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Impact of Artisanal and Small-Scale Mining on Water bodies and Treatment: The Case of Birim River Basin in Ghana

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A thesis submitted in partial fulfillment of the requirements for the Doctor of Philosophy degree in Civil and Environmental Engineering

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Abstract

Water bodies, the source of drinking water for many rural households in mining areas are at risk of contamination due to artisanal and small-scale mining (ASM) activities. Water quality therefore remains a topical issue for policymakers and researchers.

This research sought to achieve three objectives: firstly, to evaluate the effectiveness of existing policies and regulations about ASM in protecting waterbodies. Secondly, to determine the impact of ASM on waterbodies, health and livelihood of inhabitants in mining communities and thirdly, to remove heavy metals from water using locally available bio-adsorbents such as moringa seeds, coconut and corn husks.

A survey of 400 respondents and 30 interviews were conducted in three mining communities who depend on water from the River Birim Basin, in Ghana, to assess the impact of ASM activities on water bodies, health and livelihood of inhabitants of the affected communities. One hundred water samples were collected from the Birim River, tributaries, groundwater and mine ponds in the wet (June-September) and dry seasons (December to March), to determine the water quality and the concentrations of heavy metals such as Arsenic, Lead, Iron, Mercury, Cadmium and Manganese. Water containing heavy metals were treated using bio-adsorbents in the laboratory. An evaluation of existing policies related to ASM in Ghana was also carried out.

The findings indicated that lack of awareness and ineffective implementation and enforcement of the policies, in addition to limited knowledge of the impact of ASM activities on water bodies contributed to the pollution of water bodies. Heavy metal concentrations exceeded the WHO limit for drinking water in most of the samples especially in the dry season. Water from the Birim Basin was found to be contaminated and not safe for drinking and other domestic purposes and therefore treatment of the water is necessary. The bio-adsorbents developed in the present research successfully removed some arsenic, iron and lead from the water. These bio-adsorbents can therefore be used by communities dependent on the Birim Basin to reduce heavy metal related health risks. Research findings are expected to provide relevant information for policymakers, environmental experts and other stakeholders in enhancing water quality.

Keywords

Artisanal and small-scale mining (ASM), water bodies, water pollution, heavy metals, water treatment, biosorption

Summary for Lay Audience

Rivers and wells which are the main drinking water sources for many rural households in mining communities are at risk of contamination due to artisanal and small-scale mining (ASM) activities. ASM is characterized by basic techniques of mineral extraction with negative human and environmental impact, especially on water bodies. However, ASM provides employment and improved standard of living for inhabitants of the mining communities.

This research sought to, first of all, determine the effectiveness of existing policies and regulations related to ASM in protecting water bodies. Secondly, to determine the impact of ASM on water bodies in the Birim Basin, health and livelihood of inhabitants in mining communities along the Birim River. Finally, to remove heavy metals which are generally toxic, especially at high concentrations, from water using cost-effective adsorbents within the mining communities such as moringa seeds, coconut and corn husks.

A survey of 400 respondents and 30 interviews were conducted in three mining communities who depend on water from the River Birim Basin, in Ghana, to determine the impact of ASM activities on water bodies, health and livelihood of inhabitants of the affected communities. One hundred water samples were collected from the Birim River, its tributaries, groundwater and mine ponds in the rainy (June-September) and dry seasons (December to March), to determine the quality of water and the concentrations of heavy metals such as Arsenic, Lead, Iron, Mercury, Cadmium and Manganese. Water containing heavy metals were treated using moringa seeds, coconut and corn husks in the laboratory. Policies related to ASM were also evaluated.

The findings from the research showed that limited knowledge on the impact of ASM activities on water bodies, lack of awareness and ineffective implementation and enforcement of the policies, contributed to the pollution of water bodies. Heavy metal concentrations in most of the samples exceeded the WHO limit for drinking water, especially Iron, Arsenic and Lead. Water from the Birim Basin was found to be polluted and not safe for drinking and therefore treatment of the water was necessary. Moringa seeds, coconut and corn husks, were successful in removing the heavy metals from the water. These adsorbents can therefore be used by communities who depend on the Birim Basin to treat their water before drinking to reduce heavy metal related health risks.

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'*What shall I render to my God for all His mercy's store? I'll take the gifts He has bestowed, and humbly ask for more*' (MHB 399, Stanza One). To my Wonderful Counsellor and Father, who has brought me this far. What can I ever do without you? To you be all Glory and Honour.

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Last but not the least, to my siblings, friends and all those who gave wonderful ideas and support and contributed to the success of this dissertation, I say 'Ayekoo' We did it!!!!!

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List of Abbreviations and Symbols

Abbreviation	Meaning
AMD	Acid Mine Drainage
ARD	Acid Rock Drainage
ASM	Artisanal and Small-Scale Mining
ASGM	Artisanal and Small-Scale Gold Mining
ATSDR	Agency for Toxic Substances and Disease Registry
CTE	Central Tendency Exposure
DNA	Deoxyribonucleic acid
DOC	Dissolved Organic Carbon
Eh	Oxidation-reduction potential
ELOHA	Ecological Limits of Hydrologic Alteration framework
EPA	Environmental Protection Agency
GAEC	Ghana Atomic Energy Commission
HQ	Hazard quotient
IFC	International Finance Corporation
IGF	Intergovernmental Forum
IISD	International Institute of Sustainable Development
IUCN	International Union for Conservation of Nature
IWRM	Integrated Water Resources Management
HS	Shaken by hand
MMIP	Multi-Sectoral Mining Integrated Project
NCERC	Nuclear Chemistry and Environmental Research Centre
pH	Potential of Hydrogen
RME	Reasonable Maximum Exposure
TOC	Total Organic Carbon
UN	United Nations
UNEP	United Nations Environment Programme
UNESCO	United Nations
UN-WWDR	United Nations-World Water Development Report
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
WHO	World Health Organization

CHAPTER ONE

1. Introduction

1.1 Background

Water is generally recognized as a necessity for the existence of life on earth. A human being may go from feeling thirsty on the first day without water, to having organ failure by the third day (Johnson, 2019). Living creatures need water to function properly; it can therefore be said that water is indeed life. Water is used for various things including drinking and household needs, recreational, industrial and agricultural activities, all of which require freshwater sources (Owusu et al, 2016). Although, water resources are abundant on Earth, about 97.5% of the water on the Earth is saltwater, with only 2.5% freshwater (UNESCO, 1998). Moreover, about two-thirds of the earth's fresh water is frozen in glaciers and polar icecaps (USGS, 2016). The remaining unfrozen freshwater is mainly found as groundwater with only a small percentage existing as water on the earth's surfaces such as rivers, lakes, etc., and as water in the atmosphere (UN-WWDR, 2006; UNESCO, 1998; USGS, 2016).

Consequently, the demand for freshwater generally exceeds supply in many parts of the world (USGS, 2016). Increasing population sizes with the accompanying expansion in the uses of water further increase the pressure on existing freshwater sources (WHO, 2019). The situation is aggravated by the reduction of the quantity and quality of available water resources by human activity and natural forces. It is estimated that by 2025, about half of the world's population will live in water-stressed areas (WHO, 2019). These disturbing realities have driven efforts to increase public awareness on the need to better manage and protect water resources over the years.

Mining is one of the human activities which adversely affects the quality of water sources, especially surface water, including water in rivers, lakes, and wetlands (WHO, 2019). Indeed, mining has contributed significantly to various economies because of the high earnings from the export of gold, diamond, coal, copper amongst others (Walser, 2000; Ntori, 2017). The Republic of Ghana is one of the countries whose economy benefits from the export of mineral resources, the major ones being gold (the predominant mineral in the country), diamonds, manganese, and bauxite. Over the past two decades gold accounts for over 90% of all of Ghana's mineral revenues annually (Minerals and mining policy, 2014). Total revenues from gold in 2017, amounted to $3.52 billion, an increase of 10.2% compared to the previous year (Ghana Chamber of Mines, 2018). Total gold production from Artisanal and Small- Scale Mining (ASM) activities grew from an estimated 2.2% in 1989 to 31% of the national production in 2016 (MMIP, 2017). The 31% gold production from ASM includes contributions from both legal and illegal miners (MMIP, 2017).

Despite its contribution to national gold production, ASM has negatively impacted on water bodies in Ghana and several other countries (Hilson et al., 2007; Agbesi, 2017). ASM is a practice that involves basic techniques of mineral extraction characterized by highly manual processes, hazardous working conditions, and negative human and environmental health impacts (Hilson, 2002). ASM has often led to discharge and run-off of mining waste into rivers, ponds, streams, wells, and boreholes and has resulted in severe heavy metal contamination (Bortey-Sam et al., 2015). Ghana has suffered severe environmental degradation from mining activities especially those from ASM. Many rivers have been contaminated by ASM activities with adverse effects on rural communities established along these rivers. Inhabitants of such communities depend on the water bodies for their livelihoods. One such river with communities along it but affected by ASM activities in Ghana is River Birim.

River Birim flows through several communities in the Akim Municipality in the Eastern Region of Ghana and serves as the main source of water for drinking, irrigation, fishing, and for other domestic purposes. However, River Birim has been polluted by artisanal and small-scale mining activities (Afum & Owusu, 2016; Hadzi et al., 2018), and this has led to a scarcity of drinking water in some communities along the river and the destruction of aquatic lives. Discharge of chemicals from mining activities into the river, has caused a discolouration of the river water and the contamination can be fatal to aquatic organisms. The rural communities which depend on the river are exposed to serious health risks (Armah et al., 2014; Afum & Owusu, 2016).

The levels of heavy metals such as Arsenic, Lead, and Cadmium have increased in communities with artisanal and small-scale mining activities although they are naturally occurring pollutants in the environment (Obiri et al., 2016). People who live near sites where these metals have been improperly disposed are exposed to these metals by ingestion through drinking of contaminated water and eating contaminated food or inhalation of polluted air (Martin & Griswold, 2009).

According to Anderson (2013), ASM is characterized by a vicious cycle of discovery, migration, and relative economic prosperity; which is then immediately followed by resource depletion, out-migration, and economic destitution. After the depletion of the reserves, sites are abandoned, and the community is left to cope with a legacy of environmental devastation and extreme poverty. However, many people fail to realize that human existence is dependent on the environment and thus all human engagements are dependent on nature's services (Hill, 2010). Water is generally recognized as a necessity for the existence of life on earth but, our civilization has contaminated our water bodies to the extent that water has to be purified for drinking and other domestic purposes (Ahuja, 2013).

There has been extensive research on the environmental impacts of ASM in Ghana (Aryee et al., 2003; Hilson et al., 2007; Bortey-Sam et al., 2015; Sarpong, 2017). However, limited research has focused on the impacts of ASM on water bodies that serve as a source of drinking water. Research is also limited on the application of point of use treatment systems that utilize locally available, inexpensive materials to remove contaminants from ASM polluted water. The existing research gap needs to be bridged to guide the local treatment of ASM polluted water and input for policy is needed to address environmental issues and the consequences of ecological damage due to ASM.

In reviewing the case of the effect of ASM on the Birim River in Ghana, the following pertinent questions emerged: What is the level of contamination in the Birim River due to artisanal and small-scale mining activities? Has any policy or regulation resulted in minimizing the level of pollution? What impacts has the polluted water had on the health and livelihood of inhabitants of communities that depend on the river as their source of drinking water? Can the heavy metals in the water be removed using inexpensive and accessible local materials in the communities?

This thesis, therefore, presents a research study conducted in communities along the Birim River in Ghana who depend on the river as a source of water for drinking, domestic and agricultural purposes amongst others, however, the river has been exposed to heavy metals due to artisanal and small-scale mining activities in the river. The removal of heavy metals from drinking water using locally available materials such as corn husk, moringa seeds, and coconut husk was also explored. In the remaining sections of this introductory chapter, the rationale for this study is explained and an overview of the thesis is provided. This includes the problem statement, objectives of the study, research justification, the key research questions, a brief outline of the approach used in the research, and the structure of the thesis followed by definitions of terms that are commonly used in the thesis.

1.2 Problem Statement

Contamination of water bodies in Ghana has been a source of concern for many people, especially those in rural areas who depend on water bodies such as rivers for various uses including drinking water, fish and wildlife habitats, recreational activities, and economic benefits. The problem of river pollution is widespread in Ghana although rivers are a source of identity and pride for many rural communities. Many rural communities do not have access to potable water and therefore depend on rivers, groundwater, and other water bodies for drinking water and other domestic purposes. Over the years, however, several aspects of water pollution have combined to reduce the overall quality of water bodies. The UN estimates that, globally, due to the shortage of affordable potable water, about 1.2 billion people are forced to drink unsafe water which causes water-related diseases that kill about 5 million people each year, mostly children (UN, 2013). Contaminated water can transmit various diseases such as dysentery, typhoid and cholera; about 485,000 diarrhoeal deaths caused by drinking contaminated water occurs each year, (WHO, 2019).

ASM activities have resulted in a reduction in the quantity and quality of water in rivers, making it insufficient for use and unhealthy for consumption (IGF, 2017). In Ghana, there have been widespread concerns about the high prevalence of ASM, most of which are unlicensed and thereby illegal. Locally, illegal mining is popularly referred to as '*Galamsey*', a menace that has persisted for years and been the subject of political election debates. Over the years, the Government of Ghana has together with other agencies, implemented policies and put in place various measures to control and curb ASM activities that are destroying the environment, but these efforts have not been effective over the long term because waterbodies are still being polluted (Aryee et al., 2003; Hilson et al., 2007; Agbesi, 2017). There is therefore a need to assess existing policies related to

ASM and their implementation and enforcement over the years to determine their effectiveness and provide useful input for future policies. Research evidence is expected to inform policy and policy guides the actions of people.

Tests conducted on water samples collected from some mining communities indicate that the concentrations of arsenic, cadmium, manganese, mercury, lead and other metals in water have exceeded those of the WHO guidelines for drinking water and was therefore unsafe for drinking purposes (Hilson et al, 2007; Rajaee et al, 2015; Bortey-Sam et al, 2015). Samples from some ASM sites have exceeded the guidelines for acidity, turbidity, colour, total suspended solids and nitrates (Rajaee et al., 2015; Bortey-Sam et al., 2015; Ntori, 2017; Tetteh et al., 2010). Mercury pollution which leads to the contamination of drinking water sources has already been identified as a lingering problem in several of Ghana's important small-scale gold mining communities (Hilson et al., 2007). It is therefore imperative for inhabitants of these rural communities to treat their water before drinking. Point of use treatment systems that inhabitants of affected rural communities can use to treat their water is generally lacking. There is therefore, a need for a water treatment system to be developed using locally available and inexpensive materials to facilitate water treatment by the inhabitants of the affected communities to protect their health. The effectiveness of some inexpensive local materials such as coconut husk, rice husk, and moringa seeds in removing heavy metals from the water was explored in this research to aid in developing a point of use treatment system that can be used in rural communities to treat contaminated water.

1.3 Aim and Objectives

1.3.1 Aim

The aim of the present research is to investigate the impacts of Artisanal and Small-Scale Mining (ASM) activities on water bodies, health and livelihood of inhabitants of mining communities and to assess the possibility of using locally available materials to treat the contaminated water to WHO standards.

1.3.2 Research objectives

The objectives of the research are to:

- Evaluate existing policies and regulations with regards to Artisanal and Small-Scale Mining (ASM) in Ghana and their enforcement.

- Assess the level of contamination of water bodies in the mining communities and the impact on the health and livelihood of the inhabitants of the communities along the Birim River in the Eastern Region of Ghana.
- Determine whether locally available materials can be used to treat the contaminated water to meet the WHO/GEPA guidelines for drinking water quality for households in the affected communities.

1.3.3 Research Questions

- What policies and regulations have been adopted to address the negative impact of ASM on the environment, especially water bodies and why have they not yielded the expected results?
- What is the level of contamination of the water bodies in the mining communities and its impact on the health and livelihoods of the people?
- Which inexpensive available local materials can be used to treat the contaminated water to WHO/GEPA standards for the affected communities?
- What effective strategies can be adopted to minimize the negative impact of ASM on waterbodies?

1.4 Research Justification

Water plays an indispensable part in our daily lives. There is therefore the need for the quantity and quality of water bodies to be preserved through the implementation and enforcement of policies and regulations and the treatment of the already polluted water. There is a need to understand the operations of Artisanal and small-Scale Mining (licensed and unlicensed), the attitude of mine workers and non-mining inhabitants, the possible contaminants in the water bodies, and how they can be safely removed (Tschakert, 2009).

ASM serves as a major source of income for individuals within rural communities by providing employment and improving their standard of living (Anderson, 2013) but it is known to have caused the depletion and pollution of water bodies that render the quality of the water inadequate for consumption and other uses (IGF, 2017). According to Appiah (2016), the quality of Ghana's water bodies has seriously worsened after 2010 due to the introduction of heavy machinery in mining on riverbeds and on river banks, which has turned many water bodies into brown, silted streams of water which is unsafe for consumption. The economically vulnerable and the poor in the communities tend to depend on the river albeit polluted. It is therefore important to have mechanisms for treating water polluted by ASM using readily available materials in the community.

According to Rajaee et al. (2015), there is still limited research on ASM in developing countries and its impact on the natural environment. In Ghana, although some research has been carried out (Hilson et al., 2007, Bortey-Sam et al., 2015, Sarpong, 2017) on the effect of ASM on the environment, there has been limited study focused on the impacts of ASM water bodies, and the application of point of use technologies to treat the contaminated water. Research that bridges the existing gap and also provides mechanisms for treating ASM-polluted water using readily available materials in the community will positively impact the health and general well-being of the inhabitants of such communities. The outcome of the research of this nature would provide input for public health education, environmental policy, and potential entrepreneurial opportunities for locals in the area of water treatment for domestic purposes. An identification of the active ingredients in the local materials used for treatment will make the findings of the research transferable to other areas.

This research assessed the level of contamination in the Birim River and explored the possibility of removing heavy metals from contaminated water using locally available materials to make the water safe for consumption. This will make it possible for rural communities to treat the contaminated water using locally available and safe resources to avoid the health complications associated with using contaminated water. Government policy interventions that have been implemented so far were also evaluated to assess their effectiveness. The present research, therefore, seeks to, assess this issue from different angles to provide information to help formulate and implement measures to effectively address the problem. This study provides updated information to add to existing data on the quality of water in Kibi, its surrounding communities, and its environs. The findings of the study would also be a great source of information for environmental experts, stakeholders, policy policymakers, and institutions.

1.5 Research Scope

This research was limited to the Birim Basin in Ghana, some communities, and mining sites along the river, and water bodies at the mining sites within the communities. It focused on the domestic consumption of water from the Birim River Basin. Only some physio-chemical parameters, heavy metals such as lead, arsenic, cadmium, mercury, iron and manganese, and Total Organic Carbon (TOC)/Dissolved Organic Carbon (DOC) were monitored.

1.6 Structure of Thesis

This thesis is divided into seven chapters.

- The first chapter is the introduction. It includes an overview of the subject under investigation, the motivation for the study, the aims and objectives, the research questions, the research methodology, the limitation, and the structure of the dissertation.
- The second chapter is the literature review. This chapter critically reviews existing work in the field.
- The third chapter is the research methodology. It describes in detail the specific research techniques and tools used in the investigation including the kinds of resources consulted, the characteristics of the research samples, the method of data collection and analysis, and the rationale for adopting these methods.
- The fourth chapter covered data analysis, interpretation and discussion specifically for the first objective for this study which is to '*Evaluate existing policies and regulations with regards to Artisanal and Small-Scale Mining (ASM) in Ghana and their enforcement*'.
- The fifth chapter covered data analysis and interpretation and discussion specifically for the second objective for this study which is to '*Assess the level of contamination of water bodies in the mining communities and the impact on the health and livelihood of the inhabitants of the communities along the Birim River*'.
- The sixth chapter covered data analysis and interpretation and discussion specifically for the third objective for this study which is to '*Determine whether locally available materials can be used to treat the contaminated water to WHO standards for drinking water for households in the affected communities*.'
- Chapter seven captured the summary of the findings, conclusions, and recommendations including recommendations for further studies. The content of the concluding chapter

includes comments on the research objectives, personal recommendations, and limitations of the research.

1.7 Definition of Key Terms

Artisanal and small-scale mining (ASM): Artisanal and small-scale mining is a complex and diversified sector that includes poor informal individual miners seeking to eke out or supplement a subsistence livelihood, to small-scale formal commercial mining activities that can produce minerals in a responsible way respecting local laws (IGF, 2020).

Water: It is a widely distributed substance that forms the oceans, rivers, lakes, and groundwater (UNESCO, 1998).

Heavy Metals: They are a group of 19 elements that have many similar physical and chemical properties and are remarkably varying from the remaining 97 known elements which can bind to vital cellular components, such as structural proteins, enzymes, and nucleic acids, and interfere with their functioning (Rajeswari & Sailaja, 2014).

Environmental Flows: It describes the timing and amount of water to be retained in lakes, rivers, streams, and estuaries to sustain seasonal patterns of high and low water levels needed for natural functions, processes, and resilience to persist. (Kendy et al., 2012).

Water Treatment: The act or process of making water more potable or useful, as by purifying, clarifying, softening, or deodorizing it (Collinsdictionary.com, 2019).

Water Quality: It can be defined as the chemical, physical and biological characteristics of water, usually with respect to its suitability for a designated use (Roy 2019).

Biosorption: It can be defined as the ability of biological materials to accumulate heavy metals from wastewater through metabolically mediated or Physico-chemical pathways of uptake (Fourest & Roux 1992).

Licensed / legal ASM: Operations that have a mining license and environmental permits as required by law (McQuilkin & Hilson, 2016).

Unlicensed/illegal ASM: Operations that do not have a mining license and any environmental permits as required by law (McQuilkin & Hilson, 2016).

Galamsey: An adulteration of the English phrase ‘gather them and sell’, used in Ghana to refer to illegal, unlicensed, and informal artisanal and small-scale mining (McQuilkin & Hilson, 2016).

1.8 Conclusion

The negative impacts of Artisanal and Small-Scale Mining on the environment cannot be overemphasized. This research makes important contributions to the discourse on Artisanal and Small-Scale Mining and provides useful information that can also inform policy and positively impact the lives of the people in the affected communities.

This introductory chapter is followed by a critical review of existing literature on the subject.

CHAPTER TWO

2. Literature Review

2.1 Introduction

This chapter presents a critical review of literature on water resources, environmental flows, water quality and quantity, artisanal and small-scale mining, water pollution, heavy metals contamination, biosorption, and regeneration.

2.2 Conceptual Framework

'Environmental engineering involves the development of processes and infrastructure for the supply of water, the disposal of waste, and the control of pollution of all kinds' (Nathanson, 2020 p.1). The key concepts involved border on air quality, land quality, and water quality. This research explored concepts in water quality including contaminants, impact on health, and treatment of polluted surface water and groundwater to meet the required quality standards. The concepts surrounding water resources management, the environmental impact of ASM, management of the policies and interventions applied to mitigate undesirable effects of ASM are discussed. The study also considered the treatment of polluted water. Figure *2.1* illustrates the conceptual framework.

The research focussed on surface water and groundwater which serve as the main sources of drinking water for some communities in Ghana. River Birim which serves as a drinking water source for several communities has been polluted by ASM operations. Although ASM contributes to the growth of economies and improves the living standards of the individuals involved (Ntori, 2017), it is also characterized by a vicious economic cycle of relative economic prosperity followed by resource depletion (Anderson, 2013).

According to Hill (2010), surface water pollution can sometimes reach groundwater and once groundwater is polluted, it can remain that way for a very long time. The fate and transport of contaminants are affected by a variety of chemical, physical, and biological processes (Fetter, 1993). Failure to put measures in place to manage and properly dispose of inorganic/organic compounds ranging from Arsenic to Zinc has caused contamination of water supplies (Ahuja, 2013). Some of these compounds, such as heavy metals, have devastating effects on the health of people who are exposed to them. This study conceptualizes the effects of ASM on water and the resultant effect on the users of the polluted water. It further explores concepts in the policy and regulation of water pollution resulting from mining and further explores the concepts in treating water polluted by mining activities. The aim is to develop a point-of-use treatment system using affordable and available local materials which can therefore help reduce the negative effects of contaminated water on the health of the people.

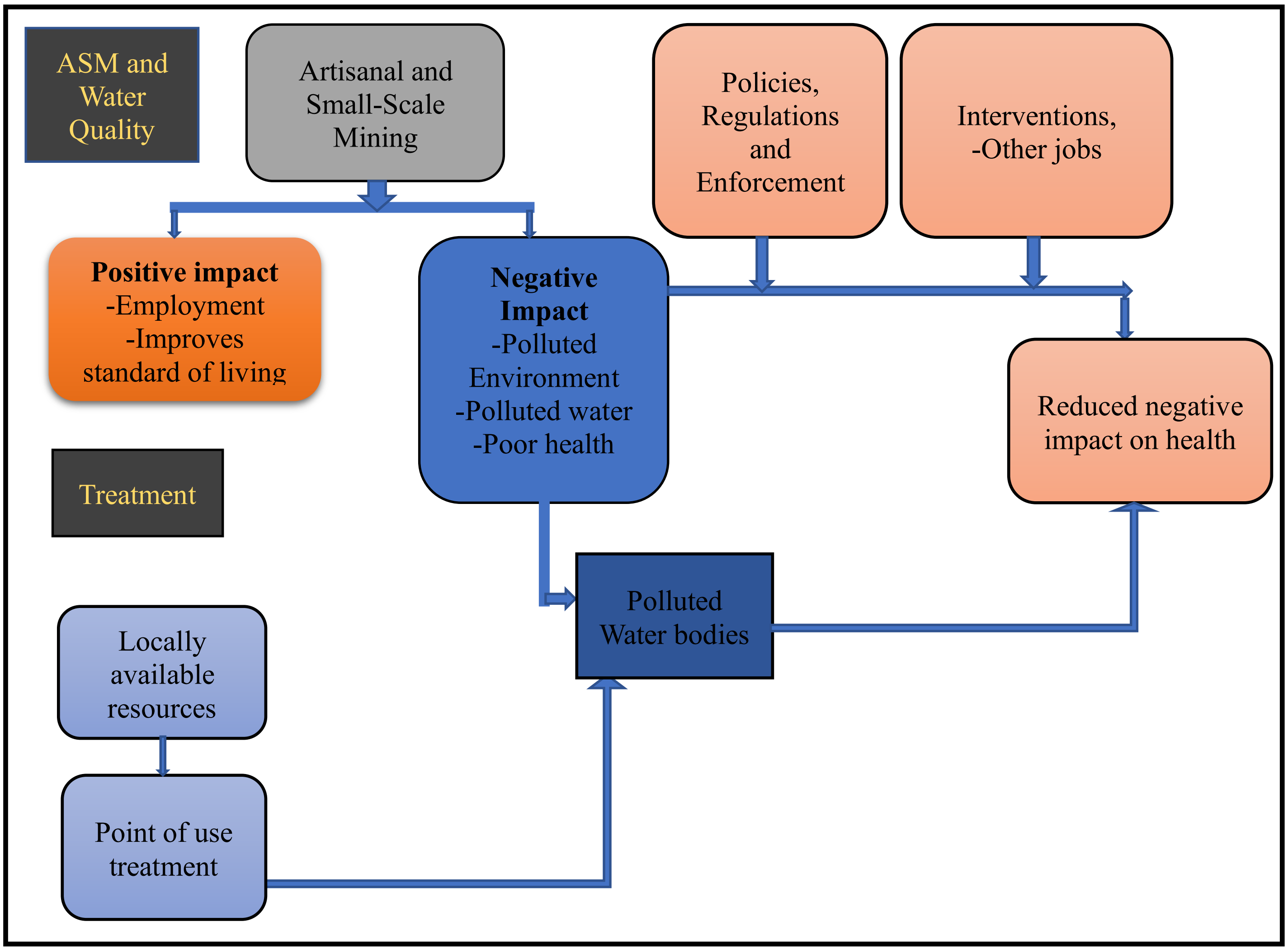


Figure 2.1: Conceptual Framework (present study)

2.3 Water Resources

Water is essential to sustain life, and a safe and adequate supply must be available to all (WHO 2011). Water, the most important and widespread resource on earth, can exist in three states; liquid, solid, and vapour. Water resources which circulate naturally and recharges constantly (Oki & Kanae, 2006), play a vital role in our environment and human life (WHO, 2011; UNESCO, 1998).

Water is a widely distributed substance that forms the oceans, rivers, lakes, and groundwater. About 97.5% of the water on earth is saline and only 2.5% is freshwater (UNESCO 1998). Human beings consume freshwater and depend on various waterbodies for other purposes. Many people have the illusion that water resources are immutable and in-exhaustible because natural water has magnificent properties and can renovate during the water cycle and self-purify (UNESCO 1998). This has led to a careless attitude in the use and contamination of surface and groundwater. Previously, water was regarded as a free commodity and considered unlimited in quantity and available as required. However, with population growth and urbanization, there has been rapid growth in demand for diverse purposes including water for irrigation, hydropower generation, industrial processes, fisheries, and aquatic ecosystem protection, making the resource increasingly scarce and often of inferior quality (Ghana Water Policy document, 2007).

All over the world, there has been a massive anthropogenic change in the hydrological cycle of rivers and lakes, affecting their water quality and quantity. This has led to several studies being carried out to assess water resources around the world and to determine how water can be preserved. Alcamo et al. (2007) analysed the impact of socio-economic driving forces and climate change on future global water stress using a global water model and they concluded increase in water withdrawal for domestic use due to income growth, is the main cause of growing water stress. Oki & Kanae (2006) believe that the flow of water should be the main focus in water assessments.

2.4 Water Resources in Ghana

Ghana is well endowed with water resources with an estimated total actual renewable water sources of 53.2 billion m^3 per year and total water available from surface water sources is 39.4

billion m^3 per annum (Namara et al., 2011). According to the Ghana Water Policy Document (2007), Ghana's water resources are generally divided into surface and groundwater sources. In Ghana, water resources are mainly used for water consumption, irrigation, and livestock watering (Owusu et al., 2016,) and domestic and industrial urban water supplies are based almost entirely on surface water resources. The main non-consumptive uses of water are hydropower generation, inland fisheries and water transport (Yeleriere et al., 2018). The first hydroelectric dam, constructed in 1965, which created one of the largest man-made lakes in the world, covering an area of about 8,500 km, is located 100 km from the source of the Volta River (Gyau Boakye, 2001).

Sarpong (2018) believes the water resources are sufficient to meet present and future water demands. Despite the availability of water to meet the present and future demands, there is a shortfall in water distribution. A national demographic and household survey found that only 40% of urban residents have piped water in their homes (Sarpong, 2018). There are also problems of high iron and fluoride contents in water in parts of the country including the Northern, Western and Upper East regions (Ghana Water Policy document, 2007).

2.4.1 Surface Water

Surface water sources are mainly from three river systems: The Coastal, Volta and South Western river systems. The Red, Black, and White Volta Rivers as well as the Oti River makes up the Volta system (Barry et al., 2005). Tano, Ankobra, and Pra rivers make up the South-Western river system and Tordzie/ Aka, Densu, Ayensu, Ochi-Nakwa, and Ochi-Amissah rivers make up the Coastal river systems (Yeleliere et al., 2018). The only significant natural freshwater lake in Ghana is Lake Bosomtwi, which is a meteoritic crater lake with a surface area of 50 km^2, and a maximum depth of 78 m, located in the forest zone, (Ghana Water Policy document, 2007).

Ghana has five river basins; the Densu River basin, the Ankobra basin, the Pra basin, the Tano basin, and the White Volta basin (Ghana Water Policy document, 2007). The drainage network of River Pra comprises the main Pra river and its major tributaries of Birim, Anum, and Offin rivers and their tributaries (Owusu et al., 2016). The Birim River is one of the main tributaries of River Pra.

Rainfall in Ghana generally decreases from the south-west of the country (2,000 mm/year) towards the north (950 mm/year) and the southeast (800 mm/year). The mean annual runoff of Ghana is about 54 billion m^3 but there are wide disparities between the wet season and dry season flows (Ghana Climate Change Policy Report, 2013).

2.4.2 Groundwater

About groundwater resources, Ghana has three main geological formations, namely the consolidated sedimentary formations underlying the Volta basin (including the limestone horizon), the basement complex formation comprising crystalline igneous and metamorphic rocks; and the mesozoic and cenozoic sedimentary rocks (Yeleliere et al., 2018). In Ghana, majority of the rural communities depend on groundwater in addition to rivers for drinking water, however, although groundwater is abundant, it has been affected by pollution which has rendered it unsafe for drinking purposes (Dorleku et al., 2019).

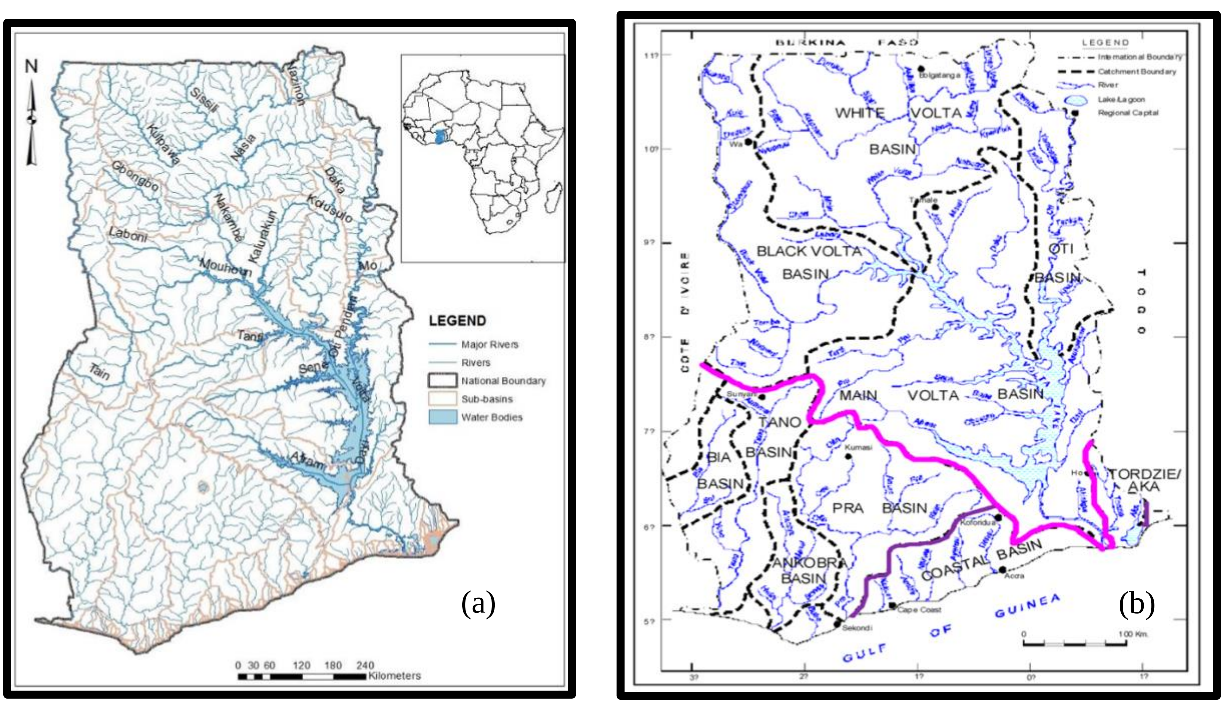


Figure 2.2: Water Network in Ghana (a) and Major River Basins in Ghana (b)
Source: Sidibé (2016) (a) and Ghanamaritime.org (b)

2.5 Ghana Water Policy

Water governance is often made up of social, economic, and political organizations and institutions and their relationships which are seen as important for water management and development (Hukka et al., 2010). A national water policy document is expected to present a broad, integrative vision of the influence of good water management on national development (Cashman, 2012). Water is considered an essential natural resource in Ghana. Article 269 of Ghana's 1992 Constitution, makes provision for the creation of an agency responsible for the management and regulation of the utilization of these natural resources and the coordination of policies related to them. The Water Resources Commission was established by the Water Resources Commission Act, 1996, Act 522 for the regulation and management of the utilization of water resources in Ghana and related matters. The Ministry of Water Resources and Works and Housing is the lead government institution responsible for water policy and has the overall responsibility for water resources management and drinking water supply in the country. The Ghana Water Policy, 2007 outlines Ghana's Water Vision for 2025. The vision seeks to promote an efficient and effective management system and environmentally sound development of all water resources in Ghana. However, a cursory glance at the poor state of water bodies in the country does not indicate commitment towards achieving this vision. There seems to be lack of coordination between the various institutions (BTI 2020).

Other sector ministries deal with sector-related issues such as irrigation under the Ministry of Food and Agriculture, fisheries under the Ministry of Fisheries, hydro-power under the Ministry of Energy, and water transport under the Ministry of Harbours and Railways (Owusu et al., 2016; Ghana Water Policy document, 2007). In addition to the Water Resources Commission, there is the Water Directorate; the Environmental Protection Agency; the Ghana Water Company Limited; the Community Water and Sanitation Agency, and the Public Utilities Regulatory Commission (Sarpong, 2018). With these institutions in place to ensure the protection and preservation of water bodies, one can deduce that a lot of inefficiencies and lack of coordination has led to the pollution of water bodies in the country.

Since the beginning of the 1980s, several policy reforms in the water sector that were intended to improve efficiency were introduced by the Government of Ghana (Ghana Water Policy document, 2007). These policies have not been effective in protecting water bodies, preserving the environment, and providing safe water to some communities especially those in the rural areas.

2.6 Environmental Flows

Environmental flows describe the timing and amount of water needed to be retained in streams, lakes, rivers, and estuaries to sustain seasonal patterns of high and low water levels needed for natural processes, functions, and resilience to continue (Kendy et al., 2012).

According to Maasri (2013), environmental flow is a major component of an Integrated Water Resources Management (IWRM) and accounts for the volume of water assigned for the functioning of the ecosystem. Implementing environmental flow systems, provides a favourable means to protect and restore wetland, riverine, and estuary ecosystems, their vital environmental services, and cultural/societal values (Arthington et al., 2018). While an all-natural flow of rivers, streams etc. provides some environmental benefit, Kendy et al. (2012) suggest the need to allocate a portion of water in lakes, rivers, streams, and estuaries to meet needs of the society for crop production, water supply, energy generation, and flood management and this requires a careful assessment and integration of competing uses. Environmental flow is therefore an important tool for allocating water among several, competing uses in a river basin or watershed and reaching agreement on allocation decisions (IUCN, 2019) based on scientific understanding of how fluctuations in the natural flow system affects ecological conditions (Kendy et al., 2012).

The call for a world-wide implementation of environmental flows was prepared at the 10th International River Symposium and Environmental Flows Conference in Brisbane Australia in 2007. The Declaration proposed a new definition of environmental flows as ‘the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems’ (Arthington et al., 2013). Environmental flow is therefore not entirely a matter of sustaining a healthy ecosystem but also supporting riparian livelihoods (Maasri, 2013).

About 50% of rivers, wetlands and lakes have been lost during the twentieth century (Maasri, 2013) and thus the need to incorporate flow management into river basin development to provide the means to reach an agreement on how to manage trade-offs between infrastructure development such as dams for hydropower and agriculture, livelihoods and ecosystems (IUCN, 2019). Globally, flow alteration is among the most severe threats to freshwater ecosystems (Kendy et al., 2012). However, this often occurs during artisanal and small-scale mining activities when the flow of the river is interrupted and diverted to create mine ponds.

According to Arthington et al. (2013), the introduction of the Ecological Limits of Hydrologic Alteration framework (ELOHA) developed by an assembly of researchers, agency scientists, and NGOs in 2010 was a good contribution to Environmental flow and they believe holistic flow–ecological models for rivers can be developed by researchers based on this framework which provides a scientifically robust basis.

Implementing environmental flows requires learning by doing approach, flexibility in effectively negotiating the objectives and outcomes of environmental flows and a step-by-step approach that gains in-country ownership (IUCN, 2019).

2.7 Water Quality and Quantity

UNEP/WHO (1996) defined water quality as a term used to express the appropriateness of water to sustain numerous uses or processes with particular uses having specific requirements for the biological, physical or chemical characteristics of water. According to UN-Water (2011), over the years, as the human population grows, industrial and agricultural activities expand and climate change threatens to cause major changes to the hydrological cycle, decreasing water quality has become a global issue. Poor water quality has a direct impact on water quantity in several ways because polluted water that is not good for consumption or other domestic purposes, effectively reduces the amount of useable water available within a given area (UN-Water 2011). Water quality, therefore, deserves increased attention alongside water quantity in water resource management.

According to Meybeck & Helmer (1996), water bodies can be fully described by the three main components: physio-chemistry, hydrology and biology, and a complete water quality assessment is based on the appropriate monitoring of these components. According to Siegel (2008), different water qualities are required for various uses, and failing to meet the water quality standards for these specific uses can result in illness in humans and even death. Each designated use of water has different defined chemical, physical and biological standards necessary to support that use (Roy, 2019). For example, water to be used for drinking or swimming will have more strict water quality standards compared to water used in agriculture or industry. Improved water quality, sanitation and better management of water resources, can boost a country's economic growth and can contribute greatly to poverty reduction (WHO, 2019).

Some physical parameters used to characterize water are temperature, color, odor taste, turbidity, pH, conductivity, and total dissolved solids. Some chemical parameters are hardness, calcium, magnesium, chloride, sulphate, fluoride, alkalinity, nitrate, phosphate, and toxic metals include lead, cadmium, iron, copper, chromium, zinc, mercury, and manganese (Roy, 2019).

Natural factors such as geological, hydrological, topographical, biological and meteorological in the drainage basin influences the composition of surface and underground waters, and this varies with seasonal changes in weather conditions, run-off volumes, and water levels (UNEP/WHO, 1996). The composition of the recharge water, the interactions between the water and the soil, residence time, and reactions that take place within the aquifer amongst others, affects the quality of groundwater (Meybeck & Helmer, 1996). The quality of surface waters and groundwater is affected by both natural processes and human activities (UN-Water, 2011).

Human intervention has also significantly affected water quality through the building of dams, draining of wetlands, diversion of flow amongst others (UNEP/WHO, 1996). They added the polluting activities such as the discharge of domestic, urban, industrial, and other wastewaters into the watercourse are more obvious.

According to UN-Water (2011), four fundamental strategies to combat water quality problems are the prevention of pollution, treatment of polluted water, safe use of wastewater, and restoration and protection of ecosystems. They noted that these strategies are very vital and should underpin water policies to protect and preserve water bodies.

2.8 Water Treatment

Treatment strategies for contaminated water range from high technology, energy-intensive approaches to low technology, biologically and ecologically focused approaches (UN-Water, 2011). Water treatment may require mechanical, chemical, physical, and biological methods to remove contaminants to make the water suitable for its required purpose. Treatment methods include coagulation, flocculation, sedimentation, filtration, and disinfection (Yanful, 2017). Household water treatment technologies are methods employed to treat water in the home or at the point of use in other settings (UN-Water, 2011).

According to WHO (2013), both conventional community and household systems follow the same basic water treatment processes of sedimentation, filtration, and disinfection. The removal of biological pathogens from water is usually the main focus of household water treatment because of the significant health risk but some of the treatment options are also able to remove chemicals and improve the physical qualities of drinking water (WHO, 2013). Metals such as lead, cadmium, and arsenic can be removed from water using activated carbon (Hill, 2010; Karnib et al., 2014; Yanful, 2017).

According to Stubbe et al. (2016), the provision of affordable safe drinking water is necessary where safe piped water supply is neither feasible nor reliably available. It is vital to understand the condition of the local source of water in terms of its quality and contaminants to be able to select the right combination of household water treatment options because, different household water treatment technologies remove different types of contaminants to different levels (Stubbe et al., 2016; Yanful, 2017).

2.9 Drinking-Water Quality Guidelines

Drinking water comes largely from rivers, lakes, wells, and natural springs, and these sources are often exposed to several conditions that can contaminate water. In developed countries, water bodies are generally cleaner compared to developing countries (Hill, 2010) and this can be because regulations are better enforced in developed countries. Drinking water guidelines provide the recommendations of the World Health Organization (WHO) for managing the risk from hazards that may compromise the safety of drinking water (WHO, 2011).

According to WHO (2011), water can be contaminated by pathogens, harmful chemicals from human activities, chemicals, and minerals from the natural environment, such as arsenic, fluorides, and some non-harmful contaminants that may only affect colour, the taste, smell or temperature of the water, and make it unacceptable to the community and aquatic life.

The WHO provides guidelines and not standards mainly because it provides the advantage of the use of a risk-benefit approach in establishing national standards and regulations specific to the country and appropriate for the situation within the nation (WHO, 2011). The researcher observed Ghana and Canada have similar drinking water guideline values with the WHO although there are few variations with some parameters.

2.10 Mining

Mining is the extraction of economically valuable minerals such as gold, diamond amongst others from the earth's surface (Balasubramanian, 2016). Mineral exploitation contributes significantly to economic growth and development in most world economies and provides adequate and dependable supplies of minerals and materials to meet their economic and defense needs (Mensah et al., 2015).

Stakeholders who benefit from mining activities suggest that mining can be carried out with minimum damage to the environment (Balasubramanian, 2016). However, the aspect of minimal environmental damage is questionable considering the effects of mining projects on water quality and the availability of water resources within the affected mining communities (IFC/WHO 2007).

According to (Smith, 2019), there are four main mining methods: underground, open surface (pit), placer, and in-situ mining. Mero, et al., (2017) indicate that more than two-thirds of the world’s yearly mineral production is estimated to be extracted by surface mining. The three most common types of surface mining are open-pit mining, strip mining, and quarrying. According to ELAW (2010), open-pit mining is a type of strip mining which necessitates the removal of layers of overburden in order to reach the ore deposit which usually extends very deep in the ground. They added that in many instances, clearing, cutting and burning of vegetation together with logging of trees precede the removal of the overburden.

Countries like Ghana rely on forest mines for 41% of their gold production and in the boreal forests of Canada and Russia, 38% and 50% of gold mines respectively are located in forests, and 100% of mining-related forest loss in Russia over the last ten years has been from natural forests (Ranieri, 2020).

Ghana is the second-largest gold producer in Africa. Mining in Ghana is either large-scale mining or artisanal small-scale mining (Hilson 2001). Yankson & Gough (2019) noted that in the past, the two have co-existed on the same mineralised land without much contact or conflict, as large-scale mining occurred underground and ASM operated mainly on the surface. He suggested that in recent times, large scale miners have transitioned from underground labour-intensive mining operation to capital-intensive surface activity and this has bought about some conflict with artisanal small-scale miners (Yankson & Gough, 2019).

2.11 Artisanal and Small-Scale Mining

According to IGF (2020), 'Artisanal and small-scale mining is a complex and diversified sector that includes poor informal individual miners seeking to eke out or supplement a subsistence livelihood, to small-scale formal commercial mining activities that can produce minerals in a responsible way respecting local laws' pp.1.

Artisanal and small-scale mining (ASM) operations exist in several countries around the world and the industry contributes to economic growth although its activities have adverse effects on the environment (Ntori, 2017; Rajaee et al., 2015). According to Anderson (2013), Artisanal gold mining accounts for approximately 50% of the world's artisanal and small-scale mining.

The 2017 IGF report stated that artisanal and small-scale mining is recognised as an important source of revenue for millions of people in about 80 countries worldwide. ASM takes place in diverse regions of the world, mostly in Africa, South America, Asia, Central amongst others (IGF, 2017; Anderson, 2013).

Over 40 million people globally work in artisanal and small-scale mining including 10 million people who live in 40 countries in sub-Saharan Africa who are directly engaged in ASM (World Bank & Pact, 2019). The World Bank & Pact, 2019 report stated that 16.3 million people worked in small-scale mining in South Asia, 9.8 million people in East Asia and the Pacific, 9.9 million in sub-Saharan Africa, a little over 2 million in Latin America and the Caribbean, 1.9 million in the Middle East and North Africa and 100,000 in Eastern Europe and Central Asia (Hobson, 2019).

Artisanal and small-scale gold mining (ASGM) generates almost 30% of Brazil's gold production, and employs up to 500,000 people (Raniera, 2020). Artisanal and small-scale mining activities are also common in Indonesia (Aspinall, 2001). A study conducted by Nurcholis et al, (2017) in Wonogiri, an artisanal gold mining area in Indonesia showed that, the concentrations of heavy metals were high in the artisanal gold mining area. They added that the distribution pattern of heavy metals in the area indicated that the contamination was caused by the mining (Nurcholis et al, 2017). High levels of heavy metals have been identified in several ASM communities in countries such as Ghana (Borte-Sam et al, 2015, Hilson et al, 2007; Rajaee et al, 2015). According to Hobson (2019), a Reuters investigation found out that billions of dollars' worth of gold is being smuggled out of Africa.

2.12 Artisanal and Small-Scale Mining in Ghana

Artisanal and small-scale mining activities have been carried out in Ghana for several years. Small-scale mining activities were abolished during the colonial era when the Europeans introduced large-scale gold mining (Kessey & Arko, 2013). Nevertheless, ASM has dominated the mining industry in Ghana from traditional times, through the colonial period and the early independence period to the present era (Sarpong, 2017). The ban was lifted in 1989 by the passing of the Small-Scale Mining Law, 1989. Over the years, small-scale mining has contributed to the production of gold in Ghana and the creation of employment for the unskilled labor force in rural communities (Sarpong, 2017).

ASM is a practice that is largely poverty-driven and involves basic techniques of mineral extraction, unsafe working conditions, highly manual processes, and frequently negative human and environmental health impacts (Hilson, 2002). According to Kessey & Arko (2013), the industry is a major employer of the rural labor force and a major source of revenue for rural communities. Artisanal miners do not make huge profits but strive to make sufficient money to support their immediate family (Anderson, 2013).

Approximately 1.1 million Ghanaians directly participate in ASM, while a further 4.4 million are considered to be dependent on ASM (IIED 2019). However, ASM activities have polluted waterbodies in the country (Afum & Owusu, 2016; Borte-Sam et al, 2015).
Access to equipment and formal finance, and, difficulties in obtaining a license are the most significant challenges facing Ghanaian small-scale miners and communities, identified through the literature review and stakeholder consultations (McQuilken & Hilson, 2016).

2.13 Policy Framework of Artisanal and Small-Scale Mining

Several policies have been implemented over the years, to prevent illegal small-scale mining and to protect the environment but they have not been successful. McDonald et al. (2014) believe that regulations on ASM alone have proven ineffective in curbing impact on aquatic ecosystems. They suggested that the regulations should be followed by a comprehensive approach that includes training and educational programs, targeted at miners and other relevant stakeholders in order for the regulations to be effective. According to McQuilken & Hilson (2016), for several years, the policy framework for Ghana's mining sector has focused mainly on the development of large-scale mining activities. They noted that one of the questionable moves by the government was the introduction of the Inter-Ministerial Task Force known as Operation Vanguard on Illegal Mining, which conducts sweeping operations to arrest illegal miners and seize their equipment. The authors opined that although there is the need to regulate and penalize illegal miners, the operation vanguard intervention has been ineffective at reducing illegal operations because it does not address the root cause of the problem. They recommended a three-way approach to deal with ASM issues: geological prospecting, land allocation, access to finance, and streamlined licensing. Policy issues related to ASM are discussed in chapter four.

2.14 ASM Operations and Waste

Most ASM operations occur near water bodies such as lakes or along streams and rivers for easy access to water needed for operations such as panning, sluicing or washing, and amalgam preparation (Rajaee et al., 2015). This has led to the destruction of several water bodies.

Amankwah (2013) described two conventional mining methods used by small scale miners. He observed that gold could be extracted by pounding gold quartz in a metal mortar with a metal pestle into powder form or by the washing of the soil in a sluice box. In the first method, the gold quartz could be extracted stones from pits of mining companies, especially by illegal miners. The gold-holding ores are then hacked from rock surfaces using a hammer and sometimes blasted with dynamite and the broken rocks are then brought to the earth's surface for pounding. The gold quartz is then crushed into pieces and the broken gold quartz is then pounded to form powdered grains that are then sieved. The powdered grains (gold dust) are then placed on a pan and rotated underwater to enable the heavier gold particle to settle under the pan. This is then further treated with mercury to amalgamate the gold particles, and the mixture is then squeezed in a white or light-colored cloth to release the mercury before the gold is subjected to fire (Amankwah, 2013).

With the second method, Amankwah (2013) indicated that a group of miners dig the soil hosting gold and mix it with water to form a slurry. A sluice system with a jute sack is set up to collect the gold particles. The system is set up by raising one side of the sluice to form a slope and the sluice is lined with the jute sacks to trap the gold particles. The slurry is fed into the sluice box and washed gently along the slope. The jute sacks are then removed and washed in a large pan full of water to release the gold particles. The water in the pan is gradually poured out and the mud gently washes out leaving the gold particles in the pan. The gold particles are then poured into a bowl for further treatment with mercury.

Amankwah (2013) notes that the method of gold extraction whereby the rock is crushed is more environmentally acceptable compared to the one that uses the sluice box. However, the former poses a health risk associated with the inhalation of the gold dust and the danger of collapsed mine which can be prevented by applying appropriate safety mechanisms. Akabzaa & Darimani (2012) argue that mine tailings which are mostly crushed ore and rock, pose potential threats to water quality and human health. Proper management of this waste often requires extensive trucking to offsite locations which is often not done due to limited resources. Thus, tailings are generally allowed to sit indefinitely in communities, either in sedimentation ponds or as piles (Akabzaa & Darimani, 2012). A review of some studies conducted in Ghana indicated that for licensed small-scale gold mining operators in the Offin River, 21% treat their tailings before discharging into the Offin River, 52% discharge directly into the river without treatment, and 27% store them in mining pits (Kessey & Arko 2013). Oyarzun et al. (2011) suggest that wastes generated by mining activities are much greater than the economic products they yield. The information above raises the question of whether the environmental impact experienced is worth the economic benefits obtained from mining.

A life cycle analysis of Artisanal and Small-Scale Gold Mining (ASGM) in Peru that examined ASGM mining impacts, found that alluvial mining required 49,019,000 L of water in the sluicing/washing step to produce one kilogram of concentrated gold ore (99.5% gold) from 23,922 tonnes of ore and thus 2,049 L of water was required to process 1 tonne of ore (Rajaee et al., 2015). Long et al. (2013) reported that samples collected from gold-washing pools at mining sites had very high concentrations of contaminants with one pool containing Al of over 460,000 μg/L and Cr, Mn, Ni, Cu, Zn, and Pb at concentrations of over 1,000 μg/L each.

2.15 Impact of ASM

ASM activities have often led to the release of mining waste into rivers, ponds, streams, wells, and boreholes for drinking water, and has resulted in severe heavy metal contamination, and deforestation (Bortey-Sam et al., 2015). The levels of heavy metals such as arsenic, lead and cadmium have increased in artisanal mining communities although they are naturally occurring pollutants in the environment (Obiri et al., 2016) and people who live near sites where these metals have been improperly disposed of are exposed to these metals by ingestion through drinking and eating or inhalation (Martin and Griswold, 2009).

According to Anderson (2013), problems such as acid mine drainage, deforestation, erosion, river silting, and the pollution of soil and water with toxic compounds arise because artisanal and small-scale mining operations are often illegal and poorly regulated with miners having no title to the land they work on and therefore no motivation for sustainable land management (Twerefour, 2009; Kessey & Arko, 2013).

Many children and youth in rural mining communities have engaged in mining activities instead of focusing on their education and Agbesi (2017) believes that the idea of acquiring money through simple means has been the motivation behind some children and youth abandoning school to engage in small scale mining activities.

Calys-Tagoe et al. (2015) sought to describe physical injuries associated with ASGM in Ghana. They interviewed 404 small-scale miners in a survey about occupational injury experienced in the past 10 years. The findings indicated that nearly a quarter (23.5%) of the miners reported getting injured during the period, and the overall injury rate was 5.39 per 100-person years. The authors noted the rate was considerably higher for women (11.93 per 100-person years) and those with little mining experience. They stated those who had worked for less than a year had a rate of 25.31 per 100-person years. They also noted that the most injury-prone mining activities were excavation (58.7%) and crushing (23.1%), and over 70% of the injuries were reported to be due to miners being hit by an object. They added that approximately one-quarter of the employees reported that their employers never seemed to be interested in their welfare or safety.

News of deaths resulting from collapsed pits are reported regularly however, the death tolls have not served as a deterrent to the miners and illegal mining is still on the rise in rural communities (Sarpong, 2017). Water, soil and sediment samples from mining communities and ASM sites have exceeded guidelines for arsenic, cadmium, manganese, mercury, lead and other metals, acidity and turbidity (Rajaee et al., 2015; Bortey-Sam et al., 2015; Ntori, 2017; Tetteh et al., 2010). Arsenic contamination of groundwater has been reported in several countries including Ghana and prolonged drinking of arsenic-contaminated water can result in arsenicosis which can lead to slow and painful death (Ahuja, 2013). Mercury pollution has already been identified as a lingering problem in several of Ghana’s important small-scale gold mining communities (Hilson et al., 2007) and this further leads to the contamination of drinking water sources. According to Siegel (2008), different water qualities are required for various uses and, failing to meet the water quality standards for these specific uses can result in sickness in humans and even death.

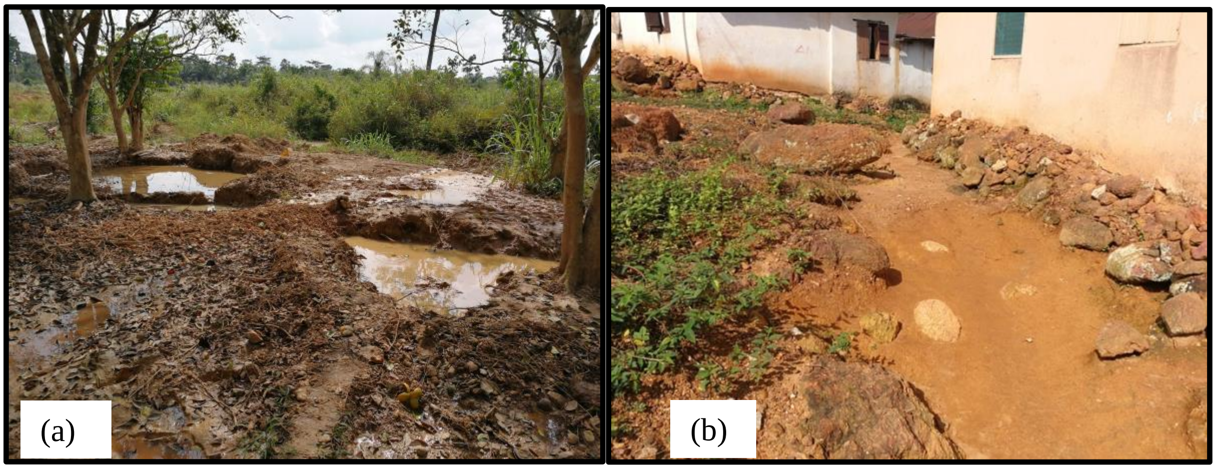


Fig.2.3: ASM impact of Orange Plantation (a) and Erosion at Apapam due to ASM (b) (present Study)

2.16 Mining and Water Pollution

The continuing increase in socio-economic activities worldwide has been accompanied by an increase in the rate of pollution on the aquatic environment and pollutants can be released into the environment as gases, dissolved substances, or in the particulate form (Meybeck & Helmer, 1996). For easy access to water for mining operations, ASM operations usually occur near water bodies and thus are easily polluted (Rajaee et al., 2015).

According to the Executive Secretary of the Ghana Water Resources Commission, as of 2017, about 60 percent of Ghana's water bodies had been polluted, with many in very critical condition (Pulse Ghana, 2017).

According to IFC/WHO (2007), three water pollution sources can occur from mining and these are Acid Mine Drainage (AMD)/Acid Rock Drainage (ARD), Erosion, and Sedimentation and Pollution by Processing Chemicals. Their explanation of the three pollution sources is summarised as follows:

- **Acid Mine Drainage (AMD)/Acid Rock Drainage (ARD)**: When mined materials (tailings, waste rock, and heap and dump leach materials, etc.) are excavated and exposed to oxygen and water, acid can form. The acid formed dissolves metals and other contaminants from mined materials to form a solution that is acidic, high in sulfate and metals. Acid drainage and contaminant leaching is the most important source of water quality impacts related to metallic ore mining (IFC/WHO, 2007).

- **Erosion and Sedimentation**: Due to the large area of land disturbed by mining operations because vegetation is stripped and trees are cut down, erosion can be a major concern at hard rock mining sites. Erosion control is necessary from the beginning of operations through to the completion. (IFC/WHO, 2007). The soil is washed into water bodies which increases the turbidity of the water.
- **Pollution by Processing Chemicals**: Mercury is commonly used in the amalgamation of gold although it is very toxic. The concentration of mercury varies considerably, even within a specific ore deposit. For example, 10 tons of mercury are potentially released to the environment, if the mercury content in gold ore is 10 mg/ kg, and one million tons of ore is processed at a particular time. This is a major source of mercury and therefore needs to be controlled (IFC/WHO, 2007).

2.17 Heavy Metal Contamination

The impact of heavy metals which are usually toxic on human health is currently an area of interest due to widespread exposure of heavy metals that are encountered in several environmental and occupational circumstances (Mahurpawar, 2015). Metals which are particularly problematic, persist in water bodies for long periods, providing a long-term source of contamination to the aquatic life because, metals do not break down in the environment (IFC/WHO 2007). Heavy metals which are a group of 19 elements with many similar chemical and physical properties, can bind to vital cellular components of the body and interfere with their functions (Rajeswari & Sailaja, 2014).

Long-term exposure to heavy metals can have severe health effects including carcinogenic, circulatory, central, and peripheral and nervous systems effects (Jaishankar et al., 2014). Lead, Cadmium and Mercury do not have any biological significance or beneficial use among the 19 heavy metals, and they are known to be extremely toxic (Rajeswari & Sailaja, 2014). In 2014, inadequate treatment and testing of water resulted in a series of major water quality and health issues related to high lead concentrations for Flint residents in Michigan (Denchak, 2018).

Some research has been carried out to determine the concentrations of heavy metals in water bodies and the environment (Banunle et al., 2018; Hadzi et al., 2015). In some of the studies, the heavy metal concentrations were generally within the WHO limits for surface water and drinking water. Banunle et al. (2018) sought to determine the physio-chemical properties and heavy metal status of the Tano River along the catchment of the Ahafo Mine in the Brong-Ahafo Region of Ghana. Their results showed that concentrations of heavy metals were also relatively low and all fell within acceptable of the EPA and WHO except for the concentrations of lead which were slightly higher than the recommended threshold at both the upstream and downstream of the river. Hadzi et al. (2015) in their study sought to determine the distribution and health risks of heavy metals in surface water from both pristine environments and major mining areas in Ghana. Their results showed that the mean concentrations of heavy metals ranged from 1.747 mg/L for iron (Fe) to 0.001mg/L for mercury (Hg) and 0.453 mg/L for Fe to 0.002 mg/L for Hg in water samples at the mining sites. In some other research studies (Kpan et al., 2014; Afum & Owusu, 2016; Bortey Sam et al., 2015), the heavy metal concentrations exceeded the WHO limits for drinking water. Kpan et al. (2014) sought to determine the level of heavy metal contamination in the environment due to the activities of the small-scale miners. Their results indicated that in most locations, the concentration for the investigated heavy metals far exceeded the concentration admitted by the guidelines. They observed that the mean concentration of Lead was 95.13 mg/kg for soil and 190.27 mg/L in water; Copper was 63.26 mg/kg in soil and 75.92 mg/L in the water and Mercury was 140.87 mg/kg in soil and 211.31 mg/L in water. Afum & Owusu (2016) in their study assessed the level of heavy metals (Cr, Fe, Ni, Zn, As, Cd, Hg, and Pb) in the Birim River of Ghana. The result obtained showed that the Birim River is heavily polluted with heavy metals, with high heavy metal concentrations located in areas where small scale mining is dominant. Bortey Sam et al. (2015) in their research sought to assess the health risk associated with the consumption of water from boreholes in 18 communities in Tarkwa, by measuring the concentrations of heavy metals and metalloid. Their results showed that mean concentrations of heavy metals exceeded the recommended values.

Investigations were also carried out on heavy metal contamination of agricultural produce. Bempah & Ewusi (2016) investigated the impact of a gold mine on heavy metals (As, Cd, Cr, Cu, Pb, Hg, Ni, Fe, Mn, and Zn) pollution and evaluated the potential health risks to residents through the consumption of vegetable crops grown at three community farms surrounding the mine at Obuasi municipality of Ghana. The vegetable samples they analyzed showed a high accumulation of As and Ni above the acceptable values for consumption. They noted that unacceptable non-cancer health risk levels were found in vegetable samples analyzed for As, Pb, and Hg. Ahiamajie et al. (2011), analyzed five species of commonly consumed vegetables to assess the concentration of 12 elements in five mining and three non-mining towns. Their results indicated that about 50% of the total concentrations recorded for cadmium and arsenic were found to be above the World Health Organization (WHO) permissible levels.

Armah et al. (2014) reviewed heavy metals of anthropogenic origin in environmental media and biota in the context of gold mining in Ghana. The authors observed that the most common biological markers of heavy metal exposure used by the various studies reviewed were urine and hair although concentrations of heavy metals reported by the studies reviewed for nails were higher than for hair. They noted that published results of the levels of heavy metals in a goldmine and non-mine workers yielded contradictory results.

2.17.1 Lead

Lead (Pb) is a naturally occurring bluish-gray heavy metal available in small amounts in the Earth's crust and has high toxicity (Nordic 2003; Tiwari 2013). Freshly cast lead is silvery in color but in the presence of air, the surface oxidises and turns dull grey to bluish-grey (Nordic, 2003). Lead is one of the most abundant heavy metals but due to its stability in contaminated sites, its toxic effects cause environmental and health problems (Tiwari, 2013). Lead toxicity affects almost every function in the human body (Rubin and Strayer, 2008). In 2013, the World Health Organization estimated 143,000 deaths were as a result of lead poisoning and 600,000 new cases of children with intellectual disabilities each year are due to lead exposure.

According to Nas & Ali (2018), lead's concentration accumulates in the environment with increasing hazards due to its important properties like softness, ductility, poor conductibility, malleability and corrosion resistance which seems to make it difficult to give up its use. Once lead is released in to the environment, it stays in circulation because it is not degradable (Nordic, 2003).

In countries like the US and Canada, the use of lead has been controlled up to a certain extent, unlike most developing countries (Wani et al., 2015). The health effects of Lead can be found in Table 2.1.

2.17.2 Cadmium

Cadmium (Cd) is a silvery-white, soft, ductile toxic metal which has been classified as a carcinogen (Sharma et al., 2015). It is generally present in the environment at low levels; however, human activity such as smoking, welding, mining etc. has greatly increased those levels (WHO, 2013). Cadmium has many uses, including metal coatings, batteries, pigments, and plastics and electroplating (Mahurpawar, 2015).

According to Mahurpawar (2015), cadmium is toxic to animals and plants and many micro-organisms in the environment and does not degrade in the environment to less toxic products but rather accumulates in the kidneys and liver of vertebrates and invertebrates. The health effects of Cadmium can be found in Table 2.1.

2.17.3 Arsenic

Arsenic (As), which is a metalloid because it has properties of both metals and non-metals is widely distributed throughout Earth’s crust, generally as arsenic sulfide or as metal arsenates and arsenides (WHO, 2013). According to Martin & Griswold (2009), arsenic is odorless and tasteless and can be released in larger quantities through volcanic activity, erosion of rocks, forest fires, and human activity such as mining into the environment although it occurs naturally in the environment. They noted that arsenic is also found in fertilizers, pesticides, paints, dyes, metals, drugs, soaps, and semi-conductors, and animal feeding operations. By high-temperature processes, arsenic can be released to the atmosphere predominantly as trioxide (WHO, 2013).

Seafood abound in organic arsenic compounds, which are less harmful to health and are rapidly eliminated by the body but inorganic arsenic is a known carcinogen and can cause cancer of the skin, lungs, liver, and bladder (WHO 2013). Intake of inorganic arsenic over a long period can lead to chronic arsenic poisoning (arsenicosis) because it is acutely toxic (Ghosh, 2015; Shankar et al., 2014). The symptoms can take years to develop depending on the level of exposure. Nausea and vomiting, abnormal heart rhythm, reduced production of red and white blood cells damage to blood vessels, amongst others can be cause by low level exposure to arsenic (Martin & Griswold, 2009).

According to Ghosh (2015), the main route of human exposure for arsenicosis is the consumption of groundwater contaminated by arsenic. A 2007 study found that over 137 million people in more than 70 countries are probably affected by arsenic poisoning from drinking water (Rajeswari & Sailaja, 2014; Shankar et al., 2014)). According to Mahurpawar (2015), long-term exposure to inorganic arsenic in drinking water in Taiwan caused black foot disease, in which the blood vessels in the lower limbs were severely damaged, resulting eventually in progressive gangrene. Arsenic contamination of groundwater has led to a massive epidemic of arsenic poisoning in Eastern India and Bangladesh (Ghosh, 2015). According to Lokuge et al. (2004), consumption of arsenic-contaminated-water in Bangladesh resulted in about 9,100 deaths and 125,000 disability-adjusted life years in 2001. The health effects of Arsenic can be found in Table 2.1.

2.17.4 Mercury

Mercury (Hg) occurs naturally and exists in various forms with different toxicities and implication for health: elemental, inorganic (e.g., mercuric chloride); and organic (e.g., methyl and ethyl-mercury) (WHO 2007). Dietary ingestion is the major source of human exposure to methylmercury, especially through seafood and fish (Mahurpawar, 2015). Metallic mercury is used to produce chlorine gas and caustic soda and is also used in thermometers, dental fillings, switches, light bulbs, and batteries (Martin & Griswold, 2009). Toxicity assessment is complicated for mercury because the exposure scenario varies for the different forms (WHO 2007). Mercury, the only metal that is liquid at room temperature, is used for gold amalgamation and has been part of the mining industry since 2700BC (Tschakert & Singha, 2007).

Alhassan et al. (2019) investigated the course of the mercury lost into the environment. Their results showed that 2 g of mercury was lost to the environment for every gram of gold recovered through ASM. The noted that due to roasting of the amalgam, 39% of the mercury was lost to the atmosphere whilst the remaining 61% was lost into water and spillage onto the ground. They noted that mercury was kept in eye-drop bottles for amalgamation on the sites and handled with bare hands. They observed that amalgamation on site was done by mixing unknown mass or volume of mercury depending on the miner's choice.

Nartey et al. (2011) assessed mercury pollution in rivers and streams around artisanal gold mining areas of the Birim North District of Ghana. They observed that the total mercury concentrations measured downstream were significantly higher than concentrations in samples taken upstream. They added that in both the dry and wet seasons, the total mercury concentration measured in the stream water samples the WHO guideline limit for drinking water. The health effects of Mercury are captured in Table 2.1.

2.17.5 Iron

Iron is the second most abundant metal and fourth most abundant element in the Earth's crust of which it accounts for about 5% (WHO, 2013). The iron ions Fe^{2+} and Fe^{3+} readily combine with oxygen and sulfur-containing compounds to form oxides, hydroxides, carbonates, and sulfides therefore elemental iron is rarely found in nature. Iron is most commonly found in nature in the form of its oxides (WHO, 2003). It is also present in many rock-forming minerals, including mica, garnet, amphibole, pyroxene, and olivine. The abundance of Fe in sedimentary rocks is determined by various factors including pH-Eh conditions, the extent of diagenetic alteration, and grain size. Iron participates in a wide variety of metabolic processes, including oxygen transport, electron transport and deoxyribonucleic acid (DNA) synthesis, and is therefore an essential element for almost all living organisms (Abbaspour et al., 2014). Low pH and the presence of dissolved organic matter mainly controls iron (Nada et al., 2007).

According to Hassan et al. (2017), dissolution of iron can occur as a result of decrease in pH and oxidation. They added it has been thoroughly documented by many researchers that Fe has the potential to alleviate metal toxicity by limiting metals uptake in different plants. They believe that Fe improves plant physiological, morphological, and biochemical parameters by neutralizing metals toxicity. Nada et al. (2007) support this claim because they reported that iron has been found beneficial regarding its role as reducing heavy metals toxicity in various plants. They observed from their research that Fe declined Cd toxicity by enhancing plant growth, photosynthetic pigments, and chloroplast quality in almond seedlings.

2.17.6 Manganese

Manganese is considered to be the twelfth most abundant element and the fifth most abundant metal in Earth's crust and (WHO, 2013). Manganese is required for the functioning of many cellular enzymes and can serve to activate many others which makes it important for human and animal function (WHO, 2011). Manganese has over 100 minerals mainly as oxides, silicates and carbonates, and but is not found naturally in its pure form (ATSDR, 2000). Fireworks, batteries, and glass are all products that contain manganese (ATSDR, 2000; WHO, 2013). Manganese violet, the inorganic pigment is widely used in in cosmetics and is also found in certain paints (Cannon et al., 2017). Organic forms of manganese are used as smoke inhibitors, fungicides, fuel-oil additives, an anti-knock additive in gasoline, and a medical imaging agent (Cannon et al., 2017).

According to Cannon et al. (2017), manganese occurs naturally in many surface water and groundwater sources and in soils that may erode into these waters. They added that however, human activities are also responsible for much of the manganese contamination in water in some areas. They noted that workers at manganese mining and processing facilities have the greatest potential to inhale manganese-rich dust and without proper protective equipment, these workers may develop a permanent neurological disorder known as manganism or manganese poisoning.

