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EFFECT OF SMALL SCALE GOLD MINING ON RIVERS JIMI AND NYAME AT OBUASI

BY

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DECLARATION

I hereby declare that this submission is my own work towards the Masters of Science Degree in Environmental Science and that, to the best of my knowledge; it contains no material(s) previously published by another person(s) which have been accepted for the award of any other degree of the University, except where acknowledgement has been made in the text.

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DEDICATION

This work is dedicated to Ronald Agyapong Brako and all my family members without their prayers and guidance, the accomplishment of this thesis would not have been possible.

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ABSTRACT

Small scale gold miners in Ghana rely mostly on water resources for gold processing resulting in the release of harmful substances that impact negatively on water quality. The purpose of this study was to examine the heavy metal content and physicochemical parameters of River Nyame and River Jimi at Obuasi and its environs in Ashanti Region of Ghana. To achieve these objective, standard methods for portable water quality were used to examine the physicochemical parameter whilst Atomic Absorption Spectrophotometer (AAS) was used to determine the concentrations of metals in the sampled water. The study found that most of the concentrations of physicochemical parameter such as, temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), and metals such as mercury, zinc, lead, and manganese, as well as toxic anions like Nitrate (NO_3^{-}), Sulphate (SO_4^{2-}) and Phosphate (PO_4^{2-}) were within the prescribed limit for water quality standards. However, the study identify higher concentrations of Arsenic slightly above the prescribed water quality guideline values and also realized that, the concentration of cadmium had also reached the maximum prescribed permissible limit of 0.003 mg/L given by World Health Organization. Retrospective analysis shows that the pH of the water bodies had influence on the concentration of metals such as zinc, arsenic, and manganese by altering their availability and toxicity. Although mitigation efforts have had a limited impact, it is expected that the policy recommendations of this study if adopted and strictly adhered to will help reduce, if not completely ameliorate the environmental ramification of small scale mining in Ghana.

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background of the Study

Ghana is a mineral rich country, possessing huge quantities of mineral deposits predominant among which is gold. Historically, the importance of mining in the economic development of Ghana is considerably documented (Aryee et al., 2003), with Ghanaian's former name 'Gold Coast', reflecting its significant role in the mining sector. Mining in Ghana however can be traced back to the pre-colonial days where gold was the main object of the mining activity. These 'precious stones' were usually designed into various artifacts.

The interrelationships between the environments and humans, employing various means of technologies to exploit available resources pose threats to the environment. Such technological advancement has enabled the progressive and extensive exploitation and utilization of resources such as gold, which has inadvertently impacted negatively on the resources of the environment such as water bodies (Ntibrey, 2001). These activities have repercussions on the general health, employment, mortality and morbidity rates as the very existence of man is dependent on the quality and soundness of water resources.

Mining activities are ramification of serious environmental compromises in Ghana (Hilson, 2001), in spite of its contribution to developmental activities. The ordinary Ghanaian has benefited from the mining activities and has rather incurred and suffered not only economic hardship but also directly from diseases resulting from the pollution of water bodies (Bannerman et al. 2003). Aside massive environmental degradation, there has been many human right violations which are linked with mining.

There have been many initiatives by the government of Ghana with assistance of the

World Bank and German Non-Governmental Organization (NGO), Gesellschaft Technishe Zusannebarbeit (GTZ) in recent years to regularise and formalize Small Scale Mining (SSM) operations solely by the citizen of Ghana. This initiatives have witnessed significant improvement in operational efficiency. However, water pollution and other negative environmental issues have become quite unimaginable. This necessitate proactive measures aim at addressing urgent specific environmental complications resulting from uncontrolled and ill-monitored smallscale mining activities.

Despite a number of issues related to small scale gold mining in Ghana, this study focused on the determination of heavy metals concentration and physicochemical characteristics of some water resources at Obuasi and its environs in Ashanti Region of Ghana.

1.2 Problem Statement

Mining activities are resulting into serious environmental problems in Ghana. For instance, a Journal titled "A Voice for Communities Affected by Mining" published in 2006 indicated that, in 2001, water sources that feeds five villages were severely polluted with thousands of toxic from mine waste in the Asaman River which affected more than 1,000 inhabitants.

Water bodies are polluted by the emissions and sometimes spillage of poisonous chemicals during the ore refining process. This, in turn, endangers fish and other aquatic life. Air quality has also deteriorated in mining areas as a result of the emissions of poisonous chemicals such as, arsenic oxide from milling plants during certain stages of the ore refining process. Such gases also adversely affect the natural vegetation when it comes into direct contact with trees and grass (Shoko and Love, 2005).

From the social perspective, it is worth noting that, such harmful gases when produced in excess, have been found to have an adverse effect on the health of workers and people residing in mining areas, causing high incidence of upper respiratory tract diseases such as asthma, tuberculosis, bronchitis, among others. These health problems also in turn lead to a fall in man- hours of work with serious economic implications for production and revenue generation efforts.

Small Scale (SS) gold miners use mercury even though they are aware of its harmful effects on their health, because they have narrow source of livelihood. The environmental problems caused by SS gold mining include mercury contamination, removal of plants, destruction of forests and jungles, contamination of water, particle emissions to the atmosphere, siltation, degradation of river banks, digging of holes and trenches that endanger wildlife and a major cause of erosion (Ravengai et al., 2005).

This study will therefore determine heavy metals concentration and physicochemical characteristics of some water resources at Obuasi and its environs in Ashanti Region of Ghana.

1.3 Research Objectives

The ultimate aim of this thesis was to determine the environmental impacts of SS gold mining on Rivers Jimi and Nyame at Obuasi and its environs in Ashanti Region of Ghana. The specific objectives of this study were to:

1. Determine the concentration of some heavy metals (Mercury, Arsenic, Cadmium, Zinc, Manganese and Lead) in water samples from two rivers

2. Determine the physicochemical characteristics of the water samples
3. Determine the relationship between the physicochemical parameters and heavy metals.

1.4 Research Question

The following research questions are developed based on the above objectives.

1. What are the concentrations of some heavy metals (Mercury, Arsenic, Cadmium, Zinc, Manganese and Lead) in river samples?
2. What are the physicochemical characteristics of the water samples from River Jimi and River Nyame?
3. Is there a relationship between the physicochemical and heavy metals of the water samples from River Jimi and River Nyame?

1.5 Scope of the Study

This study is limited to the environmental impacts of small scale gold mining on River Jimi and River Nyame at Obuasi and its environs in Ashanti Region of Ghana. Despite the availability of a number of issues related to operation of small scale gold mining in Ghana. This study assesses the environmental impacts of small scale gold mining on water resources.

1.6 Measurement and Data Collection

This empirical study will use field instruments which are calibrated according to the standard method for measurement of water. The water samples were taken monthly in duplicates from river Jimi and river Nyame at Obuasi and its environs. The samples were collected in sterile plastic bottles and transported to the laboratory for analysis.

The accuracy and precision of the analytical techniques will be assessed by analyses of reference materials and reagent blank before the samples will be analyzed.

1.7 Justification of Study

Water resources supports man's survival and requires sustained usage. The need to serve the current and future populations requires that, explicit measures are put in place to ensure that, decisions in current times and in the future are made.

Notwithstanding the above, mining has been identified to be one of the basic economic foundations of Ghana (Lombe, 2003). However, the activity has been identified with numerous adverse impacts on water resources. Hence, it is necessary to assess the environmental impacts of small scale gold mining on water resources at Obuasi and its environs in Ashanti Region.

The results of this study will inform policy interventions to help reduce the health and environmental problems to increase productivity since the health hazards will be reduced. The impact of mining on water resources which are mostly very costly to mitigate, would be reduced if the recommendations of this study are implemented thereby reducing government spending, maintaining good health and protecting the water resources. The research will also serve as source of information for other researchers.

1.8 Limitation of the Study

The study is restricted to the activities of small scale gold mining on water bodies. The research is limited to the environmental impacts of small scale gold mining on River Jimi and River Nyame at Obuasi in Ashanti Region of Ghana. These rivers have been chosen because they are most affected in the area and a lot of inhabitant rely on it for their domestic use. There is also lack of time and adequate financial resources challenge to the extent of scope that the study would have covered. Despite these limitations to the study, it was carried out diligently to make it representative and useful in order to improve upon the knowledge base in this study area.

1.9 Organization of the Study

The study has been divided into six main chapters. Chapter one provides brief background to the study, statement of problem for which this project work is indispensable and justification of the needs to carry out this study on water resources in small scale mining communities.

Chapter two dilates on the literature reviews on environmental impacts of small scale gold mining on water resources. A theoretical framework of environmental impacts of mining activities, which is based upon a review and integration of the literature, expounded upon to aid the understanding and analysis on issues of small scale gold mining on water resources.

It is axiomatic that every development problems and interventions manifest itself in space. Hence, chapter three visualised and delineate the profiles of the study area. In a sequel to the above, this chapter subsequently, bring into focus the methodological approach for assessing the environmental impacts of small scale gold mining on water resources. This is followed by the presentation of findings and discussing in chapter four.

Chapter five discussed the findings whilst chapter six recapitulate this study by dilating on the key findings from the study and as well give useful conclusions and recommendations to inform policy decisions on mitigation of environmental impacts of small scale gold mining on water resources.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The principal spillover effects of Small Scale gold mining activities on water resources have elicited emotive public concern, and have become a matter of priority for international organizations. In Ghana, the concomitant impacts of these SS gold mining activities have largely been neglected. However, publications in national academic literature has emphasized the sector contributions to foreign-exchange earnings, and are recognized by national government in the developing countries as the cornerstones of a multimillion-dollar industrial sector. The review also details theories and definitions of key concept which are coherent to better understanding of this project work.

2.2 Definition and Concepts

The key concept, inter alia, to aid retrospective analysis of environmental consequence of Small Scale Mining (SSM) activities on water resources in Ghana are expounded below.

2.2.1 Small-Scale Mining (SSM)

Different definitions have been attributed to SSM all over the world. The Intermediate Technology Development Group (ITDG) and the United Nations (UN) have in general defined SSM in respect to the level of production capacity, or on the bases of sophistication used in exploiting the mineral.

According to the United Nation (UN), SSM is defined as an individual mining operation with an annual production of unrefined minerals of 50,000 tonnes, or below measured on site. The *Intermediate Technology Development Group* refer to SS miners 'poor people; individuals or small groups who are dependent on mining activities for living by employing undeveloped tools and methods (e.g. chisels, pick axe, pans and sluices) in exploiting mineral deposits*' (ITDG, 2001).*

The World Bank Group (2001) defined SSM as hugely poverty-induced activity, mostly carried out in the most rural remote areas by areas of a state by a mainly wayfaring, uneducated segment of the population having fewer employment options. There are about 13 million SSM operations among low income countries working under risky and harsh conditions in 30 countries comprising 80 to 100 million dependencies worldwide.

According to the SS Gold Mining Law of 1989 (PNDC Law 218), SSM is defined as 'mining by any method not involving substantial expenditure by an individual or group of persons not exceeding nine in number or by a co-operative society made up of ten or more persons'. The above definitions of SSM is what is specifically refer to as 'artisanal'. Artisanal SSM operations use primitive tools that involve manual work with limited capital investment.

2.2.2 Mining Concession

The mining acts (Act 218 and 708) do not give a concise definition of mining concession. However, concessions regarding mining epitomize tangible and immovable privileges which is independent and different from ownership of land. This may belong to the similar owner; as oppose to any person or the state; transmissible and transferable; disposed to mortgage and other secure rights and, in general, to any act or contract; and are ruled by the generally civil laws relevant to other immovable rights.

Thus, mining concession is a legal entitlement which allows a person, a group or a cooperative to extract minerals from a particular plot of land.

2.3 Overview of the SSM in Ghana

Mining on a SS originate from the pre-colonial era where trading in gold was carried out with the Phoenicians and the Moors on the trans-Saharan trade routes before the coming of the European and Portuguese in 1471. According to Anin (1990), one-third of the gold mined was allotted to the Chief on whose land mining activity is done. These arrangements necessitated accurate institutionalization of the mining activity.

Furthermore, the control and regulation of SS mines operations by chiefs of lands in respect to the customary and lucrative utilization as well as customary practices on lands has existed for over two centuries (Aryee et al., 2003). Thus, even after commencement of mechanise mining operations, artisanal SSM was in operation in Ghana by Piere Bonnat in 1870.

Lack of technical ability and financial resources compelled enterprising locals to operate at artisanal SS level. It was noted that most mineral exploitations undertaken by large were discovered through SSM activities.

