

SCHOOL OF PUBLIC HEALTH

COLLEGE OF HEALTH SCIENCES

UNIVERSITY OF GHANA



**HEAVY METALS CONCENTRATIONS IN GROUNDWATER, RIVERS AND DAMS IN
TAMALE METROPOLIS AND SURROUNDING VILLAGES IN THE NORTHERN
REGION OF GHANA AND ASSESSMENT OF POTENTIAL HEALTH RISK.**

BY

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PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF MSc in
OCCUPATIONAL HYGIENE Degree.**

JANUARY, 2022

DECLARATION

I, **Issahaku Haruna** hereby declare that except for literature on other research works which are duly acknowledged, this dissertation has been written independently by me and has not been submitted for the award of any degree in any institution.

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ABSTRACT

Introduction: Contamination of the environment with metals is widespread in many developing countries due to increased and unregulated human activities such as excavation and road construction, quarrying, industrial and manufacturing activities, and mining. Overexposure to toxic metals could have negative health implications on human health, and is associated with chronic illnesses such as renal diseases, liver disorder, brain disorder, and various others.

Objective: To assess the physico-chemical parameters and metal concentrations in groundwater, dams and rivers and to estimate the potential health risk.

Method: An analytical cross-sectional study was conducted to determine the concentrations of metals in wells, dams and rivers within the Tamale Metropolis and its surrounding communities. The water and soil quality parameters were measured in situ using EZDO 7200 multi meter. The concentration of heavy metals was measured using PINAAcle 900T Perkin Elmer Atomic Absorption Spectrophotometer. The human health risk for the metals were determined by estimating carcinogenic and non-carcinogenic risk.

Results: The pH ranges for groundwater (well), river and dam were; 6.2-7.5, 6.7-6.9 and 6.7-7.2 respectively, all within World Health Organization (WHO) limit of pH 6.5-8.5 for water. The other physico-chemical parameters such as electrical conductivity (EC), total dissolved solid (TDS) and salinity were also within their respective WHO limits. Turbidity values were well within the normal WHO limits of 5NTU for both Rivers and Dams, and that for groundwater (0.1-4.2NTU) was below WHO threshold, indicating less possible contamination with TDS. Concentrations of metals in water was in the order Mercury (Hg) < Arsenic (As) < Iron (Cd) < Lead (Pb) < Cadmium (Fe). Range of concentrations of metals in water were as follows: Cd (0.20 µg/L-

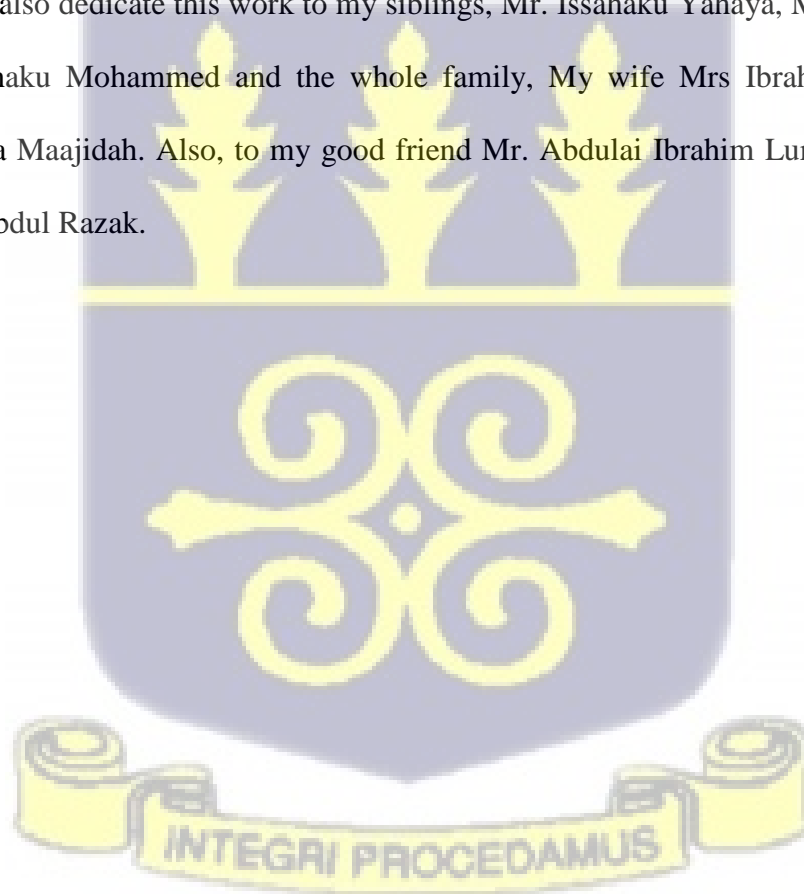
0.97 µg/L), Pb (1.33 µg/L-147.00 µg/L), Fe (1.33 µg/L-10693.4 µg/L), As (0.01 µg/L-0.19 µg/L) and Hg (0.01 µg/L-0.12 µg/L). The Average daily dose (ADD) estimates (µg/Kg/day) for water samples increased in the order Hg<As<Cd <Pb<Fe. Also, Hazard Quotient values for metals in water samples increased in the order Pb<Cd<As<Hg<Fe, and Hazard Index (HI) values increased from 0.029956281 to 1.338069194. Chronic Daily Intake (CDI) estimates for the heavy metal concentrations in water samples increased some in the order Hg<As<Cd<Pb<Fe.

This study found that the health risk assessment for Cd, Fe, As and Hg in the water samples showed values <1 except Pb whose HQ (1.319) and HI (1.338) estimates at ETW (Wavuguma Dam, Tamale) showed values >1, signifying non-satisfactory level of non-carcinogenic adverse health risk. Also, this study showed that for the water samples, the CDI values for Fe >1 occurred at ETWV (Wamali Dam, Tamale) (2.46); ETT (Taha Dam, Tamale) (6.39); ETC (Chanzeni Dam, Tamale) (1.46); ETS (Difaa Dam, Tamale) (10.56); WTD (Datooyili Dam, Tamale) (4.26); CTG (Dabokpa Dam, Tamale) (4.38); NTS (Savelugu Dam, Savelugu Municipal) (1.69); and NTN (Nawuni River, Kumbungu District) (1.38). These results indicate non-carcinogenic and carcinogenic adverse health risk for Fe and Pb. This study found that risk assessment for Cd, Pb, Fe, As and Hg in the sediment samples showed that all the HQ and HI and even CDI values to be less than 1 signifying satisfactory level of non-carcinogenic adverse health risk.

Conclusion: The physico-chemical parameters of ground and surface water were within WHO limits. However, Pb and Fe concentrations in water samples, 0.017mg/L and 1.313mg/L were above WHO permissible limits of 0.01mg/L and 0.3mg/L respectively. From the human risk estimation, consumption of water from these sources may be associated with some human health risk due to the levels of Pb and Fe.

DEDICATION

I dedicate this project to the Almighty Allah for granting me knowledge and understanding to carry out this study. I also dedicate this work to my siblings, Mr. Issahaku Yahaya, Mr. Ibrahim Abdul mugis, Dr Issahaku Mohammed and the whole family, My wife Mrs Ibrahim Barikisu, My daughter Haruna Maajidah. Also, to my good friend Mr. Abdulai Ibrahim Luru, and my cousin Mr. Alhassan Abdul Razak.



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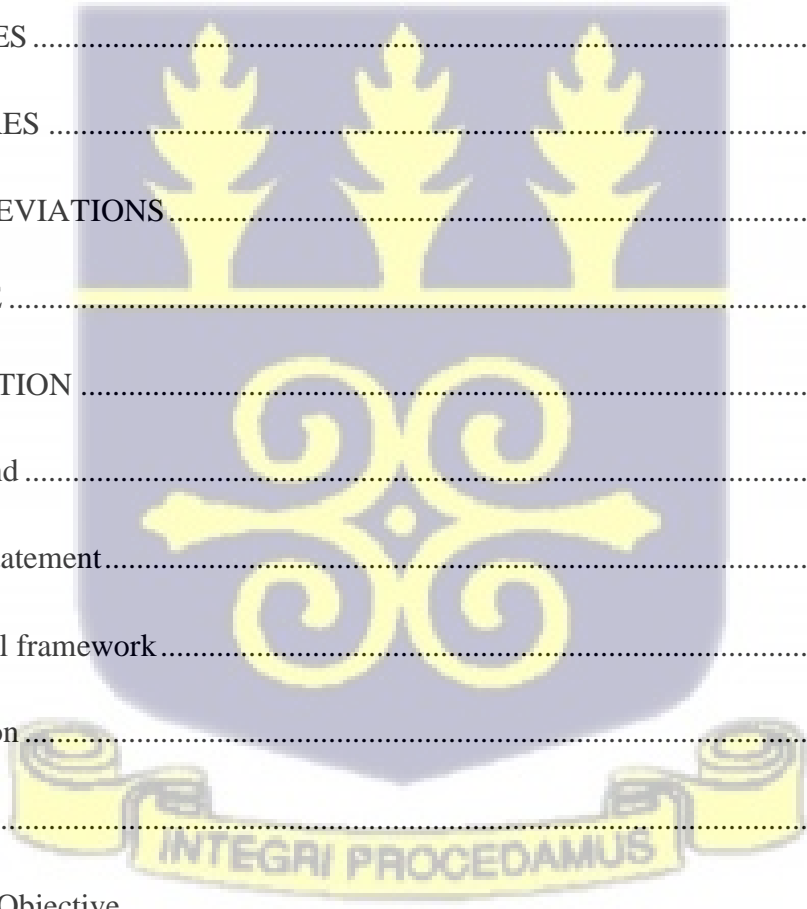
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I wish to thank all the lecturers of the Department of Biological Environmental and Occupational Health. I am also grateful to my family, friends and loved ones for their encouragement and support during my course work. Finally, to all my colleagues in the 2020 and 2021 Biological Environmental and Occupational Hygiene class, I say God bless you all.

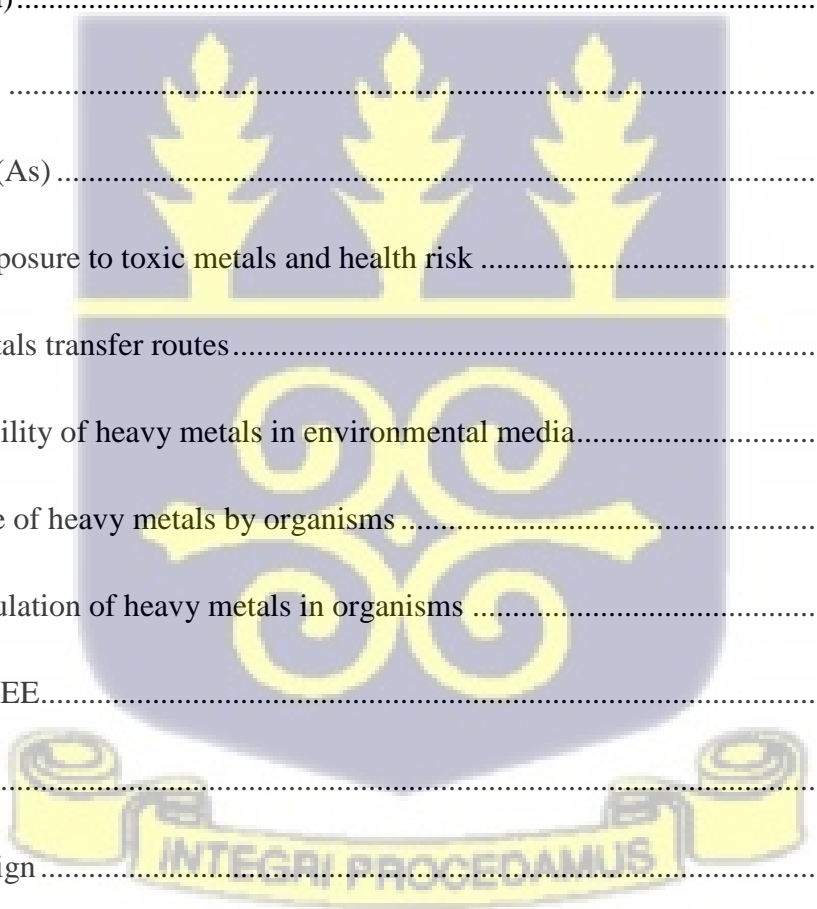
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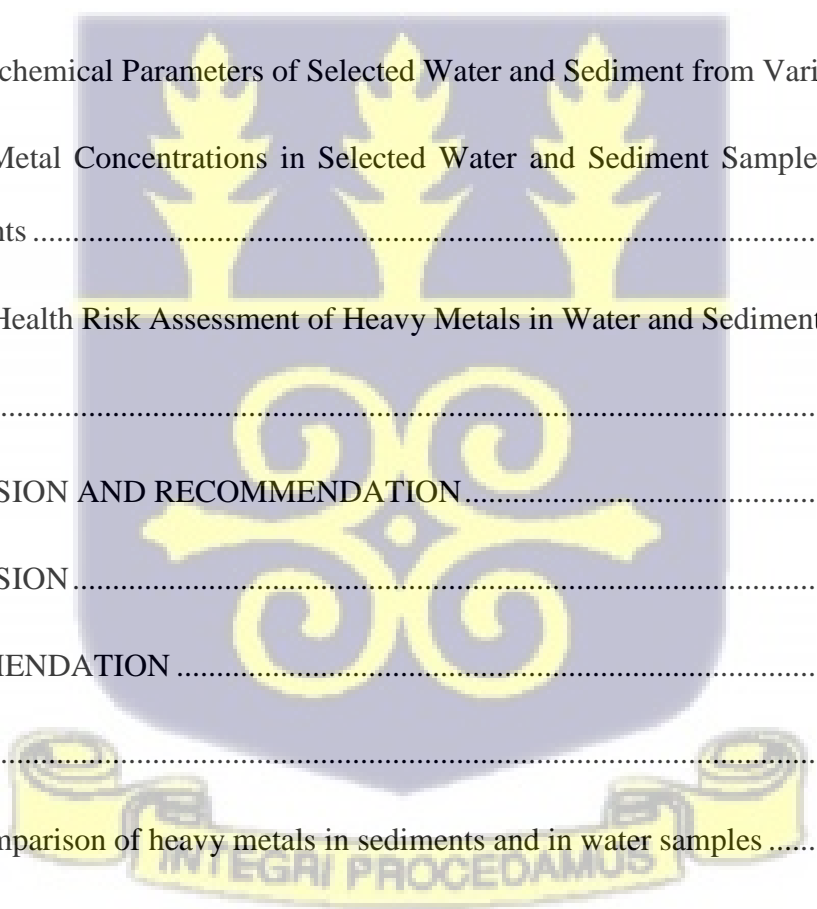
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LIST OF ABBREVIATIONS

E-waste Electronic waste

Cd Cadmium

Pb Lead

Fe Iron

As Arsenic

Hg Mercury

WHO World Health Organization

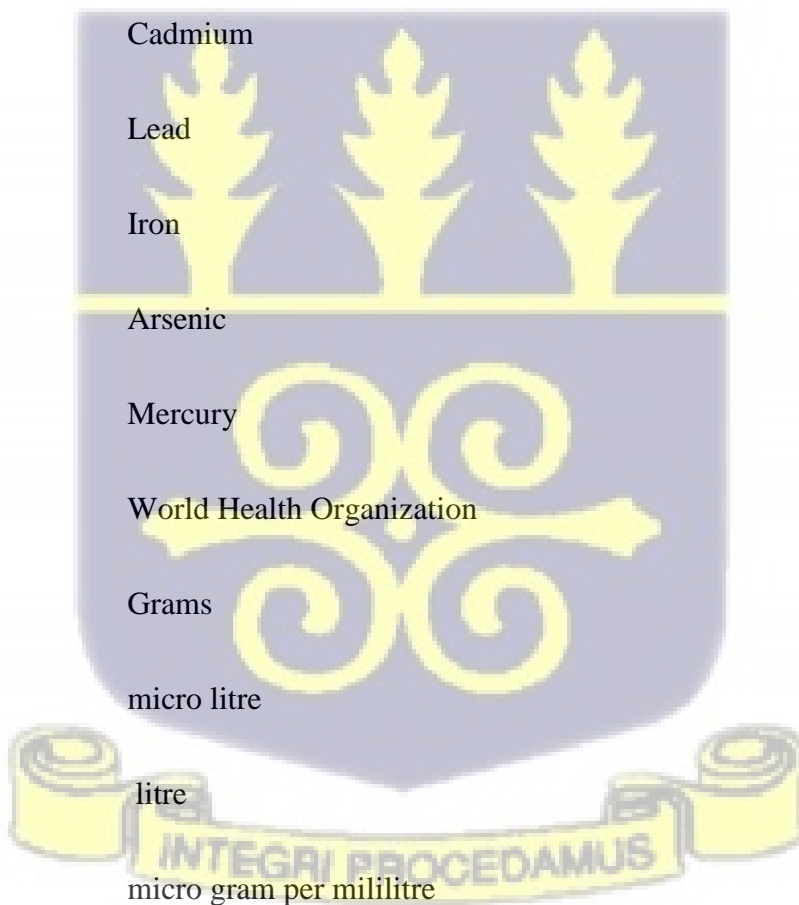
g Grams

µL micro litre

L litre

µg/mL micro gram per millilitre

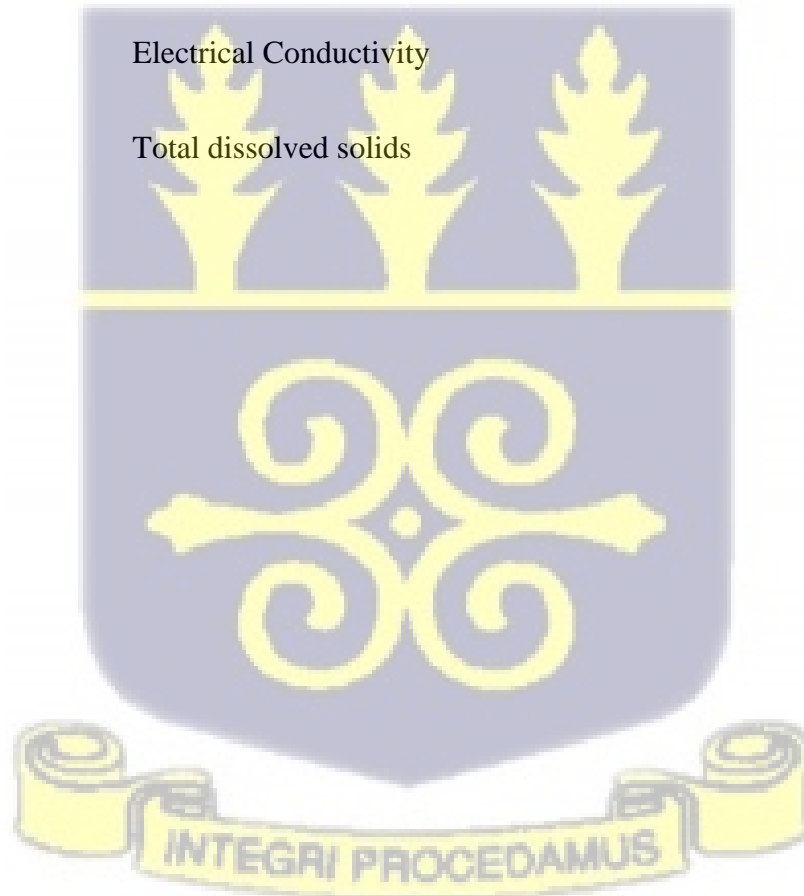
ml mililitre



mg/mL	milli gram per millilitre
OD	Optical density
HQ	Hazard quotient
HI	Hazard Index
ADD	Average daily dose
CDI	Chronic daily intake
pH	Hydrogen ion concentration

EC Electrical Conductivity

TDS Total dissolved solids



CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Water is vital for life, and without water, humans can only survive for days. Water comprises about 60% of human body weight and is crucial for cellular homeostasis as well as life (Benelam & Wyness, 2010). Nevertheless, numerous human activities release toxic waste which is finally deposited in water bodies, sometimes including underground water, thus affecting the aquatic environment (Bashir et al., 2020). Water contamination is on the increase due to human population growth, increasing agricultural and industrial processes, growth in diversity of raw materials and climate change which threatens environment and human health (Chu & Karr, 2017).