There is some controversy as to whether the neurological effects observed with inhalation exposure to manganese, also occur by oral route, although manganese is often regarded as one of the least toxic elements (WHO. 2011).

2.18 Health Effect of Heavy Metals

Obiri et al. (2016) in their research, carried out a human health risk assessment of artisanal miners exposed to toxic metals in water bodies and sediments in the Prestea Huni Valley District of Ghana. From their results, the mean concentrations of As, Cd, Pb, and Hg in water samples ranged from 15 μg/L to 325 μg/L (As), 0.17 μg/L to 340 μg/L (Cd), 0.17 μg/L to 122 μg/L (Pb,) and 132 μg/L to 866 μg/L (Hg), They calculated the cancer and non-cancer health risks from exposure to these metals in surface water bodies and sediments. They observed the hazard quotient (HQ) results obtained from this study in most cases were above the HQ guidance value of 1.0 and the cancer health risk results were found to be higher than the USEPA guidance value. Table 2.1 captures the impact of some heavy metals on the health of humans.

Table 2.1: Source of Heavy Metals and Health Effects

Heavy metal	Major source	Toxic effect
Lead	Mining, paint, pigments, electroplating, manufacturing of batteries, burning of coal	Anemia, brain damage, anorexia, malaise, loss of appetite, Liveliverdney, gastrointestinal damage, mental retardation in children.
Cadmium	Plastic, welding, pesticide, fertilizer, mining, refining	Kidney damage, bronchitis, Gastrointestinal disorder, bone marrow, cancer, lung insufficiency, hypertension, Itai-Itai disease, weight loss
Mercury	Batteries, paper industry, paint industries, mining	Damage to the nervous system, protoplasm poisoning, corrosive to skin, eyes, muscles, dermatitis, kidney damage
Arsenic	Smelting, mining, rock sedimentation, pesticides,	Bronchitis, dermatitis, bone marrow depression, hemolysis, hepatomegaly, cancer of the skin, lungs, liver, and bladder, diabetes

Source: Abbas et al (2014), Rubin and Strayer (2008), Tiwari (2013), WHO (2013), Sharma et al (2015), Martin and Griswold (2009)

2.19 Heavy Metal Removal from Water

The removal of heavy metals from water is a very important step to prevent the negative health impacts captured above in table 2.1. According to Bisht et al. (2017), although these heavy metals are harmful to living organisms, they are released into water bodies and the environment and it is necessary to eliminate them to minimise the risk of uptake by animals, plants, and humans.

According to Bisht et al., (2017), methods for the removal of metal ions from aqueous solution mainly consist of physical, chemical, and biological technologies. Conventional technologies, such as solvent extraction, lime coagulation, chemical precipitation, reverse osmosis, membrane filtration, ion exchange, and adsorption, are used for the removal of heavy metal ions from aqueous wastes and each process has its own merits and limitations in application (Abbas et al., 2014; Bisht et al., 2017; Abdel-Ghani et al., 2009). In the last few decades, several methods have been developed and extensively investigated for heavy metal removal (Bisht et al., 2017). Some of these techniques, however, have disadvantages such as energy requirements, incomplete metal removal and high reagent and generation of toxic sludge or other waste products. The authors added that, among all these techniques, adsorption is economically favorable and technically easy to separate (Abdel-Ghani et al.,2009; Abdel-Raouf & Abdul-Raheim, 2017).

Researchers have over the years, worked using inexpensive materials such as natural and agricultural products and waste to remove heavy metals from aqueous solution (Abdel-Raouf & Abdul-Raheim, 2017)**.** Anderson (2013) suggested that in areas where ASM is practiced, new technology is necessary to support the sustainable exploitation of gold and other precious metals. He suggested that a simple, inexpensive, easy to operate, and financially rewarding technology will be appropriate. Adsorption is now widely used and accepted over conventional methods (Bisht et al., 2017).

2.20 Adsorption/Biosorption

Biosorption can be defined as the ability of biological materials such as leaves, seeds, husks, root tissue, algae etc. to take up heavy metals from wastewater through metabolically mediated or physio-chemical pathways of uptake (Abbas et al., 2014; Fourest & Roux, 1992). The biosorption process involves a solid phase (sorbent or bio-sorbent) and a liquid phase (solvent, usually water) containing a dissolved species to be sorbed (sorbate, for example, metal ions) till equilibrium is reached between the amount of solid-bound sorbate species and its portion remaining in the solution (Ramachandra et al., 2005; Ahalya et al., 2003). Biosorbents such as algae, fungi, bacteria, and yeasts have proved to be potential metal bio-sorbents but the degree of sorbent affinity for the sorbate determines its distribution between the solid and liquid phases (Volesky, 1986).

Some advantages of Biosorption include low capital and operating costs, the possibility of bio-sorbent regeneration and metal recovery, selective removal of metals, rapid kinetics of adsorption and desorption, and no sludge generation (Kratochvil & Volesky, 1998; Abbas et al., 2014). Initial metal ion concentration, temperature, pH, and biomass concentration in solution are the major factors that affect biosorption processes (Das et al., 2008).

Factors affecting the adsorption process include pH (as pH increases from 7.0 to 7.5, the retention capacity of the adsorbing surface increased significantly), temperature (as the temperature increases, the adsorption capacity is found to decrease and vice versa), pressure (with an increase in pressure, adsorption increases up to a certain extent till saturation level is reached) and surface area of adsorbent (as adsorption is a surface phenomenon, it increases with an increase in surface area) (Mishra & Tripathi, 2008; Matthew et al., 2016).

2.21 Bio-Adsorbents

Most adsorbents are highly porous materials, and the overall adsorption rate is determined by the adsorption process that takes place on the pore walls or at solute diffusion rate in the capillary pores of adsorbent. (Mishra & Tripathi, 2008). The square root of contact time with the adsorbent is equal to the rate of adsorption (Matthew et al., 2016). Biological materials, such as algae, bacteria, yeast, fungi, plant leaves, and root tissues (Volesky, 1986; Abbas et al., 2014) have proved to be potential metal bio-sorbents. According to Mohammed et al. (2011), most adsorption studies have focused on the development of adsorbents with high capacity and very few have been on the development of adsorbents that can be easily regenerated. Information on three bio-adsorbents; corn husk, moringa seeds, and coconut husk captured below.

2.21.1 Corn Husk

Corn husk is a waste material that is usually discarded but in recent times, researchers have explored such waste materials for various uses. Corn husk is used in some areas as a food wrap, corn husk cigars and crafts. Corn-husk is a ligno-cellulosic fibre with cellulose being the major constituent (Kambli et al., 2016).

According to Mendes et al. (2015), corn husk has low lignin content and similar amounts of hemicellulose and cellulose to those of the other fibers. They added that the corn husk biomass showed better tensile property than piassava and coir. They noted the surface morphology showed the presence of a large number of microfibrils in its structure and the crystallinity index of corn husk was 21-26%. Kambli et al. (2016) also showed that the morphological and physico-chemical properties of the extracted corn husk fibres are comparable to ligno-cellulosic jute fibre. More information on the characteristics of corn husk is captured in chapter six.

2.22.1 Moringa seeds (*Moringa Oleifera*)

Moringa Oleifera which is commonly known as 'drumstick tree' or 'horseradish tree', grows in the tropical and subtropical regions of the world (Gopalakrishnan et al., 2016). Due to their monounsaturated fatty acids content, Moringa oleifera seeds are a promising resource for food and non-food applications, (Leone et al., 2016). Moringa is widely cultivated across the world because it can withstand both severe drought and mild frost conditions (Gopalakrishnan et al., 2016). Leone et al. (2016) noted all parts of the Moringa tree including leaves, roots, flowers and seeds are good for human and animal use, and the leaves, which are rich in protein, antioxidant compounds minerals, and β-carotene, are used not only for human and animal nutrition but also in traditional and herbal medicine. According to Gopalakrishnan et al. (2016), the moringa seed is used in water treatment because it is a natural coagulant. More information on the characteristics of moringa seeds is captured in chapter six.

2.22.2 Coconut husk

Coconut grows in the tropics mainly in coastal areas at low altitudes, in environments of high humidity and high temperatures (Perera, 2012). According to Reddy & Yang (2015), about 62 million tons of coconuts are grown in about 92 countries across the world, and coconut trees or palms and husks of the coconut fruit have extensively been used as a source of fibres. More information on the characteristics of coconut husk is captured in chapter six.

2.22 Regeneration

The reuse of adsorbents and recovery of adsorbate has been reported by various investigators and various regeneration techniques such as thermal, electrochemical and chemical methods etc. have been reported (Kulkarni & Kaware, 2014, Lata et al., 2015**).** In heavy metal removal processes, regeneration of adsorbents is an important in the water treatment technology (Ali, 2012). For regeneration and reuse of adsorbents, various possible regenerating agents such as acids, alkalis, and chelating agents were used by many researchers with very limited success in some of the studies only up to a limited number of adsorptions–desorption cycles (Kulkarni & Kaware, 2014, Lata et al., 2015).

For effective regeneration of adsorbents and metal recovery, acids (such as HCl, H_2SO_4, HNO_3, HCOOH and CH,$_3$COOH), alkalis (such as NaOH, $NaHCO_3$, Na_2CO_3, KOH and K,$_2CO_3$), salts (such as NaCl, KCl, $(NH_4)_2SO_4$, $CaCl_22H_2O$, NH_4NO_3, KNO_3 and, $C_6H_5Na_3O_72H_2O$), deionized water, chelating agents and buffer solutions (such as bicarbonate, phosphate and,tris) have been used in various studies (Ali, 2016; Rasouli, 2019; Omorogie et al., 2016; Lata et al., 2015).

2.23 Conclusion

This chapter reviewed existing literature on water resources, environmental flows, water quality and quantity, artisanal and small-scale mining, water pollution, heavy metals contamination, biosorption, and regeneration.

A review of literature shows that surface water and groundwater can be negatively affected by ASM. However, ASM has been beneficial to several countries by providing employment and improving the standard of living for inhabitants in mining communities. A review of literature indicates there is consensus about the negative impact of ASM on water bodies. The impact of ASM on water bodies in mining areas is a very serious issue which can affect the health of inhabitants in mining communities through exposure to heavy metals. Heavy metals can be removed from water using bio-adsorbents to reduce the heavy metal related health risk on inhabitants of mining communities.

The literature review chapter is followed by the methodology.

CHAPTER THREE

3 Research Design and Methodology

3.1 Introduction

This chapter explains in detail the methods used in collecting data for this research. It describes the steps taken to address the hypothesis or research question (Rudestam & Newton, 1992). The chapter captures information on the research methodologies for the policy analysis for ASM in Ghana, the questionnaires and interviews, and the laboratory analyses for the removal of heavy metal from the contaminated water using corn husk, moringa seeds, and coconut husk.

The work employed both qualitative and quantitative research methods. According to Fellow & Liu (1997), using both qualitative and quantitative techniques to research a subject area can provide very powerful insights and results to assist in making inferences and in concluding. Using a triangulation of multiple methods mitigates the disadvantages of each approach whilst gaining the advantages of each. Specifically, this research used literature review, content analysis, questionnaires, interviews, and laboratory analysis. Samples of the questionnaire and interview guides are attached in the Appendices section. The literature review served as the foundation on which questions for the questionnaire and interviews were derived. A detailed description of the methods used to achieve the research objectives are discussed in this chapter.

3.2 Research Context

This study was conducted in the Birim River Basin which is a sub-basin of the Pra Basin in the Eastern Region of Ghana. Water samples were collected from the Birim river, its tributaries, mine ponds, and groundwater (wells/boreholes). Questionnaires were also administered to three rural communities along the Birim river: Apapam, Adadientem, and Adukrom.

3.2.1 Birim River Basin

The Birim River Basin is found in the Eastern Region of Ghana. The water bodies in the basin are important to communities within the basin because it serves as an important source of water for drinking and other domestic purposes. The basin has surface water and groundwater.

Asomaning (1992) assessed water resources within the basin including surface water and groundwater. From 13 meteorological and 1 river gauging stations located within the basin, they determined the mean annual rainfall was 1578 mm, total river discharge was 1,886,588 064 $m^3 a^{-1}$, surface runoff was 1,320,611,645 $m^3 a^{-1}$, and base flow 565,976,419 $m^3 a^{-1}$.

Asare-Donkor et al (2018) in their study noted that surface water in the Birim River Basin was observed to range from neutral to mildly acidic, and had a dominance of HCO_3^-, Cl^-, Ca^{2+}, Mg^{2+}, and Na^+ in ionic strength. They noted five major surface water types: Na–HCO_3–Cl, Na–Cl–HCO_3, Na–Ca–Mg–HCO_3, Na–Ca–Mg–HCO_3 and Ca–Na–Mg–HCO_3 were revealed from the Piper diagram. They indicated the Gibbs plot showed that the major ion chemistry of surface water in the Birim River basin was mostly influenced by atmospheric precipitation.

Banoeng-Yakubo et al (2009) in their study of the groundwater in the basin, identified two water types in the basin: waters that are rich in silica, calcium, sodium, bicarbonate, and magnesium ions, and are mainly influenced by the weathering of silicate minerals from the underlying geology, and waters that have been influenced by anthropogenic activities in the area and the effects of fertilizers. They concluded that montmorillonite which is probably derived from the incongruent dissolution of feldspars and micas, is the most stable silicate phase in the groundwater as the mineral speciation and silicate mineral stability diagrams data they generated suggested. They also opined that the apparent incongruent weathering of silicate minerals in the groundwater system has led to the enrichment of sodium, calcium, magnesium and bicarbonate ions as well as silica, and has led to the supersaturation of calcite, aragonite, dolomite and quartz.

Banoeng-Yakubo et al (2009) believe that the stability in the montmorillonite field restricts flow conditions and therefore makes groundwater residence time relatively high, which leads to greater contact of groundwater with the rock to enhance weathering. They stated that cation exchange processes have also been determined to play minor roles in the hydrochemistry (Banoeng-Yakubo et al., 2009).

Asomaning (1992) noted that from the data obtained, the surface runoff coefficient was 25%, the total runoff coefficient was 36%, and the base flow coefficient was 11%. He also calculated the Permanent Water Reserve, Qt = 5,333.20 × 106 m^3 and Recoverable Water Reserve, 2,133.28 × 10^6 m^3 a^{-1} for the aquifer of the basement complex aquifer of the basin from 42 boreholes (Asomaning, 1992).

3.2.2 River Birim

River Birim is a very important river in the Akim Municipality in the Eastern Region of Ghana. It runs through several communities in the municipality and serves as the main source of water for drinking and domestic purposes, fishing, and irrigation. The Birim takes its source from the Atewa range of hills in the Eastern Region of Ghana (Fig 3.1) and follows a course of 175 km to join the Pra River (Ansa-Asare & Asante, 2000). The Birim Basin is located between latitudes 0^o 20'W, 1^o 15'W, and longitudes 5^o 45'N, 6^o 35'N and has an estimated area of 3,875 km (Ansa-Asare & Asante, 2000). The basin is very rich in minerals such as gold, bauxite, diamond and manganese. This has attracted many artisanal and small-scale miners to the area to scout for these natural resources, especially gold. The gold mining operations generate large volumes of solid and liquid wastes in the form of waste dams: slime dams and tailings dams, some of which contain elevated concentrations of metals that are toxic and contaminate the river. Ghana has five river basins; the Densu River basin, the Ankobra basin, the Pra basin, the Tano basin, and the White Volta basin. The Birim River is one of the main tributaries of the River Pra in Ghana and the drainage network comprises the main Pra river and its major tributaries of Birim, Anum, and Offin rivers and their tributaries (Owusu et al., 2016). The source of the Birim River is the Atewa Range Forest Reserve (Lindsell et al., 2019).

3.2.3 Atewa Range Forest Reserve

Atewa Range Forest Reserve is in Eastern Region of Ghana. The forest is close to Kibi Apapam. Atewa Forest is 45 km in length and 12 km wide; it covers an area of 258 km^2 (ARocha, 2019). The Birim River, the Ayensu, and Densu Rivers take their source from the Atewa Range Forest Reserve (IUCN, 2016) as shown in Figure 3.1.

According to the Atewa feasibility study report by ARocha in 2017, the Atewa Range provides water for over 5 million people in Ghana. Within Ghana, Atewa Forest ranks as one of the most important forests, that remain unprotected. Atewa is designated as a Forest Reserve and it is recognized as a high priority ecosystem in West Africa due to its high species diversity, and great hydrological importance. However, it is subject to artisanal and small-scale mining, uncontrolled hunting, which is threatening its existence (Lindsell et al., 2019).

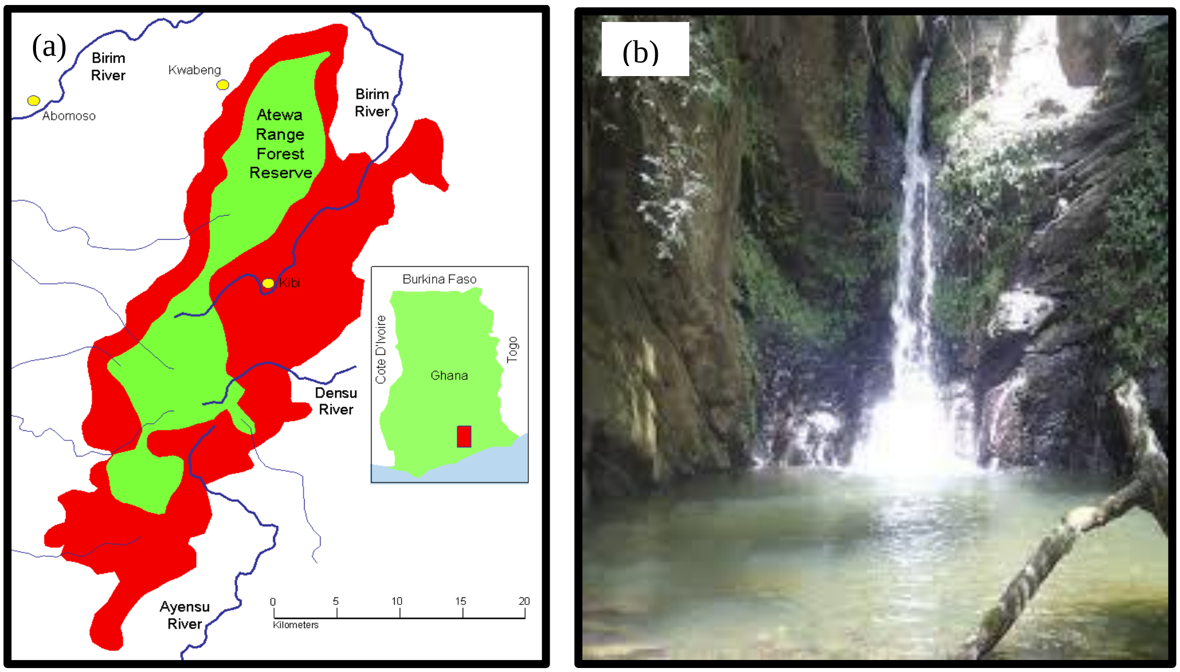


Figure 3.1: (a) Map of Atewa Range Forest Reserve and (b) Waterfall at Atewa Range Forest Source: cbd.int. (2018)

The forest has over 70 species classified as Critically Endangered, Endangered, and Vulnerable by the International Union for Conservation of Nature (IUCN) (Lindsell et al., 2019). Some of the species so classified include the Togo Slippery Frog *Conraua derooi*, White-naped Mangabey *Cercocebus lunulatus*, Nimba Flycatcher *Melaenornis annamarulae etc.* and over 570 species of butterflies already recorded, out of potentially 700 species which would make Atewa the richest forest for butterflies in West Africa (Lindsell et al., 2019).

Figure 3.2 (a) Atewa Range Forest Reserve in Ghana (b) Illegal mining in Atewa Forest
Source: Lindsell et al, (2019)

Figure 3.3: Warning Sign at Atewa Forest (Present Study)

3.2.4 Communities along River Birim and its tributaries

The Birim river flows through several rural communities from the Atewa Range forest till it joins the Pra river which empties into the sea. The first community the river flows through from Atewa forest is Apapam. Samples were taken from the following communities along the river: Kibi Apapam, Afiesa, Ahwenease, Adadientem, Kibi township, Abosua, Pano, Adukrom, Asiakwa, Bunsu, Nsuapemso, Ankaase, Anyinam, Kwaben, Asamanma, Asunafo, Abomosu, Amunum, Kade, Abodom, Twumwusu, Pram, Akim Akropon, Okyenso, Boadua, and Akwetia.

Three communities (Apapam, Adadientem and Adukrom) were selected for the administration of questionnaires based on their representation of the varying economic situations in the sampled communities. The questionnaires were administered to determine the perception of inhabitants of the communities on awareness of policies and the impact of ASM on their waterbodies, livelihood, and health.

3.3 The Climate of the Research Context

Ghana has a tropical climate with a dry season from December to March and a rainy season from April to November. Rainfall in Ghana generally decreases from the south-west of the country (2,000 mm/year) towards the north (950 mm/year) and the southeast (800 mm/year) and the total annual runoff is 56.4 billion m^3(Ghana Water Policy document, 2007) but the runoffs also have a wide disparity between the two seasons; wet and dry. Small-scale gold mining activities by some licensed operators take place all year round even during the dry season because they have relatively sophisticated equipment, unlike some unlicensed miners who operate mainly in the wet season with basic tools. Due to the seasonal variations in mining activities, water samples from the Birim river were collected during both the dry and wet seasons.

3.4 Research Methodology Framework

This research was divided into three parts with each beginning with a literature review. The three sections represent the three objectives of this study. The first part of the research focused on evaluation of policies on small scale mining in Ghana. The second part focused on water quality analysis of water bodies in the Birim Basin, administration of questionnaires (quantitative), and conducting of interviews (qualitative). Close-ended and open-ended questions were employed in the collection of data and appropriate quality assurance procedures and precautions were also carried out to ensure the reliability of results. The questionnaire and interview questions were sent to the University of Western Ontario’s Research Ethics Board for approval before the questionnaires were administered and interviews were conducted. The third part was the laboratory analysis to treat water contaminated with heavy metals using locally available materials in the communities (in Ghana), such as corn husk, moringa, seeds, and coconut husk. The research design and methodology for each part of the research are described in detail in this chapter. The research framework which summarises the methodology is shown in Figure 3.4.

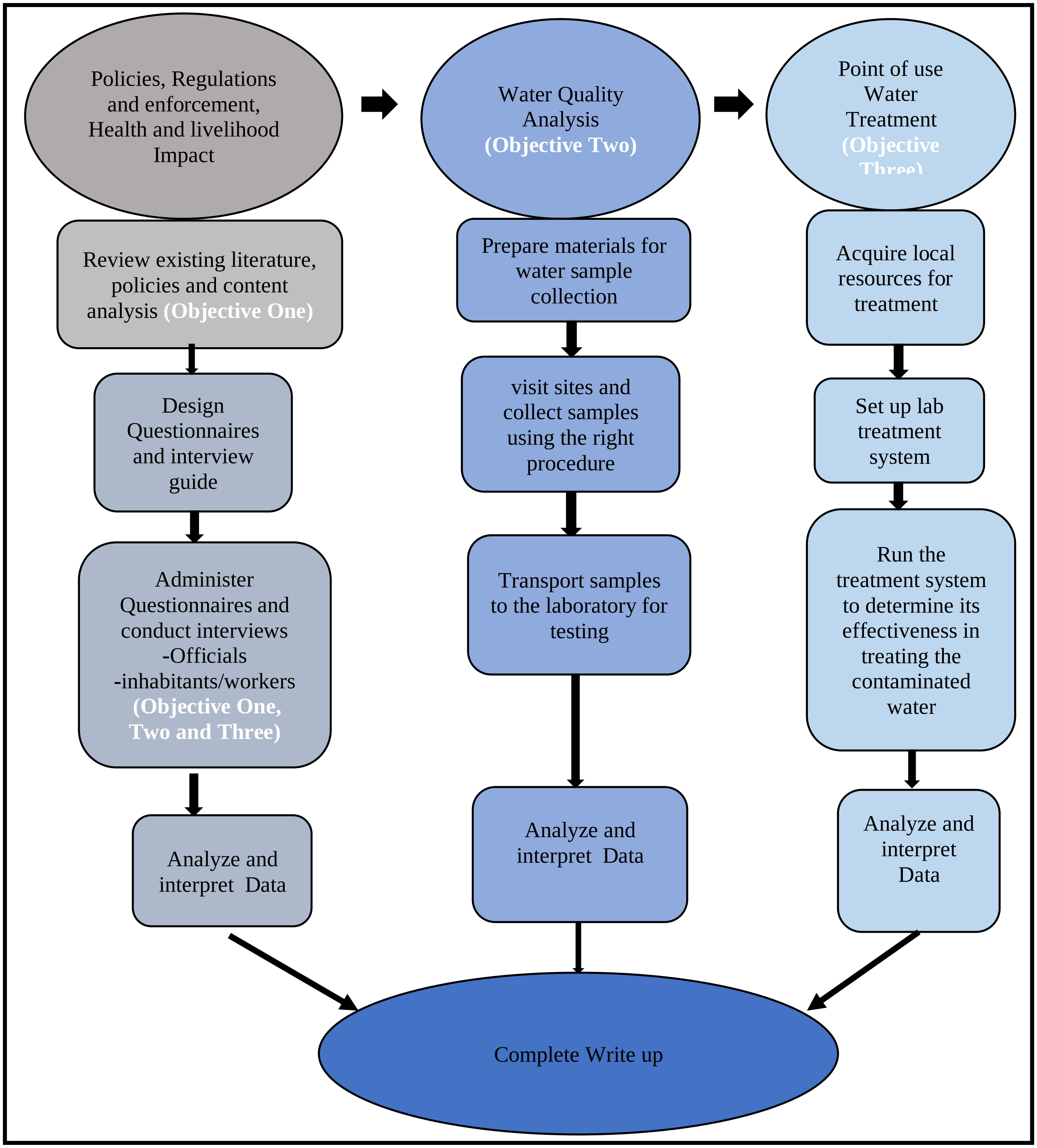


Figure 3.4: Summary of Research Methodology (Present Study)

3.5 Methodology to achieve Objective One (1)

The first objective of this study was to '*Evaluate and Analyze existing policies and regulations with regards to Artisanal and Small-Scale Mining (ASM) Ghana and their enforcement*'.

The Specific Tasks carried out to achieve Objective One included:

- Review of literature on policies and regulations on ASM, Water Resources, Environmental flows, parliamentary Hansards and Media content (Global, Western, Developing Economies and Ghanaian Context)
- Interview with inhabitants of mining communities and some public officials using an interview guide (Appendix I) with regards to existing policies and their effectiveness. Section B of the questionnaire also captured questions on awareness of policies and their effectiveness.

3.5.1 Literature Review

A comprehensive review of literature about Artisanal and Small-Scale mining (licensed and unlicensed) and its effect on water resources, the environment, health, and livelihoods of people in various mining communities was carried out. The policies in Ghana related to Artisanal and small-scale mining issues were also reviewed. Information from primary, secondary, and tertiary sources was used but information from the source material was mainly looked at so that information from reviewed articles and secondary sources are not solely relied upon.

3.5.2 Research Methodology for Policy Evaluation/Analysis

This study used content analysis, a research tool that allows the researcher to examine claims and narratives in the policy debate on artisanal and small-scale mining in Ghana. Parliamentary debates from Hansards and media content analysis from 2010 to 2020 were used to explore the claims and narratives of various stakeholders to provide more insight into the artisanal and small-scale mining policy issues. The Hansards (2010 to 2020) were obtained from the Parliament of Ghana website. Keywords such as 'artisanal and small-scale mining' or '*galamsey*' were used to search for online articles and news reports. Hansards were reviewed from 2010 because *galamsey* activities were reported to have intensified since 2010. In 2016, one major campaign message from the majority of political parties centered on 'solving the illegal artisanal and small-scale mining issue'. In the present research, claims, opinions, and beliefs about artisanal and small-scale mining by members of parliament and other interest groups were critically examined.

3.6 Methodology to achieve Objective Two (2)

The second objective of this study was to '*Assess the level of contamination of the water bodies in the mining communities and the impact on the health and livelihood of the inhabitants in mining communities along the Birim River'*.

The specific tasks carried out to achieve this objective included;

- Collection of water samples from Birim River, tributaries, wells/boreholes, and mine ponds.
- Testing of the samples in the laboratory for the level of contamination of arsenic, cadmium, iron, mercury, manganese, and lead, Physio-chemical parameters, and Total Organic Carbon (TOC)/Dissolved Organic Carbon (DOC).
- Administration of questionnaires to mining workers and non-mining inhabitants in the community on the impact of ASM activities on water resources, land, health, and livelihood of the people.
- Conducting interviews with some key persons in the mining communities.

3.6.1 Water Sample Collection

The level of contamination of Arsenic, Cadmium, Mercury, Iron, Manganese, and Lead in the Birim River, Tributaries, Wells/Boreholes, and Mine ponds were assessed. Water samples were collected to determine the level of contamination of Arsenic, Cadmium, Mercury, Iron, Manganese, and Lead in addition to the physicochemical parameters (temperature, pH, true and apparent colour, conductivity, alkalinity, bicarbonate, Total Suspended Solids (TSS), Total Dissolved Solids (TDS) and TOC/DOC. These specific contaminants were the focus of this research because they have been identified by several researchers (Rajaee et al., 2015; Bortey-Sam et al., 2015; Ntori, 2017; Tetteh et al., 2010) to be in higher amounts compared to other heavy metals. In their integrated assessment paper on artisanal small-scale mining in Ghana, Rajaee et al., (2015) noted the mean concentrations of arsenic and cadmium in water samples from some artisanal and small-scale mining sites were 348% and 1,108% higher than the recommended WHO permissible guideline value of 10 µg/L and 3.0 µg/L, respectively. Six of the sampling sites exceeded the WHO standard of 10 μg/L lead but none of the non-mining sites had mean concentrations above the guideline values for arsenic, cadmium, and lead in water.

Figure 3.5: Water sample collection at Birim Basin (Present Study)

3.6.1.1 Sampling Method

An initial 12 samples were collected and a full water quality assessment was conducted to determine the parameters the researcher had to focus on. Fifty (50) sites along the Birim River were later sampled during June-September and December-March. Purposive and snowball sampling were used in identifying the mining sites and communities along the Birim River. One hundred and two (102) water samples were collected during both rainy and dry seasons including two repeat samples. The samples were collected using grab sampling technique from midstream of the river wherever possible. Samples were collected along the River Birim. The choice of the sampling sites was based on the presence and intensity of ASM mining activities and their proximity to water bodies and accessibility to the site. Forty-two (42) water samples were collected from the Birim River (two repeat samples from a confluence), twenty-four (24) water samples from Tributaries (two water samples from Tributaries of a Tributary), twenty-four (24) water samples from wells/boreholes and twelve (12) water samples from mine ponds. In collecting water samples, conditions that could affect sampling operations were considered. Water sampling procedures by U.S. Geological Survey (USGS) National Water-Quality Assessment Program (NAWQA) were followed. Conductivity, temperature, and pH were measured in the field.

According to USGS (2006), data quality control begins before the first sample is collected from the site, by ensuring the use of proper equipment, being aware of the requirements for data quality, and being careful to avoid potential sources of sample contamination.

Water samples were collected into clean 500 mL plastic containers and 200 mL bottles obtained from the SGS laboratory in Ghana. The sampling bottles were rinsed three times with the water to be sampled at each spot before it was fully immersed in the water for collection with the bottle opening facing the direction of streamflow. The collected water samples were acidified by adding 1 mL of 10% analytical grade nitric acid to ensure that metal species remained in solution (Afum & Owusu, 2016: Bhardwaj et al., 2017). The samples were stored at 4 ºC in an ice chest before they were taken to the laboratory for analysis. One hundred and four (104) water samples in total were delivered to the laboratory to check the water quality and heavy metals including two repeat samples (BR21) and two distilled water samples -blanks (BRMP 21) which were added for quality control checks. Forty (40) water samples were delivered to the laboratory for Total Organic Carbon (TOC)/Dissolved Organic Carbon (DOC) analyses for both seasons.

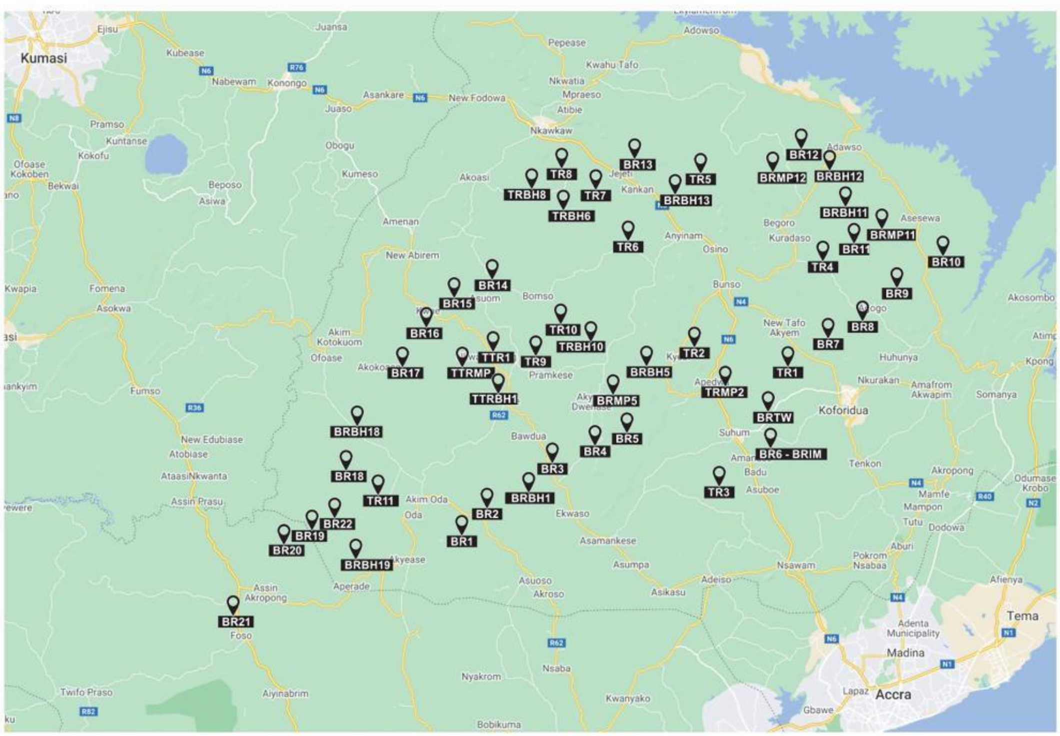


Figure 3.6: Map of Sampling Site Locations (Present Study)

Table 3.1: Sampling site location

	Name	Code	Latitude (N/S = /-)	Longitude (E/W = /-)
1	Atewa Forest	BR1	6.135426	-0.6059
2	Apapam	BR2	6.145468	-0.598137
3	Afiesa	BR3	6.15777	-0.588652
4	Ahwenease	BR4	6.160258	-0.583544
5	Adadientem	BR5	6.164568	-0.576289
6	Kibi Waterworks	BR6	6.162751	-0.549402
7	Pano	BR7	6.178507	-0.541159
8	Adukrom	BR8	6.212754	-0.519166
9	Asiakwa	BR9	6.261904	-0.472925
10	Bunsu	BR10	6.281386	-0.465083
11	Nsuapemso	BR11	6.318836	-0.463486
12	Ankaase	BR12	6.376363	-0.501811
13	Anyinam	BR13	6.386159	-0.552821
14	Abomosu	BR14	6.296422	-0.719632
15	Amunum	BR15	6.269354	-0.745754
16	Okyenso	BR16	6.220795	0.792497
17	Abodom	BR17	6.145923	-0.810866
18	Kade	BR18	6.084959	-0.83351
19	Birim-Moore Confluence	BR19	6.042673	-0.834533
20	Gyamanti (Akwetia)	BR20	6.042553	-0.840133
21	Apapam M	BRMP 1	6.137565	-0.596231
22	Apapam	BRBH 1	6.147106	-0.597243
23	Adadientem	BRMP 5	6.164568	-0.576289
24	Adadientem	BRBH 5	6.16721	-0.577301
25	Kibi Waterworks	BRTW 1	6.162751	-0.549402
26	Nsuapemso	BRMP 11	6.318858	-0.463898
27	Nsuapemso	BRBH 11	6.328358	-0.469924
28	Ankaase	BRMP 12	6.374868	-0.501504
29	Ankaase	BRBH 12	6.374115	-0.504707
30	Anyinam	BRBH 13	6.37304	-0.539559
31	Kade	BRBH 18	6.104876	-0.836211
32	Akwetia	BRBH 19	6.016613	-0.816447
33	Bukuru	TR 1	6.170981	-0.552721
34	Abosua	TR 2	6.170125	-0.568583
35	Krensen	TR 3	6.150775	-0.561361
36	Nsutem (Supon)	TR 4	6.307817	-0.472631
37	Anyinam Anikoko	TR 5	6.376337	-0.54563
38	Kwaben (Awusu)	TR 6	6.314503	-0.590212
39	Abresu	TR 7	6.338878	-0.674156
40	Si-Asunafo	TR 8	6.348539	-0.705255

	Name	Code	Latitude (N/S = /-)	Longitude (E/W = /-)
41	Pram	TR 9	6.155893	-0.685526
42	Akim Akropon (Mempong)	TR10	6.189629	-0.662818
43	Boadua (Moore)	TR 11	6.056443	-0.798315
44	Abosua	TRMP 2	6.168784	-0.567666
45	Asamanma	TRBH 1	6.339268	-0.670811
46	Asunafo	TRBH 8	6.34034	-0.708032
47	Twumwusu	TTRMP 1	6.152384	-0.731122
48	Twumwusu Fonsira	TTR 1	6.150972	-0.730905
49	Pramkese	TTRBH 1	6.15229	-0.726157
50	Akim Akropon	TRBH 10	6.193445	-0.659149

3.6.1.2 Field Equipment/Materials used

The following were used for the fieldwork:

- A field meter that measures pH, conductivity, and temperature,
- GPS to record location,
- Bottles to collect water liquid samples (500 ml bottles, 200 ml bottles)
- Temperature-controlled storage (large-sized ice chests)
- Writing kit (field notebook, pens, markers),
- Other practical accessories (rope, buckets, latex gloves, and masking tape).

Figure 3.7: Some field equipment (Present Study)

3.6.1.3 Water Quality Tests

Water samples were sent to the laboratory of the Council for Scientific and Industrial Research (CSIR) in Accra, Ghana to test for water quality parameters: Conductivity, pH, apparent colour, true colour, total suspended solids, alkalinity, and bicarbonate were tested on 104 samples.

Figure 3.8: Condition of Birim River at (a) Apapam (9th July 2018) (b) Bunsu (10th July 2018) (Present Study)

3.6.1.4 Heavy Metal Analysis

One hundred and four (104) water samples were sent to SGS laboratory in Tema, Ghana, to test for six heavy metals: lead, iron, cadmium, arsenic, mercury, and manganese. The laboratory tested for the concentration of heavy metals in the water samples using ICP-MS (inductively-coupled plasma-mass spectrometry). According to Wilschefski & Baxter (2019), a single quadrupole ICP-MS has six basic compartments which are; the sample introduction system where liquid samples are nebulised, inductively coupled plasma (ICP), ion optics, a mass analyser, interface, and detector where the ions are measured.

3.6.1.5 TOC/DOC Tests

Forty (40) water samples were sent to SGS laboratory in Germany for the TOC/DOC tests. This is because SGS Ghana did not have the facility carry out that test and there was no other laboratory in Ghana at the time of the research that offered TOC/DOC analysis.

According to Whitehead (2020), Total Organic Carbon (TOC) is an important parameter for monitoring organic compounds in water by measuring the total amount of carbon in organic compounds in pure water and aqueous systems. He added that the organic compounds are oxidised to forms such as carbon dioxide (CO_2) that can be quantified before they are measured by detection systems. He noted that the DOC procedure requires that the sample passes through a 0.45 µm filter before analysis. According to Potter & Wimsatt (2005), two approaches for the oxidation of organic carbon in water samples to carbon dioxide gas are combustion in an oxidizing gas and Ultra Violet (UV) promoted catalyzed chemical oxidation with a persulfate solution.

3.6.2 Questionnaire Administration

Quantitative surveys were conducted in three communities along the Birim River. The questionnaires enabled the researcher to gather responses in a standardized way and relatively fast way, although the closed ended questions limited the response of the people's views/ opinions. The target groups for the survey were residents in three mining communities with the following populations - Apapam (3127), Adadientem (1484) and Adukrom (4837) (Ghana Statistical Service, 2012). The sample size was calculated with a 5% margin of error and 95% confidence level. The survey was targeted at 400 participants using the random sampling technique. Purposive sampling was used in identifying the mining sites and communities. The structure of the questionnaire was based on information gathered from the literature review. The questionnaire was designed to assess the awareness level of the residents on mining policies and regulation, the impact of mining activities on their health and livelihoods, water bodies, and the environment in general. The questionnaire also assessed the importance of the waterbodies in the Birim basin to the communities and the water treatment methods used in the communities.

3.6.2.1 Questionnaire Instrument Description

The structure of the questionnaire included a series of multi-option questions with the opportunity for supporting detailed comments to be made below it. The questionnaire had five sections; Section A, B, C, D, and, E and a total of 59 questions, some with sub-questions. The questions that required respondents to select from possible options, made allowance for respondents to select 'I Don't Know' as an option instead of selecting a false answer or sitting on the fence and opting for a middle rating.

Section A had questions that provided general information about individuals such as their age, gender, marital status, level of education, occupation, involvement in mining activities, and the community to which they belonged. The information provided in this section helped in grouping the respondents and comparing responses based on communities, age, gender, marital status, level of education amongst others.

Section B had questions that provided information on involvement in ASM activities and awareness of policies and regulations related to ASM. This section provided information that addressed the first objective of the research.

Section C assessed the impact of ASM activities on the environment, the livelihood, and the health of the residents of the mining communities. Questions on residents' concerns about the environment, water bodies, and health were captured under this section. This section helped to achieve the second objective of the research.

Section D of the questionnaire examined the impact on children's health. Information on children was captured because of the numerous negative impacts of heavy metals on the health of children. This section also helped to achieve the second objective of the research.

Section E, the last section, sought to identify water treatment methods residents of the community used. This section helped to achieve the third objective of the research.

A sample of the questionnaire has been attached in Appendix 1.

3.6.2.2 Questionnaire Demographics

In Figure 3.9 (a), out of the 400 questionnaire respondents in the three communities, 30.8% of respondents were from Apapam (Community A), 26.3% from Adadientem (Community B) and 43% Adukrom (Community C). From 3.9 (b), 62.5% of respondents have lived in their community for more than 15 years, 9% have been there between 11 to 15 years, 11% from 6 to 10 years and 13.5% from 1-5 years, 3% for less than 1 year and 1% preferred not to disclose that information.

52.5% of the total respondents were males and 47.5% were females as shown in 3.9 (c). 17% of respondents were above 60 years, 21.8% were between 40 to 60 years, 52.8% were between 20 to 40 years and 8.5% were less than 20 years but above 18 years in fig 3.9 (d). Respondents that were single were 47.5%, 35.8% were married, 5.3% divorced and 11.5% were widows/widowers as shown in 3.9 (e). In Figure 3.9 (f), 8% have no formal education, 12.8% had primary school education, 53% had junior high/middle school education, 23.3% had senior high/vocational school education and 3% had tertiary education. In Ghana, until recently, there was free education up to junior high in public schools and thus the high percentage. Free Senior high school education was introduced within the last four years.

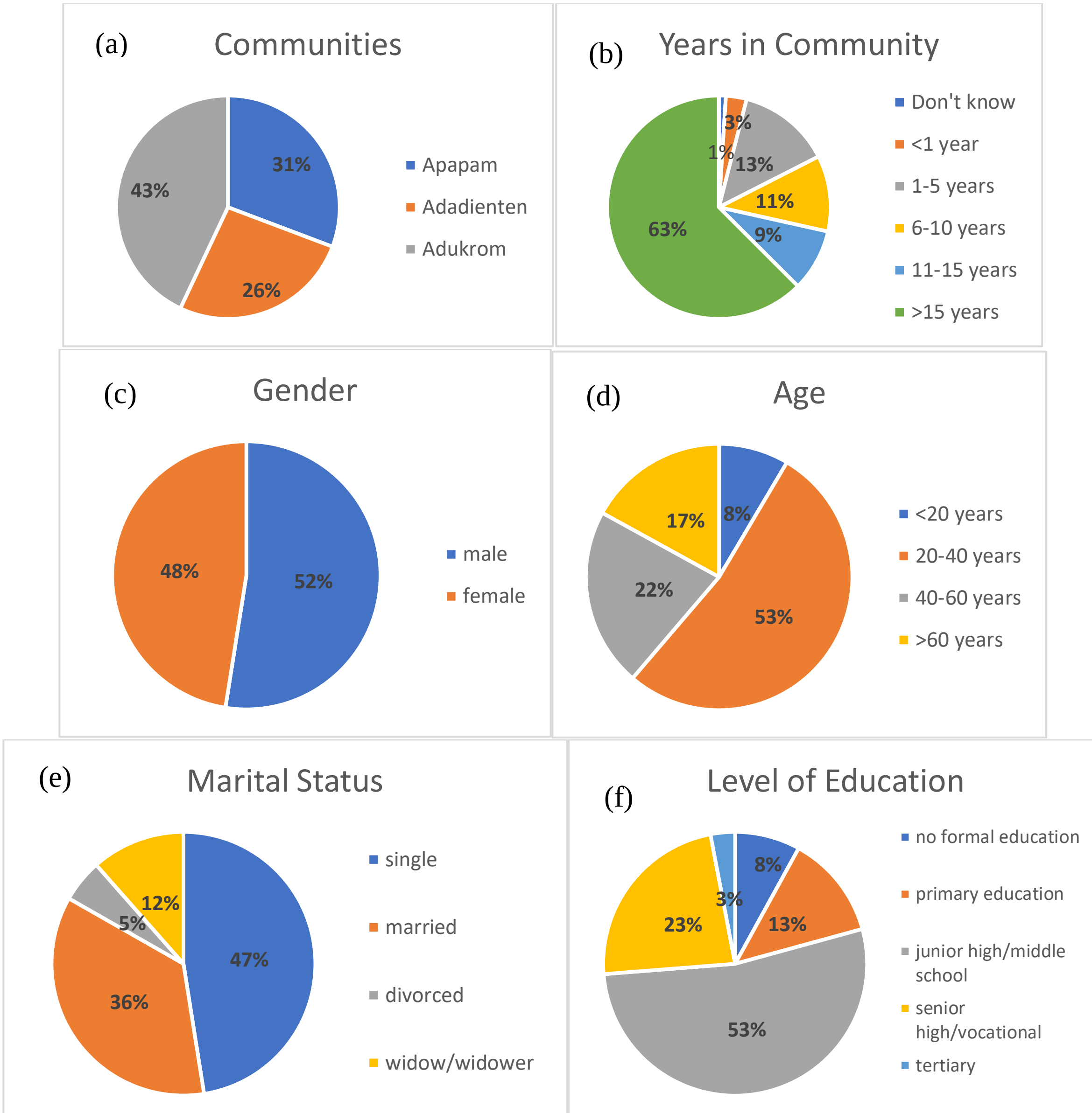


Figure 3.9: Demographics of Respondents to Questionnaire (Present Study)

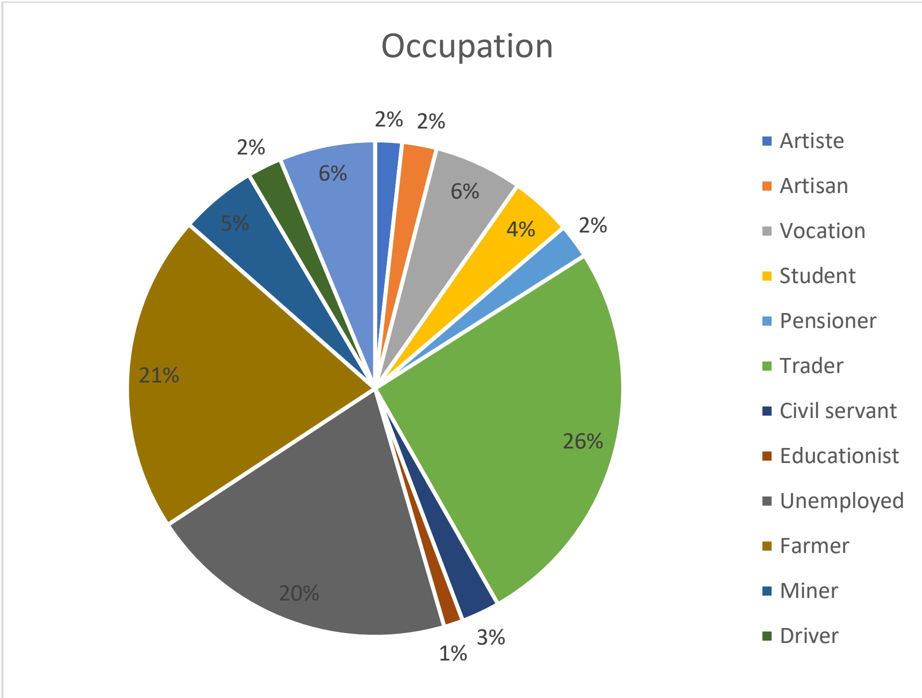


Figure 3.10: Demographics of Respondents to Questionnaire – Occupation (Present Study)

In Figure 3.10, majority of the respondents were traders (26%) followed by farmers (21%) and the unemployed (20%), most of who stated they were previously miners but were unemployed due to the ban on ASM activities during that period.

3.6.3 Interviews

Qualitative in-depth interviews were conducted in the course of the research. Both open and closed-ended questioning were employed to elicit responses that led to the gathering of facts and opinions from mine workers, inhabitants of the communities, and public officials. This form of interview made it possible to probe various areas. The structure of the interview questions was based on information gathered from the literature review.

An Interview guide that was approved by Western University Ethics Board was used. The interviews provided information on the effect of mining activities on the environment and the health and livelihood of the people.

Thirty (30) interviews were conducted involving a variety of mine stakeholders. The interviews generally lasted between 10 and 60 minutes each. The respondents in interviews that were completed under 15 minutes exhibited an immediate potential to be repetitive. After about 10 interviews with locals, a point of saturation was reached as the views and concerns began sounding similar. Five (5) of the interviews were held with Ghanaian government officials drawn from the Water Resources Commission, Minerals Commission, Council for Scientific and Industrial Research, Environmental Protection Agency (EPA). Twenty-five (25) of the interviews were held with mine workers and other inhabitants of the affected communities.

3.7 Methodology to achieve Objective Three (3)

The third objective was '*Assess locally available materials (for example, adsorbents) that can be used to treat the contaminated water to WHO standards for drinking water for households in the affected communities.'*

Literature on water treatment methods as well as information on available local resources that can be used to treat water was carried out. Three locally available materials were selected; corn husk, coconut husk, and moringa seeds. These materials were selected because they are abundant in the rural community. Coconut husk and corn husk are waste materials and the moringa seeds are readily available from the many moringa trees in the communities. A treatment system was set up in the laboratory to treat simulated contaminated water that was created in the laboratory.

Specific Tasks

- Set up the treatment system in the lab
- Run the treatment system.

Information from existing literature, the ASM workers, inhabitants of the community, and officials from the various institutions provided useful information for this part of the research. A batch study was conducted to determine the effectiveness of the various bio adsorbents under various conditions before a column study was conducted. Details of the batch study and column study are provided below.

3.7.1 Equipment/Apparatus/Materials required

The Equipment/Apparatus/Materials below were obtained for the research.

Table 3.1: Equipment/Apparatus/Materials

	Equipment, Apparatus, and Materials for Lab work		
1.	ICP-OES	**20**	Syringes
2	Thermostatically Controlled Oven	**21**	Syringe filter
3	Vial ICP	**22**	pH standards
4	Whitman filters	**23**	pH metre
5	Conical flask, 500ml, 250ml	**24**	Reagents (Pb, As, Fe)
6	Analytical balance, accuracy 0.1mg	**25**	Lab coat
7	Graduated cylinder	**26**	Protective gloves
8	Pipette from 100 µL to 10 mL.	**27**	Goggles
9	Micropipettes from 5.0 µL to 20.0 µL.	**28**	Stopwatch
10	Pipette tips	**29**	Grinder
11	Sample bottles (60ml)-250 bottles	**30**	Mortar/pestle
12	Sample bottle (200ml)-80 bottles	**31**	Paper towel
13	Sample collection containers	**32**	Distilled water
14	Orbital Shaker	**33**	Spatula
15	Glass beaker -12	**34**	Corn husk
16	Volumetric flasks, 1000mL, 250 mL	**35**	Coconut husk
17	Weighing paper	**36**	Moringa seeds (with shells)
18	Stock solution containers - 6	**37**	Column
19	Column holder	39	Glass balls

3.7.2 Preparation of Stock Solutions

The stock solutions for the three metals (Fe, As, Pb) out of the six metals (Fe, As, Pb, Hg, Mn, Cd) were prepared in the lab using the procedure below (Semerjian, 2018). Three metals were selected because they had the highest concentrations in the water samples from the Birim Basin. All the safety precautions were observed.

Table 3.2: Preparation of stock solution

Heavy metal	**Reagent**	**Procedure**
Lead	Lead (II) Chloride	Dissolved 1.589g of Lead (II) Chloride in distilled water and dilute to 1L.

Heavy metal	Reagent	Procedure
Arsenic	Arsenic (III) Oxide	Dissolved 1.320g of Arsenic trioxide in a minimum amount of NaOH and distilled water was added. The solution was acidified with 20ml conc. HNO_3 and diluted to 1L
Iron	Ferrous ammonium sulphate hexahydrate	Dissolved 0.7022g of Ferrous ammonium sulphate hexahydrate in distilled water and dilute to 1L.

3.7.3 Preparation of the Adsorbents:

The adsorbents were prepared in the lab using the procedure below.

Table 3.3: Preparation of Adsorbents

Adsorbents	Preparation Procedure
Moringa seeds	Moringa seeds with shells were washed thoroughly with distilled water to remove impurities and completely dried in the oven at 105°C for 4 hours to remove moisture. The dry mass was grinded in a mortar and then separated into two different sizes using 1.18mm BSS sieves. They were then stored in airtight bags.
Coconut husks	Coconut husks were washed thoroughly with distilled water and completely dried in the oven 105°C for 4 hours. The dry mass was grinded and then separated into two different sizes using the 1.18mm BSS sieve. They were then stored in airtight bags.
Corn husks	Corn husks were washed thoroughly with distilled water and completely dried in the oven at 105°C for 4 hours. The dry mass was grinded and then separated into two different sizes using the 1.18mm BSS sieve. They were then stored in airtight bags.

3.7.4 Batch Study

The batch study was carried out to determine the most effective adsorbent with the most favourable conditions in removing the heavy metals from the contaminated water before a column study was conducted.

3.7.4.1 Batch Study Procedure

0.1g, 0.3g, and 0.5g of adsorbents were added to 60 mL of sample (synthetically prepared solutions of Fe, Pb, and As, each with known initial concentration. The samples together with the adsorbent were shaken in an orbital shaker at 180 rpm at room temperature (30^{O}C) for 30min, 60min and 24hrs. Some samples were also hand-shaken for 3 mins and allowed to sit for 30 mins and 24 hrs. This was to simulate what can be conveniently practiced in a rural community where electrical equipment might not be available, to determine the effectiveness without an orbital shaker. These samples were filtered separately using a 0.45-micron Whatman filter paper and the filtrates were analyzed in ICP-OES to obtain the final concentrations of the heavy metals.

The percentage removal of the heavy metal was calculated as follows;

$$\textbf{Metal removal efficiency (\%)} = (C_i - C)/C_i \times 100 \quad (1)$$

$$Qe(mg/g) = (C_i - C)V/m \quad (2)$$

where C_i and C are the initial and residual concentrations of metal in mg/L,

q is the adsorption capacity in mg/g,

V is the volume of metal-spiked aqueous solution in L, and

m is the adsorbent mass in g.

For each adsorbent, the experiments were repeated with varying doses of adsorbents (01g, 0.3g, and 0.5g), adsorbent size (<1.18mm and >1.18mm), contact time (30mins, 60min, and 24hrs), and initial concentration of the synthetic solutions depending on the specific heavy metal.

3.7.4.2 Isotherms

The Langmuir adsorption isotherm assumes that there is no lateral interaction between adjacent adsorbed molecules when a single molecule occupies a single surface site and describes the surface as homogeneous and (Lui & Luo, 2019). In linear form, the equation is written as below.

$$Ce/Qe = 1/Qm\ KL + Ce/Qm. \quad (3)$$

where Q_m and K_L are the Langmuir constants. Q_m is the monolayer adsorption capacity (mg/g), K_L is adsorption constant (L/mg), Ce is the equilibrium concentration of the heavy metal (mg/L) and Q_e is the amount of heavy metal adsorbed (mg/g) The Q_m and K_L can be determined from the gradient and the intercept of the linear graph between Ce/Qe and C_e.

The Freundlich isotherm accounts for multiple sites adsorption for heterogeneous surfaces (Lui & Luo, 2019). The equation is as written below.

$$\log Q_e = \log K_F + (1 / n) \log C_e. \qquad (4)$$

Where K_F (mg g^{-1}) is the Freundlich constant and ‘n’ the Freundlich exponent.

3.7.5 Column Study

The batch study results predict the effectiveness of the adsorbent but the column experiment is needed to make the study more representative of real-life conditions. The column study can be scaled up. Flow rate and bed depth need to be determined.

3.7.5.1 Column Study Set-up

A transparent tube with an adjustable opening at the bottom was mounted in a stand. Care was taken to ensure the influent falls at the centre of the column of the bed, to avoid any influent escaping without proper contact with the adsorbent. The column was filled with glass balls and the adsorbent for depths of 5mm, 10mm, and 12.5 mm during the experiment. The effluent was collected every 15 min and analyzed for the residual metal concentration. The results obtained were analyzed. The column set up was used for only iron removal because it had the highest concentration amongst all the heavy metals.

3.8 Samples in the ICP-OES

The ICP-OES (Inductively Coupled Plasma Emission Spectrometry) is an analytical technique used for the detection of chemical elements (SOP-ICP, 2018). The following steps were carried out before samples were analyzed in the ICP-OES. The aqueous samples were filtered through 0.45□m using vacuum flasks.

- Samples were poured individually into the autosampler vials and each vial was labeled and placed and placed in sequence on the autosampler rack.
- A multi-element ICP standard that contains a mixture of elements was prepared and used. The stock solution was diluted to four (4) different concentrations which was used to make a calibration curve which the ICP uses to calculate the concentrations in the samples (SOP-ICP, 2018).

3.9 Conclusions

Data from the completed questionnaires, interviews, and lab tests were analyzed and assessed. Statistical and graphical interpretations of the results was made and data was represented in tables, histograms, bar charts and pie charts and detailed interpretation of the results was made.

The next chapter presents the data and analysis and discussion for the first objective of the research.

CHAPTER FOUR

4 ASM Policy Issues

4.1 Introduction

This chapter focused on the first objective for this study which is to '*Evaluate existing policies and regulations with regards to Artisanal and Small-Scale Mining (ASM) in Ghana and their enforcement*'. Data from the completed questionnaires and interviews about policy issues were analyzed and assessed in addition to existing literature. The data were also subjected to descriptive statistics. Analysis of variance (ANOVA) was used to determine the difference in the means of the samples. T-test was used to determine the difference in the mean of the wet season and dry season. Chi test was used to test the probability of independence of a distribution of data. Data was presented in tables; pie charts and bar charts and detailed interpretations of the results were made. The demographics of questionnaire respondents is presented in chapter three.

Content analysis was used to examine claims and narratives in the policy debate around artisanal and small-scale mining, water resource management and environmental flows in Ghana. Parliamentary debates from Hansards and media content analysis from 2010 to 2020 were used to explore the claims and narratives of various stakeholders to provide more insight into the artisanal and small-scale mining policy issue.

4.2 Mining in Communities

Three mining communities along the Birim River were identified. Apapam, Adadientem and Adukrom. These three communities were selected because they depend on water from the Birim River Basin for various purposes such as drinking and other domestic purposes, irrigation, swimming, fishing etc. and in all three communities, ASM activities are carried out in the river and within the communities. Inhabitants of the three communities were asked about their involvement in mining activities. They were also asked about their years of involvement with mining and whether they live close to any mining site. The results are captured in Figure 4.1.

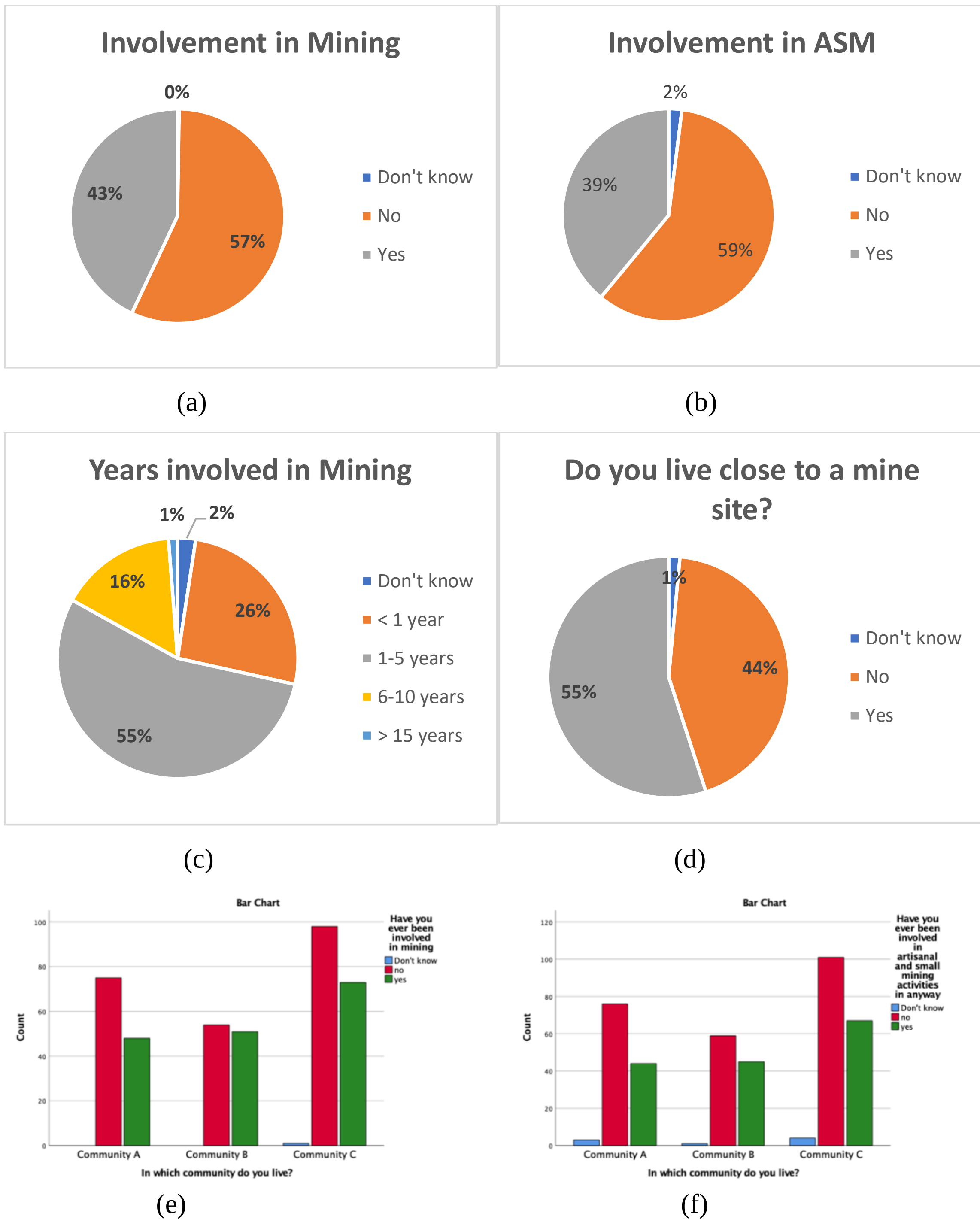
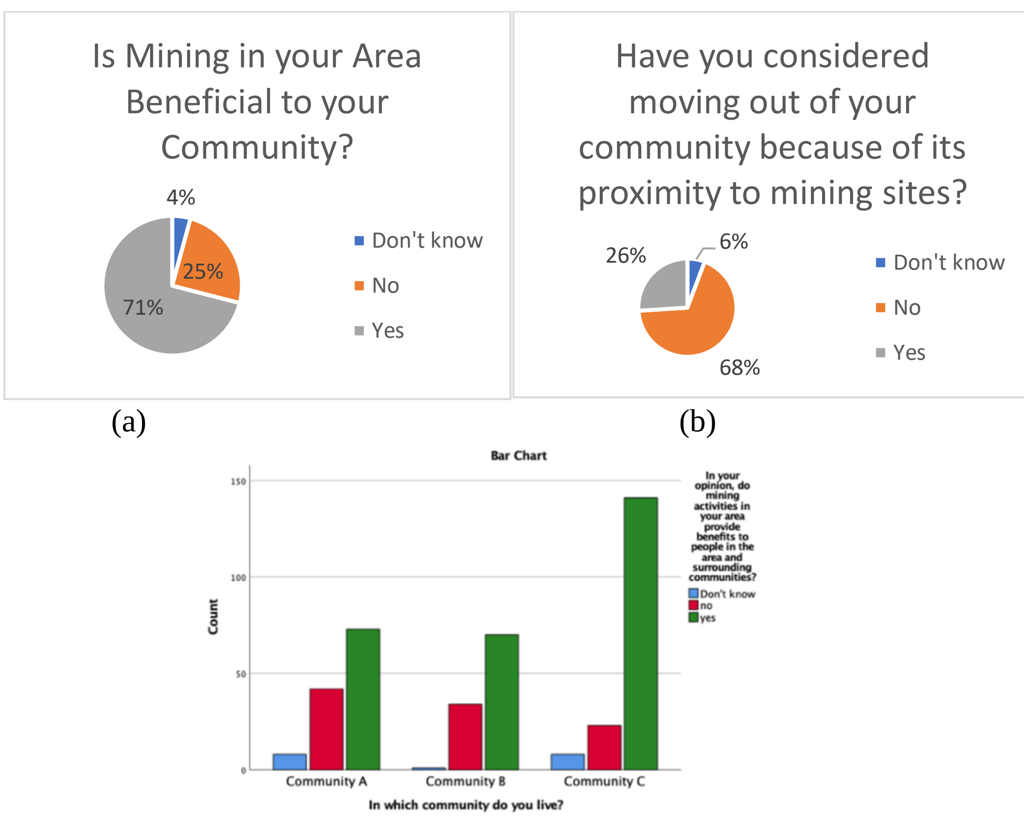


Figure 4.1: Involvement in Mining Activities within Communities (Present Study)

From the analysis presented in Figure *4.1* above, 43% of respondents stated they had been involved in mining but only 39% of the respondents indicated they had been involved in Artisanal and Small-scale mining activities. This indicates that some of the miners were working for large-scale mining companies. 55% of those who were involved in mining had worked between 1-5 years, the majority of which were the youth. 26% had worked for less than one year, 16% between 6-10 years, 1% had worked for more than 15 years and 2% indicated they did not know. 55% of the respondents live close to mining sites. This confirms that mining is carried out within the communities. The bar charts in 4.1, shows the distribution within the three communities.

From the foregoing, one can deduce that most of those involved in mining were the young men and women of the communities. Most people as they grow older, venture into other occupations or become unemployed because of the nature of mining activities which requires strength to dig and carry heavy loads among other strenuous activities.

Mining activities were carried out within the communities, in the river, in farms and close to homes. The researcher observed open pits and mining activities within the communities and in water bodies such as rivers during her visit to the communities. These open pits were in fact death traps for children and livestock in the communities.



(a) (b)

(c)

Figure 4.2: Benefits of Mining Activities (Present Study)

As shown in Figure 4.2 (a), 71% of the respondents indicated mining is beneficial to their community. Majority of the respondents indicated the major benefit from mining activities was improved standard of living. From the interview, a number of young men indicated they were able to buy cars and enjoy good daily meals. They all referred to a young man in Apapam who had invested his earnings from mining in a successful pharmaceutical retail business and was reaping the benefits. On the contrary, most of the young men had misused the money they had gained from mining. To most of them, mining provided employment but did not help with community development and long-term sustenance.

Majority (68%) indicated that although their community had been negatively affected by ASM activities, they had not considered moving out of the community (see Figure. 4.2 (b)). Only 26% had considered moving out of the community. 81.8% of respondents indicated they were concerned about ASM activities polluting water bodies, 35.8% were concerned about the destruction of farmlands, 26.8% were concerned about school dropouts occasioned by ASM, 11.5% were concerned about health risk and 5.5% were concerned about air pollution.

The Chi-square test between community and mining activities beneficial to the community produced a likelihood ratio of 0.0001. The p-value was less than 0.05 which indicated there is a dependent relationship between the community and their opinion on the benefits of mining to the community.

4.3 Awareness of ASM Related Policies

To determine why regulations and policies implemented in the past have not been successful, the researcher sought to explore questions on awareness of ASM Related policies in the three mining communities and whether in their opinion policies and regulations had been effective. The results are captured in Figure 4.3 below.

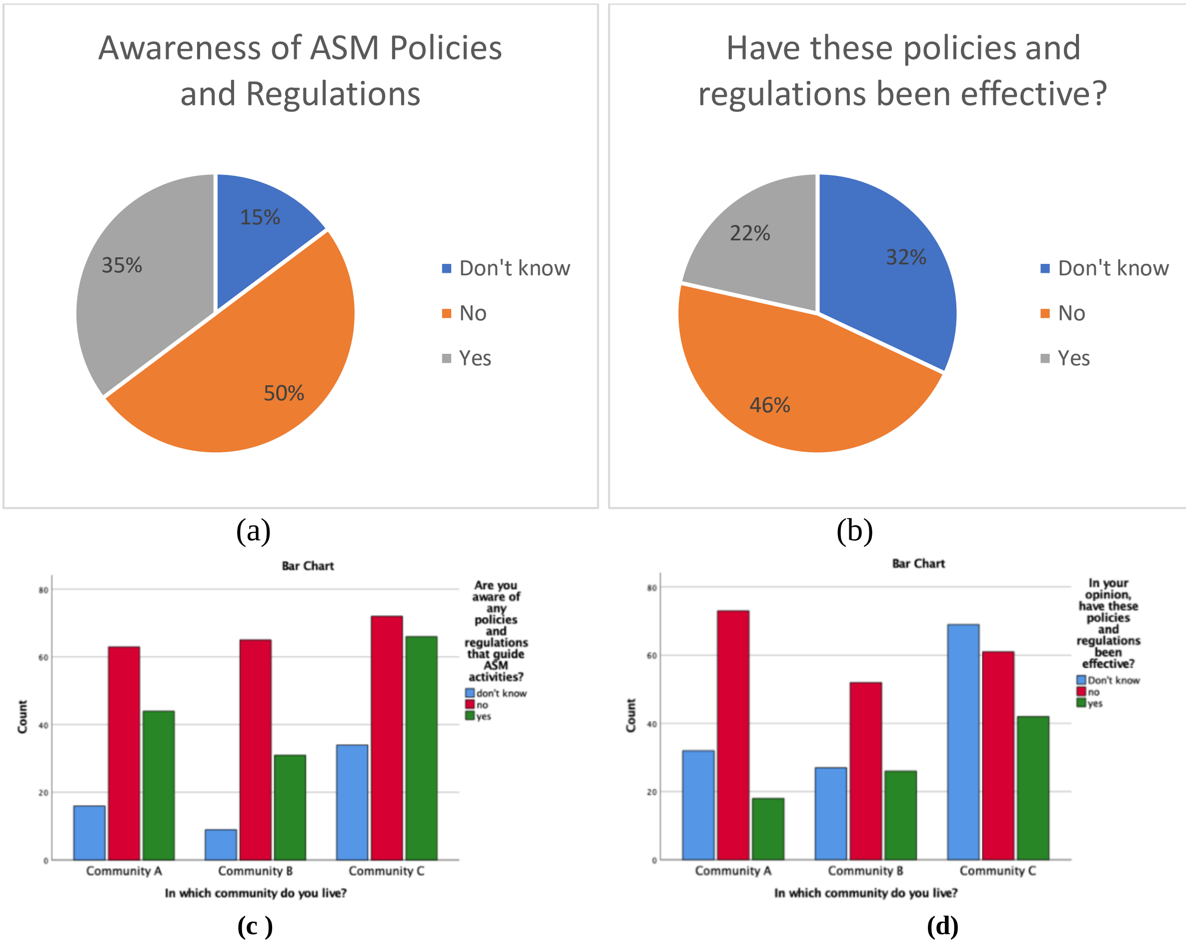


Figure 4.3: Awareness of ASM policies and Regulations (Present Study)

From Figure 4.3(a), 50% of the 400 respondents from the three mining communities; Apapam, Adadientem and Adukrom stated they were not aware of ASM policies and regulations.