SSM in Ghana was criminalized from 1932 to 1989. This was due to the promulgation of the Mercury Ordinance which prohibited all from using mercury for any mining activity. SS miners during this period were harassed by the security authorities. As a result, gold mining using SSM (known in the local language as 'galamsey') prospered and was smuggled through a well-organized black market. Hence, much revenue was lost from the mining sector during the period.

The legislation limiting SSM operation caused growth in the sector to dwindle in spite of the large scale sector beginning 1910, leading to English owned large scale mining organizations and almost entire elimination of the SSM sector.

Nevertheless, the increasing awareness of the fact that the disregarding of the SSM sector was disadvantageous to the country informed many researches, propelling the regularization via the enactment of the SS Gold Mining Law, under PNDCL 218, in 1989. At the same time, a steady market for both diamond and gold was provided by the Precious Minerals Marketing Corporation (PMMC), an agency established by the state.

Additionally, the regularization of SSM and application of associated framework for marketing in 1989, were restructured. This combined changes have led to significant improvement in the sector contributing to the export of minerals and increased foreign income. The regularization in 1989 result in increase in gold value 1989 to 2000 of 870,000 ounces of gold valued at more than US$ 280 million, and 4.9 million karats of diamonds, valued at more than US$ 110 million and indicating that 69% of Ghana's total diamond production has been mined by SSM. Furthermore, the sector, which is expanding rapidly, has provided a number of native Ghanaians with employment.

2.3.1 Mining Methods

Depending on the kind of minerals being explored, varied methods of mining were employed by SS miners (Ntibrey, 2001). Due to lack of financial resources, greater proportion of small scale miner rely on artisanal methods using simple mining tools such as chisels, pick-axes, shovels, chisels, pans, and hammers. The techniques employed in SSM in Ghana can be group as follow.

Shallow Alluvial Mining

Dig and wash or shallow alluvial mining methods are in mining shallow mineral deposits generally discovered low lands or valleys. Mineral deposits mined in through these methods are not more than three meters deep. The method begins with initial clearing of vegetation and the soil are removed till the gold located. The gold is then collected and moved to streams close by for flushing and recovery of the gold.

Deep Alluvial Mining

Deep alluvial methods involve gathering gravels stream beds and sediments are washed clean of earth and sand. Pits are excavated and dug until the gold gravel surface is reached usually 7 to 12 meters deep. Benches and Terraces are built along pit sides to stop pit collapse. And the gravel containing the gold are removed and washed.

Hard Rock Mining

In this methods of mining, reefs containing gold pits are excavated to the point where dark color stones betwixt gold is identified. Hammers and chisel are used by artisanal miners in breaking the gold ore in case of weathered reefs (Amankwah and AnimSackey, 2003). The stones are grounded to powder and washed for the gold to be discovered. Explosives are also used where the ore is hard, though they are not legally allowed (Ntibrey, 2001).

2.3.2 Processing Methods

Free milling ores are most preferred among miners compared with sulphidic ore mining. In view of this, gravity concentration associated with use of sluicing is commonest processing method. Present mining regulation prohibit the utilization of cyanide or other techniques used in leaching. Ghanaian SS miners do not find this process methods attractive since it takes longer periods to separate the minerals from the ore. With an approximate recovery rate of 60%, the traditional method involving the use of sluice box in obtaining gold concentrates are used after which mercury is supplied to amalgamate the gold for heating to separate the gold.

Due to lack of funds to acquire the necessary milling and crushing equipment, traditional means comprising the use of primitive tools are used. Manual methods in extracting gold from hard rock ore uses local pestles and mortars after which the water is mixed with powder and flushed to obtain gold concentrates and mercury amalgam is formed.

In mining diamonds, the shallow alluvial mining method is used where gravels are loaded in a jig and diamond are hand-picked during washing. There has been gradual move toward semi mechanized and advance mining techniques through financial assistance and technical supports and arrangements from both local and foreign investors.

2.4 Regulatory Framework of SSM in Ghana

The SSM sector contribution to the economy precipitated the government in 1989 to legalize the long criminalized SS gold mining activity. It is imperious to be underlined that during the times when SS gold mining was illegal, SS diamond mining was a legal activity. The activity of SS gold mining was legalized through the enactment of the following laws;

The SS Gold Mining Law (PNDCL 218) provides for the registration of activity; the granting of gold mining licenses to groups or individuals; the licensing of buyers to buy product; and the institution of district-assistance centers.

The Mercury Law (PNDCL 217) legalized the purchasing of mercury (for mineral processing purposes) from authorized dealers.

The Precious Minerals Marketing Corporation Law (PNDCL 219) was converted from Diamond Marketing Corporation into the Precious Minerals Marketing Corporation (PMMC), authorized to trade in gold.

2.5 Regulatory Institutions of SSM in Ghana

The legalization of the SSM sector led to the establishment and reform of certain institutions to ensure that the sector is regulated. These institutions include the SS Minerals Department of the Minerals Commission, the Precious Mineral Marketing Corporation and the Environmental Protection Agency.

2.5.1 The Minerals Commission

The establishment of the Minerals Commission in 1986 through the enactment of the PNDCL 154 was to reduce bureaucracy by ensuring a one-point service for investors. The mineral commission has the responsibility of instituting effective framework for regulating the sector by amending, formulating and modifying existing legislation. Standards and guidelines for monitoring the environmental impacts of mining activities were developed by the commission in addition to advising the government and giving recommendations that provides reviews necessary for developing the mining sector.

Through its SSM Department or Support Centre, established in 1989 under the PNDCL, 218, the Commission enhances SSM operations by modifying and formulating the framework regulating and enhancing the marketing of SS mineral production.

2.5.2 The Environmental Protection Agency

The Environmental Protection Council was changed to the Environmental Protection Agency (EPA) by an Act of Parliament, EPA Act, 1994 (Act 490). The aim of the Environmental Protection Agency is to ensure environmental sustainability, which is in consonance with the 7th goal of the Millennium Development Goals (MDGs).

Act 490 made Environmental Impact Assessment (EIA) a compulsory requirement for all development projects and programs, including mining. However, the agency lacked the required financial and personnel needed to ensure enforcement and compliance to standards (Akabzaa and Dramani, 2001).

2.5.3 The Precious Mineral Marketing Corporation (PMMC)

The PMMC was established in 1989 as part of the institutional reforms to regularize the SSM sector. The PMMC was only government agency responsible for buying the minerals mined by SS miners in enhancing foreign-exchange revenue from the sector. Private licensed buyers were also allowed by the government to trade in gold minerals. The PMMC is said to have been carved out of the Diamond Marketing Corporation established in 1963 shortly after incorporated by Legislative Instrument (LI) 401 of 1965 as a state corporation, The PMMC Law (PNDC Law 219) of 1989 officially established the PMMC.

The PMMC was converted by Act 461 to a limited liability company to operate under the Ghana's company's code (Act 179 of 1963) as Precious Minerals Marketing Company Limited in the year 2000.

Other public sector organizations that provide support to the SSM sector in Ghana include the Ministry of Lands, Forestry and Mines, the Geological Survey Department, the

Chamber of Mines, the Lands Commission, Land Valuation Board and the Forestry Commission. These organizations are required to provide support to ensure optimal exploitation of the country's natural resources.

2.6 Overview of the SSM Law (PNDCL 218)

The PNDC Law 218 of 1989 is subcategorized into three sections. The first section talks about the registration of the SS gold miners. The Law states that no person shall or undertake any SS gold mining operation unless there is in existence in respect of such mining operation a license granted by the Secretary for Lands and Natural Resources. This section sets the criteria for qualified applicants and excludes the following groups of persons:

1. Any person who is not a citizen of Ghana (as defined under section 13 of the Aliens Act, 1963, Act 160);
2. Any person who has not attained the age of eighteen years; or
3. Any person who is not registered by the District Centre in the designated area under subsection (1) of section 9 of the Law.

The duration of the license as stipulated by the Law is three years for individuals and five years for groups from the date of issue in the first instance. This may be subject to renewal and payment of an approved fee for further period as the Secretary finds fit. The Law further stipulates that the size for the operation of a SS mine should not exceed three acres in respect to a grant to any group comprising not more than four persons, or one person, five acres as a grant to any group of persons not beyond nine, and twenty-five acres to a co-operative society of ten or more persons. The Law stipulates the establishment of the SSM Centre by the Minerals Commission as well as their functions.

The second section of the Law deals with the procedures of the SS gold miners. This section of the Law indicate that a person licensed to mine gold under the Law may mine, win and produce gold by any efficient and effective procedure and shall in his activity observe decent mining practices, rules regarding and health and ensure the protection of the environment. The Law prohibits the use of explosives in mining and enjoins SS gold miners to purchase from any authorized mercury dealer such quantities of mercury as may be reasonably necessary for the purposes of his mining operations.

The last section of the Law looks at license to deal in gold and miscellaneous provisions. This section of the Law stipulates the Mineral Commission as the licensing authority for persons who want to buy and deal in SS miners' gold. The Law lastly sets punitive measures for any individual who goes against these regulations.

2.7 The Link between Small Scale Mining and Water Resources

The spillover effects of human activities such as small scale mining on water resources and its concomitants implication on health's of its punters has been well documented in literature (McClure and Schneider, 2001). These special effects of small scale mining inter alia pollution of both ground and surface waters have become one of the major health glitch facing humanity all over the world. It is a problem of both developed and developing countries, but is more prevalent in the poor nations of Latin America, Asia and Africa.

In the developing countries, most diseases which affect humanity can be traced to lack of safe and wholesome water supply (Shymamala *et al*., 2008). Shymamala *et al*. (2008), has established that the harm caused by SS gold mining goes beyond the lack of access to potable water, without forgetting other unquantifiable benefits.

The disaster in Minamata, Japan, where mass poisoning involving mercury (small scale mining substance) of many people received the attention of the scientific community at the latter part of 1950s. Fishing communities along Minamata Bay suffered an epidemic of neurological disorders, which were later found to be caused by Mercury (Hg) poisoning of fish consumed from the bay. Ehrlich (2002) also identified other incidents of SS mining spillover effects in Pakistan, Iraq and Guatemala with several deaths resulting from eating fish contaminated with mercury. Presently, this fearful concern of small scale mining activities implicating water bodies has been heightened as observed in the numerous scientific international conferences (Asamoah et al., 2007; Kuma and Tetteh, 2004; Kuma et al., 2002).

A publication by Project Underground (2000) noted that unavailability of clean potable water in small scale gold mining communities is related to lowered community health status, as the communities are weighed down with several water related diseases.
Hence, the Water Resources Commission was instituted in Ghana by an Act of Parliament (ACT 522 of 1996) with the purpose of managing and regulating the country's water resources and coordinating government policies in retrospect to the Environmental Protection Council convention to make potable water accessible for the entire population and also on a sustainable basis.

The effluent from processing of ore and leaching from tailings and waste rock impoundments in small scale mining processes severely impinge on water resources.
These have deprived communities of access to water, which is a basic need for human survival. According to Cunningham (2005), the small scale mining activities by its nature make use of a lot of water thereby seriously polluting water resources.

A historical trajectory into the correlation between small scale mining and water resources in Ghana has been expounded in literature. Owen's (2005) study noted that water resource depletion increased marginal cost of providing potable water in the early stages, which increased burden on women's time and hastened climate change. The small scale miners looked at water (surface water) as 'free good' which was exploited with lack of effective regulatory framework which had deforested headwaters because there was no motivation to conserve water. It was further reported that degraded quality of water resources had health implications and reduced labour productivity.

2.8 Environmental Impact of SSM

Under the auspices of the World Bank and the German NGO Gesellschaft Technishe Zusannebarbeit (GTZ), a couple of initiatives toward formalizing and regularizing resident SSM activities were undertaken by government of Ghana. Although noticeable improvements in efficient operation of SSM were observed out of this initiatives. There are still negative environmental effects of mining activities which are continuously overlooked.

The environmental costs of SSM are enormous compared with modern and large mining techniques. There are several cases of environmental pollutants concentrated in these areas with their associated impacts. Lack of personnel and financial resources makes it difficult to monitor, enforce and control environmental violations. The SSM impact negatively on the social and physical environment at different stages of mining.

The commonest environmental problems are discussed as follows.

2.8.1 Degradation of Land

The clearing of large areas of land and vegetation to make way for SS gold mining operations has crucial adverse impact on the residents in mining communities since most of them rely on farming for their livelihood. There is eventual deterioration in the viability of the land for agricultural purposes and loss of habitat for micro and macro organisms (Akabzaa and Dramani, 2001).

