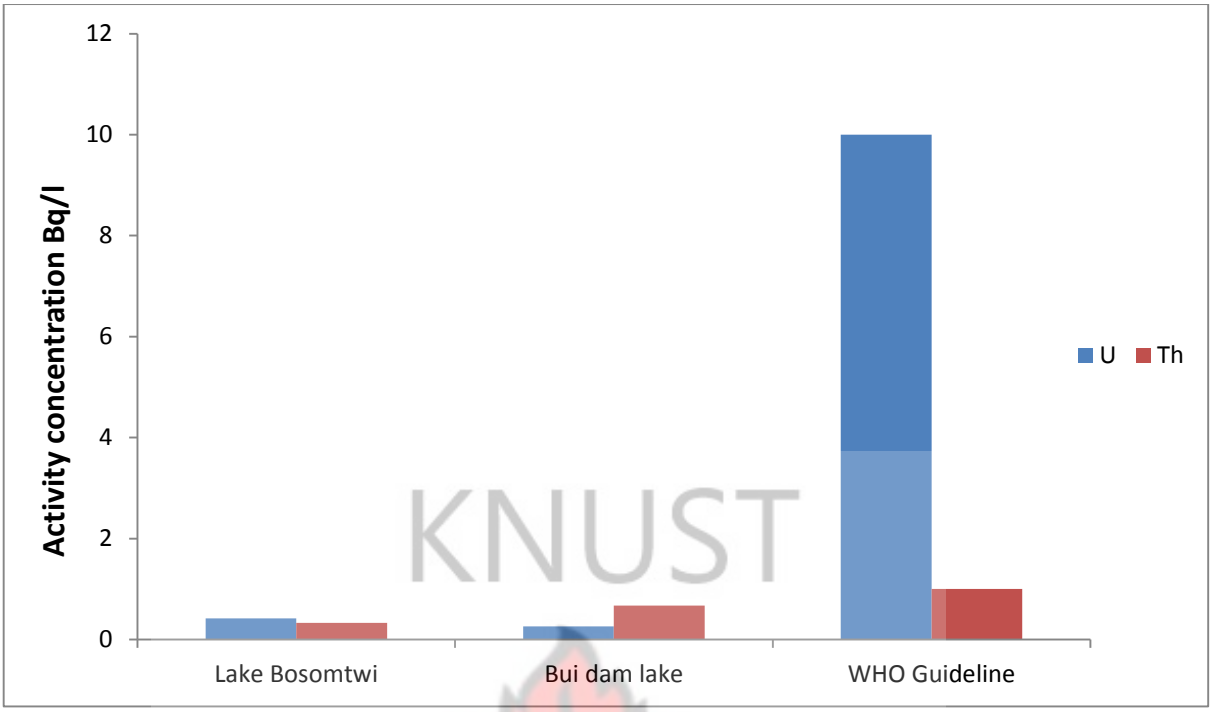


Figure 4.4: Comparing the average activities of ^{238}U and ^{232}Th in water samples with WHO recommended guideline levels.

Table 4.4 also shows the results of the hazard assessment of sediments with respect to radium equivalent activity as well as hazard indices. The natural radioactivity in building materials is usually determined from the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K. Also because 98.5% of the radiological hazard of uranium-series is due to radium and its decay products ^{238}U is replaced with concentrations of ^{226}Ra in hazard assessment. In order to assess if sediments which could be used for building purposes could pose any radiation hazard, the three hazard indices namely; radium equivalent (Ra_{eq}) activity in Bq/kg, external hazard (H_{ex}) and the internal hazard (H_{in}) indices were calculated. The average radium equivalent activity in this study was 32.17±4.37 Bq/kg in a range of 26.36 to 40.34 for Lake Bosomtwi samples while Bui dam samples was in a range of 18.88 to 25.12 Bq/kg with an average value of 22.93±2.46 Bq/kg which are below the recommended limit of 370 Bq/kg.

Table 4.4: Radium equivalent activity, external and internal hazard, and annual effective doses due to ^{232}Th, ^{238}U and ^{40}K in sediment samples in the study areas.

Lake Bosomtwi	Radium equivalent activity (Ra_{eq}), Bq/kg	External hazard index (H_{ex})	Internal hazard index (H_{in})
Abono	27.38	0.07	0.09
Adwafo	32.14	0.09	0.11
Abrodum	26.48	0.07	0.09
Anyinatiase	32.14	0.09	0.11
Essase	35.61	0.10	0.12
Detieso	35.61	0.10	0.12
Dompa	30.80	0.08	0.10
Duase	40.34	0.11	0.13
Ankaase	31.74	0.09	0.11
Amakom	26.36	0.07	0.09
Adjamam	35.24	0.10	0.12
Average	**32.17**	**0.09**	**0.11**
Standard deviation	**4.37**	**0.01**	**0.02**
Range	**26.36 -40.34**	**0.07-0.11**	**0.09-0.13**
Bui dam			
Banda Nkwanta	23.59	0.06	0.09
Bator	22.56	0.06	0.08
Donkokyina	24.52	0.07	0.09
Jama	18.88	0.05	0.07
Old soldier	25.12	0.07	0.09
Average	**22.93**	**0.06**	**0.08**
Standard deviation	**2.46**	**0.01**	**0.01**
Range	**18.88 – 25.12**	**0.05-0.07**	**0.07-0.09**

The radium equivalent activity is related to the external gamma dose from the terrestrial radionuclides and the internal dose due to radon and its decay products of ^{210}Pb and ^{210}Po. The accepted value of Ra_{eq}, in building materials must be < 370 Bq/kg for the material to be considered safe for use. The internal and external hazard indices must also be less than one to keep the hazard due to radiation insignificant.

The calculated external hazard index in the sediment samples ranged from 0.07 (Abono) to 0.11 (Duase) and an average value of 0.09±0.01 for Lake Bosomtwi and a range of

0.05 to 0.07 with an average of 0.06±0.01 for Bui dam sample in the studied areas. Similarly for the internal hazard index, the values ranged from 0.09 to 0.13 with an average of 0.11±0.02 for Lake Bosomtwi but for Bui dam, the range was 0.07 to 0.09 with an average of 0.08±0.01. All the samples measured had their Ra_{eq}, Hex and Hin within the recommended limits, which imply that the materials could be used for building purposes without posing any health hazard to the population.

Table 4.5 also gives the internal and external hazard indices for water samples from the studied areas. The hazard indices were found to be far less than unity which makes radiation in the studied areas insignificant to cause any danger. A comparison was made for both study areas of the pathways of exposure of radiation using the annual effective dose and was found that both locations had exposure due to water was higher than exposure due to sediment. Lake Bosomtwi recorded 1.89 x 10^{-11} mSv for sediment and 7.72 x 10^{-5} mSv for water whilst Bui dam recorded 1.28 x 10^{-11} mSv for sediment and 1.27x10^{-4} mSv for water.

Table 4.5: Internal and external hazard indices in water samples in the study areas.

Lake Bosomtwi	Internal hazard index	External hazard index
Abono	0.008	0.005
Adwafo	0.002	0.001
Abrodum	0.004	0.003
Anyinatiase	0.006	0.004
Essase	0.002	0.001
Detieso	0.003	0.002
Dompa	0.006	0.005
Duase	0.003	0.002
Ankaase	0.002	0.002
Amakom	0.005	0.004
Adjamam	0.003	0.001
Average	**0.004**	**0.003**
Standard deviation	**0.002**	**0.001**
Range	**0.002-0.008**	**0.001-0.005**
Bui dam		
Banda Nkwanta	0.004	0.004
Bator	0.006	0.005
Donkokyina	0.002	0.001
Jama	0.006	0.005
Old soldier	0.004	0.004
Average	**0.004**	**0.004**
Standard deviation	**0.002**	**0.001**
Range	**0.002-0.006**	**0.001-0.005**

4.3. Heavy metal concentration in water samples

The metal concentrations in the water samples were variable from one location to another (Table 4.6). The concentrations of Cu, Ni, Hg and Co in all the water samples from Lake Bosomtwi were below the method's detection limits.

4.3.1 Lake Bosomtwi sampling location

Generally the order of the average concentration of metals was; Fe > Pb > Mn > Zn = As > Cd = Cr and the order for Bui dam was; Fe > As > Pb > Mn > Cd = Zn > Cr with Co, Cu, Hg and Ni having concentrations below the detection limit of the instrument. Chromium ranged between 0.002 mg/L and 0.011 mg/L in Dompa which was more than the WHO limit of 0.010 mg/L but the mean concentration of 0.003±0.003 mg/L for the studied area was below the WHO limit, iron concentration varied from 0.116 mg/L in Amakom to 0.744 mg/L in Dompa with average of 0.284±0.227 mg/L, manganese concentration varied from 0.011 mg/L in Detieso to 0.020 mg/L in Essase with a mean of 0.014±0.003 mg/L. Zinc ranged from <0.0010 to 0.016 mg/L in Detieso having an average of 0.007±0.005 mg/L. Lead varied from <0.0010 to 0.101 mg/L in Abono with average of 0.069±0.028 mg/L which were all above the WHO threshold for Pb in water (0.010 mg/L). Cadmium was only present in Abono sample having a value of 0.003 mg/L same as the WHO limit for Cd in water and arsenic varied from 0.005 mg/L in Adwafo to 0.011 mg/L in Anyinatiase with average concentration of 0.007±0.002 mg/L.

The mean concentrations of the metals determined in this study compared with earlier work reported in the area (Asare-Donkor et al., 2014) shows that the levels of metals has reduced considerably. Considering Anyinatiase sampling area, this work recorded metal concentrations in mg/L as; Fe = 0.146, Cr = 0.002, Zn = 0.004, Pb = 0.052, Cd and Ni <0.0010 mg/L whilst in the earlier work reported, concentration of metals were; Fe =

0.357, Cr= 0.011, Zn = 0.199, Pb = 0.091, Cd, Ni and As were < 0.01 mg/L. This suggests that most of the metals recorded might be from anthropogenic activities which may have reduced considerably over the period or the metals in water might be due to chemical weathering of rocks after rainfall which might have settled down to the sediment during the sampling period. Other works in similar locations suggest the mean concentrations determined in this study are low in South Africa, Turkey and Bangladesh respectively (Awofolu, 2005; Ayas, 2007; Banu, 2013).