The level of toxic metals deposited in the environment is increasing and continues to accumulate in the soil and water bodies (Ali et al., 2019). Increased contamination of heavy metals ends up accumulating in aquatic organisms' tissues and result in physiologic, metabolic and pathologic deviations which affect the development and reproduction of these organisms (Ali et al., 2019). Industrial contamination affects the environment negatively which has an irreversible impact on nature (Ali & Khan, 2018b; Bashir et al., 2020). These non-biodegradable metals could also be transferred to other living organisms of the food web via ingestion. Physiologically, the body only requires minute amounts of these metals, thus, increasing amounts in the body could have numerous health implications (Azeh et al., 2019; Sharma et al., 2014). Some reported fatal effects due to heavy metal toxicity are irregular blood composition that could affect proper functioning of body organs e.g., liver and kidneys, or poor functioning of the brain and central nervous system (Azeh et al., 2019; Sharma et al., 2014). Also, some forms of chronic kidney diseases have been linked to environmental nephrotoxins, such as exposure to heavy metals (Ferraro et al., 2010).

In Ghana, previous studies have shown the presence of various kinds of heavy metals in the Ghanaian soil and water bodies and their associated health risk. For instance, water bodies from the major mining and eight pristine areas across Ghana were demonstrated to contain As, Fe, Al, Fe, Mn, Cr, Cu, and Pb (Hadzi, Essumang, & Ayoko, 2018). Hadzi, Essumang, and Ayoko, (2018) further proved that the levels of Al, Mn, and Fe were exceedingly above USEPA and WHO standards. In the Asunafo South District, fish muscles were found to contained unacceptable levels of Cr, Hg, and As, though the levels of Pb, Cd, and Zn were below the limits set by the Food and Agriculture Organization (Nyantakyi et al., 2021). Among adults in the mining communities in the Tarkwa Nsuaem Municipality, As, Hg, Cd and Pb were detected in their blood samples and the metals levels were above the acceptable WHO limits (Obiri, 2018).

Also, in the Tamale metropolis, Logochura, Cobbina, and Ofori, (2020) reported the presence of Copper, Iron and Manganese in both fresh and grilled sausage samples, though Lead was not spotted. Ametepey et al., (2018) also reported the presence of Cadmium and Lead in the common vegetables (cabbage, carrot, green pepper, onion and tomato) sold in the Tamale market. Milled maize and millet sampled in the Tolon District were shown to contain Fe, Ni, Pb, Cr, Zn, and Mn (Larsen et al., 2020). Moreover, Larsen et al., (2020) disclosed that locally made mill metal plates leach heavy metals into milled flour through wearing of the mill plates.

Therefore, water is key for life when free of toxic metals contaminations. In view of this, it is crucial to maintain the quality of water and therefore, this study aimed to analyze and compare metal concentrations in groundwater, dams and rivers and sediments in Tamale Metropolis and surrounding villages in the Northern Region of Ghana and estimate the potential health risk.

1.2 Problem statement

Economic growth and urbanization influence waste generation and urban areas produce tremendous quantities of waste through human and industrial activities (Miezah et al., 2015). In 2016, the generated solid waste, globally, by cities was estimated to be around 2.01 billion tones, translated as 0.74kg per person per day (Chavez, 2019). Based on the speedy industrialization and urbanization, generation of solid waste, annually, could increase to 3.40 billion tons by 2050 if the current trend continues (Chavez, 2019).

Poor arrangement in managing solid waste added to inadequate sanitation has resulted in the generation of excess waste, up to 12,710 tons per day, that translated into about 0.47 kg/person/day.

There is evidence that the nation generates non-biodegradable waste (0.096 kg/person/day) including metals, which are usually discharged into the aquatic environment (Miezah et al., 2015).

Heavy metals discharge into the aquatic environment is a major problem in many under-developed countries including Ghana. This increase in aquatic pollution is attributed to several human processes such as mineral mining (Crawford & Botchwey, 2017; Donkor et al., 2005), industrial processes (Donkor et al., 2005), electronic waste processing (Atiemo et al., 2012; Caravanos et al., 2011), discharges of domestic sewage (Fianko et al., 2007) and agricultural activities. The contamination of the aquatic environment from e-waste processing, for example, are so widespread in cities in Ghana (Suk & Mishamandani, 2016). Though most of those activities and pollution happen on land, the metallic waste is deposited into rivers and in the sea via fluvial processes, predisposing fresh and marine water to the risk of heavy metal contamination (Chen et al., 2016). This is important since large amounts of these metallic products are non-biodegradable and persist for years in the environment. Consequently, there is absence of a natural elimination system for heavy metals in the environment.

The exposure to heavy metals remains a major human health concern, since many individuals are exposed to highly polluted water bodies (Kim et al., 2010). For example, a study by Henríquez-Hernández and colleagues showed higher levels of Hg in Ghanaians than other nationals (Henríquez-Hernández et al., 2017). Hadzi, Essumang, and Ayoko, (2018) proved the presence of As, Fe, Al, Fe, Mn, Cr, Cu, and Pb in water bodies from selected major mining and pristine areas across Ghana and that the levels of Al, Mn, and Fe were above USEPA and WHO standards. In the Asunafo South District, fish muscles were found to contained unacceptable levels of Cr, Hg, and As (Nyantakyi et al., 2021). Among adults in some mining communities, As, Hg, Cd and Pb were detected in their blood samples and the metals levels were above the acceptable WHO limits (Obiri, 2018). Similarly, in the Tamale metropolis, Logochura, Cobbina, and Ofori, (2020) testified the presence of Copper, Iron and Manganese in both fresh and grilled sausage samples. Ametepey et al., (2018) also mentioned the presence of Cadmium and Lead in the common vegetables (cabbage, carrot, green pepper, onion and tomato) sold in the Tamale market. Milled maize and millet sampled in the Tolon District were shown to contain Fe, Ni, Pb, Cr, Zn, and Mn (Larsen et al., 2020). Be it non-essential nor essential, at higher level any metal could be toxic and the toxicity is associated with chronic illnesses namely renal diseases, liver disorder, brain disorder, and various others (Mamtani et al., 2011).

Appreciable levels of trace metals have been reported in Ghana, but data on heavy metals levels from water bodies and soil sediments covering the entire Tamale Metropolis and the associated risk to humans are limited. Considering the limited studies on the levels of heavy metals and their health risk in the Tamale Metropolis, available data is not clear, some reported carcinogenic effects and others recorded noncarcinogenic effects to inhabitants. Additionally, since these metals are nondegradable, continuous accumulation would reach a level that would increase the cancer risk

of the exposed individuals, therefore, there is a need to verify the levels of heavy metals and their health risk in the Tamale Metropolis. Hence, this study intends to comparatively analyze heavy metal concentrations in groundwater, dam-water, river-water and sediments from Tamale and surroundings in the Northern Region and further estimate the potential health implications to the population.

1.3 Conceptual framework

The concept of heavy metals generation and transfer from their original sources through the food chain to humans is very systematic (see Figure 1). Due to economic growth and Urbanization, urban areas produce a tremendous quantity of waste through human and industrial activities (Miezah et al., 2015). Though most of those activities and pollution happen on land, the metallic waste is deposited into rivers and in the sea via fluvial processes, predisposing fresh and marine water to the risk of heavy metal accumulation (Blight & Fourie, 2005; Chen et al., 2016). The increase in aquatic pollution is attributed to several human processes such as mineral mining (Crawford & Botchwey, 2017; Donkor et al., 2005), industrial processes (Donkor et al., 2005), electronic waste processing (Atiemo et al., 2012; Caravanos et al., 2011), discharges of domestic sewage (Fianko et al., 2007) and agricultural activities such as applications of pesticides and chemical fertilizers on farmland (Islam et al., 2018). Larsen et al., (2020) showed that locally fabricated mill metal plates leach heavy metals into milled flour through wearing of the mill plates. These processes will lead to release of metals into the environment, then through run-off and speculation will lead to contamination of rivers and ground water/sediments (Zhu et al., 2019). Some of these wastes are non-biodegradable, for example heavy metals (Miezah et al., 2015). Heavy metals are highly reactive which give them the propensity to be transferred from the soil or water to plants and microbes, from these to invertebrates, and to both small and large mammals including humans (Gall, Boyd, & Rajakaruna, 2015). Consequently, this results in plant

eutrophication, reduction in freshwater resources, pollution of the aquatic ecosystem and thereby potential exposure to humans causing diseases (Zhu et al., 2019). Consequently, humans consume contaminated foods from the polluted environment. Since many individuals are exposed to highly polluted water bodies and aquatic foods (Kim et al., 2010), the exposure to heavy metals remains a major human health concern. Henríquez-Hernández et al. (2017) study detected higher level of Hg in Ghanaians and other nationals. At higher levels, metal could be toxic and the toxicity is associated with chronic illnesses namely renal diseases, liver disorder, brain disorder, and various others (Mamtani et al., 2011).



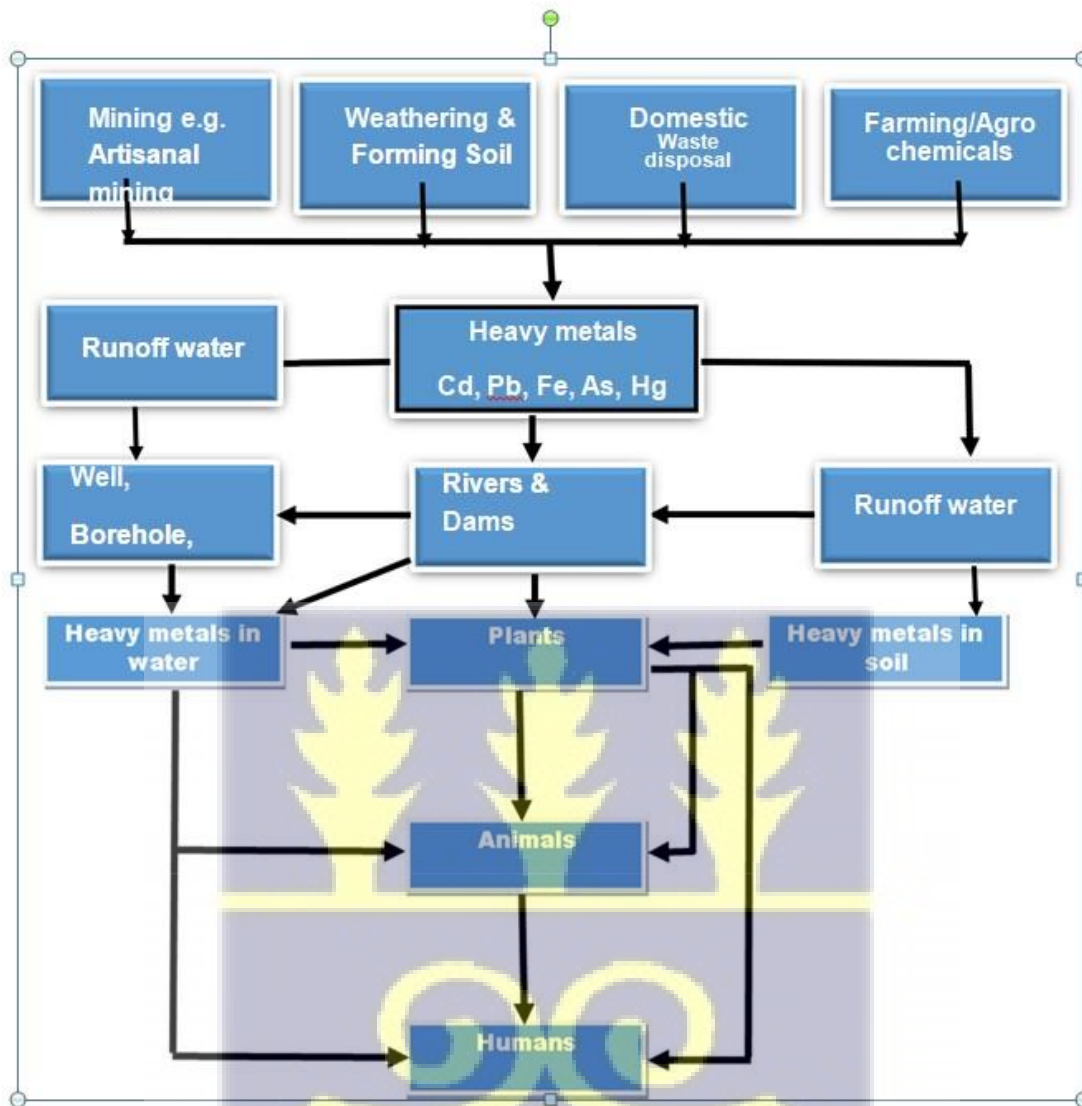


Figure 1.1: The concept of heavy metals transfers from their original sources through the food chain to humans.

1.4 Justification

Currently, there are two functional Water Treatment Plants that supply drinking water in the Northern Region. The major one is the Dalun Plant which has its source from the White Volta at Nawuni and the minor one is the Yendi Plant having its source from the river Daka. There are few mechanized boreholes in the region. More than 50% of the inhabitants in the Northern Region of

Ghana cannot get quality drinking water, and resort to use of untreated water from both surface and groundwater water (VanCalcar, 2006). Nonetheless, water quality of most natural sources has been seriously degraded through pollution due to discharge of waste from multiple human activities. Work done by Gbogbo et al. For example, high levels of Mercury were measured in the White Volta, which is the main source of water in the Northern Region (Gbogbo et al., 2016). Reports have shown that drinking water sources in some parts of the Northern Region are contaminated with heavy metals and the contamination exceeds WHO limits (Asare-Donkor & Adimado, 2020; Cobbina et al., 2015). Continuous ingestion of polluted water and aquatic organisms from these natural sources could lead to health challenges. The study of the toxic impacts of heavy metals on human's health has attracted the public's attention. Therefore, it is vital for the determination of heavy metals concentrations in both raw and treated drinking water sources so as to assess the potential risk of human consumption.

Apart from that, previous investigations on heavy metal pollution have detected significant concentrations of heavy metals in water (Apau et al., 2012); sediments (Addo et al., 2011); and fish (Laar et al., 2012), and other sea foods (Atiemo et al., 2012; Caravanos et al., 2011).

Nevertheless, there is limited information on metal contaminations of groundwater, dam-water, river-water and sediments from the Northern Region. Besides, understanding the sources and quantities of various pollutants in the environment could be the basis for formulating laws governing human activities, health and the environment as whole.

Hence, the current study aims to comparatively analyze heavy metal concentrations in selected groundwater, dam-water, river-water and sediments from Northern Region. and further estimate its potential health implications.

1.5 Objectives

1.5.1 General Objective

The aim of the study is to analyze and compare metal concentrations in groundwater, dams and rivers and sediments in Tamale Metropolis and surrounding villages in the Northern Region of Ghana and estimate the potential health risk.

1.5.2 Specific Objectives

The specific objectives of this study are to:

1. Determine the physico-chemical properties of groundwater (wells), surface water (rivers and dams) in the Northern Region of Ghana.
2. Determine heavy metals and iron concentrations in groundwater (wells) and surface water (rivers and dams) in the Northern Region.
3. Determine heavy metals and iron concentrations in sediments from rivers and dams in the Northern region of Ghana.
4. To assess human health risk of heavy metals in selected groundwater, dam water and riverwater from the Northern Region.

1.5.3 Research Questions

The research questions of this study are;

1. What are the levels of the physico-chemical properties of groundwater (wells), surface water (rivers and dams) in the Northern Region of Ghana?
2. What are the levels of heavy metals and iron concentrations in groundwater (wells) and surface water (rivers and dams) in the Northern Region?
3. What are the levels of heavy metals and iron concentrations in sediments from rivers and dams in the Northern region of Ghana?

4. Does the consumption of these groundwater, dam water and river-water pose human health risk due to the presence of heavy metals?



CHAPTER TWO

LITERATURE REVIEW

2.0 Heavy Metals Contamination of Ground and Surface Water

Water is a major constituent of all living things. It is the greatest essential nutrient that is required by plant, animal and human (Willet et al., 2019) which is generally obtain from two main sources i.e., natural; Fresh surface water, rivers, lakes, and groundwater. Normally, groundwater is found in well bore well and water (Hanasaki et al., 2018; McMurry & Fay, 2004). Numerous anthropogenic activities can cause groundwater pollution. These goings-on range from inappropriate storage and discard of wastewater, inappropriate waste management practices, inadequate application of chemicals, residual contaminants from intensive animal agriculture operation, naming a few (Kurwadkar, 2017). The contaminations of the environment by toxic substances are increasing that bring tremendous concern to the final users. A widespread area of contaminants is continually discharge into the aquatic system fundamentally owing to growing industrial work, technological development, rising human population and mistreatment of natural resources, agriculture and domestic wastes run-off (Sankhla & Kumar, 2019). When contaminants existing on ground or sediments move into water bodies underneath earth it results in groundwater contamination. Consumption of pathogen (protozoa, bacteria and viruses, and infrequently in some cases helminth eggs) contaminated groundwater can lead to illnesses like diarrhea and cholera (Kurwadkar, 2017). The extensive use of antibiotics in veterinary medicine in intensive livestock farming could lead to groundwater contamination (Yopasá-Arenas & Fostier, 2018). Groundwater contaminated with high levels of fluoride causes dental and skeletal problems (Onipe et al., 2020). Likewise, nitrates also cause groundwater pollution causing disease in adults and children (Karunanidhi et al., 2020). Among these contaminants, heavy metals are the greatest hazardous due to their stubborn nature, tendency, toxicity to accrue in organisms and the capacity to be

transferred along the food chain and above all, they are non-degradable (Dwivedi, 2017). The exposure to heavy metals remains a major human health concern, since many individuals are exposed to highly polluted water bodies (Kim et al., 2010). Heavy metals could be toxic and the toxicity is associated with chronic illnesses namely renal diseases, liver disorder, brain disorder, and various others (Mamtani et al., 2011).

2.1 Heavy Metals Contamination of Sediment

Foremost sources of heavy metals pollution of sediments include urban wastes; industrial effluents; chemical fertilizers; and pesticides (Islam et al., 2018). Additionally, sediments in Ghana are polluted with heavy metals through e-waste recycling (Kyere et al., 2018). A process where open fire melting of electronic boards is done to remove metals and valuable chips, burning of electronic cables to obtain copper wires and open burning of residual waste materials (Moeckel et al., 2020). These actions result in the release of large amounts of toxins into the atmosphere thereby polluting the environment, threatening the health of residents. Irrigation practices that use contaminated river-water and groundwater also share the responsibility for sediment contamination. Heavy metals pollution of farmland, sediments, and crops could affect food safety considerably in addition to human health (Zhu et al., 2019). Heavy metals contaminations of soil largely lead to damaging effects on plants and animals. In plants, during germination, heavy metals toxicity can kill seeds, resulting in a decrease in the rate of germination of crop seeds, causing disturbances in the cellular division of plants (Nagajyoti et al., 2010). In such circumstances, the plant growth rate is decreased, showing signs of disease, and may reduce (Sanjosé et al., 2021).

2.3 Metals

Fundamentally, heavy metals comprise the transition and post transition metals, and the most commonly found in literature include cadmium (Cd), lead (Pb), iron (Fe), arsenic (As), mercury (Hg), vanadium (V), chromium (Cr), cobalt (Co), copper (Cu), manganese (Mn), tin (Sn), nickel

(Ni), and zinc (Zn). The existence and accessibility of heavy metals through anthropogenic and natural routes continue to be a foremost worldwide health problem as far as the ecosystem is concern (Ali & Khan, 2018b; Ebadi & Hisoriev, 2018). Generally, the sources of heavy metals in the environment are anthropogenic and natural. Naturally, heavy metals are generated from activities regarding the metallic minerals and parent rocks and anthropogenic sources consist of agriculture activities metallurgy (e.g., mining and smelting); (e.g., application of fertilizers and pesticides); sewage disposal and energy production (e.g. power plant and leaded gasoline) (Nkwunonwo et al., 2020; Sankhla & Kumar, 2019).