SSM activities also cause considerable damage to landscapes, in the sense that miners typically abandon pits and trenches without properly reclaiming the lands. It is therefore quite common to find potholes virtually devoid of vegetative cover after periods of intensive prospecting (Hilson, 2001).

2.8.2 Deforestation

The rapid "urbanization" in a newly discovered gold mining areas lead to rampant deforestation and the concomitants social vices associated with urbanization which include prostitution, alcohol and drug abuse, land use conflicts with local communities, child labour as well as water pollution, and diseases. The deforestation of the area is as a result of the need for use of firewood, underground support props, shelters, and panning dishes. This over dependence on wood as a source of energy results in a decrease in biodiversity and alarming rates of desertification.

Soil erosion which in turn increases the turbidity of runoff surface waters are caused by the baring vegetation. Lubricants drainages into streams also causes de-oxygenation of water bodies thereby threatening aquatic life.

2.8.3 Water Pollution

The pollution of surface and ground water by naturally induced man's numerous activities render it unbefitting for food, human health, industry and agriculture (Cifuentes and Rodriguez, 2005). The toxic chemicals in water pose greatest threat to the safety of drinking water and their effects are enormous and can cause damage to human health, crops and aquatic organism.

The pollution of rivers and streams by activities of SSM deprives communities of their incomes, recreation and other benefits. Most of the activities of SS miners also divert watercourses away from the mining sites. This disturbs and disrupts the natural watercourse which leads to surface water pollution.

2.8.4 Acid Rock Drainage

Acid Rock Drainage (ARD) is a pollution hazard that can contaminate groundwater and surface water. The formation of ARD is exacerbated by continuous SS gold mining activities. The primary sources for acid generation are sulphide minerals, such as pyrite which decompose in air and water (Skousen et al., 1990).

Majority of these sulphide minerals originate from waste rocks in the mine. Infiltrations of pyrite-laden rocks with water in the presence of air make it acidified, often at a pH level of 2 or 3. Naturally occurring bacteria, Thiobacillusferroxidans, may accelerate the oxidation and acidification processes, leaching even more trace metals from the wastes (Rozkowski and Rozkowski, 1994). Increased acidity in the water can destroy aquatic organisms and cause significantly changes in the food web.

2.8.5 Mercury Pollution

The use of mercury during ore processing constitutes the major pollutants of surface and ground water in the SS gold mining areas in Ghana (Ntengwe, 2006). Elemental mercury (Hg) which is quite volatile and only slightly soluble in water is normally released into the environment, in the various oxidation states, from a variety of activities through the small scale mining (Donkor et al., 2006).

According to Ullrich et al. (2001), Hg compounds in water bodies are able to liberate and transform from sediments to water phase, taken by aquatic biota, evaporate and conveyed with sediment particulate matter to new locations which were not contaminated previously.

The inorganic Hg in the natural environment may undergo a change in speciation to a stable methylated state (MeHg) by non-enzymatic and microbial action, and when assimilated, eco-toxicological consequences may result. For instance, methyl mercury which can damage the central nervous system and toxic to foetus. It is very soluble in lipids and therefore, crosses biological membranes with ease (Lodenius and Malm, 1998).

2.8.6 Airborne Particulate Matter

The grinding equipment, vehicular movement, ore and waste rock heaps and site clearance which are predominant in mining sites generate harmful airborne particle. Dust arising from SS gold mining operations has a high silica content which has been responsible for silico-tuberculosis in mining areas (Baird, 1995).

Furthermore, a common practice by SS gold miners in Ghana is the roasting of gold amalgam in the open air. Mercury fumes result from these practices and are released into the air.

2.9 Physicochemical Characteristic of Water

Many parameters have been used to qualitatively measure the impact of mining activities on sample of water bodies. Quantitative analysis could be carried out by gravimetric, volumetric or colorimetric methods. Various types of electrode and automated techniques may determine certain constituents. Microbiological analyses are also employed for the determination of micro-organisms in water. However, common analyses in the field of water quality are usually based on relative straightforward analytical principles. The various physicochemical characteristics of water are reviewed as follows.

2.9.1 Hydrogen Potential (pH)

The pH measures how basic or acidic a water sample is. Logarithmic scale between 0 (extremely acidic) to 14 (extremely basic) with 7 signifying neutral conditions. Generally, life forms tolerate pH of water between 6.5 and 8. According to WHO (2003), pH is defined as the negative logarithm of the hydrogen ions concentration. Hydrogen ions interact with water molecules to form (H_30^+) ions, and the pH is expressed in terms of the concentration of hydroxonium ions. In pure water at 25^0C, hydroxonium (H_3O^+) and $(OH)^-$ ions exit in equal quantities. Hence the pH of pure water is 7.

2.9.2 Total Dissolved Solids (TDS)

The principal ions contributing to TDS are sulphate, carbonate, nitrate, chloride, sodium, calcium, potassium and magnesium (Grenne, 1993). TDS influence other qualities of drinking-water, such as corrosion properties, hardness, taste and tendency to incrustation. It is a measure of the amount of material dissolved in water.

Occurrence of Total Dissolved Solids

The TDS in water may begin from natural sources, industrial waste discharge, urban runoff, sewage efficient discharges. Waters in areas of Palaecozoic and Mesozoic sedimentary rock have higher total dissolved solids (TDS) levels, ranging from as little as 165 to 1100 mg/litre (Garrison investigation Board, 1997).

Health Effects of Total Dissolved Solids

Water with high TDS often has a high water hardness or bad taste and could result in a laxative effect. Variations in TDS concentration can be detrimental to the body since the density of the water determines the circulation of water in an organism.

2.9.3 Dissolved Oxygen

Dissolved oxygen is the most important of the dissolved gases. It is a very essential indicator of a water body's ability to support aquatic life. Aerobic micro-organisms need oxygen to decompose organic matter. This takes place mainly in surface water, but to a certain extent also in water percolating through the soil, which later forms groundwater. If dissolved oxygen is not available, anaerobic bacteria take over, this is often not wanted. Hydrogen sulphide and other undesirable substances may be originated.

Also water in the distribution system should contain enough oxygen to avoid anaerobic conditions. Otherwise odour problems could arise. In water treatment, Dissolved Oxygen is utmost importance as the aerobic processes decomposing organic substances are intensified in the treatment plants.

2.9.4 Significance of Dissolved Oxygen

Dissolved oxygen has no direct health significance; hence there is no WHO guidelines value for drinking water. However, aquatic life in surface water need dissolved oxygen for survival, metabolism and reproduction. Also water in a distribution system should contain at least 3-4 mg/L dissolved oxygen for corrosion control and the prevention of odour problems. Moreover, the absence or low concentration of dissolved oxygen in surface water is an indication of pollution.

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CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter discussed the methodology adopted in research. The research design as well as the instruments used to collecting data, including methods implemented to maintain validity and reliability of the instruments. The rationality behind the use of those particular methods adopted were outlined with clear explanation of their contribution to the effective undertaking of the study.

In a sequel to the above, it also gives a brief overview on the research scope. The profile of the study area provides relevant information on the environmental impacts of small scale gold mining on River Jimi and River Nyame at Obuasi and its environs in Ashanti region of Ghana.

3.2 The Study Area

The geographical scope of the study is the Obuasi and its environs hitherto referred as Obuasi municipality which is located in the southern part of Ashanti Region of Ghana.

It shares boundaries with the Upper Denkyira District of the Central Region in the south, Adansi South in the east, Amansie Central in the west, and Adansi North in the north. The Obuasi Municipality falls within latitudes 5º35'N and 5 º65'N, and longitudes 6º35'W and 6º90'W (OMAMTDP, 2006).

The Municipality covers a land area of about 162.4 sq. km. and it is the second largest political authority in the region after Kumasi Metropolitan Assembly (K.M.A.). The entire district comprises of 62 communities with Obuasi as the Municipal capital (OMAMTDP, 2006). The municipal capital, Obuasi, is about 64 km drive from Kumasi, the regional capital. The Figure 3.1 illustrates the study area in national and regional context.

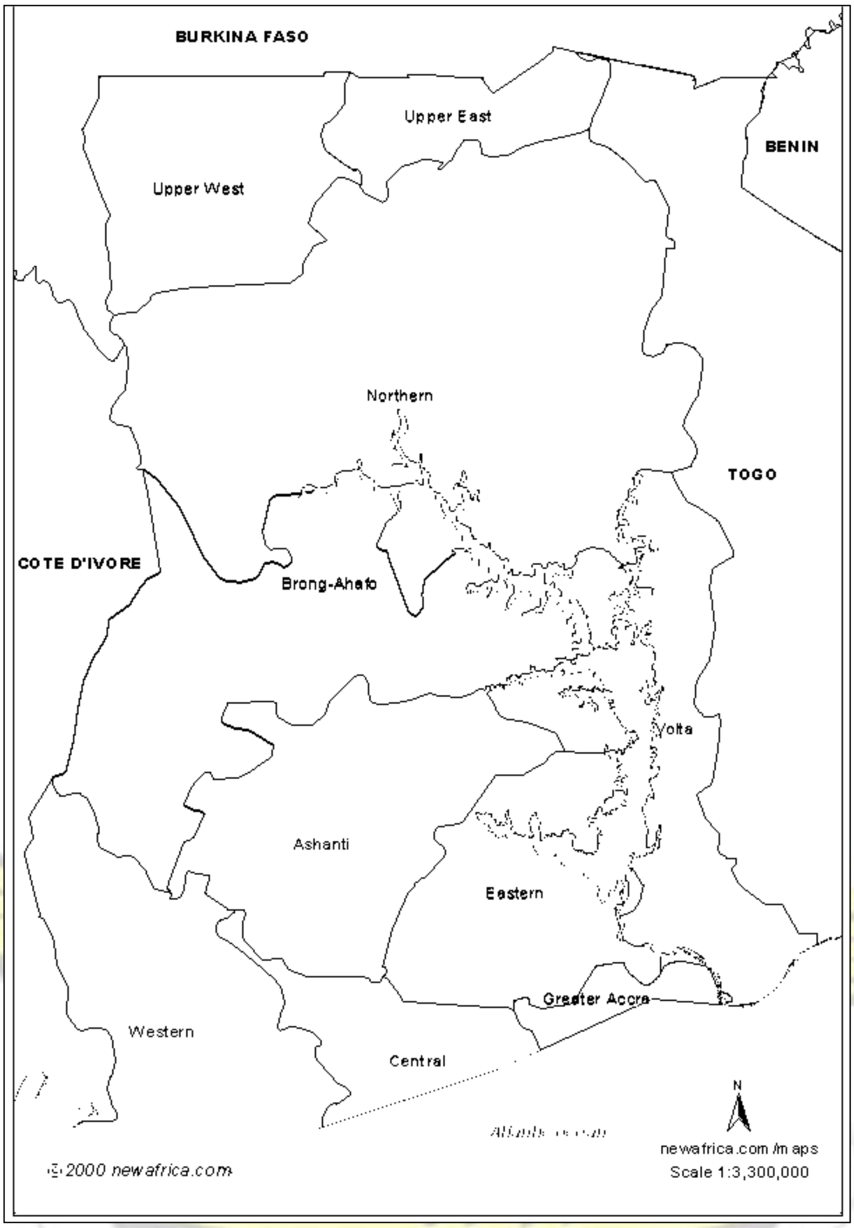

Figure 3.1: Map of Ghana Showing Ashanti Region

Source: OMAMTDP (2006).