4.3.2 Bui dam sampling location

The average concentration of metals in mg/L in water samples from the Bui dam gave the general trend of incidence as Fe (0.058) > As (0.045) > Pb (0.026) > Mn (0.014) > Cd = Zn = (0.003) > Cr (0.002) whilst the following metals were below the method's detection limit Co, Cu, Hg and Ni.

Chromium was uniformly distributed in Bui dam lake recording the same concentration, Iron levels varied between 0.025 mg/L in Banda Nkwanta and 0.074 mg/L in Old soldier, manganese ranged from 0.008 mg/L in Banda Nkwanta to 0.017 mg/L in Jama which was above the world average (0.010 mg/L), zinc varied from <0.001 to 0.004 mg/L in Donkokyina with 60% of the samples below 0.001 mg/L, lead varied from <0.001 to 0.041 mg/L in Bator having 60% of the samples below 0.001mg/L which were all above the world average (0.010 mg/L). Cadmium concentration varied from <0.002 mg/L to 0.005 mg/L in Jama with 40% of the samples below 0.002 mg/L and was also found to be above world average (0.003 mg/L) and arsenic varied from 0.041 mg/L in Jama to 0.050 mg/L in Old soldier which were all above the world average (0.010 mg/L) in drinking water.

Table 4.6 Heavy Metals in Water Samples (mg/L)

Lake Bosomtwi	Cr	Co	Fe	Mn	Cu	Zn	Pb	Cd	As	Hg	Ni
Abono	0.003	<0.005	0.213	0.012	<0.003	0.003	0.101	0.003	0.009	<0.001	<0.001
Adwafo	0.002	<0.005	0.732	0.020	<0.003	0.010	0.072	<0.002	0.005	<0.001	<0.001
Abrodum	<0.001	<0.005	0.177	0.012	<0.003	0.008	0.087	<0.002	0.010	<0.001	<0.001
Anyinatiase	0.002	<0.005	0.146	0.017	<0.003	0.004	0.052	<0.002	0.011	<0.001	<0.001
Essase	<0.001	<0.005	0.184	0.020	<0.003	0.003	<0.001	<0.002	0.008	<0.001	<0.001
Detieso	0.002	<0.005	0.240	0.011	<0.003	0.016	0.041	<0.002	0.005	<0.001	<0.001
Dompa	0.011	<0.005	0.744	0.017	<0.003	0.014	<0.001	<0.002	0.008	<0.001	<0.001
Duase	<0.001	<0.005	0.227	0.015	<0.003	0.005	<0.001	<0.002	0.006	<0.001	<0.001
Ankaase	0.003	<0.005	0.166	0.012	<0.003	0.006	0.099	<0.002	0.008	<0.001	<0.001
Amakom	0.002	<0.005	0.116	0.014	<0.003	<0.001	<0.001	<0.002	0.006	<0.001	<0.001
Adjamam	0.002	<0.005	0.182	0.012	<0.003	0.004	0.030	<0.002	0.007	<0.001	<0.001
Average	**0.003**	**<0.005**	**0.284**	**0.014**	**<0.003**	**0.007**	**0.069**	**0.003**	**0.007**	**<0.001**	**<0.001**
Standard deviation	**0.003**		**0.227**	**0.003**		**0.005**	**0.028**	**0.000**	**0.002**		
Bui dam											
Banda Nkwanta	0.002	<0.005	0.025	0.008	<0.003	<0.001	<0.001	0.003	0.047	<0.001	<0.001
Bator	<0.001	<0.005	0.048	0.011	<0.003	<0.001	0.041	<0.002	0.044	<0.001	<0.001
Donkokyina	0.002	<0.005	0.071	0.016	<0.003	0.004	<0.001	<0.002	0.043	<0.001	<0.001
Jama	<0.001	<0.005	0.074	0.017	<0.003	<0.001	<0.001	0.005	0.041	<0.001	<0.001
Old soldier	<0.001	<0.005	0.074	0.016	<0.003	0.002	0.011	0.002	0.050	<0.001	<0.001

Average	**0.002**	**<0.005**	**0.058**	**0.014**	**<0.003**	**0.003**	**0.026**	**0.003**	**0.045**	**<0.001**	**<0.001**
Standard deviation	**0.001**		**0.022**	**0.004**		**0.001**	**0.021**	**0.001**	**0.003**		
World average	**0.010**	**0.010**	**0.300**	**0.010**	**2.000**	**3.000**	**0.010**	**0.003**	**0.010**	**0.010**	**0.020**

The occurrence of these heavy metals may be attributed to chemical weathering of the rocks in the studied area, leaching of metals from fertilizers and pesticides from agricultural fields as well as seepage from sewage. Heavy metal levels in water are independent of the physical and chemical parameters of water, namely; temperature, pH, salinity, and electrical conductivity. The solubility of toxic heavy metals increases with the decrease of pH as metal concentration in water is found to increase when the solution has increased in acidity (Başyiğit & Tekin-Özan, 2013).

Average metal concentrations from Bui dam was found to be below that from Lake Bosomtwi sampling area except for average arsenic concentration which Bui dam recorded 0.045 mg/L and Lake Bosomtwi recorded 0.007 mg/L. Generally, the results of this study compare well with works done in other parts of Ghana, Africa, Europe and the middle east (Agyarko et al., 2014; Akoto, 2008; Asante, 2014; Awofolu, 2005; Ayas, 2007; Başyiğit & Tekin-Özan, 2013).

4.3.3 Heavy metal concentration in sediment samples

Occurrence of heavy metals in water samples suggests occurrence of metals in sediments also. A comparison would be made of metal concentration in water and that of sediment samples from the studied areas to ascertain the extent of pollution and whether the sediment is acting as a source or sink for the metals. Canadian Environmental Quality Guidelines (CEQG) as published by Uosif et al., (2013) was used as standards of comparison for the metal concentration in sediments as shown in Table 4.7.

Table 4.7 Heavy Metals in Sediment Samples (mg/kg)

Lake Bosomtwi	Cr	Co	Fe	Mn	Cu	Zn	Pb	Cd	As	Hg	Ni
Abono	1.035	<0.005	9.736	8.340	0.720	1.950	<0.001	<0.002	0.780	0.030	13.215
Adwafo	0.735	<0.005	9.294	6.122	0.315	1.965	<0.001	<0.002	0.345	<0.001	2.310
Abrodum	0.675	<0.005	8.807	3.184	0.105	1.275	<0.001	<0.002	0.930	0.030	2.370
Anyinatiase	0.525	<0.005	8.928	2.854	<0.003	0.930	<0.001	<0.002	0.405	0.045	0.840
Essase	1.935	0.090	10.819	9.647	1.320	2.895	<0.001	<0.002	0.450	<0.001	4.320
Detieso	0.585	<0.005	8.719	3.387	0.105	1.380	<0.001	<0.002	0.420	0.030	1.860
Dompa	2.310	0.405	11.085	17.977	1.620	4.260	<0.001	<0.002	0.495	0.030	4.965
Duase	2.190	1.140	11.551	7.374	2.415	4.485	<0.001	<0.002	0.660	<0.001	5.700
Ankaase	1.605	0.525	10.733	15.973	1.350	3.030	<0.001	<0.002	0.300	<0.001	8.010
Amakom	1.965	0.630	11.026	19.696	1.665	2.655	<0.001	<0.002	0.550	<0.001	4.950
Adjamam	1.995	0.840	11.180	16.220	1.590	3.060	<0.001	<0.002	0.300	<0.001	5.010
Average	**1.414**	**0.605**	**10.171**	**10.070**	**1.121**	**2.535**	**<0.001**	**<0.002**	**0.513**	**0.033**	**4.868**
Standard deviation	**0.706**	**0.362**	**1.081**	**6.309**	**0.775**	**1.167**			**0.203**	**0.007**	**3.444**
Bui dam											
Banda Nkwanta											
	1.095	<0.005	12.355	5.325	<0.003	0.510	<0.001	<0.002	4.590	0.090	1.980
Bator	0.908	<0.005	12.169	3.456	<0.003	0.503	<0.001	0.045	4.515	0.075	3.953
Donkokyina	0.840	<0.005	8.046	2.080	0.150	0.495	<0.001	0.210	3.990	0.045	1.725
Jama	1.125	<0.005	8.558	5.029	0.165	0.570	<0.001	0.120	3.090	0.060	1.860
Old soldier	0.660	<0.005	7.155	3.975	<0.003	0.390	<0.001	<0.002	4.665	0.045	0.900
Average	**0.926**	**<0.005**	**9.657**	**3.973**	**0.105**	**0.494**	**<0.001**	**0.125**	**4.170**	**0.063**	**2.084**
Standard deviation	**0.191**		**2.432**	**1.303**	**0.091**	**0.065**		**0.083**	**0.659**	**0.020**	**1.127**
World average	**64***	**-**	**-**	**-**	**63***	**200***	**70***	**1.4***	**-**	**-**	**50***

(*) Canadian Environmental Quality Guidelines

4.3.4 Lake Bosomtwi sampling location

The average concentration in mg/kg were in the order; Fe (10.171) > Mn (10.070) > Ni (4.868) > Zn (2.535) > Cr (1.414) > Cu (1.121) > Co (0.605) > As (0.513) > Hg (0.033) with Pb and Cd below the detection limit in sediment samples. The heavy metals concentration in the sediments were higher than that in the water samples since pH of the water was high which affect dissolution of the metal in water hence high concentration in sediment than in water.