15% of the respondents stated 'Don't know' but 35% said they were aware of some ASM policies. When the 35% who are aware of the policy were further asked to provide details as to which policies they were familiar with, about 20% of them stated they were aware of some specific policies that were captured in the questionnaire. Out of the 20%, 1.3% indicated awareness for Minerals and Mining Act 2006, 4.3% for Minerals and Mining Act 2014, 0.5% for Minerals Commission Act and 12% for Minerals and Mining (Health, Safety and Technical) Regulations. 1.8% indicated they were aware of general regulations such as 'cover pit afterwards', 'distance to water bodies', 'effect of chemicals on organisms', 'help with development' and 'mine companies have to provide amenities'. Interviews regarding awareness of ASM related policies and regulations provided additional regulations such as 'You cannot mine inside the river or close to the river', 'You have to mine some distance from the river', 'You have to be careful about the use of chemicals' and 'You have to cover open pits after mining'. An interview of some ASM miners indicated that most of the miners were not fully aware of the devastating impacts of mining on their communities when policies and regulations are not followed properly. The data distribution within the communities in the bar chart indicates that community C (Adukrom), which is much bigger was more aware of policies and regulations compared to community A and B. Chi-square test between community and Awareness of ASM policies and regulations had a likelihood ratio of 0.012. This shows that the two categorical variables; community and awareness of ASM policies and regulations are related.

Data from the questionnaire and interviews indicated that majority of the people in the mining communities were not aware of the ASM related policies and regulation and the impact of ASM on the environment and water bodies due to limited awareness creation and education.
When respondents were asked whether these policies and regulations had been effective, 46% stated 'No', 22% stated 'Yes' and 32% stated 'I don't know'. Majority of respondents stated the policies have not been effective because of the negative impact of ASM on waterbodies and their communities in general. When asked why the policies had not been effective, the majority of the respondents strongly agreed that corruption was a challenge. Most agreed lack of environmental education and awareness, lack of enforcement of regulations, the cumbersome registration process for small scale miners, inadequate personnel and resources and failure to address community needs. Community A which has experienced devastating impacts of ASM activities on their only river (Birim River) had a higher percentage indicating the policies have not been effective. Chi-square test between community and opinion on the effectiveness of policies had a likelihood ratio of 0.001. This shows that the two categorical variables; community and perception on the effectiveness of policies are related.

In one particular community (Apapam), where the people depend on water from River Birim for drinking and domestic purposes, the young men in the community lamented on the negative impact mining had on the water bodies and farms. They mentioned that if they had been fully aware of these consequences, they would have done the right thing and protected their land, water bodies, and lives of children and livestock who met their demise when they fell into open pits.

A review and evaluation of some existing policies will provide further insight on whether awareness creation, education and enforcement will indeed help protect the environment.

4.4 Review of Policies

Policies related to artisanal and small-scale mining were analysed. Some policies that were evaluated include the Multi-Sectoral Mining Integrated Project (MMIP), Minerals and Mining Policy of Ghana 2014, the National Environmental Policy, the National Land Policy, 1999; and the National Water Policy.

4.4.1 Ghana National Water Policy

According to Agyenim & Gupta (2011), the shift from government to governance, centralization to decentralization, water as a gift of God to water as an economic good, and sectoral to integrated water resource management, are four major paradigm shifts in water management.

An electronic copy of Ghana's National Water Policy was retrieved from the website of the Public Utilities Regulatory Commission of Ghana (www.purc.com.gh). The Ghana water policy document was developed as a result of sector-wide stakeholder consultations and collaboration. The process of formulation of the policy document started in 2004 with the Ministry of Water Resources, Works and Housing leading the process with other stakeholders and interest groups.

The policy is divided into three sections. The first section is an overview of Ghana's water sector, the second details the key strategic actions of policy and the third outlines the policy implementation arrangement (Ghana National Water Policy,2007).

Monney & Ocloo (2017), suggests the Ghana water policy satisfactorily addressed all the Integrated Water Resources Management (IWRM)-related issues and provided the reason for the development of the National Integrated Water Resources Management Plan in 2012 and the National Climate Change Policy in 2013, but the Water Policy neglects key generic and country-specific water management issues. They added the institutional framework for implementation has no place for institutions responsible for land management and mining which he said possibly explains why mining activities continue to pollute water resources in the country. There is a need for collaboration between these institutions to effectively manage water resources. The IWRM plan was developed to help address the problem of weak enforcement of existing regulations in

water resource management. This issue of weak enforcement seems to be a major issue in the country.
According to Pandit & Biswas (2019), a national water policy can be a paper exercise where the inscriptions are divorced from reality, and there is lack of courage to take a firm stand on any of the provisions at either the drafting or the implementation stages. This does not help the economy. The current state of water resources in Ghana, confirms the above statement. It is therefore imperative that the policy on paper is implemented, enforced and monitored for water resources to be used and managed efficiently.

Two key policy objectives of interest in the Ghana national water policy are ‘to achieve sustainable management of water resources’; and ‘ensure equitably sustainable exploitation, utilisation and management of water resources, while maintaining biodiversity and the quality of the environment for future generations.

Two of the policy measures to be implemented to achieve these policy objectives are ‘to ensure water resources planning to be made with due recognition of “environmental flow” requirements;’ and ensure preparation of IWRM strategies using the various river basins as the planning units’.
The current condition of rivers in Ghana indicates these measures have not been implemented effectively. Mining activities are carried out within the rivers and close to the rivers. The river is also diverted by miners to create mine ponds and for other selfish reasons.

The Ghana Water Resources Commission (GWRC) has the mandate to regulate and manage the water resources. During interviews with some personnel, they admitted to not being able to efficiently manage the water resources due to limited resources and personnel. One person stated that going to the river site alone to monitor meant risking their lives because they received threats from armed mine workers. He explained that in most of their sub-offices, they had only two personnel and one had to stay at the office whilst the other went out to collect samples and monitor the rivers. He admitted this situation affects their work and renders them ineffective. Policy execution requires indicators and baselines for continuous monitoring for progress, re-evaluation and at times a revision of priorities that meet obstacles (Monney & Ocloo, 2017).

Sources of drinking water such as rivers, lakes, groundwater etc., should not be allowed to get polluted. According to Singh et al. (2013), a third party can be employed to periodically inspect and monitor the water resources and heavy penalty should be imposed on identified polluters. They suggested the money can be put in a fund to facilitate water restoration and treatment.

4.4.2 Ghana National Land policy

This policy seeks to address some of the fundamental problems associated with land management in the country which includes general indiscipline in the land market, a weak land administration system and conflicting land uses, such as, the activities of mining companies, which leave large tracts of land stripped as against farming and the time-consuming land litigation which have flooded the courts.

One of the policy objectives is to 'promote community participation and public awareness at all levels in sustainable land management and development practices to ensure the highest and best use of land, and thereby guarantee optimum returns on land'. (Ghana National Land Policy, 1999). This policy has been in effect for more than 20 years but awareness creation on sustainable land management and development practice has still not been achieved. The response from the three communities indicated that awareness creation on the devastating effects of ASM and education of the proper practices to follow would have made a big difference.

4.4.3 Ghana National Environmental policy

Ghana's first Environmental Policy was enacted in 1995. The 1995 policy identified and restructured the EPA as the lead agency to drive the process towards sustainable development.

According to the Hens & Boon (1999), the environmental situation in Ghana is characterized by desertification, deforestation, soil erosion, land degradation etc. and industrial and mining activities etc, have also led to increasing effluent discharges into existing water bodies.

Some of the tools used to mitigate environmental pollution caused by the mining sector include environmental impact assessments, environmental care and management systems on-site etc. (Hens & Boon, 1999). How effective have these tools been in mitigating environmental pollution? Mining continues to degrade the environment and open pits are left uncovered in communities after mining.

However, the principal challenge confronting the environmental management process in Ghana is ineffective implementation and enforcement of the policies and laws that exist to achieve the desired result which is a big challenge in the country.

The objective of strategic goal 5 of the policy document states 'Environmental Awareness Creation and Empowerment' states that the Government will promote the education and empowerment of all Ghanaians by increasing their awareness of, and concern for environmental issues'. As stated earlier, awareness creation of environmental issues specifically with mining issues and education on the negative impact of mining on water bodies and the environment, in general, is lacking, especially in rural communities.

4.4.4 Minerals and Mining Policy of Ghana, 2014

According to the policy document, the Minerals and Mining Policy provides a written declaration of the framework of principles and policies that guide the management of the mining and minerals sector. Policymaking is centralized in national institutions and some institutions, such as the Minerals Commission (MC), are accountable to Parliament only indirectly through their supervising ministries (Ayee et al., 2013).

The small-scale mining sector was not regulated until 1989, when a Small-Scale Mining Project (SSMP) was initiated. This was done to provide the institutional framework within which legalised small scale mining of gold in order to provide an avenue for employment generation to curb rural-urban labour drift and absorb some of the excess labour that was retrenched from large scale mines (Eshun & Okyere, 2017).

The minerals and mining policy stated measures to undertake to enhance growth and opportunities in the small-scale mining sector. Two of these measures are

- 'The minerals licensing system restricts the granting of mineral rights for small-scale mining operations to Ghanaian citizens. Simplified procedures for applying for these licences will be adopted' and;
- 'To encourage the use of appropriate, affordable and safe technology, Government will continue to support the collation and dissemination of information on appropriate technologies, the provision of extension services and demonstration of improved technologies.'

Small scale mining licences are restricted to Ghanaians to offer the opportunities to support and sustain rural livelihoods, encourage business start-ups and provide raw materials for development of new products. However, some Ghanaians apply for the rights and hand over to foreign nationals. After 2010, the Chinese introduced heavy machinery which destroyed so many water bodies (Botchwey et al., 2018). Why were the Chinese allowed to carry out small scale mining activities if effective monitoring was been carried out?

The use of appropriate, affordable and safe technology needs to be encouraged by the Government. Extremely toxic mercury has been used for a long time. The Government of Ghana needs to invest in new and safe technology that will not have negative effects on the environment and the health of people. The use of toxic chemicals should be discouraged and people should be educated on the impact of these toxic chemicals on their health.

In a research by Eshun & Okyere (2017) to identify challenges small scale miners have experienced with regularisation processes, some of the challenge respondents claimed to have encountered included delays in processing the licences and the expensive cost of the licence to the small-scale operators. They added that the bureaucratic processes involved in the application and follow up on the application of licenses makes the process tedious and expensive since applicants were forced to part with some cash to try to facilitate the process. This indicates that the license application process has not been simplified as stated in the policy document.

4.4.5 Multi-Sectoral Mining Integrated Project (MMIP)

The Multi-Sectoral Mining Integrated Project (MMIP) is a five-year project that covers the strategy and activity components that the Ministry of Lands and Natural Resources (MLNR) developed to help solve the illegal mining problem in Ghana. The MMIP focuses on three approaches. The three approaches as explained in the MMIP document is captured below.

The first approach is the enforcement. Over the years, Enforcement of regulations and laws have been a challenge. Appropriate enforcement of the regulations and laws has to be carried out for any policy to be effective. This will ensure that the mineral and mining laws are adhered to and when breached, the appropriate sanctions and punishment are meted out.

The civil and integrated approach is the second one. The document states that this is a participatory approach involving all stakeholders in the fight against illegal mining, integrating social interventions to prevent illegal mining activities. Stakeholders involved in the process include the artisanal and small-scale miners, NGO's, inhabitants of the mining community, Development agencies etc. This is a step in the right direction because their involvement encourages them to own the decisions made and to ensure others also uphold the decisions.

Technology is the third approach. Innovative technology is needed to carry out small scale mining activities safely and affordably. This focuses on adapting technology to improve mining and processing efficiencies. The environment (water, air, land etc) needs to be monitored to ensure it is not been polluted. Training for miners on the proper use of equipment and chemicals in addition to the creation of awareness of the impact of negative practices on human health and the environment is important.

The MMIP mainly focuses on tackling the *galamsey* menace but it is important to also note that both the illegal miners (*galamsey*) and legal artisanal and small-scale miners use similar processes during mining which pollutes the environment (Hilson & Potter, 2003). This also needs to be addressed.

4.5 ASM Policy Analysis

According to Dunn (1981), policy problems are partly in the eyes of the beholder. This is an important statement because although many people believe policy problems are objective conditions whose existence may be established simply by determining what the facts are in a given case, this naive view fails to recognise the same facts are often interpreted in noticeably different ways. Different stakeholders perceive the ASM issues in different ways depending on some factors which will be analysed in this session. Political scientists have perceived policy change as mainly the product of power struggle among groups with different resources and values but over the years research has shown that governmental action programs are built on implicit causal theories (Sabatier, 1988). The ability to identify the differences among problem situations, policy problems and policy issues is critical for understanding the different ways that common experiences are translated into disagreements about actual and potential courses of government action (Dunn, 1981). It is therefore important to analyze the ASM issues from the view of the various stakeholders to better understand the issues at hand and provide a useful and comprehensive solution. Understanding how various actors connect to scientific knowledge to justify their claims on the impact of artisanal and small-scale mining activities in Ghana will help discover the dynamics and narratives that have inspired ASM policies over time, the different positions actors have taken, which voices count most and finally, who benefits from such stories.

This study used content analysis to examine claims and narratives in the policy debate around artisanal and small-scale mining in Ghana. Parliamentary debates from Hansards and media content analysis from 2010 to 2020 were used to explore the claims and narratives of various stakeholders to provide more insight into the artisanal and small-scale mining policy issue. Keywords such as 'artisanal and small-scale mining', '*galamsey*', 'illegal mining', 'water resources', 'waterbodies', environmental flow', 'IWRM' were used to search for online articles and news reports. Hansards were reviewed from 2010 because *galamsey* activities were reported to have intensified from 2010. In the present research, claims, opinions and beliefs about artisanal and small-scale mining by members of parliament and other interest groups were critically examined. A paper by Hilson (2001), entitled 'A Contextual Review of the Ghanaian Small-scale Mining Industry' also provided a lot of insight into the ASM issues.

4.5.1 Evaluation of water resources and environment flow in Ghana

According to Maasri (2013), environmental flow is a key component of Integrated Water Resources Management (IWRM) and accounts for the volume of water allocated for ecosystem functioning. Agyenim & Gupta, (2012) in their research, suggested Ghana, like other developing countries, often adopts such models in the management of their water resources mainly as a result of external pressures however, there are implementation, adequate resources, domestic ownership and leadership issues.

A search through media content and parliamentary Hansards on information related to environmental flow regimes which offer a means to protect and restore water bodies indicates there has not been much discourse on it. The conversation has always been linked to activities of illegal artisanal and small-scale miners whose activities affect rivers and other water bodies in the country. The policy analysis will therefore focus on the policy debate around Artisanal and small-scale mining.

4.5.2 Analysis of artisanal and small-scale mining policy in Ghana

In the 15th and 16th centuries, at the peak of European colonial exploration, Ghana was called 'Gold Coast'. Small scale mining activities were abolished during the colonial era when the Europeans introduced large scale gold mining (Kessey & Arko, 2013). In 1986 the Minerals and Mining Law (PNDC Law 153) was enacted to promote and regulate the orderly development of the sector. The Small-Scale Gold Mining Law (PNDC Law 218), the Mercury Law (PNDC Law 217) and the Precious Minerals Marketing Corporation Law (PNDC Law 219) were passed in 1989 to regularise and streamline small-scale gold mining. A new mining law, Minerals and Mining Act, 2006 (Act 703) was developed to replace the Minerals and Mining Law, 1986 (PNDCL 153). In 2015, Parliament passed the Minerals and Mining (Amendment) Law, 2014. The new law criminalised illegal small-scale mining, popularly known as '*galamsey'*, and mining by foreigners and Ghanaians without a permit. It enabled the Minister of Lands and Natural Resources to prescribe a rate for royalty payments and, to confiscation equipment used in illegal small-scale mining (McQuilkin & Hilson, 2016). According to Andrews (2015), small scale mining activities are considered illegal in Ghana when operators have not formally registered their sites with the government.

Artisanal and small-scale mining (ASM) employs a wide range of individuals comprising of men, women and children, who undertake diverse roles including labouring, supervising, machine operating, bookkeeping amongst others. The majority of the individuals involved in illegal mining are poverty-driven, from families and individuals trying to earn enough to survive and provide for their families (McQuilkin & Hilson, 2016).

Several environmental protection laws and policies and their implementation over the years have not been able to address the environmental challenges Ghana faces (Kessey & Arko, 2013) as reviewed earlier. Banchirigah (2008) in her research helped to explain why traditional strategies employed by governments to tackle illegal mining such as formalisation, alternative livelihood projects and military intervention, have proved ineffective. The research provided four explanations in support of this: the mindsets of many operators toward alternative income-earning activities, heavy involvement of traditional leaders in operations, the level of investment in operations, and the numerous and diverse range of employment opportunities provided by the sector.

It is important to note that although the Ghanaian government has regularized and formalized small-scale mining operations, which is a necessary step toward improving the sustainability of the mining sector, it has not been successful at regulating and managing the small-scale miners and this has led to the pollution of the environment, loss of lives, destruction of farms etc. This can be attributed to some weaknesses in the regulations and their implementation/enforcement.

First of all, artisanal and small-scale miners, have continued to use the same methods they used for many years even before the enactment of relevant legislation and, not much training has been offered to them. Both licensed and illegal small-scale miners tend to use the same mining methods. Hilson & Potter (2003) observed that there is little difference either organizationally or technologically between legal and illegal mining activities apart from the fact that the licensed mining activities have the security of tenure on a demarcated mineralized concession for a given period. This indicates that even the legal small-scale miners are also polluting the environment although they are supposedly being regulated. Innovative technology that will be safe, affordable and environmentally friendly should be investigated, developed and encouraged. According to Hilson (2001), the establishment of district centres created a good opportunity to offer training and education to small scale miners but although attempts were made to organize training sessions at district centres, to educate miners on important issues of health and safety, business management, environmental protection and use of technology these attempts were generally not successful because of implementation issues.

Secondly, although all these regulations exist, their enforcement has been a challenge due to limited resources and corruption. The institutions responsible for enforcing these policies and regulating this sector claim to have limited resources and small-scale miners who fail to manage the waste after mining, blame it on limited resources (Kessey & Arko 2013). At a point in time, loans were provided to needy small-scale miners who sought to purchase handheld and mechanized equipment but because of repayment issues, this initiative had to be aborted (Hilson 2001). In an attempt to implement policies for reclaiming small-scale mining sites, the Minerals Commission introduced a Reclamation Fund, where the government held back some percentage of the revenue from small-scale mining sales to fund reclamation programmes (Hilson, 2001), but according to Davidson (1993), only $17,000 was contributed to the Land Reclamation Fund between 1989 and 1991. Hilson (2001) noted that the Minerals Commission revealed that the initiative had been abandoned, mainly because of the challenges associated with getting the money from small-scale mining parties. In the 1990s, the Minerals Commission sponsored a series of independent studies on small scale mining but after over 30 years, most of the recommendations made are still in the process of being analysed. This indicates that although there are lots of deliberations about this issue and several recommendations have been put forward, the problem is not being addressed holistically and enforcement is still a major issue.

Thirdly, one of the requirements for securing a small-scale mining concession is the completion of an environmental impact assessment. Applicants are required to identify how they plan to address relevant environmental matters that form the basis on which the Minerals Commission and EPA determine whether or not the proposed initiative is environmentally sufficient. One major problem with this EIA procedure is that it does not target the specifics of environmental management, but rather makes use of vague information which does not provide specific details and a specific plan of action to protect the environment (Hilson, 2001). The form has to be designed to elicit the required information and also ensure that customized plans of action specifically tailored for the site in question should be submitted. Environmental support programmes for small-scale miners will go a long way to create awareness and better equip the miners to protect the environment by putting in place proactive measures.

Fourthly, because of gaps and weaknesses in earlier regulations, although licences are to be granted only to Ghanaian nationals, some Ghanaians illegally 'loaned' their licenses to foreign nationals especially the Chinese who had better and more sophisticated equipment and therefore destroyed the water bodies and environment in general (Hilson 2001, Kessey and Arko, 2013). The bureaucratic procedures and unnecessary delays associated with obtaining a license to operate contributes to the high number of illegal artisanal and small-scale miners.

4.5.3 Analysis of Claims and Narratives from Parliamentary debates and Media

The 2010 to 2020 Hansards which are transcripts of Parliamentary Debates and online articles and news reports were reviewed. The major discussions within this period took place in 2017 and 2018.

Three major narratives identified from the parliamentary debate and media deliberations are Environmental Narrative, Livelihood Narrative and those in the middle who draw from both sides.

4.5.3.1 Environmental Narrative

The environmental narrative was expressed by some members of parliament and the media. Concerns regarding the negative impact of illegal small-scale mining on the environment have been there for many years. For example, in 2010, an MP for Ablekuma North stated;

'……..nothing has been done as *galamsey* is being encouraged in the mining towns, especially in Amansie West, Prestea/Huni Valley in the Western Region…… streams that serve as a source of drinking water have been polluted with cyanide and mercury'. (Mr Justice Appiah, 2nd December 1010, p. 2558)

This concern was expressed in 2010 but not much was done to curb this canker. There were several deliberations in parliament and the media. In 2015, some members of parliament were hopeful that a bill that was passed will be effectively implemented and provide some solutions. An argument was also made for the establishment of the University of Environment and Sustainable Development which some believed could play a vital role in the country's developmental agenda to help provide solutions to the *galamsey* issue.

In 2017, a media house in Ghana launched the 'StopGalamseyNow' campaign in a bid to put pressure on the government to ensure that the *galamsey* menace is halted. They called on the government to undertake five steps to protect water resources, land etc. or risk Ghana resorting to the importation of clean water in the next two decades. Their demands were;

- 'The total cessation of all small and medium scale mining for six months
- The cessation of the issuance of new mining licences for a year
- The reclassification of mining categories to reflect the use of new/larger equipment
- The allowance of water bodies to regenerate their natural ecology
- Tree planting and a land reclamation project.' (Citi FM, 2017)

This campaign triggered several discussions on various platforms in the country including parliamentary debates. Some Civil Society Organizations and institutions such as IMANI Ghana, the Ghana Anti-Corruption Coalition (GACC), Centre for Democratic Development (CDD) among others supported the media house. Members of Parliament also signed a petition to pledge their support to the fight against '*galamsey*'.

In 2017, the first Deputy Speaker indicated that:

'…As far as I remember, maybe 30 years ago, issues of *galamsey* had been a front-burner and nobody seemed to be able to do anything about it. At any point in time, we all come back to say that all the high- level people are involved in it…………….. Our country abounds with how we are treating or degrading our environment. One that I would just draw our attention to is the issue of *galamsey*. The real worrying thing is the impunity with which some of the things that degrade our environment go on………… They cut the trees, divert water bodies and pollute them with very dangerous chemicals. Indeed, after they have mined, they leave the degraded land without any attempt to do anything about it. In the process, we must remember that if it is the air, soil, water or our ecosystem, it is a limited resource. To use Ghanaian parlance, if we spoil our air, none will come from anywhere; if we spoil our water, there is no replacement; it is a limited resource and we must ensure that this does not happen. Up till now, we continue to complain……….and sometimes, I wonder. Can we only complain? Is that all we can do?' (Mr, Osei Owusu, 17th February 2017)

The first speaker expressed concern about environmental degradation and the release of chemicals into the environment which have severe implications on human health. He stressed on the fact that when the country's water, soil and air are destroyed, there will be no replacement and thus the need for these valuable but limited resources to be protected. His statement indicates that this issue has been in existence for many years and has been debated and discussed in parliament over and over again but the end to this problem is still not in sight.

Another MP - remarked:

‘……we are talking about illegal farms and *galamsey*. This is an area that affects everybody in this country; it does not matter whether you are for the New Patriotic Party (NPP) or National Democratic Congress (NDC). This *galamsey* is poisoning us. According to the Council for Scientific and Industrial Research (CSIR) report that just came out, we all know that about 40 per cent of the oranges produced around Obuasi are contaminated with mercury and lead……..These two chemicals reduce the cognitive development of children. So, we are producing children who are eating fruits, and may become mentally retarded just because of the results of *galamsey*……….’, (Ms Laadi Ayii Ayamba, MP-Pusiga, 22 March 2017, p. 3367)

From the statement above this MP draws attention to the fact that this problem is a national crisis and everybody in the country, therefore, needs to be on the same page in protecting the environment. Political divide should not feature in this situation. The evidence from science on the impact of some heavy metals on oranges which results in reduced cognitive development in children is an issue that needs to be dealt with. Ghanaians for a while now have politicized many issues but it is heartwarming for members of parliament to encourage others not to view this problem through their partisan lenses.

In 2017, the president of Ghana strongly expressed his view on the need to protect the environment which is the country’s heritage. He stated that;

’…. there are things we can’t just allow to happen and one of them is the abuse of our heritage’.

The First Deputy Speaker of Parliament suggested shooting illegal small-scale miners can be an effective way of dealing with the ‘galamsey’ menace. Although this brought a lot of condemning remarks, some other MPs were in support of this suggestion.

The Chief Inspector of Mines of the Minerals Commission, Inspectorate Division, also proposed the prosecution and jailing of chiefs who involve themselves in illegal mining.

This indicates the measures some are willing to take to protect the environment but is this the best solution? This question has been presented to the house many times but an effective answer is needed from the policymakers: what are we doing as a legislative body to ensure that laws that protect our environment are made to work effectively?

4.5.3.2 Livelihood Narrative

The small-scale miners who are the people on the ground close to the resources believe it is their major source of livelihood. An interview with a miner who lost his brother a few months before the interview, because of a collapsed pit which killed 25 people had this to say;

'I need money to feed my two children, my late brother's son and my wife'.

He said he would prefer a different source of livelihood but it is only '*galamsey*' that provides enough source of income to cater for his family (myjoyonline.com).

The president of Ghana in addressing some traditional leaders at an event acknowledged that many individuals were experiencing some form of hardship in the country. He noted;

'We all know that we have been in difficult times and times like these, there is a need to keep body and soul together. Every man has a duty to provide for the family and sometimes use every means possible…….... But there are things we can't just allow to happen and one of them is the abuse of our heritage'

The president of Ghana has sought to find a solution to the artisanal and small-scale mining issue in the country after the change in government. A statement he made during his campaign created some confusion. He had said;

'I was here in Obuasi to say that '*galamsey*', which I prefer to call small-scale mining, will be regularized, to ensure that all the youth find work to do'.

Some illegal miners, therefore, took offence when after the president took office, he put in some measures to stop illegal artisanal and small-scale mining. A miner remarked;

'When he won the election, he rather directed soldiers to come and drive out all persons involved in 'galamsey in Obuasi,'

He was referring to the Operation vanguard that had been put in place, where the army has been authorized to confiscate their equipment and drive illegal miners away from mining sites.

In addressing the members of Parliament, the President stated;
'We have started various schemes to find sustainable alternative sources of income for the galamsayers. Mr Speaker, nothing would ever equate the attraction of the search for gold or diamond, but this generation of Ghanaians dares not preside over the destruction of our lands'.

The Member of Parliament for Tarkwa/Nsuem in the Western Region, one of the communities in this country, most devastated by the activities of illegal mining, suggested *galamsey* operations should be legalized. He argued that if the illegal trade is legalized, operators could be regularized and controlled and that would reduce the harm the operation causes to mankind.
'*Galamsey*' is illegal small-scale mining. I wonder why an illegal venture has to be regularized since all the illegal miners need to do is to apply for a license to operate legally. I believe reviewing the licensing process will make the application process less tedious and encourage illegal miners to apply.

Interestingly, although the miners believe '*galamsey*' is their only source of livelihood, some MP's expressed concern about the destructive nature of '*galamsey*' activities in their region, which they stated has been depriving communities of their source of livelihoods. They suggested that although miners tend to believe that is their only source of income, they fail to notice the destruction of farms, pollution of water bodies, pollution of soil and contamination of air affect their livelihood. The question is, after you gain money from *galamsey*, if all farms are destroyed and there is no food to eat nor water to drink because waterbodies have been contaminated and fresh air has been polluted, what sort of life can one live with all the money in this world?

Illegal small-scale miners defied the government's ban on their activities and interestingly were demanding compensation before they stop polluting the water bodies. The small-scale mining association called on the government to lift the ban on small-scale mining activities so that they could work and gain some income. This was one of the demands from the #stopgalamseynow campaign.

In addressing the members of parliament, the president had stated;

‘………we have had to ban small scale mining for the past nine months. We acknowledge that the banning of small-scale mining cannot be the long-term solution in a country such as ours, which is blessed with so many minerals; but as the saying goes, desperate situations call for desperate remedies….’.

An illegal miner remarked;
‘I do not blame the illegal miners, because speaking from experience I know the miners will wish to do the right thing as well as safeguard the environment but the licensing and regulatory regimes are not functioning properly and have been bedevilled with corruption’

An MP noted that

‘…….. the youth have no jobs and it is, therefore, difficult to preach to them about the danger in *galamsey*. The hungry man does not understand that *galamsey* is illegal.’ (Mr Kofi Okyere-Agyekum, MP- Fanteakwa South, 8th March 2017, p 2415)

4.5.3.3 Middle of the ground narrative

Some people took a middle ground position where they draw from both the environmental narrative and the livelihood narrative.
Majority of the people in this category are seeking for solutions. In 2017, the speaker of parliament suggested;
‘…. but on the issue of *galamsey*, I would want to hear Hon. Members propose solutions. I am not one of those who believe in the use of force to try to solve challenges of this nature’.
This indicates that constructive solutions were being sought by some who were not for the pollution of the environment but they also did not support the use of force to solve the problem.

When an MP suggested shoot and kill as the solution to the ‘*galamsey*’ problem, some MPs, interest groups and some members of the public disagreed with the suggestion.
A security analyst noted:
‘I don’t think we should be shooting people. No nation on earth, as a democracy advocates for the murder of its citizens irrespective of what crime they do. Shoot-on-site policy is something that

we do in emergencies. We have not reached there yet. I think that statement has done a massive damage to Ghana internationally that we have a shoot-to-kill policy for people who we profile and we may be wrong in profiling those people. It is most unfortunate,'

An MP noted,

'We are in desperate times but that doesn't call for desperate steps to counter the galamseyers.' (Rockson Dafeamakpor, MP- South Dayi)

Pressure group OccupyGhana called on the government to stop, prevent and then regulate all currently unlicensed and unregulated mining, explore the provision of gainful, alternative employment to persons engaged in '*galamsey*', support mass education on the '*galamsey*' menace, particularly through local civil society, and be mindful of the potential national security threat.

A former Deputy Minister for Employment and Labour Relations warned that stopping '*galamsey*' without a detailed plan on how to cater to the needs of the teeming youth could create bigger problems for the country. He suggested licensing of small-scale mining should be decentralised to remove the tired bureaucratic inertia which forces miners to mine without licences.

This is a serious issue that needs to be addressed. Young people who have driven away from mining sites can resort to other illegal means of obtaining money such as armed robbery, illegal timber logging, internet fraud amongst others.

The vice president noted a Multilateral Mining Integrated Programme (MMIP), aimed at sanitizing the small-scale landscape, had been established by the Ministry which would be implemented for five years at a total cost of US$200 million.

The MMIP, he explained, combined a Legislation Enforcement, Civil Integrated and Technological Approach (LECITA) as a sustainable and structured, but regimented conjoint concept which would encompass multi-stakeholders in dealing with the '*galamsey*' menace. Furthermore, he said, a complete restructuring of the Minerals Commission was taking place to ensure sustainability in the management of the mineral resources of the country.

In 2018, the Multi-sectoral Mining Integrated Project (MMIP) was launched. The government commitment to address the menace of illegal and unsustainable mining practices in the country upon assumption of office established the Multilateral Mining Integrated Project (MMIP). Government's five-year MMIP, an alternative livelihood programme for illegal miners, is expected to cost $10 million. MMIP is expected to deal with the issues holistically and introduce some reforms that will firmly deal with the illegal and unsustainable small-scale mining activities in Ghana.

The world bank approved 50 million dollars to support Governments efforts in addressing illegal small-scale mining and in December 2018, the ban on small scale mining which had been in place for almost two years was lifted.

The CEO of the Ghana Chamber of Mines noted that,…. 'small scale mining is an important part of the mining industry which needs to be supported and cultivated. They need capacity and appropriate technology to be able to operate more safely, productively and environmentally responsibly'.

In 2019, the CEO of Ghana Chamber of Telecommunications said … 'I plead that going forward let's go and take that document (MMIP) and let's implement it because that document has everything in it that would make it work'. He cautioned that relying on donor funding to execute the MMIP would not make it sustainable. He recommended that ..… 'If we want to fund it, we should fund it from the vault. We should fund it from our local resources. It is only then that we can control what happens'.

In 2019, additional financing of $19.39 million was approved by the World Bank Board of Executives Directors. The World Bank Task Team Leader of the Forest Investment Program noted that …… 'Community members engaged in Artisanal Small-Scale Mining, including women, will gain access to new skills and economic opportunities through rehabilitation activities at inactive mining sites, including opportunities created by tree planting and plantation establishment…'

In 2020, due to the global pandemic, some aspects of the MMIP implementation were delayed.

4.5.4 Discussion

Artisanal and small-scale mining activities have harmed the environment. Over the years, the negative impact such as pollution of water bodies, pollution of the air, destruction of farms, increased mortality rate and high school dropout rate have worsened. There is evidence from science that human health is affected by contaminated water and this can eventually lead to death. Both legal and illegal miners are polluting the environment. Enforcement of regulations and the regulations therefore need to be reviewed. Miners pollute waterbodies with impunity, and sadly, policymakers have not been able to address this problem. An analysis of artisanal and small-scale mining policies indicated that there have been some gaps and weaknesses in the policies that people have taken advantage of. Ghanaians obtain licenses and loan their license to foreigners who use heavy equipment to the detriment of water bodies in the nation. Ghanaians who also mine fail to protect the environment. There has also been a failure to train and educate small scale miners on sustainable environmental issues. Some miners might not even be aware of the implication of their actions on future generations. Waterbodies have been polluted to an extent where treatment has become a major challenge and deforestation has become another big problem besides contamination of the soil and air.

In 2017, a ban was placed on small-scale mining and the army was authorized to confiscate mining equipment from illegal mining sites in response to #stopgalamseynow campaign which was organised by a media house in Ghana. The ban was lifted in December 2018. Some illegal miners have been driven away from mining sites and their equipment have been confiscated but interestingly, illegal small-scale mining activities are still ongoing in the country. Suggestions to shoot and kill miners on mining site have been made but this has not deterred the illegal miners.

From the parliamentary debate analysis, there was consensus that artisanal and small-scale mining activities especially '*galamsey*' are polluting the environment and some measures are required to protect the environment but some MPs were not in favour of using force to stop illegal mining in the country. There have been suggestions that providing sustainable alternative sources of income will help solve the problem.

Two major problems at the root are inequality and corruption. The procedure for obtaining a license is bureaucratic and tedious because some people want to receive a bribe to carry out tasks they are being paid to do. Processes are at times unduly delayed to frustrate people and encourage

them to part with some money for the process to be completed. This has to be addressed since it has become widespread in the country especially in public offices.
Solving the '*galamsey*' problem will require policies that will cater for the welfare of low-income earners in the country, training of miners on environmental sustainability issues and a fight against corruption. The MMIP looks promising, but its implementation and enforcement will determine whether the *galamsey* issue will be a thing of the past or not.

A statement by an MP in parliament in April 2017 supports the above statement '…We have the best Minerals and Mining Act in this world apart from Kenya. If we had implemented that Act so well, we would not have had *galamsey*, and our water bodies, our forests and everything would

4.6 Conclusion

This chapter focused on the first objective for this study which is to '*Evaluate existing policies and regulations with regards to Artisanal and Small-Scale Mining (ASM), Water Resources and Environmental flows in Ghana and their enforcement*'.

Based on the information gathered, the researcher can conclude that Ghana generally has a vast number of policies and regulations but the majority of the respondents including miners are not aware of these policies and regulations. Environmental policies, water policies and mining policies which are all interrelated due to artisanal and small-scale mining have been detailed out in documents that exist online. This information is not readily available to inhabitants of rural communities who regularly engage in artisanal and small-scale mining activities. These policies exist on paper but implementation and enforcement are big challenges. A holistic approach is not adopted when implementing these policies and this has led to lack of awareness creation on the impact of ASM activities on water bodies, health and livelihood on inhabitants of mining communities and failure to protect natural resources within the country. Taxation by the government also needs to be looked at because it is crucial to the viability of a mining project in the country. By the end of 2019, An MP stated the 'The war on galamsey activities has tremendously improved our rural development, and has helped in cleaning up our waterbodies although we must admit that much still needs to be done' (26^{th} November 2019, p.3766). Research evidence is expected to inform policy and policy guides the actions of people.

This chapter is followed by the analysis and discussion for objective two; ASM impact on water bodies, health and livelihood.

CHAPTER FIVE

5 ASM impact on waterbodies, health and livelihood

5.1 Introduction

This chapter focused on the second objective for the study which is to '*Assess the level of contamination of water bodies in the mining communities and the impact on the health and livelihood of the inhabitants of the communities along the Birim River*'. Data from the laboratory tests of the water samples and completed questionnaires were analyzed and assessed. The data were also subjected to descriptive statistics. Analysis of variance (ANOVA) was used to determine the difference in the means of the samples. T-Test was used to determine the difference in the mean of the wet season and dry season. Chi test was used to test the probability of independence of a distribution of data. Data were presented in tables, bar charts, scatter diagrams and box plots and detailed interpretations of the results were made. The demographics of questionnaire respondents is captured in chapter three.

5.2 Importance of Waterbodies in the communities

Inhabitants of the three communities were asked whether they use water from the Birim River. 82% of respondents stated they use the water from the Birim River and 70% of respondents indicated they drank the water from the Birim River. 89% of respondents drank water from boreholes (groundwater). Apapam (Community A) had only one active borehole, therefore the majority of the inhabitants depended on the Birim River. The community had banned mining activities close to the river for over four (4) years before the samples were collected although illegal mining activities were still taking place within the community and close the Atewa forest (the source of Birim River). Adadienten (Community B) had two boreholes (groundwater) and another river (Subrim river) that flowed through the community, apart from River Birim. Those who lived close to the Birim River depended on it for drinking water and other domestic purposes. Adukrom (Community C) had more boreholes constructed by mining companies for the inhabitants. Those who lived close to the River Birim depended on it for domestic purposes but only a few people drank the water. In these communities, those who could afford it (about 31%), also bought sachet water for drinking purposes.

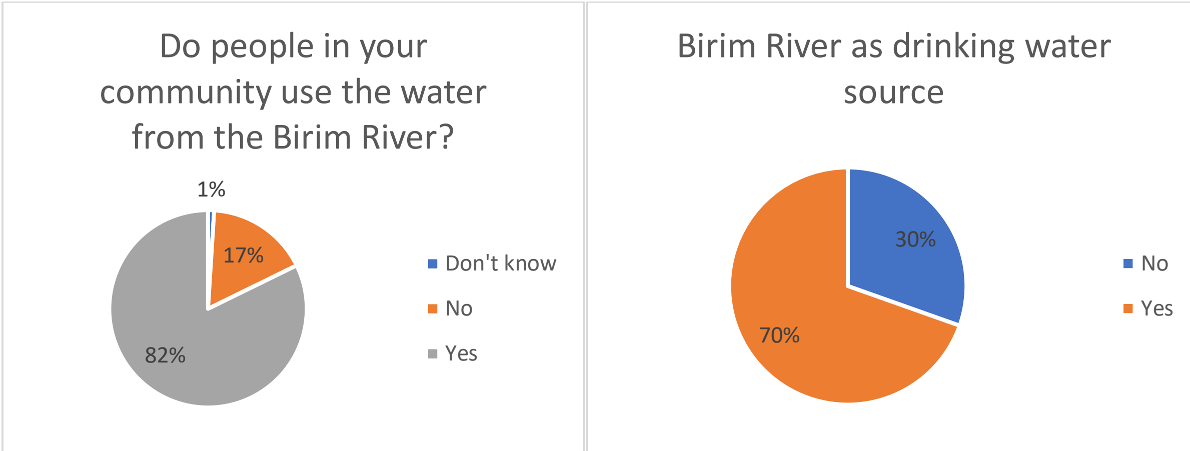


Figure 5.1: Birim river as a source of drinking water (Present Study)

When asked to select other uses of water from the Birim river in the communities, about 60% of respondents indicated water from the Birim served for other domestic purposes, 29.8% of respondents stated for swimming, 26.5% of respondents for irrigation and 22% of respondents stated for fishing. Other purposes stated were for building construction works, car washing etc. Water from the Birim river is therefore very important to the communities along the river. The researcher observed children swimming in the river during her visit.

5.3 ASM Impact on Waterbodies

5.3.1 Level of contamination of water bodies

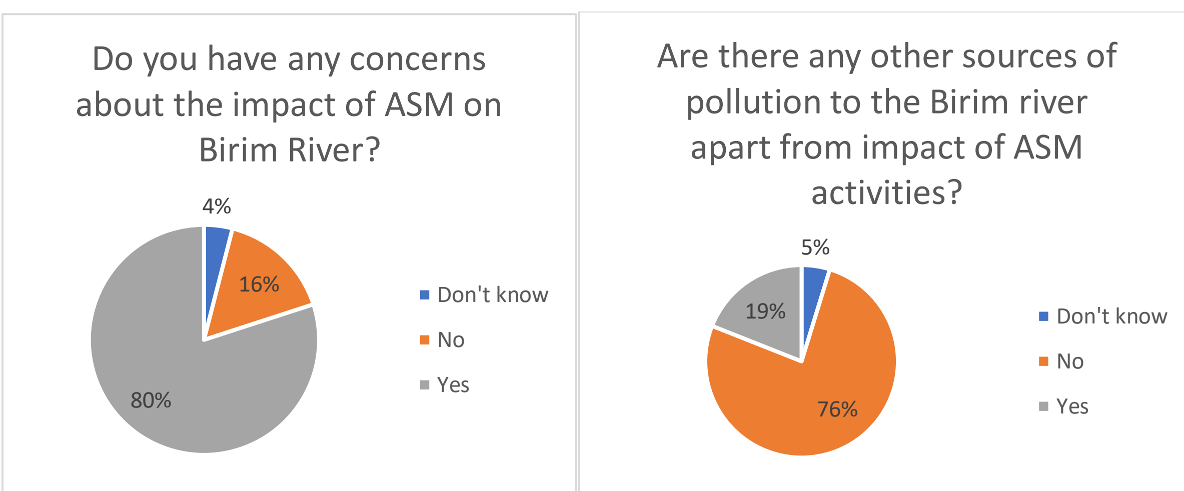


Figure 5.2: Impact of ASM on the Birim river (Present Study)

When asked whether they had any concerns about the impact of ASM on the Birim River, 80% of respondents indicated they were concerned about the negative impact of ASM on the Birim River. 69.5% were concerned about reduced quality of the water (pollution), 22% were concerned about the quantity of the water and only 18.8% of respondents were concerned about the destruction of fish (aquatic life).

When respondents were asked whether there were any other sources of pollution to the river apart from waste from mining activities, 76.3% indicated there were no other sources of pollution. Out of the 19% who indicated there were other sources of pollution, 54.1% indicated human waste and excreta could be a source of pollution, 24.3% indicated animal waste and excreta, only 17.6% stated that fertilizer from farmlands could be a source of pollution and 13.5% stated industrial waste (chemicals). Majority of the respondents believed the River Birim was pollued and the groundwater was safe because groundwater was clear and the River Birim is brownish in colour. Apart from Adukrom, the other communities do not have any industrial activities taking place very close to the communities.

5.3.2 Level of Contamination of Waterbodies in Mining Communities

Water samples were collected from the Birim River, tributaries, boreholes (groundwater) and the mine pond to determine the level of contamination. An initial trip with the CSIR (Council for Scientific and Industrial Research) team was made to the area for site reconnaissance and training in the fieldwork. Twelve (12) water samples were collected during that trip. A full water quality analysis was carried out, in addition to the test for heavy metals.

The researcher later collected 102 water samples from fifty (50) sample locations with two repeat samples. Water samples were tested for physicochemical parameters and heavy metals (As, Pb, Cd, Hg, Mn and Fe). TOC/DOC was measured on water samples from River Birim. In all, 104 samples were submitted to the laboratory for the tests and 20 were submitted for TOC/DOC tests (4 samples for quality control). The GEPA/WHO guidelines for drinking water were used as a measure to determine the quality of the water in the Birim river, tributaries and groundwater. This is because majority of inhabitants in the affected rural communities drink water directly from these sources without treatment.

5.3.2.1 Quality Control

Four (4) samples were submitted to the lab together with the actual water samples for quality control purposes. These comprised two repeat samples and two distilled water samples (BR21 and BRMP21) for both wet and dry seasons. The results for BR21 (repeat sample) were similar to BR19 and BRMP21 which was distilled water, had heavy metal concentrations of less than 0.0001. The background heavy metal concentration of the Birim River was also determined by sampling at a location nearer to the source of the river at Atewa forest range (BR1). The researcher walked for about two (2) hours into the Atewa forest range where the waters rush out of the creeks of the Atewa range of hills with limited anthropogenic activity at its upstream waters from Apapam, the closest town.

5.3.2.2 Comparison of samples and test for independence

One Way Analysis of Variance (ANOVA) was carried out to determine the difference in the means of the samples. A comparison was made between the Birim, Tributary, Groundwater and Mine pond samples. The null hypothesis for the analysis states that there is no significant difference in the means of the different sample groups. The alternate hypothesis states that there is a significant mean difference in at least one sample group. If the p-value is less than or equal to the significance level, the null hypothesis has to be rejected. The p-value (Sig.) >0.05 indicates there is no significant difference in the means between the sample groups and the sample means are equal. A p-value < 0.05 indicates there is a significant difference in at least one mean sample group. The post hoc test (LSD) was also analysed to determine which specific sample groups (relationships) were significantly different. ANOVA tests were carried out for all the parameters at a confidence level of 95%. The T-TEST was mainly used to determine the difference between the means of the two seasons (wet and dry). Chi-square was used to test how likely an observed distribution was due to chance. A p-value <0.05 indicates the null hypothesis is incorrect and the distribution is therefore not due to chance but dependent on one another.

5.3.2.3 Analysis of Initial Water Samples (1st Batch)

Seven (7) water samples were collected from the River Birim, two (2) from boreholes, two (2) from the mine pond, and one (1) from a tributary.

Table 5.1: Locations of the initial 12 samples (Present Study)

No.	Sample Location	ID	No.	Sample Location	ID
1	Osino Boreholes	**OSBH**	7	Osino Birim River	**OSBR**
2	Akanten Boreholes	**AKBH**	8	Brimso Asiakwa Birim River	**BABR**
3	Apapam Birim River	**APBR**	9	Bunso Birim River	**BNBR**
4	Oda Birim River	**ODBR**	10	Mempasem Mine pond	**MPMP**
5	Emuo River	**EMTR**	11	Akanten Mine pond	**AKMP**
6	Kade Brim River	**KDBR**	12	Anyinam Brim River	**ANBR**

5.3.2.3.1 Physiochemical Analysis for Initial 12 Samples

The twelve samples were analyzed for Turbidity, Colour (Apparent), Odour, pH, Conductivity, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Sodium, Potassium, Calcium, Magnesium, Fluoride, Ammonia, Chloride, Sulphate, Phosphate, Nitrite, Nitrate, Total Hardness, Total Alkalinity, Calcium, Hardness, Bicarbonate and Carbonate. The table of data is presented in the Appendix.

The highest turbidity recorded was 1182 NTU at BNBR. The highest colour recorded was 225mg/l Pt/Co at BNBR and BABR. Measured pH was within the 6.5-8.5 range. TDS was within acceptable limits but TSS was highest at BNBR at a mean value of 925mg/L. All the other parameters were within acceptable limits. This analysis provided information on which important physicochemical parameters should be selected for the 100-sample analysis because of the limited budget.

5.3.2.3.2 Heavy Metal Analysis for Initial 12 Samples

The concentrations of total metals and dissolved metals were measured for iron, manganese, arsenic, cadmium, lead and mercury.

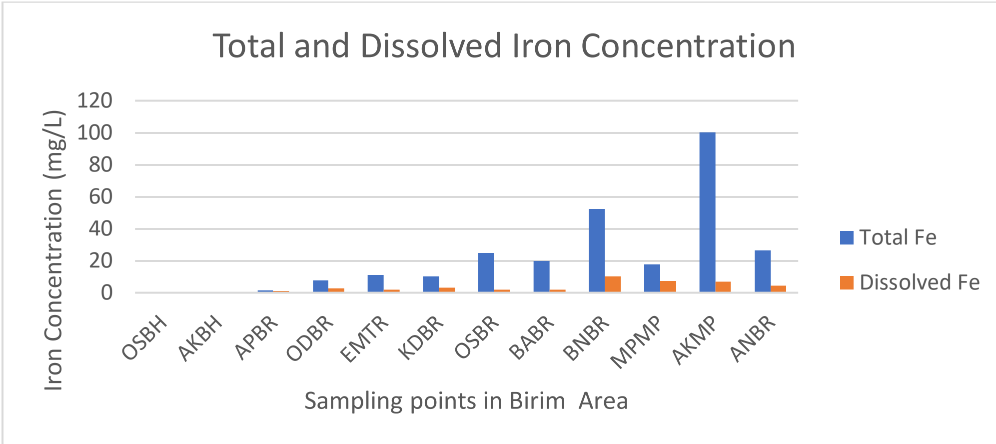


Figure 5.3: Total and Dissolved Iron Concentration (Present Study)

The highest total iron concentration was 100mg/L. Both the total and dissolved iron concentrations were above the WHO Limit for all samples except borehole samples. As seen, the total iron concentration for most samples was much higher than the dissolved iron and suggests the presence of a significant amount of particulate iron.

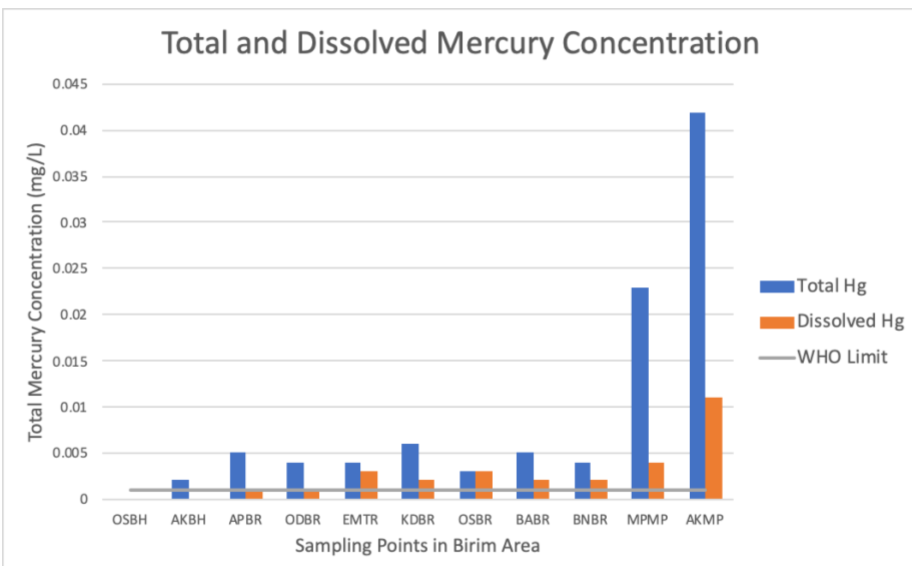


Figure 5.4: Total and Dissolved Mercury Concentration (Present Study)

The concentration of Mercury is high especially in the mine ponds. Total and dissolved mercury are generally above the WHO limits. The dissolved concentration was significant for Mercury.

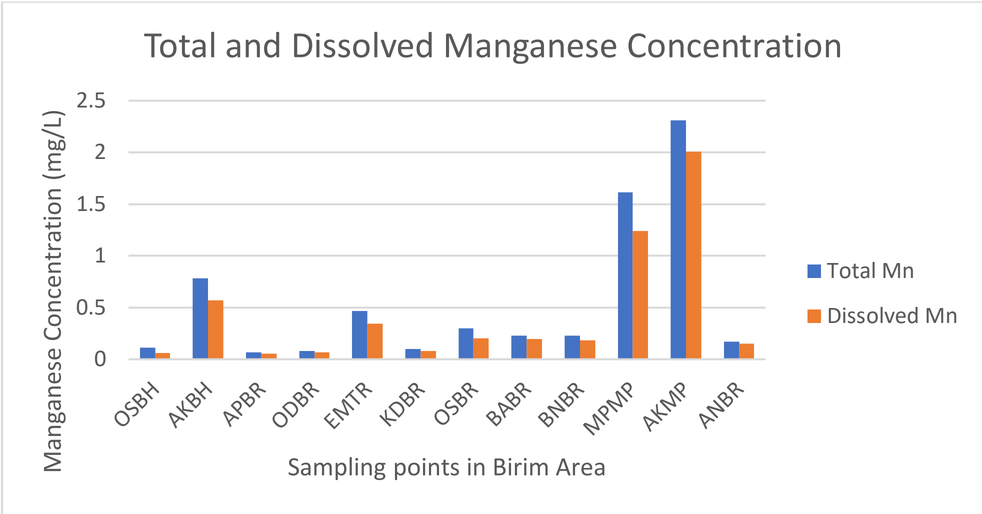


Figure 5.5: Total and Dissolved Manganese Concentration (Present Study)

The manganese concentration was highest in the mine pond samples where they significantly exceeded the WHO Limit. One borehole (AKBH) also exceeded the WHO limit for manganese. The River Birim samples had the lowest manganese concentration. The dissolved concentrations were high for Manganese.

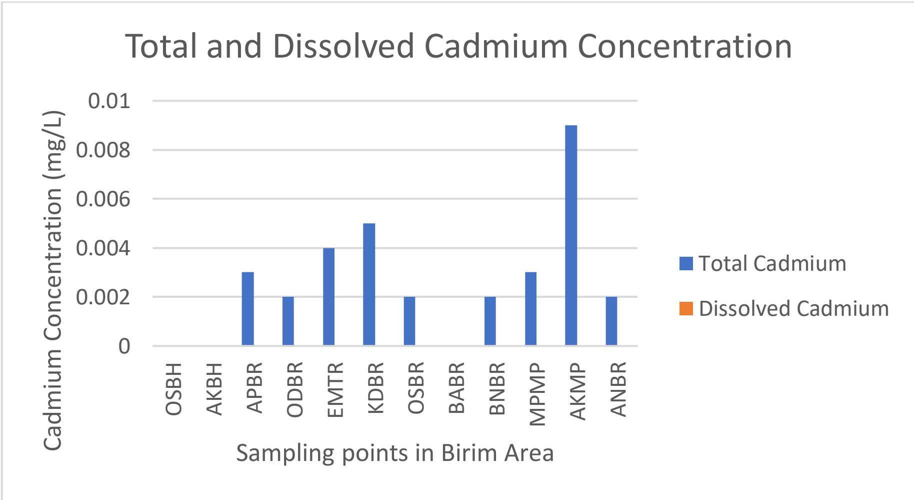


Figure 5.6: Total and Dissolved Cadmium Concentration (Present Study)

The highest cadmium concentration was from the Mine pond (AKMP) followed by River Birim (KDBR). The WHO limit was exceeded in APBR, EMTR and KDBR. Cadmium concentration was insignificant in the borehole samples. The dissolved cadmium concentration was also not significant.

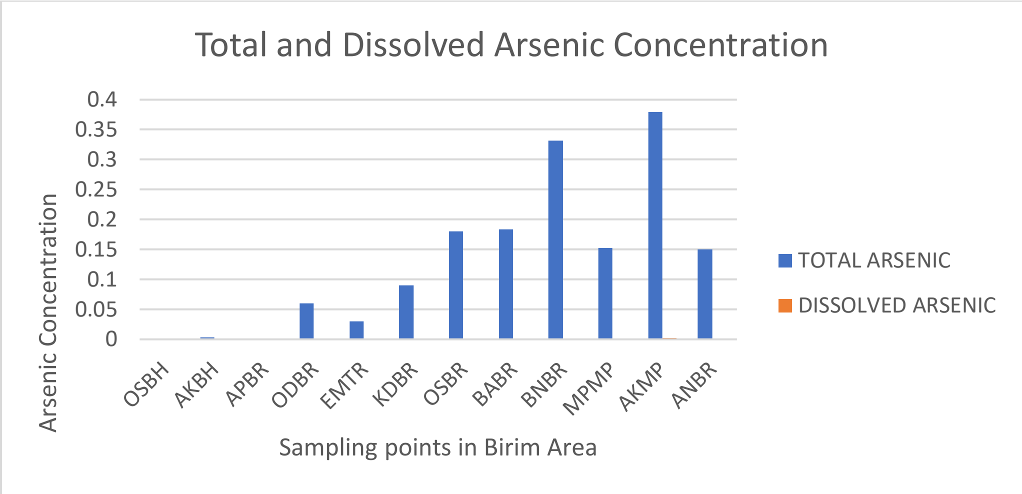


Figure 5.7: Total and Dissolved Arsenic Concentration (Present Study)

Total arsenic concentration was high in all the samples except the boreholes. The highest concentration was in the mine pond AKMP. Samples OSBH, AKBH and APBR had the lowest arsenic concentrations. The dissolved arsenic concentrations were insignificant.

5.3.2.4 Analysis for Water Samples (2nd Batch)

One hundred and four (104) samples were submitted to the lab (including 2 repeat and two distilled water or blank samples). In all, 42 samples were collected from River Birim (including repeat samples), 24 from tributaries, 22 from groundwater, 12 from mine ponds and two (2) from the water treatment plant in the main Kibi township. Water samples were tested for physicochemical parameters and heavy metals (As, Pb, Cd, Hg, Mn and Fe). TOC/DOC was measured on water samples from River Birim. Only wet season data was collected for BRMP1 because the mine pond had dried up at the time of the dry season sampling. A sample, BR19, was taken at the confluence where a tributary joined the River Birim at Akwatia. The researcher focused on the total heavy metal concentration of metals because the dissolved heavy metal concentration was not significant in general from the results of the 12 samples.

Table 5.2: Sampling location for 100 water samples (Present Study)

No.	**Sampling Location**	**ID**		**Sampling Location**	**ID**
	BIRIM RIVER			**TRIBUTARIES**	
1	Atewa (Source)	**BR1**	1	Bukuru (Kibi)	**TRI**
2	Apapam	**BR2**	2	Abosua (Kibi)	**TR2**
3	Afiesa	**BR3**	3	Krensen	**TR3**

No.	Sampling Location	ID		Sampling Location	ID
4	Ahwenease	**BR4**	4	Supon (Nsutem)	**TR4**
5	Adadientem	**BR5**	5	Anyinam Anikoko	**TR5**
6	Kibi	**BR6**	6	Kwaben Awusu	**TR6**
7	Pano	**BR7**	7	Abresu	**TR7**
8	Adukrom	**BR8**	8	Si Asunafo	**TR8**
9	Asiakwa	**BR9**	9	Pram	**TR9**
10	Bunso	**BR10**	10	Mempong (Akim Akropong)	**TR10**
11	Nsuapemso	**BR11**	11	Moore (Boadua)	**TR 11**
12	Ankaase	**BR12**	12	Twumwusu Fonsira	**TTR1**
13	Anyinam	**BR13**		**GROUNDWATER**	
14	Abomoso	**BR 14**	1	Kibi Waterworks (**treated**)	**BRTW**
15	Amunum	**BR 15**	2	Apapam BH	**BRBH1**
16	Okyenso	**BR 16**	3	Adadientem BH	**BRBH5**
17	Abodom	**BR 17**	4	Nsuapemso BH	**BRBH 11**
18	Kade	**BR 18**	5	Ankaase BH	**BRBH12**
19	Akwatia (Birim Moore Confluence)	**BR 19**	6	Anyinam BH	**BRBH 13**
20	Akwatia	**BR 20**	7	Kade BH	**BRBH 18**
21	Akwatia (Birim Moore Confluence) **Repeat**	**BR 21**	8	Akwatia BH	**BRBH 19**
	MINE POND		9	Twumwusu (Pramkese)	**TTRBH1**
1	Apapam MP	**BRMP1**	10	Asamaman	**TRBH1**
2	Adadientem MP	**BRMP5**	11	Si Asunafo BH	**TRBH8**
3	Nsuapemso	**BRMP11**	12	Akim Akropong	**TRBH 10**
4	Ankaase	**BRMP12**			
5	Abosua MP	**TRMP 2**			
6	Twumwusu (Pramkese)	**TTRMP1**			
7	**Distilled Water**	**BRMP21**			

5.3.2.4.1 Physiochemical Parameters

Physiochemical parameters such as Temperature, pH, Conductivity, True colour, Apparent colour, Alkalinity, Bicarbonate, TSS and TDS were tested.

Table 5.3: Lowest and highest value for physicochemical parameters for the dry and wet seasons (Birim river and Tributaries) (Present Study)

Parameter	**BIRIM RIVER**				**TRIBUTARIES**			
	DRY MAX	**WET MAX**	**DRY MIN**	**WET MIN**	**DRY MAX**	**WET MAX**	**DRY MIN**	**WET MIN**
Temperature (^{O}C)	**29.3** (BR20)	**28.2** (BR16)	**23.3** (BR1)	**23.6** (BR1)	**26.7** (TR2,9)	**26.1** (TR7,11)	**25.2** (TR6)	**22.4** (TR2)
pH (F)	**8.63** (BR1)	**7.48** (BR2)	**7.29** (BR 16)	**5.6** (BR15,16)	**7.82** (TR2)	**6.89** (TR1)	**6.7** (TR5)	**5.63** (TTR1)

Parameter	BIRIM RIVER				TRIBUTARIES			
pH (Lab)	**7.71** (BR7)	**7.67** (BR9)	**7.13** (BR2)	**6.81** (BR13)	**7.56** (TR2)	**7.51** (TR1)	**6.52** (TR5)	**6.45** (TR5)
Conductivity (µS/cm)	**184** (BR7)	**169** (BR7)	**107** (BR15,16)	**82.0** (BR14)	**224** (TR5)	**240** (TR5)	**74.3** (TR4)	**72.7** (TR4)
TDS (mg/L)	**123** (BR7)		**68** (BR14)		**201** (TR5)		**52.1** (TR4)	
Turbidity (NTU)	**869** (BR14)	**302** (BR12)	**<1.00 -1** (BR1-7)	**10** (BR1,2)	**235** (TR11)	**105** (TR5)	**<1.00**	**<1.00** (TR6)
Apparent Colour (mg/L Pt/Co)	**600** (BR14)	**100** (BR12)	**<2.5 -5** (BR1-7)	**<2.5** (BR1)	**125** (TR11)	100 (TR5)	**<2.5**	**7.5** (TR3)
True Colour (mg/L Pt/Co)	**150** (BR14)	**50** (BR9-12)	**<2.5-2.5** (BR1-7)	**2.5** (BR1-2)	**70** (TR11)	**50** (TR5)	**<2.5**	**2.5** (TR6)
TSS (mg/L)	**998** (BR9)	**277** (BR12)	**<1.00-1** (BR1-7)	**4** (BR2)	**240** (TR11)	**70** (TR5)	**<1.00**	**<1.00** (TR6)
Alkalinity (mg/L as $CaCO_3$)	**80.4** (BR7)	**75.6** (BR7)	**42** (BR16)	**27.8** (BR11)	**97.2** (TR5)	**99.6** (TR5)	**30.2** (TR4)	**30.2** (TR8)
Bicarbonate (mg/L as $CaCO_3$)	**98.1** (BR7)	**92.2** (BR7)	**51.2** (BR16)	**33.9** (BR11)	**119** (TR5)	**122** (TR5)	**36.8** (TR4)	**36.8** (TR8)

Table 5.4: Lowest and highest value for physicochemical parameters for the dry and wet seasons (Groundwater and Mine pond)

Parameter	GROUNDWATER				MINE POND			
	DRY MAX	**WET MAX**	**DRY MIN**	**WET MIN**	**DRY MAX**	**WET MAX**	**DRY MIN**	**WET MIN**
Temperature (^{O}C)	**28.9** (BRBH19)	**30.5** (BRBH13)	**26.2** (BRBH18)	**25.5** (BRBH5)	**32.6** (TRMP2)	**31.1** (BRMP1)	**25.5** (BRMP11)	**24.5** (TRMP2)
pH (F)	**7.4** (BRBH19)	**6.8** (BRBH19)	**5.6** (BRBH18)	**4.68** (BRBH18)	**8.92** (TRMP2)	**6.42** (BRMP5)	**7.22** (BRMP12)	**5.8** (TRMP2)
pH (Lab)	**7.36** (BRBH19)	**7.24** (BRBH19)	**5.24** (BRBH18)	**5.01** (BRBH19)	**7.35** (TRMP2)	**7.51** (TRMP2)	**6.2** (BRMP2)	**6.23** (BRMP1)
Conductivity (µS/cm)	**450** (BRBH1)	**448** (BRBH1)	**53.3** (BRBH18)	**53.0** (BRBH18)	**160** (TRMP2)	**158** (TRMP2)	**66.5** (BRMP12)	**19.7** (BRMP1)
TDS (mg/L)	**353** (BRBH19)		**40** (BRBH18)		**94.4** (TRMP2)		**47.7** (BRMP12)	
Turbidity (NTU)	**2** (BRBH2)	**7** (TRBH1)	**<1.00**	**<1.00**	**170** (BRMP11)	**55** (BRMP11)	**<1.00**	**3** (TTRMP1)
Apparent Colour (mg/L Pt/Co)	**5** (BRNH11)	**7.5** (BRBH11, TTR1)	**<2.50**	**<2.50**	**100** (BRMP11)	**40** (BRMP11)	**<2.50**	5 (TTRMP1)
True Colour (mg/L Pt/Co)	**2.5** (BRBH11)	**<2.50**	**<2.50**	**<2.50**	**50** (BRMP11)	**20** (BRMP1)	**<2.5**	**<2.5**
TSS (mg/L)	**4** (TRBH1)	**4** (BRBH11)	**<1.00**	**<1.00**	**160** (BRMP11)	**48** (BRMP11)	**<1**	**1** (TTRMP1)
Alkalinity (mg/L as $CaCO_3$)	**189** (BRBH19)	**221** (BRBH19)	**12.6** (BRBH18)	**4.8** (BRBH18)	**76** (TRMP2)	**71** (TRMP2)	**12.2** (BRMP5)	**6** (BRMP1)
Bicarbonate (mg/L as $CaCO_3$)	**231** (BRBH19)	**269** (BRBH19)	**15.4** (BRBH18)	**5.86** (BRBH18)	**92.7** (TRMP2)	**86.6** (TRMP2)	**14.9** (BRMP5)	**7.32** (BRMP1)

5.3.2.4.1.1 Temperature

Water temperature is a physical property expressing how hot or cold water is (Fondriest, 2019). Temperature is important because of its effect on water chemistry because the rate of chemical reactions generally increase with increase in temperature (USGS, 2013). Temperature is an important factor to consider when assessing water quality. In addition to its own effects, temperature influences several other parameters and can change the physical and chemical properties of water (Bennet and Di Santo, 2011). Water temperature therefore, affects biological activity and growth of organisms that live in water bodies (USGS, 2013). The temperature of the river was recorded using a field meter.

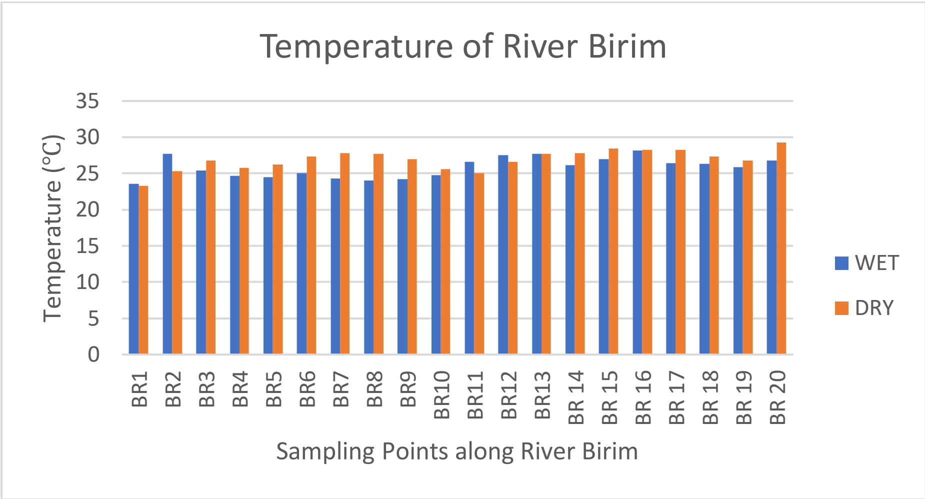


Figure 5.8: Bar chart for Temperature of Birim river (Present Study)

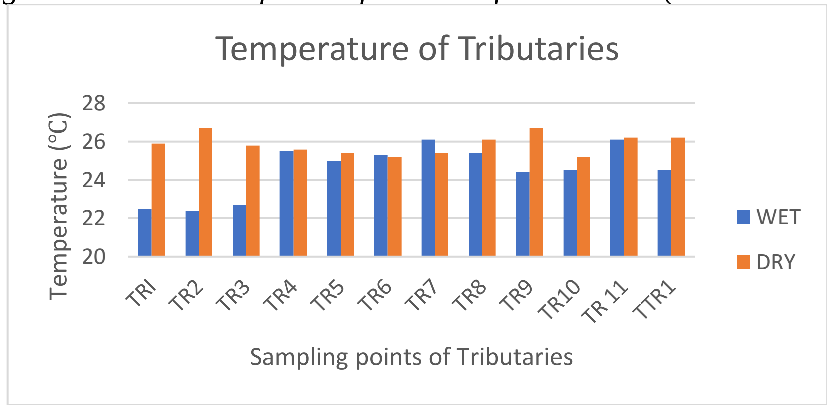


Figure 5.9: Bar chart for Temperature Tributaries (Present Study)

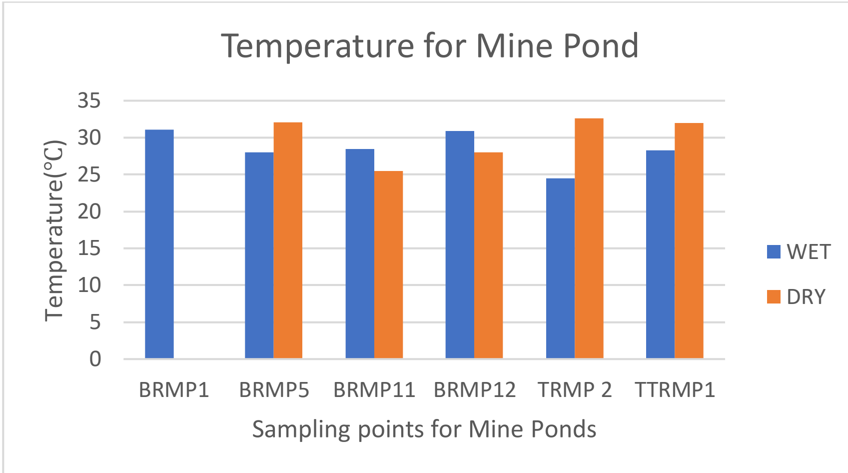


Figure 5.10: Bar chart for Temperature Tributaries (Present Study)

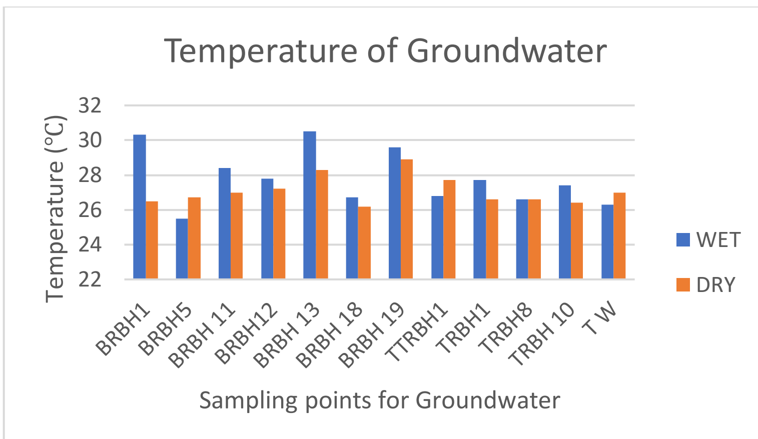


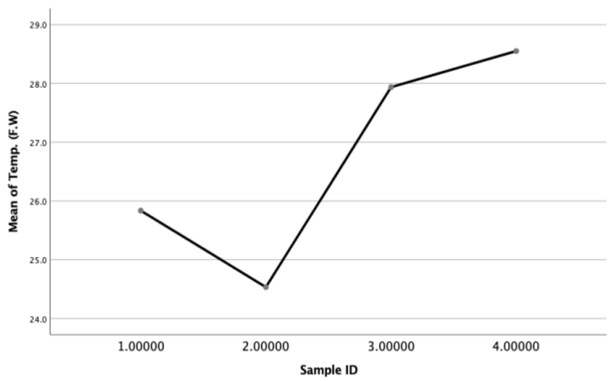
Figure 5.11: Bar chart for Groundwater (Present Study)

The temperature of the river and tributaries during the dry season was generally higher than during the wet season which is expected because during the dry season, air temperature is generally higher and humidity is higher compared to the wet season. The highest temperature recorded during the wet season was for Birim River was 28.2°C at Okyenso (BR16) and that of the dry season was 29.3°C at Akwatia (BR20). The lowest temperature recorded for the wet season was 23.6°C at the Atewa forest (BR1) and that of the dry season was 23.3°C also at Atewa forest (BR1) which has lots of trees that serve as shade for the river (local conditions). The highest temperature recorded during the wet season was 26.1°C at both Abresu (TR7) and Moore-Boadua (TR11) and that for the dry season was 26.7°C at both Abosua-Kibi (TR2) and Pram (TR9). The lowest temperature recorded for the wet season was 22.4°C at Abosua-Kibi (TR2) and that of the dry season was 25.2°C at both Kwaben Awusu (TR6) and Mempong (TR10).