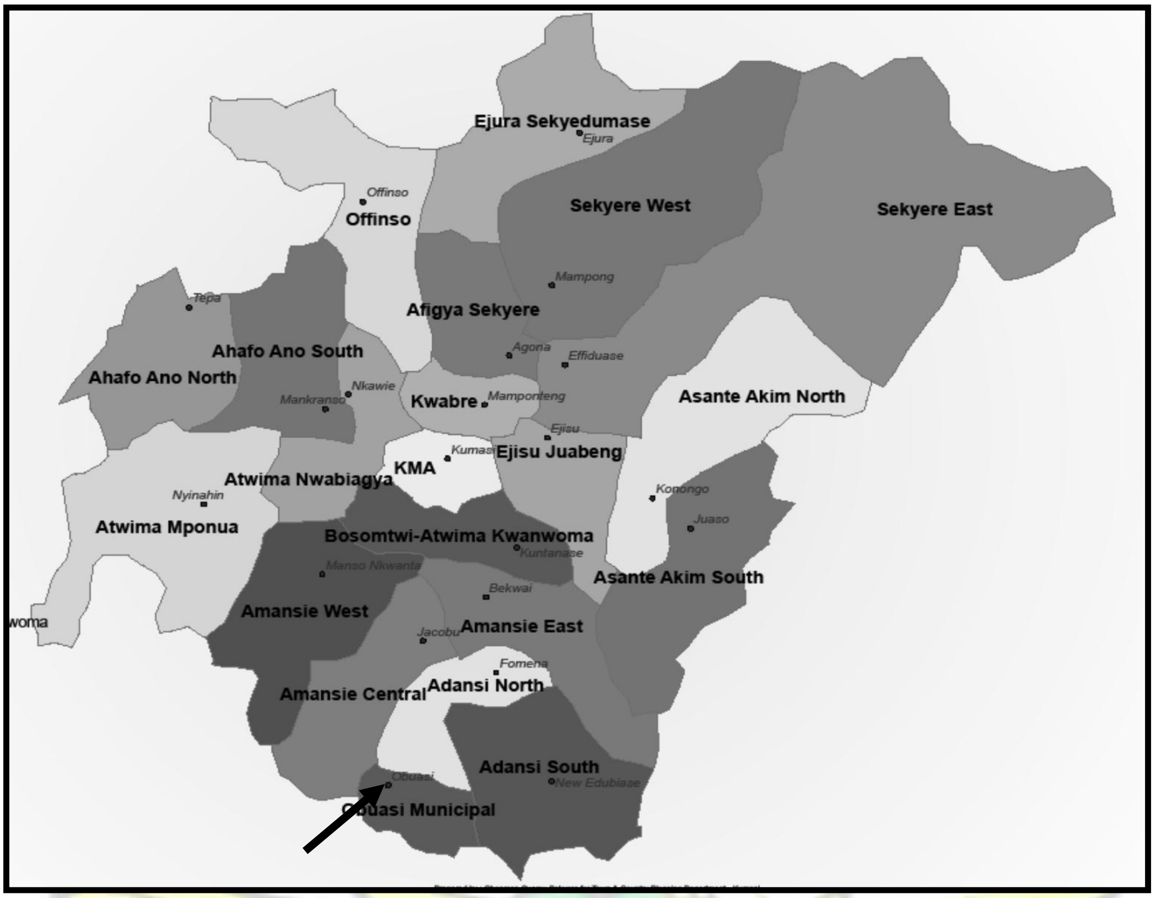

Figure 3.2: The Map of Ashanti Region indicating Obuasi Municipality

Source: OMAMTDP (2006)

3.2.1 Relief and Drainage

The topography of Obuasi and its environs is generally undulating terrains with an elevation of about 500 metres above sea level. The most prominent feature in the district is the range of hills which includes Dampaia (the most extensive) in the east, Kusa in the north east, Pompo and Sanso near Obuasi. No area falls below 100 metres above sea level. The highest point is located on the Pompo range at 634 metres near Obuasi.

The Municipality is drained by streams and rivers which include; Pompo, Nyame, Akapori, and Kunka. Other perennial streams and rivers are Subin, Menson, Kwabrafo, Hweaseamo, Kyeabo, Ankafo, Jimi and Nyame all of which depict dendritic pattern of flow.

3.2.2 Vegetation and Climate

The Municipality experiences semi-equatorial climatic conditions with a double maximum rainfall regime. Mean annual rainfall ranges between 125 mm and 175 mm.

The average rainfall in Obuasi averaged 1484 mm (58.4 in) of rainfall per year, or 123.7 mm (4.9 in) per month. On average there are 137 days per year with more than 0.1 mm (0.004 in) of rainfall (precipitation) or 11.4 days with a quantity of rain, sleet, snow etc. per month. The driest weather is in January when an average of 20 mm (0.8 in) of rainfall (precipitation) occurs. The wettest weather is in June when an average of 234 mm (9.2 in) of rainfall (precipitation) occurs. Temperatures are uniformly high all year with the hottest month being March when 30^{o}C is usually recorded. Mean average annual temperature is 25.5^{0}C. Relative humidity is highest (75% - 80%) in the wet season (OMAMTDP, 2006).

The vegetation is predominantly a degraded semi-deciduous forest. The forest consists of limited species of hard wood, which are harvested as timber. The AngloGold Ashanti has maintained large tracts of teak plantation as green belts covering 12.10 km^2 within its concession.

3.2.3 Soils

Soils in the municipality are predominantly forest ochrosols developed under forest vegetation. They are rich in humus and suitable for both cash and food crops production. Crops grown include citrus, oil palm, cocoa, plantain, maize, cassava, vegetables, etc.

Rocks in the Municipality are mostly of Tarkwaian (Pre-Cambrian) and Upper Birimian formation which are noted for their rich mineral bearing potentials. Areas around the contacts of the Birimian and Tarkwaian zones known as reefs are noted for gold deposits. The Obuasi mine (AngloGold Ashanti) which works on steeply dipping quartz veins over a strike length of 8km has since 1898 produced over 600 tons (18 million ounces) of gold from ore averaging about 0.65 ounces per ton (OMAMTDP, 2006).

3.3 Sampling Sites

Water samples were collected from the Jimi and Nyame Rivers. Six sampling points were located within the study area: three sampling points namely upstream, midstream and downstream were located within each river. The choice of the sampling sites was due to the bulk of human activities happening around the area and their effect on the water resources. The upstream stations were considered as control stations since small scale gold mining has not impacted the upstream. The sampling sites are summarized in Table 3.1.

Table 3.1: Sampling sites and their designated codes

Sampling Site Code	Site Location
UJ1	Upstream water at River Jimi
UJ2	Upstream water at River Jimi (during downpour)
UN1	Upstream water at River Nyame
UN2	Upstream water at River Nyame (during downpour)
MJ1	Midstream water at River Jimi
MJ2	Midstream water at River Jimi (during downpour)
MN1	Midstream water at River Nyame
MN2	Midstream water at River Nyame (during downpour)

DJ1	Downstream water at River Jimi
DJ2	Downstream water at River Jimi (during downpour)
DN1	Downstream water at River Nyame
DN2	Downstream water at River Nyame (during downpour)

3.4 Samples Collection

Water samples were taken in duplicates during downpours and also time during which there was no downpours at the sampling sites from October, 2012 to March, 2013. The samples were collected in 1000ml sterile plastic bottles and transported to the laboratory in a cool box for analysis.

3.5 Physicochemical Analysis

3.5.1 Measurement of pH

The pH of the sample waters (in this study) were determined in-situ at the time of sample collection using Yokogawa pH meter. The pH meter was initially calibrated by dipping the electrode into a buffer solution of known pH (pH 7.01) and the asymmetric potential control of the instrument altered until the meter reads the known pH value of the buffer solution. The standard electrode after rinsing with distilled / demonized water was then immersed in a third buffer solution (pH 10.01) and the instrument adjusted to read the pH value of this buffer solution. With the pH meter calibrated, it was immersed in the water sample, allowed to stabilize and the pH value read from the instrument. The beaker and the electrode were washed in between samples with deionised water in order to prevent contamination by other samples. Duplicate pH values were taken.

3.5.2 Measurement of Electrical Conductivity (EC)

Conductivity meter ORION 4 STAR (pH. Conductivity portable) was used to measure the conductivity of the water samples. The instrument was initially calibrated using standard solution of conductivities 1413 μS/cm and 12.9 μS/cm and duplicate values were taken.

3.5.3 Measurement of Dissolved Oxygen

The Dissolved Oxygen of each water sample was determined using the HACH Model HQ30d basic unit USB DO meter using 200 ml of the water sample.

3.5.4 Total Dissolved Solids (TDS)

TDS was measured using ORION 4 STAR (pH. Conductivity portable). One hundred milliliters of the sample were poured into a 250 ml beaker. The probe was then immersed in the sample and the value read on the digital screen.

3.6 Determination of Anions in Water Samples

Filtered water samples were poured into 10 mL sample cells (bottles) for parameters. The ion chromatogram was used to determine the levels of phosphate (PO_4^{3-}), sulphate (SO_4^{2}) and nitrates (NO_3^{-}) in the rivers samples.

3.7 Determination of Heavy Metals

The concentration of Mercury, Arsenic, Cadmium, zinc, Manganese and Lead in the rivers were determined using Varian 220 Spectra AA model of Atomic Absorption Spectrometer (AAS). The AAS was calibrated using standard solutions of the metals under investigation.

In the procedure, $100mm^3$ of each water sample was measured into a $250cm^3$ conical flask. $5mm^3$ of concentrated nitric acid was added and the mixture boiled and evaporated on a hot plate to about $50mm^3$.Another $5mm^3$ of concentrated nitric acid was added and the heating continued until a clear solution was obtained. The solution was allowed to cool and transferred into a $100cm^3$ volumetric flask and topped up with distilled water to the mark. The samples were then analyzed using the Varian 220 spectra AA model Atomic Absorption Spectrometer.

3.8 Relationship Between Physicochemical Parameters and Heavy metals

The relationship between physicochemical parameters and heavy metals was determined by correlation. The relationship between pH, electrical conductivity, dissolved oxygen and dissolved solids were each determined against mercury, lead, zinc and cadmium.

3.9 Quality Assurance

The accuracy and precision of the analytical techniques were assessed by the analyses of Standard reference materials and reagent blank before the samples were analyzed. Field instruments were calibrated according to the Standard method for the analysis of water and wastewater.

3.10 Statistical Analysis

The statistical data of the findings was collated and analyzed using Microsoft Excel by tabulations of the laboratory results. Microsoft Excel (2010) was used to draw control bar charts for the pH values, zinc concentration, manganese concentration, and arsenic concentration. The graph indicates the validity of the values measured.

CHAPTER FOUR

RESULTS

4.1 Introduction

The small scale gold mining activities results in adverse health and environmental effect. These emanate mainly from the methods of mining and processes involved in the gold extraction. Adverse health consequences may arise from exposure to the chemicals (used) following long term and, in some cases, short-term exposure. This chapter therefore deals with analysis of the empirical data on the environmental effects of small scale gold mining. It also looks at the relationship between the physicochemical characteristics and heavy metals concentration of the water samples from Rivers Jimi and Nyame at Obuasi and its environs in Ashanti Region of Ghana.

4.2 Physicochemical Characteristics of the Water Samples

A laboratory test was conducted on these water samples collected during downpour and the period without any rain, from three sampling site (namely; upstream, middle stream, and downstream) of each river.

4.2.1 pH of the Water Samples

pH is one of the most important operational water quality parameter. The result of pH characteristic of the water samples from the River Jimi and River Nyame at Obuasi and its environs are presented in Table 4.1.

Table 4.1: pH of various sample of water from rivers Jimi and Nyame collected during downpour and without downpour

pH Value at 25°c	River Nyame			River Jimi		
	Upstream	Middle stream	Down stream	Upstream	Middle stream	Down stream
During Downpour	6.61	6.65	7.01	6.81	6.72	6.93
Without Downpour	7.73	7.25	6.8	7.17	7.62	6.92
WHO Quality Water Guideline Value (2004)				**6.5 - 8.5**		

The hydrogen ion (pH) concentration of River Nyame was both slightly acidic during downpour and the period without any downpour. The maximum pH value (7.73) was recorded in the Upstream of the River Nyame when there was no downpour and minimum (6.61) in the same upstream during downpour. The pH of River Jimi was slightly acidic during downpour and ranges from 6.72 to 6.93. However, its hydrogen ion concentration was both slightly basic (7.62) and slightly acidic (6.92) during a period without any downpour. However, the pH values of all the water samples varied from 6.61 to 7.73 and were found within the limit prescribed by WHO based on aesthetic considerations.

4.2.2 Electrical Conductivity at 25^{O}C of the Water Samples

Electrical conductivity (EC) is a measure of water capacity to convey electric current. It signifies the amount of total dissolved salts. The electricity conductivity of the rivers is presented in Table 4.2.

Table 4.2: Electrical Conductivity at 25^{O}C of sample of water from rivers Jimi and Nyame collected during downpour and without downpour.

COND. at 25^{O}C	River Nyame			River Jimi		
	Upstream	Middle stream	Down stream	Upstream	Middle stream	Down stream
During Downpour	383.3	88.0	100.2	14.2	13.6	15.0
Without Downpour	5.0	10.4	91.5	7.7	7.6	7.7
WHO Quality Water Guideline Value (2004)				**100mS/m**		

The mean conductivity values of the water samples ranged from 383. 3 mS/m to 5.0 mS/m. River Nyame measured the highest mean conductivity value of 383. 3 mS/m at upstream during downpours and the lowest of 5.0 mS/m was measured at same upstream during no downpours. However, the mean conductivity values of River Jimi samples were low and varied between 15.0 mS/m and 7.6 mS/m.