Concentration of Hg ranged from 0.030 mg/kg in Detieso to 0.045 mg/kg in Anyinatiase, arsenic ranged from 0.300 mg/kg in Ankaase to 0.930 mg/kg in Abrodum. Chromium concentration ranges from 0.585 mg/kg in Detieso to 2.310 mg/kg in Dompa, cobalt was found to vary from 0.090 mg/kg in Essase to 1.140 mg/kg in Duase with 45% of the samples <0.001mg/kg, iron also varied from 8.719 mg/kg in Detieso to 11.551 mg/kg in Duase.

Manganese and iron had high concentrations as compared to all other metals analysed with Mn concentration ranging from 2.854 mg/kg in Anyinatiase to 19.696 mg/kg in Amakom depicting a high variation and an average concentration of 10.070 mg/kg. Copper varied from 0.105 mg/kg in Detieso and Abrodum to 2.415 mg/kg in Duase with 9% of the samples <0.003 mg/kg, whilst zinc ranged from 0.930 mg/kg in Anyinatiase to 4.485 mg/kg in Duase. Arsenic changed from 0.300 mg/kg in Ankaase to 0.930 mg/kg in Abrodum, mercury varied from 0.030 mg/kg to 0.045 mg/kg in Anyiantiase with 55% of the samples below detection limit and nickel concentration changed from 0.840 mg/kg in Anyinatiase to 13.215 mg/kg in Abono.

Lake Bosomtwi had cobalt, copper and nickel concentrations being below the method's limit of detection but recorded high concentrations in the sampled sediments this could

mean that the metals were insoluble in water and therefore were easily precipitated and settled at the bottom sediment. Also the concentrations (in mg/kg) determined for all the metals were found to be below the WHO 2004 and Canadian Quality guideline values of Cr (64), Cu (63), Ni (50), Pb (70), Cd (1.4) and Zn (200) (Uosif et al., 2013)

4.3.5 Bui dam sampling location

Sediment samples had cobalt and lead below the instrument's limit of detection. However, the average concentration in mg/kg were in the order; Fe (9.657) > As (4.170) > Mn (3.973) > Ni (2.084) > Cr (0.926) > Zn (0.494) > Cd (0.125) > Cu (0.105) > Hg (0.063).

The metal concentration varied as follows; Chromium from 0.660 mg/kg in Old soldier to 1.125 mg/kg in Jama, iron from 7.155 mg/kg in Old soldier to 12.355 mg/kg in Banda Nkwanta, manganese from 2.080 mg/kg in Donkokyina to 5.325 mg/kg in Banda nkwanta, copper from 0.150 mg/kg in Donkokyina to 0.165 mg/kg in Jama with 60% of the samples below detection limit of the method, zinc varied from 0.390 mg/kg in Old soldier to 0.570 mg/kg in Jama, cadmium from 0.045 mg/kg in Bator to 0.210 mg/kg in Dokokyina with 40% of the samples below the detection limit of the instrument, arsenic from 3.090 mg/kg in Jama to 4.665 mg/kg in Old soldier, mercury from 0.045 mg/kg in Dokokyina to 0.090 mg/kg in Banda nkwanta and nickel varied from 0.900 mg/kg in Old soldier to 3.953 mg/kg in Bator.

Making a comparison of the water samples to the sediment samples in Bui dam, it could be observed that copper (<0.003 mg/L) and nickel (<0.001 mg/L) were found to be below the detection limit of the method for water samples but had significant incidence in the sediment samples 0.105 mg/kg and 2.084 mg/kg respectively, Pb was found to be <0.001 mg/kg and average concentration of Fe and Mn were high.

The results of the studied metals in the two sampling areas compared well with work done elsewhere in Ghana, Africa and the rest of the world (Faanu et al., 2011; Lepane et al., 2007; Mackevièienë, 2002; Ogoyi, 2011; Opaluwa, 2012; Öztürk, 2009; Pakzadtoochaei, 2013b; Saeed & Shaker, 2008; Warmate et al., 2011).

4.3.6 Concentration of metals in fish samples

Heavy metal concentration in fish samples from the studied areas are presented and analyzed. The concentration of cobalt and arsenic in the fish samples were below the limits of detection of the method as shown in Table 4.8.

4.3.7 Lake Bosomtwi sampling location

The general trend of the average concentrations (mg/kg) of metals in fish samples were: Fe (24.870) > Zn (7.083) > Mn (2.928) > Cu (1.915) > Ni (1.683) > Pb (1.578) > Cr (0.545) > Cd (0.093) > Hg (0.060). Concentration of chromium varied from 0.405 mg/kg in Dompa to 0.720 mg/kg in Abono. Iron levels in the fish samples were very high as compared with all other metals studied, concentration of Fe varied between 6.540 mg/kg to 46.380 mg/kg in Dompa and Anyinatiase respectively. This variation depicts a relatively wider variation in Fe concentration from the study area.

Manganese concentration varied from 1.425 mg/kg in Anyinatiase to 5.355 mg/kg in Abono with an average of 2.928±1.351 mg/kg. Copper concentration showed a relatively uniform distribution in the sampling areas and varied from 1.230 mg/kg in Dompa to 2.880 mg/kg in Abono recording an average concentration of 1.915±0.734 mg/kg.

Zinc varied from 5.340 mg/kg in Dompa to 10.485 mg/kg in Abono with an average of 7.083±1.750 mg/kg. Lead varied from 0.570 mg/kg in Anyinatiase to 2.400 mg/kg in Duase and Detieso with an average of 1.578±0.765 mg/kg. Cadmium varied from 0.015

mg/kg in Abono to 0.150 mg/kg in Duase with average of 0.093±0.048 mg/kg. Mercury recorded 0.030 mg/kg in Anyinatiase and 0.090 mg/kg in Adjamam with a mean of 0.060±0.030 mg/kg and Ni recorded a low concentration of 0.435 mg/kg in Anyinatiase and a high of 6.195 mg/kg in Duase as well as an average of 1.683±2.226 mg/kg. There was a relatively wide variation in the concentration of the metal but recorded an average concentration of 1.683 mg/kg.

4.3.8 Heavy metals in fish samples from the Bui dam

The average metal concentration (mg/kg) in fish samples from the Bui dam was in the order; Fe (34.886) > Mn (6.709) > Zn (5.899) > Cu (5.239) > Ni (3.743) > Pb (1.028) > Cr (0.679) > Cd (0.075) > Hg (0.045) whilst As and Co concentrations were < 0.001 mg/kg and <0.005 mg/kg respectively. Chromium's average concentration was 0.679±0.090 mg/kg, Fe was 34.886±6.486 mg/kg, Mn was 6.709±1.957 mg/kg, Cu was 5.239±2.084 mg/kg, Zn was 5.899±0.854 mg/kg, Pb was 1.028±0.202 mg/kg, Cd was 0.075±0.021 mg/kg, Hg was 0.045±0.021 mg/kg and Ni had an average of 3.743±0.838 mg/kg.

The concentrations of metal in samples of fish from Bui dam were below the world mean concentrations set by WHO, FAO and USFDA (Akan et al., 2012). The concentrations of chromium in the fish samples had an average of 0.545 and 0.679 mg/kg in Lake Bosomtwi and Bui dam respectively. Chromium concentration determined in the fish samples were below the 12-13 mg/kg concentration accepted by the United States Food and Drugs Agency. Chromium deficiency causes impaired growth and disturbances in metabolism in man as it is an important in glucose metabolism. (Anim et al., 2011). Iron is an important element in human diet which forms part of hemoglobin responsible for oxygen transport in tissues and lungs. Iron deficiency in man results in anemia.

Table 4.8 Heavy Metals in Fish (mg/kg)

Lake Bosomtwi	Mean mass(g)	Cr	Co	Fe	Mn	Cu	Zn	Pb	Cd	As	Hg	Ni
Abono	25.80	0.720	<0.005	22.59	5.355	2.880	10.485	0.855	0.015	<0.001	0.060	0.540
Anyinatiase	8.47	0.465	<0.005	46.380	1.425	1.320	6.720	0.570	0.105	<0.001	0.030	0.435
Detieso	27.21	0.555	<0.005	25.845	2.925	2.460	6.690	2.400	0.105	<0.001	<0.001	1.155
Dompa	26.80	0.405	<0.005	6.540	2.010	1.230	5.340	1.500	0.120	<0.001	<0.001	0.960
Duase	86.28	0.525	<0.005	33.930	3.180	2.355	6.690	2.400	0.150	<0.001	<0.001	6.195
Adjamam	27.99	0.600	<0.005	13.935	2.670	1.245	6.570	1.740	0.060	<0.001	0.090	0.810
Average	**33.76**	**0.545**	**<0.005**	**24.870**	**2.928**	**1.915**	**7.083**	**1.578**	**0.093**	**<0.001**	**0.060**	**1.683**
Standard deviation	**26.78**	**0.110**		**14.188**	**1.351**	**0.734**	**1.750**	**0.765**	**0.048**		**0.030**	**2.226**
Bui dam												
Banda Nkwanta	32.15	0.615	<0.005	30.300	5.325	3.765	5.295	0.885	0.090	<0.001	0.060	4.335
Donkokyina	45.28	0.743	<0.005	39.473	8.093	6.713	6.503	1.170	0.060	<0.001	0.030	3.150
Average	**38.67**	**0.679**	**<0.005**	**34.886**	**6.709**	**5.239**	**5.899**	**1.028**	**0.075**	**<0.001**	**0.045**	**3.743**
Standard deviation	**9.36**	**0.090**		**6.486**	**1.957**	**2.084**	**0.854**	**0.202**	**0.021**		**0.021**	**0.838**
World average		**12 - 13***		**34-107***	**0.01***	**0.39***	**30.00***	**0.6***	**2.10***			**70-80***

*(Akan et al., 2012)

The maximum concentration recorded in this study was 46.380 mg/kg in Lake Bosomtwi and Bui dam had an average concentration 34.886 mg/kg which are within the accepted limits of Fe (34 - 107 mg/kg) in fish samples.