The temperature of groundwater, unlike that of surface water (River Birim and tributaries), was higher during the wet season than during the dry season. Interestingly, in communities where both river water and groundwater were sampled, the temperature of the groundwater was higher than that of the river. The highest groundwater temperature recorded during the wet season was 30.5^{o}C at Anyinam (BRBH13) followed by 30.3^{o}C at Apapam (BRBH1) and that of the dry season was 28.9^{o}C at Akwatia (BRBH19) followed by Anyinam (BRBH13).

The temperature of the water in the mine pond was generally high compared to that of the river, tributary and groundwater. The water in the mine pond is stagnant and its temperature will be affected by local conditions.

5.3.2.4.1.1.1 Comparison of means and variables



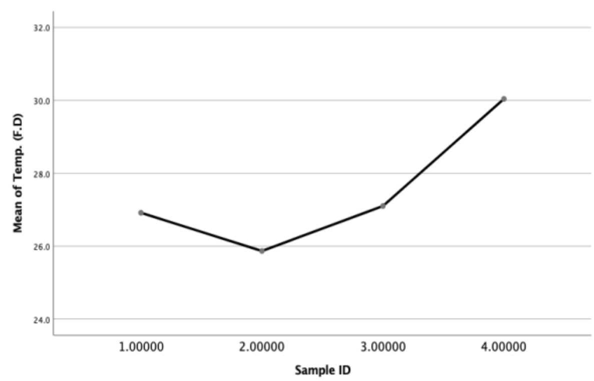


Figure 5.12: Mean plot for Temperature for the dry and wet season (Present Study)

A comparison between the sample means determined that there is a difference in the means between the sample groups. P-value (0.001) was less than 0.05 and thus the null hypothesis has to be rejected. Details from the LSD indicates that there is a significant difference between the sample groups except for the relationship between group 1 (Birim River) and group 3 (Groundwater) which did not have a significant difference for the dry season. For the wet season, there was a significant difference between all the groups except for the relationship between group 3 (groundwater) and group 4 (mine pond).

Comparing the means between the two seasons, a p-value (0.007) was less than 0.05 for Birim river and p-value (0.015) was less than 0.05 for tributaries, indicating there was a significant difference in the means of the two seasons for River Birim and tributaries, but for groundwater, p-value (0.73) was greater than 0.05, indicating there was no significant difference between the means of the two seasons for groundwater.

5.3.2.4.1.1.2 Discussion of Temperature Results

The temperature of River Birim and tributaries were generally higher during the dry season than the wet season and that is because during the dry season, atmospheric temperature is higher and humidity is higher than in the wet season. The temperature of the groundwater was the opposite, higher during the wet season compared to the dry season.

Temperature variations are generally affected by the time of the day samples are collected, altitude and elevation and local conditions. Water temperature fluctuates during day and night and seasonally as well. Samples were collected throughout the day from morning till evening and during the wet and dry season at different points along River Birim. That can influence the temperature results.

A number of studies have shown a direct relationship between metabolic rates and water temperature (Fondriest, 2019). The sun is the main source of heat for rivers etc. but inputs such as precipitation, heat exchanges with the air, surface runoff and water from upstream and upstream tributaries, and heat lost or gained by evaporation or condensation can also influence temperature (USGS, 2013).

5.3.2.4.1.2 pH

pH is a measure of how basic or acidic water is. It is a measure of the relative amounts of free hydroxyl and hydrogen ions in the water (USGS, 2013). A pH value of less than 7 indicates acidity, while pH greater than 7 indicates a base. The pH of water is a very important measurement concerning water quality. pH is reported in ‘logarithmic units’ with each number representing a 10-fold change in the acidity/basicity of the water.

pH is an important water measurement, which is often measured both at the sampling site and in the laboratory. Before taking a pH measurement, the field meter was calibrated. The probe was immersed in a solution that has a known pH, (pH of 4.0 and pH of 7.0).

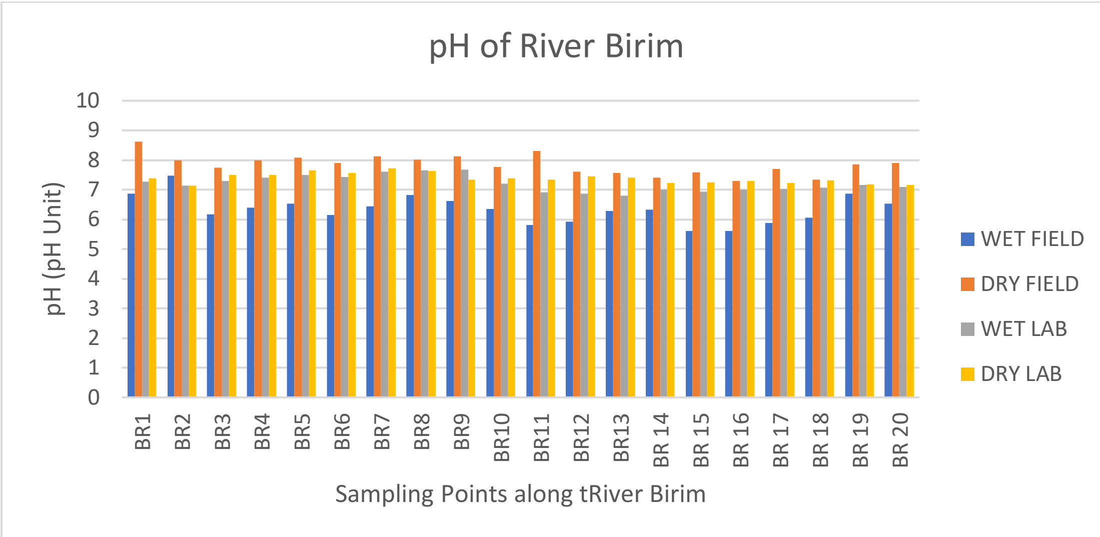


Figure 5.13: Bar chart for pH of River Birim (Present Study)

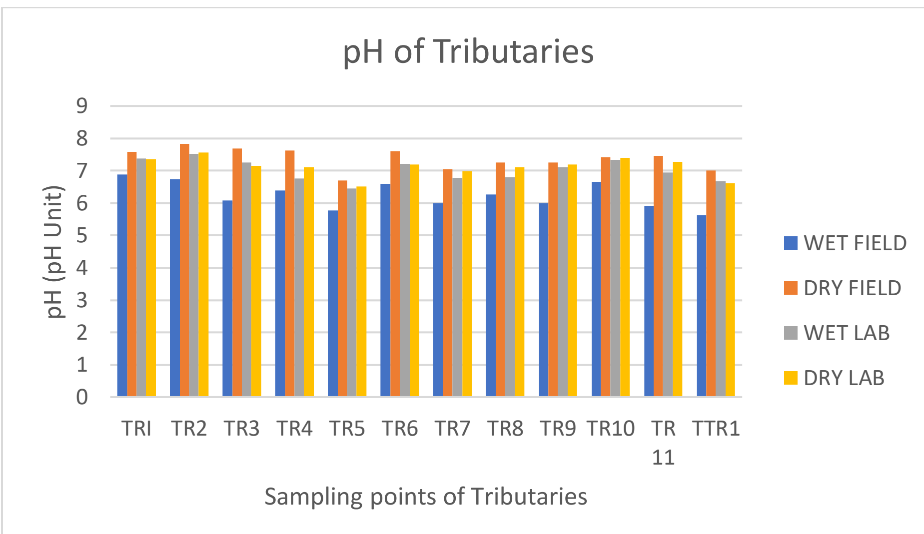


Figure 5.14: Bar chart for pH of Tributaries (Present Study)

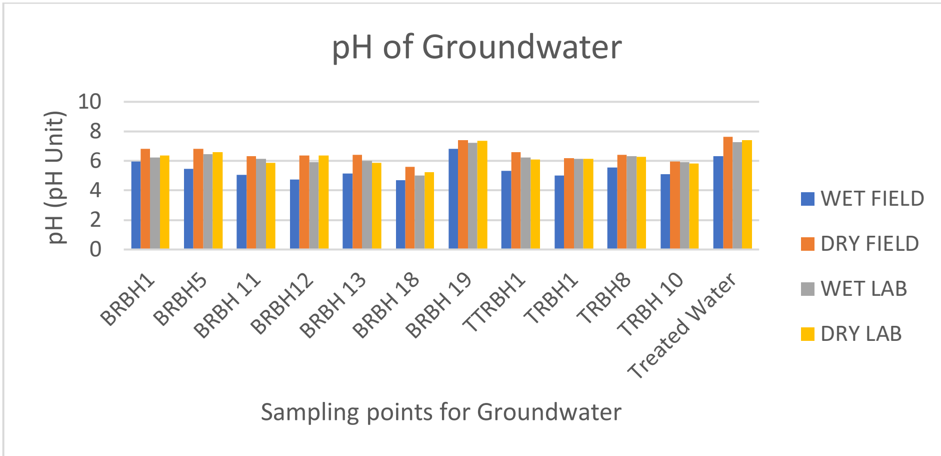


Figure 5.15: Bar chart for pH of Groundwater (Present Study)

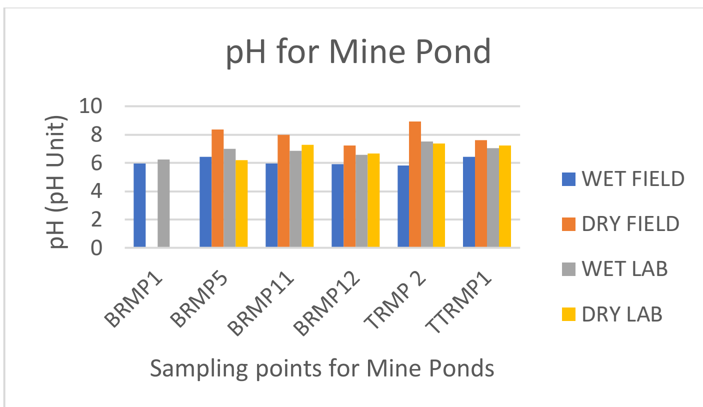


Figure 5.16: Bar chart for pH of Mine pond (Present Study)

The mean pH measured during the dry season is higher compared to the wet season for the Birim river, tributaries, groundwater and mine pond. Field pH during the dry season has the highest values, followed by pH for the dry season in the laboratory. Interestingly, during the wet season laboratory pH values are higher than the field values. The highest pH during the dry season (field) was collected at Atewa forest (BR1) which had the lowest temperature for both dry and wet seasons, with a value of 8.63 and the lowest was 7.27 at Okyenso (BR16) which had the highest temperature for the wet season. It was observed that high-temperature areas had low pH. The highest pH for the wet season was recorded at Apapam (BR2) at 7.48 and the lowest pH was 5.6 at both Amunum (BR16) and Okyenso (BR16). The laboratory pH recorded for the dry season had a value of 7.71at Pano (BR7) as the highest value and 7.13 at Apapam (BR2) as the lowest value.

For the wet season lab results, the highest was 7.67 at Asiakwa (BR9) and 6.81 at Anyinam (BR13) as the lowest.

For the tributaries, the pH collected during the dry season is also higher compared to the wet season. During the dry season, the field pH had the highest values, followed by pH for the dry season in the laboratory. Interestingly, the laboratory pH values are higher than the field values during the wet season. The laboratory values are closer for the dry and wet season whilst the field values are more widely apart for the dry and wet season. The highest pH during the dry season (field) was collected at Abosua-Kibi (TR2) which had the lowest temperature for the wet season, with a value of 7.82 and the lowest was 6.7 at Anyinam Anikoko (TR5), a river that has a reddish-brown colour. The highest pH of 6.89 for the wet season was recorded at Bukuru-Kibi (TR1) and the lowest pH (5.63) at Twumwusu Fonsira (TTR1). The pH recorded in the laboratory for the dry season had a value of 7.56 at Abosua-Kibi (TR2) as the highest value, the same location as for the highest field value and 6.52 at Anyinam-Anikoko (TR5) as the lowest value, the same location as was recorded for the lowest field value. The laboratory pH in the wet season had the highest value of 7.51 at Abosua-Kibi (TR2) and 6.45 at Anyinam Anikoko (TR5), a river that has a reddish-brown colour. The Anyinam (BR13) also recorded the lowest laboratory pH value in the wet season. The field and laboratory pH values are relatively consistent.

For Groundwater, the mean pH for the dry season is also higher than that of the wet season. The pH values for groundwater were generally low compared to River Biirim and the Tributaries. Treated water from the water treatment plant that serves the main Kibi township had a pH of 7.65 for the dry field value, 6.3 for the wet field value, 7.4 for the dry lab value and 7.28 for the wet lab value. The highest pH value for groundwater during the dry season (field) was collected at Akwatia (BRBH19) with a value of 7.4 and the lowest was 5.6 at Kade (BRBH18). The highest pH for the wet season was recorded at Akwatia (BRBH 19) at 6.8 and the lowest pH was 4.68 at Kade (BRBH18) just as with the dry season. pH recorded in the lab for the dry season had a value of 7.36 at Akwatia (BRBH 19) as the highest value, the same location as for the highest field value and 5.24 at Kade (BRBH18) as the lowest value, the same location as was recorded for the lowest field value. For the wet season lab results, the highest was 7.at Akwatia (BRBH 19) and 5.01 Kade (BRBH18). The pH values from the field and lab are relatively consistent for groundwater. In their research, Dorleku et al (2018) observed in their analysis that pH values were generally low in the basin with more than 95% of dry the season and almost all wet season values being acidic or slightly acidic. This was observed in this study.

For the mine pond, the pH collected during the dry season is also higher compared to the wet season. pH values from the field during the dry season has the highest values. The lab values are closer for the dry and wet season whilst the field values are more widely apart for the dry and wet season. The highest pH value for the mine pond during the dry season (field) was collected at Abosua (TRMP2) with a value of 8.92 followed by Adadienten (BRMP2) with a value of 8.35 and the lowest was 7.22 at Ankaase (BRMP12). The highest pH for the wet season was recorded at Adadientem (BRMP5) at 6.42 and the lowest pH was 5.8 at Abosua (TRMP2). pH recorded in the lab for the dry season had a value of 7.35 at Abosua (TRMP2) as the highest value, and 6.20 at Adadientem (BRMP5) as the lowest value, For the wet season lab results, the highest was 7.51 at Abosua (TRMP2) and 6.23 at Apapam (BRMP1).

5.3.2.4.1.2.1 Comparison of Means and variables

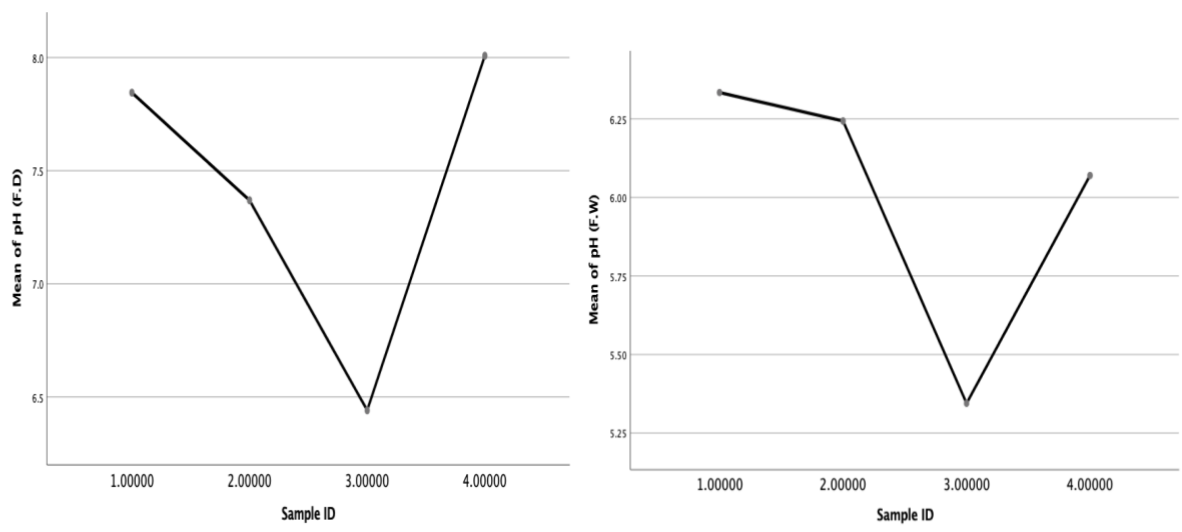


Figure 5.17: Mean plot for pH (Present Study)

A comparison between the samples means determined that there is a difference in the means between the sample groups (p-value 0.0001 was less than 0.001) and thus the null hypothesis has to be rejected. The pH showed significant differences in the mean between samples for both field and lab data. From the LSD, group 3 (groundwater) was significantly different from the other samples for the field wet and lab wet. For field dry, group 2 (tributary) was significantly different from the other sample groups.

Comparing the means between the two seasons, a p-value 0.0001 less than 0.05 for Birim river, p-value (0.0001) less than 0.05 for tributaries and a p-value (0.0001) less than 0.05 for groundwater. This indicates there was a significant difference in the means of the two seasons for Birim river, tributaries and groundwater.

5.3.2.4.1.2.2 Discussion of pH Results

High and low pHs can be harmful to the use of water. High-pH causes a bitter taste, and it reduces the effectiveness of water disinfection with chlorine and low-pH water dissolves metals and other substances (USGS 2013). Exposure to extreme pH values results in irritation to the eyes, skin, and mucous membranes and in sensitive individuals, gastrointestinal irritation may also occur (WHO 2013).

The pH of most natural waters is controlled by the carbon dioxide–bicarbonate–carbonate equilibrium system. An increased carbon dioxide concentration will therefore lower pH, whereas a decrease will cause it to rise. Temperature will also affect the equilibria and the pH. In pure water, a decrease in pH of about 0.45 occurs as the temperature is raised by 25 °C (WHO 2003).

The pH of the Birim River and tributaries were generally in the range 6.5-8.5 which is acceptable, although some field pH values measured in the wet season were a bit lower. The slightly acidic nature of some samples from the Birim River and tributaries during the wet season may be attributed to the formation of Acid Mine Drainage which occurs when rock containing sulphide minerals are excavated from an open pit reacts with water and oxygen to create sulphuric acid. The stronger the acid solution, the more the metals become soluble in water and this lowers the pH. The pH value at Atewa, the source of the river, is within the acceptable range. The pH of groundwater was generally low for most samples which does not make it suitable for drinking, according to the WHO guidelines. Living organisms, especially aquatic life, function best in the pH of 6.0 to 9.0.

Pollution can change a water's pH, which in turn can harm animals and plants living in the water.

According to USGS (2013), the pH of water determines the solubility (the amount that can be dissolved in the water) and biological availability (the amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, cadmium, etc.). In the case of heavy metals, the degree to which they are soluble determines their toxicity and metals tend to be more toxic at lower pH (USGS 2013).

5.3.2.4.1.3 Turbidity

Turbidity is a measure of the relative clarity of water and is a visual characteristic of water denoting the amount of light that is scattered by particles in the water when light goes through the water sample (USGS, 2013). The higher the intensity of scattered light, the higher the turbidity. Turbidity is measured in Nephelometric Turbidity Units (NTU).

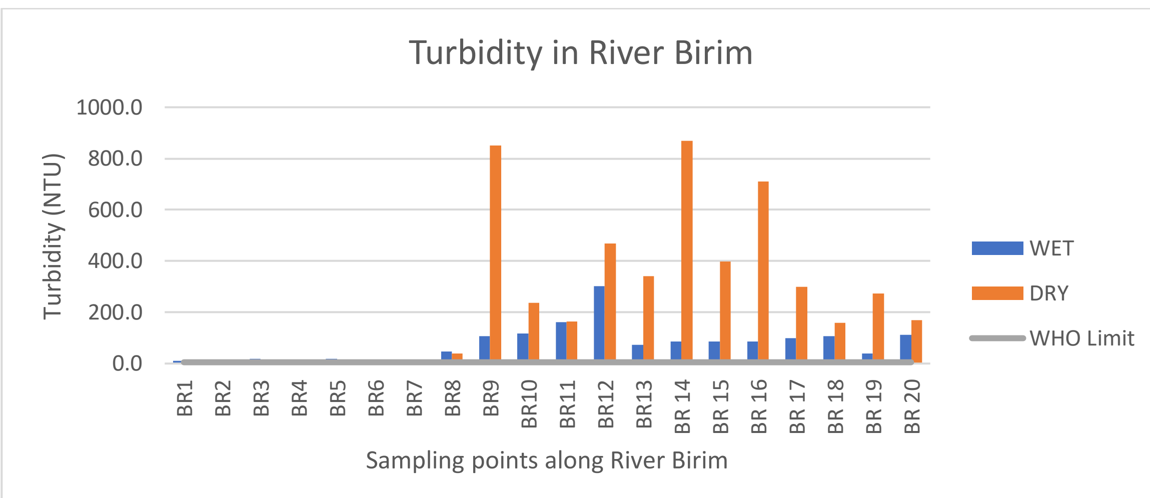


Figure 5.18:Turbidity in River Birim (Bar chart) (Present Study)

Table 5.5:Turbidity of Tributaries and Boreholes (Present Study)

TURBIDITY OF TRIBUTARIES			TURBIDITY OF BOREHOLES (NTU)		
TRIBUTARY	**WET**	**DRY**	**BOREHOLE/WELLS**	**WET**	**DRY**
TRI	35.0	<1.00	BRBH1	<1.00	<1.00
TR2	10.0	4.00	BRBH5	3.00	<1.00
TR3	9.00	<1.00	BRBH 11	4.00	2.00
TR4	19.0	80.0	BRBH12	<1.00	<1.00
TR5	105	51.0	BRBH 13	<1.00	<1.00
TR6	<1.00	1.00	BRBH 18	<1.00	<1.00
TR7	52.0	174	BRBH 19	<1.00	<1.00

TURBIDITY OF TRIBUTARIES			TURBIDITY OF BOREHOLES (NTU)		
TR8	16.0	<1.00	TTRBH1	<1.00	<1.00
TR9	37.0	<1.00	TRBH1	7.00	<1.00
TR10	10.0	<1.00	TRBH8	<1.00	<1.00
TR 11	71.0	235	TRBH 10	<1.00	<1.00
TTR1	15.0	<1.00	T W	<1.00	<1.00

Table 5.6: Turbidity of Mine ponds (Present Study)

TURBIDITY OF MINE PONDS (NTU)		
MINE POND	**WET**	**DRY**
BRMP1	40.0	
BRMP5	10.0	87.0
BRMP11	55.0	170
BRMP12	26	<1.00
TRMP 2	10.0	3.00
TTRMP1	3.00	<1.00

For the Birim river, the turbidity of River Birim was generally higher in the dry season than in the wet season. BR1 and BR2 had the lowest turbidity for both the wet and dry seasons. BR1, BR2, BR3, BR4, BR5, BR6, BR7 had relatively low values although they were slightly above the limit of 5 NTU for drinking water. During the dry season, the highest turbidity of 869 NTU was recorded at Abomosu (BR14). The highest value in the wet season was 302 NTU at Ankaase (BR12).

The turbidity of tributaries was generally lower than that of the River Birim. The highest value was recorded in the dry season as well as most of the lowest value. The highest turbidity in the dry season (235 NTU) was recorded at Moore-Boadua (TR11). The highest value in the wet season was 105 NTU at Anyinam Anikoko (TR5), a tributary that has a reddish-brown colour.

The turbidity of groundwater was generally very low in both dry season and wet seasons. In the dry season, the highest turbidity (2 NTU) was recorded at Nsuapemso (BRBH11) which is below the 5 NTU limit for drinking water. The highest turbidity in the wet season was 7 NTU recorded at Asamaman (TRBH1) and was just slightly above the limit of 5NTU.

The turbidity of Mine pond was generally higher in the dry season than the wet season. In the dry season, the highest turbidity was 170 NTU and was recorded at Abomosu (BRMP11). The highest value for the wet season was 55 NTU at Ankaase (BRMP12).

5.3.2.4.1.3.1 Comparison of means and variables

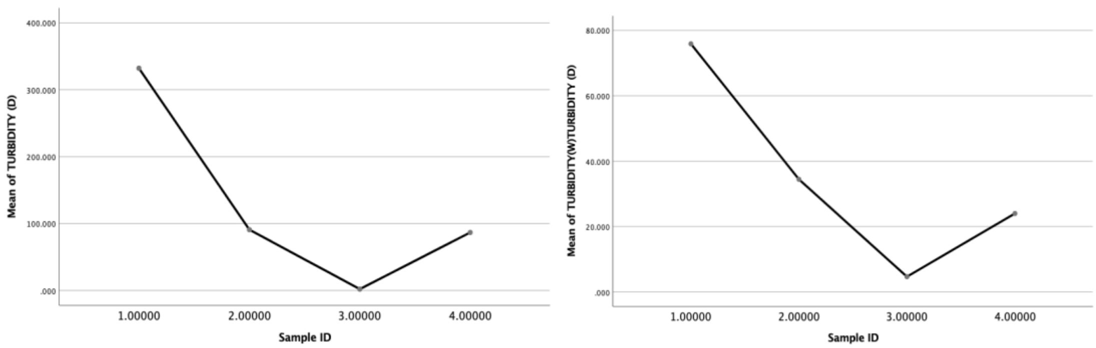


Figure 5.19: Mean plot for Turbidity (Present Study)

The comparison of the means between samples indicates that there was a significant difference in the sample means for the wet season because the p-value was 0.043 which is less than 0.5 but for the dry season, the p-value was 0.109 which is greater than 0.05. The null hypothesis is therefore rejected for the wet season but not the dry season. The LSD indicates that the mean for sample group 1 (River Birim) was significantly different compared to the other sample means.

Comparing the means between the two seasons, a p-value 0.005 was less than 0.05 for the Birim river which indicates there was a significant difference in the means of the two seasons but the p-value (0.224) for the tributaries was greater than 0.05 which indicates there was no significant difference between the means of the two seasons for Tributaries. Turbidity in groundwater was insignificant.

5.3.2.4.1.3.2 Discussion of Turbidity Results

Turbidity in River Birim and its tributaries was generally higher in the dry season than in the wet season. This could be due to dilution of the river by rain during the wet season. Turbidity of groundwater was very low. This is generally because groundwater is naturally filtered as it flows through porous layers of soil. Excessive turbidity, or cloudiness, in drinking water is aesthetically unappealing, and can also represent a health concern because high turbidity could promote regrowth of pathogens in water, leading to waterborne disease outbreaks (WHO, 2013).

High turbidity can affect chlorine disinfection of water by the formation of disinfection by-products, the most common of which are trihalomethanes (THMs), because of the reaction between chlorine and organic matter present in water. This can make treatment of water expensive.

5.3.2.4.1.4 Colour

Apparent colour is measured in water that contains suspended matter True colour is different from apparent colour by filtering the sample (Yanful, 2017). Colour can be introduced in water through dissolved and suspended components (USGS, 2013). Colour in water can also be caused by some contaminants, such as iron which changes in the presence of oxygen to yellow or red sediment. One major factor that affects the colour of natural surface water is pH (USGS, 2013).

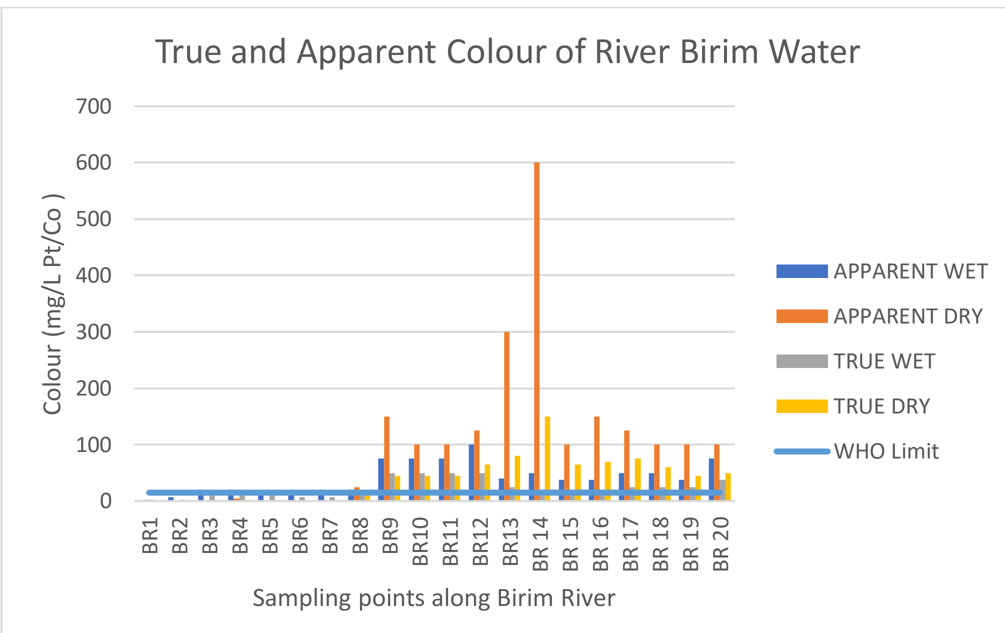


Figure 5.20: Bar chart for Colour of River Birim (Present Study)

Table 5.7: Colour in the Tributaries (Present Study)

TRIBUTARY	APPARENT WET	APPARENT DRY	TRUE WET	TRUE DRY
TRI	15.0	<2.50	10.0	<2.50
TR2	10.0	2.50	5.00	<2.50

TRIBUTARY	APPARENT WET	APPARENT DRY	TRUE WET	TRUE DRY
TR3	7.50	<2.50	5.00	<2.50
TR4	15.0	25.0	10.0	10.0
TR5	100	40.0	50.0	15.0
TR6	7.50	<2.50	2.50	<2.50
TR7	50.0	75.0	25.0	25.0
TR8	30.0	<2.50	20.0	<2.50
TR9	20.0	<2.50	15.0	<2.50
TR10	15.0	<2.50	10.0	<2.50
TR 11	30.0	125	20.0	70.0
TTR1	40.0	<2.50	30.0	<2.50

Table 5.8: Colour in Groundwater (Present Study)

BOREHOLE	APPARENT WET	APPARENT DRY	TRUE WET	TRUE DRY
BRBH1	<2.50	<2.50	<2.50	<2.50
BRBH5	<2.50	2.50	<2.50	<2.50
BRBH 11	7.50	5.00	<2.50	2.50
BRBH12	<2.50	<2.50	<2.50	<2.50
BRBH 13	<2.50	<2.50	<2.50	<2.50
BRBH 18	<2.50	<2.50	<2.50	<2.50
BRBH 19	<2.50	<2.50	<2.50	<2.50
TTRBH1	<2.50	<2.50	<2.50	<2.50
TRBH1	7.50	<2.50	<2.50	<2.50
TRBH8	<2.50	<2.50	<2.50	<2.50
TRBH 10	<2.50	<2.50	<2.50	<2.50
T W	<2.50	<2.50	<2.50	<2.50

Table 5.9: Colour in Mine pond (Present Study)

MINE POND	APPARENT WET	APPARENT DRY	TRUE WET	TRUE DRY
BRMP1	30.0		20.0	
BRMP5	5.00	37.5	2.50	15.0
BRMP11	40.0	100	15.0	50.0
BRMP12	20	<2.50	15	<2.50
TRMP 2	10.0	5.00	5.00	2.50
TTRMP1	5.00	<2.50	<2.50	<2.50
BRMP21	<2.50	<2.50	<2.50	<2.50

Apparent colour is higher than true colour. In the downstream section of River Birim, from Atewa -BR1 (the source of the river) to BR8, colour is relatively low but from BR9 to BR20, the colour is relatively high for both the wet and dry seasons. The Apparent colour is relatively higher than the True colour for both seasons which is generally expected. Both True and Apparent colours are higher in the dry season compared to the wet season. For the wet season, the values are fairly consistent along the sampling points compared to the dry season which has wider variations along the sampling points. The highest value 600 mg/L Pt/Co for Apparent colour and 150mg/L Pt/Co for Birim river was recorded at BR14 in the dry season.

Both True and Apparent colour were relatively low in the Tributaries compared to the River Birim. Apparent colour was obviously higher than True colour. The highest values were observed during the dry season at TR11with 125 mg/L Pt-Co for Apparent colour and 70 mg/L Pt-Co for True colour during the dry season. The highest colour for the wet season was at TR5 with 100 mg/L Pt-Co for Apparent colour and 50 mg/L Pt-Co for True colour.

Both True and Apparent colour in groundwater were very negligible and below the WHO and Ghana EPA limits (x and y mg/L Pt-Co respectively) for drinking water.

Colour in mine ponds was also relatively low although some sampling points exceeded the limit. BRMP12 recorded the highest values with a maximum of 100 mg/L Pt-Co for Apparent colour (Dry season) and a minimum of 2.5 mg/L Pt-Co for True colour (Wet season).

5.3.2.4.1.4.1 Comparison of means and variables

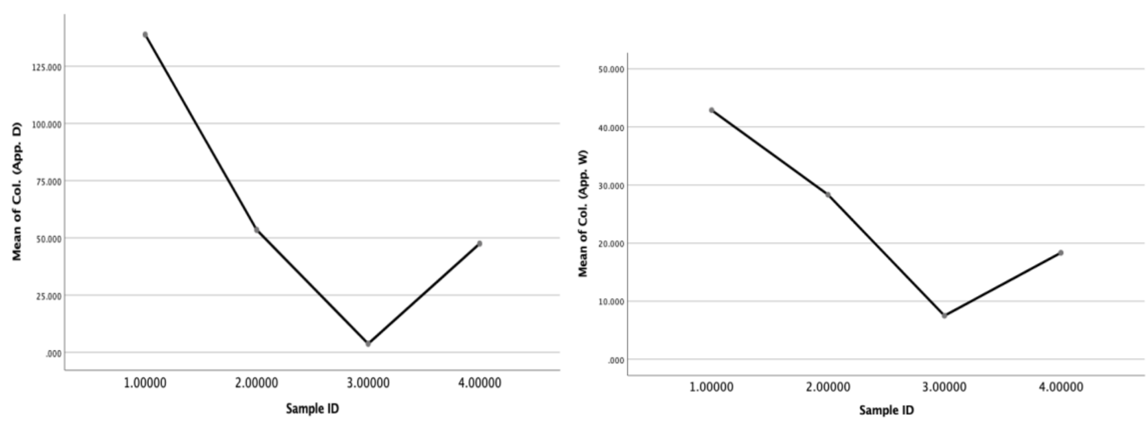


Figure 5.21: Mean plot for Apparent Colour (Present Study)

A comparison between the sample means indicated that the p values 0.07 (wet season) and 0.284 (dry season) were greater than 0.05. The null hypothesis can therefore not be rejected.

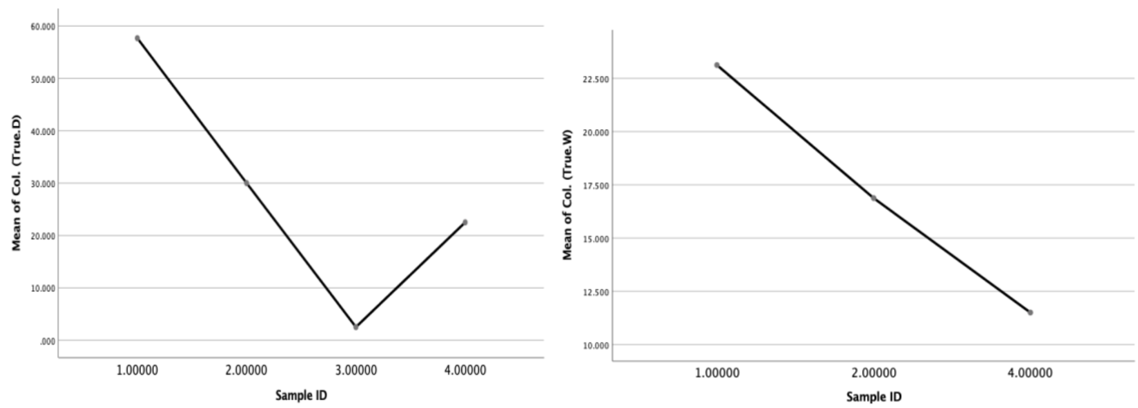


Figure 5.22: Mean plot for True Colour (Present Study)

A comparison between the sample means indicated that the p values 0.145 (wet season) and 0.226 (dry season) were greater than 0.05. The null hypothesis can therefore not be rejected.

Comparing the means between the two seasons, a p-value (0.030) for Apparent colour and (0.015) for True colour were less than 0.05 which indicates there was a significant difference in the means of the two seasons for Birim river.

Comparing the means between the two seasons p-value (0.645) for Apparent colour and p-value (0.844) for True colour is greater than 0.05 which indicates there was no significant difference between the means of the two seasons for Tributaries.

5.3.2.4.1.4.2 Discussion of Colour

Some people depend on the water to determine how safe or unsafe the water is for drinking. This was the perception of many inhabitants of the three communities especially Apapam who suggested their river looked clearer after the ban on ASM activities and was therefore safe for drinking. Frequent panning which is carried out in and around the Birim river can affect the colour of the river water. Acid mine drainage can also affect the colour of the river. The Tributary TR5 which has the highest mean value for Apparent colour (100 mg/L Pt-Co) and the highest True colour (50 mg/L Pt-Co) for the wet season. That tributary is referred to as Anyinam koko because of its reddish-brown colour. That tributary has the highest mean iron concentration of 21.9 mg/L for the dry season and 14.9 mg/L for the wet season. Therefore, the high values of true colour recorded at the sampling site could be attributed to the formation of acid mine drainage which has been accelerated as a result of excavations made by the small-scale gold mining operators along the River. Aquatic life is affected by highly coloured water because it limits the penetration of light which is necessary for the growth of aquatic life.

5.3.2.4.1.5 Electrical Conductivity

Electrical conductivity (EC) measures the presence of ions in a solution that allows it to transmit electrical current (Meride and Ayenew, 2016). According to WHO standards, EC values should not exceed 400 µS/cm in drinking water. The geology of the area through which the water flows, affects conductivity in streams and rivers (USEPA, 2012).

Although EC is related to the amount of dissolved ions in water, it does not give an indication of which specific minerals are present.

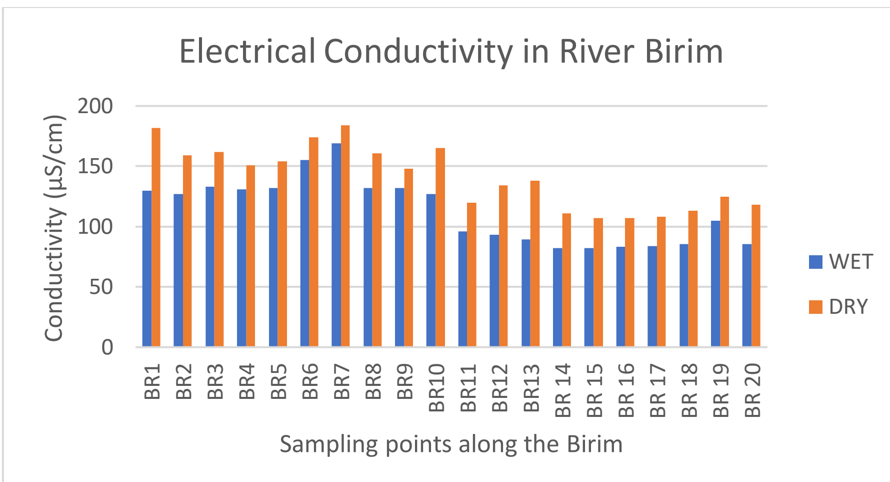


Figure 5.23: Bar chart for Conductivity in the Birim River (Present Study)

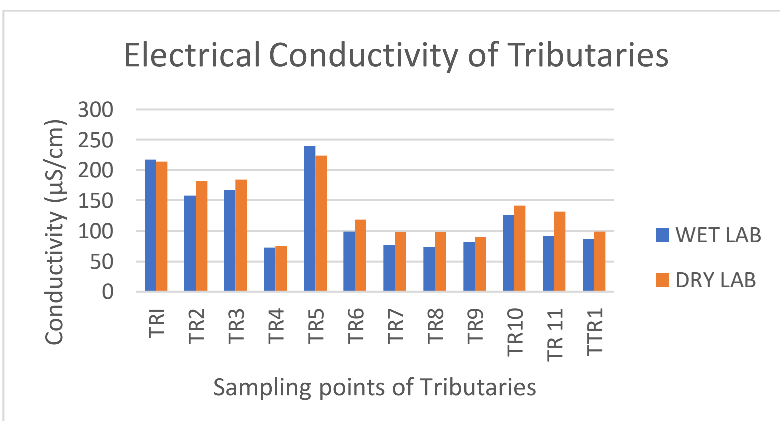


Figure 5.24: Bar chart for Conductivity in Tributaries (Present Study)

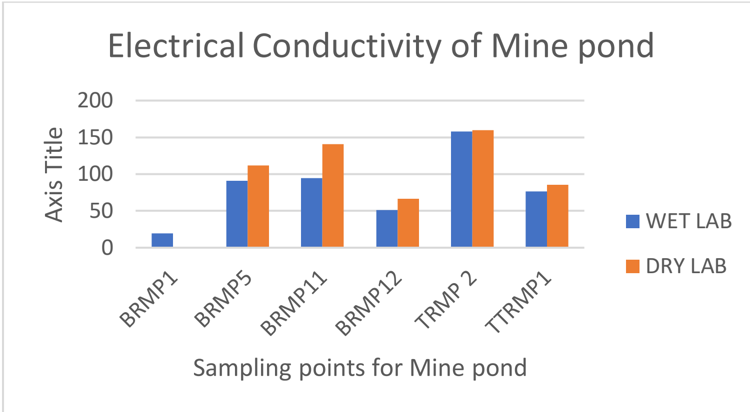


Figure 5.25: Bar chart for Conductivity in Mine pond (Present Study)

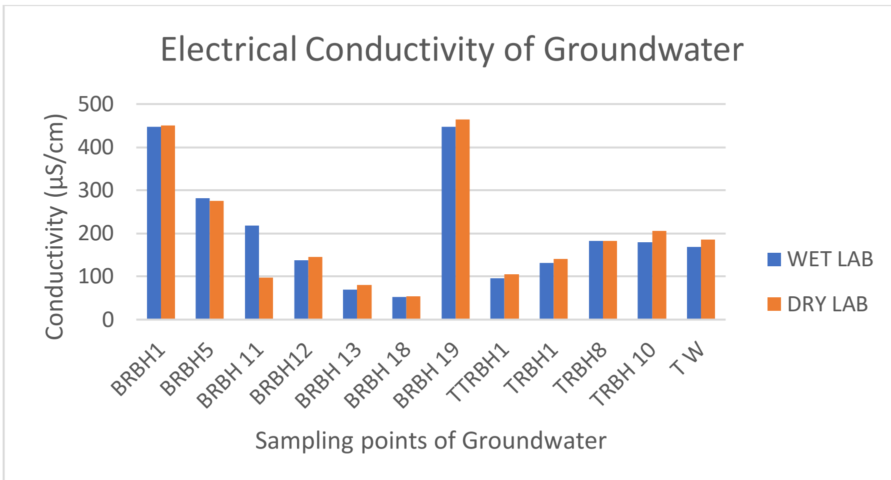


Figure 5.26 Bar charts for Electrical Conductivity Groundwater (Present Study)

Electrical conductivity for River Birim and tributaries were generally higher during the dry season than in the wet season except for Anyinam koko (TR5). Mean values upstream of the river (BR1-BR10) were higher than the mean values downstream (BR11-BR20). The highest mean electrical conductivity for Birim river was 184 µS/cm at BR7 (dry) and the lowest was 82 µS/cm at BR14. The highest mean value for tributaries was 240 µS/cm (wet) at TR5 and the lowest was 72.7 µS/cm (wet) at TR4. Anyinam koko (TR5) also recorded the highest TDS value of 201mg/L which confirms the amount of dissolved solids in water influences conductivity. All the mean values for the river and tributaries did not exceed the WHO limit of 400 µS/cm.

The electrical conductivity of groundwater was generally higher during the dry season than in the wet season, except for values at BRBH5 and BRBH11. The highest mean value was 464 µS/cm (dry season) at BRBH19 and the lowest was 53.0 µS/cm (wet season) at BRBH18. Two samples, BRBH1 and BRBH19, exceeded the WHO limit of 400 µS/cm. BRBH 19 also recorded the highest TDS value (353mg/L) which also confirms that the amount of dissolved solids in water influences conductivity.

The electrical conductivity of Mine pond was generally higher during the dry season than in the wet season. The highest mean value was 160 µS/cm (dry season) at TRMP2 and the lowest was 19.7 µS/cm (wet) at BRMP12.

5.3.2.4.1.5.1 Comparison of means and variables

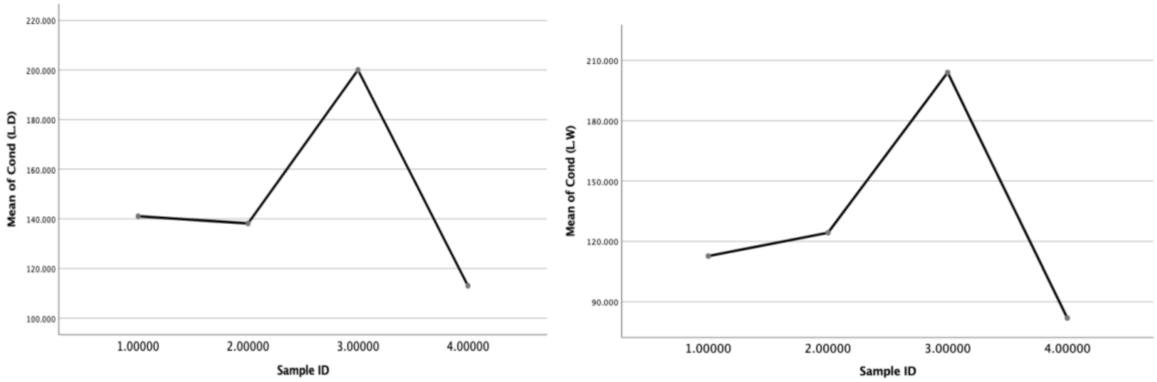


Figure 5.27: Mean plot for Conductivity (Present Study)

The comparison of the means between samples indicates that there was a significant difference in the sample means for the wet season because the p-value was 0.005 which is less than 0.5 but for the dry season, the p-value was 0.99 which is greater than 0.05. The null hypothesis is therefore rejected for the wet season but not the dry season. The LSD indicates that the mean for sample group 3 (groundwater) was significantly different compared to the other sample means.

Comparing the means between the two seasons, p-value (0.0001) was less than 0.05 for the Birim river and p-value (0.008) less than 0.05 for the tributaries which indicate there was a significant difference in the means of the two seasons. For groundwater, a p-value (0.747) greater than 0.05 indicates there was no significant difference between the means of the two seasons for groundwater.

5.3.2.4.1.5.2 Discussion of Conductivity Results

The results show that electrical conductivity is higher in the dry season than in the wet season. Two samples of groundwater exceeded the WHO limit for drinking water. The samples with the highest TDS value also had the highest conductivity value. The difference in mean values of EC at the various sampling sites along the Birim River may be attributed to the fact that a lot of particles may be introduced into the river water and dissolved into solution as a result of frequent panning at these sites and the intensity of mining activities at these different sampling sites varies. Significant increases in conductivity can indicate the presence of pollutants in the aquatic resource. The significant changes in conductivity observed in this study can indicate that there is a source of pollution in or near the river, which is likely due to ASM activities.

Meride and Ayenew (2016) reported electrical conductivity values of 179.3–20 μS/cm with an average value of 192.14 μS/cm for some rivers. However, the mean conductivity values for the Birim river and tributaries were all below the WHO limit of 400 μS/cm.

5.3.2.4.1.6 Alkalinity

Alkalinity is a measure of a water's ability to neutralize acids. Alkalinity is also a measure of a water's buffering capacity or its ability to resist changes in pH upon the addition of acids or bases (Yanful, 2017). The alkalinity of natural waters is primarily due to the presence of weak acid salts although strong bases may also contribute OH^- in extreme environments (Yanful, 2017).

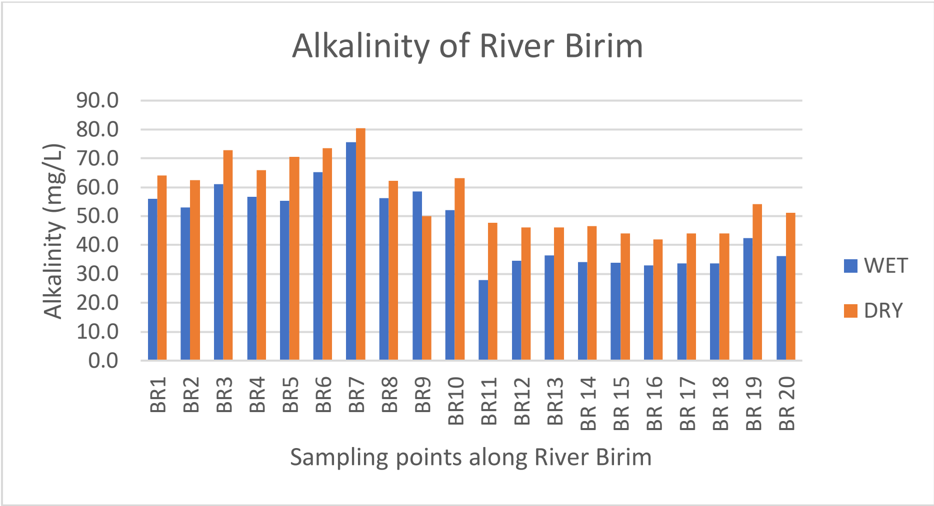
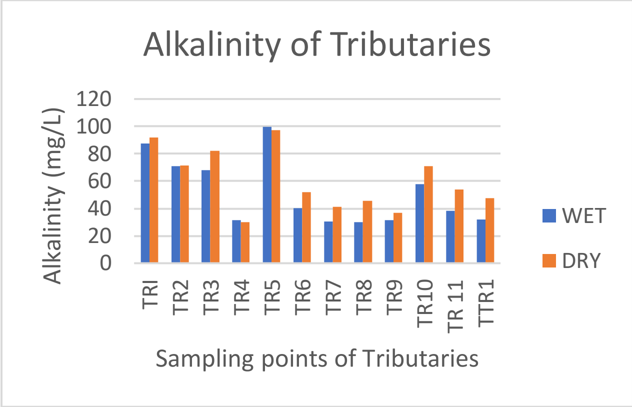


Figure 5.28: Bar chart of Alkalinity for River Birim (Present Study)



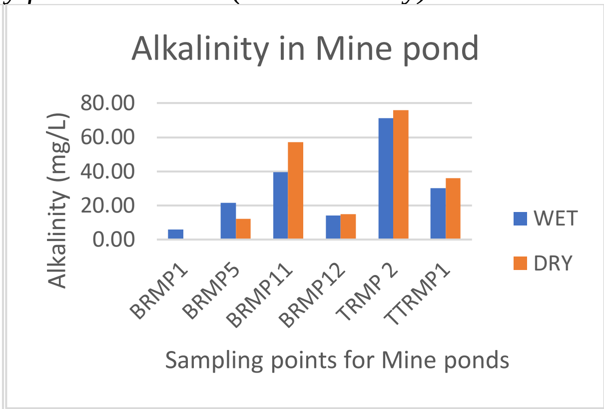


Figure 5.29: Bar chart of Alkalinity for Tributaries and Mine pond (Present Study)

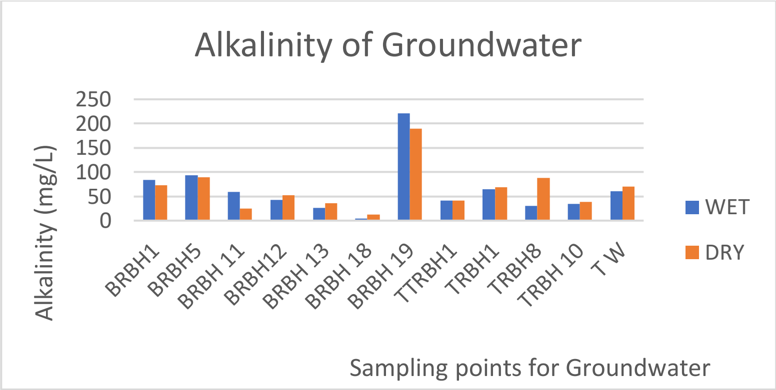


Figure 5.30: Bar charts for Alkalinity of Groundwater (Present Study)

The alkalinity of River Birim and tributaries were higher during the dry season than in the wet season. Alkalinity generally reduced along the river with distance from its source. The highest

Alkalinity 80.4mg/L as $CaCO_3$ (dry season) and 75.6mg/L as $CaCO_3$ (wet season) were recorded at BR7. The difference between alkalinity in the dry season and wet season was not as high for the tributaries compared to River Birim. The highest alkalinity value for tributaries was 92 mg/L as $CaCO_3$ in the dry season and 87.4 mg/L as $CaCO_3$ in the wet season at TR1 (Bukuru-Kibi). The lowest value was 30.2 mg/L as $CaCO_3$ in the dry season and 31.4 mg/L as $CaCO_3$ in the wet season at TR4 (Supon-Nsutem).

The alkalinity of groundwater was highest in BRBH 19 (Akwatia) with 221 mg/L as $CaCO_3$ for the wet season and 189 mg/L as $CaCO_3$ for the dry season and lowest in BRBH 18 (Kade) at 6.86 mg/L as $CaCO_3$ for the wet season and 15.4 mg/L as $CaCO_3$ for the dry season.

The highest value was recorded at TRMP 2 at 76.0 mg/L as $CaCO_3$ in the dry season and 71 mg/L in the wet season. The lowest value was recorded at BRMP 1 (Apapam) at 6 mg/L as $CaCO_3$ during the wet season.

5.3.2.4.1.6.1 Comparison of means and variables

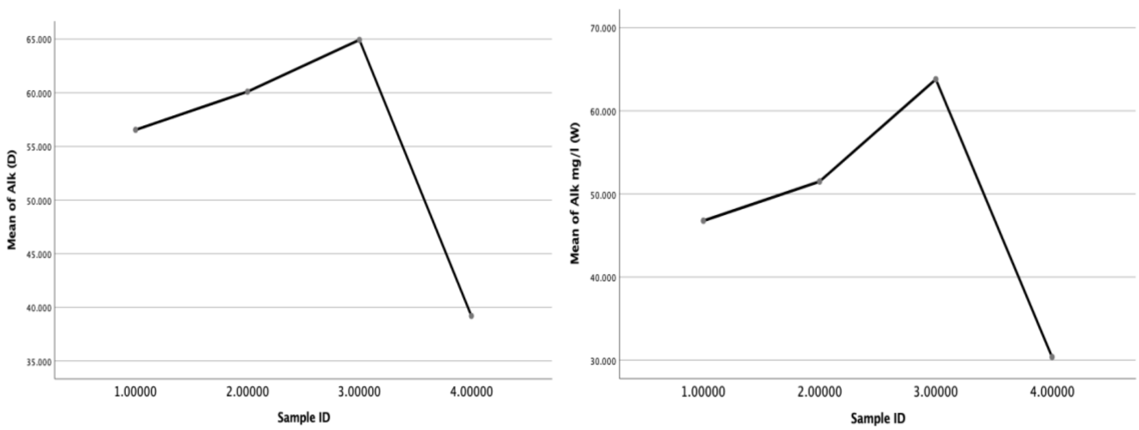


Figure 5.31: Mean plot for Alkalinity (Present Study)

A comparison between the sample means indicated that the p values 0.23 (wet season) and 0.393 (dry season) were greater than 0.05 for both the dry and the wet season. The null hypothesis can therefore not be rejected.

Comparing the means between the two seasons, a p-value 0.0001 less than 0.05 for Birim river and p-value (0.001) less than 0.05 for tributary indicates there was a significant difference in the means of the two seasons. For groundwater, a p-value (0.881) greater than 0.05 indicates there was no significant difference between the means of the two seasons.

5.3.2.4.1.6.2 Discussion of Alkalinity Results

The alkalinity of natural water is determined by the soil and bedrock through which it passes (USGS, 2013). The main sources of natural alkalinity are rocks which contain carbonate, bicarbonate, and hydroxide compounds. High alkalinity is good to have in drinking water because it keeps the water safe. The recommended alkalinity for drinking water is 20-200 mg/L.

Alkalinity was generally in the 20-200 mg/L range except for BRBH19 (Akwatia) which had the highest value (221mg/L as $CaCO_3$), BRBH18 (Kade) which had a value of 4.8 mg/L as $CaCO_3$ in the wet season and 12.6 mg/L as $CaCO_3$ in the dry season and three (3) mine ponds BRMP1 (Apapam), BRMP5 (Adadientem) and BRMP12 (Ankaase). Alkalinity is important for fish and other aquatic life because it protects or buffers against rapid pH changes. The presence of calcium carbonate or other compounds can contribute carbonate ions to the buffering system. Alkalinity is often related to hardness because the main source of alkalinity is usually from carbonate rocks (limestone, which is mostly $CaCO_3$) (Yanful, 2017). Akwatia (BRBH19) had the highest bicarbonate concentration of 231mg/L as $CaCO_3$. Carbon dioxide in the atmosphere is one of the primary sources of natural alkalinity which dissolves in rain, groundwater and surface water (USGS, 2013). Dissolution of carbonate minerals which releases bicarbonate also contributes to alkalinity (Yanful, 2017).

5.3.2.4.1.7 Bicarbonate

Bicarbonates represent the major form of alkalinity in natural waters with their primary source being the partitioning of CO_2 from the atmosphere and the weathering of carbonate minerals in rocks and soil (USGS, 2013; Yanful, 2017).

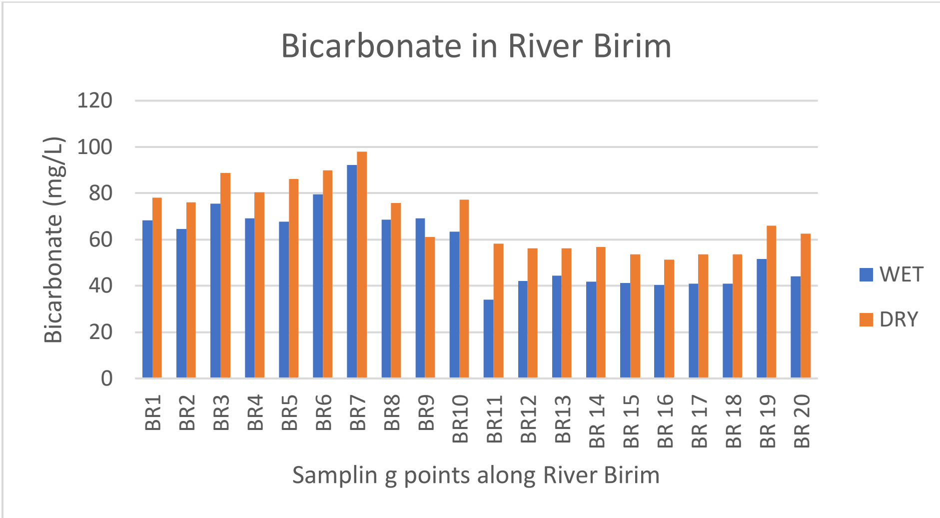
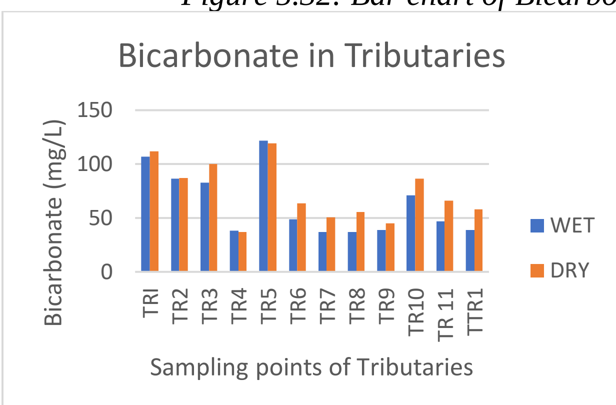


Figure 5.32: Bar chart of Bicarbonate in River Birim (Present Study)



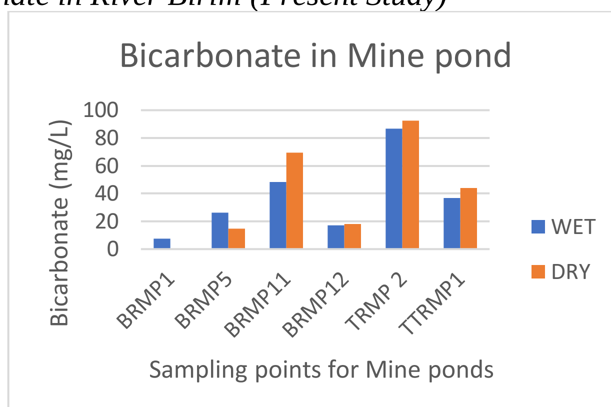


Figure 5.33: Bar chart of Bicarbonate in Tributaries and Mine pond (Present Study)

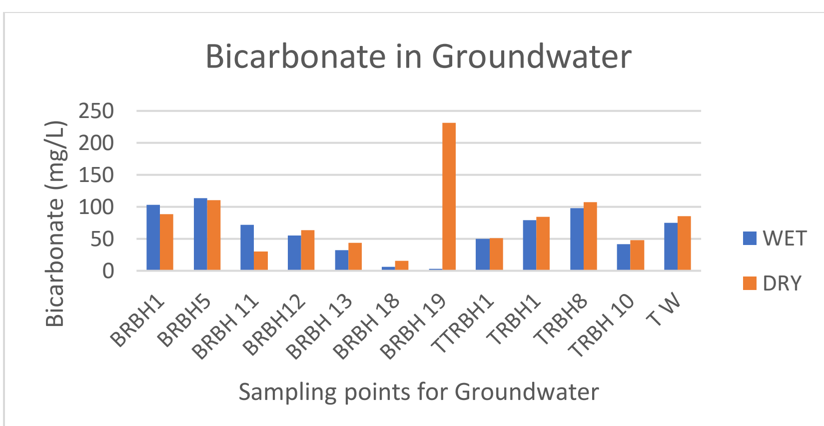


Figure 5.34:Bar chart of Bicarbonate in Groundwater (Present Study)

The mean bicarbonate concentrations upstream (BR1-BR10) are generally higher compared to downstream values (BR10-BR20) for the Birim river. The highest value was recorded at Pano (BR7) as 98.1 mg/L as $CaCO_3$ for the dry season and 92.2 mg/L as $CaCO_3$ for the wet season. The lowest value was recorded at Nsuapemso (BR11) with a value of 33.9 mg/L as $CaCO_3$ for the wet season. For tributaries, the highest value was recorded at Anyinam Anikoko (TR5) with 119 mg/L as $CaCO_3$ for the dry season and 122 mg/L as $CaCO_3$ for the wet season. The lowest values were recorded at Supon-Nsutem (TR4) with a value of 36.8 mg/L as $CaCO_3$ for the dry season and Si Asunafo (TR8) at 36.8 mg/L as $CaCO_3$ for the wet season.

The bicarbonate concentration in groundwater was highest in BRBH 19 (Akwatia) with 231 mg/L for the dry season and interestingly, lowest in BRBH 19 (Akwatia) at 2.69 mg/L for the wet season. Bicarbonate in the mine pond was lowest at Apapam (BRMP1) at 7.32 mg/L in the wet season and highest at Abosua (TRMP2) at 92.7 mg/L in the dry season and 86.6 mg/L in the wet season.

5.3.2.4.1.7.1 Comparison of means and variables

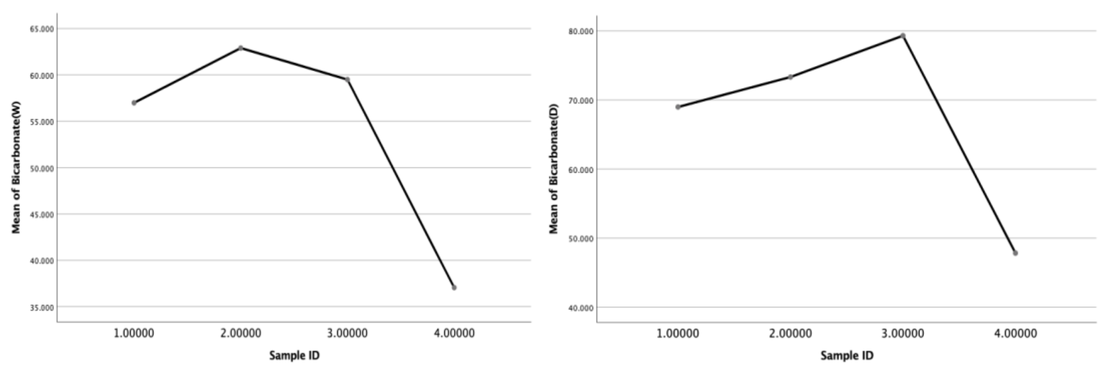


Figure 5.35: Mean plot for Bicarbonate (Present Study)

A comparison between the sample means indicated that the p-value 0.290 (wet season) and 0.392 (dry season) was greater than 0.05 for both the dry and the wet season. The null hypothesis can therefore not be rejected.

Comparing the means between the two seasons, a p-value 0.0001 was less than 0.05 for Birim river and p-value (0.001) less than 0.05 for tributary indicates there was a significant difference in the means of the two seasons. For groundwater, a p-value (0.376) greater than 0.05 indicates there was no significant difference between the means of the two seasons.

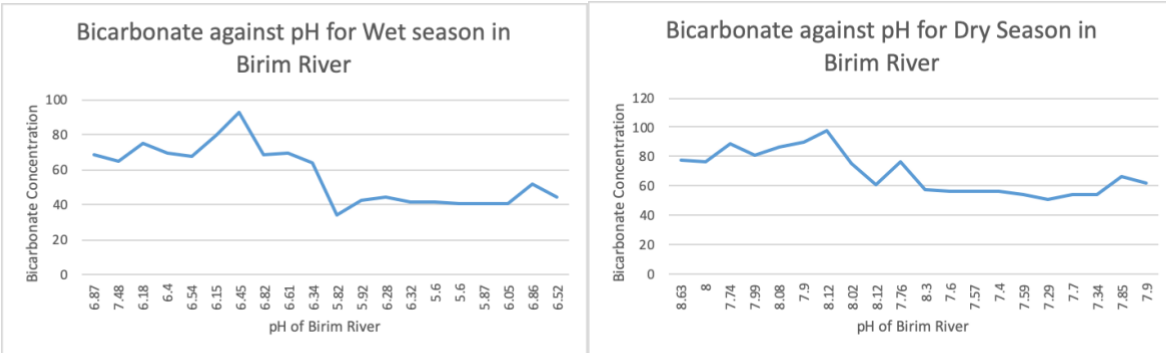


Figure 5.36: Bicarbonate against pH for wet and dry seasons for River Birim (Present Study)

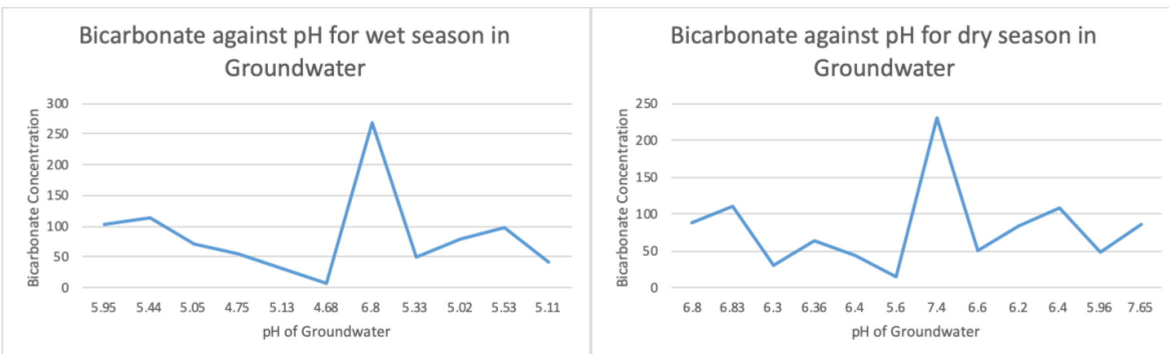


Figure 5.37: Bicarbonate against pH for wet and dry seasons for Groundwater (Present Study)

From figure 5.37 and 5.38, Bicarbonate is the dominant species in the river and groundwater. This is because the pH ranges from 5 to 8. The bicarbonate against pH graph shows the bicarbonate concentration is generally high when the pH is high but within the range, 5 to 8 and low when it is low (not lower than 5) but the concentration is much higher in groundwater than surface water which has a lower pH.

5.3.2.4.1.7.2 Bicarbonate Discussion

The bicarbonate concentration was higher in the dry season than in the wet season in general. Bicarbonate is the dominant species in the river, tributaries and groundwater because the pH ranges between 5 to 8. The bicarbonate concentration was higher in groundwater than in both River Birim and the tributaries.

The high value can be attributed to bicarbonate released through the dissolution of carbonate minerals. In groundwater, the carbonate species predominate depending on the pH, and an endpoint of about pH 4.5 marks the consumption of bicarbonate in solution. When CO_2 dissolves in water, it may form carbonic acid which may also dissociate to form bicarbonate and hydrogen ions, depending on the buffering capacity of the groundwater (Yanful, 2017).

CO_2 is present the atmosphere and when it rains and the rain contacts the ground, reactions between the acidic H_2CO_3 and minerals consume the acid portion (H+) leaving the HCO_3. As the groundwater moves through the aquifer, more reactions can lower the H_2CO_3 content and increase the HCO_3 and CO_3 content depending on the pH (Robinson, (2019).

5.3.2.4.1.8 Total Suspended Solids (TSS)

Total suspended solids (TSS) are particles that are larger than 2 microns found in the aqueous solution (Fondriest Environmental, 2014). Most suspended solids are made up of inorganic materials such as solids silt, sediments, sand etc in water. (Fondriest Environmental, 2014). An increase in the amount of solids in the water, will decrease the clarity of the water.

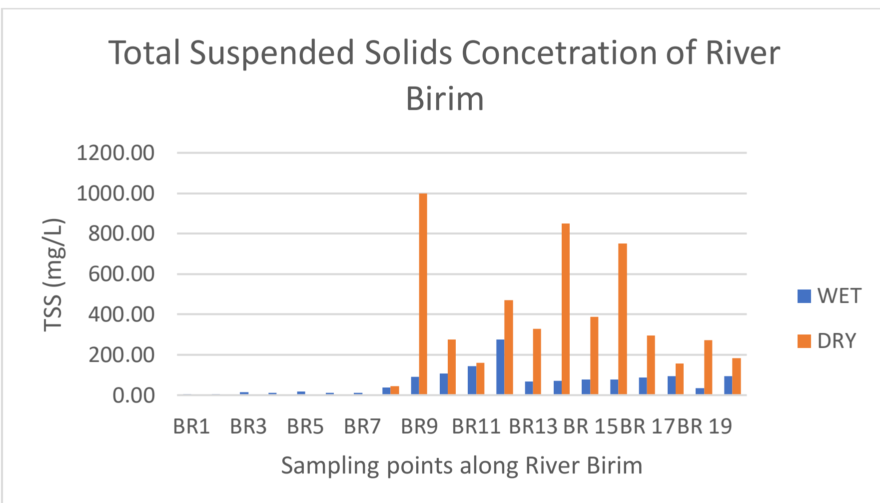


Figure 5.38:Bar chart of TSS concentration of River Birim (Present Study)

Table 5.10:TSS in Tributaries and Groundwater (Present Study)

TSS IN TRIBUTARIES mg/L			TSS IN GROUNDWATER		
TRIBUTARIES	**WET**	**DRY**	**BOREHOLE**	**WET**	**DRY**
TRI	30.0	<1.00	BRBH1	<1.00	<1.00
TR2	8.00	3.00	BRBH5	1.00	<1.00
TR3	5.00	<1.00	BRBH 11	2.00	1.00
TR4	17.0	76.0	BRBH12	<1.00	<1.00
TR5	70.0	50.0	BRBH 13	<1.00	<1.00

TSS IN TRIBUTARIES mg/L

TRIBUTARIES	WET	DRY
TR6	<1.00	1.00
TR7	39.0	170
TR8	12.0	<1.00
TR9	35.0	<1.00
TR10	7.00	<1.00
TR 11	66.0	240
TTR1	10.0	<1.00

TSS IN GROUNDWATER

BOREHOLE	WET	DRY
BRBH 18	<1.00	<1.00
BRBH 19	<1.00	<1.00
TTRBH1	<1.00	<1.00
TRBH1	4.00	<1.00
TRBH8	<1.00	<1.00
TRBH 10	<1.00	<1.00
T W	<1.00	<1.00

Table 5.11: TSS in Mine Ponds (Present Study)

TSS IN MINE POND

MINE POND	WET	DRY
BRMP1	28.0	
BRMP5	7.00	90.0
BRMP11	48.0	160
BRMP12	20	<1.00
TRMP 2	8.00	2.00
TTRMP1	1.00	<1.00

The total suspended solids in River Birim was generally higher in the dry season than the wet season. The difference in the mean TSS in the dry and wet seasons was quite significant. The upstream values (BR1-BR8) were significantly lower and below the Ghana EPA background value of 50 mg/L compared to the upstream values (BR9-BR20) which were above the background value.