The mean electricity conductivity values of the River Jimi were within the limit prescribed by World Health Organization. However, high EC values above the prescribed WHO standard values for water quality were observed for River Nyame during downpours.

4.2.3 Total Dissolved Solids in the Water Samples

Total Dissolved Solids (TDS) indicate the salinity behaviour of the rivers. As already indicated, it comprises of inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulphates) and small amounts of organic matter that are dissolved in water. Water containing more than 1000 mg/L of TDS is not considered desirable for drinking (WHO, 2006). Table 4.3 presents the Total Dissolved Solids in the waters.

Table 4.3: Total Dissolved Solids in the Water Samples in mg/L

Total Dissolved Solids	**River Nyame**			**River Jimi**		
	Upstream	**Middle stream**	**Down stream**	**Upstream**	**Middle stream**	**Down stream**
During Downpour	2938	627.6	869.2	156.2	152.1	150.0
Without Downpour	37.4	77.6	642.7	57.1	56.6	56.3
WHO Quality Water Guideline Value (2004)					**1000 mg/litre**	

The total dissolved solids of the two rivers ranged from 2938 mg/L to 37.4 mg/L. The maximum value (2938 mg/L) was recorded in the upstream of River Nyame due to heavy rainfall during downpours. Whilst the lowest mean value of 37.4 mg/L was recorded in the same upstream of River Nyame during a period without any downpours. The highest mean dissolved solids for River Jimi (156.2 mg/L) was recorded during downpours and the lowest value of 56.3 mg/L was recorded in the down streams during a period without any downpours. The upstream of River Nyame during downpours gave higher TDS values than the prescribed limit given by World
Health Organization.

4.2.4 Dissolved Oxygen in the Water Samples

Dissolved oxygen is important parameter in water quality assessment and reflects the physical and biological processes prevailing in the water. The dissolved oxygen values indicate the degree of pollution in water bodies. The laboratory analysis of the dissolved oxygen in the sampled waters from the Rivers Nyame and River Jimi is shown in Table 4.4.

Table 4.4: Dissolved Oxygen in the Water Samples in mg/L

	River Nyame			**River Jimi**		
	Upstream	**Middle stream**	**Down stream**	**Upstream**	**Middle stream**	**Down stream**
During Downpour	6.81	4.61	4.44	5.01	4.98	4.81
Without Downpour	4.91	2.49	3.66	3.25	3.20	3.23
WHO Quality Water Guideline Value (2004)					**20 mg/litre**	

In this study, dissolved oxygen was as low as 2.49 mg/L and as high as 6.81 mg/L. The maximum value (6.81 mg/L) was recorded in the upstream of River Nyame during downpour and minimum values (2.49 mg/L) in the period without any downpour. The mean dissolved oxygen (DO) values of the River Nyame and River Jimi samples were generally low and ranged from 2.49 mg/L to 6.81 mg/L and 3.20 mg/L to 5.01 mg/L respectively. Generally, the two Sampled Rivers gave lower dissolved oxygen values than the prescribed limit of 20 mg/L given by World Health Organization.

4.3 Anions present in the Water Samples of the Rivers

Water quality was measured on anions such as Nitrate (NO_3^-) Sulphate (SO_4^{2-}) and Phosphate (PO_4^{2-}).

4.3.1 Nitrate in the Water Samples

Nitrate is a naturally occurring ion that is part of the nitrogen cycle. The formation of nitrate is as a consequence of microbial activity and may be intermittent. Table 4.5 shows the concentrations of nitrate in the river samples.

Table 4.5: Nitrite Concentration in the Water Samples in mg/L

Nitrate (NO_3^-)	**River Nyame**			**River Jimi**		
	Upstream	**Middle stream**	**Down stream**	**Upstream**	**Middle stream**	**Down stream**
During Downpour	0.423	0.5967	6.0073	0.5264	1.1621	1.3728
Without Downpour	0.4166	0.579	5.9934	0.502	1.1525	1.1622
WHO Quality Water Guideline Value (2004)			**50.00 mg/L (Short-term exposure)**			

The value of nitrate ranges from 0.4166 mg/L to 6.0073 mg/L. The maximum value (6.0073 mg/L) was observed in the downstream of River Nyame during the downpour and minimum (0.4166 mg/L) in the upstream of River Nyame. The nitrate content in the study area was found to be within the prescribed limit and does not indicate any significance health implication in the short term.

4.3.2 Sulphate Concentration of the Water Samples

No health-based guideline is proposed for sulphate. However, because of the gastrointestinal effects resulting from ingestion of drinking-water containing high sulphate levels, it is recommended that health authorities be notified of sources of drinking water that contain sulphate concentrations in excess of 500 mg/L (WHO, 2003b).

For River Nyame, the mean highest sulphate concentration of 200.527 mg/L was measured in the downstream during a period of downpour whilst the lowest value of 3.550 mg/L was recorded in the middle stream during a period without any downpour. The River Nyame recorded the highest value of 200.527 mg/L whiles the River Jimi recorded the lowest mean value of 1.582 mg/L for the sample taken in the downstream during no downpour. The sulphate concentrations of the two rivers varied between 200.527 mg/L and 1.582 mg/L and were within the prescribed limit for chemical water quality parameter.

Table 4.6: Sulphate Concentration of the Water Samples in mg/L

Sulphate (SO_4^{2-})	**River Nyame**			**River Jimi**		
	Upstream	**Middle stream**	**Down stream**	**Upstream**	**Middle stream**	**Down stream**
During Downpour	19.697	3.871	200.519	3.423	2.166	1.772
Without Downpour	19.385	3.550	200.527	3.2346	1.639	1.582
WHO Quality Water Guideline Value (2004)				**500 mg/L**		

4.3.3 Phosphate Concentration in the Water Samples

The phosphate concentration was found in all the samples from River Nyame and only the upper stream of River Jimi. Thus, the sample taken from the middle stream and downstream of River Jimi both during downpours and the period without any downpours did not have any trace of phosphate. The results for the phosphate concentrations are summarized in Table 4.7.

Table 4.7: Phosphate Concentration of the Water Samples in mg/L

Phosphate ($PO4^{2-}$)	River Nyame			River Jimi		
	Upstream	Middle stream	Down stream	Upstream	Middle stream	Down stream
During Downpour	0.5633	0.1924	0.2911	0.1157	N.D	N.D
Without Downpour	0.514	0.108	0.271	0.1	N.D	N.D
WHO Quality Water Guideline Value (2004)				**10.00 mg/L**		

The value of phosphate ranges from not detected (N.D) to 0.5633 mg/litre. The highest value, 0.5633 mg/L of phosphate was recorded in the upper stream of River Nyame during downpour. No phosphate concentrations were also recorded in the middle stream and downstream of River Jimi both during downpours and the period without any downpours. River Nyame showed slightly higher concentrations of phosphate than River Jimi. However, the concentration of phosphate in the entire river sampled were below the health tolerable level, 10.00 mg/L.

4.4 Heavy Metals Concentration of the Water Samples

The concentrations of arsenic, mercury, zinc, lead, cadmium, and manganese were determined during downpour and the period without any downpour from the six sampling sites.

4.4.1 Arsenic Concentration of the Water Samples

Arsenic may occur naturally, and excess exposure to arsenic in drinking-water may result in a significant risk of cancer and skin lesions. The concentrations of arsenic in the Sampled Rivers are shown in Table 4.8.

Table 4.8: Arsenic Concentration of the Water Samples in mg/L

Arsenic	River Nyame			River Jimi		
	Upstream	Middle stream	Down stream	Upstream	Middle stream	Down stream
During Downpour	0.182	0.341	0.248	0.013	0.015	0.018
Without Downpour	0.177	0.413	0.295	0.251	0.236	0.264
WHO Quality Water Guideline Value (2004)				**0.01 mg/L**		

Mean Arsenic concentrations in the water samples ranged from 0.013 mg/litre to 0.413 mg/litre. The highest values were recorded in the River Nyame at the middle stream (for the sample taken during no rain downpour) whiles the lowest value was recorded at the upstream of River Jimi during downpour. There were high concentrations of Arsenic in the river bodies which were above the prescribed limit of 0.01 mg/L given by World Health Organization. This could be attributed to the nature of the soil in the study area which is known to contain substantial amount of arsenic.

4.4.2 Lead Concentration of the Water Samples

The table below shows the concentration of Lead in the rivers sampled.

Table 4.9: Lead Concentration of the Water Samples in mg/L

Lead	River Nyame			River Jimi		
	Upstream	Middle stream	Down stream	Upstream	Middle stream	Down stream
During Downpour	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Without Downpour	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
WHO Quality Water Guideline Value (2004)				**0.01 mg/L**		

The mean lead concentrations in the sampled waters taken both during downpour and without any downpour were generally low. All the water sampled from the rivers measured lead concentration less than 0.002 mg/L, which were lower than the allowable concentration of 0.01 mg/L, based on health concerns.

4.4.3 Mercury Concentration of the Water Samples

The table 4.10 shows the concentration of mercury in the rivers sampled.

Table 4.10: Mercury Concentration of the Water Samples in mg/L

	River Nyame			River Jimi		
Mercury	**Upstream**	**Middle stream**	**Down stream**	**Upstream**	**Middle stream**	**Down stream**
During Downpour	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Without Downpour	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
WHO Quality Water Guideline Value (2004)				**0.006 mg/L for inorganic mercury**		

It can be inferred from table 4.10 above that, the highest concentration of mercury in all the rivers sampled was less than 0.001 mg/L. The mercury concentration of the rivers sampled is therefore within the allowable concentration of 0.006 mg/litre mercury, based on health concerns.

4.4.4 Zinc Concentration of the Water Samples

The maximum allowable or permissible concentration of zinc at levels above 3mg/L may not be acceptable to consumers. The concentration of zinc in the river bodies are recorded in Table 4.11.

Table 4.11: Zinc Concentration of the Water Samples in mg/L

Zinc	River Nyame			River Jimi		
	Upstream	Middle stream	Down stream	Upstream	Middle stream	Down stream
During Downpour	0.005	0.007	0.006	0.012	0.011	0.010
Without Downpour	0.0057	0.0127	0.021	0.004	0.008	0.012
WHO Quality Water Guideline Value (2004)				3.00 mg/L		

The zinc concentrations of the water samples ranged from 0.004 mg/L to 0.021 mg/L. The highest concentration of zinc was recorded in the downstream of River Nyame during a period without rain downpour. The minimum concentration of zinc was also recorded in the upstream of River Jimi during a period without any downpours. The concentrations of zinc in the entire rivers sampled were below permissible concentration level which could impair the portability of the water.

4.4.5 Cadmium Concentration of the Water Samples

The Concentrations of cadmium in large amount constitute a serious health hazard. The concentrations of cadmium in the water samples from the rivers are presented in Table 4.12.

Table 4.12: Cadmium Concentration of the Water Samples in mg/L

Cadmium	River Nyame			River Jimi		
	Upstream	Middle stream	Down stream	Upstream	Middle stream	Down stream
During Downpour	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Without Downpour	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
WHO Quality Water Guideline Value (2004)				0.003 mg/L		

All the rivers sampled had some level of cadmium concentration. The mean cadmium concentrations in the water samples were less than 0.004 mg/L. The concentrations of cadmium in the rivers sampled were within the maximum prescribed permissible limit of 0.003 mg/litre given by World Health Organization.

4.4.6 Manganese Concentration of the Water Samples

The Table 4.13 shows the concentration of manganese in the rivers sampled.

Table 4.13: Manganese Concentration of the Water Samples in mg/L

Manganese	River Nyame			River Jimi		
	Upstream	Middle stream	Down stream	Upstream	Middle stream	Down stream
During Downpour	0.004	0.005	0.010	0.003	0.00 6	0.011
Without Downpour	0.006	0.008	0.011	0.002	0.007	0.012
WHO Quality Water Guideline Value (2004)				0.4 mg/litre		

The mean manganese concentrations in water in this study ranged from 0.002 mg/L to 0.012 mg/L. The mean concentrations of manganese for all the rivers sampled were found within the prescribed limit for chemical water quality parameters.