Manganese, an important element for plants and animals. Deficiencies of Mn result in severe reproductive and skeletal defects in mammals (Akan et al., 2012). It is fairly spread in the mammalian system with slight variations and do not pile up with age. Mn had an average of 2.928 and 6.709 mg/kg in Lake Bosomtwi and Bui dam respectively. Mn concentrations in the fish samples collected were above the recommended 0.01 mg/kg therefore with time may pose danger to the fishes as well as consumers of fish from these areas.

Copper is an integral part of several enzymes and it is needed for the production of hemoglobin. Toxic effects of Cu in fish is taken up directly from the water as most of the copper compounds are soluble in water. The average values of Cu recorded were 1.915 mg/kg in Lake Bosomtwi and 5.239 mg/kg in Bui dam which were all above the Food and Agricultural Organization recommended limit (0.39 mg/kg) (Akan et al., 2012).

Zinc is an important metal required by humans and animals. Zinc deficiency in man and animals causes loss of taste, retarded growth amongst others whilst exerting toxic effects of loss of appetite, irritability, nausea and muscular stiffness and pain above 40 mg/kg concentration. Average Zn in Lake Bosomtwi was 7.083 mg/kg and Bui dam recorded an average of 5.899 mg/kg all below the recommended limit of 30 mg/kg (Anim et al., 2011).

The source of Cadmium in human system is through consumption of food. Average Cd concentration of 0.093 mg/kg and 0.021mg/kg was recorded for Lake Bosomtwi and Bui dam samples respectively which were below the threshold value of 2.10 mg/kg. High

cadmium intake above the threshold limit can cause renal failure in man (Akan et al., 2012).

Lead recorded a mean of 1.028 mg/kg and 1.578 mg/kg for Bui dam and Lake Bosomtwi respectively with the threshold value being 0.60 mg/kg. The determined concentration exceeded the recommended limit for Pb. Lead is a toxic heavy metal that causes liver damage and renal failure in humans (Akan et al., 2012).

Human beings get their Ni needs from natural sources such as food intake and food processing. Ni smelter workers have reported the occurrence of cancers of the nasal cavity and the lung as a result of their exposure to high amounts of Ni. (Anim et al., 2011). Lake Bosomtwi recorded an average Ni of 1.683 mg/kg and Bui dam recorded an average of 3.743 mg/kg. These values were well below the recommended limit of 70 to 80 mg/kg (Anim et al., 2011).

4.3.9 Biota Sediment Accumulation

Biota sediment accumulation factor was determined for the two studied areas and are shown in Table 4.9. Lake Bosomtwi recorded BSAF in the sequence: Zn (2.794) > Fe (2.445) > Hg (1.818) > Cu (1.708) > Cr (0.385) > Ni (0.346) > Mn (0.291). Bui dam was in the order; Cu (49.895) > Zn (11.941) > Fe (3.613) > Ni (1.796) > Mn (1.689) > Cr (0.733) > Hg (0.714) > Cd (0.600). These values are indicative of how the fish samples have accumulated metals in the studied areas which may be due to their essentiality to the fish or their bio-availability for ingestion.

Table 4.9 Biota Sediment Accumulation Factor

LAKE BOSOMTWI

	Cr	Co	Fe	Mn	Cu	Zn	Pb	Cd	As	Hg	Ni
Average conc. in Fish	0.545	0.000	24.870	2.928	1.915	7.083	1.578	0.093	0.000	0.060	1.683
Average conc. in Sediment	1.414	0.605	10.171	10.070	1.121	2.535	0.000	0.000	0.513	0.033	4.868
BSAF	0.385	0.000	2.445	0.291	1.708	2.794	0.000	0.000	0.000	1.818	0.346

BUI DAM

Average conc. In Fish	0.679	0.000	34.886	6.709	5.239	5.899	1.028	0.075	0.000	0.045	3.743
Average conc. In Sediment	0.926	0.000	9.657	3.973	0.105	0.494	0.000	0.125	4.170	0.063	2.084
BSAF	0.733	0.000	3.613	1.689	49.895	11.941	0.000	0.600	0.000	0.714	1.796

4.3.10 Determination of metal pollution of sediments

The degree to which metals have accumulated and polluted the sediment was determined by using pollution load index, contamination factor (CF) and the geo- accumulation index (Igeo). These were employed to ascertain how polluted the sediments are with respect to the analysed metals in the studied areas.

Geo- accumulation indices for the studied areas are presented in Table 4.10. Samples from Lake Bosomtwi were unpolluted (Igeo < 0) with respect to all the metals analysed except for Fe with an average Igeo = 0.530 is in the class of unpolluted to moderately polluted (0 ≤ Igeo ≤ 1). Bui dam sediment samples were not polluted with the examined metals except for Fe (Igeo = 0.427) which would be classified as moderately polluted (0 ≤ Igeo ≤ 1).

Contamination factor which informs the extent of contamination and how the sediments are deteriorating was assessed for the studied areas as shown in Table 4.11. Lake Bosomtwi and Bui dam had low contamination (CF < 1) for all the metals except for Fe which recorded average CF of 2.178 and 2.068 for Lake Bosomtwi and Bui dam respectively. It can then be concluded that the studied areas are moderately contaminated (CF = 1-3) with Fe.

Table 4.12 gives the pollution load index for the studied areas. Both Lake Bosomtwi and Bui dam samples recorded PLI < 1 which denote perfection or unpolluted for all the studied metals in the sampling location, this is because the PLI takes into consideration the product of the contamination factors with respect to all the analysed metals for which most of them recorded CF < 1.

Table 4.10 Index of Geoaccumulation of Sediment Samples

Lake Bosomtwi	Igeo Cr	Igeo Co	Igeo Fe	Igeo Mn	Igeo Cu	Igeo Pb	Igeo Zn	Igeo As	Igeo Cd	Igeo Hg	Igeo Ni
Abono	-8.442	0.000	0.475	-7.256	-7.188	-	-5.265	-5.113	-	-3.184	-1.768
Adwafo	-8.936	0.000	0.408	-7.702	-8.381	-	-5.254	-6.290	-	0.000	-4.284
Abrodum	-9.059	0.000	0.330	-8.645	-9.966	-	-5.878	-4.860	-	-3.322	-4.247
Anyinatiase	-9.421	0.000	0.350	-8.803	0.000	-	-6.334	-6.059	-	-2.737	-5.743
Essase	-7.540	-7.966	0.627	-7.046	-6.314	-	-4.695	-5.907	-	0.000	-3.381
Detieso	-9.265	0.000	0.316	-8.556	-9.966	-	-5.764	-6.006	-	-3.322	-4.597
Dompa	-7.284	-5.796	0.662	-6.148	-6.018	-	-4.138	-5.769	-	-3.322	-3.180
Duase	-7.361	-4.303	0.722	-7.434	-5.442	-	-4.064	-5.354	-	0.000	-2.981
Ankaase	-7.809	-5.421	0.616	-6.319	-6.281	-	-4.630	-6.492	-	0.000	-2.490
Amakom	-7.517	-5.158	0.654	-6.016	-5.979	-	-4.820	-5.617	-	0.000	-3.184
Adjamam	-7.495	-4.743	0.674	-6.297	-6.045	-	-4.615	-6.492	-	0.000	-3.167
Average	**-8.194**	**-3.035**	**0.530**	**-7.293**	**-6.507**	**-**	**-5.042**	**-5.815**	**-**	**-1.444**	**-3.547**
Bui dam											
Banda Nkwanta	-8.361	0.000	0.819	-7.904	0.000	-	-7.200	-2.556	-	-1.737	-4.506
Bator	-8.631	0.000	0.797	-8.527	0.000	-	-7.220	-2.580	-	-2.000	-3.509
Donkokyina	-8.743	0.000	0.200	-9.260	-9.451	-	-7.243	-2.758	-	-2.737	-4.705
Jama	-8.322	0.000	0.289	-7.986	-9.314	-	-7.040	-3.127	-	-2.322	-4.597
Old soldier	-9.091	0.000	0.031	-8.325	0.000	-	-7.587	-2.533	-	-2.737	-5.644
Average	**-8.630**	**0.000**	**0.427**	**-8.400**	**-3.753**	**-**	**-7.258**	**-2.711**	**-**	**-2.307**	**-4.592**

Table 4.11 Contamination Factor for Sediment Samples

Lake Bosomtwi	CF Cr	CF Co	CF Fe	CF Mn	CF Cu	CF Pb	CF Zn	CF As	CF Cd	CF Hg	CF Ni
Abono	0.004	0.000	2.085	0.010	0.010	-	0.039	0.043	-	0.165	0.441
Adwafo	0.003	0.000	1.990	0.007	0.005		0.039	0.019	-	0.000	0.077
Abrodum	0.003	0.000	1.886	0.004	0.002	-	0.026	0.052	-	0.150	0.079
Anyinatiase	0.002	0.000	1.912	0.003	0.000	-	0.019	0.023	-	0.225	0.028
Essase	0.008	0.006	2.317	0.011	0.019	-	0.058	0.025	-	0.000	0.144
Detieso	0.002	0.000	1.867	0.004	0.002	-	0.028	0.023	-	0.150	0.062
Dompa	0.010	0.027	2.374	0.021	0.023	-	0.085	0.028	-	0.150	0.166
Duase	0.009	0.076	2.473	0.009	0.035	-	0.090	0.037	-	0.000	0.190
Ankaase	0.007	0.035	2.298	0.019	0.019	-	0.061	0.017	-	0.000	0.267
Amakom	0.008	0.042	2.361	0.023	0.024	-	0.053	0.031	-	0.000	0.165
Adjamam	0.008	0.056	2.394	0.019	0.023	-	0.061	0.017	-	0.000	0.167
Average	**0.006**	**0.022**	**2.178**	**0.012**	**0.015**	**-**	**0.051**	**0.028**	**-**	**0.076**	**0.162**
Std. deviation	**0.003**	**0.027**	**0.232**	**0.007**	**0.012**		**0.023**	**0.011**		**0.090**	**0.115**
Bui dam											
Banda Nkwanta	0.005	0.000	2.646	0.006	0.000	-	0.010	0.255	-	0.450	0.066
Bator	0.004	0.000	2.606	0.004	0.000	-	0.010	0.251	-	0.375	0.132
Donkokyina	0.004	0.000	1.723	0.002	0.002	-	0.010	0.222	-	0.225	0.058
Jama	0.005	0.000	1.833	0.006	0.002	-	0.011	0.172	-	0.300	0.062
Old soldier	0.003	0.000	1.532	0.005	0.000	-	0.008	0.259	-	0.225	0.030
Average	**0.004**	**0.000**	**2.068**	**0.005**	**0.001**	**-**	**0.010**	**0.232**	**-**	**0.315**	**0.069**
Std. deviation	**0.001**	**0.000**	**0.521**	**0.002**	**0.001**	**-**	**0.001**	**0.037**	**-**	**0.098**	**0.038**