These toxic substances get to the water, farmland, and exposed food by regularly the process of leaching and runoff (Nkwunonwo et al., 2020). Anthropogenic processes pollute diverse environmental media, for example the soil, air, and water which support the growth, production, and supply of foods (Nkwunonwo et al., 2020). Ingestion, inhalation, plus dermal penetration are the main exposure routes through which heavy metals in locally produced foods reach the consumers (Nkwunonwo et al., 2020). Toxicity of these heavy metals could result in potential health hazards. Therefore, chronic consumption of heavy metals contaminated foods is a public health issue.

2.3.1 Cadmium (Cd)

Cd is usually adsorbed onto organic constituents, for instance, fulvic and humic acids, and consequently waters that are rich in organic matter may contain larger Cd amount (Plant et al., 2001; Carla, 2002). Cd consumption at higher levels/day, may raise the risk of Chronic Kidney Diseases by 73%, heart illness, cancer and Alzheimer's syndrome (Satarug et al., 2020). Prolonged exposure to Cd could result in emphysema, anemia, anosmia (loss of sense and smell), kidney disorders, vascular illnesses, renal conditions, and hypertension (J. A. Plant & Thornton, 1983).

Cd-associated illnesses include Itai-itai syndrome, which results in a seriously painful sensation and leads to bone wastage and embrittlement (WHO, 2017).

2.3.2 Lead (Pb)

Pb is a bluish-gray-colored heavy metal with low melting point. Pb can enter the body through lead-based dust, water, soil, folk medicines, tableware, and paint. Pb toxicity is one of the greatest hazardous metal toxicities and children are particularly susceptible to develop Pb toxicity (Bikash et al., 2019). Pb activates its toxic effects by inducing oxidative stress owing to ineffective renewal of glutathione (Bikash et al., 2019; Flora et al., 2012). Human exposure to Pb causes countless harmful effects on the renal, hematopoietic, and central nervous as well as reproductive system (Flora et al., 2012). Pb can similarly cause hemolytic anemia as a result of distraction of the cellular membrane through lipid peroxidation (Flora et al., 2012). Pb toxicity also affects neurotransmitter levels and causes severe health issues related to organ damage, some even leading to death. Pb blocked blood vessels can result to instantaneous heart attack plus death (Bikash et al., 2019). Owing to Pb exposure, nephrotoxicity may occur because Pb is eliminated via the kidney (Satarug et al., 2020).

2.3.3 Iron (Fe)

Fe is a trace metal needed to guarantee the survival of nearly all organisms. Fe is involved in multiples of vital functions such as cellular respiration, oxygen transport, DNA processing, and metabolic energy (Ng et al., 2019). Fe triggers oxidative stress, lipid peroxidation, and DNA damage, which can lead to genomic instability and DNA repair defects (Gaharwar et al., 2017) that eventually limits cell viability and then upregulate programmed cell death (Dixon & Stockwell, 2014).

Excessive Fe promotes competition among pathogens for Fe and increases the morbidity and mortality of communicable diseases (Chen & Ayres, 2020). Fe roles in neurodegenerative illnesses have been reported. increased Fe intake is connected to diseases such as Parkinson's, Alzheimer's, Huntington's, Prions, and multiple system atrophy (Fibach & Rachmilewitz, 2017; Yang & Wells, 1991). Fe overload related hematological illnesses such as Thalassemias, Myelodysplastic syndrome, Autoimmune hemolytic anemia, sickle cell syndrome (Fibach & Rachmilewitz, 2017)

2.3.4 Arsenic (As)

As is regarded as a heavy metal and its prolonged exposure affects human health including numbness, tingling, and peripheral neuropathy (Plant & Thornton, 1983). Heavy metal contamination is a global issue (Ali & Khan, 2018a; Rai et al., 2019). On the other hand, the toxicity of As in cattle is shown to cause dysentery and respiratory distress (Faires, 2004). An ecological correlation between the arsenic level of well water and mortality from various malignant proven an important connection with the level of concentration of arsenic in well water and its range of 0.35-1.14 mg/l for liver cancer, lung, nasal cavity, skin, kidney, and bladder, and hyperpigmentation, hyperkeratosis, Blackfoot illness in males and females, and prostate cancer (Chen & Wang, 1990).

2.4 Human exposure to toxic metals and health risk

Human exposure to toxic metals is now an alarming public health concern. This is because human survival is largely dependent on his environment and evidence showed that the human environment is heavily contaminated with these toxic metals. An extensive area of contaminants is continually discharge into the aquatic system fundamentally owing to growing industrial work, technological development, rising human population and mistreatment of natural resources, agriculture and domestic wastes run-off (Sankhla & Kumar, 2019). Considering human environment globally, traces of heavy metals have been shown the water we drink (Yopasá-Arenas & Fostier, 2018), the

air we breathe in (Suvarapu, & Baek, 2017), farm lands (Islam et al., 2018), fishes (Nyantakyi et al., 2021), vegetables (Ametepey et al., 2018), and food products (Logochura, Cobbina, & Ofori, 2020). Heavy metals contamination of sediments, farmland, and crops could affect food safety significantly as well as human health (Zhu et al., 2019). The heavy metals are the greatest hazardous due to their stubborn nature, tendency, toxicity to accrue in organisms and the capacity to be transferred along the food chain and above all, they are non-degradable (Dwivedi, 2017). The fundamental challenge is that these toxic metals get in to the human body directly or indirectly through eating contaminated foods and drinking contaminated water. The exposure to heavy metals remains a major human health concern, since many individuals are exposed to highly polluted foods and water bodies (Kim et al., 2010).

Generally, toxic metals are known for their carcinogenic effects, especially arsenic, beryllium, chromium, cadmium, and nickel (Chen, DesMarais, & Costa, 2019). Globally, millions of people suffer the consequences of long period heavy metal exposure, which is connected to threatening illnesses such as cancer (Chen, DesMarais, & Costa, 2019). Evidence from the literature showed that human exposure to these toxic metals is becoming a great concern. For this reason, human health risk regarding heavy metals exposure is measured by considering the metals carcinogenic effects. Several studies have reported the human health risk of some common toxic metals. For instance, detection of As, Hg, Cd and Pb in the blood samples of adults living in the mining communities and the metals levels were above the acceptable WHO limits (Obiri, 2018). The findings by Obiri, (2018) established a significant association between exposure to As in drinking water and the occurrence of cancer among inhabitants in the study location. Also, water bodies from the major mining and eight pristine areas across Ghana were demonstrated to contain As, Fe, Al, Fe, Mn, Cr, Cu, and Pb (Hadzi, Essumang, & Ayoko, 2018). Hadzi, Essumang, and Ayoko,

(2018) further proved that the levels of Al, Mn, and Fe were above USEPA and WHO standards with Arsenic showing a carcinogenic risk value greater than the permissible level ($1.8E-02$) which show carcinogenic health threat. Similarly, Logochura, Cobbina, and Ofori, (2020) reported the presence of Copper, Iron and Manganese in both fresh and grilled sausage samples, though the health risks assessment estimated showed that there were no possible risks of cancer associated. Ametepey et al., (2018) also reported the presence of Cadmium and Lead in the common vegetables (cabbage, carrot, green pepper, onion and tomato) sold in the Tamale market. Milled maize and millet sampled in the Tolon District were shown to contain Fe, Ni, Pb, Cr, Zn, and Mn however, the health risks assessment estimated showed that there were no possible risks of cancer associated (Larsen et al., 2020). Moreover, Larsen et al., (2020) disclosed that locally made mill metal plates leach heavy metals into milled flour through wearing of the mill plates. In the Asunafo South District in Ghana, fish muscles were found to contained unacceptable levels of Cr, Hg, and As, though the levels of Pb, Cd, and Zn were below the limits set by the Food and Agriculture Organization and there was no cancer risk associated (Nyantakyi et al., 2021).

2.5 Heavy metals transfer routes

The idea of heavy metals transfer from their sources via the food chain to humans is a gradual process. Heavy metals are natural part of the elements found in the Earth's crust. Disruptive human activities, have led to an uneven distribution of these elements to all parts of the environment including aquatic environments. Humans and animals are exposed to heavy metals through several routes: inhalation of polluted air; drinking of polluted water; exposure to polluted soils particles or industrial waste; and the consumption of polluted food such as fruits, vegetables, grains, shellfish

and fish as well as meat (Witkowska et al., 2021). In the soil or water, plants and microbes become the first transfer routes to pick up heavy metals (Boshoff et al., 2014; Picó et al., 2022; Pollard et al., 2014). Plants and microbes are the major source of nutrients to vertebrates and via ingestion of contaminated plants and microbes, water and other soil debris, irrigation activities heavy metals are transferred to secondary sources (Bourioug et al., 2015; Meindl et al., 2014). Through consumption of these vertebrates, heavy metals are transferred to small mammals (Drouhot et al., 2014; Moriarty et al., 2012). These elements are then transferred to both small and large mammals and to humans (Gall, Boyd, & Rajakaruna, 2015). Therefore, the transfer of heavy metals follows a similar path of energy transfer in the food chain within the ecosystem.

2.6 Bioavailability of heavy metals in environmental media

Heavy metals have now become common environmental pollutants globally. Activities such as mineral mining (Crawford & Botchwey, 2017), industrialization processes (Donkor et al., 2005), electronic waste processing (Atiemo et al., 2012; Caravanos et al., 2011), discharges of domestic sewage and runoff water (Fianko et al., 2007) and applications of pesticides and chemical fertilizers on farmland (Islam et al., 2018) cause the redistributions of these metals in the environment. Heavy metals have been found in soil samples from farm lands (Alengebawy et al., 2021), mining areas, and non-mining areas and with levels higher than WHO standards. the most harmful environmental contaminants, particularly in areas with high anthropogenic pressure (Fosu-Mensah et al., 2017; Hadzi et al., 2019). Heavy metals in Soil sediments, food crops and grasses were previously reported (Kfle et al., 2020). Orisakwe et al. (2017) disclosed the distribution of heavy metals in farm produce and livestock. Work done by Shams et al., (2022) showed the presence of heavy metals in ground as well as surface water and other drinking water (Sankhla et al., 2016). Faridullah et al., (2014) have revealed that heavy metals were also found in both fresh and composited livestock manures.

2.7 The uptake of heavy metals by organisms

The uptake of heavy metals by organisms, especially plants is an important step for these elements to enter the food chain. Changes in the root architecture, stimulation of root-based transport system and coordination with useful soil microorganism permits plants to maintain optional nutrient content during changing soil environments (Morgan, & Connolly, 2013). These is influence by the surrounding pH, type of microbes presents, levels of the heavy metal ions, nature of solute, temperature, presence of other metal ions (Abbas et al., 2014; Seneviratne et al., 2017). The mechanism of essential nutrients assimilation is also used in the absorption, translocation, and storage of heavy metals, in which their chemical properties mimics those of micronutrients (Zakaria et al., 2021). Studies disclosed that the heavy metals are adsorbed fairly rapidly and the assimilation of a single metal is delayed by the existence of other metals in the same vicinity (Abbas et al., 2014; Seneviratne et al., 2017). Plants also immobilize heavy metals through a type of chemical reaction involving microbial processes (Seneviratne et al., 2017). Phytochelatin metabolism allows the intracellular compilation of heavy metals in organisms (García-García et al., 2016). Additionally, Molluscs and algae absorb and accumulate heavy metals but algae are seen as good accumulators of these metals (Jitar et al., 2015). Humans and animals pick up heavy metals through inhalation, gastrointestinal tract and skin and absorbed (Witkowska et al., 2021).

2.8 Bioaccumulation of heavy metals in organisms

Reports on the accumulation of heavy metals in organisms are increasing each day. Owing to their non-degradability, heavy metal ions are accumulated and their concentrations rise along the food chain (Abdi, & Kazemi, 2015). Evidence from literature showed greater levels of heavy metals in leafy and nonleafy vegetables including their leaves, roots, stems and tuber (Khan et al., 2015). These elements were found accumulating in microorganisms such as Molluscs, and Algae (Jitar et al., 2015) as well as in freshwater fish (Ali & Khan, 2018b). Studies reported the bio-accumulation

of heavy metals in *Bellamya sp.* (edible snail) (Bo et al., 2015), in zooplankton, shrimp, shellfish, fishes and prawn and benthic species such as mollusc, polychaetes, and crustaceans (Pandiyan et al., 2021; Zhang et al., 2016). These toxic elements were also disclosed in farm animals such as swine and cattle and their faces (Hejna et al., 2019). Orisakwe et al., (2017) mentioned the distribution of toxic metals in farm produce and livestock such soil, water, vegetables, blood, and different samples of meat prepared from sheep, goat, cattle, and chicken. Obiri, (2018) reported the detection of heavy metals in adults blood samples. It was shown that kidneys collected from slaughtered cattle had excess level of Cd (Canty et al., 2014).



CHAPTER THREE

METHODS

3.1 Study Design

An analytical cross-sectional study was conducted to determine the concentrations of heavy metals and iron in surface water (rivers and dams), groundwater (wells) and sediments from rivers and dams in the Northern region of Ghana.

3.2 Study Area

Tamale Metropolis is strategically located in the central portion of the Northern Region, sharing boundaries with Sagnarigu-District to the north-west, Mion-District to the east, East-Gonja to the south while Central-Gonja towards south-west. The Metropolis, geographically, lies between latitude 9°16 and 9° 34 north, and longitudes 0° 36 and 0° 57 west. Considering data from 2021 Population and Housing Census, it has 115 communities, 89,011 households and population density of 825.0 (individuals per sq. Km), and total population of 374,744 with 185,051 males and 189,693 females living in urban and rural areas. Additionally, the household structure was mostly the extended type (46.1%) consisting of mainly children (40.4%) with fewer (16.1%) household heads. Within the metropolis there are 742 basic schools: 14 senior high schools, 112 junior high, 304 primary and 94 kindergartens. Out of the population (aged 11 and above), majority were literates (60.1%) and 39.9% were non-literates. Among the population of the metropolis, 84,897 (aged 3 and older) were currently in school (52.9% males and 45.1% females), 15.1% were in the nursery, JSS/JHS pupils were 18.2%, SSS/SHS students were 12.5% and the largest percentage (40.0%) was in primary, whereas 58.6 and 41.4 percent males and females, respectively, have attended school in the past.

Among those currently attending school, 15.1 percent are in nursery, 18.2 percent in JSS/JHS, 12.5 percent in SSS/SHS, 5.7% in tertiary institutions and the largest proportion (40.0%) was in primary.

The main source of water in the Tamale Metropolis is pipe-borne water. The Nawuni River, is the main source of drinking water for inhabitants in the Tamale Metropolis and its surrounding villages. The Nawuni River also known as the White Volta is located in the Kumbungu District connects the Black Volta at Yeji which flow into the Akosombo Dam. Other source of drinking water for the inhabitants in the Tamale Metropolis and its surrounding villages include mechanized and non-mechanized boreholes, duked-out wells, and dams. Another important source of water is the Kanshegu mechanized borehole cluster designed for the production of sachet water for inhabitants in the Tamale Metropolis and its surrounding villages and it is located in the Savelugu Municipality. Other important Damps are the Gburima Dam is located in the Sagnarigu District, Libga and Fazihini Dams in the Savelugu Municipal and the Tolon Dam located in the Tolon Distric. Generally, the mechanized boreholes and pipe-borne water are processed in to sachet water which serve as the main drinkable form of water in the Tamale Metropolis and its surrounding villages.

On a whole, solid and liquid waste are the main types of waste generated in the Tamale Metropolis and its surrounding villages. Solid wastes are generated from packaging items and foods as well as condemned or outmoded products. Solid wastes disposal methods are widely used where wastes are dumped at public dump or indiscriminate dumping and most urban households collect their solid waste, whereas most rural households do not. The management and treatment of solid waste particularly electronic waste by burning becomes a major source of contaminants for the atmosphere, soil, and water bodies in the area. The metal scraps processing sites are increasing

across Tamale Metropolis and its surrounding villages and burning of condemned electronic items and machines to recover metal scraps is becoming a common practice in these areas. Generally, liquid waste disposal is done by discharging or pouring onto the outside/street or into the gutter. Most households in the Tamale Metropolis share the bathrooms and only a few households own separate bathrooms for their personal use. For toilet facilities, the commonest is the public toilet (WC/KVIP/Pit latrine/pan) followed by KVIP, however, approximately 26.1% of households in the metropolis have no toilet structure.



Figure 3.1: Geographical demarcation of the sampling sites with Tamale Metropolis as capital.

3.3 Study variables

Outcome or dependent variables: Cancer and non-cancer health risk.

Independent variables: concentrations of heavy metals in groundwater (wells), surface water (rivers and dams) and sediment.

3.4 Sampling

3.4.1 Water sampling and treatment

Water samples were collected from the various sampling points (Table 3.1) in the Tamale Metropolis and its surrounding communities. At each sampling point, water samples were collected into a 500 mL plastic bottle which was pre washed with detergents, soaked and washed in 10% nitric acid for 24 hours, rinsed thoroughly with double distilled water and oven dried overnight (APHA, 2005; Boadi *et al.*, (2011)). The entire samples collected for dissolved metal analysis were filtered through 0.45 μm filter on site while those for total recoverable metal analysis were not filtered and both acidified with 5 mL of nitric acid (HNO_3) to a pH below 2.0 according to EPA Method 3005. Water quality parameters such as pH, electrical conductivity, salinity, total dissolved solids, and turbidity were measured *in situ* using EZDO 7200 multi meter. The electrode of the meter was dipped into the water samples while the values are read and recorded. The electrode of the meter was rinsed with distilled water after each sample measurement. All samples collected were well labeled, stored in an ice chest at 4 °C, and sent to the laboratory for analysis within 48 hours of sampling. Samples were kept in the refrigerator at 4 °C for 48 hours in the laboratory before heavy metal analysis was done.

3.4.2 Sediment sampling and treatment

Sediment samples were collected from the various sampling sites in the Tamale Metropolis and its surrounding communities at a depth of 0-15 cm using soil auger. Twenty (20) representative composite sediment samples (Table 3.1) were collected, stored in well labeled zip polyethylene bags, and then transported to the laboratory for further sediment treatment and analysis. The sediment samples were then air-dried at room temperature (25 – 29 °C) for 5 days in the laboratory. The samples were ground using porcelain pestle and mortar and passed through a 2 mm mesh sieve to remove plant roots, debris, stones and other materials to obtain soil fraction (sand, silt and clay).

The sieved sediment samples were stored in well labeled zip polyethylene bags for the various analytical determination in the laboratory.

3.4.3 Sampling sites

A purposive sampling technique was employed in the sampling of the sites. Generally, purposive sampling is an approach by which specific settings individuals or happenings are chosen intentionally so as to offer vital information that could not be attained from other available choices (Ames et al., 2019). Etikan et al., (2016) mentioned that purposive sampling method has the advantage that the researcher may use his/her knowledge, skills and experience to select appropriate respondents for the study. Therefore, most of the major sources of water in Tamale and its surrounding villages were included in the study. The Nawuni River also known as the White Volta located in the Kumbungu District, mechanized and non-mechanized boreholes, duked-out wells, and dams were the main source of drinking water for the inhabitants in the Tamale Metropolis and its surrounding villages. Generally, the mechanized boreholes and pipe-borne water are processed in to sachet water which serve as the main drinkable form of water in the Tamale Metropolis and its surrounding villages. The initial aim of this study was to consider only Tamale Metropolis as the sampling site; however, the growth of the Metropolis has extended to near districts where they use common sources of water. Therefore, it was necessary to consider the major sources of water located outside the Tamale Metropolis yet supply water to the people in the Tamale Metropolis and its surrounding villages. The sampling considered most of the major sources of water use in the Tamale Metropolis and its surrounding villages. In all, thirteen dams, one river (The white Volta) serving the entire Tamale and surrounding districts and their corresponding sediments, four wells, seven mechanized boreholes and one treated pipe-borne water from the Nawunli plant and a sachet water produced from Kanshegu cluster of boreholes located in the Kumbungu District where commercial sachet water production is been carried out

(Table 3.1). Other important Damps sampled were the Gburima Dam located in the Sagnarigu District, Libga and Fazihini Dams in the Savelugu Municipal and the Tolon Dam located in the Tolon Distric. In the case of the Dams and the river, three samples each of the water was taken in to a separate bottle and labelled as upstream, midstream and downstream, sediments were taken as well in the corresponding Dams and river (Table 3.1).