The TSS values in the Tributaries was lower compared to River Birim. Almost all the values from the sampling sites were lower than the Ghana EPA background value of 50mg/L except Moore (Bodua) TR11which had 66 mg/L in the wet season and 240 mg/L in the dry season. This river had a collapsed old bridge in the water. TR7 recorded 170 in the dry season, TR5 had 70 in the wet season and TR4 had 75mg/L in the dry season.

The TSS values in Groundwater was significantly lower compared to River Birim and Tributaries. All the values from the sampling sites were lower than the Ghana EPA background value of 50mg/L for both the wet and the dry season. This is because water is filtered through the aquifer.

The TSS values for mine ponds was highest at BRMP11 at a value of 160 mg/L in the dry season followed by BRMP5 which had a value of 90 mg/L in the dry season.

5.3.2.4.1.8.1 Comparison of means and variables

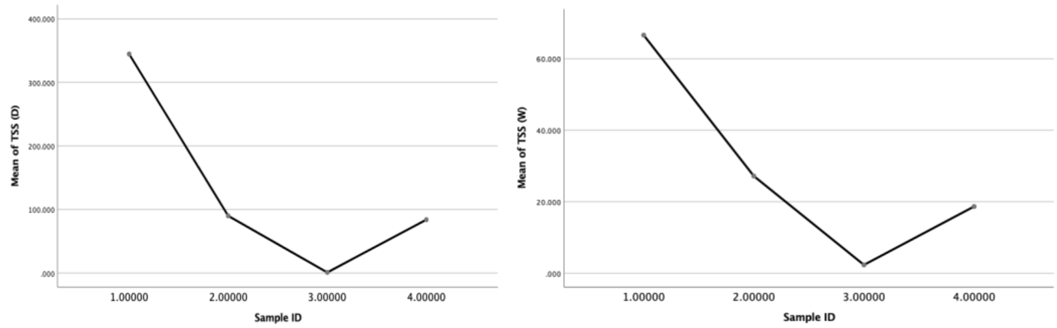


Figure 5.39: Mean plot for Total Suspended Solids (Present Study)

A comparison between the sample means indicated that the p-value (0.116) was greater than 0.05 for both the dry and the wet season. The null hypothesis can therefore not be rejected.

Comparing the means between the two seasons, a p-value 0.004 was less than 0.05 indicates there was a significant difference in the means of the two seasons for Birim river.

Comparing the means between the two seasons, a p-value (0.146) greater than 0.05 indicates there was no significant difference between the means of the two seasons for tributaries.

5.3.2.4.1.8.2 Discussion of TSS Results

The Birim river had values higher for downstream than upstream. This indicates that anthropogenic activities were taking place along the river. This can be due to the excavations made by miners. Small-scale mining activities may discharge wastewater from their gold processing activities or introduce silt when the excavate the river banks or riverbeds. This can increase the total suspended solids. High levels of total suspended solids will affect water quality by increasing water temperature and decreasing dissolved oxygen levels and this is because suspended particles absorb more heat from solar radiation than water molecules will (Fondriest Environmental, 2014).

5.3.2.4.1.9 Total Dissolved Solids

Total dissolved solids (TDS) are a measurement of a variety of compounds like minerals, salts and organic compounds that are dissolved into the water (Yanful, 2017). Fondriest Environmental

(2014) suggested that anything smaller than 2 microns is considered a dissolved solid. TDS content can affect the taste and appearance of water. TDS is made up of inorganic salts such as sodium, chlorides, nitrates, calcium, bicarbonates, sulphates, magnesium and potassium amongst others (Yanful, 2017). Data for only the dry season is available for the TDS.

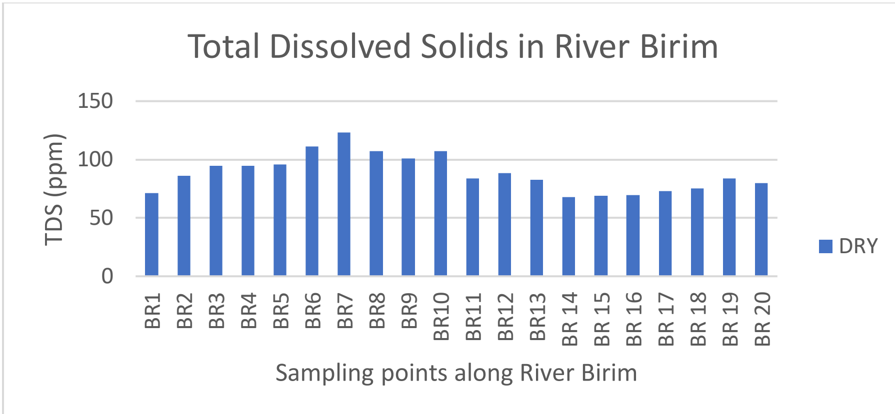
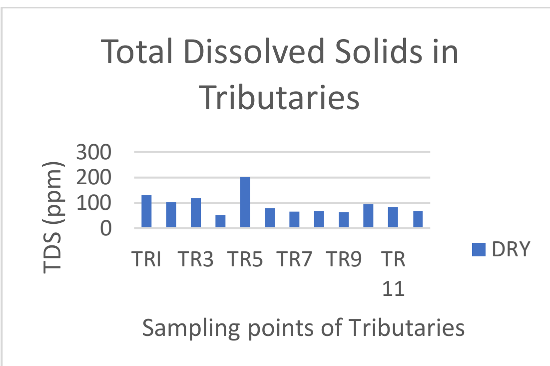


Figure 5.40: Bar chart of TDS in River Birim (Present Study)



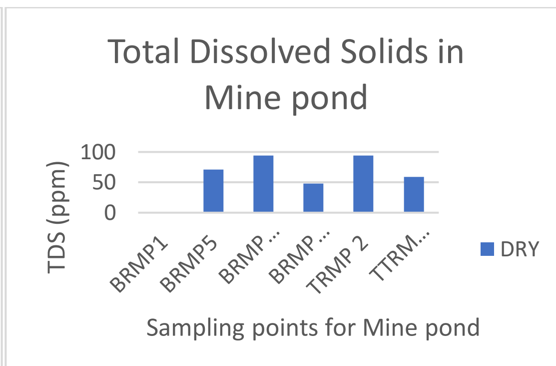


Figure 5.41: Bar chart of TDS in Tributaries and Mine pond (Present Study)

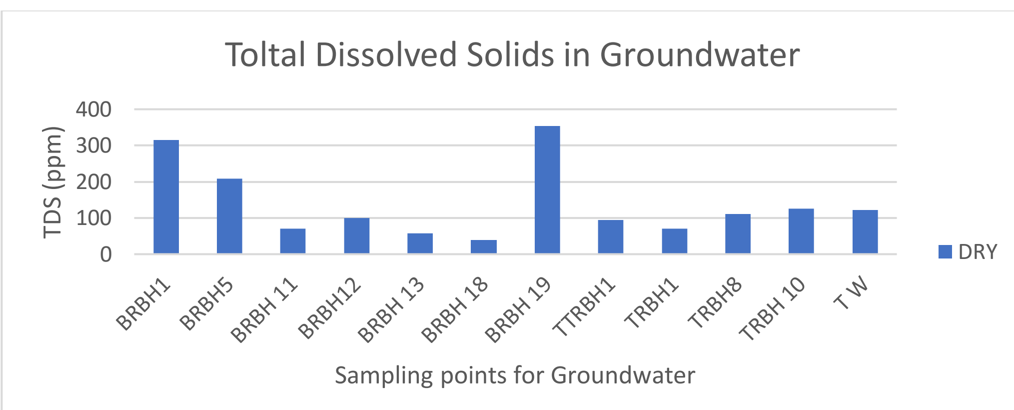


Figure 5.42: Bar chart of TDS in Groundwater (Present Study)

TDS in River Birim was generally low. The highest value 123 mg/L was at Pano (BR7) which had the highest Bicarbonate value of 98.1mg/L in the dry season.

The TDS in the Tributaries had the highest value 201mg/L at Anyinam Koko (TR5) where the highest value for Iron concentration 21.9 mg/L was recorded.

The Groundwater had the highest TDS values 353mg/L compared to the River Birim and Tributaries, at Akwatia (BRBH19) which had the highest value for Bicarbonate in Groundwater. The lowest value 40mg/L was at Kade (BRBH18). All the samples were below the acceptable limit of 500mg/L.

TDS in Mine pond was also below the acceptable limit. The highest value 94.4mg/L was at BRMP11 which had the highest turbidity of 170 NTU.

5.3.2.4.1.9.1 Comparison of means and variables

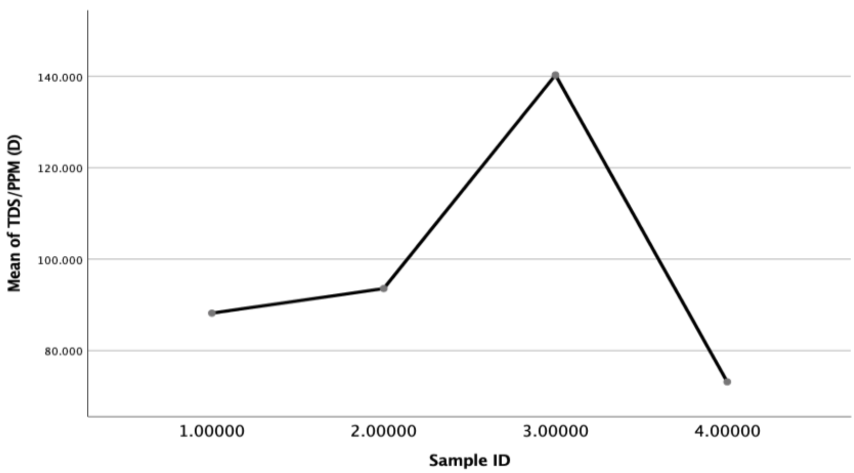


Figure 5.43: Mean plot for Total Dissolved Solids (Present Study)

A comparison between the sample means indicated that the p-value was greater than 0.05 for both the dry and the wet season. The null hypothesis can therefore not be rejected.

5.3.2.4.1.9.2 Discussion of TDS Results

TDS was in River Birim, Tributaries, Groundwater and Mine pond were below the acceptable limit of 500mg/L. The researcher identified that sites with high TDS values also had very high Iron concentration, Bicarbonate concentration or Turbidity. A low TDS concentration can give drinking water a flat taste and a high TDS concentration can give a metallic taste and also stain household fixtures. Dissolved solids such as calcium and magnesium can also make water hard. When the water has very high TDS, it can be an indicator that the water is polluted.

5.3.2.4.1.10 TOC/DOC

TOC is the measure of organic molecules or contaminants in water and DOC is the organic carbon in the water filtered through 0.45 μm filter (Yanful, 2017). The main sources of these organic materials include animal and plant remains deposited in a river/stream, industrial waste, waste from treatment facilities etc. (Malcom and Durum, 1976).

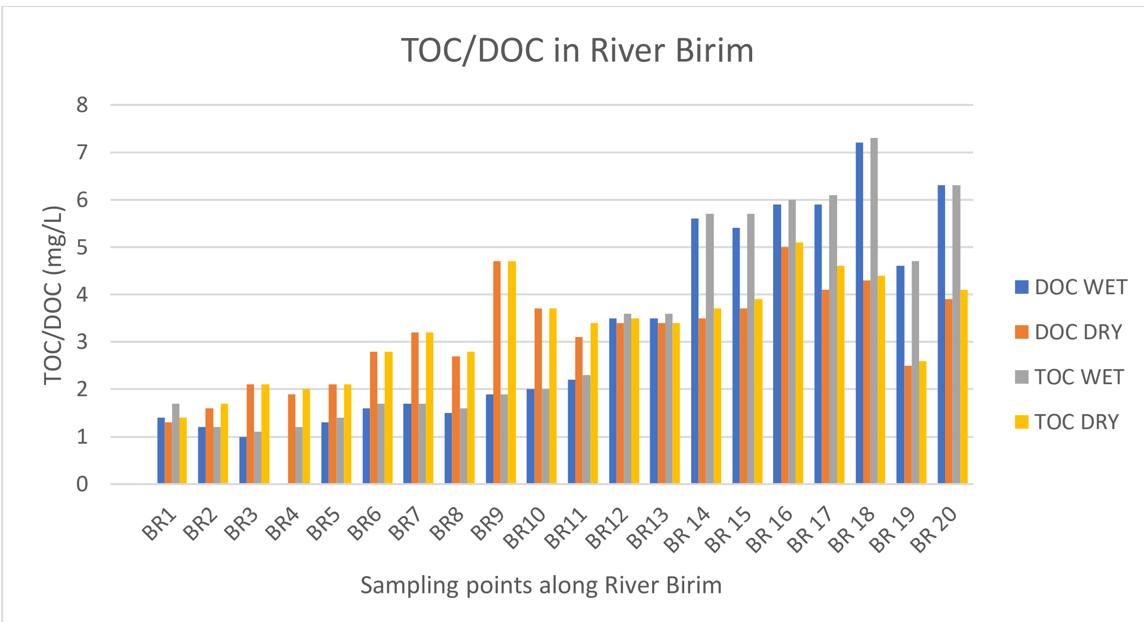


Figure 5.44: TOC/DOC in River Birim (Bar chart) (Present Study)

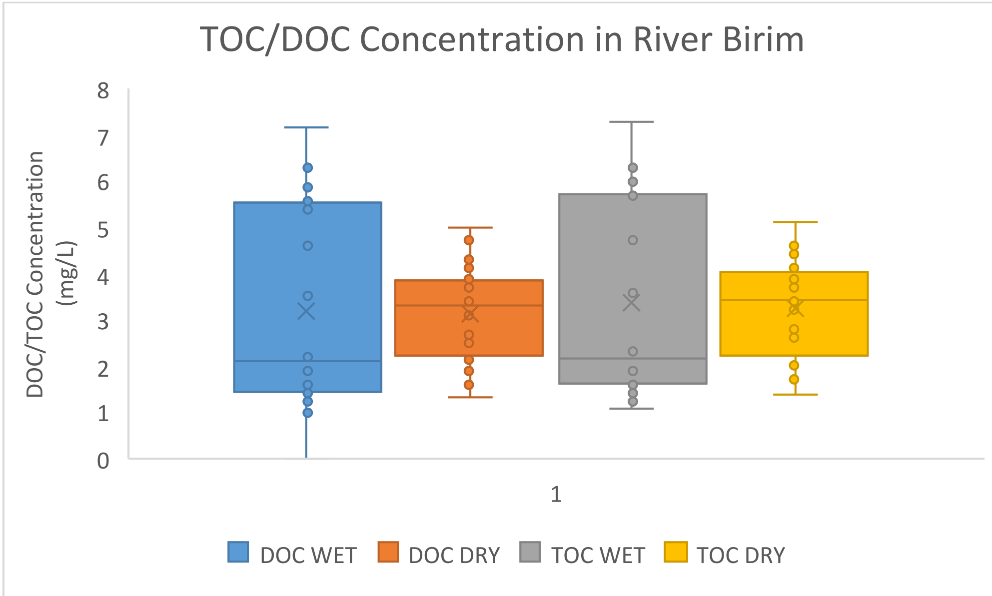


Figure 5.45: Box plot of TOC/DOC in River Birim (Present Study)

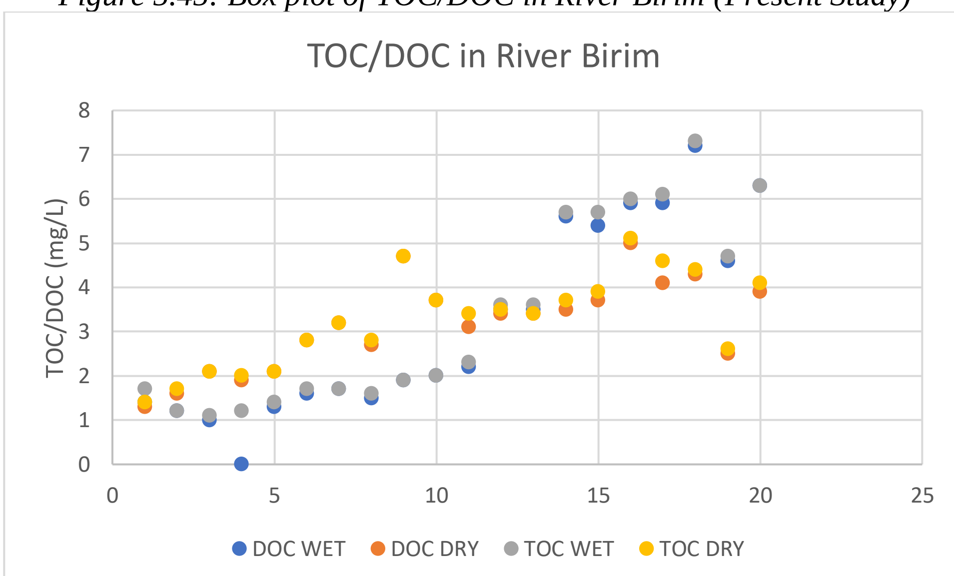


Figure 5.46: Scatter diagram of TOC/DOC in River Birim (Present Study)

TOC/DOC gradually increased from upstream to downstream steadily except at BR19, the confluence between the River Moore and River Birim. The concentration upstream was higher in the dry season than in the wet season, but the concentration downstream was higher in the wet season compared to the dry season. In all, the mean TOC/DOC values in the wet season were generally higher than in the dry season. The total mean values of TOC and DOC were almost the same, although as expected, the DOC was lower than the TOC.

5.3.2.4.1.10.1 Comparison of variables

Comparing the means between the two seasons for DOC, a p-value (0.720) greater than 0.05 indicated there was no significant difference between the means of the two seasons. For TOC, a p-value (0.823) greater than 0.05 indicated there was no significant difference between the means of the two seasons.

5.3.2.4.1.10.2 Discussion of TOC/DOC

TOC indicates the organic chemical content of water. This is important because the amount of carbon in a river is an indicator of the organic character of the river. A high organic content indicates an increase in the growth of microorganisms and this leads to the depletion of oxygen supplies (Malcom and Durum, 1976).

The concentration upstream was higher in the dry season than in the wet season, but the concentration downstream was higher in the wet season compared to the dry season. In all, the mean TOC/DOC values in the wet season were generally higher than in the dry season. The total mean values of TOC and DOC were almost the same, although as expected, the DOC was lower than the TOC.

The TOC/DOC mean values were found to vary during the wet and dry seasons in the present research but according to Siepak (1999), DOC concentrations in Polish rivers ranged from 10.0 to 14.2 mg/L and did not vary during the vegetative season. The increasing value and seasonal variation of TOC/DOC along the Birim River in the present research may be attributed to anthropogenic pollution (Afum & Owusu, 2016; Hadzi et al., 2018).

5.3.2.4.2 Heavy Metals

Heavy metals, such as Hg, Pb, As, Mn, Cd and Fe are released into water bodies and water bodies during ASM activities. Most of these heavy metals are known for their toxicity in similar mining environments. Under natural conditions, some of these metals can be relatively stable but once ASM operations take place, the minerals are broken down due to exposure to oxygen and water (Yanful, 2017).

Table 5.12: Lowest and highest value for heavy metals for the dry and wet seasons (Birim river and Tributaries) (Present Study)

Heavy metal (mg/L)	BIRIM RIVER				TRIBUTARIES			
	DRY MAX	WET MAX	DRY MIN	WET MIN	DRY MAX	WET MAX	DRY MIN	WET MIN
Arsenic	**0.006** (BR10)	**0.0046** (BR20)	**<0.0005**	**<0.0005**	**0.0094** (TR5)	**0.0092** (TR5)	**<0.0005** (TR4,9)	**<0.0005** (TR4,9)
Lead	**0.011** (BR10)	**0.0042** (BR11)	**0.0009** (BR3)	**0.0005** (BR7)	**0.0077** (TR7)	**0.001** (TR7)	**0.0007** (TR1)	**<0.0005**
Cadmium	**0.0002** (BR9)	**<0.0001**	**<0.0001**	**<0.0001**	**0.0002** (TR3,8)	**<0.0001**	**<0.0001**	**<0.0001**
Mercury	**0.003** (BR13)	**0.0004** (BR1)	**<0.0001**	**<0.0001**	**0.002**	**<0.0001**	**<0.0001**	**<0.0001**
Manganese	**0.41** (BR9)	**0.35** (BR20)	**0.022** (BR5)	**0.038** (BR1)	**0.56** (TR5)	**0.76** (TR5)	**0.023** (TR10)	**0.038** (TR10)
Iron	**19.3** (BR9)	**6.5** (BR20)	**0.3** (BR1)	**0.3** (BR1)	**14.9** (TR5)	**21.9** (TR5)	**0.6** (TR6)	**0.5** (TR6)

Table 5.13: Lowest and highest value for heavy metals for the dry and wet seasons (Groundwater and Mine pond) (Present Study)

Heavy metal (mg/L)	GROUNDWATER				MINE POND			
	DRY MAX	WET MAX	DRY MIN	WET MIN	DRY MAX	WET MAX	DRY MIN	WET MIN
Arsenic	**0.028** (BRBH5)	**0.014** (BRBH12)	**<0.0005**	**<0.0005**	**0.017** (BRMP12)	0.0013 (TRMP2)	**<0.0005**	**<0.0005**
Lead	**0.0056** (TRBH1)	**0.0055** (BRBH18)	**<0.0005**	**<0.0005**	**0.0034** (BRMP11)	**0.0011** (BRMP1)	**<0.0005** (BRMP12)	**0.0005** (TTRMP1)
Cadmium	**0.02** (BRBH5)	**0.0002** (BRBH1)	**<0.0001**	**<0.0001**	**0.001** (TTRMP1)	**<0.0001**	**<0.0001**	**<0.0001**
Mercury	**0.06** (TRBH1)	**0.001** (TTRBH1)	**<0.0001**	**<0.0001**	**0.0005** (BRMP12)	**0.0005** (TTRMP1)	**<0.0001**	**<0.0001**
Manganese	**0.35** (BRBH1)	**0.56** (BRBH1)	**0.007** (TRBH8,10)	**<0.002**	**0.33** (TRMP2)	**0.15** (BRMP11)	**0.011** (BRMP12)	**0.019** (BRMP1)
Iron	**2.4** (TRBH1)	**2.3** (TRBH1)	**<0.1**	**<0.1**	**5.7 (TRMP2)**	**2.7 (BRMP11)**	**0.2** (BRMP12)	**0.2** (BRMP2)

5.3.2.4.2.1 Arsenic

Arsenic is an element that is used for a variety of purposes in industry and agriculture and it occurs naturally in rocks and soil (CDC, 2019). When arsenic is released into the environment, it remains in the environment for an extended period of time and can slowly enter groundwater if it ends up in the soil or surface water (CDC, 2019). Arsenic contamination in drinking water has been one of the WHO's major global public health concerns (Fischer et al., 2017).

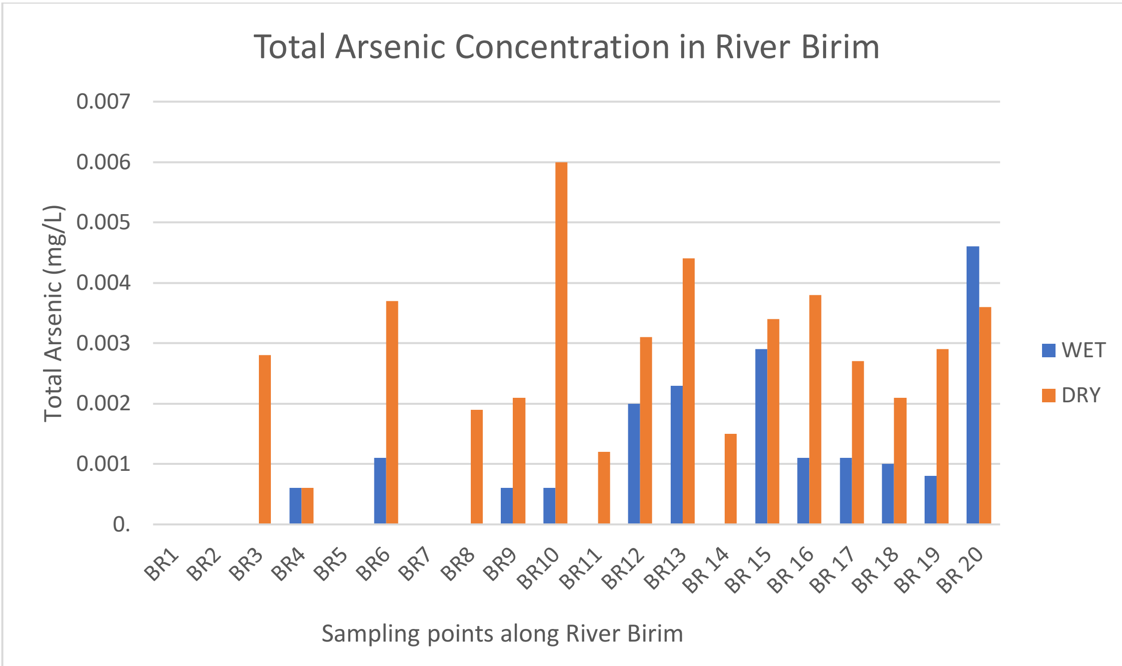


Figure 5.47: Bar chart of Total Arsenic Concentration in River Birim (Present Study)

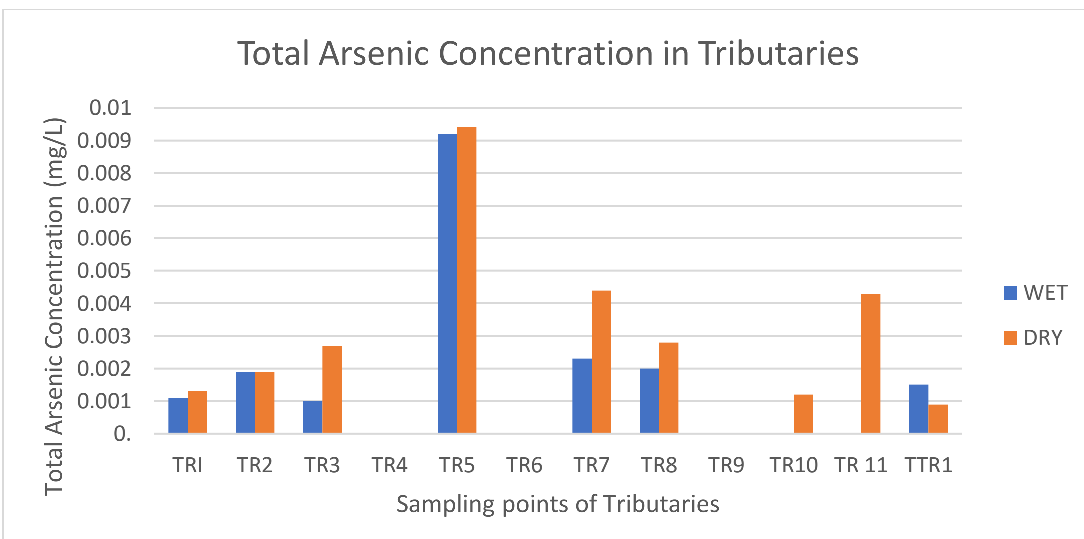


Figure 5.48: Bar chart of Total Arsenic Concentration in Tributaries (Present Study)

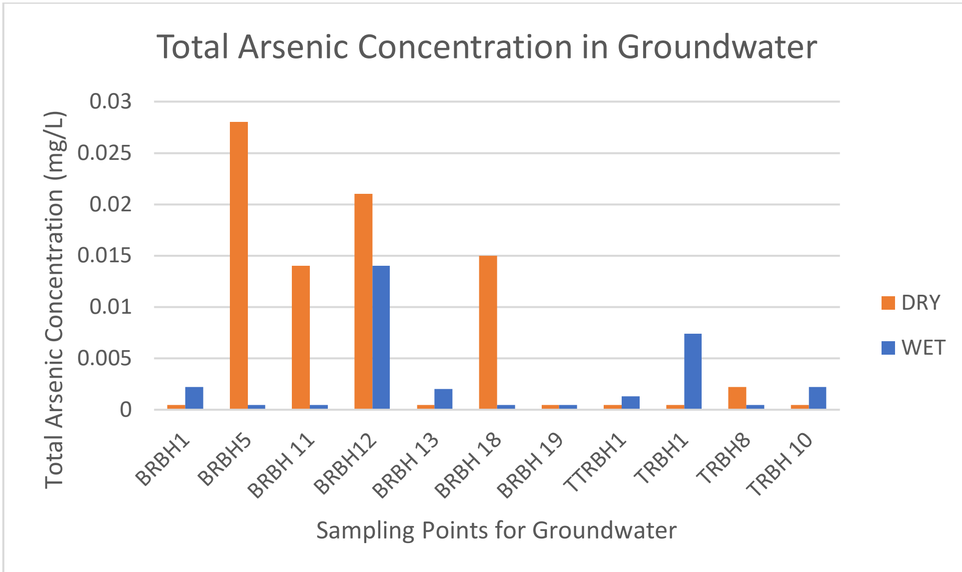


Figure 5.49: Bar chart of Total Arsenic Concentration in Groundwater (Present Study)

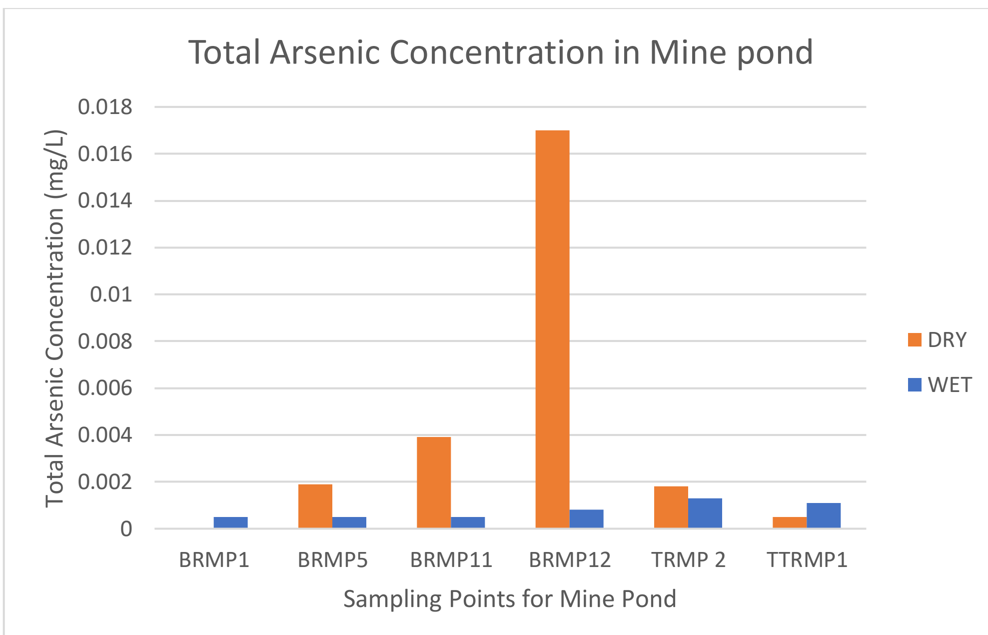


Figure 5.50: Bar chart of Total Arsenic Concentration in Mine pond (Present Study)

The highest arsenic concentration of Birim river was 0.006 mg/L at Bunso (BR10) during the dry season. Anyinam Anikoko (TR5) had the highest arsenic concentration of 0.0094 mg/L (dry) and 0.0092 mg/L (wet season) amongst the tributaries. This tributary had the highest iron concentration and the highest TDS concentration. A registered small-scale mining company carries out its operations not too far from this tributary.

The arsenic concentration of groundwater was significantly higher than that of the other water bodies. The highest arsenic concentration was at Adadienten (BRBH5) during the dry season with a value of 0.028 mg/L, followed by Ankaase (BRBH12) with 0.021 mg/L (wet season) and 0.014 mg/L (dry season). These exceeded the WHO/GEPA limit for arsenic (0.01mg/L) in drinking water, unfortunately, some people depend on this polluted groundwater as their source of water for water for domestic purposes. The arsenic concentration of the treated water from the main Kibi township was <0.0005 mg/L. This indicates the mining activities have had a detrimental effect on groundwater and is therefore not safe for human consumption.

The highest arsenic concentration recorded for the mine ponds was 0.017 mg/L. The concentrations in the mine pond were lower compared to that of groundwater. This is because due to the ban on ASM operations, some of the mine ponds are not been actively used and some like BRMP1 had dried up during the dry season.

5.3.2.4.2.1.1 Comparison of means and variables

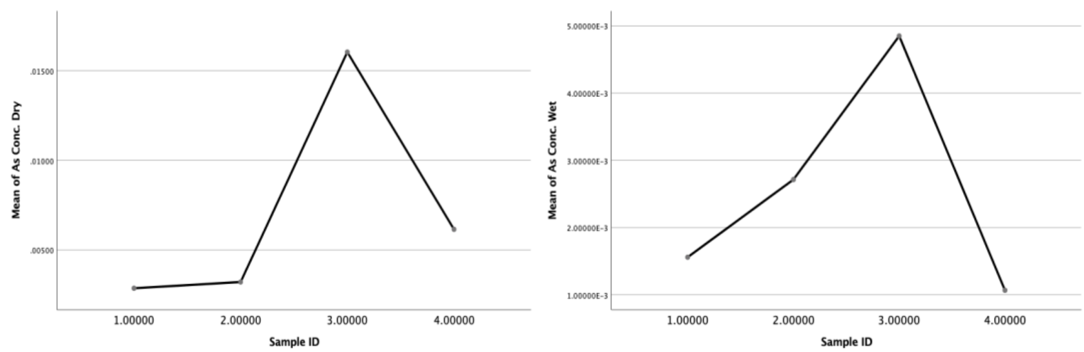


Figure 5.51:Mean plot for Arsenic (Present Study)

The comparison of the means between samples indicates that there was a significant difference in the sample means for the dry season because p-value less than 0.0001 but for the wet season, the p-value was 0.127 which is greater than 0.05. The null hypothesis is therefore rejected for the dry season but not the wet season. The LSD indicates that the mean for sample group 3 (groundwater) was significantly different compared to the other sample means.

Comparing the means between the two seasons, a p-value (0.005) less than 0.05 indicates there was a significant difference in the means of the two seasons for Birim river. For the tributary, a p-value (0.136) greater than 0.05 indicates there was no significant difference between the means of the two seasons for Tributaries.

5.3.2.4.2.1.2 Discussion of Arsenic Concentration Results

The arsenic concentration at Atewa (BR1), the source of River Birim, was less than 0.0005 mg/L in both wet and dry seasons. Apapam (BR2), the first town the Birim River flows through also recorded less than 0.0005 mg/L in both wet and dry seasons. The arsenic concentration was highest in groundwater, a source of drinking water for most of the affected communities. The WHO drinking water guideline for arsenic is 0.01 mg/L. This poses a health risk to the communities that depend on this contaminated water source. It is, therefore, necessary to treat the water to remove the heavy metals. Arsenic is usually present in the environment in inorganic form (USGS, 2013). The inorganic arsenic easily dissolves and enters underground and surface waters (CDC,2019). The presence of arsenic in the environment may be due to panning and ore crushing by the small-scale gold miners.

5.3.2.4.2.2 Lead

Lead is a bluish-grey metal found in small quantities on the earth's outer layer; it can be found in in our environment due to human activities such as mining (CDC, 2014). Because of health concerns, the amount of lead found in various products such as toys, paint, gasoline, and ceramic amongst others has reduced in recent years (CDC, 2014).

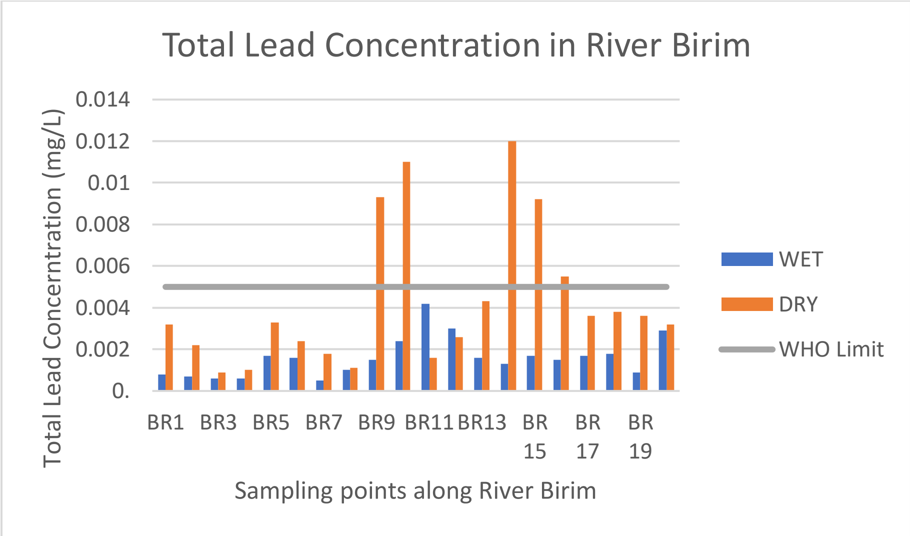


Figure 5.52: Bar chart of Total Lead Concentration in River Birim (Present Study)

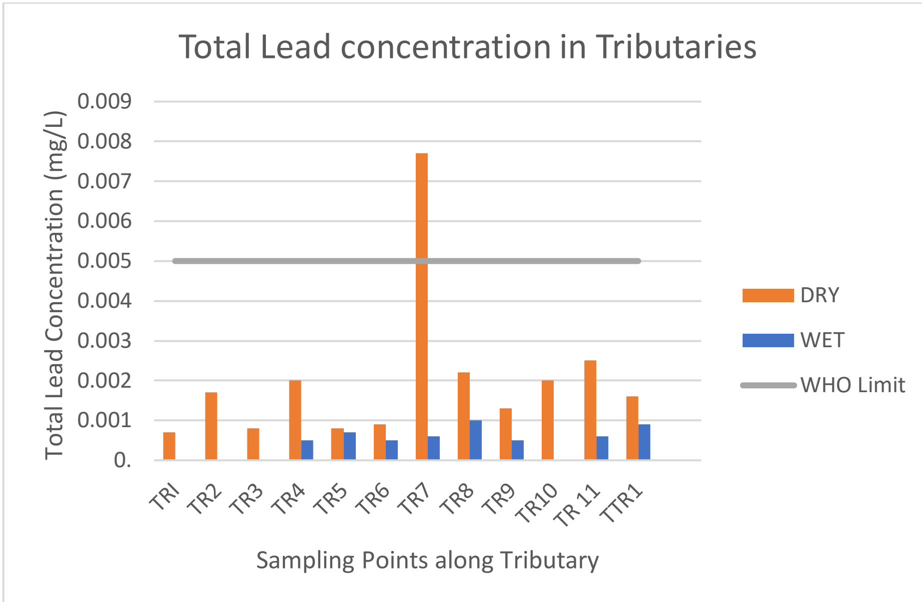


Figure 5.53: Bar chart of Total Lead Concentration in Tributaries (Present Study)

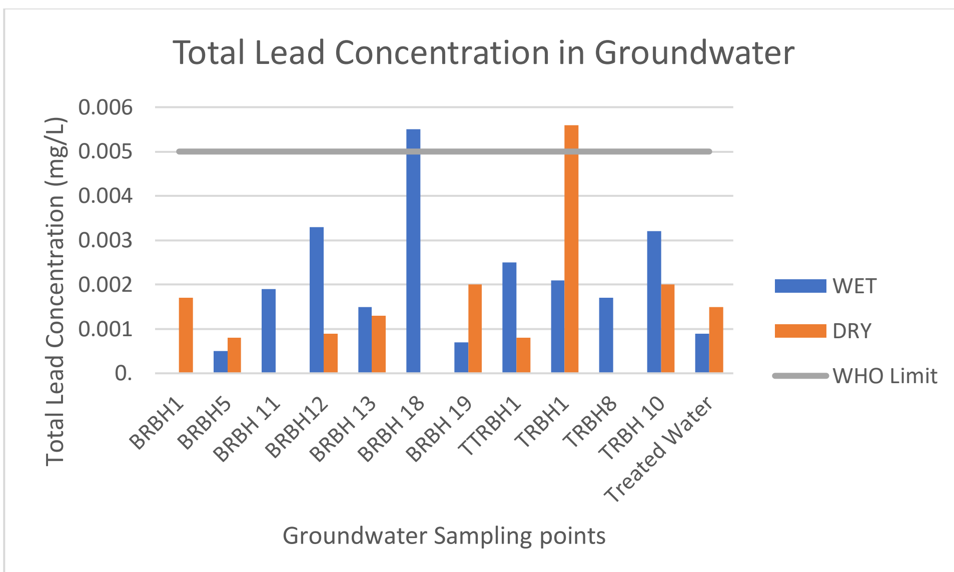


Figure 5.54: Bar chart Total Lead Concentration in Groundwater (Present Study)

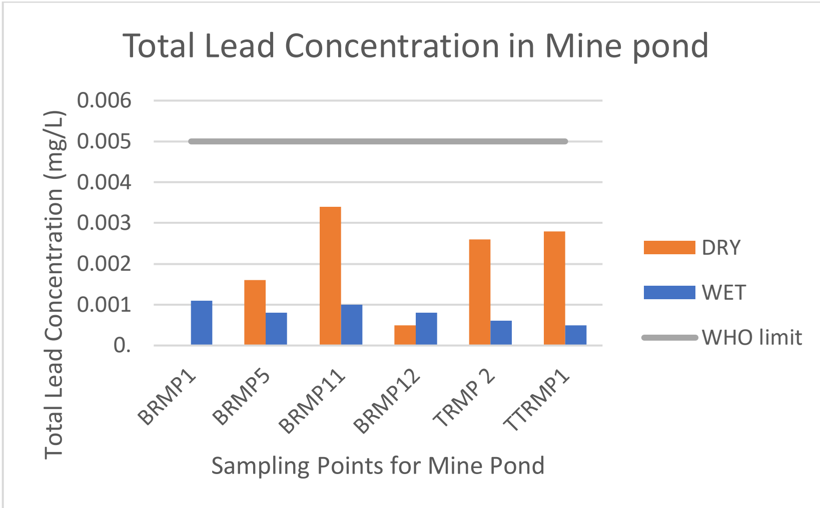


Figure 5.55:Bar chart of Total Lead Concentration in Mine Pond (Present Study)

The WHO guideline for Lead in drinking water is 0.01 mg/L but the GEPA limit is 0.005 mg/L. Lead concentration at Atewa (BR1), the source of the river was 0.0032mg/L (dry) and 0.0008mg/L (wet). Most of the samples were within the limit except for five sites, 0.093mg/L (dry) at Asiakwa (BR9), 0.011mg/L (dry) at Bunso (BR10), 0.012mg/L (dry) at Abomoso (BR14), 0.0092mg/L (dry) at Amunum (BR15) and 0.0055mg/L (dry) at Okyenso (BR16).

All the Tributary samples were below the WHO/GEPA guidelines for drinking water except TR7 which had a mean value of 0.0077mg/L which is slightly above the limit. All the groundwater samples were below the WHO/GEPA drinking water guideline for lead, except Kade (BRBH18) which had a mean lead concentration of 0.0055 mg/L (wet season) and Asamaman (TRBH1) a value of 0.0056 mg/L, both of which are slightly above the GEPA limit. The lead concentrations in the mine pond were below the WHO/GEPA guidelines.

5.3.2.4.2.2.1 Comparison of means and variables

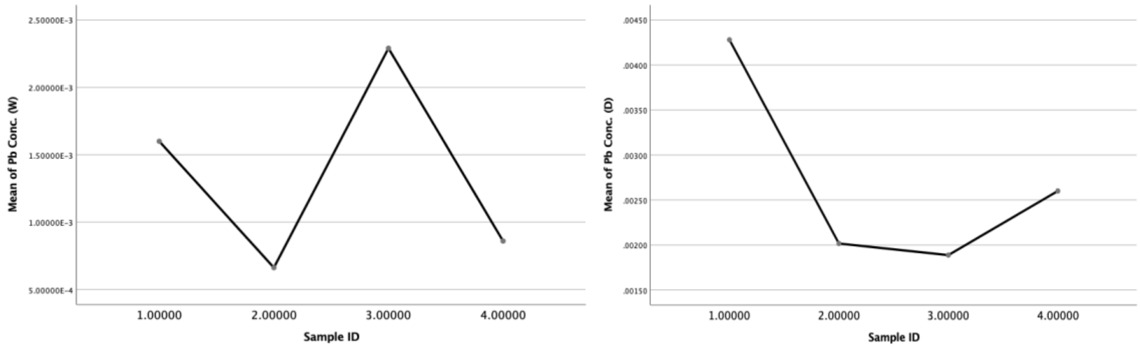


Figure 5.56:Mean plot for Lead (Present Study)

The comparison of the means between samples indicates that there was a significant difference in the sample means for the wet season because the p-value was 0.005 which is less than 0.5 but for the dry season, the p-value was 0.62 which is greater than 0.05. The null hypothesis is therefore rejected for the wet season but not the dry season. The LSD indicates that the mean for sample group 3 (groundwater) was significantly different compared to the other sample means.

Comparing the means between the two seasons, a p-value (0.002) less than 0.05 indicates there was a significant difference in the means of the two seasons for Birim river.
For tributaries, p-value (0.057) is slightly greater than 0.05 and indicates there was no significant difference between the means of the two seasons.

5.3.2.4.2.2.2 Discussion of Lead Results

The highest concentrations of lead in River Birim were detected during that dry season and two boreholes showed lead concentrations that were slightly above the acceptable limit. Lead is a highly toxic metal to humans since it causes brain damage, particularly to children (Lidsky & Schneider, 2003). The presence of lead in the study area may be due to excavations made by artisanal and small-scale miners as these results in the weathering and leaching of the metals from waste rock when exposed to water and oxygen. It is therefore important for water to be treated for lead removal to meet the drinking water and domestic purposes.

5.3.2.4.2.3 Cadmium

Cadmium, a carcinogen, has toxic effects on the skeletal and respiratory systems as well as the kidneys (WHO, 2013). It is generally found in the environment at low concentrations.

Table 5.14: Total Cadmium Concentration in River Birim (Present Study)

TOTAL CADMIUM CONCENTRATION IN RIVER BIRIM		
BIRIM RIVER	**WET**	**DRY**
BR1	<0.0001	<0.0001
BR2	<0.0001	<0.0001
BR3	<0.0001	<0.0001
BR4	<0.0001	<0.0001
BR5	<0.0001	<0.0001
BR6	<0.0001	<0.0001
BR7	<0.0001	<0.0001
BR8	<0.0001	<0.0001
BR9	<0.0001	0.0002
BR10	<0.0001	<0.0001
BR11	<0.0001	<0.0001
BR12	<0.0001	<0.0001
BR13	<0.0001	<0.0001
BR 14	<0.0001	<0.0001
BR 15	<0.0001	<0.0001
BR 16	<0.0001	<0.0001
BR 17	<0.0001	<0.0001
BR 18	<0.0001	<0.0001
BR 19	<0.0001	<0.0001
BR 20	<0.0001	<0.0001

Table 5.15: Total Cadmium Concentration in Tributaries and Groundwater (Present Study)

TOTAL CADMIUM CONCENTRATION IN TRIBUTARIES			**TOTAL CADMIUM CONCENTRATION IN GROUNDWATER**		
TRIBUTARY	**WET**	**DRY**	**BOREHOLE**	**WET**	**DRY**
TRI	<0.0001	<0.0001	BRBH1	0.0002	<0.0001
TR2	<0.0001	<0.0001	BRBH5	<0.0001	0.02
TR3	<0.0001	0.0002	BRBH 11	<0.0001	<0.0001
TR4	<0.0001	<0.0001	BRBH12	<0.0001	<0.0001
TR5	<0.0001	<0.0001	BRBH 13	<0.0001	0.0009
TR6	<0.0001	<0.0001	BRBH 18	<0.0001	0.0008
TR7	<0.0001	0.0001	BRBH 19	<0.0001	0.0007
TR8	<0.0001	0.0002	TTRBH1	<0.0001	0.001
TR9	<0.0001	0.0001	TRBH1	<0.0001	<0.0001

TR10	<0.0001	<0.0001	TRBH8	<0.0001	0.0006
TR 11	<0.0001	<0.0001	TRBH 10	<0.0001	0.0007
TTR1	<0.0001	<0.0001			

Table 5.16: Total Cadmium Concentration in Mine ponds (Present Study)

TOTAL CADMIUM CONCENTRATION IN MINE POND		
MINE POND	**WET**	**DRY**
BRMP1	<0.0001	
BRMP5	<0.0001	<0.0001
BRMP11	<0.0001	<0.0001
BRMP12	<0.0001	<0.0001
TRMP 2	<0.0001	<0.0001
TTRMP1	<0.0001	**0.001**

The results in Table 5.14 above show that cadmium concentrations of River Birim and tributaries were very low and insignificant compared to the values reported earlier for arsenic and lead. The highest cadmium concentration recorded for the river during the dry season was 0.0002 mg/L which lower than the WHO/GEPA drinking water guideline for cadmium (0.003mg/L).

The concentration of Cadmium in groundwater was very low except for Adadientem (BRBH5) where a value of 0.02mg/L was recorded which is significantly higher than the WHO/GEPA limit for drinking water 0.003mg/L. According to Dorleku et al (2019), in their research, approximately 35% of boreholes in the wet season recorded values for cadmium above WHO/GEPA guideline value of 0.003mg/L.

The concentration of Cadmium in the mine pond was very low. The highest value recorded from the mine pond during the dry season was 0.001mg/L which is lower than the WHO/GEPA limit for drinking water which 0.003mg/L.

5.3.2.4.2.3.1 Comparison of means and variables

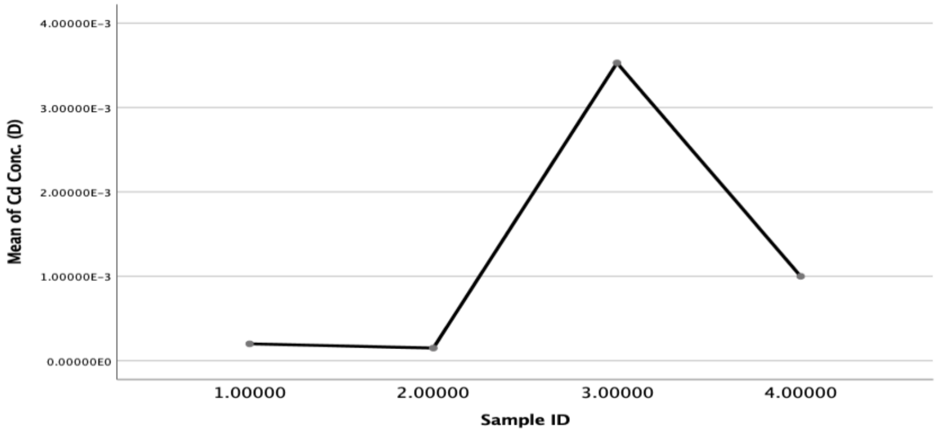


Figure 5.57:Mean plot for Cadmium (Present Study)

Robust teste of equality of means could not be performed for Cd because at least one group has the sum of case weights less than or equal to 1. The values for Cadmium were very low and insignificant.

5.3.2.4.2.3.2 Discussion of Cadmium Results

Cadmium concentration was generally low in the Brim River, Tributaries, Groundwater and Mine pond. Only one groundwater sample had Cadmium concentration above the acceptable limit. Cadmium has adverse health effects but because of the low level of concentration, it is not a source of worry in this study area compared to Arsenic and Lead. That notwithstanding, because a concentration above the acceptable limit was found in one groundwater sample, measures have to be put in place to ensure the water is safe for the community to drink and use for other domestic purposes.

5.3.2.4.2.4 Mercury

Mercury is a toxic metal which is harmful to human health. According to GEF (2017), ASM miners are exposed to toxic mercury when they extract the gold using that chemical. They added that gold is extracted by vaporizing the mercury.

Table 5.17: Total Mercury Concentration in River Birim (Present Study)

TOTAL MERCURY CONCENTRATION IN RIVER BIRIM		
BIRIM RIVER	**WET**	**DRY**
BR1	0.0004	0.002
BR2	0.0003	0.0009
BR3	0.0001	0.0003
BR4	0.0001	<0.0001
BR5	0.0001	0.001
BR6	0.0001	<0.0001
BR7	<0.0001	<0.0001
BR8	<0.0001	<0.0001
BR9	<0.0001	<0.0001
BR10	<0.0001	<0.0001
BR11	<0.0001	<0.0001
BR12	<0.0001	<0.0001
BR13	<0.0001	0.003
BR 14	<0.0001	0.0004
BR 15	<0.0001	<0.0001
BR 16	<0.0001	<0.0001
BR 17	<0.0001	<0.0001
BR 18	<0.0001	0.0004
BR 19	<0.0001	<0.0001
BR 20	<0.0001	<0.0001

Table 5.18: Total Mercury Concentration in Tributaries (Present Study)

TOTAL MERCURY CONCENTRATION IN TRIBUTARIES			TOTAL MERCURY CONCENTRATION IN TRIBUTARIES		
TRIBUTARY	**WET**	**DRY**	**BOREHOLE**	**WET**	**DRY**
TRI	<0.0001	<0.0001	BRBH1	<0.0001	0.002
TR2	<0.0001	<0.0001	BRBH5	<0.0001	0.02
TR3	<0.0001	<0.0001	BRBH 11	<0.0001	0.002
TR4	<0.0001	<0.0001	BRBH12	<0.0001	0.002
TR5	<0.0001	<0.0001	BRBH 13	<0.0001	0.0001
TR6	<0.0001	<0.0001	BRBH 18	<0.0001	0.001
TR7	<0.0001	<0.0001	BRBH 19	0.0001	<0.0001
TR8	<0.0001	<0.0001	TTRBH1	0.001	<0.0001
TR9	<0.0001	<0.0001	TRBH1	0.0003	0.06
TR10	<0.0001	0.002	TRBH8	<0.0001	0.002
TR 11	<0.0001	<0.0001	TRBH 10	0.0005	<0.0001
TTR1	<0.0001	<0.0001	Treated Water	<0.0001	<0.0001

Table 5.19: Total Mercury Concentration in Groundwater (Present Study)

TOTAL MERCURY CONCENTRATION IN GROUNDWATER		
BOREHOLE	**WET**	**DRY**
BRBH1	<0.0001	0.002
BRBH5	<0.0001	0.02
BRBH 11	<0.0001	0.002
BRBH12	<0.0001	0.002
BRBH 13	<0.0001	0.0001
BRBH 18	<0.0001	0.001
BRBH 19	0.0001	<0.0001
TTRBH1	0.001	<0.0001
TRBH1	0.0003	0.06
TRBH8	<0.0001	0.002
TRBH 10	0.0005	<0.0001
Treated Water	<0.0001	<0.0001

Table 5.20: Total Mercury Concentration in Mine Pond (Present Study)

TOTAL MERCURY CONCENTRATION IN MINE POND		
MINE POND	**WET**	**DRY**
BRMP1	<0.0001	
BRMP5	<0.0001	<0.0001
BRMP11	<0.0001	<0.0001
BRMP12	<0.0001	0.0005
TRMP 2	<0.0001	<0.0001
TTRMP1	0.0005	<0.0001

The GEPA limit for Mercury is 0.001mg/L for drinking water. Almost all the samples were below the GEPA guidelines apart from Atewa (BR1) with 0.002mg/L and Anyinam (BR13) with 0.003mg/L for Birim river. This indicates that some illegal ASM activities might be taking place in the Atewa forest range. For the tributaries, all the samples except Mempong-Akim Akropong (TR10) with a value of 0.002 mg/L was slightly above the GEPA guidelines.

The concentration of mercury in groundwater is significantly higher than that of the River Birim and tributaries. The highest value 0.06mg/L was recorded during the dry season at Asamaman (TRBH1) followed by 0.02mg/L at Adadientem (BRBH5). 0.002mg/L was recorded at during the dry season at Apapam (BRBH1), Nsuapemso (BRBH11), Ankaase (BRBH12) and Si Asunafo

(TRBH8). This indicates that ASM activities have negatively impacted groundwater in the study area. Total mercury in mine pond was not significant.

5.3.2.4.2.4.1 Comparison of means and variables

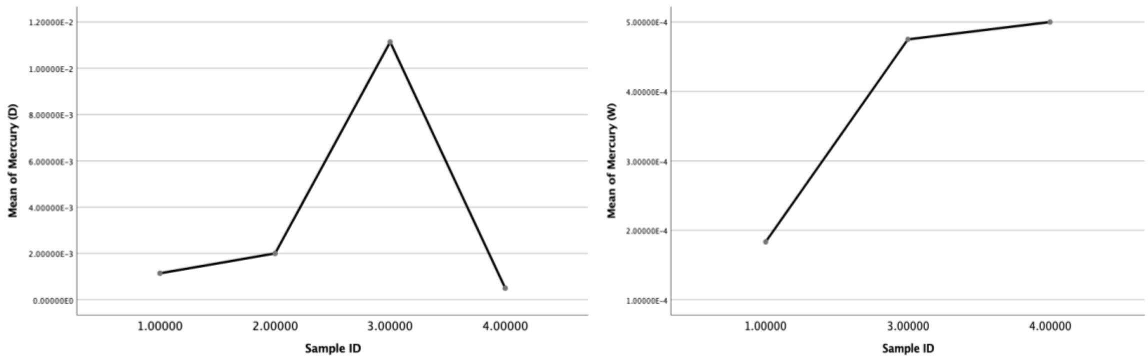


Figure 5.58: Mean plot for Mercury (Present Study)

A comparison between the sample means indicated that the p-value 0.227 (wet season) was greater than 0.05 for both the dry and the wet season. The null hypothesis can therefore not be rejected. Post hoc tests are not performed for Mercury because at least one group has fewer than two cases.

5.3.2.4.2.4.2 Discussion of Mercury Results

The concentration of mercury in the groundwater was significantly higher than that of River Birim and tributaries. Mercury is a very toxic metal and its presence in groundwater even in very small quantities, poses a serious health risk to inhabitants of the communities who depend on the water source. Mercury is introduced into the environment during gold processing when mercury is used to recover gold from ore minerals by the process of amalgamation. Mercury is poorly handled on mining sites daily due to lack of knowledge of its impact on health and the environment. Many miners expose themselves as well as their families to this toxic metal.

Mercury can accumulate in living organisms when ingested and cause serious damage to the nervous system after it reaches high levels. In recent time, some organisations have sought to discourage the use of mercury by encouraging various economies to use the right policies and market incentives to fight mercury use and contamination to protect miners' health and the environment.

5.3.2.4.2.5 Manganese

Manganese is a chemical element that is naturally found in the soil and is also an essential nutrient (Yanful, 2017). High concentrations of Manganese can have adverse health effects, although the human body requires small amounts to function properly.

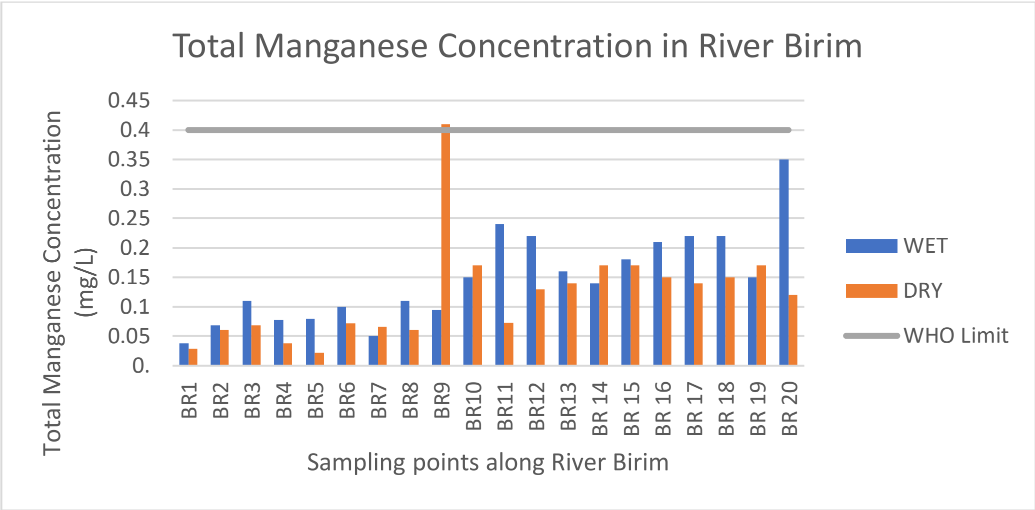


Figure 5.59: Bar chart of Total Manganese Concentration in River Birim (Present Study)

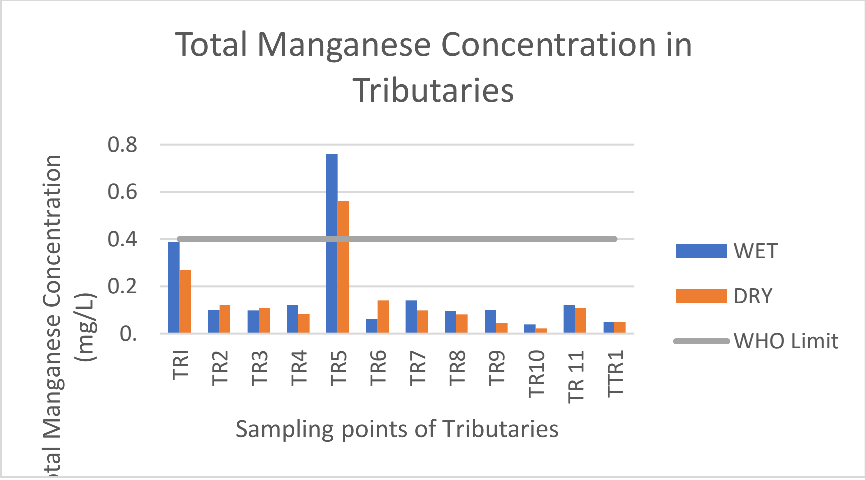


Figure 5.60: Bar chart of Total Manganese Concentration in Tributaries (Present Study)

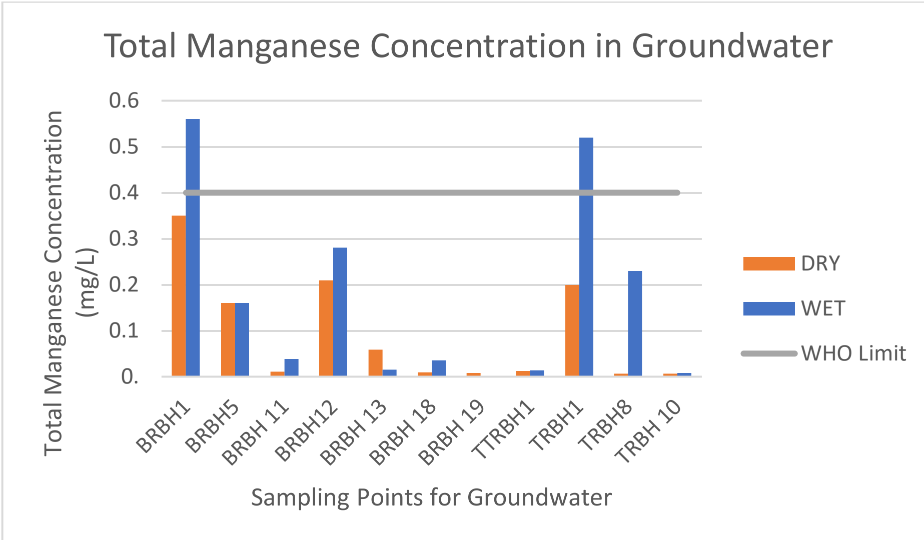


Figure 5.61: Bar chart of Total Manganese Concentration in Groundwater (Present Study)

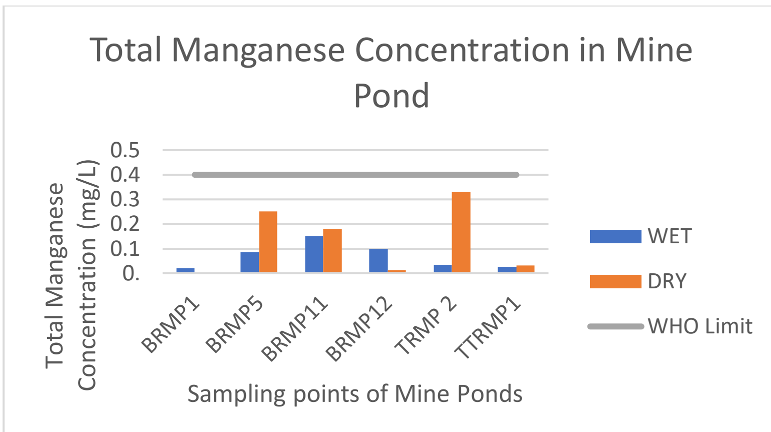


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Figure 5.62: Bar chart of Total Manganese Concentration in Mine Pond (Present Study)

The concentration of Mn was generally below the limit for drinking water except for BR9 which was slightly above the WHO limit. The concentration of Manganese in the wet season was generally higher than that of the dry season.

The concentration of Mn was generally below the limit for drinking water except for TR5 which was above the WHO limit for both wet and dry seasons.

The level of Manganese concentration in groundwater was generally below the WHO guideline except BRBH1which had a mean value of 0.56mg/L and TRBH1, with a value of 0.52mg/L.

5.3.2.4.2.5.1 Comparisons of means and variables

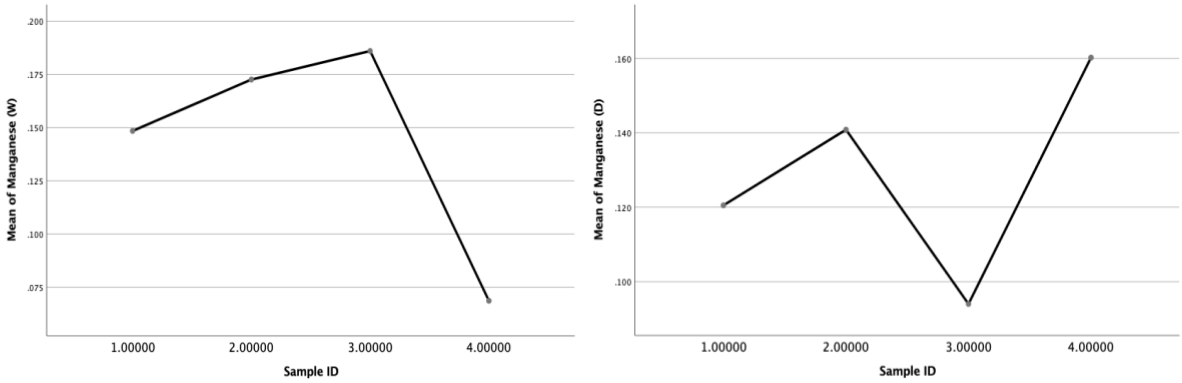


Figure 5.63:Mean plot for Manganese (Present Study)

A comparison between the sample means indicated that the p-value was greater than 0.05 for both the dry and the wet season. The null hypothesis can therefore not be rejected.

Comparing the means between the two seasons, a p-value (0.238) greater than 0.05 indicates there was no significant difference between the means of the two seasons for Birim River.

Comparing the means between the two seasons, a p-value (0.150) greater than 0.05 indicates there was no significant difference between the means of the two seasons for Tributaries.

5.3.2.4.2.5.2 Discussion of Manganese Results

The concentration of Manganese in the Birim River, Tributaries, Groundwater and Mine pond was generally below the WHO acceptable limit for drinking water except for one tributary sample and two groundwater samples. Manganese is therefore not a major concern in the Birim Basin. Manganese generally increased from upstream to downstream but the values were still within the acceptable limits.

5.3.2.4.2.6 Iron

Iron is also an essential nutrient but high concentrations of iron can have adverse health effects.

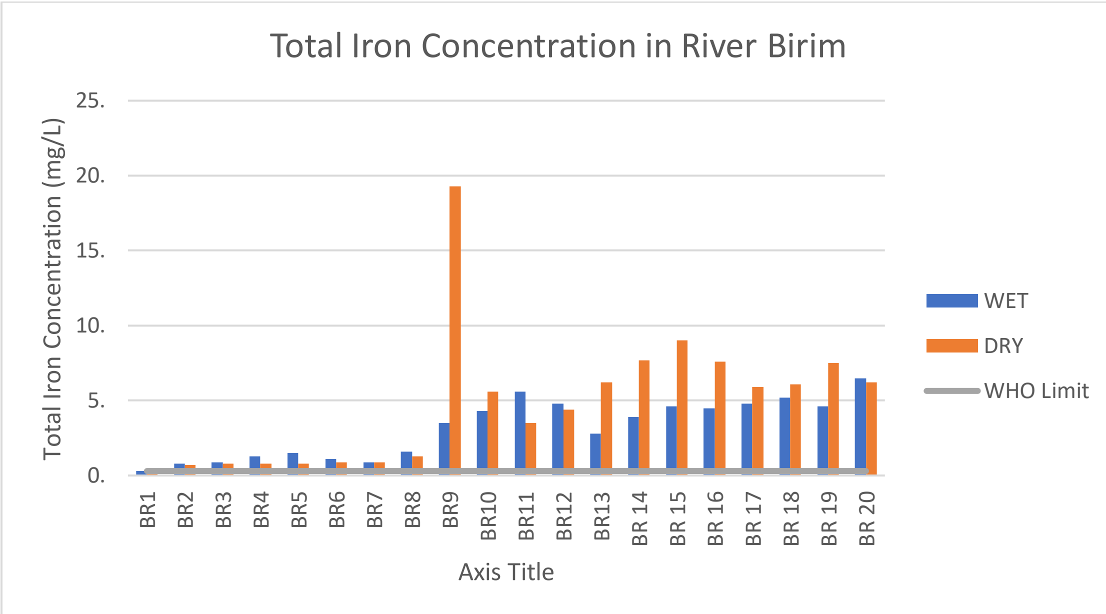


Figure 5.64: Bar chart of Total Iron Concentration in River Birim (Present Study)

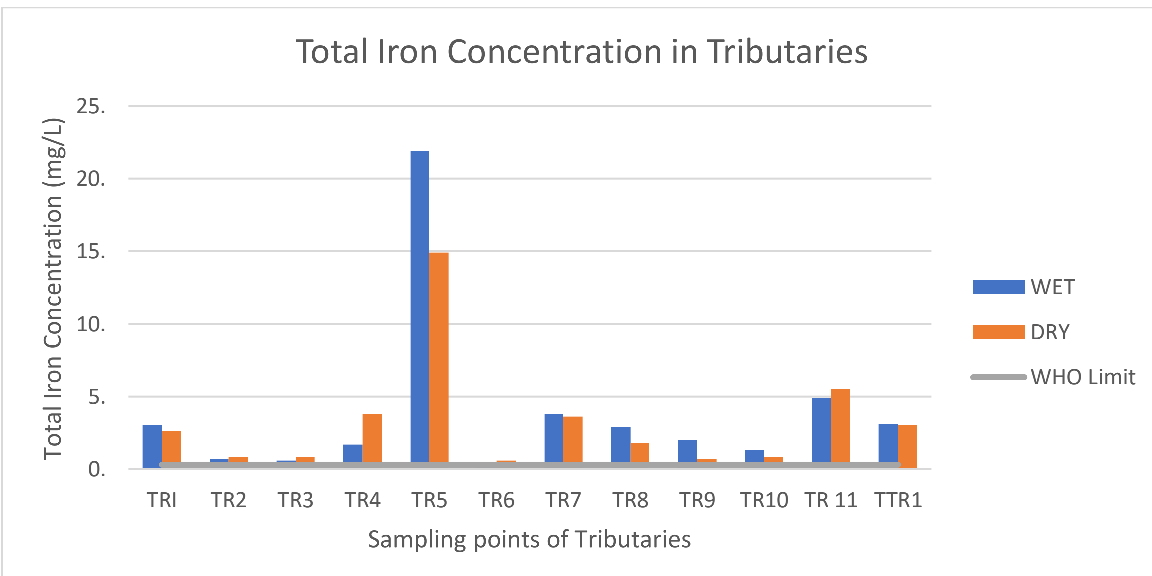


Figure 5.65: Bar chart of Total Iron Concentration in Tributaries (Present Study)

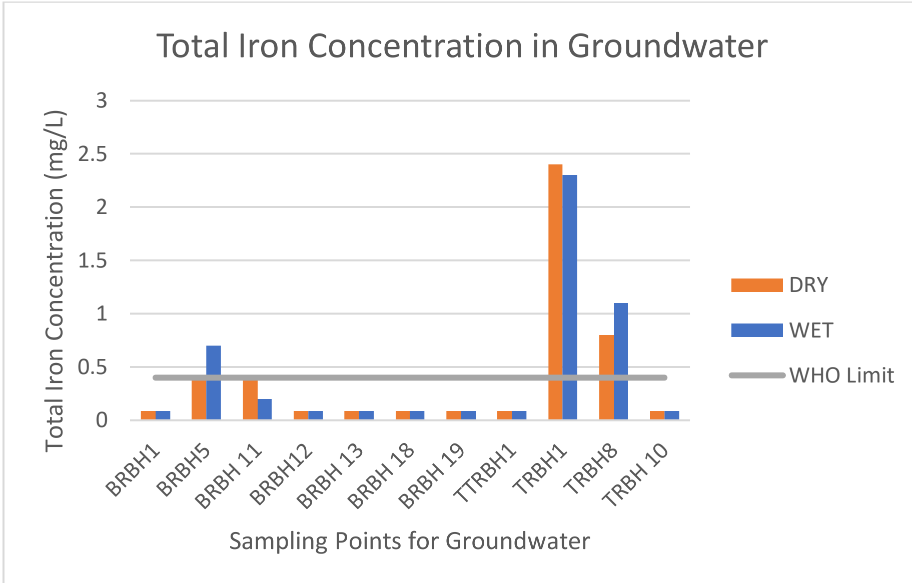


Figure 5.66: Bar chart of Total Iron Concentration in Groundwater (Present Study)

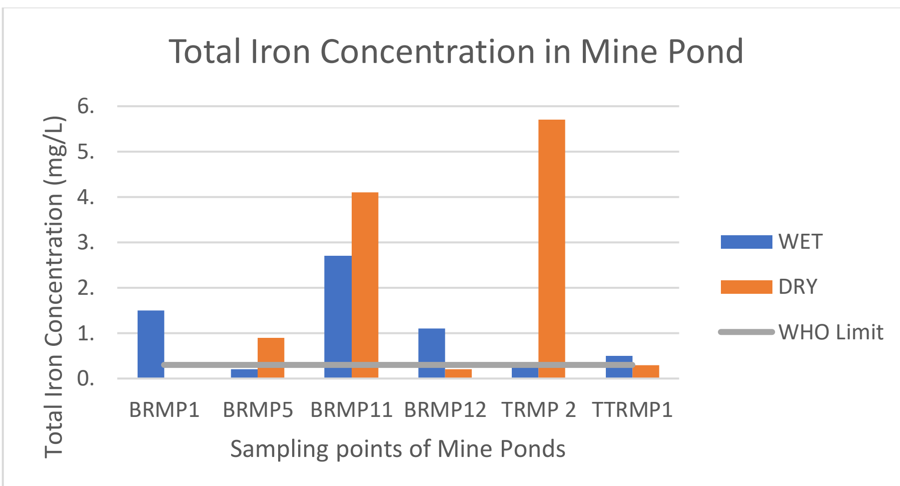


Figure 5.67: Bar chart of Total Iron Concentration in Mine Pond (Present Study)

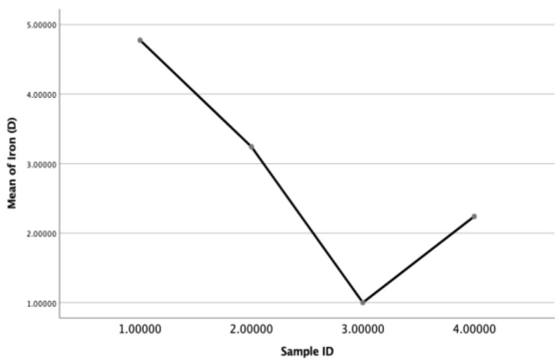
The mean values of total iron in the river water at sampling sites were above the WHO standard. Comparing the mean values of iron among the sampling sites, it was evident that Asiakwa (BR9) recorded the highest value 19.3mg/L(dry) and the lowest was Atewa (BR1) at 0.3mg/L for both wet and dry seasons.