Table 4.12 Pollution Load Index for Sediment Samples

Lake Bosomtwi	Pollution Load Index	Interpretation
Abono	0.000	UNPOLLUTED
Adwafo	0.000	
Abrodum	0.000	
Anyinatiase	0.000	
Essase	0.000	
Detieso	0.000	
Dompa	-0.133	
Duase	0.000	
Ankaase	0.000	
Amakom	0.000	
Adjamam	0.000	
Average	0.000	
Bui dam		
Banda Nkwanta	0.000	UNPOLLUTED
Bator	0.000	
Donkokyina	0.000	
Jama	0.000	
Old soldier	0.000	
Average	0.000	

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

This study determined the exposure of the inhabitants around Lake Bosomtwi and Bui dam as well as tourist and patrons of the two sites to radioactivity and heavy metals (Co, Cr, Cu, Fe, Mn, Pb, Zn, Cd, As, Hg and Ni) through ingestion of water and fish consumption. The average concentrations of Fe, Pb, Zn, Ni, Mn, Hg, Cd, Cu, Co, Cr, and As in the various media assessed were generally below the world average (WHO, FAO, US-FDA and CEQG) and maximum permissible limits.

The hazard indices determined for sediments suggest that they are unpolluted with heavy metal concentrations but biota sediment accumulation factor determined for the fish samples were indicative of bioaccumulation of metals by fish from the studied areas. The relatively low hazard indices recorded suggest that the population of indigenes, tourist and patrons of these areas are not at any imminent health risk due to excess heavy metals exposure from fish consumption or water ingestion. Activities of ^{232}Th, ^{40}K and ^{238}U in the studied samples were below the WHO and ICRP limits and therefore do not pose any radiological health risks to people who have access to Lake Bosomtwi and Bui dam.

It can be concluded that all the samples investigated at Lake Bosomtwi and Bui dam posed no health risk to the public from consumption of fish, ingestion of water and use of sediments for building purposes. It is hoped that results obtained in this study would serve as a useful source of information for further work in other parts of the country to assess the doses of radioactivity and metal concentration that the populace is exposed and also serve as a baseline data for future studies.

5.2 Recommendations

Based on the findings of this research, there is a need to monitor the seasonal variation of metal levels in the various media from the studied areas and also extend it to other communities around the lake to make conclusive prediction on exposure levels. There is also the need to determine national consumption averages for fish to enable a good determination of consumption patterns and maximum tolerable levels of metals in a given area to establish maximum permissible limits of heavy metal concentration in Ghana to be used as a basis for comparison.

It is also recommended that further studies on radioactivity should be carried out to cover the catchment area of the lakes and radon gas in air to obtain a baseline data for future studies. Gathering and storing the obtained information would help in formulating national guidelines for radioactivity levels in food, water and other environmental samples.

REFERENCES

Adu, S., Darko, E. O., Awudu, A. R., Adukpo, O. K., Obeng, M., Otoo, F., & Faanu, A. (2011). Preliminary Study of Natural Radioactivity in the Lake Bosumtwi Basin. *Environmental and Earth Sciences*, *3*(5), 463–468.

Adukpo, O. K., Faanu, A., Lawluvi, H., Darko, E. O., Kansaana, C., Kpeglo, D. O., & Awudu, A. R. (2014). Distribution and assessment of radionuclides in sediments, soil and water from the lower basin of river Pra in the Central and Western Regions of Ghana. *Radioanalytical and Nuclear Chemistry*, *302*(1). doi:10.1007/s10967-014-3637-5

Adukpo, O. K., Faanu, A., Lawluvi, H., Darko, E. O., Kansaana, C., Kpeglo, D. O., & Awudu, A. R. (2015). Distribution and assessment of radionuclides in sediments, soil and water from the lower basin of river Pra in the Central and Western Regions of Ghana. *Journal of Radioanalytical and Nuclear Chemistry*, *303*(3), 1679–1685. doi:10.1007/s10967-014-3637-5

Agbalagba, E. O., Avwiri, G. O., & Chad-Umoreh, Y. E. (2012). Gamma-Spectroscopy measurement of natural radioactivity and assessment of radiation hazard indices in soil samples from oil fields environment of Delta State, Nigeria. *Journal of Environmental Radioactivity*, *109*, 64–70. doi:10.1016/j.jenvrad.2011.10.012

Agbalagba, E. O., Avwiri, G. O., & Chad-Umoren, Y. E. (2013). Gross α and β activity concentration and estimation of adults and infants dose intake in surface and ground water of ten oil fields environment in Western Niger Delta of Nigeria. *Journal of Applied Sciences and Environmental Management*, *17*(2), 267–277. doi:10.4314/jasem.v17i2.10

Agbalagba, E. O., Avwiri, G. O., & Ononugbo, C. P. (2013). Activity concentration and radiological impact assessment of 226Ra, 228Ra and 40K in drinking waters from (OML) 30, 58 and 61 oil fields and host communities in Niger Delta region of Nigeria. *Journal of Environmental Radioactivity*, *116*, 197–200. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/23121713

Agbalagba, E. O., & Onoja, R. A. (2011). Evaluation of natural radioactivity in soil, sediment and water samples of Niger Delta (Biseni) flood plain lakes, Nigeria. *Journal of Environmental Radioactivity*, *102*(7), 667–71. doi:10.1016/j.jenvrad.2011.03.002

Agyarko, K., Dartey, E., Kuffour, R., & Sarkodie, P. (2014). Assessment of trace elements levels in sediment and water in some artisanal and small-scale mining (ASM) localities in Ghana. *Current World Environment Journal*, *9*(1), 7–16. doi:10.12944/CWE.9.1.02

Akan, J. C., Mohmoud, S., Yikala, B. S., & Ogugbuaja, V. O. (2012). Bioaccumulation of Some Heavy Metals in Fish Samples from River Benue in Vinikilang, Adamawa State, Nigeria. *American Journal of Analytical Chemistry*, *2012*(November), 727–736. doi:10.4236/ajac.2012.311097

Akoto, O., Bruce, T. N., & Darko, G. (2008). Heavy metals pollution profiles in streams serving the Owabi reservoir. *African Journal of Environmental Sciences and Tech.*, *2*(11), 354–359.

Akram, M., Qureshi, R. M., & Ahmad, N. (2006). Concentration of Natural and Artificial Radionuclides in bottom sediments of Karachi Harbour. *Journal of Chem. Soc. Pak*, *28*(3), 306–312.

Akyil, S., Aytas, S., Turkozu, D. A., Aslani, M. A. A., Yusan, S. (Doyurum), & Eral, M. (2009). Radioactivity levels in surface water of lakes around Izmir/Turkey. *Radiation Measurements*, *44*(4), 390–395. doi:10.1016/j.radmeas.2009.04.013

Al-Amir, S. M., Al-Hamarneh, I. F., Al-Abed, T., & Awadallah, M. (2012). Natural radioactivity in tap water and associated age-dependent dose and lifetime risk assessment in Amman, Jordan. *Applied Radiation and Isotopes : Including Data, Instrumentation and Methods for Use in Agriculture, Industry and Medicine*, *70*(4), 692–698. doi:10.1016/j.apradiso.2011.12.002

Alloway, B. J., & Ayres, D. C. (1998). Chemical Principles of Environmental Pollution. *Water, Air, and Soil Pollution*, *102*(1-2), 216–218. doi:10.1023/A:1004986209096

Amiard, J.-C., Caquet, T., & Lagadic, L. (Eds.). (2000). *Use of biomarkers for environmental quality assessment* (2nd ed.). Paris: CRC Press.

Anim, A. K., Ahialey, E. K., Duodu, G. O., Ackah, M., & Bentil, N. O. (2011). Accumulation Profile of Heavy Metals in Fish Samples from Nsawam , Along the Densu River , Ghana. *Environmental and Earth Sciences*, *3*(1), 56–60.

Asante, F., Agbeko, E., Addae, G., & Quainoo, A. K. (2014). Bioaccumulation of heavy metals in water, sediments and tissues of some selected fishes from the Red Volta, Nangodi in the Upper East Region of Ghana. *British Journal of Applied Sciences*, *4*(4), 594–603.

Asare-Donkor, N. K., Boadu, A., & Adimado, A. A. (2014). Seasonal Variation in Heavy Metal Content of Lake and Underground Water in Some Selected Towns around the Bosomtwe Crater Lake. *Journal of Environment and Earth Science*, *4*(23), 48–59.

Ashnani, M. H. M., Yavari, A. R., & Hassani, E. (2010). A Survey of Pollutions of the Aras River and The South-West of Caspian Sea Case-Study: Radioactivity Pollutions. *World Applied Sciences Journal*, *9*(1), 76–80.