Table 3.1 Sampling locations showing their zones, codes, and GPS Coordinates.

No	Sample zone	Sample code	Sample GPS Coordinates	Location Name
1	East Tamale	ETGB	NT-0997-7421	Gburima Dam, Sagnarigu District
2		ETWV	NT-0993-7647	Wovaguma Dam, Sagnarigu District
3		ETT	NT-0600-9138	Taha Dam, Tamale
4		ETC	NT-1085-4439	Chanzeni Dam, Tamale
5		ETW	NT-0977-6542	Wamali Dam, Tamale
6		ETK	NT-0154-0118	Borade Ave borehole, Tamale
7		ETS	NT-0659-0791	Difaa Dam, Tamale
	West Tamale			
9		WTSH		Shishagu Dam
11		WTD	NT-1127-0268	Datooyili Dam, Tamale
12		WTMB	NT-0113-2070	Magazine borehole, Tamale
13		WTDU	NT-0177-2213	Dungu-UDS Dam, Tamale
14		WTGO	NL-1946-1892	Golinga Dam
	Central Tamale			
15		CTG	NT-0157-8217	Dabokpa Dam, Tamale
16		CTPO	NT-0001-9782	Bank Street, Tamale
17		CTQE	NT-0002-4289	Dagomba Street, Tamale

18		CTSW	NT-0028-0386	Atta Mills Ave, Tamale
19		CTAA	NT-0013-5661	North High Street borehole, Tamale
20		CTBD	NT-0024-1069	Tinzamnaa Stfreet, Tamale
	North Tamale			
21		NTL	NU-0268-5726	Libga, Tamale
22		NTK	NU-0505-2132	Savelugu South High Street Borehole
23		NTS	NU-2583-8380	Savelugu Dam, Savelugu Municipal
24		NTFB	NU-2435-4317	Fazihini Dam, Savelugu Municipal
25		NTN	NK-1403-7815	Nawuni River, Kumbungu District.
26		NTSS		Sahakpaligu Dam, Sagnarigu District.

3.4.3 Digestion of sediment samples

Approximately, 1.0 g of sediment sample was weighed into the digestion tube, digested with 10 mL of ternary mixture of HClO_4 , HNO_3 , and H_2SO_4 and placed on an electric hot plate at $95\text{ }^\circ\text{C}$ for 1-2 hrs under fume chamber until the solution was reduced to near dryness. The samples were then removed from the hot plate and allowed to cool at room temperature. Distilled water was added to the digested samples and filtered through Whatman No. 42 filter paper into a 100 mL volumetric flask and the volume adjusted to the 100 mL mark with distilled water.

3.4.4 Digestion of water samples

A 50mL portion of water sample was measured into a beaker, 2 mL of concentrated HNO_3 and 5mL of concentrated HCl were added. The mixture was heated on a hot plate at $90 - 95^\circ\text{C}$, evaporated and to obtain a reduced volume of 15–20 mL. The beaker was then removed from the hot plate and left to cool, the walls rinsed with distilled water and transferred into a 50 mL

Volumetric flask and the final volume were top up to a 50 mL level. The concentration of heavy metals was measured using PINAAcle 900T Perkin Elmer Atomic Absorption Spectrophotometer for total recoverable metals. However, for dissolved metal determination the samples were directly aspirated into the atomic absorption spectrophotometer to measure the metals contents.

3.5. Determination of heavy metals

3.5. Determination of heavy metals in water samples

The concentration of heavy metals such as Cadmium (Cd) and lead (Pb) were determined using flame atomic absorption spectrophotometer (FAAS). Arsenic (As) was determined using flow injection analysis system – atomic absorption spectrophotometer (FIAS-AAS) (Hydride Generation Technique) while mercury (Hg) was determined using flow injection analysis system – atomic absorption spectrophotometer (FIAS-AAS) (Cold Vapor Technique). Air-acetylene gas was used as the source of fuel for Fe, Pb, and Cd while argon gas was used for As and Hg.

Table 3.2 Instrument analytical condition of investigated metal ion

Spectrometer parameter	Fe	Pb	Cd	As	Hg
Wavelength (nm)	248.33	283.3	228.8	193.7	253.7
Slit width (nm)	0.7	0.7	0.7	0.5	0.2
Lamp current (mA)	10	10	8	10	5
Fuel	Acetylene	Acetylene	Acetylene	Argon	Argon
Support	Air	Air	Air	Air	Air

3.6 Determination of sediment pH, electrical conductivity, and salinity

The sediment pH, electrical conductivity, and salinity were measured using EZDO 7200 multi meter. Accurately weigh 10.0 ± 0.01 g of sediments into a beaker and 10 mL of distilled water to obtain a soil to water solution ratio of 1:1. The mixture was stirred several times for 30 minutes

and left to stand for one hour for the suspended soil particles to settle. The pH meter was calibrated with standard buffer solution of pH 4.0 and 7.0 respectively. The electrode was then immersed into the solution and the pH, electrical conductivity and salinity reading were taken. The electrode was rinsed with distilled water after each sample measurement.

3.7 Human health risk assessment

This study conducted human health risk assessment of the detected heavy metals in the water and sediment samples. This study employed the risk assessment approaches and parameters already reported by Wongsasuluk et al. (2014). Human risk assessment involves identification of hazard, assessment of exposure, the response dose and characterization of risk (Lee et al., 2005). (Lim et al., 2008), proposed two toxicity risk indices which are: (i) the slope factor (SF) for the characterization of carcinogen risk in addition to the oral reference dose (RfD) for the characterization of noncarcinogen risk (Table 3.4).

Using the method already reported by (Siriwong, 2006), this estimated the magnitude; frequency; as well as the period of human exposure in relation to the environment by calculating the average daily dose (ADD) for the individual sediment and water samples as:

$$ADD_i = \frac{(C_i \times IR \times EF \times ED)}{BW \times AT}$$

Where all the parameters are defined in Table 3.3 below.

Table 3.3 Input parameters for estimation of the ADD values Wongsasuluk et al. (2014).

Exposure parameters	Symbols	Units	Value
Concentration of sample	C	mg/L	Table 4.2 & 4.3
Ingestion rate (water)	IR _w	L/day	2.2

Ingestion rate (sediments)	IRs	Kg/day	0.0001
Exposure frequency	EF	Days/year	365
Exposure duration	ED	Years	70
Body weight	BW	Kg	70
Average time	AT	Years	25,550 days

Generally, heavy metals effects on human health can be carcinogenic or non-carcinogenic effects (Sall et al., 2020). Hence the assessment was done by calculating the carcinogenic and noncarcinogenic effects of the heavy metals in the water and sediments.

The non-carcinogen risk was determined using the oral reference dose (RfD) values in Table 3.4 and the equation:

$$\text{Hazard quotient (HQ)} = \frac{ADD}{RfD}$$

For the health risk assessment of a combination of metals, each metal HQs are added together to form hazard Index (HI) i.e.

$$\text{Hazard Index (HI)} = \sum \text{HQ}_i$$

Table 3.4 the toxicity response (response dose) to heavy metals such as the oral reference dose (RfD) (USEPA IRIS, 2011; USEPA, 2012).

Heavy metals	Oral RfD (mg/kg/day)
--------------	----------------------

Cd	0.0005
Pb	0.0035
Fe	0.7
As	0.0003
Hg	0.0003

Lim et al. (2008) proposes that HI/HQ >1 signifies an undesirable risk of non-carcinogenic impact on health, while HI/HQ <1 signifies acceptable level of risk.

The non-carcinogen risk was estimated by calculating the chronic daily intake (CDI) values using the modified equation previously used by (Miguel et al., 2007; Muhammad et al., 2011; Wu et al., 2009) Muhammed et al. (2011); Wu et al. (2009) and De Miguel et al. (2007). i.e.:

$$CDI = Ci \times \frac{DI}{BW}$$

Where C= metal concentrations, DI=2.2 L/day, body weight BW = 70 kg.

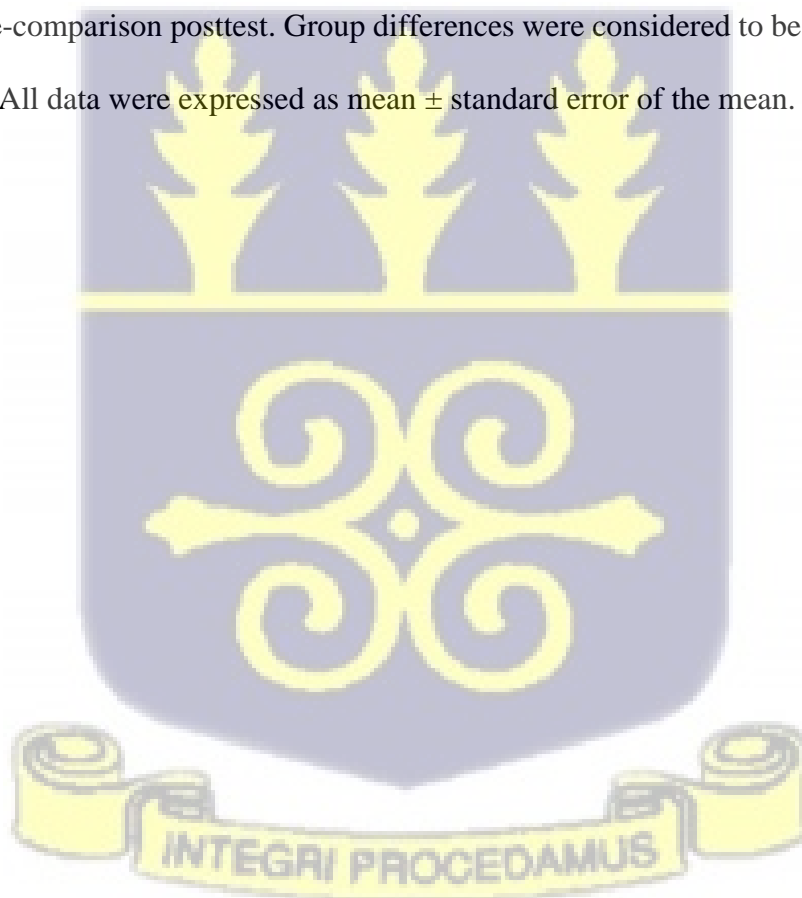
3.8 Quality control

All the reagents used were of analytical grade. Plastic and glass wares were soaked in 10% HNO₃ for 24 hours, rinsed with distilled water and oven dried overnight. A blank was run for each digestion procedure to correct the measurement. Each sample was analyzed in triplicates and two standards were tested after every 10 samples to check for interference and cross contamination. The percent recovery of the metals analyzed are presented in Table 2. In order to guarantee the

accuracy of the data, standard reference material ISE Sample 999 of moist clay from Liteta/Ivory Coast, WEPAL (Wageningen Evaluating Programs for Analytical Laboratories) were included in every batch of the sample digestion and analysis as part of the quality control protocol. To calculate mean concentration, it was assumed that the values below the limit of detection (LOD) were equal to half the LOD. For several samples, the concentration of metals was below the limit of detection or quantification.

3.9 Statistical Analysis

Data analyses were done using GraphPad Prism 9.0 (GraphPad Software, Inc., San Diego, CA) and excel. The levels of significance were determined using analysis of variance (ANOVA) and Tukey's multiple-comparison posttest. Group differences were considered to be *significant at a p value of < 0.05 . All data were expressed as mean \pm standard error of the mean.



CHAPTER FOUR

RESULTS

4.0 The Physico-chemical Parameters of water and sediment samples, and metal concentrations in ground and surface water were determined.

4.1 Physico-chemical Parameters of Selected Water Samples Obtained from Various Sources

The results on the estimates of the physico-chemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), salinity and turbidity of the water sampled from groundwater (boreholes) and surface water (rivers and dams) are presented in Table 4.0. pH of the water samples was in the range of (6.21-6.80) (at CTBW1) to 6.8-7.1 (at NTS) as compared to the recommended levels of 6.5-8.5 by WHO. Furthermore, EC values ranged from (42.7-1440) $\mu\text{S}/\text{cm}$ at WTD and NTFB, in reference to WHO standard of 1000 $\mu\text{S}/\text{cm}$. The minimum value (33.3 \pm 1.7 mg/L) for TDS occurred at ETT while the maximum value (964 \pm 0.0) was recorded at NTFB. From Table 4.0, the lower Salinity value was 23.3 mg/L (at point ETT) and its greatest value was 717 \pm 0.0 mg/L (at point NTFB). The Turbidity estimates were between 2.1 \pm 0.0 NTU (at site CTPO) and 691.5 \pm 0.0 NTU (at site ETS) compared to WHO limits of 5 NTU.

Table 4.0 Physico-chemical parameters of the water samples obtained from various sources and different sampling points. The values are presented as Mean \pm SD for the triplicate’s tests for each category and the codes represent the sampling points (see Table 3.3).

				WATER - Physico-chemical Analysis				
				pH	($\mu\text{S}/\text{cm}$)	(mg/L)	(mg/L)	(NTU)
Zone	Source	No.	Code		EC	TDS	Salinity	Turbidity
	Bore-hole	1	ETGB	6.8 \pm 1.03	71 \pm 0.01	47 \pm 1.03	32 \pm 1.01	10.4 \pm 1.01
		2	ETWV	6.8 \pm 1.14	107.6 \pm 8.72	74 \pm 4.21	51.7 \pm 3.62	192.7 \pm 7.91
		3	ETT	7.2 \pm 0.10	50.3 \pm 2.3	33.3 \pm 1.22	23.3 \pm 1.22	229 \pm 4.12
		4	ETC	6.9 \pm 2.11	449.6 \pm 8.82	316.3 \pm 5.81	234.6 \pm 9.1	30.8 \pm 4.43

		5	ETW	6.8±2.33	77.3±4.07	52.3±3.71	34±5.02	20.9±2.32
		6	ETK	6.8±1.10	188±9.08	130±6.22	92±4.01	61.9±5.30
		7	ETS	6.8±1.11	52.7±3.06	35.7±3.21	25.3±2.11	691.5±5.42
	Dam	8	WTSH	6.67±2.01	121.3±7.04	82±4.22	58.3±7.11	53.1±5.40
	Bore-hole	9	WTAS	6.30±0.96	640±15.33	594±11.02	450±10.10	4.2±0.11
		10	WTD	7.1±1.04	42.67±2.31	28.3±4.11	20±1.51	238.43±23.1
		11	WTDU	6.7±1.21	86±12.6	63.3±6.21	47.6±6.64	9.8±2.22
		12	WTGO	6.8±2.53	66±7.91	43.6±8.55	31±6.28	8.5±2.89
		13	WTMB	6.78±1.11	294±9.88	202±11.03	145±19.04	3.2±0.48
	Dam	14	CTG	6.8±1.089	129±9.33	86.6±5.43	60.6±8.23	140.4±10.88
		15	CTPO	6.5±1.8	640±13.12	442±9.22	221±8.86	2.1±0.01
		16	CTG	6.92±1.12	588±17.94	394±22.01	287±11.12	3.2±0.01
		17	CTS	6.69±1.1	451±11.10	298±9.02	175±9.84	0.1±0.00
		18	CTBW	6.21±1.71	1429±26.62	964±14.07	720±9.95	2.6±0.02
		19	CTAA	6.85±1.07	91±10.42	60±7.91	42±4.68	3±0.11
		20	CTBD	6.32±1.02	830±12.03	564±9.87	410±7.99	3.2±0.48
	Dam	21	CTS	6.74±1.12	71±8.65	51±3.02	36±5.20	2.2±0.01
		22	NTL	6.7±2.21	52.3±6.45	34.6±5.01	23.6±5.04	17.7±2.70
		23	NTK	7.08±1.75	655±12.28	438±8.79	319±13.81	2.6±0.02
		24	NTK	7.28±1.99	64±6.75	42±4.60	30±6.01	2.5±0.10
	Dam	25	NTS	6.8±1.87	64.6±8.98	43.3±4.05	30.3±5.81	89.3±7.91

	Bore-hole	26	NTFB	7.50±2.01	1440±28.11	964±21.13	717±12.43	2.3±0.01
		27	NTN	6.7±1.06	65±7.81	43±4.92	30.3±4.23	68.6±7.34
		28	NTSS	6.92±1.83	90±9.87	57±5.02	40±6.04	4.3±1.01
WHO Limits (2011)				6.5-8.5	1000	1000	200	5

4.0.2 Physico-chemical Parameters of Selected Sediment Samples Obtained from Different Sampling Points

Physico-chemical parameters such as pH, EC, and Salinity of the sediment samples are exhibited in Table 4.1. The results showed that sediment pH values ranged from 4.363±0.008 (at ETW-Wamali Dam, Tamale) to 8.316±0.012 (at WTASS). The data further illustrate that EC values was lowest at NTL

(0.024±0.001 dS/m) and highest at WTASS (0.886±0.001 dS/m) compared to WHO standard of 1000 µS/cm. The results also show that the minimum value (10.897±0.641 ppm) for Salinity was measured at NTL while the greatest value (437.179±1.923 ppm) recorded at WTASS.

Table 4.1 Physico-chemical parameters of the sediment samples obtained from different sampling points. The values are presented as Mean±SD for the triplicates tests and the codes represent the sampling points (see Table 3.3).

			Physicochemical Analysis		
				(1:2)	(dS/m)
Zone	No.	CODE	Ph	EC (dS/m)	Salinity
	1	ETW	4.4±1.10	0.30±0.01	0.22±0.01
	2	ETWV	5.9±0.31	0.03±0.01	0.03±0.01
	3	ETK	6.4±0.52	0.05±0.01	0.04±0.01
	4	ETS	6.9±0.68	0.07±0.01	0.05±0.01

	5	ETT	6.3±0.54	0.03±0.01	0.02±0.01
	6	WTGO	5.2±0.64	0.39±0.034	0.25±0.01
	7	WTASS	8.4±1.42	0.89±0.01	0.68±0.03
	8	WTD	5.8±0.41	0.08±0.01	0.06±0.01
	9	WTSH	6.3±0.22	0.03±0.01	0.02±0.01
	10	WTDUS	6.3±0.82	0.04±0.01	0.03±0.01
Central Tamale	11	CTG	6.3±0.68	0.05±0.01	0.04±0.01
	12	NTL	6.9±0.49	0.02±0.01	0.02±0.01
	13	NTN	6.1±0.31	0.06±0.01	0.04±0.01

4.0.3 Comparison of physico-chemical parameters of the water and sediment samples at the various sampling points.

The physico-chemical parameters of the water and sediment samples at the various sampling points is shown in Figure 4.2. Generally, the results showed that the physico-chemical parameters of the water samples are relatively higher than that of the sediments at the different sampling points. Figure 4.2 showed that the values for pH (6.67-7.20), EC (0.43-1.88) and Salinity (0.2-2.35) of water samples are relatively higher compared to pH values (4.36-6.95), EC (0.024-0.391) and Salinity (0.018-0.25) of the sediment samples. A One-way ANOVA (Appendix 1) was used to compare the parameters of the water and sediment samples. The ANOVA test (Table A1 and A2) yielded a P value (0.0001) less than 0.05, signifying a statistically significant variation between the estimated physico-chemical parameters of the water and sediment samples at the various sampling points.