The mean values of total iron in Tributaries were generally above the WHO standard. Comparing the mean values of iron among the sampling sites, it was evident that Anyinam Anikoko (TR5) a reddish-brown river, recorded the highest value 19.3mg/L(dry) and the lowest was Atewa (BR1) at 0.3mg/L for both wet and dry seasons.

Iron concentration in groundwater was generally below the acceptable limit except for Asamaman (TRBH1) at a mean value of 2.3mg/L(wet) and 2.4mg/L (dry), Si Asunafo (TRBH8) at 1.1mg/L (wet) and 0.8mg/L(dry), Adadienten (BRBH5) at 0.7mg/L(wet) and 0.4mg/L(dry) and Nsuapemso (BRBH11) at 0.4mg/L(dry). The treated water had iron concentration less than 0.1mg/L.

Iron concentration in the mine pond was also generally above the WHO acceptable limit. The highest value was 5.7mg/L (dry) at Abosua (TRMP2) followed by 4.1 mg/L(dry) and 2.7mg/L(wet) at Nsuapemso (BRMP11), 1.5mg/L (wet) at Apapam (BRMP1) and 0.5mg/L(wet) at Twumwusu-Pramkese (TTRMP1).

5.3.2.4.2.6.1 Comparison of means and variables



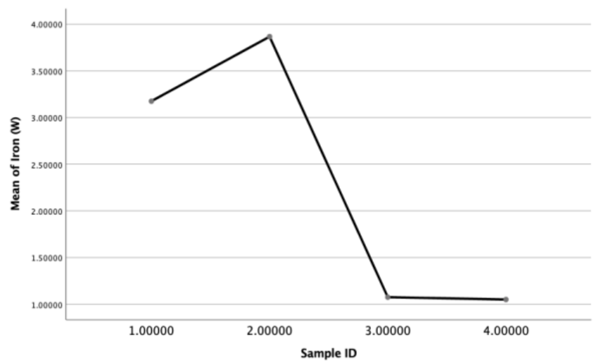


Figure 5.68: Mean plot for Iron (Present Study)

A comparison between the sample means indicated that the p-value was greater than 0.05 for both the dry and the wet season. The null hypothesis can therefore not be rejected.

Comparing the means between the two seasons, a p-value (0.074) greater than 0.05 indicates there was no significant difference between the means of the two seasons for Birim river.
Comparing the means between the two seasons, a p-value (0.342) greater than 0.05 indicates there was no significant difference between the means of the two seasons.

5.3.2.4.2.6.2 Iron Discussion

A comparison of iron concentration in water samples from the study area with the WHO drinking water guideline for iron revealed that observed mean concentrations of total iron were above the recommended value of 0.3 mg/L. The high concentration of iron in the study area can be associated with the weathering of the Birimian rock system but the low amount of iron in the groundwater compared to that of River Birim, tributaries and the mine pond can be an indication of mining activities in or near the river, which can lead to the formation of acid mine drainage that can increase iron concentrations in surface water. Exposure to high concentrations of iron recorded in water samples in this study area can pose significant health risks to inhabitants of these mining communities who depend on the river and groundwater for drinking and other domestic purposes. High amounts of Fe in drinking water can cause severe health risks (Afum and Owusu, 2016).

5.3.2.4.2.7 General Discussion

A comparison between the samples determined that there is no difference in the means between the sample groups. This is because the main source of Alkalinity is usually from carbonate rocks (limestones). Bicarbonate released through the dissolution of carbonate minerals also contributes to alkalinity. The null hypothesis was not rejected because all the sample groups are found in the same area with the same rock formation, the Biriman rock formation which contains carbonate minerals.

A comparison between the samples determined that there is a difference in the means between the sample groups (p-value was less than 0.05 at a confidence level of 95% and thus the null hypothesis has to be rejected for temperature, pH, conductivity (wet season), turbidity (wet season), arsenic (dry season) and lead (wet season). Details from the LSD indicate mostly a significant difference between the sample group 3 (groundwater) compared to the others for both seasons. From the descriptive analysis, groundwater (group 3) was different with regard to temperature, pH, conductivity and turbidity compared to the other water bodies. This is expected because surface water is exposed to external conditions but groundwater is not.

A comparison between the samples determined that there is no difference in the means between the sample groups for alkalinity and bicarbonate. This is because the main source of alkalinity is usually from carbonate rocks (limestones). Bicarbonate released through the dissolution of carbonate minerals also contributes to alkalinity. At the pH, HCO_3^- would be the dominant carbonate species. CO_3^{2-} concentration would be quite low. The null hypothesis was not rejected because all the sample groups are found in the same area with a similar rock formation, the Birimian rock formation which contains carbonate minerals.

The t-test was carried out to determine if there is a significant difference in the means between the wet and the dry seasons. This was conducted for the Birim river, tributaries and groundwater. The t-test was not done for the mine pond because of the very small number of samples which were collected to mainly determine the concentration of heavy metals and further, no one drinks from the mine pond so it is not of critical importance to this research.

For River Birim, the results showed there was a significant difference between the means of samples for the dry season and wet season, specifically for temperature, pH, true colour, apparent colour, conductivity, turbidity, alkalinity, bicarbonate, total suspended solids, arsenic and lead. Significant changes in pH, conductivity etc. is an indicator that a discharge or some other source of pollution has entered the aquatic resource and, in this case, pollution by ASM activities. The only parameters that showed no significant seasonal difference in the mean were manganese, iron, TOC and DOC.

For tributaries, there was a significant difference between the means of samples from the dry season and wet season for temperature, pH, conductivity, alkalinity and bicarbonate. The only parameters that showed no significant seasonal difference in the mean were true colour, apparent colour, turbidity, total suspended solids, arsenic, lead, manganese and iron.

For groundwater, there was a significant difference between the means of samples from the dry season and wet season for pH. All other parameters, temperature, conductivity, alkalinity, bicarbonate, lead, manganese and iron showed no significant seasonal difference in the mean.

The study has established that the concentrations of heavy metals, mainly arsenic, lead and iron recorded in the River Birim, tributaries and boreholes were above WHO guideline limits thus making the water unsafe for drinking and other domestic purposes. Evidence of pollution of the River includes water colouration (high apparent and true colour), siltation (high TSS and Turbidity) and resulting in the formation of sulphuric acid and ferrous hydroxide. The River displays a brownish-orange-reddish colour with fluctuation in electrical conductivity and high levels of some heavy metals, depicting possible chemical pollution.

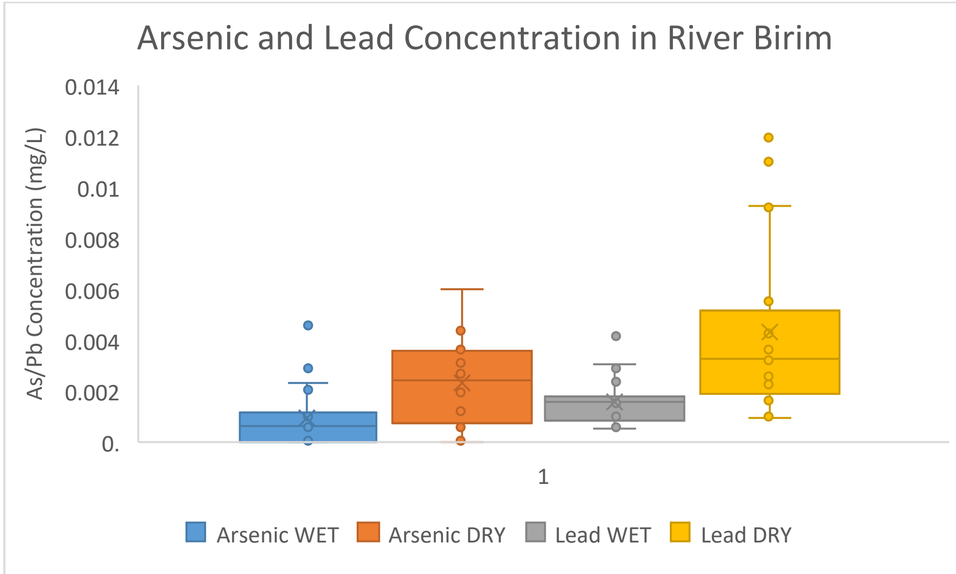


Figure 5.69: Arsenic and Lead Concentration in River Birim (Box plot) (Present Study)

The concentrations of heavy metals in the dry season were generally higher than in the wet season, which was expected although in some cases the wet season values were higher than those of the dry season, an observation also made by Dorleku et al. (2019). This suggests an anthropogenic influence. In their research in the River Pra Basin, Dorleku et al. (2019) reported high concentrations of iron, manganese, lead, aluminium and mercury. Afum and Owusu (2016), noted that measured dissolved concentrations of heavy metals from all the sampling sites were below the WHO standards except for Iron which was also observed in this research. They recorded concentrations above WHO limit for total metal concentrations and concluded the River Birim was polluted.

The study area is therefore prone to heavy metal pollution resulting from ASM activities in and around the Birim River. Treatment of water from the river and borehole to remove heavy metals is strongly recommended before usage for domestic and drinking purposes to avoid health risks. A cost-effective method for removing heavy metal from the water will greatly benefit the affected communities. Arsenic and other heavy metals cannot be removed from water before consumption through boiling of water or chlorine disinfection which only kills pathogens (CDC, 2015).

5.4 ASM Impact on Health

The researcher also sought to assess the impact of ASM on health. Questions such accessibility to health facilities, visits to health facilities, awareness and concern of health risks associated with mining amongst others were asked.

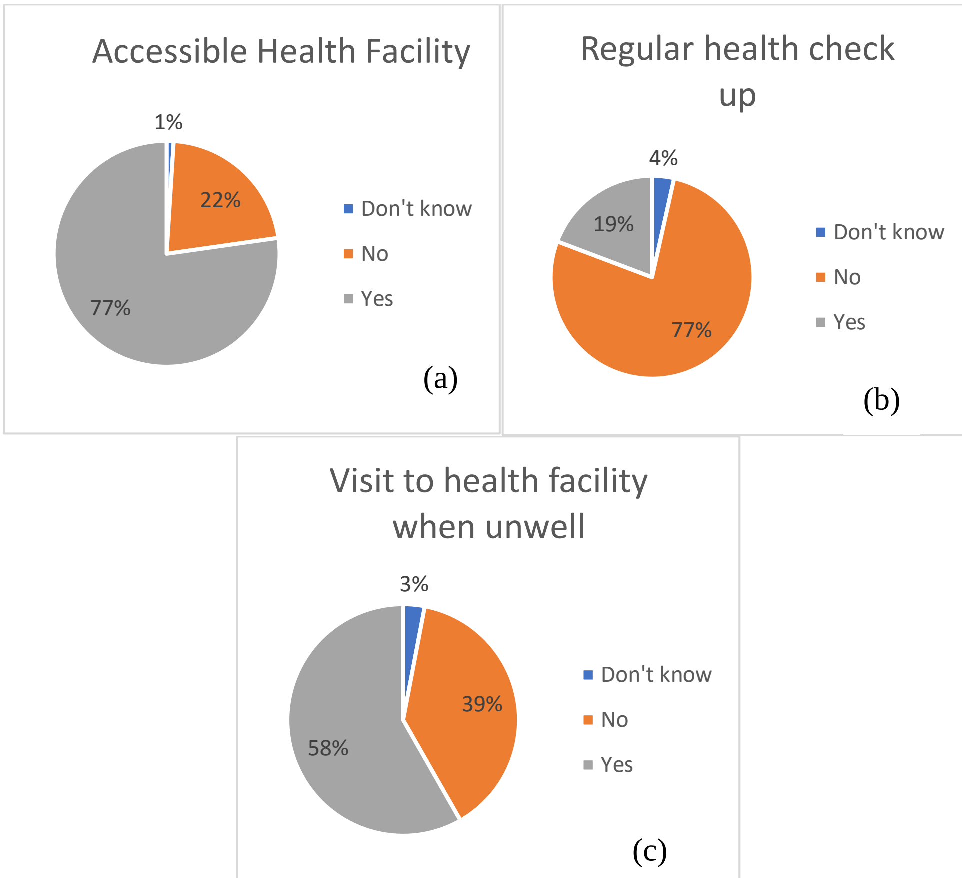
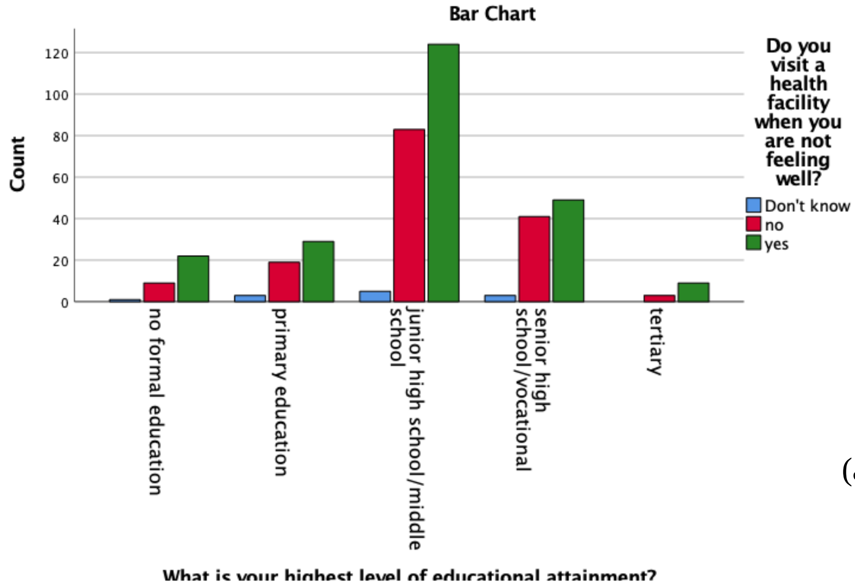
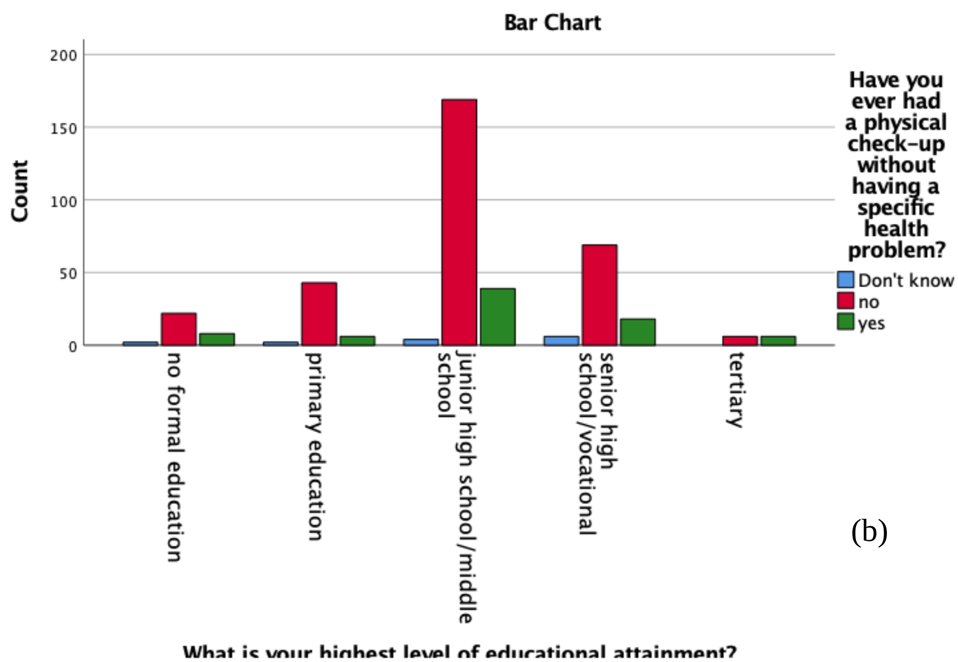


Figure 5.70: Accessibility and visits to health facilities (Present Study)



(a)



(b)

Figure 5.71: Accessibility and visits to health facilities based on Educational level (Present Study)

All three communities have accessible health facilities. The researcher observed there is a clinic between Apapam and Adadienten and a clinic within Adukrom. The three communities also have access to Kibi Hospital which is within the main Kibi township between Adadientem and Adukrom. From Figure 5.71(a) above, 77% of respondents indicated they have easy access to a health facility. I believe this is due to the distance from their residence to the health facility. In another question where respondents were asked about the time it takes to travel from their residence to the health facility, 63% of them indicated it is less than 30 minutes, 30.3% selected 30min to 1 hour, 2.5% indicated 1 to 2hrs and 1.3% selected more than 2 hours. This is influenced by their mode of transportation (whether they travel on foot or by a vehicle) and how close their residence is to the facility. 58% of respondents visit the health facility when they feel unwell in Figure 5.71c.

Respondents were asked whether they have regular check-ups without having specific health problems. Only about 19% stated they have regular health check-ups. Amongst those who have regular check-ups, 45.8% of them go for check-ups more than 2 times in a year. 37.5% once a year, 6.9% don't know, 5.6% every three years and 4.2% once every two years.

From Figure 5.72, for respondents who have tertiary education, half of them visit the health facility for regular check-ups, unlike the other categories which indicate the level of education can influence the importance placed on health matters.

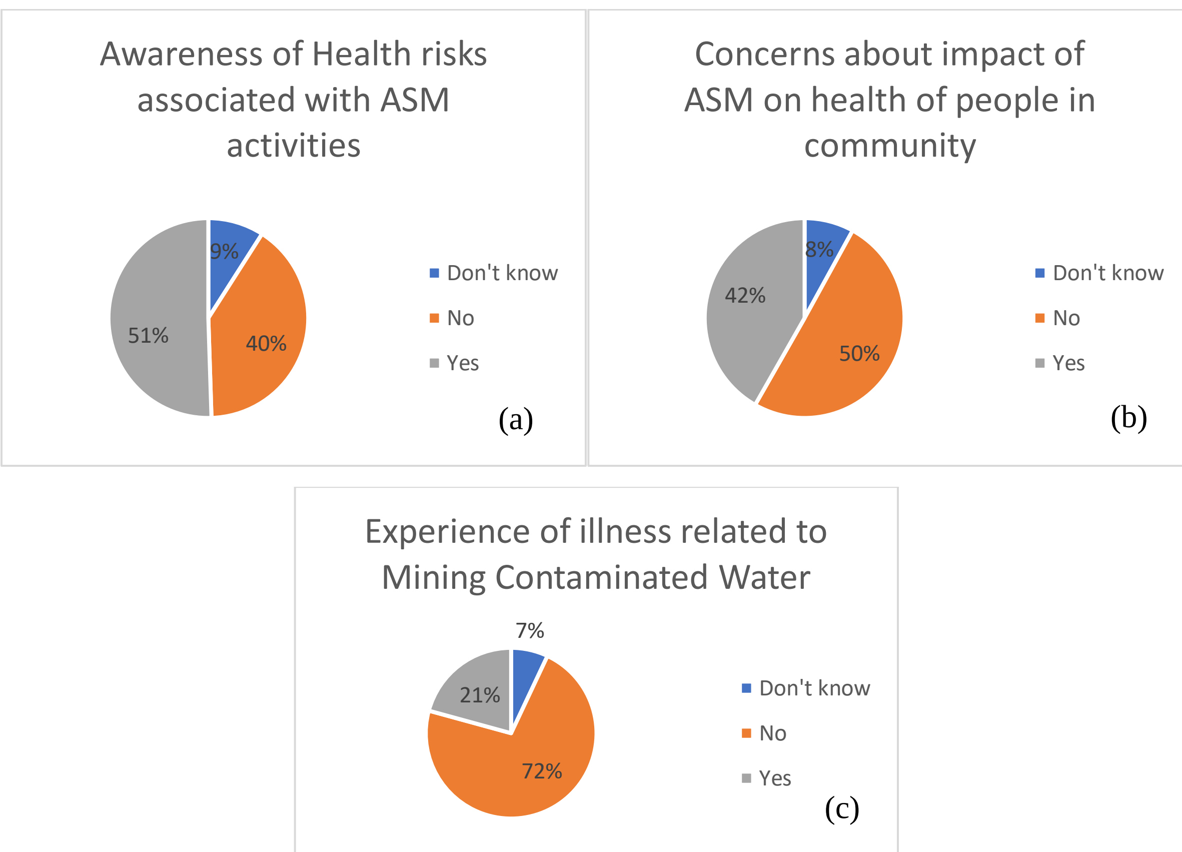


Figure 5.72: Awareness, Concerns and Experience of Health Risks (Present Study)

Respondents in the three mining communities were asked about their awareness of health risks associated with ASM activities. 51% of respondents indicated they were aware of ASM related health risks, 40% of respondents stated they were not aware and 9% indicated they did not know. 42% stated they have concerns about the impact of ASM activities on the health of people in the communities, 50% indicated they were not concerned and 8% stated they did not know. 55% of respondents live close to mine sites as mentioned in chapter four. 21% of respondents have experienced an illness or disease related to contaminated water due to mining activities. A senior nurse at the Kibi main hospital during an interview mentioned that the hospital had observed an increase in mining-related injuries and illness over the past 5 years. She added that there has also been an increase in the number of perinatal deaths which she believes can be associated with the increased mining cases within the communities.

5.4.1 Discussion on Impact of ASM on Health

From the results above, all the three communities have access to health facilities. Most people visit the health facility when they are unwell. Only a few people go for regular check-ups. This is very common in Ghana. About half of the respondents were aware of health risks associated with mining and exposure to chemicals but they still engage in artisanal and small-scale mining activities. The need to make a living to provide for their families outweighs the concern on health risks. Miners carelessly handle mercury, go home to their families and expose them to these chemicals. Inhabitants of the mining communities especially the miners need to be educated about the effects of these chemicals especially on children and their development.

5.5 ASM Impact on Livelihood

Respondents were asked questions to determine the impact of ASM activities on their livelihood. Questions such as 'in your opinion, do mining activities in your area provide benefits to people in the area and surrounding communities?' 'What is the major benefit?' 'Are mining activities affecting farmlands?' amongst others.

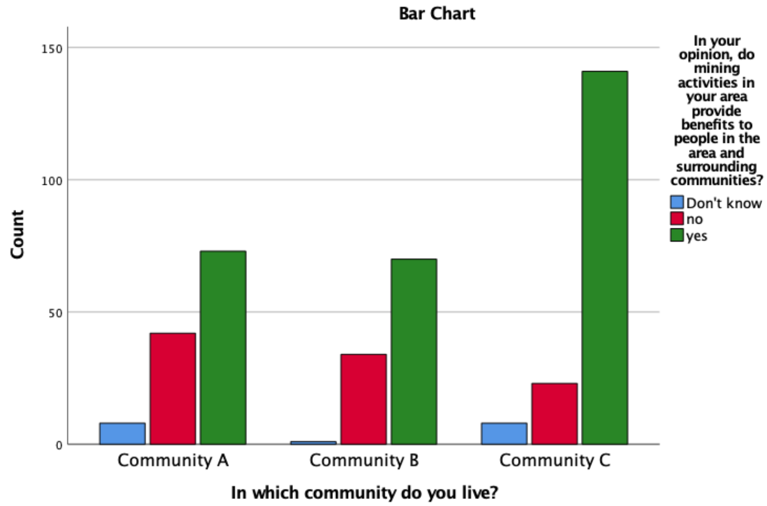


Figure 5.73: Benefits of mining based on Communities (Present Study)

71% of respondents believe mining activities provide benefits to people in the communities. About 51% believe it provides employment, 75% improved standard of living, 14.9% community development. This shows that many of the respondents believe that ASM activities within their communities employ individuals especially the youth and improved standard of living for individuals and families in general. For the community as a whole, many see the detrimental effects of ASM activities on water bodies, the environment in general, farmlands etc. and do not believe ASM brings about community development.

From Demographics chart in chapter three regarding the occupation of the respondents, majority of the respondents were traders (26%) followed by farmers (21%) and the unemployed (20%), majority of who stated they were previously miners but were unemployed due to the ban on ASM activities. 6% refused to disclose their occupation (some of who were illegal miners) and 5% stated they were miners, the majority of them worked with licensed mining companies.

Traders who were the majority of the respondents benefitted from the ASM activities. Some traders mentioned during the interview that business was booming before the ban on ASM activities. They noted that they made more profit from selling several items to miners who had a lot of money to spend before the ban.

Farmers had a different experience compared to the traders. Some farmers sold their land to miners who gave them a lump sum of money. That money was not wisely invested and run out in no time. Some farmers who found themselves in the middle of mining sites were also forced to sell their land to miners because the neighbouring farms had all been sold to miners. Others who refused to sell had their farms illegally mined during the night. Their source of livelihood was affected by ASM activities.

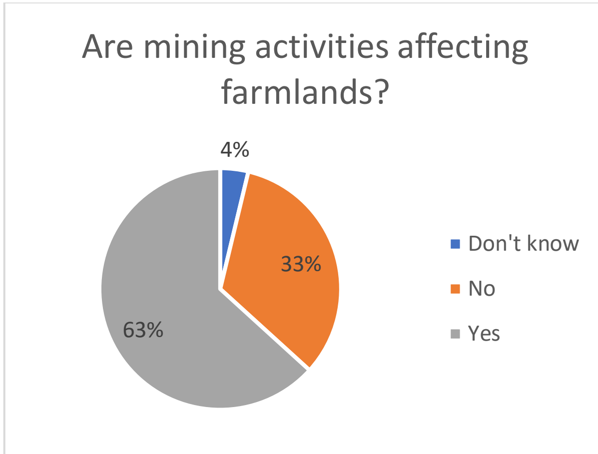


Figure 5.74: ASM impact on Farmlands (Present Study)

Respondents were asked if farmlands had been affected by mining activities. The majority (63%) indicated 'yes'. 91% of those who stated mining is affected by ASM activities noted the effects on farmlands is negative. Only 4% indicated it is positive. This supports the information above from the interviews.

About 20% of the respondents stated they were unemployed. Majority of them were young men and women who were miners before the ban was placed on small-scale mining activities. During the interview, some stated, 'There is no work for the youth in the communities', 'Job opportunities were lost due to the ban which introduced hardship and increase in crime rate', 'The youth have started stealing in the communities because of lack of unemployment' and 'Government has to find a way to engage the youth in employment'.

During the interview, majority of the interviewees, generally agreed that mining improved the standard of living with comments such as 'Mining improved the standard of living for our people', 'Mining boosted our market', 'Life is difficult because of the ban on ASM activities', and 'Employment has been a great challenge after the ban was placed'. Some also noted mining has had a negative impact on their livelihood. They made comments such as 'Mining negatively affected the water bodies which are much clearer now after a ban had been in place', '*Galamsey* has destroyed most of the fertile farmlands in the community', 'Mining destroyed our land', 'ASM resulted in bad water and poverty' and 'Bring new jobs instead of *galamsey*',

Others also suggested 'We need environmentally safe mining solutions and jobs', 'Government should build factories that will undertake proper mining activities' and 'We need work to care for our families'.

5.5.1 Discussion on Impact on Livelihood

From the above, ASM has a positive effect on the lives of individuals within the communities but a negative effect on the community as a whole. It improves the standard of living for individuals within rural communities. During the ban, many young men and women who had made a lot of money had spent it on frivolous things and were destitute again. Only a handful of people had invested in a sustainable venture. Several teenage girls had also been impregnated by miners who left the community after mining activities were over. This placed the burden of caring for the young girls and their baby on the families who were already struggling. A number of the interviewees indicated they need employment in general not specifically mining. Most people are concerned about the youth who are unemployed and resort to criminal activities because they are idle. Increased employment opportunities within the communities will improve the livelihood of inhabitants of the communities.

5.6 Conclusion

This chapter focused on the second objective for the study which is to '*Assess the level of contamination of water bodies in the mining communities and the impact on the health and livelihood of the inhabitants of the communities along the Birim River*'.

Waterbodies in the communities are very important to the inhabitants because that is their main source of water for drinking and other domestic purposes. The results above indicate the Birim river, tributaries and groundwater are not safe for consumption because heavy metals such as Lead, Arsenic and Iron exceeded the WHO guidelines in a number of the samples.

For the impact on health, the researcher observed that all the three communities have access to health facilities but very few people have regular health check-ups. About half of the respondents are aware of the health risks associated with mining activities but many are not too concerned about the health risks because less of than a quarter of the respondents have experienced any form of illness or disease due to contamination of water bodies by mining activities.

Concerning the impact on livelihood, majority of the respondents believe ASM activities provide employment especially for the youth of the communities and it improves their standard of living. Many of them also noted that although it improves the standard of living for individuals within the community, it has negative effects on the development of their communities in general because of the pollution of water bodies which serve as their main source of drinking water, destruction of farmlands which affects their source of food, the open pits which cause the demise of children and animals and the chemicals which exposes them to health risks. One interviewee summed it up nicely by saying 'We like the gold mining activities but we do not want it to destroy the Birim river which we drink from'.

The next chapter focuses on the third objective which seeks to remove heavy metals from contaminated water.

CHAPTER SIX

6 TREATMENT OF CONTAMINATED WATER

This chapter focuses on the third objective for the study which is to '*Determine whether locally available materials can be used to treat the contaminated water to Ghana EPA and WHO standards for drinking water for households in the affected communities.'* Data from the completed questionnaires as well as the laboratory results were analyzed and assessed. Data was presented in tables, pie charts, bar charts and detailed interpretations of the results were made. According to Mishra and Tripathi (2008), adsorption can be carried out as a batch, semi-batch, and continuous processes. The researcher carried out some batch tests and column studies.

6.1 Importance of Water Treatment in Mining Communities

The level of contamination in the River Birim, tributaries and groundwater which are the main sources of drinking water for the rural mining communities, was assessed in chapter five. The results indicated that the water was generally contaminated with heavy metals such as arsenic, lead and iron which exceeded the WHO guidelines for drinking water in several samples. Turbidity, total suspended solids and colour also greatly exceeded their limits for drinking water in the Birim River and its the tributaries. In chapter five, Figure 5.1, 82% of the respondents indicated they use water from River Birim and 70% drink the water from River Birim.

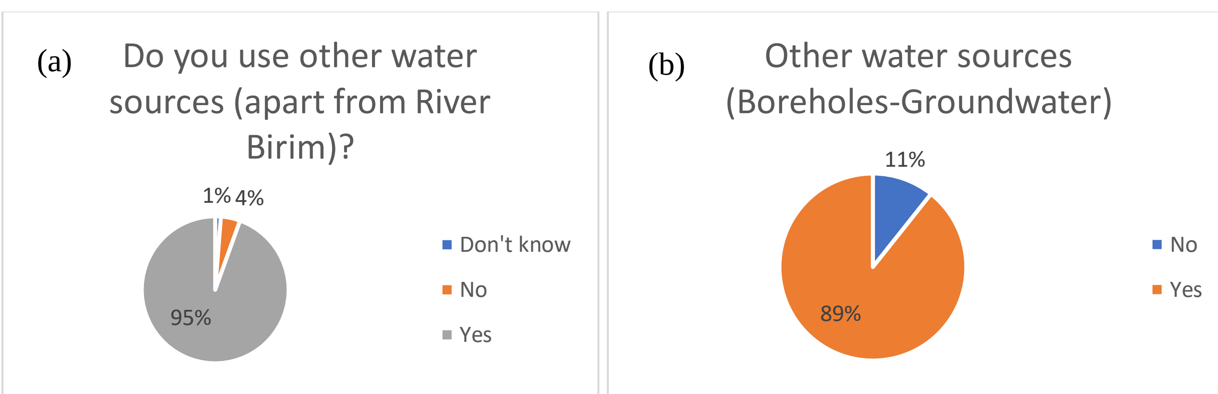


Figure 6.1: Use of Water Sources (Present Study)

When respondents were asked whether they use other water sources apart from the Birim River, 95% stated they use other water sources in addition to water from the River Birim (Figure 6.1). About 89% of respondents indicated they depend on groundwater which is also polluted. These sources of water do not meet the WHO guidelines for drinking water. It is therefore important for water to be treated before it is consumed.

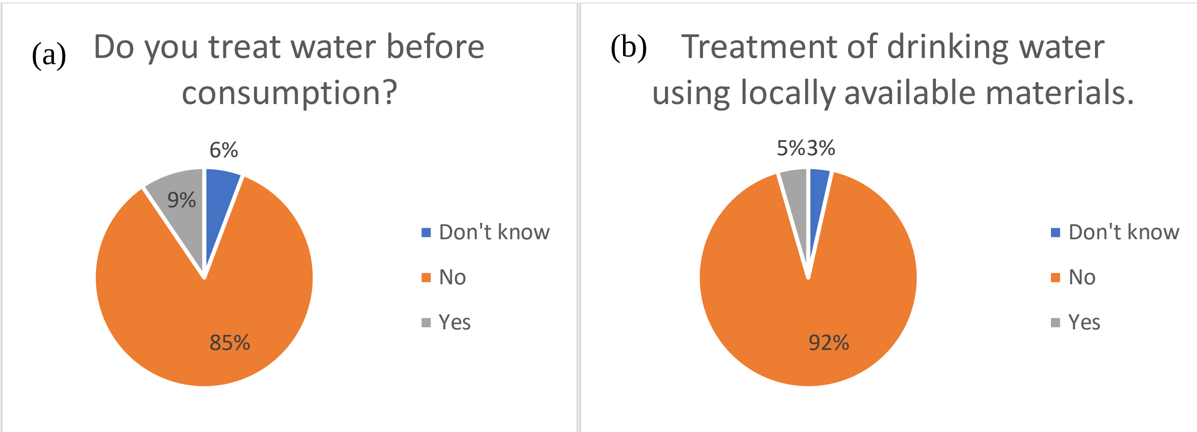


Figure 6.2: Treatment of water before consumption (Present Study)

Respondents were asked whether they treat their water before consumption (Figure 6.2). Only about 9% (38 out of 400 respondents) indicated they treat their water and only 5% of those who treat their water have ever used locally available materials to treat it. Only 18 out of the 38 respondents who treat their water, very often boil their water before drinking, 2 respondents very often filter their water using cloth, 1 very often filters using sand, 6 very often allow their water to settle, 3 very often use solar disinfection and 2 use chlorine disinfection.

Based on these results, the researcher proceeded to explore the use of three locally available and inexpensive adsorbents (Moringa seeds, corn husk and coconut husk) to remove the heavy metals (Iron, Arsenic and lead) that exceeded the WHO/GEPA limit for drinking water.

6.2 Removal of Heavy Metals

Results from the water samples from the River Birim, tributaries and boreholes indicated that, after about a year's ban of ASM activities, the water was still not safe for drinking because the concentration of some heavy metals exceeded the WHO limits. The researcher, therefore, sought to find a safe and cost-effective way of removing the heavy metals from the water to ensure the concentrations are within safe limits. Chemicals used for water treatment are expensive and are not readily available locally in most developing countries.

Three adsorbents: moringa seeds, corn husk and coconut husk, were selected for the treatment process. These adsorbents are inexpensive and common in the communities along the river.

Coconut husk and corn husk are regarded as waste materials in some communities and so can be obtained at virtually no cost. The choice of the adsorbents was influenced by their large surface area, an abundance of functional groups as well as their availability in the local environment.
The adsorbents were used to remove heavy metals from synthetically prepared solutions in the lab. The adsorbents were ground slightly and sieved with a 1.18mm sieve. This sieve size was selected because it is similar to a regular sieve used in many households. A comparison was also made between the use of an orbital shaker and shaking by hand. This can readily be replicated in the rural communities where electrical kits for grinding the adsorbents into very fine particles and shaking are not available. (The process is described in chapter three).

6.2.1 Iron Removal from Water (Batch study)

Moringa seeds, corn husk and coconut husk were used to remove iron from water. Figures 6.1 and 6.2 shows the results of the tests. It was observed that all three adsorbents were quite effective in removing iron especially moringa seeds. An initial batch study was carried out to determine the effect of adsorbent size with varying concentrations, contact time and adsorbent dosage. The result is shown in Table 6.1.

Table 6.1: Iron Removal Efficiency Results (1st set) (Present Study)

No.	Adsorbent	Mass (g)	Sieve size	Contact time	Initial mg/L	Final mg/L	% Removal Efficiency
1.	Moringa	0.5	<1.18mm	30min	1.374	0.011	99.19
2.	Moringa	0.5	>1.18mm	30min	1.374	0.013	99.02
4.	Moringa	0.5	<1.18mm	30min	7.311	0.034	99.53
5.	Moringa	0.5	>1.18mm	30min	7.311	0.233	96.82
6.	Moringa	0.5	<1.18mm	24 hrs	7.311	0.029	99.61
7.	Moringa	0.5	>1.18mm	24 hrs	7.311	0.042	99.42
8.	Corn	0.5	<1.18mm	30min	1.374	0.215	84.33
9.	Corn	0.5	>1.18mm	30min	1.374	0.153	88.90
10.	Corn	0.5	<1.18mm	30min	7.311	1.320	81.94
11.	Corn	0.5	>1.18mm	30min	7.311	0.989	86.47
12.	Corn	0.5	<1.18mm	24 hrs	7.311	1.203	83.54
13.	Coconut	0.5	<1.18mm	30min	1.374	0.207	84.93
14.	Coconut	0.5	>1.18mm	30min	1.374	0.196	85.75
15.	Coconut	0.5	<1.18mm	30min	7.311	0.383	94.77
16.	Coconut	0.5	>1.18mm	30min	7.311	0.689	90.58
17.	Coconut	0.5	>1.18mm	24 hrs	7.311	0.215	97.06
18.	Coconut	0.5	<1.18mm	24 hrs	7.311	0.342	95.32

6.2.1.1 Adsorbent Size

Moringa seeds (with shell), coconut husk and corn husk were washed thoroughly with distilled water to remove impurities and completely dried in the oven to remove moisture. The dry mass was ground in a mortar and then separated into two different sizes using 1.18 mm BSS sieves. They were then stored in airtight bags. The effect of adsorbent size is indicated in Table 6.1.

6.2.1.1.1 Effect of Size of Adsorbent (Moringa seeds) on Iron removal

From Table 6.1, moringa seeds were the most successful in removing iron from the water. In 30 mins, seeds <1.18 mm had a removal efficiency of 99.19% and seeds >1.18 mm had a removal efficiency of 99.02%. This indicates that the smaller particle size which gives a wider surface area increases the adsorption rate but the difference between the two is not much (0.17%). When the concentration was increased, moringa seeds <1.18 mm had a removal efficiency that increased from 99.19% to 99.53% in 30 min and seeds >1.18 mm had a removal efficiency that decreased from 99.02% to 96.82%. This suggests that smaller particle sizes provide a wider surface area which increases the adsorption rate.

6.2.1.1.2 Effect of Size of Adsorbent (Corn husk) on Iron removal

From Table 6.1, corn husk <1.18 mm had a removal efficiency of 84.33% in 30min and corn husk >1.18mm had a removal efficiency of 88.9% in 30mins. The corn husk fibres that were greater than 1.18mm, were longer and therefore had a wider surface area compared to those less than 1.18mm, which were neither long nor fine. When the concentration was increased, corn husk <1.18mm had a removal efficiency of 81.94% in 30min and corn husk >1.18mm had a removal efficiency of 86.47%. According to Yang & Volesky (1999), particle size of adsorbents should not be an important factor in Adsorption studies because they believe adsorbents' surfaces are not homogenous and the difference in the surface texture, pore size etc. of adsorbents can bring about variations in the impact of particle size on the removal efficiency.

6.2.1.1.3 Effect of Size of Adsorbent (Coconut husk) on Iron removal

From 6.1, coconut husk was also successful in removing iron from polluted water although not as effective as moringa seeds. Coconut husk <1.18mm had a removal efficiency of 84.93% in 30min and coconut husk >1.18mm had a removal efficiency of 85.75%. The coconut husk fibres that were greater than 1.18mm, were longer and therefore had a wider surface area compared to those less than 1.18mm, which were neither long nor fine. When the concentration was increased, coconut husk <1.18mm had a removal efficiency of 94.77% in 30min and seeds >1.18mm had a removal efficiency of 97.06%. According to Yang & Volesky (1999), particle size of adsorbents should not be an important factor in Adsorption studies because they believe adsorbents' surfaces are not homogenous and the difference in the surface texture, pore size etc. of adsorbents can bring about variations in the impact of particle size on the removal efficiency.

6.2.1.2 *Effect of Contact time, Concentration and Adsorbent Dosage*

The second batch study focused on the contact time, adsorbate concentration and adsorbent dosage. The moringa seeds were ground to <1.18 mm because they were more effective based on the results in Table 6.1, but the coconut and corn husk were not ground to <1.18 mm because >1.18 mm was more effective. Some samples (HS) were shaken by hand for 3 min and allowed to sit for 24 hrs to determine its effectiveness compared to using the orbital shaker. The results are shown in Table 6.2.

Table 6.2: Iron Removal Efficiency Results (2nd set) (Present Study)

No.	Adsorbent	Weight	Contact time	Initial mg/L	Final mg/L	% Removal	Qe(mg/g)	Ce/Qe
1.	Moringa	0.1	30min	1.9846	0.2651	86.6	1.0317	0.2570
2.	Moringa	0.1	60min	1.9846	0.1360	93.1	1.1091	0.1227
3.	Moringa	0.1	24hrs	1.9846	0.0090	99.5	1.1854	0.0076
4.	Moringa (HS)	0.1	24hrs	1.9846	0.2263	88.6	1.0549	0.2145
5.	Moringa	0.3	30min	1.9846	0.0158	99.2	0.3937	0.0402
6.	Moringa	0.3	60min	1.9846	0.0101	99.5	0.3949	0.0255
7.	Moringa	0.3	24hrs	1.9846	0.0037	99.8	0.3962	0.0092
8.	Moringa (HS)	0.3	24hrs	1.9846	0.0050	99.7	0.3959	0.0126
9.	Moringa	0.5	30min	1.9846	0.0094	99.5	0.2370	0.0395
10.	Moringa	0.5	60min	1.9846	0.0083	99.6	0.2371	0.0352
11.	Moringa	0.5	24hrs	1.9846	<0.005	100%		
12.	Moringa (HS)	0.5	24hrs	1.9846	<0.005	100%		
13.	Moringa	0.1	30min	0.1493	<0.005	100%		
14.	Moringa	0.1	60min	0.1493	<0.005	100%		
15.	Moringa	0.1	24hrs	0.1493	<0.005	100%		
16.	Moringa	0.3	30min	0.1493	<0.005	100%		
17.	Moringa	0.3	60min	0.1493	<0.005	100%		
18.	Moringa	0.3	24hrs	0.1493	<0.005	100%		
19.	Moringa	0.5	30min	0.1493	<0.005	100%		
20.	Moringa	0.5	60min	0.1493	<0.005	100%		
21.	Moringa	0.5	24hrs	0.1493	<0.005	100%		

No.	Adsorbent	Weight	Contact time	Initial mg/L	Final mg/L	% Removal	Qe(mg/g)	Ce/Qe
22.	Corn husk	0.1	30min	1.9846	0.8606	56.6	0.6744	1.2762
23.	Corn husk	0.1	60min	1.9846	0.7797	60.7	0.7229	1.0786
24.	Corn husk	0.1	24hrs	1.9846	0.7233	63.6	0.7567	0.9559
25.	Corn husk	0.3	30min	1.9846	0.6960	64.9	0.2577	2.7007
26.	Corn husk	0.3	60min	1.9846	0.6511	67.2	0.2667	2.4413
27.	Corn husk	0.3	24hrs	1.9846	0.6032	69.6	0.2763	2.1834
28.	Corn husk (HS)	0.3	24hrs	1.9846	0.8895	55.2	0.2190	4.0614
29.	Corn husk	0.5	30min	1.9846	0.6254	68.5	0.1631	3.8345
30.	Corn husk	0.5	60min	1.9846	0.5930	70.1	0.1670	3.5508
31.	Corn husk	0.5	24hrs	1.9846	0.4601	76.8	0.1829	2.5147
32.	Corn husk	0.1	30min	0.1493	0.1305	12.6	0.0113	11.5564
33.	Corn husk	0.1	30min	0.1493	0.0618	58.6	0.0525	1.1760
34.	Corn husk	0.1	24hrs	0.1493	0.0320	78.6	0.0704	0.4537
35.	Corn husk	0.3	30min	0.1493	0.1260	15.6	0.0047	26.9733
36.	Corn husk	0.3	60min	0.1493	0.0534	64.2	0.0192	2.7868
37.	Corn husk	0.3	24hrs	0.1493	0.0308	79.4	0.0237	1.2984
38.	Corn husk	0.5	30min	0.1493	0.0967	18.7	0.0063	15.3238
39.	Corn husk	0.5	60min	0.1493	0.0500	66.6	0.0119	4.1885
40.	Corn husk	0.5	24hrs	0.1493	0.0288	80.7	0.0145	1.9945
41.	Coconut husk	0.1	30min	1.9846	0.4450	77.6	0.9238	0.4817
42.	Coconut husk	0.1	60min	1.9846	0.2212	88.9	1.0580	0.2091
43.	Coconut husk	0.1	24hrs	1.9846	0.0953	95.2	1.1336	0.0840
44.	Coconut husk	0.3	30min	1.9846	0.2234	88.7	0.3522	0.6342
45.	Coconut husk	0.3	60min	1.9846	0.1987	90.0	0.3572	0.5563
46.	Coconut husk	0.3	24hrs	1.9846	0.0204	99.0	0.3928	0.0520
47.	Coconut husk (HS)	0.3	24hrs	1.9846	0.3373	83.0	0.3295	1.0237
48.	Coconut husk	0.5	30min	1.9846	0.1605	91.9	0.2189	0.7332
49.	Coconut husk	0.5	60min	1.9846	0.1565	92.1	0.2194	0.7135
50.	Coconut husk	0.5	24hrs	1.9846	<0.005	100%		
51.	Coconut husk	0.1	30min	0.1493	0.1409	5.7	0.0051	27.6960
52.	Coconut husk	0.1	60min	0.1493	0.0624	58.2	0.0522	1.1948
53.	Coconut husk	0.1	24hrs	0.1493	0.0461	69.1	0.0619	0.7443
54.	Coconut husk	0.3	30min	0.1493	0.1374	8.0	0.0024	57.2921
55.	Coconut husk	0.3	60min	0.1493	0.0808	45.9	0.0137	5.8992
56.	Coconut husk	0.3	24hrs	0.1493	0.0662	55.7	0.0166	3.9840
57.	Coconut husk	0.5	30min	0.1493	0.1215	18.7	0.0033	36.3485
58.	Coconut husk	0.5	60min	0.1493	0.0731	51.0	0.0091	7.9919
59	Coconut husk	0.5	24hrs	0.1493	0.0548	63.3	0.0113	4.8302

6.2.1.2.1 Effect of Concentration in Iron removal

For iron, specifically in the case of Moringa seeds, four concentrations, 0.15mg/L, 1 mg/L, 2 mg/L and 7 mg/L (Tables 6.1 and 6.2) were used. For corn husk and coconut husk, they were not sieved after they were ground because from the 1st batch test, >1.18 mm particles were found to be more effective than <1.18 mm particles. Therefore, comparisons among the four concentrations will not be made for corn and coconut husk.

6.2.1.2.1.1 Effect of Concentration in Iron removal (Moringa)

It was observed that the removal efficiency increased as the concentration increased. With 0.5g moringa seeds <1.18mm, there was a removal efficiency of 99.19% for 1 mg/L, 99.5% for 2 mg/L and 99.53% for 7 mg/L although there was 100% removal for 0.15 mg/L as shown in Figure 6.3.

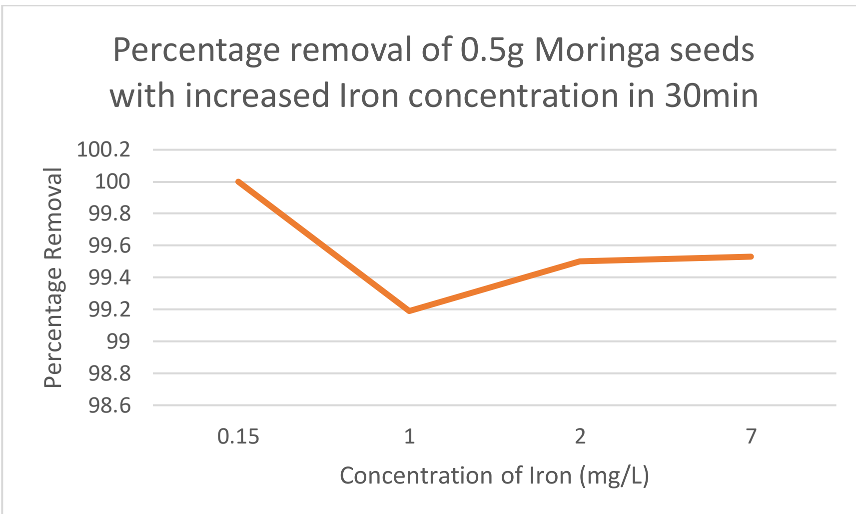


Figure 6.3: Effect of concentration in Iron removal (Present Study)

6.2.1.2.1.2 Effect of Concentration in Iron removal (Corn husk)

It was observed that the removal percentage generally increased as the concentration increased but for the 24 hrs, the lower concentration had a higher removal percentage than the high concentration. 0.3g of corn husk for 30 min with 0.15mg/L concentration had removal percentage of 15.6% which increased to 64.9% with 2mg/l concentration.

6.2.1.2.1.3 Effect of Concentration in Iron removal (Coconut husk)

It was observed that the removal percentage increased as adsorbate concentration increased. Removal percentage increased from 51% to 92.1% when concentration was increased from o.15mg/L to 2mg/L for 0.5g of Coconut in 60min in Table 6.2.

In Table 6.1, percentage removal increased from 84.93% to 94.77% when concentration was increased from 1mg/L to 7mg/L for 0.5g of coconut husk <1.18mm.

6.2.1.2.2 Effect of Adsorbent Dosage on Iron removal

The adsorbent dosage used was 0.1g, 0.3g and 0.5g for the three adsorbents. This was carried to determine which dosage will be most effective.

6.2.1.2.1.1 Effect of Adsorbent Dosage in Iron removal (Moringa)

From Table 6.2, an increase in moringa dosage from 0.1g to 0.3g and 0.5g increased percentage removal as shown in Figure 6.4 below.

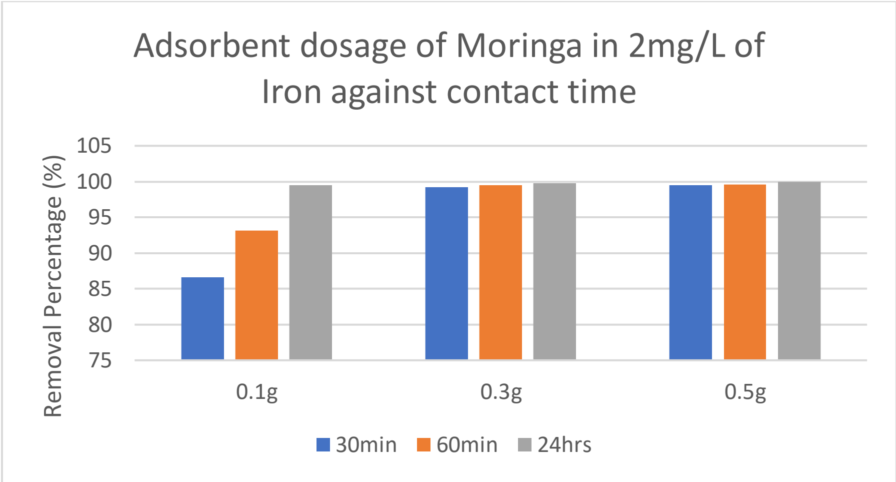


Figure 6.4: Effect of Adsorbent Dosage in Iron removal – Moringa (Present Study)

6.2.1.2.1.2 Effect of Adsorbent Dosage in Iron removal (Corn husk)

An increase in the corn husk dosage from 0.1g to 0.3g to 0.5g increased the percentage removal of iron for both 0.15mg/L and 2mg/L concentrations as shown in Figures 6.5 and 6.6 below.

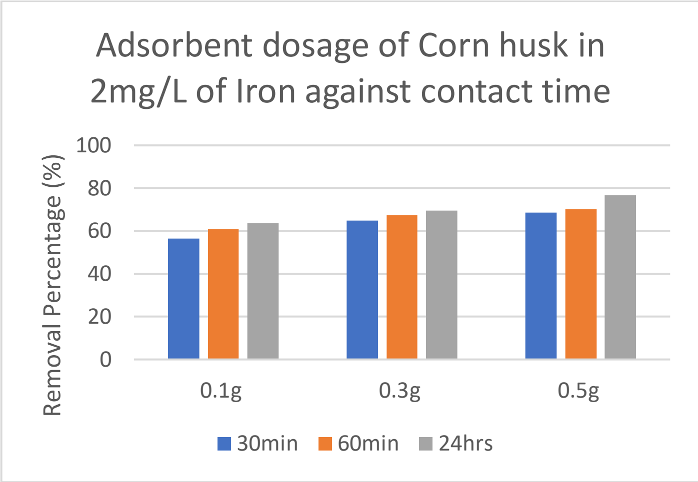


Figure 6.5: Effect of Adsorbent Dosage in 2mg/L Iron removal - Corn husk (Present Study)

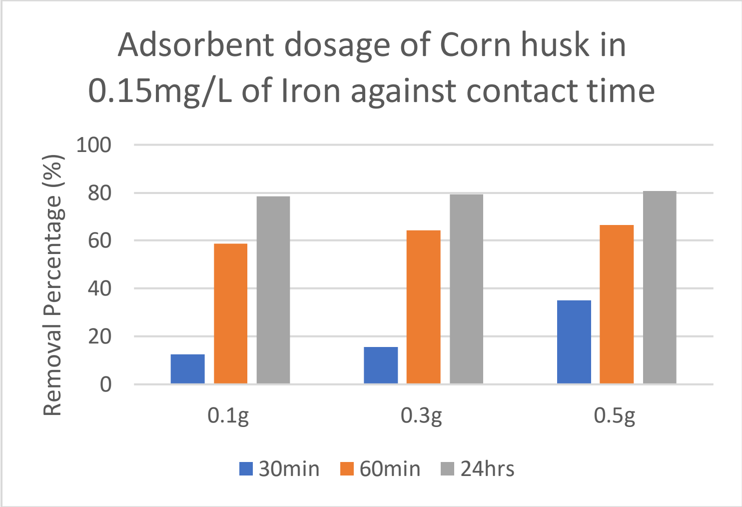


Figure 6.6: Effect of Adsorbent Dosage in 0.15mg/L Iron removal - Corn husk (Present Study)

6.2.1.2.1.3 Effect of Adsorbent Dosage in Iron removal (Coconut husk)

An increase in the coconut husk dosage from 0.1g to 0.3g to 0.5g increased the percentage removal of iron for both 0.15mg/L and 2mg/L concentrations as shown in Figures 6.7 and 6.8 below which is expected.

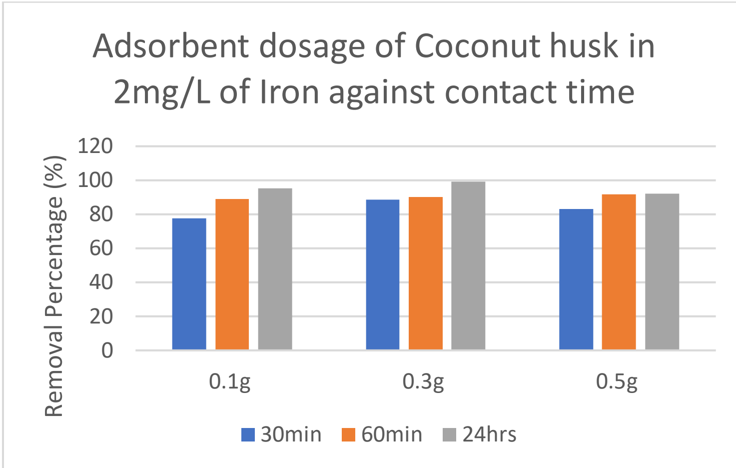


Figure 6.7: Effect of Adsorbent Dosage in 2mg/L Iron removal - Coconut husk (Present Study)

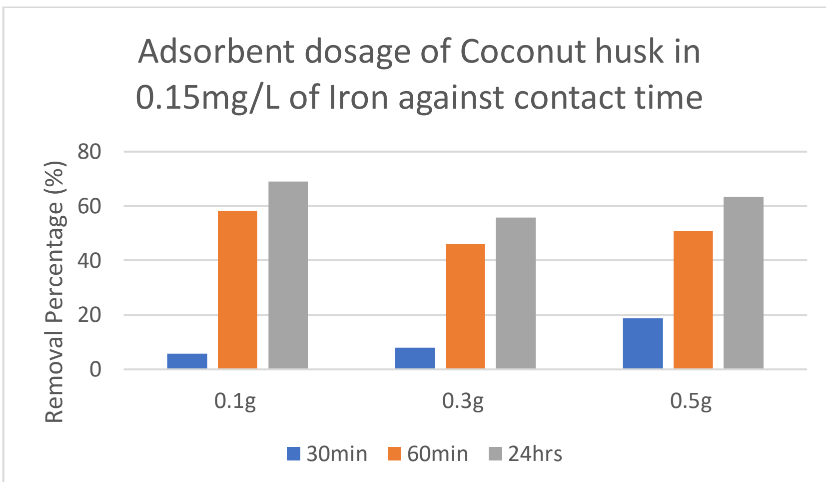


Figure 6.8:Effect of Adsorbent Dosage in 0.15mg/L Iron removal - Coconut husk (Present Study)

6.2.1.2.3 Effect of Contact time

The contact time was increased from 30min to 60 min and to 24hrs to determine its effect on the removal efficiency.

6.2.1.2.1.1 Effect of Contact time in Iron removal (Moringa)

An increase in contact time from 30min to 60min to 24hrs increased percentage removal which indicates increased contact time improves removal efficiency as shown in Figures 6.9, 6.10 and 6.11.

From Table 6.1, an increase in the contact time from 30min to 24hrs of 0.5g of the adsorbent for seeds <1.18mm improved the removal efficiency from 99.19% to 99.61% and for seeds >1.18mm from 99.02% to a removal efficiency of 99.42% which is generally expected.

6.2.1.2.1.2 Effect of Contact time in Iron removal (Corn husk)

An increase in contact time from 30min to 60min to 24hrs increased percentage removal which indicates increased contact time improves removal efficiency as shown in Figures 6.9, 6.10 and 6.11.

An increase in the contact time from 30min to 24hrs of 0.5g of the adsorbent for corn husk <1.18mm increased the removal efficiency from 81.94% to 83.54% as shown in Table 6.1.

6.2.1.2.1.3 Effect of Contact time in Iron removal (Coconut husk)

An increase in contact time from 30min to 60min to 24hrs increased percentage removal which indicates increased contact time improves removal efficiency as shown in Figures 6.9, 6.10 and 6.11.

An increase in the contact time from 30min to 24hrs of 0.5g of adsorbent in 7mg/L Fe for coconut husk <1.18mm had a removal efficiency that increased from 94.77% of 95.32% and for coconut husk >1.18mm had removal efficiency increase from 90.58% to 97.06% as shown in Table 6.1.

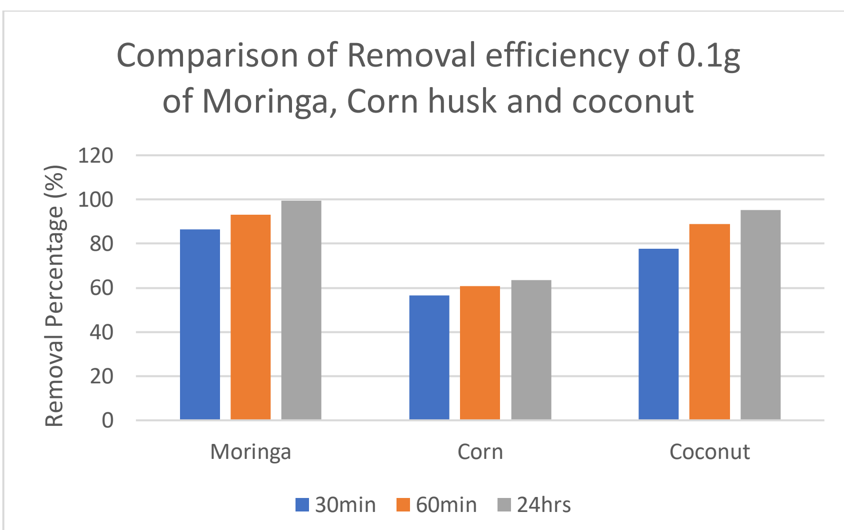


Figure 6.9:Comparison of 0.1g of Moringa, Corn husk and Coconut in 2mg/L Fe (Present Study)

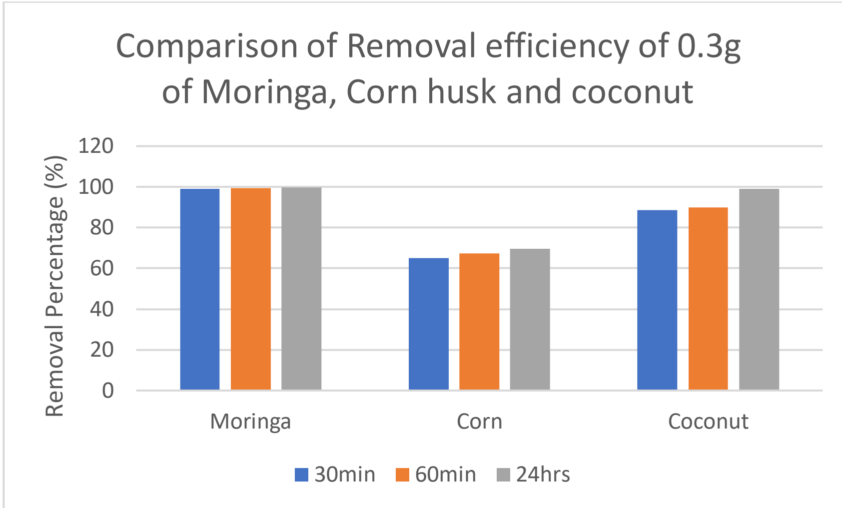


Figure 6.10:Comparison of 0.3g of Moringa, Corn husk and Coconut in 2mg/L Fe (Present Study)

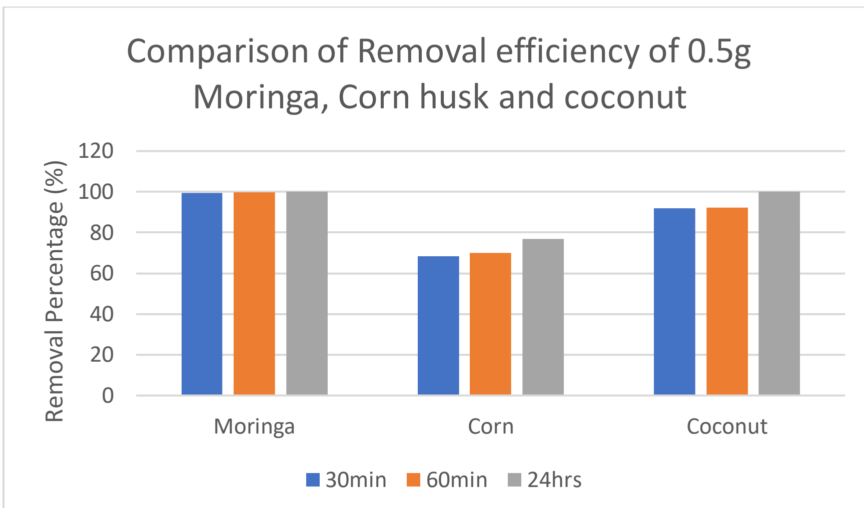


Figure 6.11: Comparison of 0.5g of Moringa, Corn husk and coconut in 2mg/L Fe (Present Study)

6.2.1.2.4 Comparison between use of orbital shaker and shaking by hand

A comparison was made between the use of an orbital shaker and shaking by hand as shown in Figure 6.12. It was observed that the orbital shaker is slightly more efficient than shaking by hand but the difference is not much. This shows that shaking by hand is also very effective and this can be replicated in rural communities that do not have electrical kits.

A comparison was also made between the three adsorbents with shaking by hand in Figure 6.13. Moringa seeds were the most effective followed by coconut husk. Corn husks were not as effective as the moringa seeds and the coconut husk.

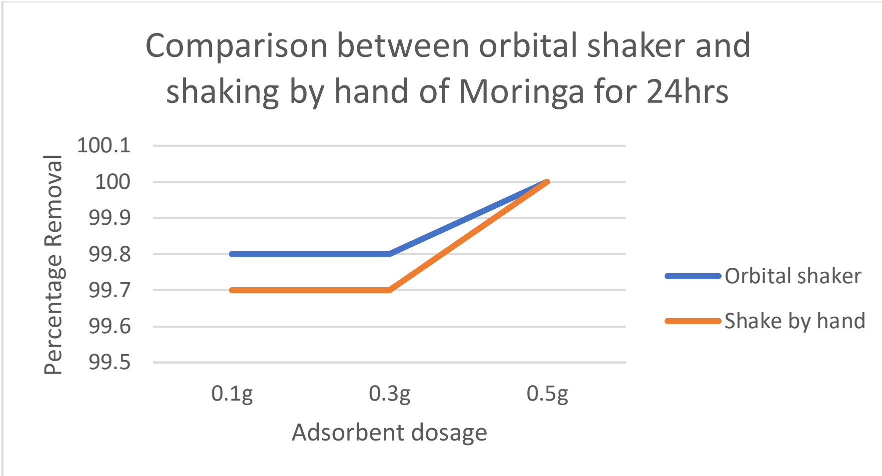


Figure 6.12: Comparison between orbital shaker and shaking by hand of Moringa for 24hrs (Present Study)

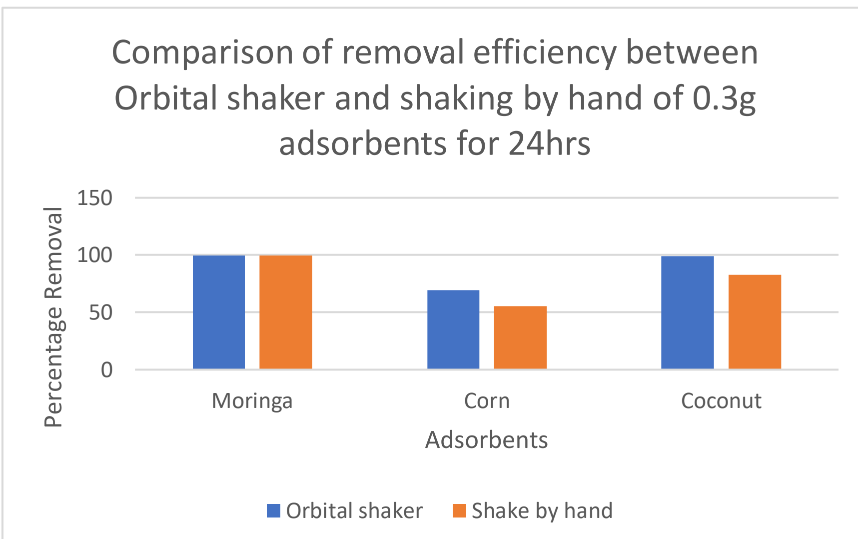


Figure 6.13: Comparison between Orbital shaker and shaking by hand of 0.3g adsorbents for 24hrs (Present Study)

6.2.1.3 Discussion

All the adsorbents were effective in removing some iron from the synthetic solution. Moringa seeds significantly removed more iron followed by coconut husk and then corn husk. An increase in surface area and contact time increased the removal efficiency. Dried, ground moringa seeds which is a natural cationic polyelectrolyte, coagulate debris in water due to their active soluble protein component (Pritchard et al, 2010). Generally, an increase in contact time, adsorbent dosage and concentration increased the removal efficiency. An increase in adsorbent size reduced the removal efficiency for moringa seeds but increased the removal efficiency for the raw untreated corn and coconut husk because of the heterogenous nature of the surface of the adsorbents (Yang and Volesky, 1999). The comparison between using the orbital shaker and shaking by hand indicated it is still possible to remove iron from the water even without a mechanical device, especially with Moringa seeds.

6.2.2 Lead Removal from Water (Batch study)

Moringa seeds, corn husk and coconut husk were used to remove lead from water. Figure 6.3 shows the results of the tests. It was observed that all three adsorbents were quite effective in removing Lead.

Table 6.3: Lead Removal Efficiency Results (Present Study)

No.	Adsorbent	Mass (g)	Contact time	Initial mg/L	Final mg/L	% Removal Efficiency	q(mg/g)	Ce/Qe
1.	Moringa	0.1	30 min	0.7952	<0.005	100%		
2.	Moringa	0.1	60	0.7952	<0.005	100%		
3.	Moringa	0.1	24	0.7952	<0.005	100%		
4.	Moringa	0.3	30	0.7952	<0.005!	100%		
5.	Moringa	0.3	60	0.7952	<0.005!	100%		
6.	Moringa	0.3	24	0.7952	<0.005	100%		
7.	Moringa	0.5	30	0.7952	<0.005	100%		
8.	Moringa	0.5	60	0.7952	<0.005!	100%		
9.	Moringa	0.5	24	0.7952	<0.005	100%		
10.	Moringa	0.1	30	7.1948	<0.005!	100%		
11.	Moringa	0.1	60	7.1948	<0.005!	100%		
12.	Moringa	0.1	24	7.1948	<0.005	100%		
13.	Moringa	0.3	30	7.1948	<0.005	100%		
14.	Moringa	0.3	60	7.1948	<0.005	100%		
15.	Moringa	0.3	24	7.1948	<0.005	100%		
16.	Moringa	0.5	30	7.1948	<0.005	100%		
17.	Moringa	0.5	60	7.1948	<0.005	100%		
18.	Moringa	0.5	24	7.1948	<0.005	100%		
19.	Corn	0.1	30	0.7952	<0.005	100%		
20.	Corn	0.1	60	0.7952	<0.005	100%		
21.	Corn	0.1	24	0.7952	<0.005	100%		
22.	Corn	0.3	30	0.7952	<0.005	100%		
23.	Corn	0.3	60	0.7952	<0.005	100%		

No.	Adsorbent	Mass (g)	Contact time	Initial mg/L	Final mg/L	% Removal Efficiency	q(mg/g)	Ce/Qe
24.	Corn	0.3	24	0.7952	<0.005	100%		
25.	Corn	0.5	30	0.7952	<0.005	100%		
26.	Corn	0.5	60	0.7952	<0.005	100%		
27.	Corn	0.5	24	0.7952	<0.005	100%		
28.	Corn	0.1	30	7.1948	0.8116	87.5	3.8299	0.2119
29.	Corn	0.1	60	7.1948	0.8218	88.6	3.8238	0.2149
30.	Corn	0.1	24	7.1948	0.1414	98.0	4.2320	0.0334
31.	Corn	0.3	30	7.1948	0.6991	90.3	1.2991	0.5382
32.	Corn	0.3	60	7.1948	0.5442	92.4	1.3301	0.4091
33.	Corn	0.3	24	7.1948	0.8218	98.6	1.2746	0.6448
34.	Corn	0.5	30	7.1948	0.5475	92.4	0.7977	0.6864
35.	Corn	0.5	60	7.1948	0.1576	97.8	0.8445	0.1866
36.	Corn	0.5	24	7.1948	<0.005	100%		
37.	Coconut	0.1	30	0.7952	<0.005	100%		
38.	Coconut	0.1	60	0.7952	<0.005	100%		
39.	Coconut	0.1	24	0.7952	<0.005	100%		
40.	Coconut	0.3	30	0.7952	<0.005	100%		
41.	Coconut	0.3	60	0.7952	<0.005	100%		
42.	Coconut	0.3	24	0.7952	<0.005	100%		
43.	Coconut	0.5	30	0.7952	<0.005	100%		
44.	Coconut	0.5	60	0.7952	<0.005	100%		
45.	Coconut	0.5	24	0.7952	<0.005	100%		
46.	Coconut	0.5	30	7.1948	0.3224236	95.5	0.8247	0.3910
47.	Coconut	0.5	60	7.1948	0.2244738	96.9	0.8364	0.2684
48.	Coconut	0.5	24	7.1948	0.0933663	98.0	0.8522	0.1096

6.2.2.1 Effect of Concentration in Lead removal

Two concentrations of lead adsorbate were tested in this experiment, 0.8mg/L and 7mg/L.