Avwiri, G. O., Tchokossa, P., & Mokobia, C. E. (2007). Natural radionuclides in borehole water in Port Harcourt, Rivers State, Nigeria. *Radiation Protection Dosimetry*, *123*(4), 509–514. doi:10.1093/rpd/ncl526

Awofolu, O., Mbolekwa, Z., Mtshemla, V., & Fatoki, O. (2005). Levels of trace metals in water and sediment from Tyume River and its effects on an irrigated farmland. *Water SA*, *31*(1), 87–94. doi:10.4314/wsa.v31i1.5124

Ayas, Z., Ekmekci, G., Yerli, S. V., & Ozmen, M. (2007). Heavy metal accumulation in water, sediments and fishes of Nallihan Bird Paradise, Turkey. *Journal of Environmental Biology*, *28*(3), 545–549.

Bala, M., Shehu, R. A., & Lawal, M. (2008). Determination of the level of some heavy metals in water collected from two pollution - prone irrigation areas around Kano Metropolis. *Bayero Journal of Pure and Applied Sciences*, *1*(1), 36–38. doi:10.4314/bajopas.v1i1.57511

Banu, Z., Chowdhury, M. S. A., Hossain, M. D., & Nakagami, K. (2013). Contamination and ecological risk assessment of heavy metal in the sediment of Turag River, Bangladesh: An Index Analysis Approach. *Journal of Water Resource and Protection*, *5*(2), 239–248. doi:10.4236/jwarp.2013.52024

Barlas, N., Akbulut, N., & Aydoğan, M. (2005). Assessment of Heavy Metal Residues in the Sediment and Water Samples of Uluabat Lake, Turkey. *Bulletin of Environmental Contamination and Toxicology*, *74*(2), 286–293. doi:10.1007/ s00128 - 004 - 0582 - y

Başyiğit, B., & Tekin-Özan, S. (2013). Concentrations of some heavy metals in water, sediment, and tissues of Pikeperch (Sander lucioperca) from Karataş Lake related to physico-chemical parameters, fish size, and seasons. *Polish Journal of Environmental Studies*, *22*(3), 633–644.

Begum, A., Harikrishna, S., & Khan, I. (2009). Analysis of Heavy metals in Water , Sediments and Fish samples of Madivala Lakes of Bangalore, Karnataka. *International Journal of Chem Tech Research*, *1*(2), 245–249.

Bhatt, Ramesh Prasad and Khanal, S. N. (2011). Impoundment after Damming the Rivers Change in Flow Regime and Effect in Water Quality of Chilime Hydropower Project in Rasuwa District Nepal. *Advances in Bioresearch*, *2*(June), 33–39.

Bonotto, D. M., Bueno, T. O., Tessari, B. W., & Silva, A. (2009). The natural radioactivity in water by gross alpha and beta measurements. *Radiation Measurements*, *44*(1), 92–101. doi:10.1016/j.radmeas.2008.10.015

Boszke, L., Sobczyński, T., Głosińska, G., Kowalski, a., & Siepak, J. (2004). Distribution of mercury and other heavy metals in bottom sediments of the middle Odra River (Germany/Poland). *Polish Journal of Environmental Studies*, *13*(5), 495–502. doi:10.1023/B:WATE.0000049171.22781.bd

Camusso, M., Viganò, L., & Balestrini, R. (1995). Bioconcentration of trace metals in rainbow trout: a field study. *Ecotoxicology and Environmental Safety*, *31*(2), 133–41. doi:10.1006/eesa.1995.1053

Caroli, S., Forte, M., Nuccetelli, C., Rusconi, R., & Risica, S. (2013). A short review on radioactivity in drinking water as assessed by radiometric and Inductively Coupled Plasma-Mass Spectrometry techniques. *Microchemical Journal*, *107*, 95–100. doi:10.1016/j.microc.2012.07.014

Censi, P., Spoto, S. E., Saiano, F., Sprovieri, M., Mazzola, S., Nardone, G., & Di Geronimo, S. I. (2006). Heavy metals in coastal water systems. A case study from the northwestern Gulf of Thailand. *Chemosphere*, *64*(7), 1167–76. doi:10.1016/j.chemosphere.2005.11.008

Chambers, J. E., Boone, J. S., Carr, R. L., Chambers, H. W., & Straus, D. L. (2002). Biomarkers as Predictors in Health and Ecological Risk Assessment. *Human and Ecological Risk Assessment: An International Journal*, *8*(1), 165–176. doi:10.1080/20028091056809

Chang, J., Yu, K., Tsai, L., & Ho, S. (1998). Spatial distribution of heavy metals in bottom sediment of Yenshui River, Taiwan. *Water Science and Technology*, *38*(11), 159–167. doi:10.1016/S0273-1223(98)00651-9

Dankwah, J. (2011). *Concentration of some heavy metals in the water and sediment of Lake Tadee at Ashanti Mampong in Ashanti region of Ghana.* Kwame Nkrumah University of Science and Technoogy, Kumasi (MSC thesis).

Darko, E. O., Adu, S., Awudu, A. R., Adukpo, O. K., Emi-Reynolds, G., Faanu, A., & Obeng, M. K. (2011). Preliminary study of natural radioactivity in soils of some selected towns along the Bosumtwi Lake, Ghana, *41*, 5761–5765.

Darko, G., Faanu, A., Akoto, O., Acheampong, A., Goode, E. J., & Gyamfi, O. (2015). Distribution of natural and artificial radioactivity in soils, water and tuber crops. *Environmental Monitoring and Assessment*, *187*(6), 1–11. doi:10.1007/s10661-015-4580-9

Darko, G., Faanu, A., Akoto, O., Atta-Agyeman, F., Aikins, M. A., Agyemang, B., & Ibrahim, A. (2014). Assessment of the activity of radionuclides and radiological impacts of consuming underground water in Kumasi, Ghana. *Environmental Earth Sciences*. doi:10.1007/s12665-014-3433-0

Degerlier, M., & Karahan, G. (2010). Natural radioactivity in various surface waters in Adana, Turkey. *Journal of Desalination*, *261*(1-2), 126–130. doi:10.1016/j.desal.2010.05.020

Diab, H. M., Killa, H. A., Ramadan, A. A., & El-Desokey, D. A. (2010). Evaluation of natural radioactivity in north western coast of Egypt. *Isotope and Radiation Research*, *42*(2), 417–426.

Duruibe, J. O., Ogwuegbu, M. O., & Egwurugwu, J. N. (2007). Heavy metal pollution and human biotoxic effects. *International Journal of Physical Sciences*, *2*(5), 112–118. doi:10.1016/j.proenv.2011.09.146

El-Aydarous, A. (2007). Gamma Radioactivity and their corresponding external exposure of some soil samples from Taif Governate, Saudi Arabia. *Global Journal of Environmental Research*, *1*(2), 49–53.

Elmaci, A., Teksoy, A., Topaç, F. O., Özengin, N., Kurtoğlu, S., & Başkaya, H. S. (2007). Assessment of heavy metals in Lake Uluabat, Turkey. *African Journal of Biotechnology*, *6*(19), 2236–2244.

El-Mageed, A. I. A., El-Kamel, A. E., Abbady, A. E., Harb, S., & Issa, I. (2011). Natural radioactivity of ground and hot spring water in some areas in Yemen. *Desalination*. doi:10.1016/j.desal.2011.11.022

El-Sayed, A., El-Ayyat, M., Nasr, E.-S., & Khater, Z. (2011). Assessment of heavy metals in water, sediment and fish tissues, from Sharkia province, Egypt. *Egypt. J. Aquat. Biol. & Fish.*, *15*(2), 125–143.

El-Sayed, N. (2014). *Studying of Naturally Occurring Radionuclides for Some Environmental Samples and Its Hazardous Effects*. Fayoum University,Egypt (MSC thesis).

Faanu, A. (2011). *Assessment Of Public Exposure To Naturally Occurring Radioactive Materials From Mining And Mineral Processing Activities Of Tarkwa Goldmine In Ghana*. Kwame Nkrumah University of Science and Technology, Kumasi (PHD thesis).

Faanu, A., Adukpo, O. K., Okoto, R. J. S., Diabor, E., Darko, E. O., Awudu, A. R., & Glover, E. T. (2011). Determination of radionuclides in underground water sources within the environments of University of Cape Coast. *Research Journal of Environmental and Earth Sciences*, *3*(3), 269–274.

Faanu, A., Darko, E. O., & Ephraim, J. H. (2006). Determination of Natural Radioactivity and Hazard in Soil and Rock Samples in a Mining Area in Ghana. *West African Journal of Applied Ecology*, *11*(1), 1–11.

Faanu, A., Ephraim, J. H., Darko, E. O., Kpeglo, D. O., Lawluvi, H., & Adukpo, O. (2011). Determination of the Concentrations of Physicochemical Parameters in Water and Soil from a Gold mining area in Ghana. *Research Journal of Environmental and Earth Sciences*, *3*(2), 177–186.

Faanu, A., Kpeglo, D. O., Sackey, M., Darko, E. O., Lawluvi, H., Awudu, R., & Adukpo, O. K. (2013). Natural and artificial radioactivity distribution in soil, rock and water of the Central Ashanti Gold Mine, Ghana. *Environmental Earth Sciences*. doi:10.1007/s12665-013-2244-z

Fahmi, N. M., El-Khatib, A., El-Salam, Y. M. A., Shalaby, M. H., El-Gally, M. M., & Naim, M. A. (2010). Study of the environmental impacts of the natural radioactivity presents in beach sand and lake sediment samples Idku, Behara, Egypt. *Tenth Radiation Physics & Protection Conference*, (November), 391–402.

Gadzała-Kopciuch, R., Berecka, B., Bartoszewicz, J., & Buszewski, B. (2004). Some considerations about bioindicators in environmental monitoring. *Polish Journal of Environmental Studies*, *13*(5), 453–462.