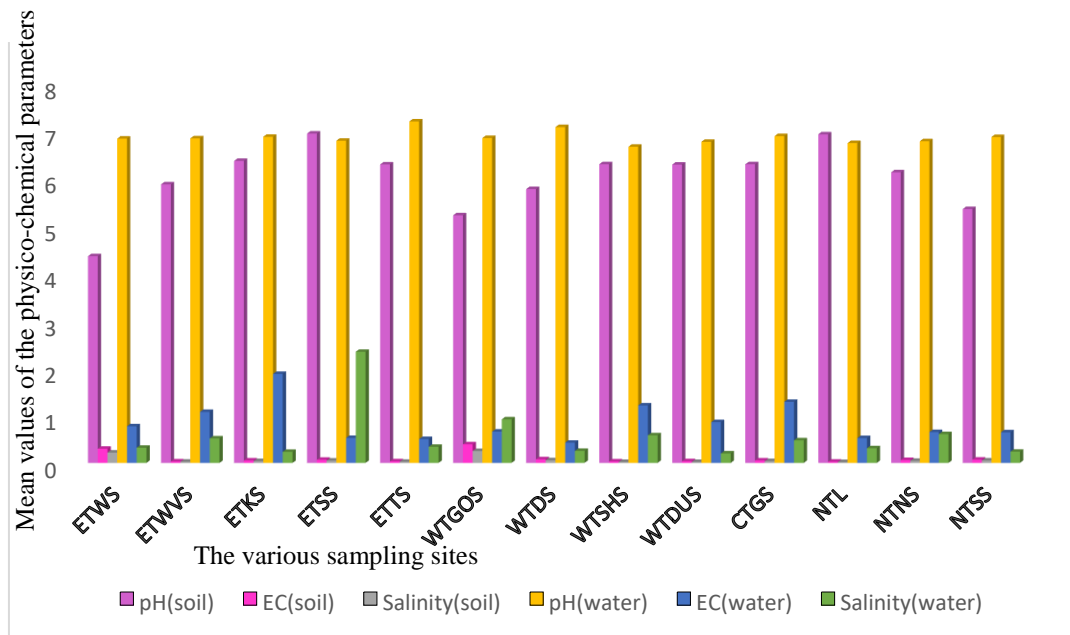


Figure 4.2 Comparison of physico-chemical parameters (pH, EC, and Salinity) of the water and sediment samples at the various sampling points.

4.1 Heavy Metal Concentrations of Selected Water and Sediment Samples at the Various Sampling Points.

4.1.1 Heavy Metal Concentrations in Sediment Samples at the Various Sampling Points.

Table 4.2 showed that heavy metals such as Cd, Pb, Fe, As and Hg were found in the sediment samples at the different sampling sites. The ANOVA test (Table A3 and A4) showed a statistically significant variation among the metal’s concentrations at 0.05. From the results (Figure A.8) it can be deduced that the concentrations of these heavy metal in the sediment samples increases in the order Cd<Hg<As<Pb<Fe. The averages also increase in the same order Cd = 0.626 mg/kg, Hg = 0.635 mg/kg, As = 1.182 mg/kg, Pb = 10.879 mg/kg and Fe = 1812.257 mg/kg. The range for metal concentration for Cd was 0.33±0.01 mg/kg at NTL and NTN to 0.94±0.01 mg/kg at ETT. The lowest concentration for Pb (0.43±0.08 mg/kg) was at ETWV while the highest (39.30±0.23 mg/kg) was at WTD. The results also showed the concentrations of Fe in the samples to be in the range 781.9±3.5 mg/kg -3129.63±29.36 mg/kg where the least concentrations were at ETT and the largest at ETWV. Also, the range of As concentration was 0.66±0.12 mg/kg at ETW

to 1.33 ± 0.01 mg/kg at NTSS and WTASS. For Hg concentrations, the lowest was 0.38 ± 0.15 mg/kg at ETS and the highest was 1.2 ± 0.01 mg/kg at NTN. In comparison with WHO standards, Cd, Pb, Fe, As, and Hg concentrations were higher than WHO limits.

Table 4.2 Heavy Metal Concentrations of the Sediment Samples at the Various Sampling Points. The values are presented as Mean \pm SD for the triplicate tests and the codes represent the sampling points (see Table 3.3).

		Cd	Pb	Fe	As	Hg
	ETW	0.49 ± 0.11	1.47 ± 0.01	1220.97 ± 26.45	0.66 ± 0.01	0.51 ± 0.11
	ETWV	0.52 ± 0.01	0.43 ± 0.01	3129.63 ± 28.61	1.03 ± 0.01	0.84 ± 0.12
	ETK	0.54 ± 0.02	9.33 ± 2.76	2654.97 ± 27.23	1.26 ± 0.01	0.81 ± 0.01
	ETS	0.64 ± 0.02	2.43 ± 0.01	2720.97 ± 19.91	1.03 ± 0.01	0.38 ± 0.01
	ETT	0.94 ± 0.02	6.27 ± 2.03	781.9 ± 10.5	1.09 ± 0.01	0.41 ± 0.01
	WTGO	0.45 ± 0.01	11.10 ± 3.14	1578.63 ± 28.91	1.19 ± 0.01	0.44 ± 0.01
	WTASS	0.93 ± 0.02	9.17 ± 2.13	2238.3 ± 29.79	1.39 ± 0.01	0.68 ± 0.12
	WTD	0.53 ± 0.01	39.30 ± 6.23	1316.63 ± 16.15	1.33 ± 0.01	0.64 ± 0.13
	WTSH	0.81 ± 0.02	29.67 ± 6.67	1595.31 ± 21.36	1.06 ± 0.11	0.54 ± 0.12
	WTDUS	0.83 ± 0.02	11.07 ± 5.09	1390.97 ± 23.11	1.33 ± 0.01	0.41 ± 0.10
Central Tamale	CTG	0.81 ± 0.02	11.43 ± 6.09	2307.63 ± 34.87	1.23 ± 0.01	0.61 ± 0.11
	NTL	0.33 ± 0.02	1.13 ± 0.08	1245.63 ± 15.64	1.23 ± 0.01	0.71 ± 0.19
	NTN	0.34 ± 0.02	11.27 ± 4.14	2320.97 ± 17.74	1.32 ± 0.01	1.21 ± 0.01
	NTSS	0.58 ± 0.03	8.23 ± 2.15	869.1 ± 9.27	1.39 ± 0.01	0.64 ± 0.11
WHO Limit (2011)		0.003	0.01	0.3	0.01	0.001

4.1.2 Heavy Metal Concentrations in the Water Samples at the Various Sampling Points.

The results in Table 4.3 presents the type and concentrations of heavy metals (Cd, Pb, Fe, As and Hg) found in the water samples at the sampling sites. Comparison among the metals concentrations at 95% significant level using ANOVA test (Table A5 and A6) indicated a statistically significant variations within and between the values. The results as shown in Figure A.9 illustrates that the concentrations of the metals increase in the order $Hg < As < Cd < Pb < Fe$ in the water samples.

The averages of the metals concentrations in the water samples are Cd = 0.00062 mg/L, Hg = 2.9 ± 10^{-05} mg/L, As = 4.8 ± 10^{-05} mg/L, Pb = 0.0170 mg/L and Fe = 1.313 mg/L. Table 4.3 displayed the concentrations of Cd in the water samples to fall in the range $0.0002 \pm 0.00 - 0.00097 \pm 0.00$ mg/L where the least concentrations was at NTL and the biggest at ETT. The lowest concentration for Pb (0.00133 ± 0.00 mg/L) was at CTPO, CTG, CTSW, CTAA and CTBD while the highest (0.147 ± 0.14 mg/L) was at ETW. The range for metal concentration for Fe was 0.00133 ± 0.00 mg/L at CTG and TFB1 to 10.6934 ± 1.85 mg/L at ETS. Similarly, the range of As concentration was 0.00001 ± 0.00 mg/L at ETK, WTAS, WTD, and WTMB to 0.00019 ± 0.00 mg/L at ETWV. The metal concentration for Hg was measured lowest (0.00001 ± 0.00 mg/L) at ETC, WTSH, WTAS, etc (Table 4.3) and the highest was 0.00012 ± 0.00 mg/L at ETS. In comparison with WHO reference values, only the Fe concentrations were higher than WHO limits.

Table 4.3 Heavy Metal Concentrations of the Water Samples at the Various Sampling Points.

The values are presented as Mean±SD for the triplicate tests and the codes represent the sampling points (see Table 3.3).

Zone	No.	Cd (mg/L)	Pb (mg/L)	Fe (mg/L)	As (mg/L)	Hg (mg/L)
	.					

East Tamale	1	ETGB	0.00078 ±0.00	0.10233 ±0.01	0.61767 ±0.01	0.00012 ±0.00	0.00001 ±0.00
	2	ETWV	0.00071 ±0.00	0.00167 ±0.00	2.49378 ±0.69	0.00019 ±0.00	0.00011 7±0.00
	3	ETT	0.00097 ±0.00	0.02756 ±0.01	6.46711 ±2.72	0.00004 ±0.00	0.00003 ±0.00
	4	ETC	0.00068 ±0.00	0.00222 ±0.00	1.48178 ±0.89	1.6E- 05±0.00	0.00001 ±0.00
	5	ETW	0.00022 ±0.00	0.14689 ±0.10	0.00578 ±0.00	0.00003 ±0.00	0.00002 ±0.00
	6	ETK	0.00084 ±0.00	0.00211 ±0.00	0.32711 ±0.18	0.00001 ±0.00	0.00001 ±0.00
	7	ETS	0.00065 ±0.00	0.00267 ±0.00	10.6934 ±2.64	0.00018 ±0.00	0.00012 ±0.00
	8	WTSH	0.00096 ±0.00	0.00233 ±0.00	0.99200 ±0.12	0.00012 ±0.00	0.00001 ±0.00
	9	WTAS	0.00062 ±0.00	0.003 ±0.00	0.00267 ±0.00	0.00001 ±0.00	0.00001 ±0.00
	10	WTD	0.00036 ±0.00	0.01289 ±0.01	4.318 ±0.68	0.00001 ±0.00	0.00001 ±0.00

11	WTMB	0.00061 ±0.00	0.003 ±0.00	0.00233 ±0.00	0.00001 ±0.00	0.00001 ±0.00
12	WTDU	0.00056 ±0.00	0.00333 ±0.00	0.00678 ±0.00	0.00006 ±0.00	0.00001 ±0.00
13	WTGO	0.00082 ±0.00	0.00333 ±0.00	0.17678 ±0.01	0.00002 ±0.00	0.00001 ±0.00
14	CTG	0.00045 ±0.00	0.05067 ±0.01	4.43078 ±1.10	0.00016 ±0.00	0.00007 ±0.00
15	CTPO	0.0009± 0.00	0.00133 ±0.00	0.00233 ±0.00	0.00001 ±0.00	0.00001 ±0.00
16	CTG	0.00083 ±0.00	0.00133 ±0.00	0.00133 ±0.00	0.00001 ±0.00	0.00001 ±0.00
17	CTSW	0.00052 ±0.00	0.00133 ±0.00	0.00267 ±0.00	0.00001 ±0.00	0.00001 ±0.00
18	CTAA	0.00032 ±0.00	0.00133 ±0.00	0.032 ±0.00	0.00001 ±0.00	0.00001 ±0.00
19	CTBD	0.00063 ±0.00	0.00133 ±0.00	0.01467 ±0.00	0.00001 ±0.00	0.00002 ±0.00

	20	NTL	0.00020 ±0.00	0.00133 ±0.00	0.24511 ±0.01	0.00003 ±0.00	0.00001 ±0.00
	21	NTK	0.00066 ±0.00	0.00133 ±0.00	0.0075± 0.00	0.00002 ±0.00	0.00001 ±0.00
	22	NTS	0.00024 ±0.00	0.00411 ±0.00	1.71356 ±0.02	0.00003 ±0.00	0.00001 ±0.00
	23	NTFB	0.00076 ±0.00	0.00333 ±0.00	0.00133 ±0.00	0.00001 ±0.00	0.00001 ±0.00
	24 25	NTN	0.00052 ±0.00	0.00233 ±0.00	1.399 ±0.11	0.00001 ±0.00	0.00001 ±0.00
	26	NTSS	0.00069 ±0.00	0.00433 ±0.00	0.013 ±0.01	0.00001 ±0.00	0.00001 ±0.00
WHO Limit (2011)			0.003	0.01	0.3	0.01	0.001

4.1.3 Comparison of heavy metal concentrations measured in the water and sediment samples at the various sampling points.

The variations of the heavy metal concentrations measured in water and sediment samples at the various sampling points is presented in Figure 4.

In general, the results showed that the heavy metal concentrations of the sediment samples were significantly higher than that of the water samples at the various sampling sites. Figure 4.5 showed that the range of metal concentrations for Cd (0.333-0.943ppm) (Figure A), Pb (0.433-39.3 ppm) (Figure D), Fe (781.93129.63 ppm) (Figure C), As (0.66-1.39 ppm) (Figure B) and Hg (0.38-1.21

ppm) (Figure E) of sediment samples are relatively higher compared to range of concentrations of Cd (0.0002-0.00097 ppm), Pb (0.00133-0.10233 ppm), Fe (0.00267-10.6934 ppm), As (1.3 ± 10^{-05} -0.00019 ppm) and Hg (1.1 ± 10^{-05} -0.00012 ppm) of the water samples and WHO standards. A One-way ANOVA (Appendix 1) was used to compare the metal concentrations in the water and sediment samples at the various sampling points. The ANOVA test (Table A7 and A8) produces a P value (0.0001) not more than 0.05 at 95% significance level, demonstrating a statistically significant variation between and within the metal concentrations in the water and sediment samples at the various sampling points.



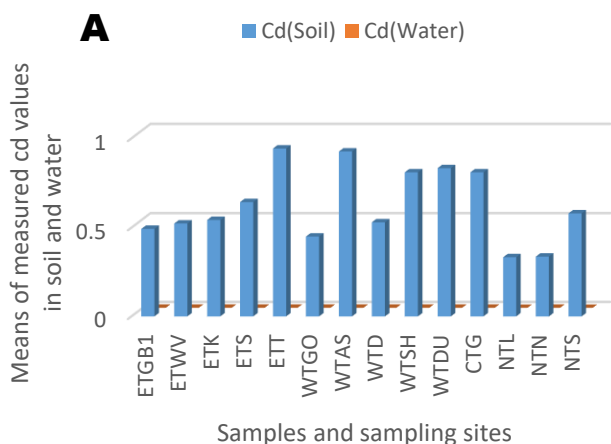


Figure A: Comparison of cd concentrations measured in the water and soil at the various sampling points.

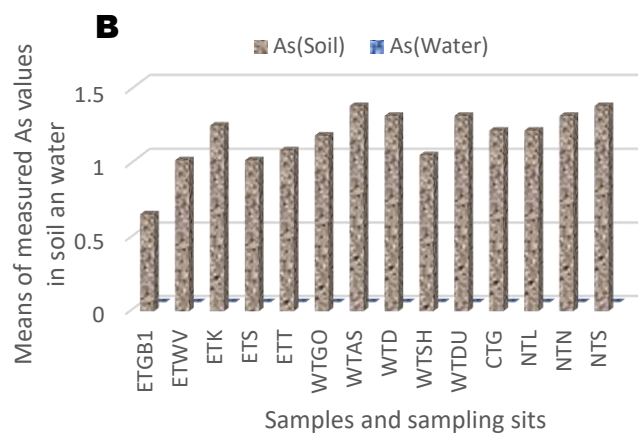


Figure B: Comparison of cd concentrations measured in the water and soil at the various sampling points.

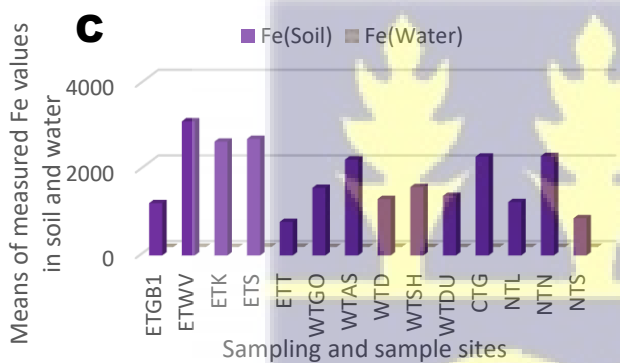


Figure C: Comparison of cd concentrations measured in the water and soil at the various sampling points.

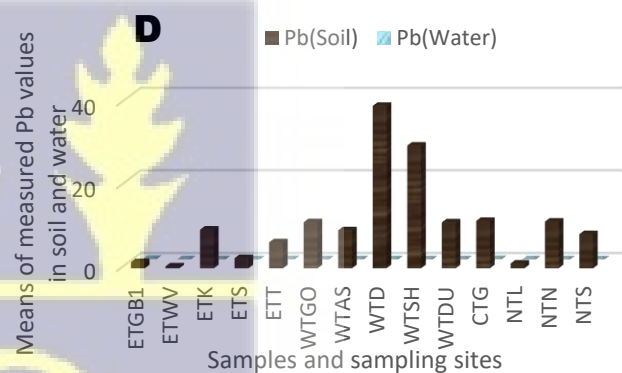


Figure D: Comparison of cd concentrations measured in the water and soil at the various sampling points.

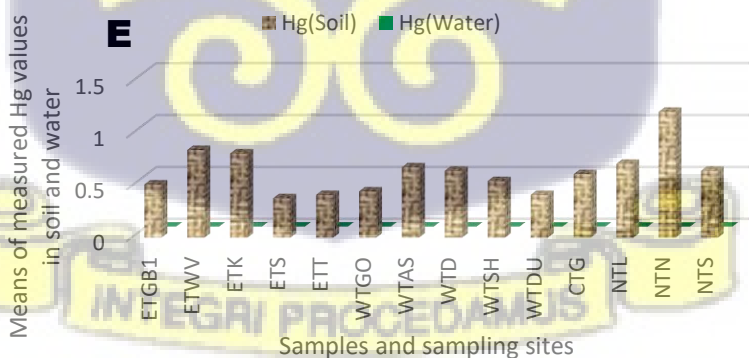


Figure E: Comparison of cd concentrations measured in the water and soil at the various sampling points.

Figure 4.5: Comparison of heavy metal concentrations measured in the water and sediment at the various sampling points.

4.2 Human Health Risk Assessment of Heavy Metals in Water and Sediment Samples

The human health risk was determined using two approaches. These was achieved by assessing the risk of non-carcinogenic and carcinogenic effects of the metals concentrations in water and soil using metal parameters published in literature.

4.2.1 Human Health Risk Assessment of the Heavy Metals in Sediment Samples

4.2.1.1 Average Daily Dose (ADD) estimates ($\mu\text{g}/\text{Kg}/\text{day}$) for heavy metal concentrations in the sediments

Exposure duration or ADD estimates ($\mu\text{g}/\text{Kg}/\text{day}$) for sediment samples are displayed in Table 4.4. Considering the results in Table 4.4, it is clear that the ADD values increases in the order $\text{Hg} < \text{As} < \text{Cd} < \text{Pb} < \text{Fe}$ with Averages Cd (1.67×10^{-06}); Pb (0.0001); Fe (0.0025); As (1.612×10^{-06}) and Hg (8.4×10^{-07}) (Table 4.10). The lowest ADD estimates for Cd was recorded at sampling sites NTL ($4.7619\text{E}-05$); NTN (4.81×10^{-05}); WTGO ($6.42857\text{E}-05$) and ETW ($7.04762\text{E}-05$) whilst lager ADD estimates recorded at ETT (0.000134762); WTASS (0.000132381); WTDU (0.000119048) and CTG (0.000115714). Also, the least ADD value for Pb was recorded at sampling sites ETWV (6.2×10^{-05}); NTL (0.00016); ETW (0.00021); ETS (0.00035) whereas the highest values occurred at WTD (0.00561); WTSH (0.00424); NTN (0.00161) and CTG (0.00163). The results further shows that the lowermost ADD values for Fe was recorded at sampling sites ETT (0.1117); NTSS (0.12416); ETW (0.17442); NTL (0.17795) whereas the uppermost values occurred at ETWV (0.44709); ETS (0.38871); ETK (0.37928); and NTN (0.33157). Additionally, Table 4.4 demonstrates that the smallest ADD estimates for As was noted at sampling sites ETW (9.4×10^{-05}); ETWV (0.00015); ETS (0.00015); ETT (0.00016) however the maximum values

occurred at WTAS (0.0002); NTS (0.0002); NTN (0.00019); and WTD (0.00019). The lowest ADD estimates for Hg was observed at sites ETS (5.4×10^{-05}); ETT (5.9×10^{-05}); WTGO (6.4×10^{-05}); WTDU (5.9×10^{-05}) whereas the highest values occurred at ETWV (0.00012); ETK (0.00012); NTN (0.00017); and NTL (0.0001).