6.2.2.1.1 Effect of Concentration in Lead removal (Moringa)

Moringa was able to effectively remove lead from the water for 0.8mg/L and 7mg/L. The ICP was unable to detect any lead concentration in the samples with moringa seeds.

6.2.2.1.2 Effect of Concentration in Lead removal (Corn husk)

Corn husk effectively removed lead from the synthetic solution with 0.8mg/L and no lead concentration was detected. For 7mg/L concentration, for 30min, 0.1g had a percentage removal of 87.5%, 0.3g had 90.3% and 0.5g had 92.4%.

6.2.2.1.3 Effect of Concentration in Lead removal (Coconut husk)

Coconut husk effectively removed lead from the synthetic solution with 0.8mg/L and no lead concentration was detected. For 7mg/L concentration, for 30min, 0.5g had a percentage removal of 95.5.5%, 60min had 96.9% and 24hrs had 98%.

6.2.2.2 Effect of Adsorbent Dosage in Lead removal

Adsorbent dosage of 0.1g, 0.3g and 0.5g were used. The effect of adsorbent dosage on lead removal is shown in Figure 6.14 below.

6.2.2.2.1 Effect of Adsorbent Dosage in Lead removal (Moringa)

Lead was not detected in any of the samples with moringa. The effect of dosage can therefore not be determined since moringa removed all the lead from the synthetic solution.

6.2.2.2.2 Effect of Adsorbent Dosage in Lead removal (Corn husk)

An increase in the adsorbent dosage from 0.1g to 0.3g to 0.5g increased the removal efficiency as shown in Figure 6.14 below.

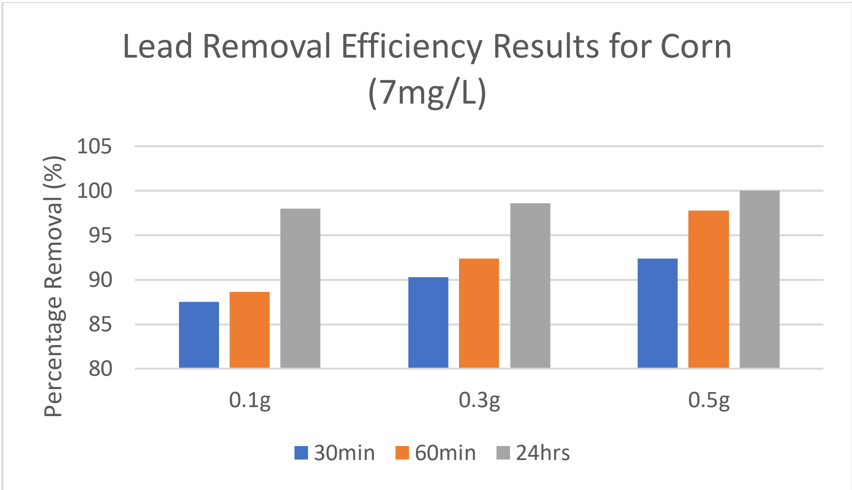


Figure 6.14: Lead Removal Efficiency Results for Corn (7mg/L) (Present Study)

6.2.2.2.3 Effect of Adsorbent Dosage in Lead removal (Coconut husk)

Lead was not detected in any of the 0.8mg/L samples with moringa. Varying adsorbent dosage was not explored with 7mg/L samples. The effect of dosage can therefore bot be determined since moringa removed all the lead from the synthetic solution.

6.2.2.3 Effect of Contact time

Effect of contact time on removal efficiency was explored with 30min, 60min and 24hrs contact time for the adsorbents.

6.2.2.3.1. Effect of Contact time in Lead removal (Moringa)

Moringa was able to effectively remove lead from the water for 0.8mg/L and 7mg/L at 30min, 60min and 24hrs. No lead concentration was detected in the samples with moringa seeds.

6.2.2.3.2 Effect of Contact time in Lead removal (Corn husk)

An increase in the contact time from 30min to 60min to 24hrs of 0.5g of adsorbent for corn husk increased the removal efficiency from 92.4% to 97.4% to 100%. This shows that increase in contact time results in improved removal efficiency.

6.2.2.3.3 Effect of Contact time in Lead removal (Coconut husk)

Coconut husk effectively removed lead from the synthetic solution with 0.8mg/L at 30min, 60min and 24hrs and no lead concentration was detected. For 7mg/L concentration, for 30min, 0.5g had a percentage removal of 95.5.5%, 60min had 96.9% and 24hrs had 98% as shown below. This shows that an increase in contact time increased removal efficiency.

6.2.2.4 Discussion (lead)

Moringa seeds significantly removed lead from the synthetic solution. No lead concentration was detected in the samples with moringa for both 0.8mg/L concentration and 7mg/L concentrations. Increased contact time and adsorbent dosage generally increased the removal efficiency. Increased concentration did not improve efficiency for corn husk and coconut husk. This is because the dosage might have to be increased with increased concentration. The higher dosage had a higher removal efficiency.

6.2.3 Arsenic Removal from Water (Batch study)

Moringa seeds, corn husk and coconut husk were used to remove arsenic from the synthetic solution. Table 6.4 shows the results of the tests. It was observed that all three adsorbents were able to remove some arsenic from the solution. Only one concentration (0.5mg/L) was used with two contact times, 30min and 60min.

Table 6.4: Arsenic Removal Efficiency Results (Present Study)

No.	Adsorbent	Weight	Contact time	Initial mg/L	Final mg/L	% Removal Efficiency	Qe(mg/g)	Ce/Qe (g/L)
1.	Moringa	0.1	30	0.5278917	0.159659	69.8	0.2209	0.7226
2.	Moringa	0.1	60	0.5278917	0.15765	70.1	0.2221	0.7097
3.	Moringa	0.3	30	0.5278917	0.154735	70.7	0.0746	2.0733
4.	Moringa	0.3	60	0.5278917	0.146224	72.3	0.0763	1.9156
5.	Moringa	0.5	30	0.5278917	0.157342	70.2	0.0445	3.5385
6.	Moringa	0.5	60	0.5278917	0.151918	71.2	0.0451	3.3672
7.	Corn husk	0.1	30	0.5278917	0.151916	71.2	0.2256	0.6734
8.	Corn husk	0.1	60	0.5278917	0.159697	69.7	0.2209	0.7229
9.	Corn husk	0.3	30	0.5278917	0.159368	69.8	0.0737	2.1622
10.	Corn husk	0.3	60	0.5278917	0.159165	69.8	0.0737	2.1583
11.	Corn husk	0.5	30	0.5278917	0.155498	70.5	0.0447	3.4797
12.	Corn husk	0.5	60	0.5278917	0.147144	72.1	0.0457	3.2205
13.	Coconut husk	0.1	60	0.5278917	0.158125	70.0	0.2219	0.7127
14.	Coconut husk	0.3	60	0.5278917	0.152883	71.0	0.0750	2.0384
15.	Coconut husk	0.5	60	0.5278917	0.15556	70.5	0.0447	3.4817

6.2.3.1 Effect of Adsorbent Dosage in Arsenic removal

Adsorbent dosage of 0.1g, 0.3g and 0.5g were used. The effect of adsorbent dosage on arsenic removal is shown in Figure 6.15 below.

6.2.3.1.1 Effect of Adsorbent Dosage in Arsenic removal (Moringa)

An increase in the adsorbent dose increased removal efficiency from 0.1g to 0.3g but decreased slightly from 0.3g to 0.5g as shown in Figure 6.15 below.

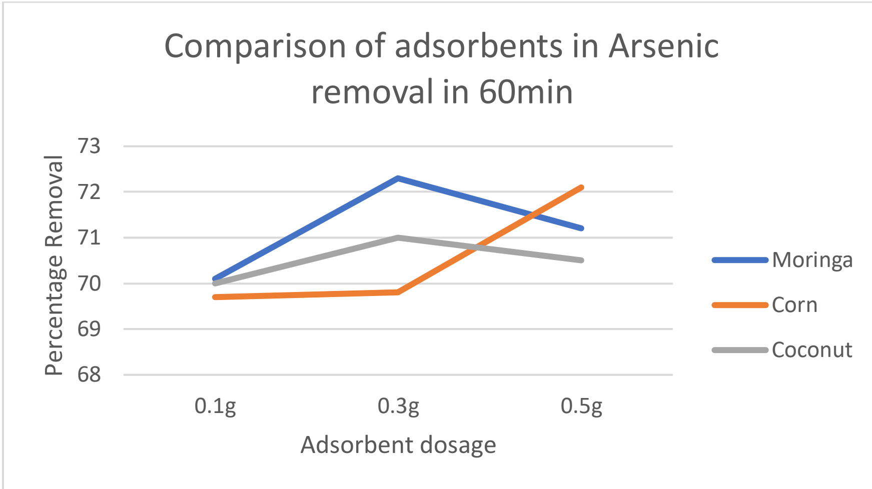


Figure 6.15: Arsenic Removal Efficiency of moringa, corn and coconut in 60 min (Present Study)

6.2.3.1.2 Effect of Adsorbent Dosage in Arsenic removal (Corn husk)

In Figure 6.15, the removal efficiency increased when the dosage increased from 0.1g to 0.3g to 0.5g.

6.2.3.1.3 Effect of Adsorbent Dosage in Arsenic removal (Coconut husk)

An increase in the adsorbent dose increased removal efficiency from 0.1g to 0.3g but decreased slightly from 0.3g to 0.5g similar to Moringa seeds as shown in Figure 6.15.

6.2.3.2 Effect of Contact time

For Arsenic contact time was observed for 30min and 60min.

6.2.3.2.1 Effect of Contact time in Arsenic removal (Moringa)

An increase in contact time generally increased removal efficiency as seen in Table 6.4.

6.2.3.2.2 Effect of Contact time in Arsenic removal (Corn husk)

An increase in contact time generally increased removal efficiency as seen in Table 6.4.

6.2.3.2.3 Effect of Contact time in Arsenic removal (Coconut husk)

An increase in contact time generally increased removal efficiency as seen in Table 6.4.

6.2.3.4 Discussion (Arsenic)

All three adsorbents removed arsenic up between 69% to 72% in 30 to 60min. Moringa seeds and coconut husks were slightly more efficient than the corn husk.

An increase in contact time generally led to an increase in removal efficiency. An increase in adsorbent dosage did not generally lead to an increase in the removal efficiency although the difference was very small.

6.2.4 Heavy metal mix (Lead, Arsenic and Iron)

The heavy metals, lead, arsenic and iron were mixed and 0.3g of adsorbents (moringa and corn were added. Some were put in the orbital shaker and some were done manually using the hand to simulate what can happen in a typical rural community. The samples were mixed to determine if there will be a difference in the adsorption compared to testing the single heavy metals. Lime (fruit) which is acidic and naturally contains citric acid (2-hydroxy-1,2,3-propanetricar-boxylic acid), a weak tricarboxylic acid with a pH of 2.4 (Penniston et al, 2008), was added to some samples to determine the effect of pH change on the adsorption.

Table 6.5: Lead, Iron and Arsenic (Mix) Removal Efficiency Results (Present Study)

No.	**Adsorbent**	**Time**	**Initial (As) mg/L**	**Final (As) mg/L**	**% Removed**	**Initial (Fe) mg/L**	**Final (Fe) mg/L**	**% Removed**	**Initial (Pb) mg/L**	**Final (Pb) mg/L**	**% Removed**
1.	Moringa	30min	0.5279	0.1923	**63.6**	0.1493	<0.005	**100**	0.7952	<0.05	**100**
2.	Moringa (HS)	30min	0.5279	0.2044	**61.3**	0.1493	<0.005	**100**	0.7952	<0.05	**100**
3.	Moringa(Lime)	30min	0.5279	0.2162	**59.1**	0.1493	0.0296	**80.2**	0.7952	<0.05	**100**
4.	Moringa	24hrs	0.5279	0.1922	**63.6**	0.1493	<0.005	**100**	0.7952	<0.05	**100**
5.	Moringa (HS)	24hrs	0.5279	0.1963	**62.8**	0.1493	<0.005	**100**	0.7952	<0.05	**100**
6.	Moringa	30min	0.5279	0.2045	**61.3**	1.9846	<0.005	**100**	0.7952	<0.05	**100**
7.	Moringa (HS)	30min	0.5279	0.2174	**58.8**	1.9846	<0.005	**100**	0.7952	<0.05	**100**
8.	Moringa (Lime)	30min	0.5279	0.2315	**56.2**	1.9846	0.1829	**90.8**	0.7952	<0.05	**100**
9.	Corn (HS)	30min	0.5279	0.2174	**58.8**	0.1493	0.0182	**87.8**	0.7952	<0.05	**100**
10.	Corn (Lime)	30min	0.5279	0.2220	**57.9**	0.1493	0.0244	**83.7**	0.7952	<0.05	**100**
11.	Corn	30min	0.5279	0.2090	**60.4**	0.1493	0.0177	**88.2**	0.7952	<0.05	**100**
12.	Corn (HS)	30min	0.5279	0.1978	**62.5**	1.9846	0.1700	**91.4**	0.7952	<0.05	**100**
13.	Corn (Lime)	30min	0.5279	0.1995	**62.2**	1.9846	0.2703	**86.4**	0.7952	<0.05	**100**
14.	Corn	30min	0.5279	0.1888	**64.2**	1.9846	0.1555	**92.2**	0.7952	<0.05	**100**

6.2.4.1 Effect of pH change

The addition of lime to the samples generally reduced the adsorption removal efficiency compared to the samples without the lime addition including those shaken by hand. This indicates that a change in pH affected the removal efficiency. Lead removal was not affected by the change in pH.

6.2.4.2 Discussion (Mix)

0.3g of Moringa and coconut husk totally removed lead when the samples were placed in an orbital shaker, shaken by hand and also when lime (fruit) was added. 0.3g of Moringa was able to totally remove the iron from the mix except for the samples that had lime. This shows that change in pH (to acidic conditions) affects the removal of iron and arsenic using moringa seeds. Lead removal was not affected by the change in the pH.

0.3g of Corn was efficient but unable to totally remove iron from the solution. The removal efficiency ranged from 83.7% to 92.2% as shown in Figures 6.16 and 6.17. The samples containing lime had the lowest removal efficiency. The samples shaken in the orbital shaker had the highest efficiency but was almost the same as the one shaken by hand.

0.3g of Moringa and 0.3g of Corn husk were unable to totally remove Arsenic from the water. The removal efficiency ranged from 56.2% to 64.2% as shown in Figures 6.16 and 6.17.

The removal efficiency was lower with corn husk compared to Moringa seeds for Arsenic removal. Lead was totally removed by both Moringa seeds and corn husks.

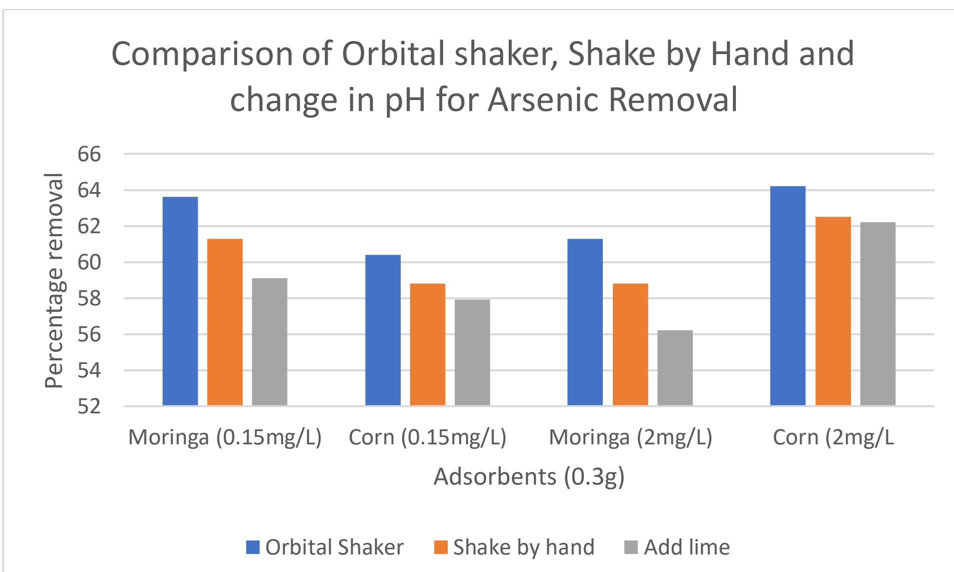


Figure 6.16: Comparison of Orbital shaker, Shake by Hand and change in pH for Arsenic Removal (Present Study)

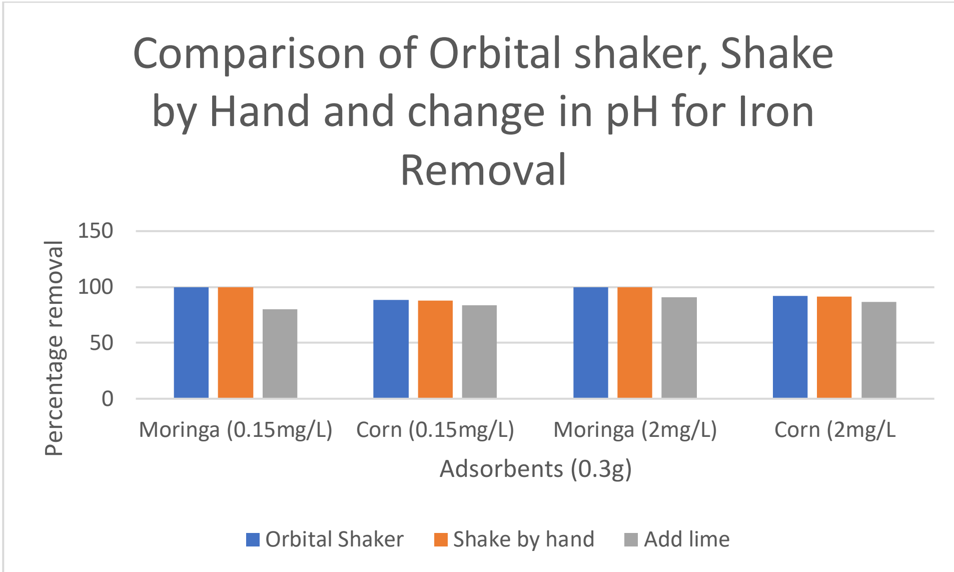


Figure 6.17: Comparison of Orbital shaker, Shake by Hand and change in pH for Iron Removal (Present Study)

6.2.5 Adsorption Isotherm

Adsorption of Fe, Pb, and As by Moringa seeds, Corn husk and Coconut husk were modelled using the Langmuir and Freundlich isotherms with the quality of the fit assessed using the coefficient of determination (R^2).

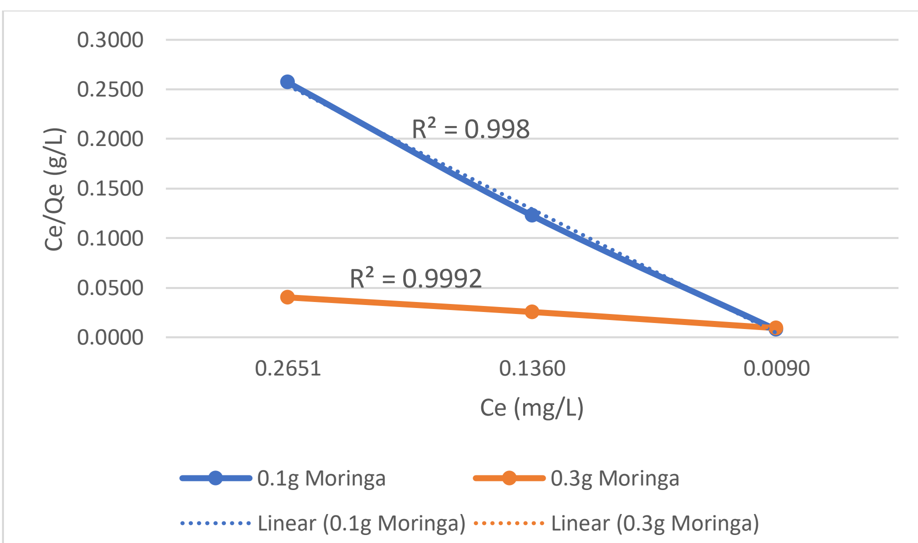


Figure 6.18:Langmuir isotherm for Moringa seeds (Present Study)

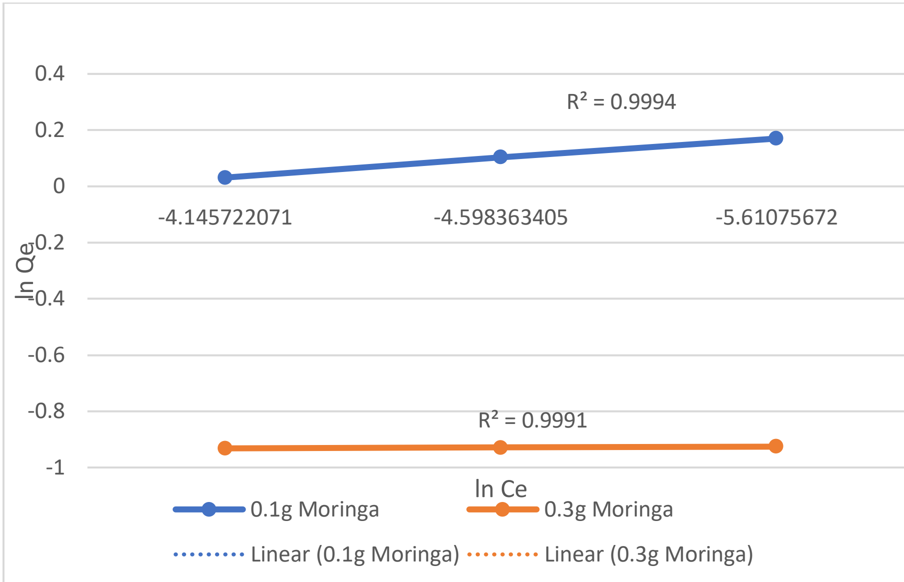


Figure 6.19: Freundlich isotherms for Moringa seeds (Present Study)

The difference between the R^2 values (0.998 and 0.999) and (0.9991 and 0.9992) from both models (Langmuir and Freundlich) were insignificant when adsorption of iron by Moringa seeds was considered. This suggests that there is a possibility that there is a possible existence of more than one type of adsorption site interacting with the metal.

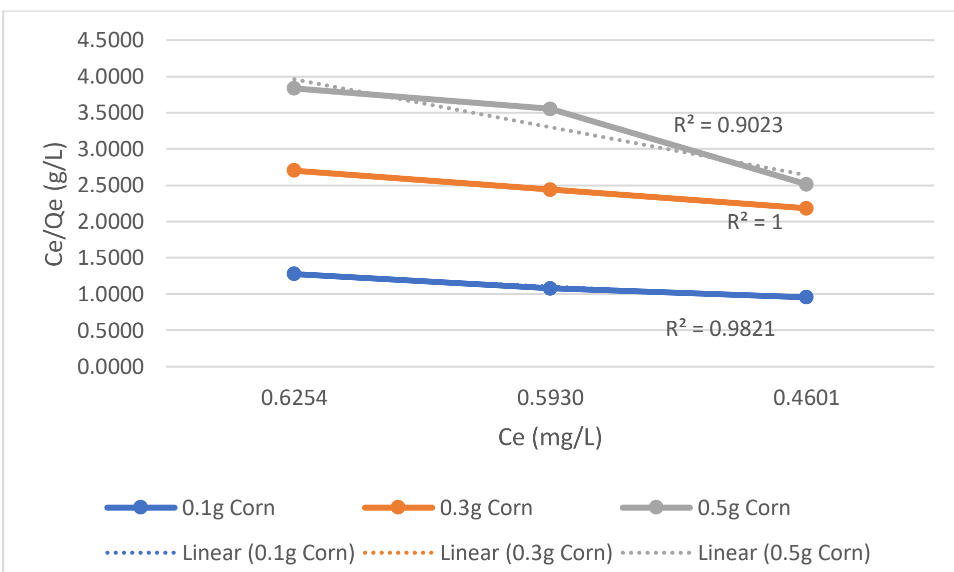


Figure 6.20: Langmuir isotherm for Corn husk (Present Study)

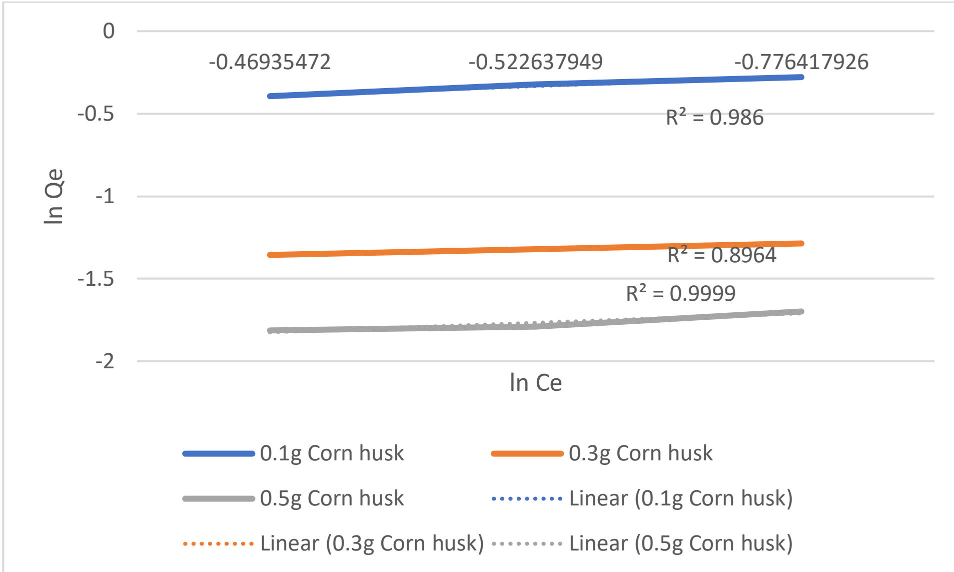


Figure 6.21: Freundlich isotherms for Corn husk (Present Study)

The difference between the R^2 values from both models (Langmuir and Freundlich) were insignificant when adsorption of iron by Corn husk was considered. This suggests that there is a possibility that there is a possible existence of more than one type of adsorption site interacting with the metal.

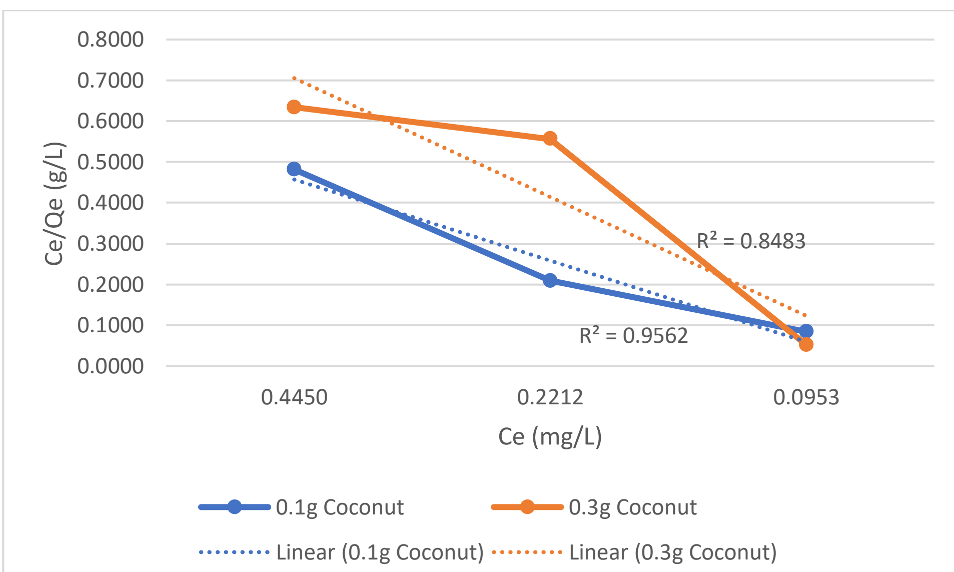


Figure 6.22: Langmuir isotherm for Coconut husk (Present Study)

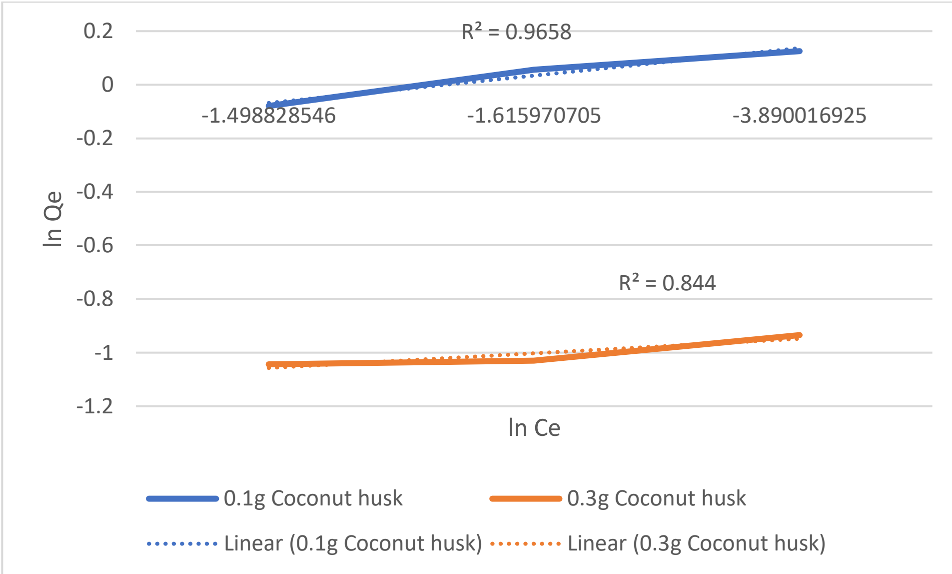


Figure 6.23: Freundlich isotherms for Coconut Husk (Present Study)

The difference between the R^2 values (0.844 and 0.848) and (0.9562 and 0.9658) from both models (Langmuir and Freundlich) were insignificant when adsorption of iron by Coconut husk was considered. This suggests that there is a possibility that there is a possible existence of more than one type of adsorption site interacting with the metal.

6.2.5 Results conclusion (batch test)

Moringa seeds were the most effective in removing iron, lead and arsenic from the synthetic solution, followed by coconut husk and the corn husk. Moringa seeds are therefore effective adsorbents as well as coagulants. The column study was therefore carried out with moringa seeds for iron removal because moringa seeds were the most effective and iron had the highest concentration in the samples from the Birim Basin. The moringa seeds were compacted on glass balls in the column. The characteristics of the three adsorbents are reviewed after the column study. Moringa seeds were still most effective when the three metals were mixed in one solution.

6.3 Column Study (Iron Removal)

The batch study results predict the effectiveness of the adsorbent but the column experiment is needed to make the study more representative. Flow rate and bed depth need to be determined. The diameter of the column was 105mm.

Table 6.6: Column study Results (Present Study)

No.	depth	Time (min)	Initial Vol. (ml)	Final Vol. (ml)	Initial Conc. mg/L	Final Conc. mg/L	% Removal	Flow rate (ml/min)	Av. Flowrate (ml/min)
1.	5mm	15	500	100	0.1493	0.0277	81.48		
2.	5mm	30	500	48	0.1493	0.0257	82.78	3.69	
3.	5mm	45	500	50	0.1493	0.0186	87.54	3.33	
4.	5mm	60	500	40	0.1493	<0.005	100	2.6	
5.	5mm	75	500	40	0.1493	<0.005	100	2.6	
6.	5mm	Final (3hrs 8 min)	500	200 (Total=473)	0.1493	<0.005	100		**3.1**
7.	12.5mm	15	500	90	0.1493	0.1132	24.18		
8.	12.5mm	30	500	80	0.1493	<0.005	100	5.3	
9.	12.5mm	45	500	80	0.1493	<0.005	100	5.3	
10.	12.5mm	60	500	70	0.1493	<0.005	100	4.6	
11.	12.5mm	Final (1hr 28min)	500	100 (Total=420)	0.1493	<0.005	100		**5.07**
12.	10mm	15	500	98	0.1493	0.0672	54.99		
13.	10mm	30	500	60	0.1493	0.0501	66.48	4	
14.	10mm	45	500	47	0.1493	0.0123	91.76	3.1	
15.	10mm	60	500	50	0.1493	<0.005	100	3.3	
16.	10mm	Final (2hrs 50min)	500	165 (Total=420)	0.1493	<0.005	100		**3.5**
17.	10mm	15	1000	130	1.9846	0.0839	95.77		
18.	10mm	30	1000	80	1.9846	<0.005	100	5.3	
19.	10mm	45	1000	70	1.9846	<0.005	100	4.7	
20.	10mm	60	1000	100	1.9846	<0.005	100	6.7	
21.	10mm	Final (2hrs 19min)	1000	570 (Total=950)	1.9846	<0.005	100		**5.6**
22.	10mm	15	500	95	1.9846	0.1009	94.91		
23.	10mm	30	500	60	1.9846	0.0205	98.97	4	
24.	10mm	45	500	50	1.9846	<0.005	100	3.3	
25.	10mm	60	500	60	1.9846	<0.005	100	4	
26.	10mm	Final (2hrs 58min)	500	163 (Total=428)	1.9846	<0.005	100		**3.8**
27.	5mm	15	500	100	1.9846	0.9631	51.47		
28.	5mm	30	500	45	1.9846	0.6620	66.64	3	
29.	5mm	45	500	48	1.9846	0.4837	75.63	3.2	
30.	5mm	60	500	40	1.9846	0.293	85.24	2.7	
31.	5mm	Final (3hrs 13min)	500	237 (Total=470)	1.9846	0.0559	97.18		**3.0**

No.	depth	Time (min)	Initial Vol. (ml)	Final Vol. (ml)	Initial Conc. mg/L	Final Conc. mg/L	% Removal	Flow rate (ml/min)	Av. Flowrate (ml/min)
32.	12.5mm	15	500	90	1.9846	0.2591	86.95		
33.	12.5mm	30	500	90	1.9846	0.1343	93.23	6	
34.	12.5mm	45	500	80	1.9846	0.0212	98.93	5.3	
35.	12.5mm	60	500	80	1.9846	0.0458	97.70	5.3	
36.	12.5mm	Final (1hr 22min)	500	70 (Total=410)	1.9846	<0.005	100		5.53

6.3.1 Depth of Adsorbent in the Column

Three column depths, 5mm, 10mm and 15mm were used for this column study. Moringa was able to remove iron from the synthetic solution. The results are captured below.

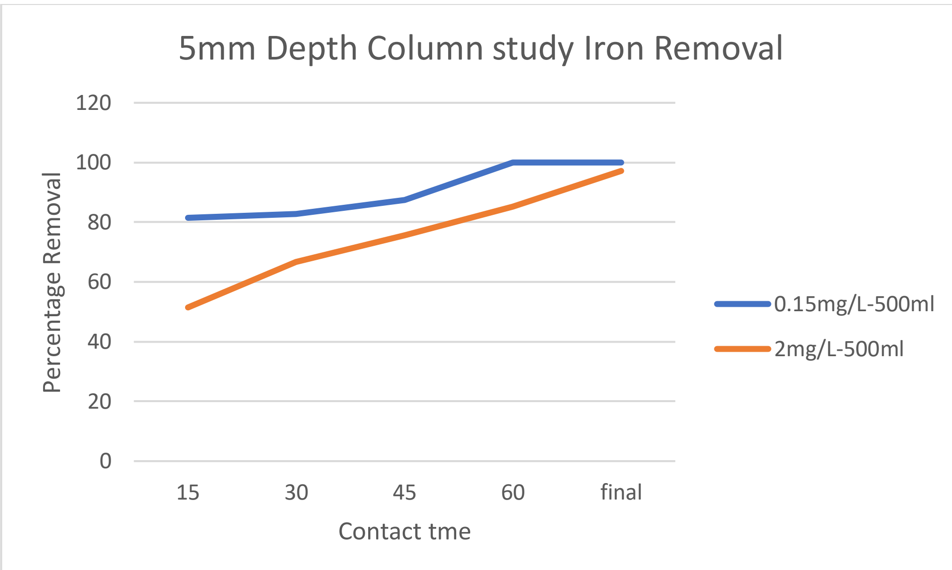


Figure 6.24: 5mm Depth Column study Iron Removal (Present Study)

For the 5mm depth, the removal efficiency was higher for the lower concentration compared to the higher one although iron was effectively removed from both. After 60min, iron was not detected in the solution for the 0.15mg/L concentration but 2mg/L had a removal percentage of 85.24%.

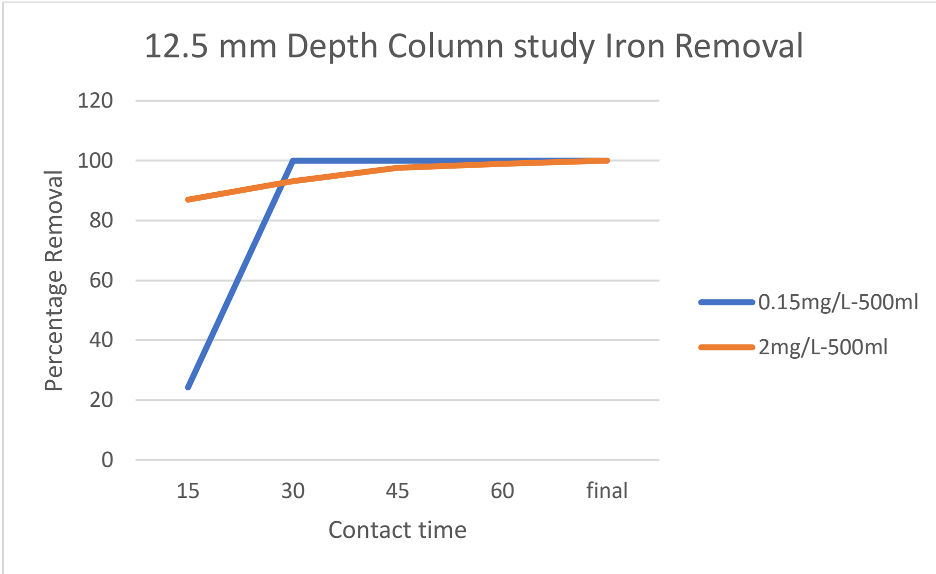


Figure 6.25: 12.5 mm Depth Column study Iron Removal (Present Study)

For the 12.5mm depth, iron was effectively removed from the water. In 30 min, iron concentration could not be detected in the 0.15mg/L solution but the 2mg/L solution had a removal percentage of 93.23%.

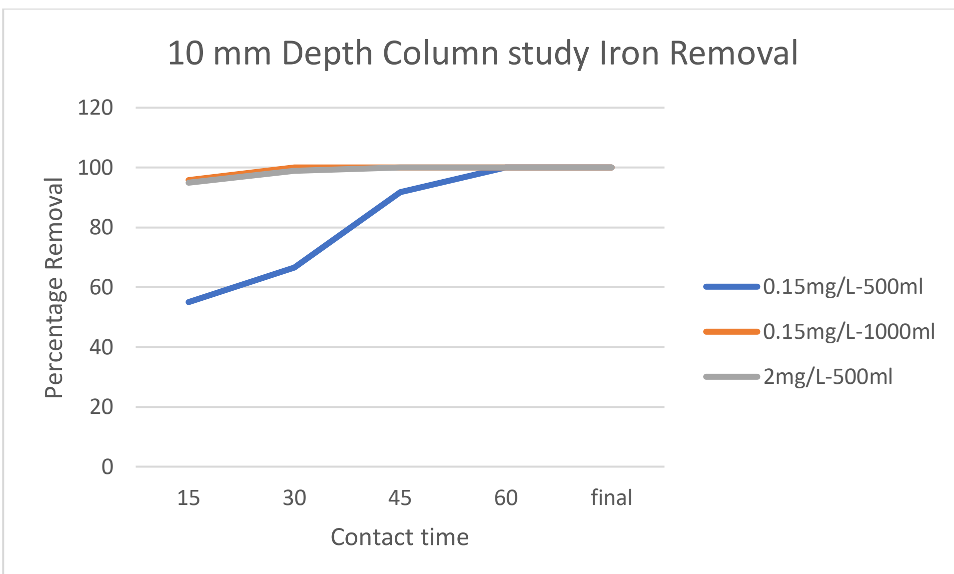


Figure 6.26: 10 mm Depth Column study Iron Removal (Present Study)

For the 10mm depth, in 30min iron could not be detected in the 2mg/L solution but 0.15mg/L had removal efficiency of 82.78%.

6.3.2 Volume of solution in Column

An increase in the volume of water in the column, increased the removal efficiency. This is because of the pressure head which exerts pressure on the base of the column and thus increasing the flow rate.

6.3.3 Flow rate in Column

The flow rate was determined by dividing the effluent volume by the time. The volume for the first 15min was not considered because the researcher believes hand pouring the synthetic solution in the middle can affect the initial effluent but as the system settles after a few minutes, the actual flow rate can be captured.

The flow rate was highest for the 10mm depth with 1000ml volume (5.6ml/min), followed by the 12.5mm depth with 500ml (5.07 to 5.53ml/min), then the 10mm depth with 500ml (3.5 to 3.8ml/min) and lastly the 5mm depth. (3 to 3.1ml/min). This is because the 1000ml in the 10mm depth had more pressure head which exerted pressure on the base of the column compared to the others.

6.3.4 Discussion of Column Study

The 5mm depth was the least effective in removing the iron from the synthetic water. The 12.5mm was effective in totally removing iron from solution with a flow rate of about 5.6mL/min but the 10mm depth with increased volume of water (1000ml) had a similar removal efficiency and flowrate with a reduced amount of Moringa. The 10mm depth with 500ml of water was not as effective and efficient as the 10mm depth with 1000ml. The 10mm depth column with increased volume is recommended because it was more efficient compared to the other depths.

6.3.5 Implication of Batch and Column Study Results

The concentration of heavy metals in the batch test was higher than what was detected in most of the samples except for iron which exceeded in about three samples. Moringa seeds will still significantly remove iron from the contaminated water.

Locally available seeds such as Moringa, corn husk and coconut husk were used for water purification. The results from the batch study and column study show that Moringa seeds with shell were much more effective in water purification in terms of adsorption of heavy metals.

Moringa seeds will therefore improve the quality of drinking water in the mining communities and provide significant benefits to the health of inhabitants of rural communities. The use of local Moringa seeds as primary coagulants is important in rural communities in developing countries where the purchase of other chemicals for water treatment can be expensive.

6.4 Moringa seeds

The *Moringa Oleifera* seeds are three-angled, globular shaped seeds, about 1 cm in diameter and with an average weight of about 0.3 g and 3-winged with wings produced at the base of the seed to the apex 2–2.5 cm long, 0.4–0.7 cm wide (Leone et al, 2016). *Moringa Oleifera* seeds are a good source of proteins and lipids (Saa et al, 2019). Sajudi et al (2005) in their research using Moringa Oleifera ram press cake in removing lead, iron and cadmium, observed a removal efficiency ranging from 70.86+2.22% to 89.40+0.00% for lead, 66.33+3.38% to 92.14+0.00% for iron and 44.95+3.95% to 47.73+6.38% for cadmium. Pramanik et al (2016), in their research, observed that the removal efficiency for arsenic and iron was 63% and 58% respectively using alum, and 47% and 41% respectively using Moringa oleifera with an initial dose of 5mg/L.

Shan et al. (2016) in their research on treatment using *Moringa Oleifera* seeds for both wastewater and river water observed that the seeds reduced and prevented bacterial growth. These authors observed turbidity reductions of 85-94% and Dissolved Oxygen was improved from 2.58+0.01 to 4.00+0.00%. Chemical and oxygen demand and Biological Oxygen demand were increased from 99.5+0.71 to 164+2.83 for COD and 48.0+0.42 to 76.65+2.33mg/L for BOD. They also observed no significant changes in pH, conductivity, salinity and total dissolved solids after treatment. Copper and Cadmium were successfully removed by up to 98%.

To find a cost-effective solution for the affected rural communities and the researcher decided to include the shell of the *Moringa Oleifera* seeds to determine if it could improve its efficiency without adding other chemicals or altering the pH to create a simple solution for the inhabitants of the affected communities.

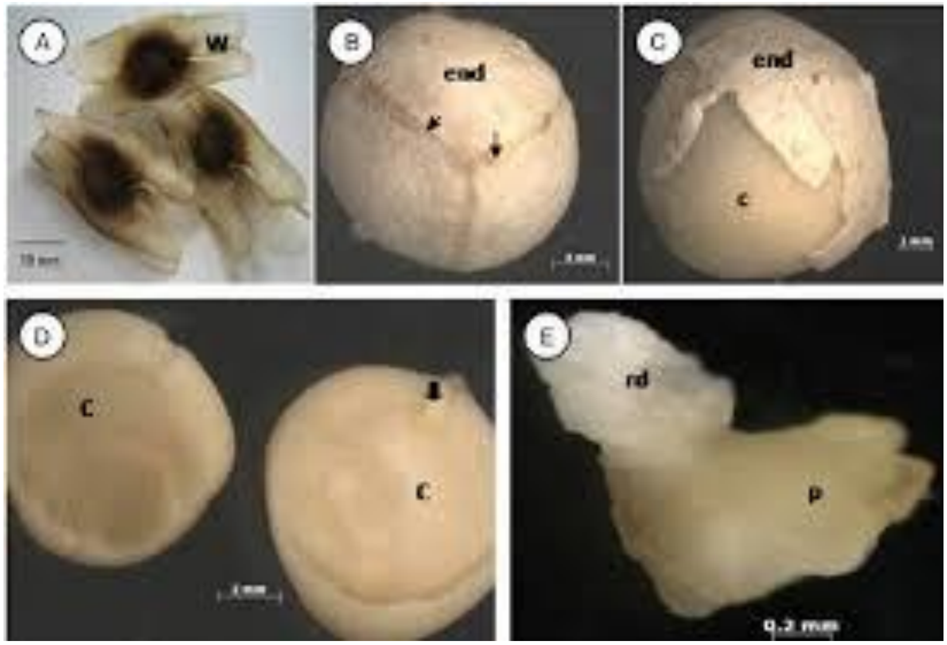


Figure 6.27: Moringa seed morphology. Source: Fortoup et al (2015)

(A) Seed with seed coat and wings. (B) Seed with internal seed coat and vascular bundle. (C) Seed with partially removed internal seed coat. (D) Separated cotyledon. (E) Embryo axis. Wing (w), vascular bundle (arrowhead), cotyledon (c), endotesta (end), embryonic axis (black arrow), radical (rd), plumule (p).

6.4.1 The Moringa plant

Moringa Oleifera is a fast-growing softwood with about 13 species (Saa et al, 2019). Moringa is mainly found in the Asia, Middle East and Africa but, it is spreading to other tropical and subtropical areas due to its adaptability (Anwar et al, 2007).

The rapid growth of moringa trees even under prolonged drought conditions, makes this plant a reliable resource to improve the nutritional status of local populations (Leone et al, 2016). Various parts of the tree have so many benefits. Moringa flowers, roots, leaves, seed, fruit, bark and immature pods are used as anti-diabetic, anti-ulcer, cardiac, circulatory stimulants amongst others (Anwar et al, 2007).

Fig. 6:28 and 6.29 below shows the benefit of the moringa tree and the key nutrients obtained from it.

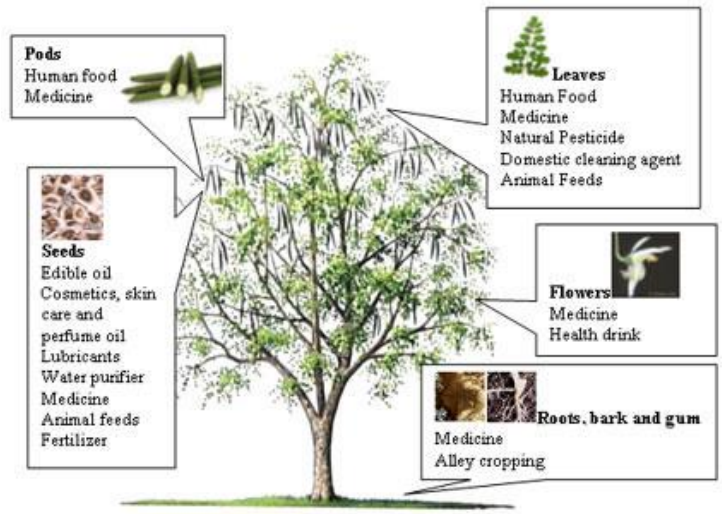


Figure 6.28: The benefits of the Moringa tree.   (Source: moringathemiraclecure.weebly.com)

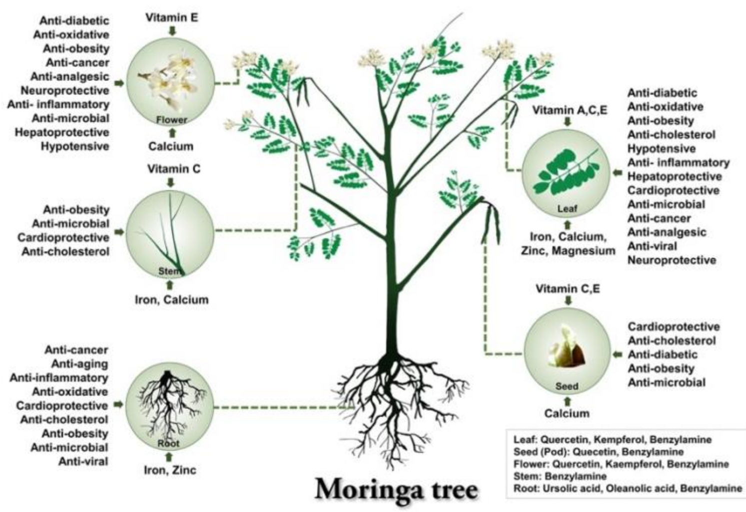


Figure 6.29: Key nutrients and medicinal values. (Source: phys.org. (2019). Credit: Mr. Mohammed Shafi)

6.4.2 Characteristics of Moringa Oliefera seeds

Araujo et al (2010) evaluated the morphological characteristics as well as the chemical composition of *Moringa Oliefera* using Fourier Transform Infrared (FT-IR) spectroscopy, Thermogravimetric Analysis (TGA), X-Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM).

6.4.2.1 Fourier Transform Infrared (FTIR) spectroscopy

Fourier Transform Infrared (FTIR) spectroscopy, was used to detect the specific functional groups, which gives insight into the sorption capability of Moringa seed powder and the nature of charge which provides knowledge about the charge concerning coagulation (Kumar et al, 2016). Araujo et al (2010) stated the spectra of the functional group appeared predominantly in the protein and fatty acid structures present in Moringa seeds. They noted it showed a broad band centred at 3,420 cm^{-1} assigned to O-H stretching. They added that there was also N-H stretching of amide groups and the peaks at 2,923 cm^{21} and 2,852 cm^{-1} were assigned to symmetrical and asymmetrical stretching of the C-H of CH_2 group present in fatty acids. They observed in the region between 1,800 and 1,600cm^{-1} that there were three intense bands assigned to C-O bond stretching and the carbonyl group which was present in the fatty acid and protein structures and this case, the spectra showed two bands at 1,740 and 1,715 cm^{-1} associated with fatty acids and a band at 1,658 cm^{-1} associated with the amide group in the protein. They suggested the presence of a peak at 1,587 cm^{-1} can be assigned to C-N stretching and/or N-H deformation and the presence of this band confirmed the protein structure in the Moringa seeds.

According to Kumar et al (2016), the interpretation of infrared spectra involves the correlation of absorption bands in the spectrum of an unknown compound with the known absorption frequencies for types of bonds. In their research, a total of 19 peaks were observed in the spectra, indicating a variety of functional groups within the range. They noted that several bands could be distinguished in the region of 4,000–1,000cm^{-1} and the moderately intense band at 3,317.93cm^{-1} indicated alkynes C–H stretch while the band at 1,161.9cm^{-1} showed either C–N stretch or O–CN stretch and the intense peak at 1,746.23cm^{-1} indicated either alkyl carbonate or ester stretch. They stated that the peak at 1,234.22cm^{-1} indicated amines stretch while the ones at 476.33 cm^{-1} and 466.689 cm^{-1} indicated the presence of polysulfide (Araujo et al, 2010; Kumar et al, 2016).

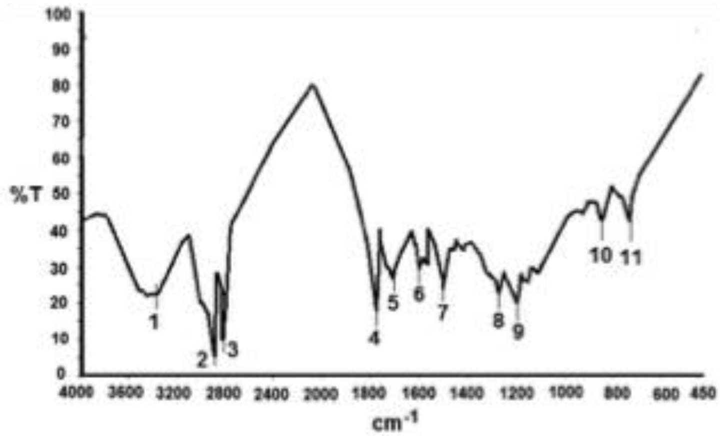


Figure 6.30: FT-IR spectra of M. oleifera seed powder
Source: Kumar et al (2016)

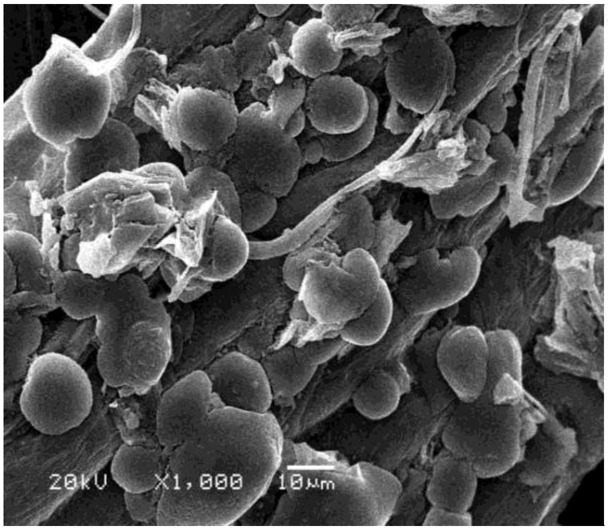
6.4.2.2 X-Ray Diffraction

X-ray diffraction (XRD) is a rapid analytical technique mainly used for phase identification of a crystalline material and provides information on unit cell dimensions (Dutrow and Clark, 2020). According to Araujo et al (2010), a poorly resolved peak that indicates a prevalence of amorphous material was observed in the X-ray pattern for moringa. They also observed a heterogeneous and complex matrix with numerous substances, including lipids and proteins, and to a lesser extent carbohydrates and ash. They suggested the non-shelled moringa seeds that were used influenced this behaviour.

6.4.2.3 Scanning Electron Microscopy (SEM).

The scanning electron microscope (SEM) generates a variety of signals at the surface of solid specimens using focused beam of high-energy electrons (Swapp, 2020).

According to Araujo et al (2010), the morphology of the moringa seeds presented a heterogeneous and relatively porous matrix. They added the moringa structure enables the processes of ion adsorption, due to the interstices and the protein component of the seed. In their research, Kumar et al (2016) observed that the moringa seeds had small pores around the edges, indicating the possibility of sorption with a surface that was irregular and rough at some places but smooth at other places. Araujo et al (2010) opined moringa seeds have an adequate morphological profile for the retention of metal ions such as Cd (II), Pb (II), Co (II), Cu (II) and Ag (I). The researchers concluded that moringa seeds have an adequate morphological profile for retaining metal ions (Kumar et al, 2016; Araujo et al, 2010).



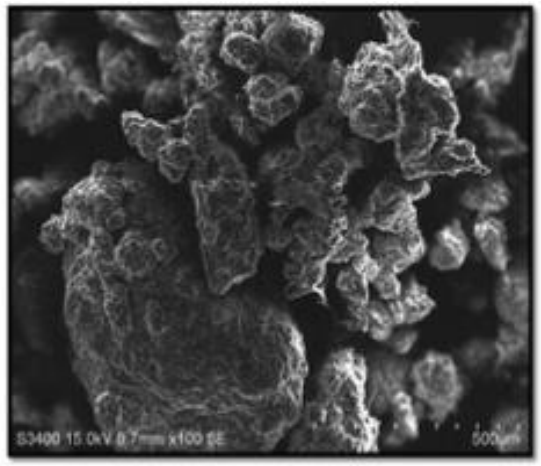


Figure 6.31: SEM for Moringa Oleifera seeds *Source: Kumar et al (2015)*

6.5 Corn Husk

Corn husks are the outer covering on a cob of corn which is usually discarded although, in some cultures, it is used to wrap food for steaming such as kenkey in Ghana.

6.5.1 The Corn plant

The corn plant has large narrow leaves and is spaced alternately on opposite sides of the stem. It is exceptionally easy to grow and has some resilience. Corn (*Zea Mays)* is widely used all over the world as human food, feed for livestock, fuel and as a raw material in some industries and it is a staple food in many places.

Figure 6.32: Corn plant. *Source: zhaojiankangphoto*

6.5.2 Characteristics of Corn Husk

The corn husk is the fibrous covering over the corn cob. It is usually green whilst on the stalk as shown in Figure 6.33 but it turns yellowish-brown when peeled off and dried in the sun.

6.5.2.1 Fourier Transform Infrared (FT-IR) spectroscopy

FTIR technique is an important tool to identify some characteristics of functional groups, which are capable of adsorbing metal ions and at the same time instrumental in the adsorption process. According to Batagarawa, and Ajibola (2019), the most important constituent of agricultural waste which includes corn husks are carbohydrates; therefore, the functional groups of choice are C=O and OH.

6.5.2.2 X-Ray Diffraction

According to Mendes et al (2015), in biomass, cellulose is considered the only component responsible for the crystalline contribution, whereas hemicellulose and lignin are amorphous parts although cellulose has a portion of imperfect crystallites that also contributes to the amorphous content in lignocellulosic biomass.

They noted that despite the low resolution of the XRD diffraction spectra, the crystallinity index of corn husk could be determined, resulting in a mean interval of 21- 26% and, the interval of the crystallinity index was lower than the confidence intervals of cellulose content in the lignocellulosic biomass. They stated that the chemical composition of corn husk comprised 34-41% hemicellulose, 31-39% cellulose, 2- 14% lignin, 3-7% ash, 10-18% extractives and water-soluble components. They added the corn husk crystallinity was 21-26% and the maximum safe temperature was 187 ^{O}C, which can restrict its use in some applications.

6.5.2.3 Scanning Electron Microscopy (SEM).

According to Mendes et al (2015), the SEM images of the corn husk confirm that corn husk fibre has an irregular cross-section, a non-uniform surface, a significant number of short microfibrils, lumens (vessel structures) and some impurities on the surface, which are normal for raw natural fibres. They noted that the amount and the size of lumens, which are correlated to the voids in the structure, affect the fibre tensile behaviour and the longitudinal section of corn husk fibres, showed three ribs on the adaxial surface (white asterisks) and a large number of microfibrils randomly distributed (white arrows) as shown in Figure 6.34. below.

They added that the opposite longitudinal corn husk view showed part of the adaxial surface with some visible microfibrils (white arrows), but mainly the abaxial surface (white circle) and some stomata (white arrowhead). They concluded the longitudinal and transverse surface morphology of corn husk fibre showed the presence of a large number of microfibrils on the adaxial surface.

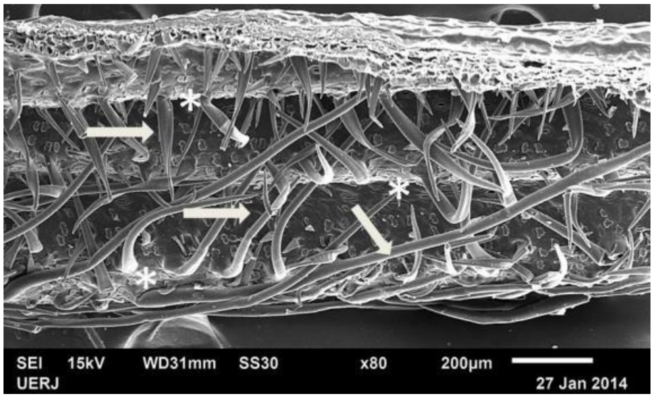
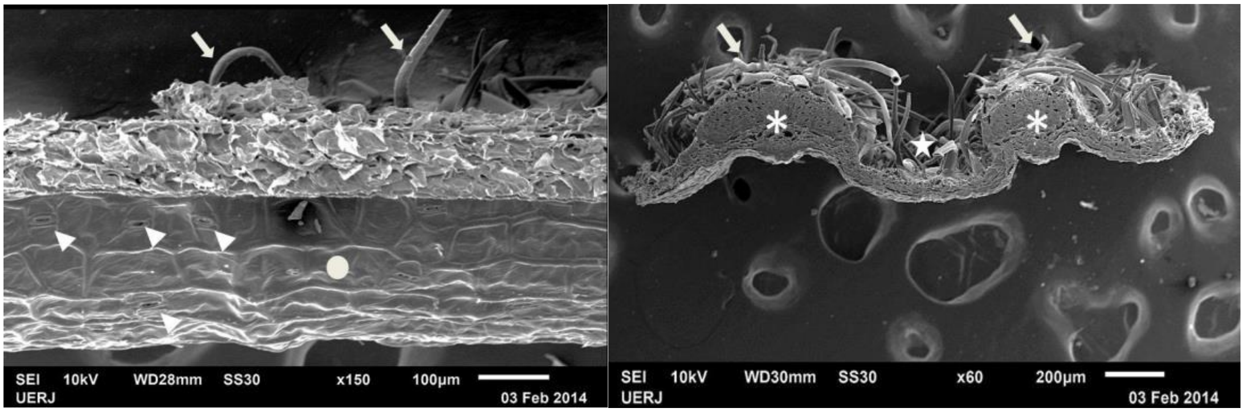


Figure 6.33: Adaxial SEM morphology of longitudinally cut corn husk fiber (x80 magnification)
Source: Mendes et al (2015)



(a) (b)

Figure 6.34: (a)Abaxial SEM morphology of longitudinally and (b) SEM morphology of transversely cut corn husk fiber. Source: Mendes et al (2015)

Batagarawa and Ajibola (2019) in their research used Scanning Election Microscopy (SEM) to characterize the microstructure of carbonized corn husks before and after adsorption. Their resulting image for the carbonized corn husk showed partially developed honeycomb-like and highly defined pores which indicated that carbonization influenced the topographical characteristics of the adsorbents. According to their research, before metal uptake for both carbonized and uncarbonized corn husks, the images revealed that the external surface was full of cavities, roughly characterized by an irregular heterogeneous surface which suggested that uncarbonized corn husk show a high surface area, however, the carbonized corn husk has more distinguished pores than that of uncarbonized corn cob which indicates that it will have more surface area than uncarbonized corn cob, and the large surface area is expected to increase the rate of adsorption. They concluded that the absence of some pores and the lighter surface of the adsorbents after metal ion adsorption suggested that, metal ions adsorption had taken place.

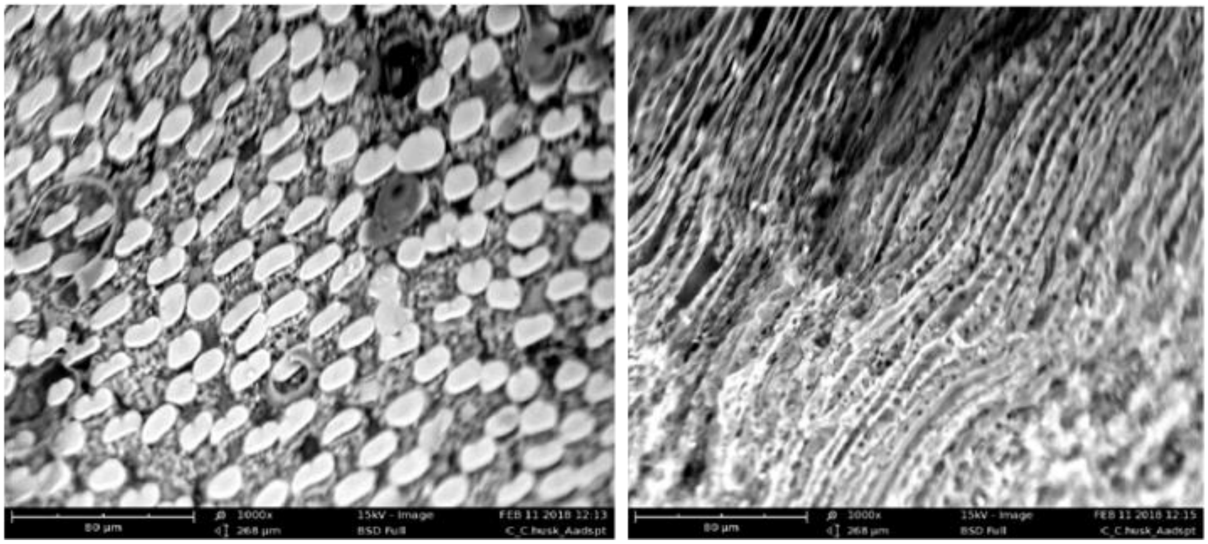


Figure 6.35: Carbonized Corn Husk (a) before adsorption and (b) after adsorption. Source: Batagarawa, and Ajibola (2019)

Regarding density, the interval for the mean obtained for corn husk was 1270 kg/m^3(Mendes et al, 2015). They also noted the equilibrium moisture content of corn husk residue is also following the value reported in the literature (9 wt%). From the above, it can be concluded that the corn husk is lignocellulosic biomass with low content of lignin and similar amounts of hemicellulose and cellulose.

Based on the above information on the characteristics of the corn husk, one can conclude that corn husk is generally a good adsorbent for metal ions. Although carbonized corn husk is a better adsorbent based on the above characteristics, for this research, the raw corn husk was used for easier processing for inhabitants of the rural communities in mining-affected areas.

6.6 Coconut Husk fibre

Coconut fiber (*Cocos Nucifera*) which is part of the husk called coir is composed mainly of cellulose, lignin and hemicellulose (Arsyad et al, 2015).

6.6.1 The Coconut tree

The coconut tree which grows in the subtropical coastal regions is a member of the palm tree family. It has often grown in places that are difficult to use for other crops and it bears fruit all year round. Coconut is of great importance and has many uses such as food, oil, building material, fuel etc. Coconuts are rich in nutrients and minerals and can be stored for a period without deteriorating. The fruit consists of thin hard skin on the outside, a thicker fibrous layer, the hard shell, the white kernel and a large cavity filled with watery liquid (coconut water).

6.6.2 Characteristics of Coconut Husk

6.6.2.1 Fourier Transform Infrared (FT-IR) spectroscopy

The lignin content in coconut fibers is very high. The lignin is a macro-molecule polyphenolic compound whilst cellulose and hemicellulose are polysaccharide compound (Arsyad et al, 2015).

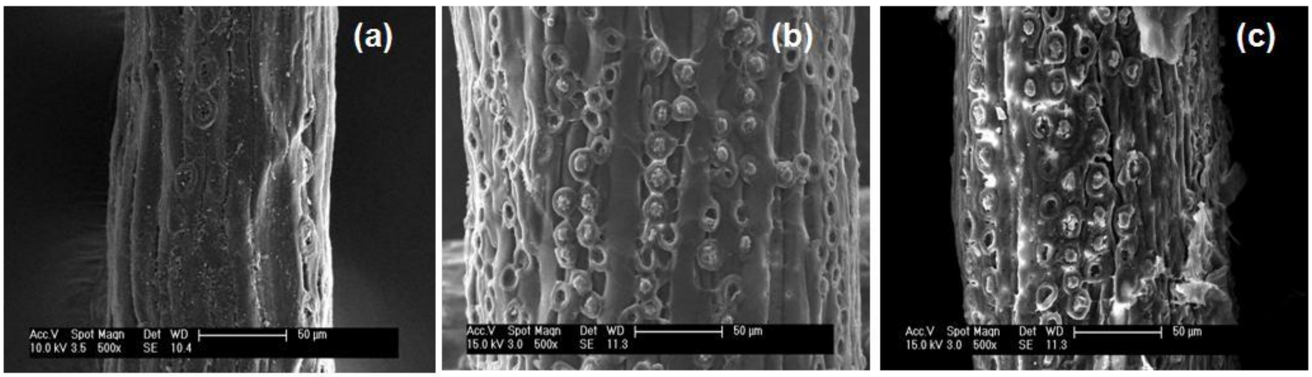


Figure 6.36: SEM micrographs of the RCF (a), TCF 1 (b) and TCF 2 (c) source: Fonseca et al (2015)

6.6.2.2 X Ray Diffraction

Fonseca et al (2015) in their research sought to assess the capability of coconut fibre in removing heavy metals from aqueous solutions. They assessed the characteristics of raw coconut fiber (RCF) as well as treated coconut fibers with 1.5g (TCF 1) and 8 g (TCF 2) of H_2O_2 at 60^{o}C. They carried out X-ray diffraction analyses were performed in the RCF, TCF 1 and TCF 2 in order to characterize the crystalline structure of each fiber, as shown in Figure 6.38 below.

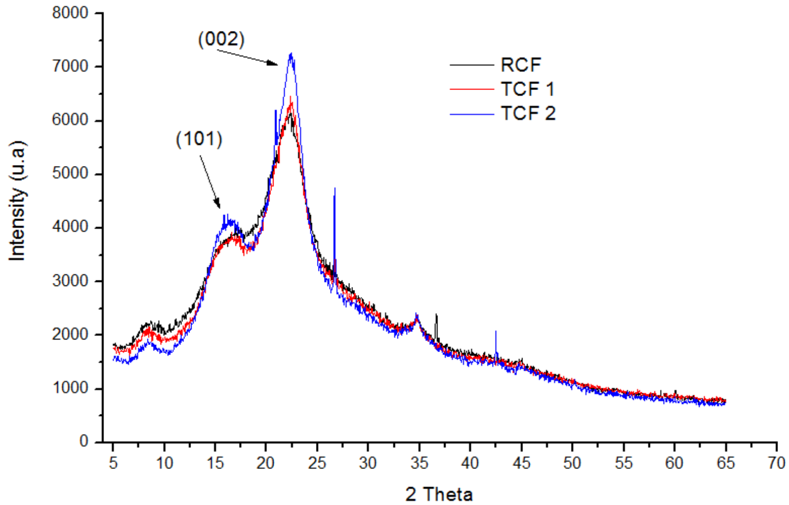


Figure 6.37: X ray diffraction patterns of the raw coconut fiber (RCF) and treated coconut fibers (TCF 1 and TCF 2). Source: Fonseca et al (2015)

Their results indicated that the crystallinity index of raw coconut fibre (RCF) was 39% which they believe is in line with existing literature and that of the treated coconut fibre was 46% for TCF 1 and 56% for TCF 2. These results indicate that the processing conditions of the oxidative treatment can affect the crystallinity of the material.

6.6.2.3 Scanning Electron Microscope

Fonseca et al (2015) observed coconut fibre that had been treated with hydrogen peroxide had more pores than the raw coconut fibre, although the raw coconut fibres also have an adequate number of pores. They noted that the increased porosity was due to the oxidation process of the fibre's components (lignin and hemicelluloses) with hydrogen peroxide in basic condition.

The review of the characteristics of Moringa seeds, Corn husk and Coconut husk indicates that all the adsorbents present an open pore structure wherein the pores are interconnected. This indicates they are good adsorbents but further research and investigation was needed to know which of them will be most appropriate for which metal ions. The results from this research indicate that the three adsorbents were effective in removing iron, lead and arsenic from the aqueous solution especially Moringa seeds. There is therefore great potential in the application of these adsorbents especially moringa seeds in drinking water treatment without treatment of the adsorbents, which makes the process economically and technically attractive. Moringa is one of the most important substances that can be used in drinking water purification at low cost and at a low risk to human health and the environment.