Gordon, B., Callan, P., & Vickers, C. (2008). *WHO guidelines for drinking-water quality. WHO chronicle* (3rd ed., Vol. 38). Geneva. doi:10.1016/S1462-0758(00)00006-6

Görür, F. K., Keser, R., Akçay, N., Dizman, S., As, N., & Okumuşoğ lu, N. T. (2012). Radioactivity and heavy metal concentrations in food samples from Rize, Turkey. *Journal of the Science of Food and Agriculture*, *92*(2), 307–312. doi:10.1002/jsfa.4576

Harb, S., El-Mageed, A. I. A., Abbady, A., & Negm, H. H. (2008). Natural Radioactivity Measurements in Soil and Phosphate Samples from. *IX Radiation Physics & Protection Conference*, (November, 15-19).

Hosseini, S. A. (2007). Naturally Occurring Radioactivity in the City and Across Near by Cities in Iran. *Journal of Applied Sciences*, *7*, 3091–3095. Retrieved from http://adsabs.harvard.edu/abs/2007JApSc.7.3091H

Hu, Q., Weng, J., & Wang, J. (2010). Anthropogenic radionuclides in the environment. *Journal of Environmental Radioactivity*, *101*(6), 426–437.

IAEA. (1996). *International Basic Safety standards for Protection against Ionizing radiation and for the Safety of Radiation Sources*. *Safety series* (Vol. 115). Vienna, Austria.

ICRP. (1990). *Recommendations of the International Commission on Radiological Protection. ICRP Publication 60*. *Annals of the ICRP* (Vol. 21). Pergamon Press, Oxford.

ICRP. (2007). Recommendations of the International Commission on Radiological Protection. ICRP publication 103. *Annals of the ICRP*, *37*(2-4), 1–332. doi:10.1016/j.icrp.2007.10.003

Ikem, A., Egiebor, N. O., & Nyavor, K. (2003). Trace Elements In Water, Fish and Sediment from Tuskegee Lake, Southeastern Usa. *Water, Air, and Soil Pollution*, *149*(1-4), 51–75. doi:10.1023/A:1025694315763

Jovanovic, L., Kaldybaev, B., Djenbaev, B., & Tilenbaev, A. (2012). Distribution of Natural (U-238, Th-232, Ra-226) and Technogenic (Sr-90, Cs-137) Radionuclides in Soil-Plants Complex Near Issyk-Kul Lake, Kyrgyzstan. *Geophysical Research*, 1795.

Kabir, K. A., Islam, S. M. A., & Rahman, M. M. (2009). Distribution of Radionuclides in Surface Soil and Bottom Sediment in the District of Jessore, Bangladesh and Evaluation of Radiation Hazard. *Journal of Bangladesh Academy of Sciences*, *33*(1), 17–29. doi:10.3329/jbas.v33i1.2956

Kamble, S. M. (2014). Water Pollution and Public Health Issues in Kolhapur City in Maharashtra. *International Journal of Scientific and Research Publications*, *4*(1), 1–6.

Kessaratikoon, P., Benjakul, S., & Udomsomporn, S. (2007). Gamma-Absorbed Dose Rate and Distribution of Natural Radionuclides in Songkhla Beach Sands, *10*, 16–17.

Khayet, M., & Matsuura, T. (2013). Radioactive decontamination of water. *Desalination*, *321*, 1–2. doi:10.1016/j.desal.2013.05.004

Khodashenas, A., Roayaei, E., Abtahi, S. M., & Ardalani, E. (2012). Evaluation of naturally occurring radioactive materials (NORM) in the South Western oil wells of Iran. *Journal of Environmental Radioactivity*, *109*, 71–75. doi:10.1016/j.jenvrad.2012.01.014

Kiekens, L. (1995). *Heavy metals in soils*. Springer Science & Business Media. Retrieved from http: // books . google.com /books? hl=en&lr =&id = CX1GwLBhkC4C&pgis = 1

Kishe, M. A., & Machiwa, J. F. (2003). Distribution of Heavy Metals In Sediments of Mwanza Gulf of Lake Victoria, Tanzania. *Environment International*, *28*(7), 619–625.

Lawluvi, H., Darko, E. O., Schandorf, C., Fannu, A., Awudu, a. R., & Kpeglo, D. O. (2011). Natural radioactivity concentrations in beach sands from some tourists resorts. *Research Journal of Environmental and Earth Sciences*, *3*(6), 729–736.

Lepane, V., Varvas, M., Viitak, A., Alliksaar, T., & Heinsalu, A. (2007). Sedimentary record of heavy metals in Lake Rõuge Liinjärv, Southern Estonia. *Estonian Journal of Earth Sciences*, *56*(4), 221–232. doi:10.3176/earth.2007.03

Luoma, S. N., & Bryan, G. W. (1982). A statistical study of environmental factors controlling concentrations of heavy metals in the burrowing bivalve Scrobicularia plana and the polychaete Nereis diversicolor. *Estuarine, Coastal and Shelf Science*, *15*(1), 95–108. doi:10.1016/0272-7714(82)90040-3

Mackevièienë, G. (2002). Accumulation of heavy metals and radionuclides in bottom sediments of monitoring streams in Lithuania. *Ekologija Vilnus*, (2), 69–74.

Newman, M. C., & Evans, D. A. (2008). *Ecotoxicology*. Wiley Online Library.

Nriagu, J., Nam, D.-H., Ayanwola, T. a, Dinh, H., Erdenechimeg, E., Ochir, C., & Bolormaa, T.-A. (2012). High levels of uranium in groundwater of Ulaanbaatar, Mongolia. *The Science of the Total Environment*, *414*, 722–762. doi:10.1016/j.scitotenv.2011.11.037

Obed, R. I., Farai, I. P., & Jibiri, N. N. (2005). Population dose distribution due to soil radioactivity concentration levels in 18 cities across Nigeria. *Journal of Radiological Protection*, *25*(3), 305–312. doi:10.1088/0952-4746/25/3/007

OECD. (1979). *Organisation for Economic Cooperation and Development. Exposure to radiation from natural radioactivity in building materials. Report by a Group of Experts of the OECD Nuclear Energy Agency, OECD*. Paris.

Ogoyi, D. O., Mwita, C. J., Nguu, E. K., & Shiundu, P. M. (2011). Determination of heavy metal content in water, sediment and microalgae from Lake Victoria, East Africa. *The Open Environmental Engineering Journal*, *4*, 156–161.

Opaluwa, O. D., Aremu, M. O., Ogbo, L. O., Abiola, K. A., Odiba, I. A., Abubakar, M. M., & Nweze, N. O. (2012). Heavy metal concentrations in soils , plant leaves and crops grown around dump sites in Lafia Metropolis , Nasarawa State , Nigeria. *Pelagia Research Library*, *3*(2), 780–784.

Ownby, D. R., Newman, M. C., Mulvey, M., Vogelbein, W. K., Unger, M. A., & Arzayus, F. L. (2002). Fish (Fundulus heteroclitus) populations with different exposure histories differ in tolerance of creosote-contaminated sediments. *Environmental Toxicology and Chemistry / SETAC*, *21*(9), 1897–1902. doi:10.1002/etc.5620210917

Ozmen, H., Külahci, F., Cukurovali, A., & Doğru, M. (2004). Concentrations of heavy metal and radioactivity in surface water and sediment of Hazar Lake (Elaziğ, Turkey). *Chemosphere*, *55*(3), 401–408. doi:10.1016/j.chemosphere.2003.11.003

Öztürk, M., Özözen, G., Minareci, O., & Minareci, E. (2009). Determination Of Heavy Metals In Fish, Water And Sediments Of Avsar Dam Lake In Turkey. *Iran J.Environ. Health. Sci. Eng*, *6*(2), 73–80.

Pakzadtoochaei, S. (2013a). Comparing the concentration of heavy metals (Cd, Cu, Ni and Zn) in the sediment and different tissues of Avicenna marina in Iranian coasts of the Oman sea. *International Research Journal of Applied and Basic Sciences*, *4*(3), 561–569. Retrieved from www.irjabs.com

Pakzadtoochaei, S. (2013b). Comparing the concentration of heavy metals (Cd, Cu, Ni and Zn) in the sediment and different tissues of Avicenna marina in Iranian coasts of the Oman sea. *International Research Journal of Applied and Basic Sciences*, *4*(3), 561–569.

Philips, D. (1994). Biomonitoring of Trace Aquatic Contaminants Environmental Management Series. *Journal of Applied Toxicology*, *14*(4), 315–316. doi:10.1002/jat.2550140415

Radenkovic, M., Masaud, A., Andric, V., & Miljanic, S. (2009). Radioactivity of sand from several renowned public beaches and assessment of the corresponding environmental risks. *Journal of the Serbian Chemical Society*, *74*(4), 461–470.

Ramasmy, V., Govindasamy, S. V. M., & Ponnusamy, V. (2010). Distribution And Characterization Of Minerals And Naturally Occurring Radionuclides In River Sediments. *Carpathian Journal of Earth and Environmental Sciences*, *5*(1). Retrieved from http://www.ubm.ro/sites/CJEES/viewTopic.php?topicId=73

Redondo-Gómez, S. (2013). Bioaccumulation of heavy metals in Spartina. *Functional Plant Biology*, *40*(9), 913–921. doi:10.1071/FP12271

Sabo, A., Gani, A. M., & Ibrahim, A. Q. (2013). Pollution Status of Heavy Metals in Water and Bottom Sediment of River Delimi in Jos, Nigeria. *American Journal of Environmental Protection*, *1*(3), 47–53. doi:10.12691/env-1-3-1

Saeed, S. M., & Shaker, I. M. (2008). Assessment of heavy metals pollution in water and sediments and their effect on Oreochromis Niloticus in the northern Delta Lakes, Egypt, (1999), 475–490.