Table 4.4 Exposure duration (ADD) estimates ($\mu\text{g}/\text{Kg}/\text{day}$) for heavy metal concentrations of the sediment samples at the various sampling points. The codes represent the sampling points (see Table 3.3).

		Cd	Pb	Fe	As	Hg
1	ETW	7.047×10^{-05}	0.00021	0.17442	9.4×10^{-05}	7.3×10^{-05}
2	ETWV	7.476×10^{-05}	6.2×10^{-05}	0.44709	0.00015	0.00012
3	ETK	7.762×10^{-05}	0.00133	0.37928	0.00018	0.00012
4	ETS	9.190×10^{-05}	0.00035	0.38871	0.00015	5.4×10^{-05}
5	ETT	1.347×10^{-05}	0.0009	0.1117	0.00016	5.9×10^{-05}
6	WTGO	6.428×10^{-05}	0.00159	0.22552	0.00017	6.4×10^{-05}
7	WTASS	1.323×10^{-05}	0.00131	0.31976	0.0002	9.7×10^{-05}
8	WTD	7.571×10^{-05}	0.00561	0.18809	0.00019	9.2×10^{-05}
9	WTSH	1.157×10^{-05}	0.00424	0.2279	0.00015	7.8×10^{-05}
10	WTDUS	1.191×10^{-05}	0.00158	0.19871	0.00019	5.9×10^{-05}
11	CTG	1.157×10^{-05}	0.00163	0.32966	0.00018	8.8×10^{-05}
12	NTL	4.761×10^{-05}	0.00016	0.17795	0.00018	0.0001
13	NTN	4.809×10^{-05}	0.00161	0.33157	0.00019	0.00017
14	NTSS	8.285×10^{-05}	0.00118	0.12416	0.0002	9.2×10^{-05}

4.2.1.2 Hazard Quotient (HQ) and Hazard Index (HI) Estimates for Heavy Metal Concentrations in the Sediment Samples

Hazard Quotient (HQ) and Hazard Index (HI) for sediment samples are exhibited in Table 4.5. The results showed that HQ values for the metals in the sediment samples increases in the order Cd<Hg<Fe<Pb<As with HQ averages (Table 4.10) ranging from Cd (0.00018); Hg (0.0003); Fe (0.00037); Pb (0.0004) to As (0.00056) and HI values increases from ETW (0.00101) to WTD (0.00296). With regards to the individual HQs for the metals, data shows that the lowest HQ estimates for Cd was recorded at sampling sites NTL (9.52×10^{-5}) whilst lager HQ estimates recorded at ETT (0.000269524). The lowermost HQ estimates for Pb was observed at sampling sites ETWV (1.8×10^{-5}) though the uppermost value occurred at WTD (0.001604082). Also, The lowest HQ estimates for Fe were recorded at sampling sites ETT (0.00016) while the highest values occurred at ETWV (0.00064). For As, the smallest HQ estimates for As was measured at sampling sites ETW (0.00031) meanwhile the highest values occurred at WTAS (0.00066) and NTSS (0.00066).

The lowest HQ estimates for Hg were recorded at sampling sites ETS (0.00018) whereas the highest values occurred at NTN (0.00058).

Table 4.5 Hazard Quotient (HQ) and Hazard Index (HI) estimates for heavy metal concentrations in the sediment samples at the various sampling points. The codes represent the sampling points (see Table 3.3).

		Cd	Pb	Fe	As	Hg	Σ HQ=HI
1	ETW	0.00014	5.986E-05	0.00025	0.00031	0.00024	0.00101
2	ETWV	0.00015	1.768E-05	0.00064	0.00049	0.00040	0.00170
3	ETK	0.00016	0.00030	0.00054	0.0006	0.00039	0.00207

4	ETS	0.00018381	9.93197E-05	0.00056	0.00049	0.00018	0.00151
5	ETT	0.00027	0.00026	0.00016	0.00052	0.0002	0.0014
6	WTGO	0.00013	0.00045	0.00032	0.00057	0.00021	0.00168
7	WTASS	0.00027	0.00037	0.00046	0.00066	0.00032	0.00208
8	WTD	0.00015	0.00160	0.00027	0.00063	0.00031	0.00296
9	WTSH	0.00023	0.00121	0.00033	0.0005	0.00026	0.00253
10	WTDUS	0.00024	0.00045	0.00028	0.00063	0.00020	0.00180
11	CTG	0.00023	0.00047	0.00047	0.00058	0.00029	0.00205
12	NTL	9.524E-05	4.626E-05	0.00025	0.00058	0.00034	0.00132
13	NTN	9.619E-05	0.00046	0.00047	0.00063	0.00058	0.00224
14	NTSS	0.00017	0.00034	0.00018	0.00066	0.00031	0.00165

4.2.1.3 Chronic Daily Intake (CDI) Estimates for Heavy Metal Concentrations in the Sediment Sampling

Chronic Daily Intake (CDI) estimates for the heavy metal concentrations in sediment samples are exhibited in Table 4.6. From Table 4.6 it is clear that CDI values for the heavy metals increases in the order Cd < Hg < Fe < Pb < As with averages ranging from Cd (2.55×10^{-10}); Hg (4.32×10^{-10}); Fe (5.28×10^{-10}); Pb (6.34×10^{-10}); and As (8.04×10^{-10}) (Table 4.10). The lowest CDI estimates for Cd was recorded at sampling sites NTL (1.4×10^{-10}) and NTN (1.4×10^{-10}) whilst larger HQ estimates recorded at ETT (3.9×10^{-10}). Additionally, the lowermost CDI estimates for Pb was recorded at sampling sites WTD (2.5×10^{-11}) while the maximum values occurred at WTD (2.3×10^{-09}). Also, the smallest CDI estimates for Fe was observed at sampling sites ETT (2.3×10^{-10}) while the highest

values occurred at ETWV (9.1×10^{-10}). The lowest CDI estimates for As was recorded at sampling sites ETW (4.5×10^{-10}) whereas the highest values occurred at WTASS (9.5×10^{-10}) and NTSS (9.5×10^{-10}). The bottommost CDI estimates for Hg was recorded at sampling sites ETS (2.6×10^{-10}) whereas the highest values observed at NTN (8.3×10^{-10}).

Table 4.6 Chronic Daily Intake (CDI) estimates for heavy metal concentrations in the sediment samples at the various sampling points. The codes represent the sampling points (see Table 3.3).

	Sample Code	Cd	Pb	Fe	As	Hg
1	ETW	2.0136×10^{-10}	8.551×10^{-11}	3.6×10^{-10}	4.5×10^{-10}	3.5×10^{-10}
2	ETWV	2.1360×10^{-10}	2.526×10^{-11}	9.1×10^{-10}	7×10^{-10}	5.8×10^{-10}
3	ETK	2.2176×10^{-10}	5.442×10^{-10}	7.7×10^{-10}	8.6×10^{-10}	5.5×10^{-10}
4	ETS	2.625×10^{-10}	1.418×10^{-10}	7.9×10^{-10}	7×10^{-10}	2.6×10^{-10}
5	ETT	3.850×10^{-10}	3.654×10^{-10}	2.3×10^{-10}	7.4×10^{-10}	2.8×10^{-10}
6	WTGO	1.836×10^{-10}	6.472×10^{-10}	4.6×10^{-10}	8.1×10^{-10}	3×10^{-10}
7	WTAS	3.7823×10^{-10}	5.345×10^{-10}	6.5×10^{-10}	9.5×10^{-10}	4.6×10^{-10}
8	WTD	2.163×10^{-10}	2.291×10^{-9}	3.8×10^{-10}	9×10^{-10}	4.4×10^{-10}
9	WTSH	3.3061×10^{-10}	1.729×10^{-9}	4.7×10^{-10}	7.2×10^{-10}	3.7×10^{-10}
10	WTDU	3.401×10^{-10}	6.452×10^{-10}	4.1×10^{-10}	9×10^{-10}	2.8×10^{-10}
11	CTG	3.3061×10^{-10}	6.666×10^{-10}	6.7×10^{-10}	8.3×10^{-10}	4.2×10^{-10}
12	NTL	1.360×10^{-10}	6.608×10^{-11}	3.6×10^{-10}	8.3×10^{-10}	4.9×10^{-10}
13	NTN	1.374×10^{-10}	6.569×10^{-10}	6.8×10^{-10}	9×10^{-10}	8.3×10^{-10}
14	NTS	2.367×10^{-10}	4.800×10^{-10}	2.5×10^{-10}	9.5×10^{-10}	4.4×10^{-10}

4.2.2 Human Health Risk Assessment of the Heavy Metals in Water Samples

4.2.2.1 Average Daily Dose estimates (mg/Kg/day) for heavy metal concentrations in water samples

Exposure duration or ADD estimates (mg/Kg/day) for water samples are demonstrated in Table 4.7. Considering the results in Table 4.7, ADD values increases in the order Hg<As<Cd <Pb<Fe with averages Cd (0.01947); Pb (0.48707); Fe (44.5638); As (0.0016) and Hg (0.00095) (Table 4.10). The lowest ADD estimates for Cd was recorded at sampling sites CTPO (0.0419); CTQE (0.0419); CTSW (0.0419); CTAA (0.0419); CTBD (0.0419); NTL (0.0419) and

NTK (0.0419) whilst larger ADD estimates recorded at ETW (4.61651); CTG (1.59238); ETT (0.86603); and WTD (0.40508). Furthermore, the bottommost ADD estimates for Cd was recorded at sampling sites NTL (0.006425397); ETW (0.006914286) and NTS (0.007542857) but the highest values occurred at ETT (0.030380952); WTSH (0.030031746); CTPO (0.028285714) and ETK (0.026295238). The lowest ADD estimates for Fe was recorded at sampling sites CTQE (0.0419); NTFB (0.0419); WTMB (0.07333); and CTPO (0.07333) whereas the highest values occurred at ETWV (0.00608); ETS (0.00552); CTG (0.00492) and WTSH (0.00384). The lowest ADD estimates for As was recorded at sampling sites WTAS (0.00042); NTN (0.00045); NTK (0.00047); and ETC (0.00049) whereas the highest values occurred at ETT (0.030380952); WTSH (0.030031746); CTPO (0.028285714) and ETK (0.026295238). The lowest ADD estimates for Hg was recorded at sampling sites CTPO (0.00031); NTSS (0.00031); NTL (0.00035); and WTGO (0.00038) whereas the highest values occurred at ETS (0.00384); ETWV (0.00367); WTSH (0.00262) and ETGB (0.00262).

Table 4.7 Exposure duration (ADD) estimates (mg/Kg/day) for heavy metal concentrations of the water samples at the various sampling points. The codes represent the sampling points (see Table 3.3).

	Cd	Pb	Fe	As	Hg
ETGB	0.02445	3.21619	19.4124	0.00367	0.00262
ETWV	0.02242	0.05238	78.37590	0.00608	0.00367
ETT	0.03038	0.86603	203.252	0.00119	0.00087
ETC	0.02123	0.06984	46.5702	0.00049	0.00042
ETW	0.00692	4.61651	0.18159	0.00094	0.00063
ETK	0.02630	0.06635	10.2806	0.00052	0.00042
ETS	0.02053	0.08381	336.08	0.00552	0.00384

WTSH	0.03003	0.07333	31.1771	0.00384	0.00262
WTAS	0.01938	0.09429	0.08381	0.00042	0.00042
WTD	0.01121	0.40508	135.709	0.00049	0.00042
WTMB	0.01927	0.09429	0.07333	0.00052	0.00042
WTDU	0.01750	0.10476	0.21302	0.00203	0.00042
WTGO	0.02577	0.10476	5.55587	0.00063	0.00038
CTG	0.01425	1.59238	139.253	0.00492	0.0022
CTPO	0.02829	0.04190	0.07333	0.00199	0.00031
CTQE	0.02598	0.0419	0.0419	0.00115	0.00042
CTSW	0.01624	0.0419	0.08381	0.00042	0.00042
CTAA	0.01016	0.0419	1.00571	0.00052	0.00042
CTBD	0.01970	0.0419	0.46095	0.00042	0.00052
NTL	0.00643	0.0419	7.70349	0.00119	0.00035
NTK	0.02064	0.0419	0.23571	0.00047	0.00042
NTS	0.00754	0.12921	53.8546	0.00119	0.00038
NTFB	0.02399	0.10476	0.0419	0.00052	0.00042
NTN	0.01631	0.07333	43.9686	0.00045	0.00045
NTSS	0.02179	0.13619	0.40857	0.00042	0.00031

4.2.2.2 Hazard Quotient (HQ) and Hazard Index (HI) Estimates for Heavy Metal Concentrations in the Water Samples

The HQ and HI values for heavy metal concentrations in water samples are exhibited in Table 4.8.

The results showed that HQ values increases in the order Pb<Cd<As<Hg<Fe with averages (Table 4.10) Pb(0.1391632); Cd (0.03893588), As (0.00533); Hg (0.00317) and Fe (6.4×10^{-5}) and

Hazard index (HI) values increases in from NTL (0.029956281) to ETW (1.338069194). The

lowermost HQ estimates for Cd was recorded at sampling sites NTL (0.012851) whilst lager HQ estimates recorded at ETT (0.000134762); WTASS (0.000132381); WTDU (0.000119048) and

CTG (0.000115714). The lowest HQ estimates for Pb was recorded at sampling sites CTPO (0.01197); CTQE (0.01197); CTSW (0.01197); CTAA (0.01197); CTBD (0.01197) and NTK (0.01197) whereas the highest values occurred at ETW (1.319). Also, the lowest HQ estimates for Fe were recorded at sampling sites CTQE (6×10^{-8}) and NTFB (6×10^{-8}) whereas the highest values occurred at WTD (0.00019). The lowest HQ estimates for As was recorded at sampling sites CTSW (0.0014) and CTBD (0.0014) whereas the highest values occurred at ETWV (0.02025). The lowest HQ estimates for Hg were recorded at sampling sites NTN (0.00151) and NTSS (0.00105) whereas the highest values occurred at ETS (0.0128).

Table 4.8 Hazard Quotient (HQ) and Hazard Index (HI) estimates for heavy metal concentrations in the water samples at the various sampling points. The codes represent the sampling points (see Table 3.3).

	Cd	Pb	Fe	As	Hg	$\sum HQ=HI$
ETGB	0.04890	0.91891	2.773E-05	0.01222	0.00873	0.98880
ETWV	0.04483	0.01497	0.00011	0.02025	0.01222	0.09239
ETT	0.06076	0.24744	0.00029	0.00395	0.00291	0.31536
ETC	0.04246	0.01995	6.653E-05	0.00163	0.00140	0.06551
ETW	0.01383	1.31900	2.594E-07	0.00314	0.00210	1.33807
ETK	0.05259	0.01896	1.4687E-05	0.00175	0.00140	0.07471
ETS	0.04107	0.02395	0.00048	0.01840	0.01280	0.09669
WTSH	0.06006	0.02095	4.4539E-05	0.01280	0.00873	0.10260
WTAS	0.03876	0.02694	1.197E-07	0.00140	0.00140	0.06845
WTD	0.02243	0.11574	0.00020	0.00163	0.00140	0.14138
WTMB	0.03855	0.02694	1.048E-07	0.00175	0.00140	0.06863

WTDU	0.03499	0.02993	3.043E-07	0.00675	0.00140	0.07307
WTGO	0.05154	0.02993	7.9374E-06	0.0021	0.00128	0.08486
CTG	0.02850	0.45497	0.00020	0.01641	0.00733	0.50741
CTPO	0.05657	0.01197	1.048E-07	0.00664	0.00105	0.07623
CTQE	0.05196	0.01197	5.986E-08	0.00384	0.00140	0.06917
CTSW	0.03248	0.01197	1.197E-07	0.00140	0.00140	0.04724
CTAA	0.02032	0.01197	1.437E-06	0.00175	0.00140	0.03544
CTBD	0.03939	0.01197	6.58E-07	0.00140	0.00175	0.05451
NTL	0.01285	0.01197	1.1000E-05	0.00396	0.00116	0.02996
NTK	0.04128	0.01197	3.367E-07	0.00157	0.00140	0.05622
NTS	0.01509	0.03692	7.693E-05	0.00396	0.00128	0.05732
NTFB	0.04798	0.02993	5.986E-08	0.00175	0.00140	0.08106
NTN	0.03262	0.02095	6.281E-05	0.00151	0.00151	0.05666
NTSS	0.04359	0.03891	5.837E-07	0.00140	0.00105	0.08494

4.2.2.3 Chronic Daily Intake (CDI) Estimates for Heavy Metal Concentrations in the Water

Chronic Daily Intake (CDI) estimates for the heavy metal concentrations in water samples are exhibited in Table 4.9. According to the results the CDI values for the metals increases in the order $Hg < As < Cd < Pb < Fe$ with averages Hg (0.00003); As (0.00005); Cd (0.000612); Pb (0.01531) and Fe (1.400578) (Table 4.10). The table shows that the lowest CDI estimates for Cd was noted at sampling sites NTL (0.0002) whilst larger HQ estimates recorded at ETT (0.000955). The lowest CDI estimates for Pb was recorded at sampling sites CTPO (0.00132); CTQE (0.00132); CTSW (0.00132); CTAA (0.00132); CTBD (0.00132) and NTL (0.00132) whereas the highest values

occurred at ETW (0.14509). The lowest CDI estimates for Fe was recorded at sampling sites CTQE (0.00132) and NTFB (0.00132) whereas the highest values occurred at ETS (10.5625). Also, the smallest CDI values for As was measured at sampling sites ETC (1.537×10^{-05}) and WTD (1.537×10^{-05}) whereas the greatest value occurred at ETWV (0.000191). The lowest CDI estimates for Hg was recorded at sampling sites CTPO (9.9×10^{-06}) and NTN 4 (9.9×10^{-06}) whereas the highest values occurred ETS (0.00012).

Table 4.9 Chronic Daily Intake (CDI) estimates for heavy metal concentrations in the water samples at the various sampling points. The codes represent the sampling points (see Table 3.3).

Sample	Cd	Pb	Fe	As	Hg
ETGB	0.00077	0.10108	0.61010	0.00011	8.231E-05
ETWV	0.00070	0.00165	2.46324	0.00019	0.00012
ETT	0.00096	0.02722	6.38792	3.732E-05	2.744E-05
ETC	0.00067	0.00220	1.46363	1.537E-05	1.317E-05
ETW	0.00021	0.14509	0.00571	2.963E-05	1.976E-05
ETK	0.00083	0.00209	0.32311	1.646E-05	1.317E-05
ETS	0.00065	0.00263	10.56250	0.00017	0.00012
WTSH	0.00094	0.00230	0.97985	0.00012	8.231E-05
WTAS	0.00060	0.00296	0.00263	1.317E-05	1.317E-05
WTD	0.00035	0.01273	4.26513	1.537E-05	1.317E-05
WTMB	0.00061	0.00296	0.002305	1.646E-05	1.317E-05
WTDU	0.00055	0.00329	0.00670	6.366E-05	1.317E-05
WTGO	0.00081	0.00329	0.17461	1.976E-05	1.2073E-05

CTG	0.00045	0.05005	4.37653	0.00015	6.9143E-05
CTPO	0.00089	0.00132	0.00231	6.256E-05	9.8776E-06
CTQE	0.00082	0.00132	0.001320	3.622E-05	1.317E-05
CTSW	0.00051	0.00132	0.00263	1.317E-05	1.317E-05
CTAA	0.00032	0.00132	0.03161	1.646E-05	1.317E-05
CTBD	0.00062	0.00132	0.01449	1.317E-05	1.6463E-05
NTL	0.00020	0.00132	0.24211	3.732E-05	1.0975E-05
NTK	0.00065	0.00132	0.00741	1.482E-05	1.317E-05
NTS	0.00024	0.00406	1.69257	3.732E-05	1.2073E-05
NTFB	0.00075	0.00329	0.00132	1.646E-05	1.317E-05
NTN	0.00051	0.00230	1.38187	1.427E-05	1.4268E-05
NTSS	0.00069	0.00428	0.01284	1.317E-05	9.8776E-06

Table 4.10 Average estimates of HQ, ADD, and CDI for the heavy metal concentrations in the water and sediment.