4.5 Relationship between Heavy metals and physicochemical characteristics of the Water Samples

The relationship between physicochemical parameters such as pH electric conductivity (EC), Dissolved Oxygen (DO), Phosphate (PO_4^{-2}), Nitrate (NO_3^-) and heavy metals such as Mercury (Hg), Lead (Pb), Zinc (Zn), Cadmium (Cd) have been analyzed. The result of the analysis is indicated in Table 4.14.

Table 4.14: Correlation analysis of the relationship between heavy metals and physicochemical parameters

	pH	EC	DO	PO_4^{2-}	NO_3^-	R^2 value, *P* value
Mercury (Hg)	0.81	0.84	-0.756	-0.312	0.931	0.102,
Lead (Pb)	0.092	0.156	-0.124	-0.141	0.286	0.340,
Zinc (Zn)	0.312	0.507	0.004	0.590	0.321	1
Cadmium (Cd	0.815	0.946	-0.746	-0.156	0.827	(Insignificant)

Correlation is significant at 0.01 level (2.tailed)

Table 4.14 showed that a strong positive relationship exists between pH levels and mercury levels, pH levels and Cadmium, as well as Zinc and Lead. Positive relationship could again be observed between Nitrate and all the four heavy metals under consideration. Thus, there is a positive relationship between pH levels and heavy metals under study. On the other hand, negative relationship has been observed among physicochemical parameters such as Phosphate (PO_4^{2-}) and Dissolved Oxygen (DO) and heavy metals Mercury, Lead and Cadmium.

Further analysis that compared heavy metals with physicochemical parameters have been undertaken using the Figure 4.2.

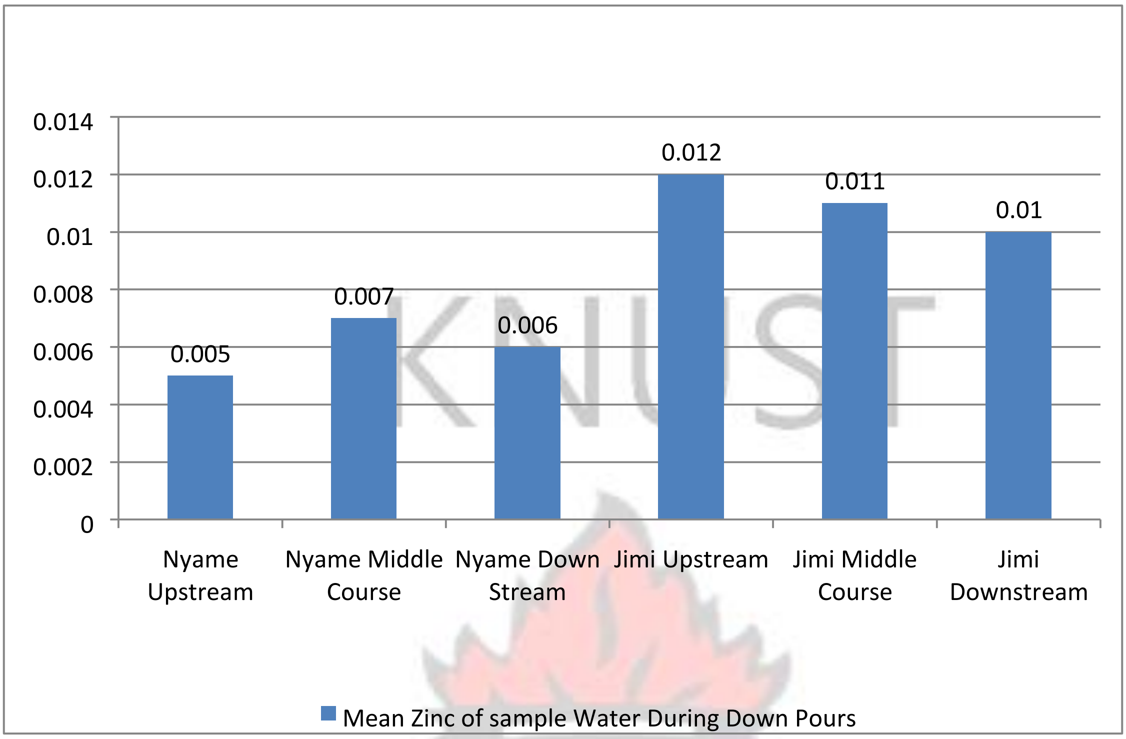

Figure 4.2: Control chart indicating the concentrations of zinc of the sampled water at 25^{0}C and pH during downpours from Jimi and Nyame Rivers

The mean zinc values of both river samples were within the permissible value by WHO. However, the mean concentrations in river Jimi were slightly higher than river Nyame. The lower pH recorded at temperature 25^{0}C of river Nyame made it slightly acidic leading to dissolution of more zinc as compared to river Jimi. The lower the pH value, the more the concentration of zinc. When the pH of river Nyame decreased from 7.01 to 6.65, the concentration of zinc increased from 0.006 mg/L to 0.007 mg/L. When the pH of river Jimi decreased from 6.81 to 6.72, the concentration of zinc increased from 0.011 mg/L to 0.012 mg/L. The chart for Nyame rose at midstream and declined at downstream but, in river Jimi, the chart shows a decline pattern.

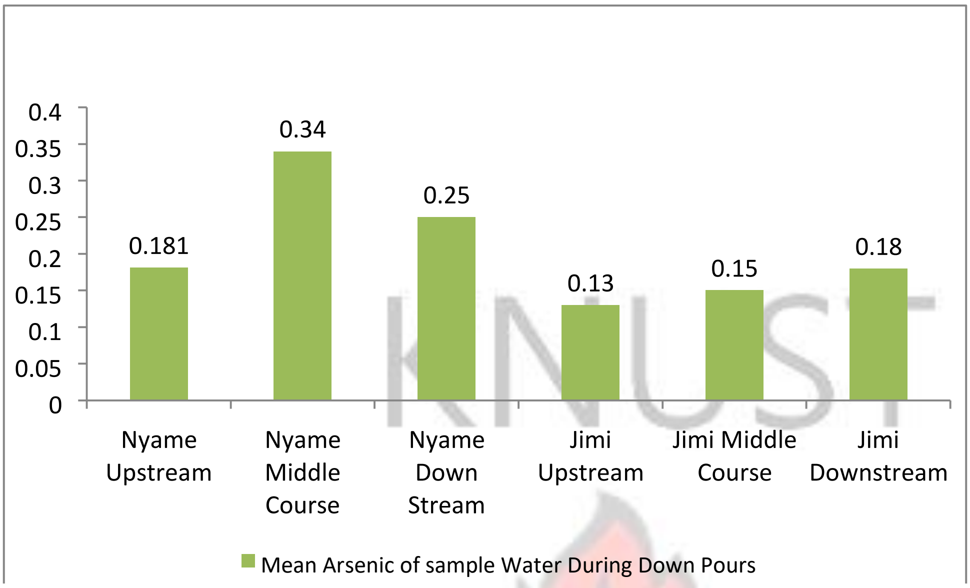

Figure 4.3: Control chart indicating the concentrations of arsenic of the sampled water at 25^{0}C and pH during downpours from Jimi and Nyame Rivers

The mean arsenic concentration of both river samples were slightly above WHO (2004) value of 0.01 mg/L. River Nyame recorded higher arsenic concentration as compared to river Jimi. An increased in pH at 25^{0}C resulted in increased arsenic concentration. When the pH of river Nyame was increased from 6.61 to 7.01, arsenic concentration increased from 0.18 mg/L to 0.25 mg/L. However, the highest arsenic concentration was recorded at pH of 6.65. This could be attributed to an increased small scale gold mining activities in the midstream of river Nyame. The concentration of arsenic showed gradual increase with increased pH of river Jimi. When the pH increased from

6.81 to 6.93 at 25^{0}C, arsenic concentration increased from 0.013 mg/L to 0.018 mg/L. Decreased in arsenic concentration of river Jimi is as a result of less small scale mining activities in the area. The chart for river Nyame rose and declined but, that for river Jimi shows slight decline.

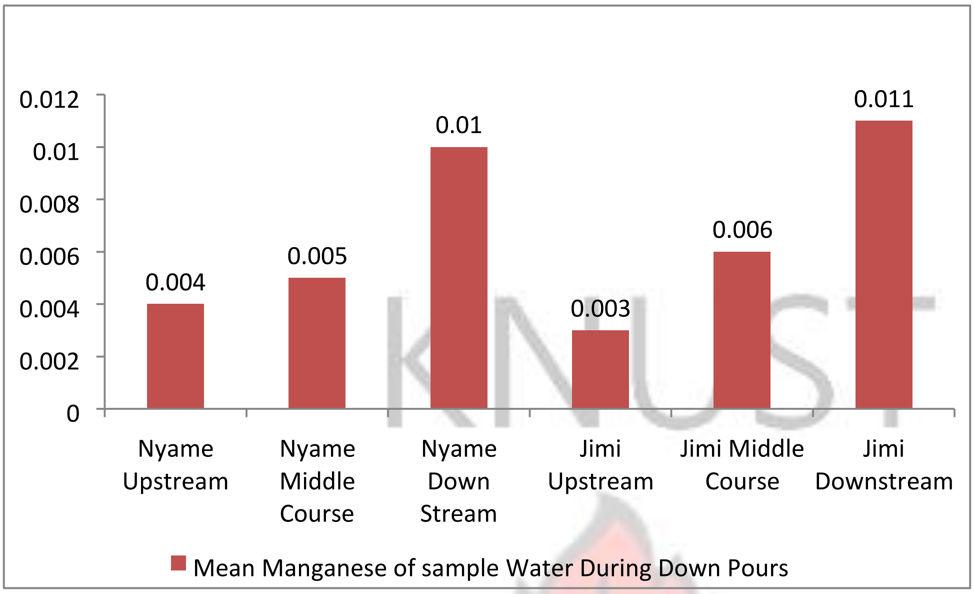

Figure 4.4: Control chart indicating the concentrations of manganese of the Sampled water at 25ºC and pH during downpours from Jimi and Nyame Rivers

The mean manganese concentration of both rivers were within the 0.4 mg/L WHO (2004) guideline value. An increased in pH at 25^{0}C showed a gradual increase of manganese concentration. The highest concentration was recorded at downstream of both river Nyame (0.010 mg/L) and river Jimi (0.011 mg/L) at pH 7.01 and 6.93 respectively. As the pH increased, manganese become less oxidized. The chart for river Nyame rose and declined but, river Jimi shows an increasing pattern.

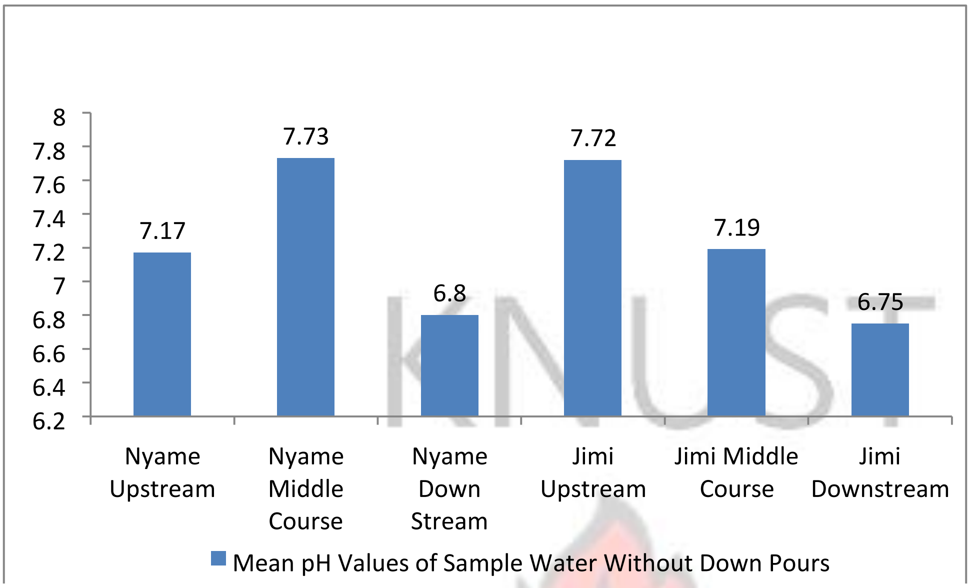

Figure 4.5: The mean chart for pH values of the sampled water at 25^{0}C measured at different depths in Jimi and Nyame without downpour

The mean pH values of both sampled rivers were within the WHO (2004) guideline value. The chart for river Jimi rose and declined but, that for Nyame shows a decreasing trend. The upstream and midstream of both rivers were slightly basic whilst the downstream of both rivers were acidic.