Spencer, K. L., & MacLeod, C. L. (2002). Distribution and partitioning of heavy metals in estuarine sediment cores and implications for the use of sediment quality standards. *Hydrology and Earth System Sciences*, *6*(6), 989–998. doi:10.5194/hess-6-989-2002

Tso, M. Y. W., & Leung, J. K. C. (2000). Population Dose Due To Natural Radiation In Hong Kong. *Health Physics*, *78*(5). Retrieved from http://journals.lww.com/health-physics/Fulltext/2000/05000/Population Dose Due To Natural Radiation In Hong Kong.13.aspx

Turner, B. F., Gardner, L. R., & Sharp, W. E. (1996). The hydrology of lake Bosumtwi, a climate-sensitive lake in Ghana, West Africa. *Journal of Hydrology*, *183*(3-4), 243–261. doi:10.1016/0022-1694(95)02982-6

United States Department of Energy. (1998). *Biota Sediment Accumulation Factors for Invertebrates : Review and Recommendations for the Oak Ridge Reservation*. Bechtel Jacobs Company LLC.

UNSCEAR. (2000a). *Sources and Effects of Ionizing Radiation.Report to General Assembly, ANNEX B, Exposures from Natural Radiation Sources.* New York.

UNSCEAR. (2000b). *United Nations Scientific Committee on the Effects of Atomic Radiation. Report to General Assembly, ANNEX A, Dose Assessment Methodologies.*

Uosif, M. A. M., Mostafa, A. M. A., Elsaman, R., & Moustafa, E. (2014). Natural radioactivity levels and radiological hazards indices of chemical fertilizers commonly used in Upper Egypt. *Journal of Radiation Research and Applied Sciences*, *7*(4), 430–437. doi:10.1016/j.jrras.2014.07.006

Uosif, M., Abuel-Fadl, K., Issa, S. M., Mostafa, A., & Taha, M. M. (2013). The status of natural radioactivity and heavy metals pollution on soil at Assiut Zone in Central Upper-Egypt. *Radiation Protection and Environment*, *36*(1), 20–26. doi:10.4103/0972-0464.121819

Van der Oost, R., Beyer, J., & Vermeulen, N. P. E. (2003). Fish bioaccumulation and biomarkers in environmental risk assessment: A review. *Environmental Toxicology and Pharmacology*. doi:10.1016/S1382-6689(02)00126-6

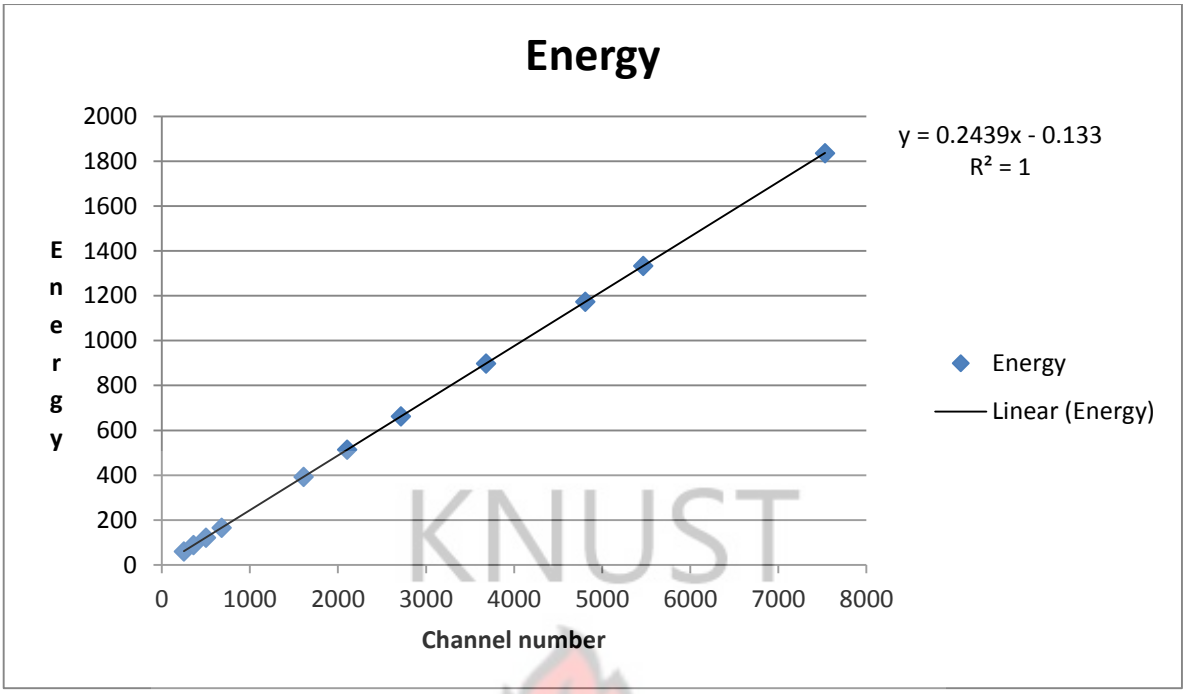
Warmate, A. G., Ideriah, T. J. K., Tamunobereton, I. T., Inyang, U., & Ibaraye, T. (2011). Concentrations of heavy metals in soil and water receiving used engine oil in Port Harcourt , Nigeria. *Journal of Ecology and the Natural Environment*, *3*(2), 54–57.

Zorer, O. S., Ceylan, H., & Doğru, M. (2008). Assessment of some trace heavy metals and radioactivity concentration in water of Bendimahi River Basin (Van, Turkey). *Environmental Monitoring and Assessment*, *147*(1-3), 183–90. doi:10.1007/s10661-007-0109-1

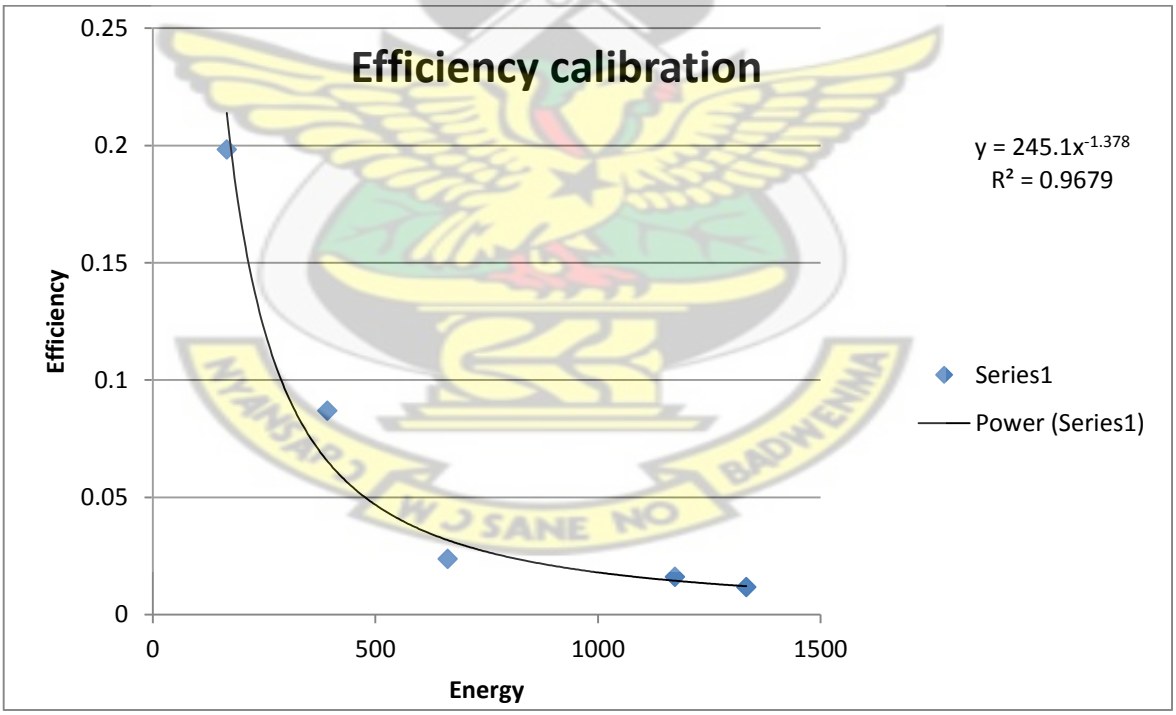
APPENDICES

Appendix 1: Working Conditions of the A.A.S.

ELEMENT	**WAVELENGTH nm**	**SLIT WIDTH nm**	**LAMP CURRENT mA**	**FUEL GAS**	**SUPPORT GAS**
Co	240.7	0.2	7	ACETYLENE	AIR
Fe	248.3	0.2	5	ACETYLENE	AIR
Mn	279.5	0.2	5	ACETYLENE	AIR
Cu	324.7	0.5	4	ACETYLENE	AIR
Zn	213.9	1.0	5	ACETYLENE	AIR
Pb	217.0	1.0	5	ACETYLENE	AIR
Cd	228.8	0.5	4	ACETYLENE	AIR
Ni	232.0	0.2	4	ACETYLENE	AIR
Cr	357.9	0.2	7	ACETYLENE	AIR
As (By hydride)	193.7	0.5	10	ACETYLENE	ARGON
Hg (By hydride)	253.7	0.5	4	ARGON	AIR



Appendix 2: Energy calibration curve



Appendix 3: Efficiency calibration for energy values >200keV

Appendix 4: Gamma spectrometer set-up for determining γ- activity

Appendix 5: 25 L Dewar containing liquid nitrogen to cool the detector

Appendix 6: AAS Varian AA240FS

Appendix 7

Publications

1. Ansah, E.; Faanu, A. & Darko, G. "Natural radioactivity and heavy metal concentration in some reservoirs in Ghana" Conference paper at the 18th GCS Annual conference held at University of Cape Coast (27 - 28th August, 2015).
2. Darko, G.; Ansah, E.; Faanu, A.; Azanu, D.; Darko, E.O. & Emi-Reynolds, G. "Natural radioactivity and heavy metal concentration in reservoirs in Ghana" Article in Press: Journal of Environmental Processes.