Averages	Cd	Pb	Fe	As	Hg
HQ(water)	0.03890	0.13916	6.4×10^{-05}	0.00533	0.00317
HQ(sediment)	0.00018	0.00044	0.00037	0.00056	0.00030
CDI(water)	0.00061	0.01531	1.40058	5.03E-05	3E-05
CDI(sediment)	2.55×10^{-10}	6.34×10^{-10}	5.3×10^{-10}	8.04×10^{-10}	4.3×10^{-10}
ADD(sediment)	0.00010	0.00250	1.6×10^{-6}	8.4×10^{-7}	1.7×10^{-6}
ADD(water)	0.01947	0.48707	44.5638	0.0016	0.00095

CHAPTER FIVE

5.0. DISCUSSION

5.1. DISCUSSION

The exposure to heavy metals remains a major human health concern, since many individuals are exposed to highly polluted water bodies (Kim et al., 2010). Hence, the main purpose of this study was to comparatively analyze heavy metal concentrations in water and sediment sources from Northern Region of Ghana and further estimate the potential health implications.

4.3.1 Physico-chemical Parameters of Selected Water and Sediment from Various Sources

Humans are under great threat due to unsuitable changes in the chemical, physical, and biological properties of air, water and sediment. Due to increased human processes such as mineral mining (Crawford & Botchwey, 2017; Donkor et al., 2005), industrial processes (Donkor et al., 2005), electronic waste management (Atiemo et al., 2012; Caravanos et al., 2011), discharges of domestic sewage (Fianko et al., 2007) and agricultural activities, Ghanaian waters and soils are highly contaminated with diverse harmful contaminants. Therefore, it is essential that drinking water and sediment quality be assessed frequently, since working with contaminated water and sediment is related to multiple human diseases.

This study examined the physico-chemical parameters of selected water and sediment samples to check their quality in relation to WHO standards. According to the results, the physico-chemical parameters of the water samples are significantly higher than that of the sediment at the various sampling points. Additionally, this study revealed that the water physico-chemical parameters such as pH, EC, TDS, and Salinity were all below the WHO limits. Similarly, physico-chemical parameters such as pH, EC, and Salinity of the sediment samples were also within WHO permissible limits. This observation could be attributed to the low agricultural practices and low industrial waste discharge in these areas. However, Turbidity values were found to be far above

the WHO limits of 5 NTU. This is possible because most dams in these areas are also use by animals, apart from humans and the dams are the major source of water for constructional works. Therefore, the frequent use of these dams by trucks and animals can lead to increased turbidity. This finding is in concordance with a similar work by Nkansah & Ephraim who disclosed that borehole water in the Bosomtwi-Atwima-Kwanwoma District had permissible quality (Nkansah & Ephraim, 2009). Besides, the study done in the Volta Region of Ghana (Kodom et al., 2018) published similar results. In Accra, Pesewu et al. (2015) mentioned that most water physico-chemical parameters, except conductivity values, were within the permissible limits.

4.3.2 Heavy Metal Concentrations in Selected Water and Sediment Samples at the Various Sampling Points.

Heavy metal contamination in sediment and water is a potential threat to human health as it renders food unsafe. As nonessential heavy metals are harmful to living organisms, so are the essential ones at extreme concentrations (Bolan et al., 2013). Because heavy metals are not degradable (Adriano et al., 2004), bioaccumulation takes place at most levels of the food chain, resulting in human poisoning as well as various diseases (Vareda et al., 2016; WHO, 2017). Heavy metals toxicity is associated with chronic illnesses including renal diseases, liver disorder, brain disorder, and various others (Mamtani et al., 2011). In this regard, heavy metals are considered crucial contaminants in any environment and assessing their levels become an essential human health measure.

The present study assessed heavy metal concentrations of selected groundwater, dam-water, river water and sediment from the Northern Region of Ghana. The results showed the presence of different heavy metals in the water and sediment samples with varied concentrations across this area.

Heavy metals such as Cd, Pb, Fe, As and Hg were found in the water samples and its concentrations increases in the order $Hg < As < Cd < Pb < Fe$. The study revealed that the ranges for the metal's concentrations are Cd (0.0002 to 0.00097 mg/L), Pb (0.00133 mg/L to 0.147 mg/L), Fe (0.00133 mg/L to 10.6934 mg/L), As (0.00001 mg/L to 0.00019 mg/L) and Hg (0.00001 mg/L to 0.00012 mg/L) in the water samples. In general, this study found that the heavy metal concentrations of the water samples were significantly higher at some sampling points. This observation could be attributed to the rising e-waste burning and metal processing in Tamale and its surrounding areas. These findings are not different from previous studies in Ghana. The findings are in agreement with studies by Abagale et al. (2013) and (Ametepey et al., 2018) in Tamale, Larsen et al. (2020) in the Tolon District and Nkansah & Ephraim, (2009), though Saana et al. (2016) work in the Northern and Upper West regions of Ghana did not detect As in their samples. Additionally, this study revealed that among the dissolved metals Pb and Fe concentrations were above permissible limits. In line with this finding, Abagale et al. (2013) already reported that Pb and Fe concentrations were above standards in Tamale. In agreement, Larsen et al., (2020) previously reported the extreme concentration values for Pb in the Tolon District and Ametepey et al. (2018) mentioned Cd in the Tamale Metropolis.

4.3.3 Human Health Risk Assessment of Heavy Metals in Water and Sediment Samples

The impact of heavy metals pollution affects plants and animals. Prolonged ingestion of substantial quantities of heavy metals contaminated drinking water could harm human health, leading to many types of cancers (Mamtani et al., 2011; Sall et al., 2020). Most researchers have mentioned Cd, Cr, Ni, Pb and As as the most common toxic metals in the human environment (Suvarapu, & Baek, 2017). This study assessed human health risks by calculating the carcinogenic and non-carcinogenic effects of the heavy metals found in the water and sediment. The carcinogenic effects

were determined by calculating exposure durations or the Average Daily Doses (ADDs), Hazard Quotient (HQ) and Hazard Index (HI) for both water and sediment samples.

This study found that ADD estimates ($\mu\text{g}/\text{Kg}/\text{day}$) for sediment samples increases in the order $\text{Hg} < \text{As} < \text{Cd} < \text{Pb} < \text{Fe}$ and ADD estimates ranges were Cd (4.8×10^{-5} to 0.00015); Pb (6.2×10^{-5} to 0.00561); Fe (0.11170 to 0.44709); As (9.4×10^{-5} to 0.0002); and Hg (5.4×10^{-5} to 0.00012). Also, the results showed that the Hazard Quotient values for the metals in the sediment samples increases in the order $\text{Cd} < \text{Hg} < \text{Fe} < \text{Pb} < \text{As}$ and HQs estimates ranges were Cd (9.5×10^5 to 0.00027); Pb (1.8×10^{-5} to 0.00160); Fe (0.00016 to 0.00064), As (0.00031 to 0.00066); and Hg (0.00018 to 0.00058) and HI values increases from 0.00101 to 0.00296. This study showed that Chronic Daily Intake (CDI) estimates for the metal concentrations in sediment samples increases in the order $\text{Cd} < \text{Hg} < \text{Fe} < \text{Pb} < \text{As}$ and the CDI estimates ranges were Cd (1.4×10^{-10} to 3.9×10^{-10}); Pb (2.5×10^{-11} to 2.3×10^{-9}); Fe (2.3×10^{-10} to 9.1×10^{-10}); As (4.5×10^{-10} to 9.5×10^{-10}) and Hg (2.6×10^{-10} to 8.3×10^{-10}). Risk assessment for Cd, Pb, Fe, As and Hg in the sediment samples showed that all the HQ and HI and even CDI values to be less than 1 signifying satisfactory level of non-carcinogenic and carcinogenic adverse health risk. The findings are in agreement with studies by Frimpong & Koranteng, (2019) and (Boateng et al., 2015). However, study by Kortei et al., (2020) and Hadzi et al., (2019) mentioned that Cd, As, and Pb were above 1 in sediments.

This study found that ADD estimates ($\mu\text{g}/\text{Kg}/\text{day}$) for water samples increases in the order $\text{Hg} < \text{As} < \text{Cd} < \text{Pb} < \text{Fe}$ and ADD estimates ranges were Cd (0.04190 to 4.61651); Pb (0.00643 to 0.03038); Fe (0.04190 to 0.00608); As (0.00042 to 0.03038); and Hg (0.00031 to 0.00038). Also, the results showed that the Hazard Quotient values for the metals in water samples increases in the order $\text{Pb} < \text{Cd} < \text{As} < \text{Hg} < \text{Fe}$ and HQs estimates ranges were Cd (0.012851 to 0.00014); Pb (0.01197

to 1.3190); Fe (6×10^{-08} to 0.00019); As (0.0014 to 0.02025); and Hg (0.00151 to 0.0128) and Hazard index (HI) values increases in from 0.02996 to 1.33810.

Chronic Daily Intake (CDI) estimates for the heavy metal concentrations in water samples increases in the order $Hg < As < Cd < Pb < Fe$ with the ranges estimates for Cd (0.0002 to 0.00096); Pb (0.00132 to 0.14509); Fe (0.00132 to 10.56250); As (1.537×10^{-05} to 0.00019); and Hg (9.9×10^06 to 0.00012).

In this study, it was revealed that the risk assessment for Cd, Fe, As and Hg in the water samples showed values < 1 but for Pb both the HQ (1.32) and HI (1.34) at only ETW (Wavuguma Dam, Tamale) showed values > 1 . Also, this study showed that for the water samples, the CDI values for Fe > 1 occurred at ETWV (Wamali Dam, Tamale) (2.46); ETT (Taha Dam, Tamale) (6.39); ETC (Chanzeni Dam, Tamale) (1.46); ETS (Difaa Dam, Tamale) (10.56); WTD (Datooyili Dam, Tamale) (4.26); CTG (Dabokpa Dam, Tamale) (4.38); NTS (Savelugu Dam, Savelugu Municipal) (1.69); and NTN (Nawuni River, Kumbungu District) (1.38). These results indicate non-carcinogenic and carcinogenic adverse health risk for Fe and Pb. This finding is reasonable due to the wide spread of e-waste processing and metal scrabs activities along and close to eroded water gutters which lead to most of these dams in Tamale and its surrounding areas (Caravanos et al., 2011; Moeckel et al., 2020). The findings are in agreement with studies by Ametepey et al., (2018), Adimalla, (2019) and (Boateng et al., 2015).



CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

The main purpose of this study was to assess the physico-chemical parameters, heavy metal concentrations and estimate the potential health risk of the metals in groundwater, dam's water and river-water.

According to the results, the physico-chemical parameters of the water samples are significantly higher at some sampling points. Additionally, this study revealed that the water physico-chemical parameters such as pH, EC, and Salinity were all within the WHO limits, however Turbidity values were far above the WHO limits of 5 NTU and TDS values fall below the WHO threshold value of 1000mg/L.

The study illustrates that the heavy metals such as Cd, Pb, Fe, As and Hg were found in the water and sediment samples and their concentrations increases in the order $Hg < As < Cd < Pb < Fe$ for the water samples and $Cd < Hg < As < Pb < Fe$ for the sediment samples. Additionally, this study revealed that concentrations of Cd, Pb, Fe, As and Hg in the sediment's samples and Pb and Fe metals in the water samples were above permissible limits.

This study found that ADD estimates ($\mu g/Kg/day$) for sediment samples increases in the order $Hg < As < Cd < Pb < Fe$. Also, the results showed that the Hazard Quotient values for the metals in the sediment samples increases in the order $Cd < Hg < Fe < Pb < As$. The study showed that Chronic Daily Intake (CDI) estimates for the metal concentrations in sediment samples increases in the order $Cd < Hg < Fe < Pb < As$. Risk assessment for Cd, Pb, Fe, As and Hg in the sediment samples showed that all the HQ and HI and even CDI values to be less than 1 signifying satisfactory level of noncarcinogenic and carcinogenic adverse health risk.

This study found that ADD estimates ($\mu\text{g}/\text{Kg}/\text{day}$) for water samples increases in the order $\text{Hg}<\text{As}<\text{Cd}<\text{Pb}<\text{Fe}$. Also, the results showed that the Hazard Quotient values for the metals water samples increases in the order $\text{Pb}<\text{Cd}<\text{As}<\text{Hg}<\text{Fe}$ and Hazard index (HI) values increases from 0.029956281 to 1.338069194. Chronic Daily Intake (CDI) estimates for the heavy metal concentrations in water samples increases in the order $\text{Hg}<\text{As}<\text{Cd}<\text{Pb}<\text{Fe}$.

This study found that risk assessment for Cd, Fe, As and Hg in the water samples showed values <1 but for Pb both the HQ (1.319) and HI (1.338) at only ETW showed values >1 , signifying non-satisfactory level of non-carcinogenic adverse health risk. This study showed that for the water samples, the CDI values for Fe >1 . In this study, it was revealed that the risk assessment for Cd, Fe, As and Hg in the water samples showed values <1 but for Pb both the HQ (1.32) and HI (1.34) at only ETW (Wavuguma Dam, Tamale) showed values >1 . Also, this study showed that for the water samples, the CDI values for Fe >1 occurred at ETWV (Wamali Dam, Tamale) (2.46); ETT (Taha Dam, Tamale) (6.39); ETC (Chanzeni Dam, Tamale) (1.46); ETS (Difaa Dam, Tamale) (10.56); WTD (Datooyili Dam, Tamale) (4.26); CTG (Dabokpa Dam, Tamale) (4.38); NTS (Savelugu Dam, Savelugu Municipal) (1.69); and NTN (Nawuni River, Kumbungu District) (1.38). These results indicate non-carcinogenic and carcinogenic adverse health risk for Fe and Pb. This study found that risk assessment for Cd, Pb, Fe, As and Hg in the sediment samples showed that all the HQ and HI and even CDI values to be less than 1 signifying satisfactory level of non-carcinogenic adverse health risk.

5.3 RECOMMENDATION

Based on the findings of this study the following recommendations were made.

1. In this study, it was revealed that concentrations of Cd, Pb, Fe, As and Hg in the soil samples and Pb and Fe metals in the water samples were above permissible limits. Based on

this observation, the study recommends that the government with the support of the communities should ensure that the use of safe methods for fertilizer application, e-waste processing and metal scraps processing in these areas.

2. Furthermore, this study found that risk assessment for Fe and Pb in the water samples may be associated with non-carcinogenic and carcinogenic adverse health risk. As such the use of water from these sources is unsafe, therefore the study recommends that the government and the communities should provide alternative sources of water for human consumption in this area.
3. Although the levels of most of these metals are below reference points, regular investigations to check the concentrations of heavy metals on the soil and in the drinking waters for the assessment of the inhabitance health risk in Tamale and its surrounding areas.
4. Additionally, close monitoring of the possibility of these heavy metals in human blood is necessary since the metals appear in most dinking waters in Tamale and its surrounding areas.
5. It is similarly vital to use remediation interventions such as bacteria which are Capable of recycling toxic metals to get rid of them in contaminated areas especially where waters are used for drinking and growing of crops.
6. The current investigation provides solid support for additional research on the impact of heavy metals on plants, animals and human health. Further studies should consider investigating the cause and source of the heavy metals in these areas. Also, another study on the detection of these metals in humans and the associated effects on normal organ functioning and disease is equally vital in the study area.

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Appendix 1: One Way ANOVA Results

Table A1: ANOVA summary of the physico-chemical parameters (pH, EC, and Salinity) of the water and sediment samples at the various sampling points.

ANOVA summary	
F	741.9
P value	<0.0001
P value summary	****
Significant diff. among means (P < 0.05)?	Yes
R squared	0.9810

Table A2: ANOVA table of the physico-chemical parameters (pH, EC, and Salinity) of the water and sediment samples at the various sampling points.

ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Treatment (between columns)	643.9	5	128.8	F (5, 72) = 741.9	P<0.0001
Residual (within columns)	12.50	72	0.1736		
Total	656.4	77			

Table A3: ANOVA summary of the metals concentrations in the sediment samples.

ANOVA summary

F	83.82
P value	<0.0001
P value summary	****
Significant diff. among means (P < 0.05)?	Yes
R squared	0.8376

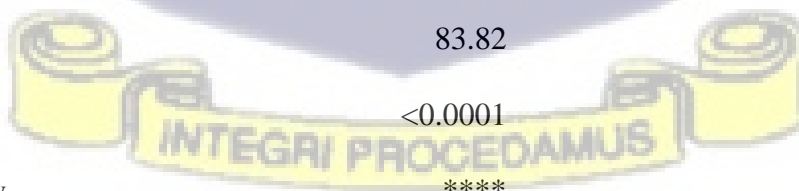


Table A4: ANOVA table of the metals concentrations in the sediment samples.

ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Treatment (between columns)	36649899	4	9162475	F (4, 65) = 83.82	P<0.0001
Residual (within columns)	7105301	65	109312		
Total	43755200	69			

Table A5: ANOVA summary of the metals concentrations in the water samples.

ANOVA summary

F	8.49
P value	<0.0001
P value summary	****
Significant diff. among means (P < 0.05)?	Yes
R squared	0.343

Table A6: ANOVA table of the metals concentrations in the water samples.

ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Treatment (between columns)	65.4	4	16.3	F (4, 65) = 8.49	P<0.0001
Residual (within columns)	125	65	1.93		
Total	191	69			

Table A7: ANOVA summary of the comparison of the metals concentrations in the sediment and water samples.

ANOVA summary

F	84.0
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P value	<0.0001
P value summary	****
Significant diff. among means (P < 0.05)?	Yes
R squared	0.853

Table A8: ANOVA table of the comparison of the metals concentrations in the sediment and water samples.

ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Treatment (between columns)	41303343	9	4589260	F (9, 130) = 84.0	P<0.0001
Residual (within columns)	7105426	130	54657		
Total	48408769	139			



Appendix 2: Comparison of heavy metals in sediments and in water samples

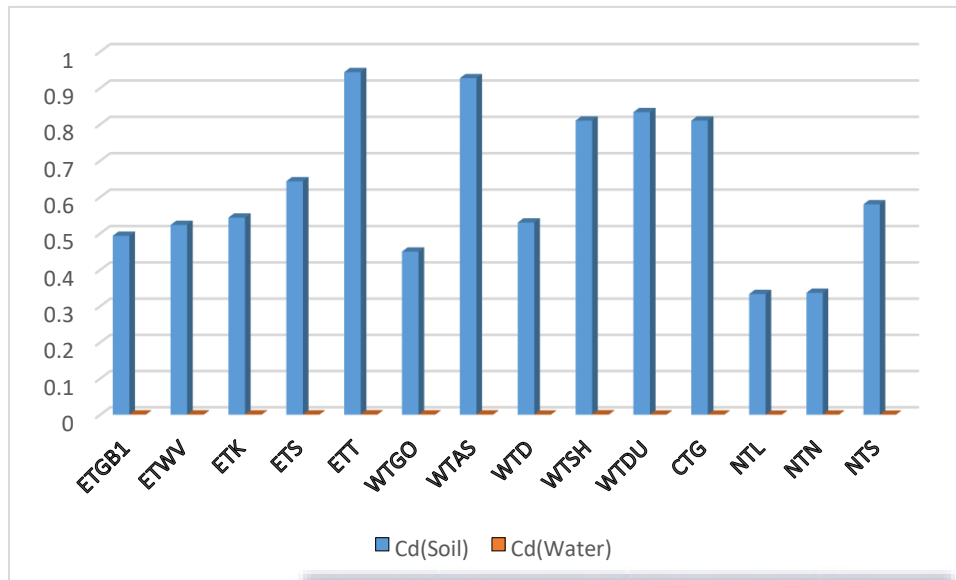


Figure A.1 Comparison of Cd concentrations measured in the water and sediments at the various sampling points.