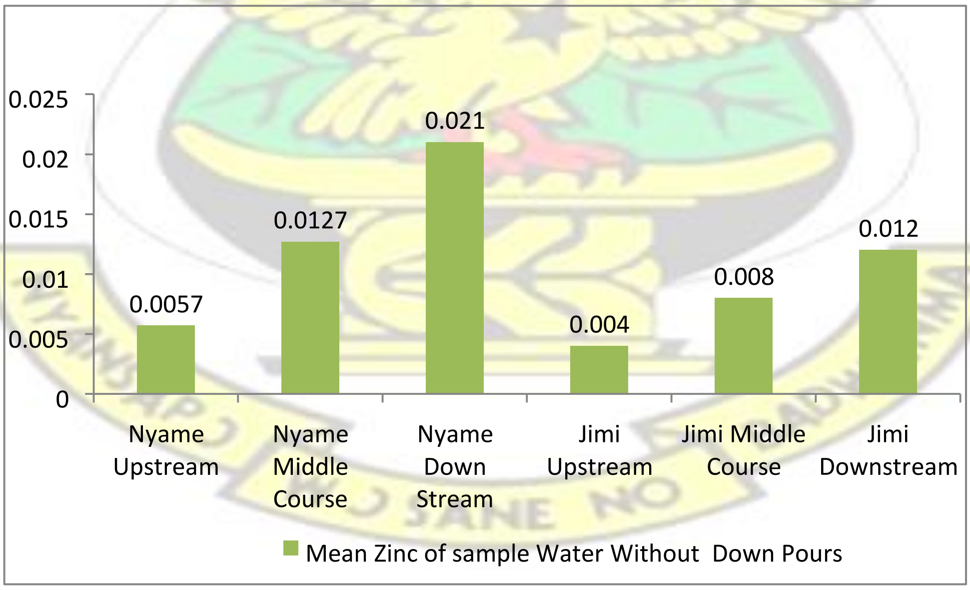

Figure 4.6: The mean zinc concentrations of the sampled water at 25^{0}C measured at different depths in Jimi and Nyame without downpour

The mean zinc concentration in both rivers shows an increasing pattern. The concentration increased with decreased pH. For river Nyame, when the pH decreased from 7.73 to 6.8, zinc concentration increased from 0.0057 mg/L to 0.0210 mg/L. For river Jimi, when the pH decreased from 7.73 to 6.8, zinc concentration increased from 0.004 mg/L to 0.012 mg/L. Zinc is an amphoteric metal and therefore dissolves in both acidic and basic Region but, dissolves more in acidic Region.

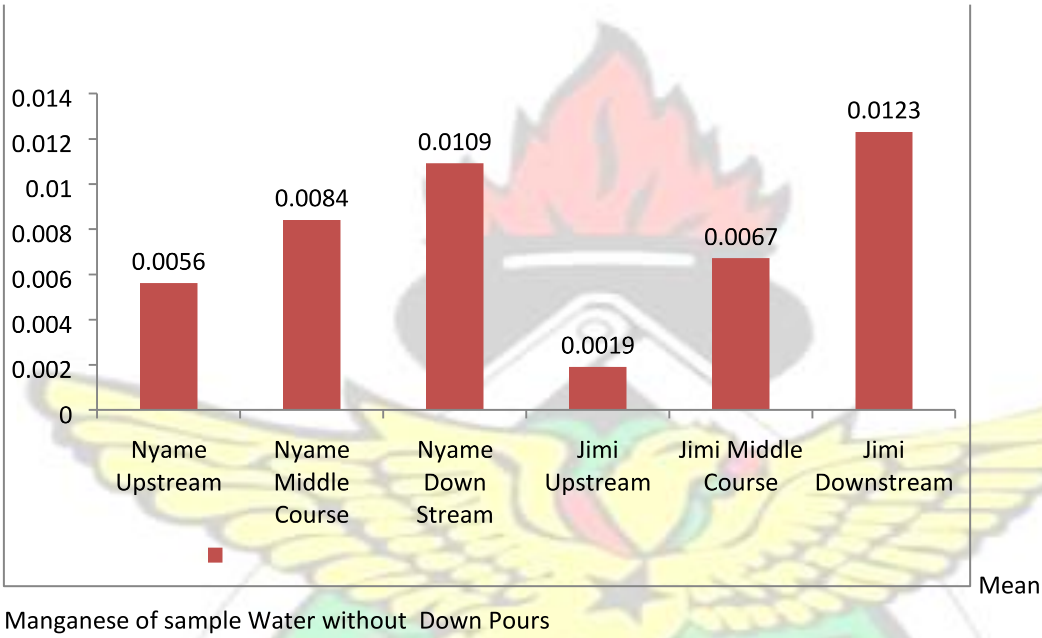

Figure 4.7: The mean manganese concentrations of the sampled water at 25^0C and pH measured at different depths in Jimi and Nyame without downpour

The mean manganese concentrations of both rivers show an increasing pattern with decreased pH. For river Nyame, when the pH was decreased from 7.73 to 6.8, zinc concentration increased from 0.006 mg/L to 0.011 mg/L. When the pH of river Jimi was decreased from 7.73 to 6.8, manganese concentration increased from 0.002 mg/L to 0.012 mg/L. The manganese therefore dissolves more in slightly acidic solution.

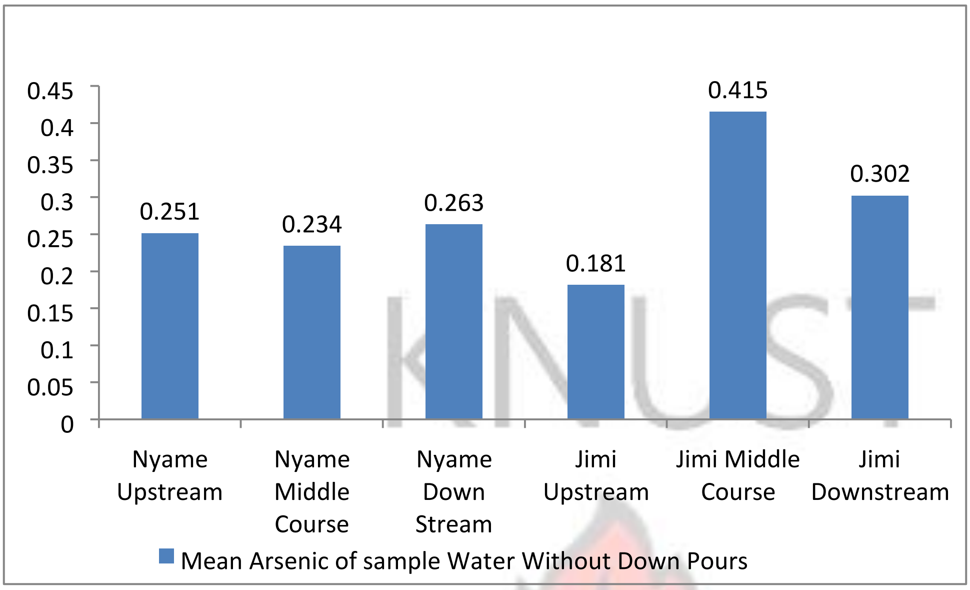

Figure 4.8: The mean arsenic concentrations of the sampled water at 25^{0}C and pH measured at different depths in Jimi and Nyame without downpour

The chart for mean arsenic concentrations of both rivers shown above, move in different pattern. For river Jimi, it decreased at midstream and rose but, in river Nyame, the chart rose at midstream and declined. The downstream of river Nyame and Jimi recorded highest mean concentrations of 0.011 mg/L and 0.012 mg/L when the pH was slightly acidic.

The relationship between other elements such as lead, cadmium and mercury with physicochemical parameters such as temperature and pH are shown in Table 4.14 below shows physicochemical parameters with metals in the river sampled.

Table 4.15: Relationship Between Physiochemical and Metals During Downpours

Relationship Between Physiochemical and Metals During Downpours		
Parameters	**River Nyame**	**River Jimi**

	Upstream	Middle stream	Down stream	Upstream	Middle stream	Down stream
pH Value at $25^{o}C$	6.61	6.65	7.01	6.81	6.72	6.93
Lead con.	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Mercury	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cadmium	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004

Table 4.16: Relationship Between Physicochemical and Metals During a Period Without any Downpours

Relationship Between Physicochemical and Metals During A Period Without any Downpours						
Parameters	**River Nyame**			**River Jimi**		
	Upstream	**Middle stream**	**Down stream**	**Upstream**	**Middle stream**	**Down stream**
pH Value at $25^{o}C$	6.61	6.65	7.01	6.81	6.72	6.93
Lead con.	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Mercury	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cadmium	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004

This study did not find any significant relationship between pH and concentration of lead, mercury and cadmium in the river sampled both during downpours and a period without any downpours. When the pH of river Nyame increase from 6.65 to 7.01, the concentration of lead, mercury and cadmium in the river sampled remain unchanged. In a similar vein, the concentration of these metals in river Jimi remain also unchanged when the pH decrease from 6.93 to 6.72 and vice versa. The pH of both rivers did not effect on the concentration of metals during downpour and without downpour.

CHAPTER FIVE

DISCUSSION OF RESULTS

Introduction

This chapter presents the discussion of the results in chapter four. It also painted a picture of the concentration of some heavy metals and physicochemical characteristics of the water samples from River Jimi and River Nyame. In furtherance to the above, the relationship between the physicochemical and heavy metals of the water samples was further discussed.

5.1 Physico-Chemical Parameters

This study further determined some physicochemical parameters of river Nyame and river Jimi in Obuasi and its environments. It was observed that, most of the physicochemical quality of the river samples analyzed in terms of pH, temperature and dissolved oxygen met prescribed standards by World Health Organization and other international bodies.

5.1.1 pH Characteristics

The hydrogen ion concentration is considered a significant ecological factor and provides important information on many types of geochemical equilibrium. It is an important parameter in water bodies since most aquatic organisms are adapted to an average pH and do not withstand abrupt changes (Shymamala *et al.*, 2008). The hydrogen ion concentrations of the sampled rivers varied from 6.61 to 7.73 and were found within the limit prescribed by World Health Organization based on aesthetic considerations. These pH increases from slightly acidic during downpour to slightly basic during a period without any downpours. However, there was slight change in pH concentration in the downstream of both rivers. The downstream of river Nyame during downpour and without downpour were neutral and slightly acidic respectively. The downstream of river Jimi during downpour and without downpour remained slightly acidic. The factors like air temperature bring about changes in these pHs of water. Most of bio-chemical and chemical reactions are influenced by the pH. The reduced rate of photosynthetic activities during a period without any downpours reduces the assimilation of carbon dioxide and bicarbonates which are ultimately responsible for increase in pH.

5.1.2 Electrical Conductivity at 25^{O}C

The mean conductivity values of the water samples ranged from 383.3mS/m to 5.0mS/m. The mean electric conductivity values of the River Jimi were found within the limit prescribed by World Health Organization. However, high EC values above the prescribed WHO standard values for water quality were observed for River Nyame during downpours. The high value of the electric conductivity for River Nyame indicates the presence of high amount of dissolved inorganic substances in ionized form during downpours.

5.1.3 Total Dissolved Solids

Total dissolved solids (TDS) indicate the salinity behaviour of rivers. Water containing more than 500 mg/L of TDS is not considered desirable for drinking, but in unavoidable cases 1500 mg/L is also allowed. The total dissolved solids of the two rivers varied between 2938mg/L to 37.4mg/L. The maximum values were recorded during downpours due to heavy rainfall whilst the lowest mean values were recorded during a period without any downpours. The upstream of River Nyame during downpours gives higher TDS values than the prescribed limit given by World Health Organization. A high level of

TDS is an indicator of potential concerns and warrants further investigation. Most often, high levels of TDS are caused by the presence of potassium, chlorides and sodium. High TDS results in undesirable taste which could be salty, bitter, or metallic. It could also indicate the presence of toxic minerals.

5.1.4 Total Dissolved Oxygen

Dissolved oxygen is also important parameter in water quality assessment and reflects the physical and biological processes prevailing in the water. The dissolved oxygen in the rivers sampled was as low as 2.49 mg/L and as high as 6.81 mg/L. The soluble gases in rain water influence the dissolved oxygen in the rivers to give higher dissolved oxygen during downpour. This possibly accounts for the greater quantities of oxygen recorded during downpour. Generally, the two sample rivers gave lower dissolved oxygen values than the prescribed limit of 20 mg/L given by World Health
Organization.