6.7 Recommended Treatment System

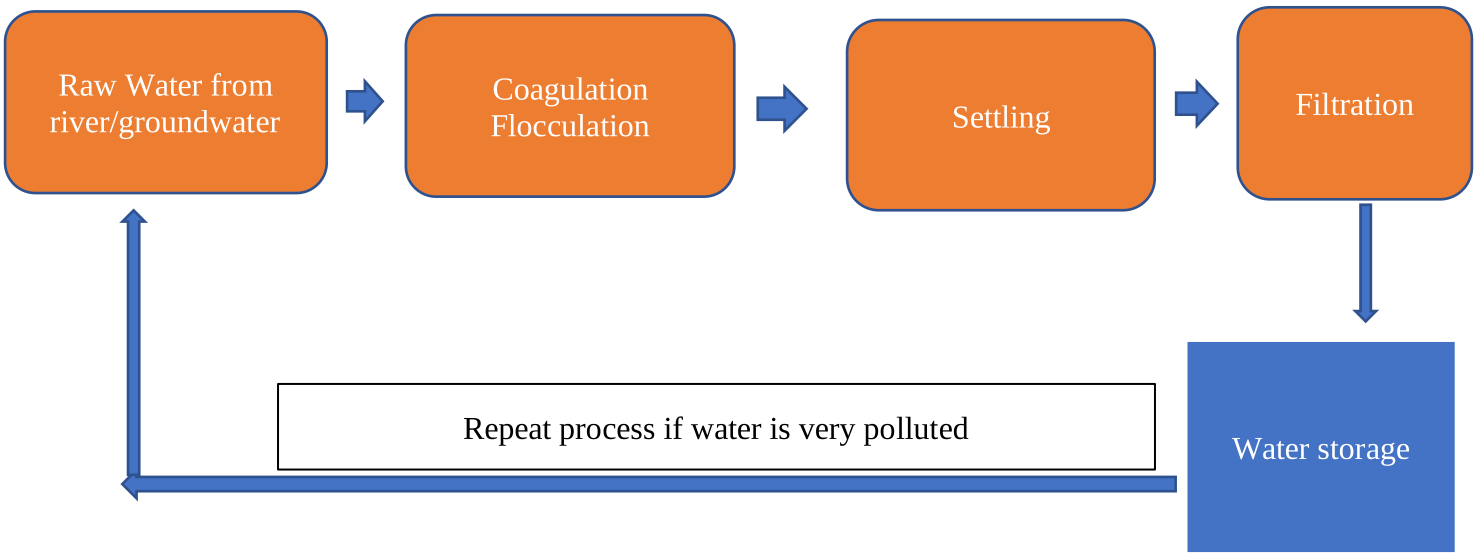


Figure 6.38: Water treatment system

Step One: Obtain Adsorbents/raw water

Obtain Moringa seed pods after it has been allowed to dry naturally on the tree. Sun dry the seeds to ensure they are thoroughly dried and then crush the seeds together with the husk or shell and grind with a stone or pestle in a mortar. (Use corn husk or coconut husk if moringa is not available). Fetch the raw water from the river, tributary or groundwater (water from mine pond is not recommended for this process because it is stagnant water).

Step Two: Coagulation/Flocculation

This step requires the addition of a coagulant. Coagulation can remove organic compounds, suspended precipitates such as heavy metals. Most of the time, aluminium sulphate or ferric sulphate are used as coagulants but the researcher recommends Moringa seeds as the coagulant.

This is because research has shown the moringa seeds are good coagulants. Research conducted by Delelegn et al (2018) showed that treatment of 0.016 g/L of *Moringa Oleifera* decreased water turbidity from 208.3 nephelometric turbidity units (NTU) to 33.66 NTU (83.84%) and from 129

NTU to 16.8 NTU (86.98%) for the Shinta and Angereb river water samples, respectively. They observed that the addition of aluminum sulfate as a coagulant lowered the water pH from 7.2 to 3.66, but in the case of the Moringa seeds the pH remained the same. Sajudi et al (2005) in their research using Moringa Oleifera ram press cake had observed a 99% in wastewater turbidity and 89% reduction in faecal coliform counts without a significant effect on pH or BOD. Vishal et al (2020) also observed removal of about 90-96% of turbidity reduction without a significant effect on pH. Pramanik et al (2016), in their research, observed that the removal efficiency for arsenic and iron was 63% and 58% respectively using alum, and 47% and 41% respectively using Moringa oleifera with an initial dose of 5mg/L. Vishal et al 2020 in their research used Moringa Oleifera seed cakes to remove heavy metals such as chromium, copper, zinc, cobalt and lead from wastewater. The removal efficiency they observed was 79% for lead, 50% for copper and zinc and more than 90% for chromium and cobalt.

Generally, the turbidity of the Birim river was below 300 NTU during the wet season but as high as 869 NTU during the dry season. To simplify the water purification process for the inhabitants of the mining communities, moringa as a coagulant is recommended. Moringa is a natural coagulant and will therefore not negatively affect the other parameters. It can effectively reduce turbidity to WHO limit and reduce the concentration of some heavy metals. This was attributed to the adsorption of these contaminants into the flocs and precipitation of some of these contaminants with precipitates. In this research Moringa seeds removed iron and lead from the water up to 100%.

The ground moringa seeds must be added to the raw water and the mixture must be stirred to ensure it is thoroughly mixed. The positive charge of the coagulant neutralizes the negative charge of suspended and dissolved particles in the water and causes the particles to bind together, a process that is also referred to as flocculation. The floc which is now heavy, settle to the bottom of the container or tank.

Step Three: Settling/Filtration

With settling, the floc settles to the bottom of the container or tank. The water in the container can then be filtered to separate the floc from the treated water. This is done by pouring the water through a porous media such as a clean light-coloured cloth, sand, gravel or charcoal. The pore size of the filter determines the particles it can remove from the water. The water can be poured through a strainer or sieve covered with a clean cloth into a clean bottle or container.

Step Four: Disinfection

Water can further be disinfected as a precautionary measure using chlorine if it is available. Shan et al (2017) in their research on treatment using Moringa Oleifera seeds for both wastewater and river samples observed that the seeds reduced and prevented bacterial growth. They observed turbidity reduction of 85-94% and Dissolved Oxygen was improved from 2.58+0.01 to 4.00+0.00%.

6.8 Conclusion

Moringa seeds, coconut husk and corn husks were all effective in removing iron, lead and arsenic from the water. They all have morphological characteristics that are conducive for metal ions adsorption from aqueous solution. Moringa seeds can totally remove lead and iron from the water at low concentrations. Households can treat their water by mixing ground moringa with water, shaking for 3 minutes and allowing it to sit for 30 minutes. A column with moringa depth of 10mm can be used to treat at least 1 Litre of water. This can be scaled up by communities to develop a large-scale treatment system that can serve the whole community.

This chapter is followed by the final chapter which captures the summary of the results, the conclusions and the recommendations.

CHAPTER SEVEN

7 Conclusions and Recommendations

This chapter captures a brief summary of the results for this research. Conclusions are drawn and recommendations are made, including recommendations for further studies.

7.1 Summary of Findings

The objectives of this research were three-fold:

To evaluate existing policies and regulations with regards to Artisanal and Small-Scale Mining (ASM) in Ghana and their enforcement.

The research evaluated existing policies related to Artisanal and Small-scale Mining in Ghana. The findings showed that Ghana has quite a vast number of policies and regulations, but the implementation and enforcement for most of the policies and regulations have been dysfunctional. This issue with implementation and enforcement of policies has been observed in several public institutions in the country. Majority of the respondents indicated they were not aware of policies related to ASM. Corruption has been identified as one of the main issues of why enforcement and implementation is a challenge. Law enforcers and officials from regulatory institutions, request for bribes and payment from offenders instead of applying the stipulated sanctions. When respondents were asked why the policies have not been effective, majority of the respondents strongly agreed that corruption was a major challenge. This has to be addressed to restore confidence in public institutions within the country. The chi-square test between community and opinion on the effectiveness of policies had a likelihood ratio of 0.001. The lack of engagement with local communities at the policy level means many inhabitants of rural communities including the individuals or persons engaged in mining activities, are not aware of policies related to ASM. Waterbodies are therefore polluted because of nonadherence to policy regulations and lack of enforcement of existing policies.

To assess the level of contamination of water bodies in the mining communities and the impact on the health and livelihood of the inhabitants of the communities along the Birim River.

In assessing the level of contamination of water bodies in the Birim Basin, it was concluded that ASM activities in the area have impacted negatively on the quality of the water. Between 70 to 90% of respondents in the rural mining communities depend mainly on the water from the river and groundwater as their main source of drinking water. About 80% of respondents expressed concern about the negative impact of ASM on water quality. Concentrations of heavy metals such as iron, lead and arsenic were above the WHO limit in more than 80% of the samples. However, samples collected from the source (Atewa) of the Birim River, had heavy metal concentrations that were relatively lower, indicating that anthropogenic activities along the river which is mainly artisanal and small-scale mining, affected the quality of the water. Majority of respondents suggested there was no other source of pollution.

ASM had a negative impact on the community by destroying water bodies, farmlands and leaving open-pit death traps for children and animals. In relation to the impact on health, some of the inhabitants of the communities have experienced health problems possibly due to the contaminated water bodies and exposure to chemicals. Although some of inhabitants of the mining communities are aware of health risks associated with ASM activities due to exposure to heavy metals, the need to earn some income to provide for their families overshadows the health concerns. All the three mining communities have access to health facilities. Majority of the inhabitants do not have regular health check-ups but visit the health facility when they feel unwell.

ASM positively impacted the livelihood of inhabitants of the rural mining communities by providing employment and improving the standard of living. Seventy-one percent (71%) of respondents believe mining activities provide benefits to people in the communities. About 51% believe ASM provides employment, 75% improved standard of living and 14.9% community development. This shows that many of the respondents believe that ASM activities within their communities employ individuals especially the youth which results in an improved standard of living for individuals and their families. For the community as a whole, many see the detrimental effects of ASM activities on water bodies, the environment in general, farmlands etc. and do not believe ASM brings about community development.

To determine whether locally available materials can be used to treat the contaminated water to WHO standards for drinking water for households in the affected communities.

The three locally available and inexpensive adsorbents; moringa seeds, coconut husks and corn husks in their raw nature were all effective in removing iron, lead and arsenic from the contaminated water in the batch study. The adsorbents were effective in removing the heavy metals when single heavy metals were found in solution as well as when all three heavy metals were combined in one aqueous solution. 0.5g of adsorbents effectively removed the heavy metals from the aqueous solution in 30min. All the adsorbents were most effective in removing lead from the water. Moringa seeds were most effective for removal of the three heavy metals followed by coconut husk and corn husk. Change in pH affected the removal efficiency of the adsorbents. Acidic conditions reduced the removal efficiency of the adsorbents for iron and arsenic, However, lead was not affected. A comparison between shaking the samples using the orbital shaker and shaking by hand showed an insignificant difference in the removal percentage between the two indicating it is still possible to remove the heavy metals from the water even without electrical equipment, especially with moringa seeds. The column study also determined that a depth of 10mm of moringa seeds in a column with at least 1L of the aqueous solution has a flow rate around 5.6ml/min and is optimum for iron removal in about 30 min. Based on the findings, a treatment system using moringa seeds in the study context will be the most effective option. Nevertheless, in areas where coconut husks and corn husks are more abundant and easily available, they can be used in place of moringa seeds.

The adsorption of iron by the three adsorbents using the Langmuir and Freundlich isotherms was modelled with the quality of the fit assessed using the coefficient of determination (R^2). Both the Langmuir and Freundlich isotherms were a good fit. This indicates that with iron adsorption onto Moringa seeds, coconut husks and corn husks, there is a possible existence of more than one type of adsorption site interacting with the metal, and/ or the three adsorbents have a high adsorption capacity. An extended range of adsorbate concentrations may provide different results between the two models.

7.2 Conclusions

- The survey revealed inhabitants of the mining communities are not aware of ASM policies and regulations. Most of them indicated they would use safe practices to protect water bodies and their health if they were aware of the severe impact of heavy metals. The majority of the persons engaged in ASM activities were also not aware of the impact ASM activities could have on their water bodies and land in general.

- Enforcement of policies would be necessary for the effective management of water resources in the country.
- The water quality analysis shows that waterbodies in the Birim River Basin are not safe for human consumption. The mean values for turbidity, true and apparent colour, total suspended solids of the river water, iron, arsenic and lead at the various sampling sites exceeded the WHO permissible limits for drinking water. This raises severe concerns about the quality of water for drinking and domestic purposes being used by inhabitants of mining-affected communities. It is therefore imperative for water to be treated for drinking and domestic purposes.
- ASM activities in rural areas employ individuals especially the youth in the communities and improve their standard of living, but it has detrimental effects on the community as a whole. Alternative job opportunities with income comparable to that of ASM should be made available to the youth to reduce the numbers engaged in illegal ASM activities.
- Moringa seeds, coconut husk and corn husk are effective adsorbents in removing iron, lead and arsenic from contaminated water. Moringa seeds are most effective in removing iron, lead and arsenic from drinking water to WHO standards.

7.3 Implications

The research presented in this thesis is diverse and explored issues from policy to water treatment. The research has important implications for various stakeholders such as policymakers, inhabitants of rural mining communities, ASM miners, Environmental expects, Public Institutions, Regulatory bodies, Educational institutions and many others.

- Policies that are not implemented and enforced effectively cannot fully address issues they were intended for, no matter how good they look on paper.
- Inhabitants of rural mining communities cannot depend on water sources such as rivers and groundwater within their communities for drinking and domestic purposes without treatment of the water.

- Water bodies especially in mining communities that are not effectively monitored can get polluted from ASM activities.
- Moringa seeds can be used in a point-of-use water treatment system to remove heavy metals from contaminated water to reduce health risks.

7.4 Recommendations

Based on the results of this study, it is recommended that:

- Awareness creation and education on the impact of ASM activities on water bodies, health and livelihood of people in mining areas and safe mining practices should be initiated to protect the environment and minimize the negative impact of ASM on the environment. Given the ubiquitous nature of mining in Ghana, education on the impact of mining can be weaved into school curriculums. Traditional communities can also be provided with the necessary resources to organise the youth and miners in the communities and provide education and training on safe mining practices. Some free courses in safe mining practices should be introduced at the local levels and all miners should be required to take these courses to receive training and education of safe mining practices before they can work on mining sites.
- Government's policy interventions to address ASM impact on water quality issues should include a better understanding of water quality and its impacts on the health of inhabitants of affected communities through improved monitoring. There is the need for effective communication and collaboration, improved financial and economic approaches and improved technology and infrastructure.
- The government as well as the mining industries can invest in innovative new technology that is safe for the environment and eliminates the use of mercury in the gold amalgamation process.
- Frequent monitoring of all surface water bodies and groundwater be undertaken to ensure the quality of the water is not compromised. There should be regular follow-up studies to measure the levels of heavy metals and other toxic chemicals in the Birim River Basin.
- Adequate resourcing of regulatory bodies and stricter sanctions against offenders be undertaken.

- The MMIP uses a holistic approach to solve some of the ASM issues. Management and monitoring structures should be established at the village/town level and local participation should be encouraged to create a strong sense of ownership.
- Water from the Birim River Basin should be treated before drinking. The water can be treated with Moringa seeds to remove the iron, reduce turbidity and disinfect the water without affecting the pH of the water.
- Policy initiatives must be instituted to deal with this environmental issue and the consequences of environmental damage due to ASM. Such initiatives should guide policies and actions to address the unique challenges posed by ASM on waterbodies.
- The policies initiated must also cater for the welfare of low-income earners in Ghana, provide miners with training on environmental sustainability issues, and fight against corruption.

7.5 Recommendations for further studies

Although the research generally achieved its objectives and addressed several issues, further studies are required to address uncertainties that were identified and explore new areas of research. The researcher recommends further studies into the following areas

- Synthesis and characterization of magnetic bio-adsorbents using Arachis hypogaea shell powder and its application in the removal of Arsenic.
- In situ water and sediment treatment using cost-effective ways to the removal of Arsenic (V) from contaminated rivers in mining communities.
- In situ remediation of heavy metal contaminated soil using raw untreated Moringa seeds
- Remediation of mining contaminated farmlands using moringa seeds and coconut husks to make it conducive for food production.
- The influence of activated carbon surface from coconut husk on the removal of Arsenic from Drinking water.
- Adsorption and desorption of Arsenic trioxide on charred corn cobs.
- Bio-regeneration of adsorbents for heavy metal removal using edible, accessible and environmentally friendly acids and bases from food products.
- Kinetic, equilibrium and thermodynamic investigation on Fe, Pb and As adsorption on coconut husk ash.

- Arsenic removal from water using biochar, a low-cost adsorbent: equilibrium uptake and sorption dynamic modelling.
- Effects of pre-treatment of moringa seeds, corn husks and coconut husk on Arsenic adsorption from aqueous solution.
- Kinetics, isotherms and thermodynamic studies of iron lead and arsenic bio-adsorption from aqueous solution onto Arachis hypogaea shells.
- Explore the use of environmentally safe and sustainable methods in gold amalgamation.
- Studies to explore the flow of water through the column for varying depths of moringa seeds. Although this study carried out the column study for three depths, 5mm,10mm and 12.5mm, the 12.5mm depth, had a better flowrate compared to 10mm and 5mm depth which is not expected generally. Further research will provide more insight.

Appendices

Appendix I - Questionnaire

QUESTIONNAIRE ON THE IMPACT OF ARTISANAL AND SMALL-SCALE MINING ACTIVITIES ON WATERBODIES AND TREATMENT

I am undertaking this research as part of my PhD programme. I would be most grateful if you could take a few minutes to complete this questionnaire by checking the appropriate box (☐). If possible, please try to answer all the questions.

Information is required solely for academic purposes and strict confidentiality is assured. Please kindly return the questionnaires before ……...

SECTION A: SOCIO-DEMOGRAPHIC

1.	In which community do you live?	☐1 Community A ☐2 Community B ☐3 Community C	[ ]
2.	How many years have you lived in this community?	☐1 Less Than 1 Year ☐2 1-5 Years ☐3 6-10 Years ☐4 11-15years ☐5 More Than 15 Years ☐0 Don't know	[ ]
3.	What is your Gender?	☐1 Male ☐2 Female	[ ]
4.	What is your Age?	☐1 Less Than 20 Years ☐2 20-40 Years ☐3 40-60 Years ☐4 Above 60 Years ☐0 Don't know	[ ]
5.	What is your Marital status?	☐1 Single ☐2 Married ☐3 Divorced ☐4 Widow / Widower ☐0 Don't know	[ ]
6.	What is your highest level of educational attainment?	☐1 No Formal Education ☐2 Primary Education ☐3 Junior High School/ Middle School	[ ]

		¨4 Senior High School / Vocational ☐5 Tertiary ☐0 Don't know	
7.	What is your current occupation?	☐1 Miner ☐2 Farmer ☐3 Trader ☐4 Civil Servant ☐5Other, ………………………. ☐0 Don't know	[ ]
8.	Have you ever been involved in mining activities?	☐1 No ☐2 Yes ☐0 Don't know	[ ]
9.	If '**YES**' to **Q8**, How long have you been involved in mining?	☐1 Less than 1 Year ☐2 1-5 Years ☐3 6-10 Years ☐4 11-15years ☐5 More than 15 Years ☐0 Don't know	[ ]
10.	Do you live close to the mine site?	☐1 No ☐2 Yes ☐0 Don't know	[ ]

SECTION B: ASM ACTIVITIES AND REGULATIONS

11.	Have you ever been involved in Artisanal and small-scale mining activities in anyway?	☐1 No ☐2 Yes ☐0 Don't know	[ ]
11a.	If '**YES**' to **Q11**, what role did you play?	☐1 Mine operator ☐2 Panner ☐3 Ore Carrier ☐4 Ore processor ☐5 Concession owner ☐6 Other………….. ☐0 Don't know	[ ]
12.	Are you aware of any policies and regulations that guide ASM activities?	☐1 No ☐2 Yes ☐0 Don't know	[ ]

12a.	If '**YES**' to **Q12**, please select the policy or regulation you are aware of.	☐1 Minerals and mining Act 2006 ☐2 Minerals and mining Act 2015 ☐3 Minerals commission Act ☐4 Minerals and mining (Health, safety and technical) regulations ☐5 Other……………………. ☐0 Don't know	[ ]
13.	In your opinion, have these policies and regulations been effective?	☐1 No ☐2 Yes ☐0 Don't know	[ ]
13a.	If '**YES**' to **Q13**, Why do you think they have been effective? (Please check as many as apply)	☐1 Protection of the environment ☐2 Booming Industry ☐3 Other………… ☐0 Don't know	[ ]
13b.	If '**NO**' to **Q13**, For each of the factors below, indicate your level of agreement or disagreement of their contribution to the ineffectiveness of the policies and regulations. Please indicate your answer by checking the appropriate box in the table below (☐). **4= Strongly Agree 3= Agree 2= Disagree 1= Strongly Disagree 0=Don't know**		

No.	Factors	4	3	2	1	0
13.1	Lack of coordination amongst regulatory bodies	☐	☐	☐	☐	☐
13.2	Inadequate personnel and resources	☐	☐	☐	☐	☐
13.3	Lack of environmental education and awareness	☐	☐	☐	☐	☐
13.4	Cumbersome registration process for small scale miners	☐	☐	☐	☐	☐
13.5	Lack of enforcement of regulations	☐	☐	☐	☐	☐
13.6	Failure to address community needs	☐	☐	☐	☐	☐
13.7	Corruption	☐	☐	☐	☐	☐
13.8		☐	☐	☐	☐	☐

14.	In your opinion, what measures can be put in place to make these policies and regulations effective? (please check as many as apply.)	☐1 Enforcement of policies and regulations ☐2 Awareness creation and education ☐3 Stakeholder involvement ☐5 Other………………………… ☐0 Don't know	[ ]

SECTION C: ENVIRONMENTAL CONTAMINATION AND HEALTH IMPACT

15.	In your opinion, do mining activities in your area provide benefits to people in the area and surrounding communities?	☐1 No ☐2 Yes ☐0 Don't know	[ ]

15a.	If '**YES**', to **Q15**, what is the major benefit?	☐1 Employment ☐2 Improved standard of living ☐3 Community development ☐4 Other……………….. ☐0 Don't know	[ ]
16.	Have you ever considered moving out of your community because of its proximity to the mining sites?	☐1 No ☐2 Yes ☐0 Don't know	[ ]
17.	What is the major concern you have with the impact of the mining activities?	☐1 Water Pollution ☐2 Air Pollution ☐3 School drop out ☐4 Destruction of farmlands ☐5 Health risks ☐6 Other……………….. ☐0 Don't know	[ ]
18.	Do you have any concerns about the impact of the mining activities on Birim River?	☐1 No ☐2 Yes ☐0 Don't know	[ ]
18a.	If '**YES**' to **Q18**, what are your major concerns? (Select as many as apply)	☐1 Reduced Quality (pollution) ☐2 Reduced Quantity ☐3 Destruction of fish etc. ☐4 Other……………….. ☐0 Don't know	[ ]
19.	Are there other sources of pollution to the river apart from the waste from the mining sites?	☐1 No ☐2 Yes ☐0 Don't know	[ ]
19a.	If '**YES**' to **Q19**, what are the sources? (select as many as apply)	☐1 Fertilizer from farmlands ☐2 Human waste and excreta ☐3 Animal waste and excreta ☐4 Industrial waste (chemicals) ☐5 Others……………………….. ☐0 Don't know	[ ]
20.	Do people in your community use the water from the Birim River?	☐1 No ☐2 Yes ☐0 Don't know	[ ]
21.	Please select the purpose the Birim River serves to various members of the community. (Please check as many as apply)	☐1 Drinking Water Source ☐2 Irrigation ☐3 Fishing ☐4 Swimming ☐5 Domestic purposes ☐6 Others………………………. ☐0 Don't know	[ ]

22.	In your opinion what is the current condition of the Birim River?	☐1 Not polluted ☐2 Slightly polluted ☐3 Moderately polluted ¨4 Very polluted ☐0 Don't know	[ ]
23.	In your opinion, are mining activities affecting farmlands?	☐1 No ☐2 Yes ☐0 Don't know	[ ]
23a.	If '**YES**' to **Q23**, in which way?	☐1 Positively ☐2 Negatively ☐3 No change ☐4 Others………………… ☐0 Don't know	[ ]
24.	Are you aware of health risks associated with Artisanal and small-scale mining activities?	☐1 No ☐2 Yes ☐0 Don't know	[ ]
25.	Do you have any concerns about the impact of the mining activities on the health of the people in your community?	☐1 No ☐2 Yes ☐0 Don't know	[ ]
26.	Have you or a family member experienced any illness or disease which you believe was caused by water contamination from the mining sites?	☐1 No ☐2 Yes ☐0 Don't know	[ ]
27.	How does your health compare with that of other people of your age group?	☐1 Poor ☐2 Good ☐3 Very Good ☐4 Excellent ☐0 Don't know	[ ]

28. Please indicate how often you have had the following health symptoms **over the past four (4) weeks** by checking the appropriate box in the table below (☐). **4= Very often 3= Often 2= Not Often 1= Not at all 0= Don't know**

No.	**Impact on Health**	**4**	**3**	**2**	**1**	**0**
1	I have stomach ulcer or ulcers	☐	☐	☐	☐	☐
2	I have headaches	☐	☐	☐	☐	☐
3	I have body pains and ache in some parts of my body	☐	☐	☐	☐	☐
4	I have difficulty sleeping	☐	☐	☐	☐	☐
5	I have physical trouble or difficulty walking	☐	☐	☐	☐	☐
6	I have difficulty concentrating	☐	☐	☐	☐	☐
7	I give up too easily	☐	☐	☐	☐	☐
8	I get dizzy spells	☐	☐	☐	☐	☐
9	I get tired easily	☐	☐	☐	☐	☐
10	I am sad and depressed	☐	☐	☐	☐	☐
11	I am almost always nervous	☐	☐	☐	☐	☐

12	I get sinus congestion without cold	☐	☐	☐	☐	☐
13	I have irritated, sore or red eyes	☐	☐	☐	☐	☐
14	I get chest pains	☐	☐	☐	☐	☐
15	I often have coughs without colds	☐	☐	☐	☐	☐
16	I often have a stuffy, runny nose with cold	☐	☐	☐	☐	☐
17	I often get ill	☐	☐	☐	☐	☐
18	I have wheezing and trouble breathing	☐	☐	☐	☐	☐
19	I get hives or skin rashes	☐	☐	☐	☐	☐
20	I have nosebleeds	☐	☐	☐	☐	☐
21	I have Hay fever and other allergies	☐	☐	☐	☐	☐
22	I have arthritis or rheumatism	☐	☐	☐	☐	☐
23	I have heart disease	☐	☐	☐	☐	☐
24	I have asthma	☐	☐	☐	☐	☐
25	I have respiratory problems	☐	☐	☐	☐	☐
26	I have high blood pressure or hypertension	☐	☐	☐	☐	☐
27	I have diarrhoea	☐	☐	☐	☐	☐
28	I have urinary problems or kidney disease	☐	☐	☐	☐	☐
29	I am basically a healthy person	☐	☐	☐	☐	☐
30	I have joint pains and swellings	☐	☐	☐	☐	☐
31	I have loss of appetite	☐	☐	☐	☐	☐
32	I bruise easily and get sores which do not heal fast	☐	☐	☐	☐	☐
33	I get very thirsty and drink more water compared to others	☐	☐	☐	☐	☐
34	I have lower back pains	☐	☐	☐	☐	☐
35	I experience burning and discomfort when urinating	☐	☐	☐	☐	☐
36		☐	☐	☐	☐	☐
37		☐	☐	☐	☐	☐

29.	In the past four (4) weeks, has there been an instance where you were unable to carry out your daily activities?	☐1 No ☐2 Yes ☐0 Don’t know
29a.	If ‘**YES**’ to **Q29**, how often have you missed your daily activities in the past **four weeks** because of ill-health?	☐1 Not often ☐2 Often ☐3 Very Often ☐4 Other……………….. ☐0 Don’t know
30.	Do you visit a health facility when you are not feeling well?	☐1 No ☐2 Yes ☐0 Don’t know
31.	Do you have a health facility that is easily accessible to your community?	☐1 No ☐2 Yes ☐0 Don’t know

31a.	If '**YES**' to **Q31**, how far away is the health facility from your residence?	☐1 Less than 30 min ☐2 30min to 1hr ☐3 1hr to 2 hrs ☐4 More than 2hrs ☐0 Don't know
32.	Have you ever had a physical check-up without having a specific health problem?	☐1 No ☐2 Yes ☐0 Don't know
32a.	If '**YES**' to **Q32**, how often do you have a physical check-up?	☐1 Once a year ☐2 More than 2 times a year ☐3 Once every two years ☐4 Once every three years or longer ¨0 Don't know
33.	Have you been away from your community for more than 6 months within the past two years?	☐1 No ☐2 Yes ☐0 Don't know
34.	At present, how often do you smoke cigarettes/cigar?	☐1 Not at all ☐2 Daily ☐3 Occasionally ☐4 Other………………. ☐0 Don't know
35.	At present, how often do you drink alcohol?	☐1 Not at all ☐2 Daily ☐3 Occasionally ☐4 Other………………. ☐0 Don't know
36.	How do you dispose of your garbage?	☐1 I burn it ☐2 Bury in the ground ☐3 I throw it out ☐4 Community dump ☐5 Other………………….. ☐0 Don't know
37.	How often do you dispose of your garbage?	☐1 Not at all ☐2 Daily ☐3 Occasionally ☐4 Other………………. ☐0 Don't know
38.	Are you currently or have you ever been exposed to gases, fumes or chemicals at work or at home?	☐1 No ☐2 Yes ☐0 Don't know
39.	Are you currently or have you ever been exposed to dust at work or at home e.g., sanding, sweeping, etc?	☐1 No ☐2 Yes ☐0 Don't know

40.	Have you ever stopped working at a job or changed your job because of reasons related to your health?	☐1 No ☐2 Yes ☐0 Don't know
41.	In the past twelve months have you been exposed to pesticides around your home or at work?	☐1 No ☐2 Yes ☐0 Don't know
42.	What do you use in cooking food or boiling water?	☐1 Fire wood ☐2 Coal pot (charcoal) ☐3 Gas stove ☐4 Other…………………… ☐0 Don't know
43.	In the past twelve months have either cats, dogs, birds, sheep and goat been kept in your home or your yard?	☐0 No ☐1 Yes ☐7 Don't know
44.	What material is your house made of?	☐1 Mud and thatch ☐2 Timber ☐3 Sandcrete blocks ☐4 Concrete ☐5 Other…………………… ☐0 Don't know
45.	What types of flooring or carpets does your house have? Does it have	☐1 Bare floor ☐2 Screed ☐3 Tiles ☐4 Carpet ☐5 Other…………………… ☐0 Don't know

46. Please indicate how often people in your community experience the health risks outlined below. Please indicate your answer by checking the appropriate boxes in the table below. ☐ **4= Very Often 3= Often 2= Not Often 1= Not at all 0= Don't know**

No. .	**HEALTH RISK**	**4**	**3**	**2**	**1**	**0**
1	Skin Disease	☐	☐	☐	☐	☐
2	Respiratory disease	☐	☐	☐	☐	☐
3	Reproductive problems	☐	☐	☐	☐	☐
4	Reduced IQ in children	☐	☐	☐	☐	☐
5	Reduced attention span in children	☐	☐	☐	☐	☐
6	Kidney Disease	☐	☐	☐	☐	☐
7	Behavioural problems in children	☐	☐	☐	☐	☐

8	Liver Disease	☐	☐	☐	☐	☐
9	Cancer	☐	☐	☐	☐	☐
10	Diabetes	☐	☐	☐	☐	☐
11	Heart Disease	☐	☐	☐	☐	☐
12	Eye Disease	☐	☐	☐	☐	☐
13	Nausea and Diarrhoea	☐	☐	☐	☐	☐
14		☐	☐	☐	☐	☐
15		☐	☐	☐	☐	☐

SECTION D: IMPACT ON CHILDREN'S HEALTH

47.	Do you have children under 12 years who currently live in your home?	☐1 No ☐2 Yes ☐0 Don't know	[ ]
48.	Is the oldest child under 12 years currently enrolled in school?	☐1 No ☐2 Yes ☐0 Don't know	[ ]
49.	What is the general health condition of your oldest child under 12years?	☐1 Poor ☐2 Good ☐3 Very Good ☐4 Excellent ☐0 Don't know	[ ]

50. Please indicate how often your child (oldest child under 12 years) has had the following health symptoms **over the past FOUR (4) WEEKS** by checking the appropriate box in the table below (☐). **4= Very Often 3= Often 2= Not Often 1= Not at all 0= Don't know**

No.	Impact on Health	4	3	2	1	0
1.	Headaches	☐	☐	☐	☐	☐
2	Body pains and ache in some parts of my body	☐	☐	☐	☐	☐
3	Difficulty sleeping	☐	☐	☐	☐	☐
4	Physical trouble or difficulty walking	☐	☐	☐	☐	☐
5	Difficulty concentrating	☐	☐	☐	☐	☐
6	Give up too easily	☐	☐	☐	☐	☐
7	Dizzy spells	☐	☐	☐	☐	☐
8	Get tired easily	☐	☐	☐	☐	☐
9	Feel sad and depressed	☐	☐	☐	☐	☐
10	Sinus congestion without cold	☐	☐	☐	☐	☐
11	Irritated, sore or red eyes	☐	☐	☐	☐	☐

12	Chest pains	☐	☐	☐	☐	☐
13	Coughs without colds	☐	☐	☐	☐	☐
14	Stuffy, runny nose with cold	☐	☐	☐	☐	☐
15	Get ill often	☐	☐	☐	☐	☐
16	Wheezing and trouble breathing	☐	☐	☐	☐	☐
17	Hives or skin rashes	☐	☐	☐	☐	☐
18	Nosebleeds	☐	☐	☐	☐	☐
19	Hay fever and other allergies	☐	☐	☐	☐	☐
20	Asthma	☐	☐	☐	☐	☐
21	Respiratory problems	☐	☐	☐	☐	☐
22	Diarrhoea	☐	☐	☐	☐	☐
23	Urinary problems	☐	☐	☐	☐	☐
24	Loss of appetite	☐	☐	☐	☐	☐
25	Bruise easily and get sores which do not heal fast	☐	☐	☐	☐	☐
26	Burning and discomfort when urinating	☐	☐	☐	☐	☐
27		☐	☐	☐	☐	☐
28		☐	☐	☐	☐	☐
29		☐	☐	☐	☐	☐

SECTION E: WATER TREATMENT

51.	Do you use water from the Birim River?	☐1 No ☐2 Yes ☐0 Don’t know	[ ]
52.	Would you say that the colour of the river has changed compared to 5 years ago?	☐1 No ☐2 Yes ☐0 Don’t know	[ ]
52a.	If ‘**YES**’ to **Q52**, in what way? Water is	☐1 Clearer ☐2 Light Brown ☐3 Very Brown ☐4 No Change ☐5 Others…………………… ☐0 Don’t know	[ ]
53.	Would you say there is a lot more dirt/silt in the water compared to 5 years ago?	☐1 No ☐2 Yes ☐0 Don’t know	[ ]
54.	Would you say the taste of water has changed compared to 5 years ago?	☐1 No ☐2 Yes ☐0 Don’t know	[ ]

54a.	If '**YES**' to **Q54**, in what way? Water is…… (select as many as apply)	☐1 Unpleasant ☐2 Metallic ☐3 Salty ☐4 Bitter/Sour ☐5 Sweet ¨6 Others…………………… ☐0 Don't know	[ ]
55.	Do you use water from other sources (apart from Birim River)?	☐1 No ☐2 Yes ☐0 Don't know	[ ]
55a.	If '**YES**', to **Q55**, please state the other source(s)…….	☐1 Boreholes ☐2 Wells ☐3 Supply from tankers ☐4 Sachet water ☐5 Bottled water ☐6 Others…………………… ☐0 Don't know	[ ]
56.	Do you treat the water before using it for domestic purposes?	☐1 No ☐2 Yes ☐0 Don't know	[ ]

56a. If you answered '**YES**' to **Q56**, which water treatment method do you use? Please indicate which water treatment method you often use by checking the appropriate box in the table below (☐). **4= Very Often 3= Often 2= Not Often 1= Not at all 0= Don't know**

No.	**Treatment Methods**	**4**	**3**	**2**	**1**	**0**
1	Boiling	☐	☐	☐	☐	☐
2	Filter using cloth	☐	☐	☐	☐	☐
3	Filter using sand	☐	☐	☐	☐	☐
4	Allow to sit for particles to settle	☐	☐	☐	☐	☐
5	Chlorine Disinfection	☐	☐	☐	☐	☐
6	Solar Disinfection	☐	☐	☐	☐	☐
7		☐	☐	☐	☐	☐

57. In your opinion, how important are the water treatment objectives below? Please indicate how important they are by checking the appropriate box in the table below (☐). **4= Very Important 3= Important 2= Not Important 1= Not at all 0= Don't know**

No.	**Water treatment objectives**	**4**	**3**	**2**	**1**	**0**
1	Reduced turbidity (clear water)	☐	☐	☐	☐	☐
2	Reduced colour	☐	☐	☐	☐	☐

	3	Removal of chemicals (Heavy metals)	☐	☐	☐	☐	☐
	4	Killed or inactivated disease-causing pathogens	☐	☐	☐	☐	☐
	5		☐	☐	☐	☐	☐
	6		☐	☐	☐	☐	☐

58.	Have you ever treated your drinking water using locally available materials in your community?	☐1 No ☐2 Yes ☐0 Don't know	[ ]
58a.	If '**YES**' TO **Q58**, which of these materials have you ever used to treat water? (Select as many as apply)	☐1 Corn husk ☐2 Moringa ☐3 Coconut husk ☐4 Other…………………. ☐0 Don't know	[ ]

59. Is there any contribution you would like to make that has not been captured? Please state below……………………………………………………………………………………………

……………………………………………………………………………………………………

………………………………………………………………………………………

End of Questionnaire…… Thank you for responding

Appendix II - Interview Outline

Interview Guide Questions -Semi structured (Community)

1. Which community do you belong to?
2. How many years have you lived in this community?
3. Which major role do you play in your community?
4. Are you familiar with artisanal and small-scale mining activities in Ghana?
5. In your opinion what impacts are artisanal and small scaler mining activities having on your community?
    1. what are some of the positive impacts?
    2. what are some of the negative impacts?
    3. would you say the positive impacts outweigh the negative impacts or vice versa?
6. Are you aware of any policies and regulations that guide artisanal and small-scale mining activities and its impact on the environment?
7. In your opinion, have the existing policies and regulations been effective in regulating ASM activities and protecting the environment especially waterbodies?
8. What impact can ASM activities have on waterbodies such as rivers, lakes etc.?
9. Do people in your community use water from the Birim River?
    1. for what specific purpose?
    2. Has the quantity and quality of the river water changed in the past 5 years? In what way?
10. What measures can be put in place to protect waterbodies from the impact of mining activities?
11. What impact can ASM activities have on the health and livelihood of inhabitants in your community who use water from the affected waterbodies?
12. What measures can be put in place to protect the health and livelihood of people in your community?
13. Is there any contribution you will like to make that has not been captured?

Interview Guide Questions -Semi structured (Public Institution)

1. Are you familiar with artisanal and small-scale mining activities in Ghana?
2. What is the role of your organisation in artisanal and small-scale mining and environmental issues?
3. In your opinion what impacts are artisanal and small scaler mining activities having on the economy?
   a. what are some of the positive impacts?
   b. what are some of the negative impacts?
   c. would you say the positive impacts outweigh the negative impacts or vice versa?
4. What are some of the policies and regulations guiding artisanal and small-scale mining activities and its impact on the environment?
5. Does your organisation play a specific role in the implementation or enforcement of any policies or regulations that guide ASM activities?
   a. what specific role does your organisation play?
   b. how does your organisation carry out this role?
   c. Is your organisation well-resourced to carry out such tasks?
6. In your opinion, have the existing policies and regulations been effective in regulating ASM activities and protecting the environment especially waterbodies?
7. What impact can ASM activities have on waterbodies such as rivers, lakes etc.?
8. What measures can be put in place to protect waterbodies from the impact of mining activities?
9. What impact can ASM activities have on the health and livelihood of inhabitants of communities near mining sites who use water from the affected waterbodies?
10. What measures can be put in place to protect the health and livelihood of affected communities?
11. Is there any contribution you will like to make that has not been captured?

Appendix III - Water Sample Results (Initial 12 samples)

Parameter	**Unit**	Akanteen Mine Pond	Kade Brim	Brimso Asiakwa	Bunso	Osinor Borehole	Oda River
Turbidity	NTU	812	104	276	1182	<1.00	30.0
Colour (apparent)	Hz	75.0	150	225	225	<2.50	50.0
Odour	-	-	-	-	-	-	-
pH	pH Units	6.87	6.85	7.31	6.95	6.50	6.89
Conductivity	µS/cm	186	82.5	128	115	265	84.7
Tot. Susp. Solids (SS)	mg/l	738	96.0	211	925	<1.00	29.0
Tot. Dis. Solids (TDS)	mg/l	112	49.5	76.8	69.0	165	50.8
Sodium	mg/l	5.70	5.00	5.90	5.80	121.0	5.30
Potassium	mg/l	1.60	1.40	1.30	1.20	2.50	1.20
Calcium	mg/l	25.7	6.41	13.9	16.8	18.0	7.54
Magnesium	mg/l	4.63	3.49	3.19	0.806	11.8	3.54
Fluoride	mg/l	0.319	0.778	0.603	0.171	<0.005	0.458
Ammonia (NH_4-N)	mg/l	<0.001	0.246	0.440	0.421	<0.001	0.459
Chloride	mg/l	7.44	6.65	7.25	8.73	26.5	6.75
Sulphate (SO_4)	mg/l	27.1	4.50	8.75	9.00	41.5	3.63
Phosphate (PO_4-P)	mg/l	0.211	0.153	0.105	0.190	0.147	0.100
Nitrite (NO_2-N)	mg/l	0.04	0.021	0.012	0.027	0.019	0.007
Nitrate (NO_3-N)	mg/l	0.894	0.085	0.111	0.538	0.230	0.106
Total Hardness (as $CaCO_3$)	mg/l	83.2	30.4	47.8	45.4	85.1	33.4
Total Alkalinity (as $CaCO_3$)	mg/l	62.4	32.0	46.6	33.8	58.2	30.0
Calcium Hardness (as $CaCO_3$)	mg/l	64.1	16.0	34.7	42.1	41.8	18.8
Mag. Hardness as $CaCO_3$)	mg/l	19.1	14.4	13.1	3.32	45.1	14.6
Bicarbonate (as $CaCO_3$)	mg/l	76.1	39.0	56.9	41.2	72.0	36.6
Carbonate	mg/l	0	0	0	0	<1.00	0

Parameter	Anyinam Brim River	Emuo River	Apaapam (Kibi)	Akanten Borehole	Mempasem Mining	Osinor River

Turbidity	485	54.0	7.00	<1.00	98.0	556
Colour (apparent)	150	15.0	15.0	<2.50	15.0	150
Odour	-	-	-	-	-	-
pH	6.59	7.30	7.27	6.37	5.51	6.84
Conductivity	89	177	108	250	60.5	96.5
Tot. Susp. Solids (SS)	376	69.0	4.00	<1.00	91.0	466
Tot. Dis. Solids (TDS)	53.4	106	64.8	150	375	57.9
Sodium	13.0	4.90	5.10	18.0	4.50	5.70
Potassium	2.20	1.30	1.20	2.30	1.30	1.20
Calcium	5.13	6.01	12.0	16.0	5.45	9.62
Magnesium	0.820	15.4	2.32	10.9	0.965	3.44
Fluoride	0.705	0.076	<0.005	<0.005	0.58	0.681
Ammonia (NH_4-N)	0.738	<0.001	<0.001	<0.001	0.227	0.927
Chloride	7.74	10.7	9.03	26.1	12.2	7.44
Sulphate (SO_4)	3.50	12.4	2.25	40.6	38.9	5.00
Phosphate (PO_4-P)	0.109	0.056	0.431	0.145	0.275	0.085
Nitrite (NO_2-N)	0.069	0.021	0.018	0.017	0.035	0.095
Nitrate (NO_3-N)	1.11	0.972	0.346	0.222	0.091	0.058
Total Hardness (as $CaCO_3$)	16.2	78.4	39.6	84.8	17.6	38.2
Total Alkalinity (as $CaCO_3$)	33.8	65.6	40.6	58.0	11.0	37.8
Calcium Hardness (as $CaCO_3$)	12.8	15.0	30.1	39.9	13.6	24.0
Mag. Hardness as $CaCO_3$)	3.37	63.4	9.54	44.9	3.97	14.2
Bicarbonate (as $CaCO_3$)	41.2	80.0	49.5	70.8	13.4	46.1

Sample ID (Dissolved)	ID	Fe	Mn	Hg	As	Pb	Cd
Osino Boreholes	OSBH	<0.010	0.059	<0.001	<0.001	<0.005	<0.002
Akanten Boreholes	AKBH	0.187	0.573	<0.001	<0.001	<0.005	<0.002

Apaapam Birim River	APBR	1.00	0.053	0.001	<0.001	<0.005	<0.002
Oda Birim River	ODBR	2.62	0.067	0.001	<0.001	<0.005	<0.002
Emuo River	EMTR	2.01	0.342	0.003	<0.001	<0.005	<0.002
Kade Brim River	KDBR	3.03	0.078	0.002	<0.001	<0.005	<0.002
Osino Birim River	OSBR	2.10	0.201	0.003	<0.001	<0.005	<0.002
Brimso Asiakwa Birim River	BABR	2.02	0.198	0.002	<0.001	<0.005	<0.002
Bunso Birim River	BNBR	10.4	0.183	0.002	<0.001	<0.005	<0.002
Mempasem Mine pond	MPMP	7.31	1.24	0.004	<0.001	<0.005	<0.002
Akanten Mine pond	AKMP	7.02	2.01	0.011	0.002	<0.005	<0.002
Anyinam Brim River	ANBR	4.30	0.152	<0.001	<0.001	<0.005	<0.002
Sample ID (Total) Total		**Fe**	**Mn**	**Hg**	**As**	**Pb**	**Cd**
Osino Borehole	OSBH	<0.010	0.109	<0.001	<0.001	<0.005	<0.002
Akanten Borehole	AKBH	0.437	0.783	0.002	0.003	<0.005	<0.002
Apaapam Birim River	APBR	1.65	0.065	0.005	0.001	<0.005	0.003
Oda Brim River	ODBR	7.64	0.083	0.004	0.060	<0.005	0.002
Emuo River	EMTR	11.3	0.466	0.004	0.030	<0.005	0.004
Kade Brim River	KDBR	10.2	0.097	0.006	0.090	<0.005	0.005
Osino Birim River	OSBR	24.9	0.300	0.003	0.180	<0.005	0.002
Brimso Asiakwa Birim River	BABR	20.0	0.226	0.005	0.332	<0.005	<0.002
Bunso Birim River	BNBR	52.1	0.230	0.004	0.332	<0.005	0.002
Mempasem Mining Pond	MPMP	17.6	1.61	0.023	0.152	<0.005	0.003
Akanten Mine Pond	AKMP	100	2.31	0.042	0.380	<0.005	0.009
Anyinam Brim River	ANBR	26.4	0.169	0.005	0.150	<0.005	0.002

Appendix IV - Water Sample Results (Physiochemical parameters)

Sample ID	Temp (F.W)	Temp (F.D)	pH (F.W)	pH (F.D)	pH (L.W)	pH (L.D)	Cond (L.W)	Cond (L.D)	Alk mg/l (W)	Alk (D)	Bicarb (W)	Bicarb (D)
BR1	23.6	23.3	6.87	8.63	7.26	7.38	130	182	56.0	64.0	68	78
BR2	27.7	25.3	7.48	8	7.14	7.13	127	159	53.0	62	65	76
BR3	25.4	26.8	6.18	7.74	7.29	7.50	133	162	61.0	73	75	89
BR4	24.7	25.8	6.4	7.99	7.41	7.50	131	151	57	66.0	69	81
BR5	24.5	26.2	6.54	8.08	7.49	7.66	132	154	55	71	68	86
BR6	25	27.3	6.15	7.9	7.42	7.56	155	174	65	74	80	90
BR7	24.3	27.8	6.45	8.12	7.61	7.71	169	184	76	80	92	98
BR8	24	27.7	6.82	8.02	7.66	7.62	132	161	56	62	69	76
BR9	24.2	27	6.61	8.12	7.67	7.33	132	148	59	50.0	69	61.0
BR10	24.8	25.6	6.34	7.76	7.21	7.38	127	165	52.0	63	63	77
BR11	26.6	25	5.82	8.3	6.91	7.34	96.1	120	28	48	34	58
BR12	27.5	26.6	5.92	7.6	6.86	7.46	93.4	134	35	46.0	42	56
BR13	27.7	27.7	6.28	7.57	6.81	7.40	89.6	138	36	46.0	44	56
BR 14	26.1	27.8	6.32	7.4	6.99	7.23	82.0	111	34	47	42	57
BR 15	27	28.4	5.6	7.59	6.94	7.25	82.4	107	34	44.0	41	54
BR 16	28.2	28.3	5.6	7.29	6.99	7.29	83.1	107	33.0	42.0	40	51
BR 17	26.4	28.3	5.87	7.7	7.03	7.22	83.8	108	34	44.0	41.0	54
BR 18	26.3	27.3	6.05	7.34	7.06	7.32	85.3	113	34	44.0	41.0	54
BR 19	25.9	26.8	6.86	7.85	7.15	7.17	105	125	42	54	52	66
BR 20	26.8	29.3	6.52	7.9	7.10	7.15	85.4	118	36	51	44	63
BR 21	25.9	26.8	6.86	7.85	7.17	7.41	107	114	41.0	45	50.0	55
TRI	22.5	25.9	6.89	7.58	7.37	7.36	218	214	87	92.0	107	112
TR2	22.4	26.7	6.74	7.82	7.51	7.56	158	182	71.0	71	87	87
TR3	22.7	25.8	6.07	7.68	7.26	7.15	167	185	68	82.0	83	100
TR4	25.5	25.6	6.39	7.63	6.75	7.1	72.7	74.3	31	30	38	37
TR5	25	25.4	5.78	6.7	6.45	6.52	240	224	100	97	122	119
TR6	25.3	25.2	6.59	7.6	7.21	7.19	99.3	119	40	52.0	49.0	63
TR7	26.1	25.4	6	7.04	6.77	6.98	77.0	98.3	31	41	37	51
TR8	25.4	26.1	6.26	7.25	6.80	7.1	73.7	98.1	30	46	37	56
TR9	24.4	26.7	6	7.25	7.11	7.19	81.6	90.3	32	37.0	39	45
TR10	24.5	25.2	6.65	7.42	7.34	7.39	126	142	58.0	71	71	86
TR 11	26.1	26.2	5.92	7.45	6.95	7.27	91.0	132	38	54.0	47	66
TTR1	24.5	26.2	5.63	7.01	6.68	6.62	87.1	98.9	32	48	39	58
BRBH1	30.3	26.5	5.95	6.8	6.25	6.35	448	450	84	72	103	88
BRBH5	25.5	26.7	5.44	6.83	6.47	6.59	282	276	93	90.0	114	110
BRBH 11	28.4	27	5.05	6.3	6.13	5.85	218	97.5	59	25	72	30
BRBH12	27.8	27.2	4.75	6.36	5.92	6.35	138	146	43	52	56	64
BRBH 13	30.5	28.3	5.13	6.4	6.02	5.87	69.1	80.5	26	36.0	32	44

Sample ID	**Temp (F.W)**	**Temp (F.D)**	**pH (F.W)**	**pH (F.D)**	**pH (L.W)**	**pH (L.D)**	**Cond (L.W)**	**Cond (L.D)**	**Alk mg/l (W)**	**Alk (D)**	**Bicarb (W)**	**Bicarb (D)**
BRBH 18	26.7	26.2	4.68	5.6	5.01	5.24	53.0	53.3	4.80	13	5.86	15
BRBH 19	29.6	28.9	6.8	7.4	7.24	7.36	447	464	221	189	2.7	231
TTRBH1	26.8	27.7	5.33	6.6	6.24	6.11	95.8	105	41.0	42	50.0	51
TRBH1	27.7	26.6	5.02	6.2	6.13	6.12	132	140	65.0	69.0	79	84
TRBH8	26.6	26.6	5.53	6.4	6.33	6.26	182	182	30	87	98	107
TRBH 10	27.4	26.4	5.11	5.96	5.91	5.84	179	206	34	39	42.0	48
Treated Water	26.3	27	6.3	7.65	7.28	7.4	168	186	61	70	75	85
BRMP1	31.1		5.95		6.23		19.7		6.00		7.3	
BRMP5	28	32.1	6.42	8.35	6.97	6.20	91.3	112	22	12	26	15
BRMP11	28.5	25.5	5.94	7.96	6.86	7.27	94.5	141	40	57.0	48	70
BRMP12	30.9	28	5.9	7.22	6.58	6.64	50.9	66.5	14	15	17	18
TRMP 2	24.5	32.6	5.8	8.92	7.51	7.35	158	160	71.0	76.0	87	93
TTRMP1	28.3	32	6.41	7.59	7.03	7.24	76.8	85.6	30.0	36.0	37	44

Sample ID	TDS/PPM (D)	TURB (W)	TURB **(D)**	Col. (App W)	Col. (App D)	Col. (True W)	Col. (True D)	TSS (W)	TSS (D)
BR1	71.2	10.0	<1.00	<2.50	2.50	2.50	<2.50	6.00	<1.00
BR2	86	10.0	<1.00	7.50	<2.50	2.50	<2.50	4.00	<1.00
BR3	94.4	18.0	<1.00	20.0	<2.50	15.0	<2.50	15.0	<1.00
BR4	94.4	15.0	1.00	20.0	5.00	10.0	2.50	13.0	1.00
BR5	95.8	18.0	<1.00	15.0	<2.50	10.0	<2.50	17.0	<1.00
BR6	111	15.0	1.00	15.0	<2.50	7.50	<2.50	12.0	1.00
BR7	123	12.0	<1.00	15.0	<2.50	7.50	<2.50	12.0	<1.00
BR8	107	46.0	39.0	20.0	25.0	10.0	10.0	38.0	45.0
BR9	101	107	850	75.0	150	50.0	45.0	91.0	998
BR10	107	118	237	75.0	100	50.0	45.0	106	275
BR11	83.7	161	163	75.0	100	50.0	45.0	143	160
BR12	88.4	302	469	100	125	50	65.0	277	470
BR13	82.5	74.0	341	40.0	300	25.0	80.0	68.0	328
BR 14	68	85.0	869	50.0	600	20.0	150	70.0	850
BR 15	69.2	87.0	398	37.5	100	20.0	65.0	76.0	388
BR 16	69.4	85.0	711	37.5	150	20.0	70.0	76.0	750
BR 17	72.8	99.0	300	50.0	125	25.0	75.0	86.0	294
BR 18	75	106	160	50.0	100	25.0	60.0	94.0	156

Sample ID	TDS/PPM (D)	TURB (W)	TURB **(D)**	Col. (App W)	Col. (App D)	Col. (True W)	Col. (True D)	TSS (W)	TSS (D)
BR 19	84	39.0	273	37.5	100	25.0	45.0	33.0	271
BR 20	80	111	170	75.0	100	37.5	50.0	95.0	184
BR 21	84	53.0	138	37.5	100	25.0	55.0	42.0	150
TRI	132	35.0	<1.00	15.0	<2.50	10.0	<2.50	30.0	<1.00
TR2	102	10.0	4.00	10.0	2.50	5.00	<2.50	8.00	3.00
TR3	118	9.00	<1.00	7.50	<2.50	5.00	<2.50	5.00	<1.00
TR4	52.1	19.0	80.0	15.0	25.0	10.0	10.0	17.0	76.0
TR5	201	105	51.0	100	40.0	50.0	15.0	70.0	50.0
TR6	77.6	<1.00	1.00	7.50	<2.50	2.50	<2.50	<1.00	1.00
TR7	66.1	52.0	174	50.0	75.0	25.0	25.0	39.0	170
TR8	67	16.0	<1.00	30.0	<2.50	20.0	<2.50	12.0	<1.00
TR9	62.6	37.0	<1.00	20.0	<2.50	15.0	<2.50	35.0	<1.00
TR10	94.4	10.0	<1.00	15.0	<2.50	10.0	<2.50	7.00	<1.00
TR 11	83.2	71.0	235	30.0	125	20.0	70.0	66.0	240
TTR1	66.8	15.0	<1.00	40.0	<2.50	30.0	<2.50	10.0	<1.00
BRBH1	315	<1.00	<1.00	<2.50	<2.50	<2.50	<2.50	<1.00	<1.00
BRBH5	209	3.00	<1.00	<2.50	2.50	<2.50	<2.50	1.00	<1.00
BRBH 11	70.7	4.00	2.00	7.50	5.00	<2.50	2.50	2.00	1.00
BRBH12	99	<1.00	<1.00	<2.50	<2.50	<2.50	<2.50	<1.00	<1.00
BRBH 13	56.7	<1.00	<1.00	<2.50	<2.50	<2.50	<2.50	<1.00	<1.00
BRBH 18	40	<1.00	<1.00	<2.50	<2.50	<2.50	<2.50	<1.00	<1.00
BRBH 19	353	<1.00	<1.00	<2.50	<2.50	<2.50	<2.50	<1.00	<1.00
TTRBH1	95	<1.00	<1.00	<2.50	<2.50	<2.50	<2.50	<1.00	<1.00
TRBH1	69.7	7.00	<1.00	7.50	<2.50	<2.50	<2.50	4.00	<1.00
TRBH8	110	<1.00	<1.00	<2.50	<2.50	<2.50	<2.50	<1.00	<1.00
TRBH 10	125	<1.00	<1.00	<2.50	<2.50	<2.50	<2.50	<1.00	<1.00
Treated Water	122	<1.00	<1.00	<2.50	<2.50	<2.50	<2.50	<1.00	<1.00
BRMP1		40.0		30.0		20.0		28.0	
BRMP5	71.1	10.0	87.0	5.00	37.5	2.50	15.0	7.00	90.0
BRMP11	94	55.0	170	40.0	100	15.0	50.0	48.0	160
BRMP12	47.7	26	<1.00	20	<2.50	15	<2.50	20	<1.00
TRMP 2	94.4	10.0	3.00	10.0	5.00	5.00	2.50	8.00	2.00
TTRMP1	58.6	3.00	<1.00	5.00	<2.50	<2.50	<2.50	1.00	<1.00

Appendix V - Water Sample Results (Heavy Metals)

Sample ID	As Conc. Wet	As Conc. Dry	Pb Conc. (W)	Pb Conc. (D)	Cd Conc. (W)	Cd Conc. (D)
BR1	<0.0005	<0.0005	0.0008	0.0032	<0.0001	<0.0001
BR2	<0.0005	<0.0005	0.0007	0.0022	<0.0001	<0.0001
BR3	<0.0005	0.0028	0.0006	0.0009	<0.0001	<0.0001
BR4	0.0006	0.0006	0.0006	0.001	<0.0001	<0.0001
BR5	<0.0005	<0.0005	0.0017	0.0033	<0.0001	<0.0001
BR6	0.0011	0.0037	0.0016	0.0024	<0.0001	<0.0001
BR7	<0.0005	<0.0005	0.0005	0.0018	<0.0001	<0.0001
BR8	<0.0005	0.0019	0.001	0.0011	<0.0001	<0.0001
BR9	0.0006	0.0021	0.0015	0.0093	<0.0001	0.0002
BR10	0.0006	0.006	0.0024	0.011	<0.0001	<0.0001
BR11	<0.0005	0.0012	0.0042	0.0016	<0.0001	<0.0001
BR12	0.002	0.0031	0.003	0.0026	<0.0001	<0.0001
BR13	0.0023	0.0044	0.0016	0.0043	<0.0001	<0.0001
BR 14	<0.0005	0.0015	0.0013	0.012	<0.0001	<0.0001
BR 15	0.0029	0.0034	0.0017	0.0092	<0.0001	<0.0001
BR 16	0.0011	0.0038	0.0015	0.0055	<0.0001	<0.0001
BR 17	0.0011	0.0027	0.0017	0.0036	<0.0001	<0.0001
BR 18	0.001	0.0021	0.0018	0.0038	<0.0001	<0.0001
BR 19	0.0008	0.0029	0.0009	0.0036	<0.0001	<0.0001
BR 20	0.0046	0.0036	0.0029	0.0032	<0.0001	<0.0001
BR 21	<0.0005	<0.0005	0.0009	0.002	<0.0001	<0.0001
TRI	0.0011	0.0013	<0.0005	0.0007	<0.0001	<0.0001
TR2	0.0019	0.0019	<0.0005	0.0017	<0.0001	<0.0001
TR3	0.001	0.0027	0.0005	0.0008	<0.0001	0.0002
TR4	<0.0005	<0.0005	0.0007	0.002	<0.0001	<0.0001
TR5	0.0092	0.0094	0.0005	0.0008	<0.0001	<0.0001
TR6	<0.0005	<0.0005	0.0006	0.0009	<0.0001	<0.0001
TR7	0.0023	0.0044	0.001	0.0077	<0.0001	0.0001
TR8	0.002	0.0028	0.0005	0.0022	<0.0001	0.0002
TR9	<0.0005	<0.0005	<0.0005	0.0013	<0.0001	0.0001
TR10	<0.0005	0.0012	0.0006	0.002	<0.0001	<0.0001
TR 11	<0.0005	0.0043	0.0009	0.0025	<0.0001	<0.0001
TTR1	0.0015	0.0009	<0.0005	0.0016	<0.0001	<0.0001
BRBH1	0.0022	<0.0005	<0.0005	0.0017	0.0002	<0.0001
BRBH5	<0.0005	0.028	0.0005	0.0008	<0.0001	0.02

Sample ID	As Conc. Wet	As Conc. Dry	Pb Conc. (W)	Pb Conc. (D)	Cd Conc. (W)	Cd Conc. (D)
BRBH 11	<0.0005	0.014	0.0019	<0.0005	<0.0001	<0.0001
BRBH12	0.014	0.021	0.0033	0.0009	<0.0001	<0.0001
BRBH 13	0.002	<0.0005	0.0015	0.0013	<0.0001	0.0009
BRBH 18	<0.0005	0.015	0.0055	<0.0005	<0.0001	0.0008
BRBH 19	<0.0005	<0.0005	0.0007	0.002	<0.0001	0.0007
TTRBH1	0.0013	<0.0005	0.0025	0.0008	<0.0001	0.001
TRBH1	0.0074	<0.0005	0.0021	0.0056	<0.0001	<0.0001
TRBH8	<0.0005	0.0022	0.0017	<0.0005	<0.0001	0.0006
TRBH 10	0.0022	<0.0005	0.0032	0.002	<0.0001	0.0007
Treated Water	<0.0005	<0.0005	0.0009	0.0015	<0.0001	0.0009
BRMP1	<0.0005		0.0011		<0.0001	
BRMP5	<0.0005	0.0019	0.0008	0.0016	<0.0001	<0.0001
BRMP11	<0.0005	0.0039	0.001	0.0034	<0.0001	<0.0001
BRMP12	0.0008	0.017	0.0008	<0.0005	<0.0001	<0.0001
TRMP 2	0.0013	0.0018	0.0006	0.0026	<0.0001	<0.0001
TTRMP1	0.0011	<0.0005	<0.0005	0.0028	<0.0001	0.001

Sample ID	Mercury (W)	Mercury (D)	Manganese (W)	Manganese (D)	Iron (W)	Iron (D)
BR1	0.0004	0.002	0.038	0.029	0.3	0.3
BR2	0.0003	0.0009	0.068	0.06	0.8	0.7
BR3	0.0001	0.0003	0.11	0.069	0.9	0.8
BR4	0.0001	<0.0001	0.078	0.038	1.3	0.8
BR5	0.0001	0.001	0.08	0.022	1.5	0.8
BR6	0.0001	<0.0001	0.1	0.072	1.1	0.9
BR7	<0.0001	<0.0001	0.05	0.066	0.9	0.9
BR8	<0.0001	<0.0001	0.11	0.061	1.6	1.3
BR9	<0.0001	<0.0001	0.095	0.41	3.5	19.3
BR10	<0.0001	<0.0001	0.15	0.17	4.3	5.6
BR11	<0.0001	<0.0001	0.24	0.073	5.6	3.5
BR12	<0.0001	<0.0001	0.22	0.13	4.8	4.4
BR13	<0.0001	0.003	0.16	0.14	2.8	6.2
BR 14	<0.0001	0.0004	0.14	0.17	3.9	7.7
BR 15	<0.0001	<0.0001	0.18	0.17	4.6	9.
BR 16	<0.0001	<0.0001	0.21	0.15	4.5	7.6

Sample ID	Mercury (W)	Mercury (D)	Manganese (W)	Manganese (D)	Iron (W)	Iron (D)
BR 17	<0.0001	<0.0001	0.22	0.14	4.8	5.9
BR 18	<0.0001	0.0004	0.22	0.15	5.2	6.1
BR 19	<0.0001	<0.0001	0.15	0.17	4.6	7.5
BR 20	<0.0001	<0.0001	0.35	0.12	6.5	6.2
BR 21	<0.0001	<0.0001	0.17	0.14	4.5	6.1
TRI	<0.0001	<0.0001	0.39	0.27	3.	2.6
TR2	<0.0001	<0.0001	0.1	0.12	0.7	0.8
TR3	<0.0001	<0.0001	0.097	0.11	0.6	0.8
TR4	<0.0001	<0.0001	0.12	0.085	1.7	3.8
TR5	<0.0001	<0.0001	0.76	0.56	21.9	14.9
TR6	<0.0001	<0.0001	0.062	0.14	0.5	0.6
TR7	<0.0001	<0.0001	0.14	0.097	3.8	3.6
TR8	<0.0001	<0.0001	0.094	0.08	2.9	1.8
TR9	<0.0001	<0.0001	0.1	0.045	2.	0.7
TR10	<0.0001	0.002	0.038	0.023	1.3	0.8
TR 11	<0.0001	<0.0001	0.12	0.11	4.9	5.5
TTR1	<0.0001	<0.0001	0.05	0.05	3.1	3.
BRBH1	<0.0001	0.002	0.56	0.35	<0.1	<0.1
BRBH5	<0.0001	0.02	0.16	0.16	0.7	0.4
BRBH 11	<0.0001	0.002	0.038	0.011	0.2	0.4
BRBH12	<0.0001	0.002	0.28	0.21	<0.1	<0.1
BRBH 13	<0.0001	0.0001	0.015	0.059	<0.1	<0.1
BRBH 18	<0.0001	0.001	0.035	0.01	<0.1	<0.1
BRBH 19	0.0001	<0.0001	<0.002	0.008	<0.1	<0.1
TTRBH1	0.001	<0.0001	0.014	0.012	<0.1	<0.1
TRBH1	0.0003	0.06	0.52	0.2	2.3	2.4
TRBH8	<0.0001	0.002	0.23	0.007	1.1	0.8
TRBH 10	0.0005	<0.0001	0.008	0.007	<0.1	<0.1
Treated Water	<0.0001	<0.0001	0.003	<0.002	<0.1	<0.1
BRMP1	<0.0001		0.019		1.5	
BRMP5	<0.0001	<0.0001	0.085	0.25	0.2	0.9
BRMP11	<0.0001	<0.0001	0.15	0.18	2.7	4.1
BRMP12	<0.0001	0.0005	0.099	0.011	1.1	0.2
TRMP 2	<0.0001	<0.0001	0.034	0.33	0.3	5.7
TTRMP1	0.0005	<0.0001	0.025	0.03	0.5	0.3

Appendix VI - Additional Materials

Table 1.1: Organisations and their responsibilities (Water Resource Management)

Institution	Responsibility
Ministry of Water Resources and Works and Housing (MWRWH)	The lead government institution responsible for water is responsible for overall policy formulation, planning, coordination, collaboration, monitoring and evaluation of programmes for water supply and sanitation.
Ministry of Local Government, Rural Development and Environment	Responsible for implementing the Environmental Sanitation Policy including management and regulation of solid and liquid wastes by local government bodies viz. Metropolitan, Municipal and District Assemblies (DAs).
District Assembly	This is the basic unit of Government at the district level and is the statutory deliberative and legislative body for the determination of broad policy objectives of the development process within their jurisdictions. DAs are responsible for the planning, implementation, operation and maintenance of water and sanitation facilities and the legal owners of communal infrastructures in rural communities and small towns. The detailed functions and mandates of Metropolitan, Municipal and District Assemblies (DAs) are defined in Local Government Act, 1993 (Act 462) and establishment instruments ((Legislative Instruments) of the Assemblies.
Water Resources Commission	Responsible for the regulation and management of water resources and for the coordination of policies in relation to them, and provides a focal point in fostering coordination and collaboration among the various actors involved in the water resources sector. The responsibilities of the Commission are wide ranging and key responsibilities are set out in Water Resources Commission Act, 1996 (Act 522).

Institution	Responsibility
Ghana Water Company Limited (GWCL)	is responsible for overall planning, managing and implementation of urban water supply. Their roles, responsibilities and mandates are set in the Ghana Water Company Limited (GWCL) Act, 1999 (Act 461).
Community Water and Sanitation Agency (CWSA) of the MWRWH.	This emerged from the Community Water and Sanitation Division of the Ghana Water and Sewerage Corporation (GWSC). CWSA is the lead facilitator of the rural water supply and sanitation sub-sector (rural communities and small towns), and is responsible for external liaison and co-ordination of the National Community Water and Sanitation Programme (NCWSP). The key functions of CWSA are set out in the Community Water and Sanitation Agency (CWSA) Act, 1998 (Act 564).
Ghana Irrigation Development Authority (GIDA)	Established in 1977 by SMCD 85 under the Ministry of Food and Agriculture (MOFA) to replace the Irrigation Department which started as a purely Water and Soil Conservation Unit and later expanded into Irrigation and Reclamation. GIDA focuses mainly on water conservation and irrigation and is responsible for the development of the country's water resources for irrigated farming, livestock watering and supports fish culture in irrigation ponds and dams. GIDA dams also serve as sources of water for domestic supplies in many rural communities.
Ministry of fisheries	Responsible for fisheries and fish culture and regulates activities for both in-land water and marine fishing.
Ministry of Harbours and Railways	Responsible for water transport and navigation and regulates activities within both in-land and coastal territory of Ghana.
Ministry of Energy	Responsible for water-for-energy and regulates the provision of hydro-power including its distribution.

Institution	Responsibility
Ministry of Health	Responsible for policy formulation and implements its plans and programmes through the Ghana Health Service (GHS)
Water Resources Information Services (WRIS) institutions	The WRIS institutions provide data and other water resources related information and services to support planning and decision making.
Public Utilities Regulatory Commission	Regulates the standard of services including the quality of drinking water provided by the GWCL and also the tariff set.

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Curriculum Vitae

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Education

- **2016 – 2021:** University of Western Ontario
  Programme: **PhD Candidate (Civil and Environmental Engineering)**
- **2008– 2009:** Sheffield Hallam University, Sheffield, England
  Qualification: **MSc Project Management (Distinction)**
- **2003–2007:** Kwame Nkrumah University of Science and Technology, Ghana
  Qualification: **BSc Building Technology (First Class Honours)**

Awards

- **2016 Emerald Literati Network Awards for Excellence -** for Journal paper “An analysis of risk management in practice: the case of Ghana’s construction industry” published in Journal of Engineering, Design and Technology 2015.
- **2008 – 2009 Commonwealth Shared Scholarship (CSS) Award**

Journal Publications (6)

- **Yirenkyi-Fianko, A. B**. and Chileshe, N. (2015) "An analysis of risk management in practice: the case of Ghana’s construction industry", Journal of Engineering, Design and Technology, Vol. 13 Iss: 2, pp.240 – 259
- **Yirenkyi-Fianko, A. B.,** Chileshe, N., and Stephenson, P. (2012) ‘Critical Success Factors of Risk Assessment and Management Processes (RAMP) in Ghanaian Construction Related Organisations’, *International Journal of Project Organisation and Management*, Vol. 4, No. 4, pp 379-396.
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Recent Conference Presentations [3]

- **Yirenkyi-Fianko, A.** and Yanful, E. (2020), Perception of Water Quality in Communities along Rivers in Mining Areas - The Case of the Birim Basin in Ghana. Presentation at Africa-Western Collaboration on 18th November 2020
- **Yirenkyi-Fianko, A.** and Yanful, E. (2020) Will a ban on Artisanal and Small-Sclae Mining activities improve the health of inhabitants of rural mining communities? An assessment of Arsenic and Lead in Drinking Water, Poster Listing of the 26th Canadian Conference on Global Health, Canada -19th -22nd October 2020
- **Yirenkyi-Fianko, A.** and Yanful, E (2018) Impact of Artisanal and Small-scale Mining on Water bodies. Poster Presentation. Africa-Western Collaboration. November 2018.

Work in progress

- Assessment of Water Quality in the Birim Basin
- Perception of Water Quality in Communities along Rivers in Mining Areas-The Case of the Birim River Basin in Ghana
- Assessment of contamination and health risk of heavy metals in the Birim River Basin in Ghana.

- Iron, Lead and Arsenic removal from water using Moringa seeds, Coconut husk and Corn husk.