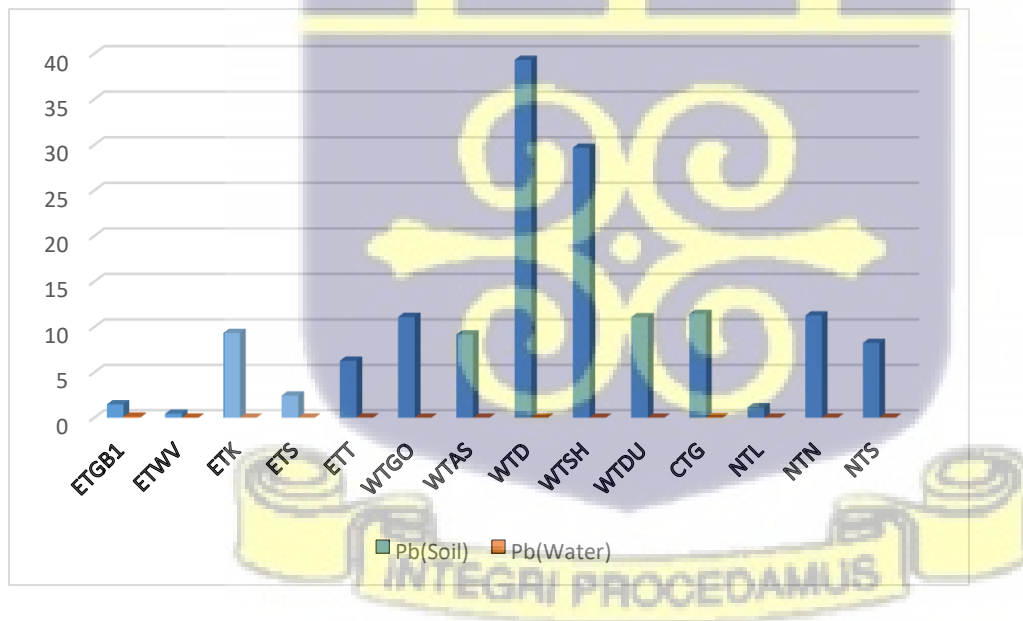


Figure A.2 Comparison of Pb concentrations measured in the water and sediments at the various sampling points.

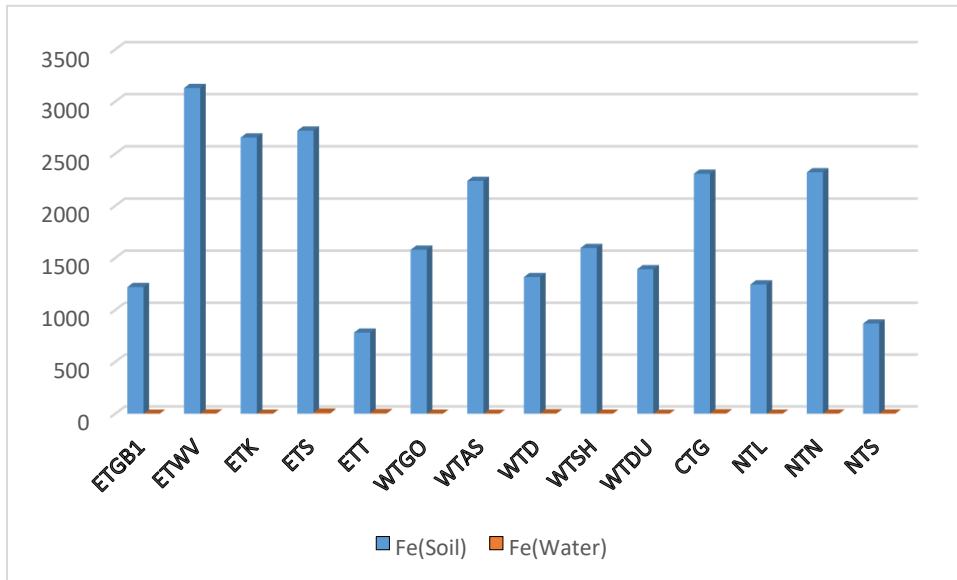


Figure A.3: Comparison of Fe concentrations measured in the water and sediment at the various sampling points.

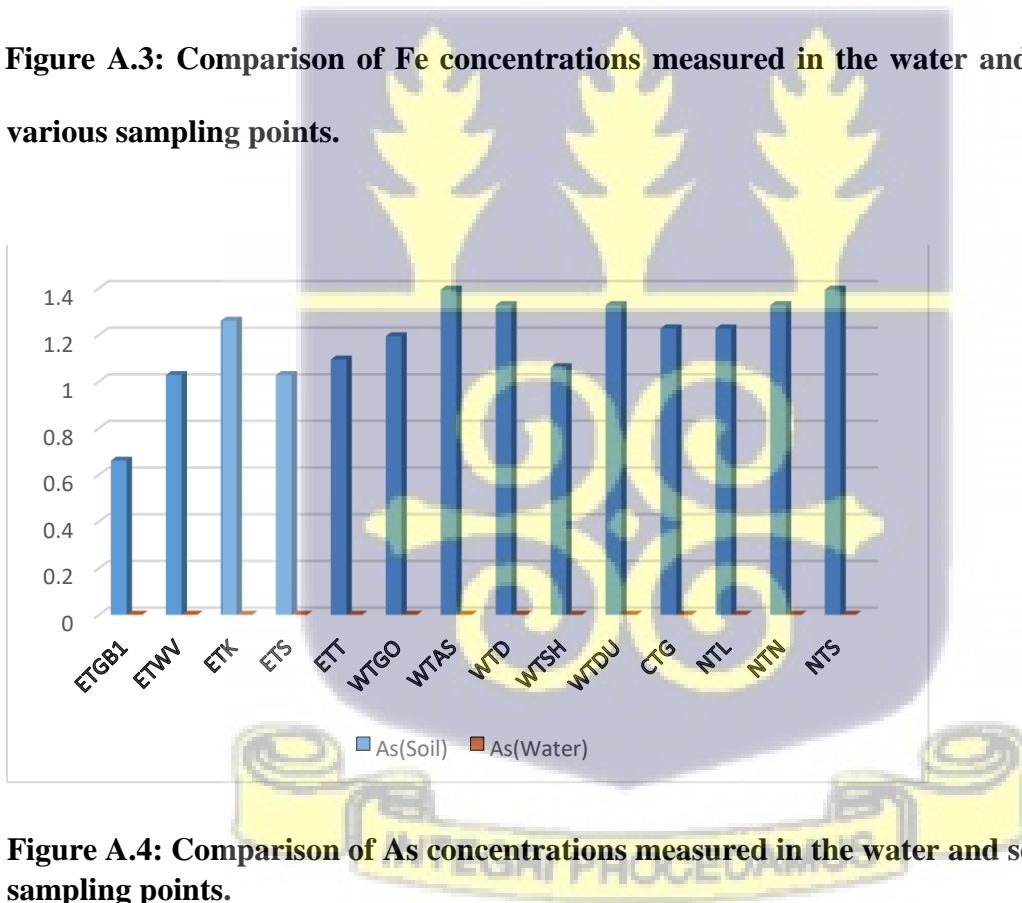


Figure A.4: Comparison of As concentrations measured in the water and sediment at the various sampling points.

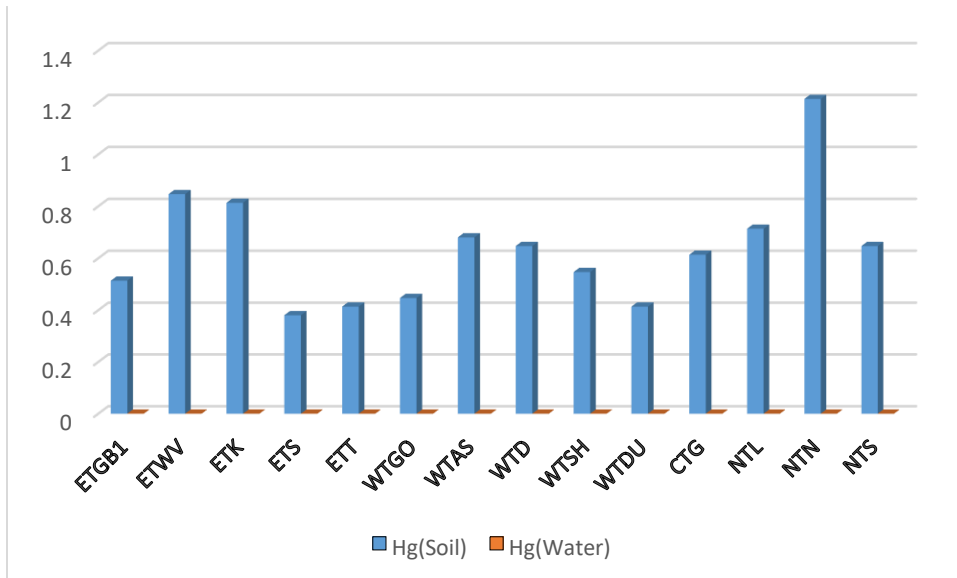


Figure A.5: Comparison of Hg concentrations measured in the water and sediment at the various sampling points.

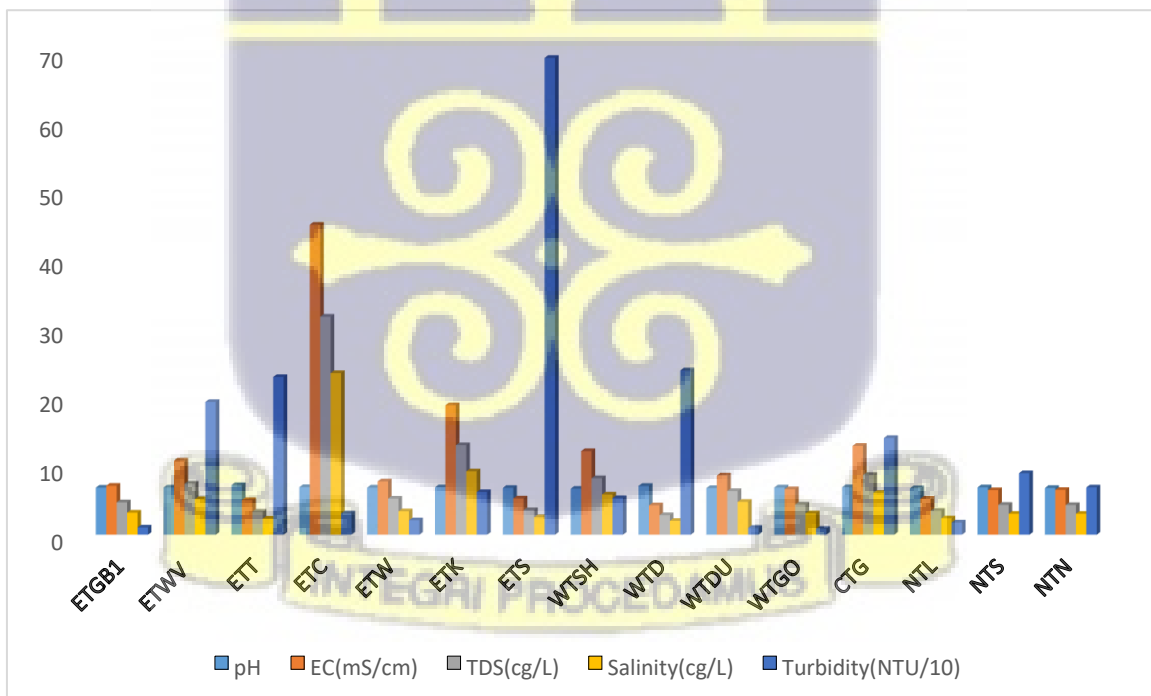


Figure A.6 Comparison of physico-chemical parameters of the water samples at the various sampling points.

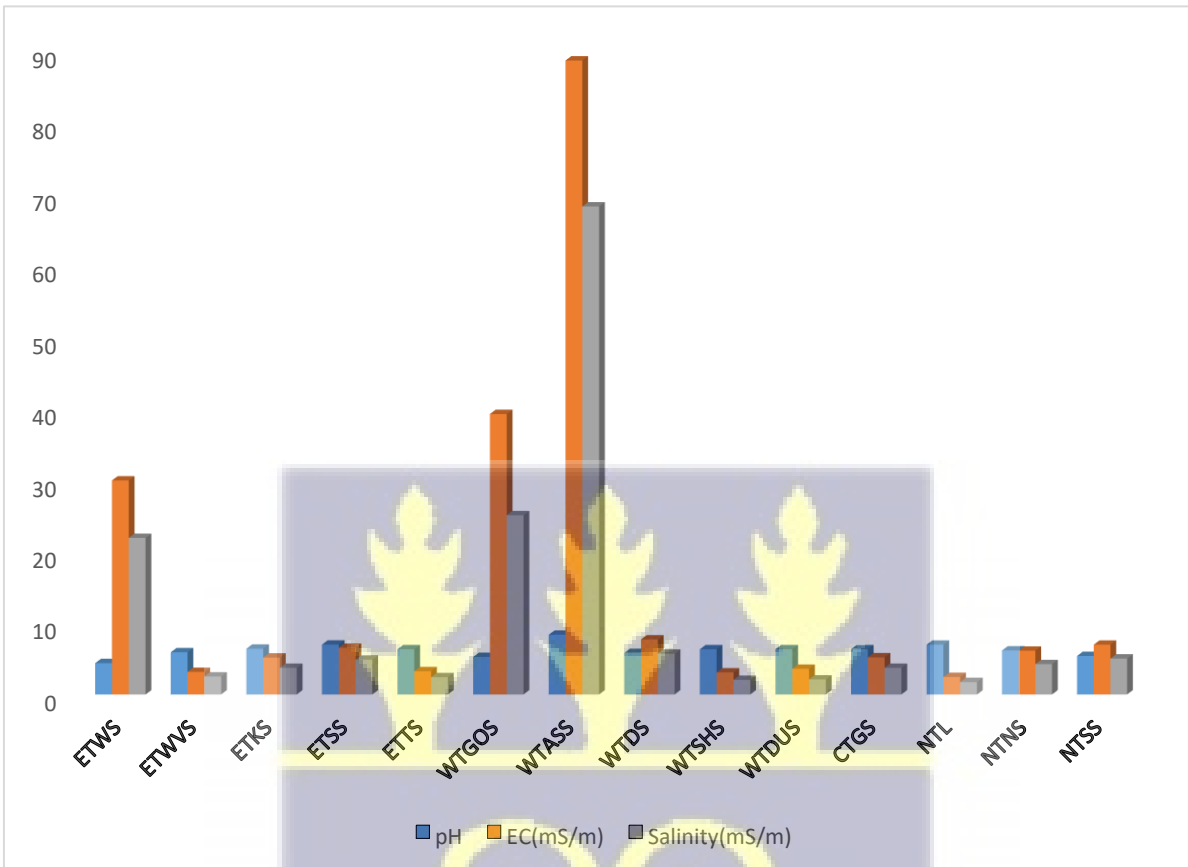


Figure A.7 Comparison of physico-chemical parameters of the water samples at the various sampling points.



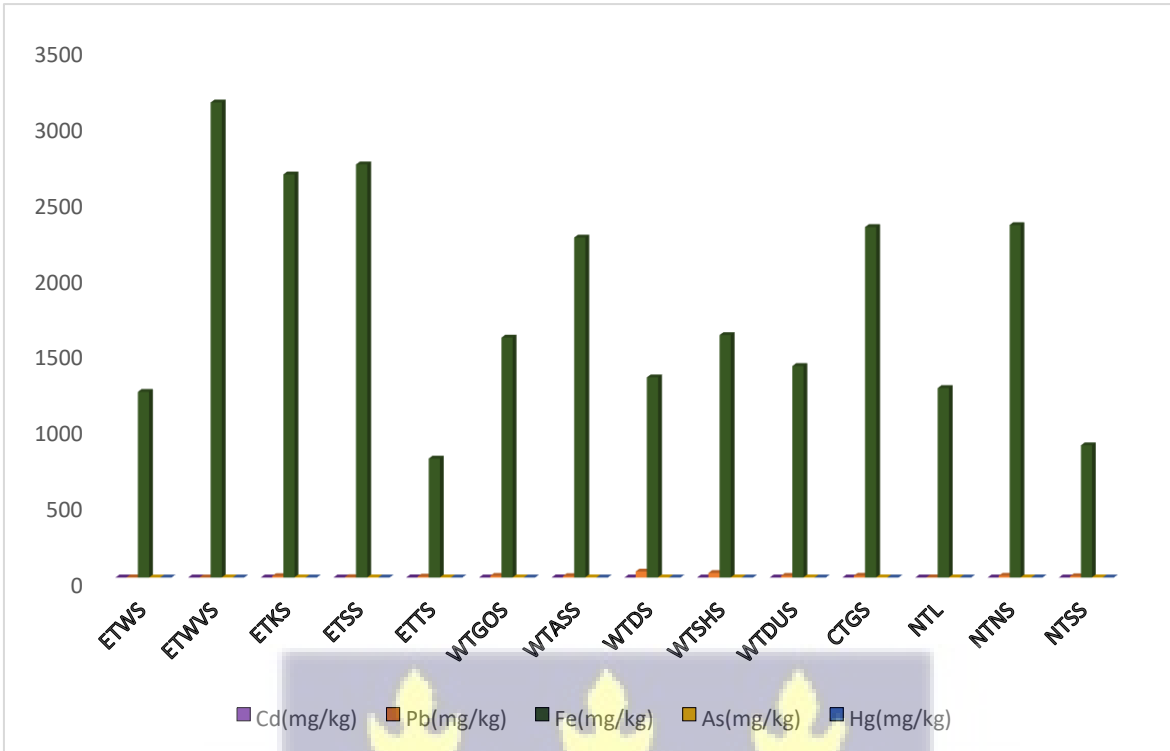


Figure A.8 Comparison of heavy metal concentrations measured in the sediment samples at the various sampling points.

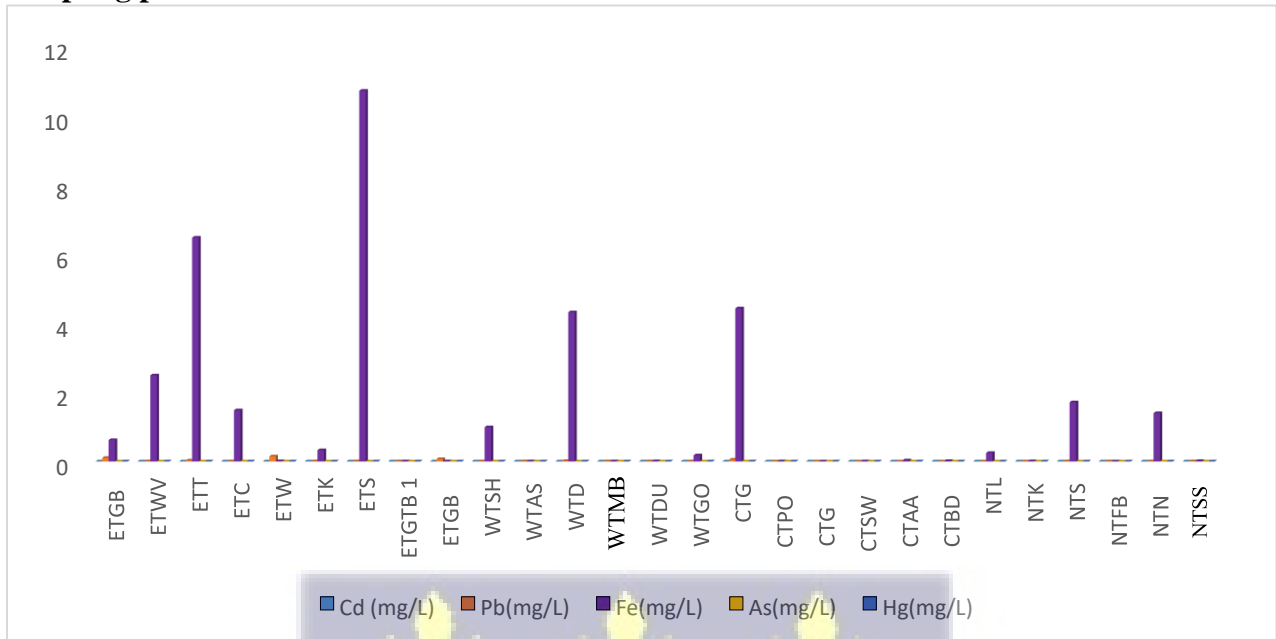


Figure A.9 Comparison of heavy metal concentrations measured in the water samples at the various sampling points.