5.2 Anions Concentrations

This study further identified some level of toxic anions such as Nitrate (NO_3^{-}),
Sulphate (SO_4^{2-}) and Phosphate ($PO4^{2-}$) in most of the river sampled.

5.2.1 Nitrate Concentration

The river sampled contains nitrate due to leaching of nitrate with the percolating water. The water bodies can also be contaminated by sewage and other wastes rich in nitrates. The nitrate concentration in the rivers ranged from 0.4166 mg/L to 6.0073 mg/L. The presence of nitrate in water causes methaemoglobinaemia so-called "blue-baby syndrome", especially in bottle-fed infants (WHO, 2003a). Nitrate concentration value of 50 mg/L is considered safe for against methaemoglobinaemia in infants. The nitrate content in the study area were found to be within the prescribed limit and does not show any significance health implication in the short run.

5.2.2 Sulphate Concentration

Sulphate occurs naturally in water as a result of leaching from gypsum and other common minerals. Discharge of industrial wastes and domestic sewage increase sulphate concentration in water. The sulphate concentrations varied between 200.527 mg/L and 1.582 mg/L and were found within the prescribed limit for chemical water quality parameter. However, comparing the two Sample Rivers, it was realized that, River Nyame recorded the highest value of 200.527 mg/L whiles River Jimi recorded the lowest mean value of 1.582 mg/L. This could be attributed to the exposure of sulphide bearing rocks through mining in the water bodies (Ravengai *et al*., 2005).

5.2.3 Phosphate Concentration

The value of phosphate ranged from 0.0 mg/l to 0.5633 mg/L. The River Nyame showed slightly higher concentration of phosphate than River Jimi. However, the high values of phosphate in River Nyame are mainly due to rain, surface water runoff, agriculture run off, washer man activity could have also contributed to the inorganic phosphate content. However, the concentration of phosphate in the entire river sampled does not exceed tolerable risk to the health of the consumer over a lifetime of consumption.

5.3 Heavy Metal Concentrations

Concentrations of some metals in water are beneficial; whereas some of the metals are harmful or toxic. The presence of toxic metals in environmental matrices is one of the major concerns of pollution control for environmental agencies in most parts of the world. This is mainly due to the health implications of these toxic metals since they are non-essential metals with no benefit to humans. Their presence in aquatic ecosystems, mainly due to anthropogenic influences has far-reaching implications directly on the biota and indirectly on man.

Hence, one of the specific objectives of the study was to determine the concentration of some heavy metals (Mercury, Arsenic, Cadmium, Zinc, Manganese and Lead) in water samples from River Jimi and River Nyame at Obuasi and its environs in Ashanti Region of Ghana.

5.3.1 Arsenic Concentration

Arsenic is an important drinking-water contaminant, as it is one of the few substances shown to cause cancer in humans through consumption of contaminated water (IPCS, 2001). The research revealed that the mean Arsenic concentrations in the water samples ranged from 0.013 mg/L to 0.413 mg/L. Arsenic can be liberated from arsenopyrite rocks through mining. Since arsenic in soils and rocks is highly mobile, once it is liberated, it results in higher concentrations in water resources. However, there is evidence from this study that the concentration of Arsenic in the river bodies were slightly above the prescribed limit of 0.01 mg/L given by World Health Organization (2003f). The higher concentration of Arsenic is due to the mining activities which is widespread in the area.

5.3.2 Lead Concentration

According to World Health Organization (2003c), infants, children up to 6 years of age and pregnant women are most susceptible to adverse health effects of lead. The mean lead concentrations in the sampled waters taken both during downpour and a period without any rain were generally low. Evidence from this study shows that the river bodies sampled measured less than 0.002 mg/L concentration of lead, which was within the allowable concentration of 0.01 mg/L for lead, based on health concerns (WHO, 2004).

5.3.3 Mercury concentration

According to WHO (2005), toxic effects of mercury are mainly acute oral poisoning resulting in haemorrhagic gastritis and colitis; causing ultimate damage to the kidney. The research revealed that the highest concentration of mercury in all the rivers sampled was less than 0.001 mg/L, which is within the allowable concentration of 0.006 mg/L mercury, based on health concerns. Mercury is used to recover gold from ore minerals by the process of amalgamation; hence, the presence of mercury in the water samples could be attributed to the processing of gold which is widespread in the study area.

5.3.4 Zinc Concentration

The maximum allowable or permissible concentration of zinc at levels above 3 mg/L may not be acceptable to consumers. It is one of the earliest known trace metals and a common environmental pollutant, which is widely distributed in the aquatic environment. The zinc concentration of the rivers sampled ranged from 0.004 mg/L to 0.021 mg/L. This indicates the intensity of anthropogenic influence within the catchments of the rivers in Obuasi, resulting from industrialization and urbanization. However, the concentration of zinc in the entire river sampled does not exceed the maximum allowed or permissible concentration to impair the portability of the water.

5.3.5 Cadmium Concentration

Cadmium accumulates primarily in the kidneys and has a long biological half-life in humans of 10-35 years (JECFA, 2000). The Concentrations of cadmium in large amount also constitute a serious health hazard. It was revealed that the concentration of cadmium in the rivers sampled had reached the maximum prescribed permissible limit of 0.003 mg/L given by World Health Organization. Soil and mineral whethering, urban storm-water runoff, discharge of domestic effluents containing cadmium-laden materials are major sources of cadmium. The high concentration of Cadmium could be attributed to the runoff from the small scale mining activities in the area.

5.3.6 Manganese Concentration

The mean manganese concentrations in the rivers sampled ranged from 0.002 mg/L to 0.012 mg/L. The manganese concentrations were within the allowable limit of 0.4 mg/L. Water dissolves the manganese traces while percolating through the ground, carrying it along in solution (Griffith, 2004). This accounts for the levels of Manganese concentrations in the water sampled. The Manganese concentrations were higher in the downstream which experienced high small scale mining activities. Adverse effects can result from both deficiency and overexposure. Manganese is known to cause neurological effects following inhalation exposure, particularly in occupational settings, and there have been epidemiological studies that report adverse neurological effects following extended exposure to magnesium in drinking-water is high (WHO, 2003d).

5.4 Relationship Between Physicochemical paraeters and Heavy Metals

According to Department of Water Affairs and Forestry guidelines on water quality; metals such as zinc (Zn) and cadmium (Cd) are most likely to have increased detrimental

environmental effects as a result of lowered pH (DWAF, 1996). Temperatures at which environmental samples are collected and at which physicochemical measurements are made are important for data correlation and
interpretation.

The presence of zinc, arsenic, and manganese concentration in the water samples are mainly due to the acidic nature of the river bodies. It was observed that the hydrogen ion concentration of the water body had influences the concentration of many metals such as zinc, arsenic, and manganese by altering their availability and toxicity. When the pH is low more metals are dissolved in the water bodies which will results in high concentration of metals in the water samples. For instance, during the downpour, when the pH of river Nyame decrease from 7.01 to 6.65, the concentration of zinc increased from 0.006 mg/L to 0.007 mg/L, arsenic increased from 0.248 mg/L to 0.341 mg/L, and manganese also increased from 0.010 mg/L to 0.011 mg/L.

Zinc is an amphoteric metal and as a result dissolves both in bases and acids. Hence, when the pH of river Jimi during the downpour decreased from 6.93 to 6.81, the concentration of zinc increased from 0.01 mg/L to 0.012 mg/L, whilst the concentration of arsenic and manganese decreased from 0.018 mg/L to 0.013 mg/L, and 0.005 mg/L to 0.003 mg/L respectively. The more the zinc went into the rivers sampled, preventing the manganese and arsenic from being oxidised.
The next chapter will discuss the implications of these results and conclude the dissertation.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter recapitulate this special study on assessing the environmental impacts of small scale gold mining on River Jimi and River Nyame at Obuasi and its environs in Ashanti Region of Ghana. In a sequel to this, it also entails policy recommendation which if strictly adhered to will help reduce, if not completely ameliorate the environmental ramification of small scale mining in Ghana.

6.2 Conclusions

The physicochemical quality of the rivers sampled from the mining communities in terms of pH, temperature and dissolved oxygen (DO) in the entire river sampled were within the tolerable health risk level of pH of 6.5. to 8.5, DO of 20 mg/L according WHO (2004) standard. The concentration of metals such as Arsenic, mercury, zinc, lead, cadmium, and manganese, as well as toxic anions like Nitrate (NO_3^-), Sulphate (SO_4^{2-}) and Phosphate ($PO4^{2-}$) were found within the prescribed limit for chemical water quality parameter in respect to WHO (2004) standard of Arsenic level of 0.01 mg/L, Mercury level of 0.006 mg/L, Zinc level of 3.0 mg/L, Lead level of 0.01 mg/L, Cadmium level of 0.003 mg/L, Manganese level of 0.4 mg/L, Nitrate level of 50.0 mg/L, Sulphate level of 500 mg/L, Phosphate level of 10 mg/L.

However, the upstream of River Nyame during downpours gaves higher total dissolved solids (TDS) values than the prescribed limit given by World Health Organization. Moreover, there were high concentrations of Arsenic in the river bodies slightly above the prescribed limit of 0.01 mg/L given by World Health Organization. The concentration of cadmium in the rivers sampled had also reached the maximum prescribed permissible limit of 0.003 mg/L given by World Health Organization.

The study also shows that the pH of the water body had influenced the concentration of many metals such as zinc, arsenic, and manganese by altering their availability and toxicity. When the pH is low more metals are dissolved in the water bodies which will results in high concentration of metals in the water samples. Zinc as an amphoteric metal dissolve in both bases and acids. However, the acidic or basic nature of the rivers sampled did not significantly influence the concentration of lead, mercury and cadmium in the rivers sampled.

6.3 Recommendations

After a thorough and meticulous study and analysis of the water quality parameters and its ramifications as indicated in the preceding chapters, the following recommendations are made to address the environmental effect of SS gold mining on water resources:

1. Continuous study on the health implications of small scale gold mining activities on the communities along the two studied rivers is recommended.
2. The presence and the effect of heavy metals concentration on living organisms in the water bodies can also be considered for further research.
3. There should be further study on bioaccummilation of heavy metals on inhabitants that depend on the water bodies for consumption and other activities.

REFERENCES

Akabzaa, T. and Dramani, A. (2001). *Impact of Mining Sector in Ghana: A Study of the Tarkwa Mining Region*, Report to SAPRI, Pp 4-7.

Amankwah, R.K. and Anim-Sackey, C. (2003). *Some Developments in the Small- scale Mining of Precious Minerals,* Ghana Mining Journal, 7, 38-45.

Anin, T.E. (1990). *Gold in Ghana,* Selwyn Publishers Ltd, London, UK.

Aryee, B. N. A., Ntibrey, B. K. and Atorkui E. (2003). *Trends in the Small Scale Mining of Precious Minerals in Ghana: A perspective on its environmental impact,* Accra: Journal of Cleaner Production, (11th ed. Pp. 131-140).

Asamoah, V. E., Asiam, E. K., Kuma, J. S. (2007). *Assessment of a natural wetland for the remediation of acid mine drainage at Tarkwa, Ghana.* First International Conference on Environmental Research Technology and Policy (ERTEP), Accra, 16th - 19th July 2007.

Baird, C. (1995). *Environmental Chemistry.* W.H. Freeman and Company, New York Press Pp.301-302.

Bannerman, W., Potin-Gautier, M., Amouroux, D., Tellier, S., Rambaud, A. and Beinhoff, C. (2003). *Mercury and arsenic in the gold mining Regions of the Ankobra river basin in Ghana.* (4th ed. pp. 107-110). J. Phys.

Cifuentes, E., Rodriguez, S. (2005). *Urban Sprawl Water Insecurity and Enteric Diseases in Children from Mexico City*. Eco Health, (2005), Pp.70-75.

Cunningham, W.P., Cunningham, M.A. and Saigo, B. (2005). *Environmental Science: A global concern.* 8th edition. McGraw-hill, Boston.

Department of Water Affairs and Forestry (1996). *Water Quality Guidelines, Aquatic Ecosystem.* Use. Vol. 1, 2nd edn. DWAF, Pretoria.

Donkor, A. K., Nartey, V. K., Bonzongo, J. C. and Adotey D. K. (2006). *Artisanal mining of gold with mercury in Ghana* (9thed.) West Africa Journal of Applied Ecology (WAJAE).Retrieved on [10th October, 2012] from www.wajae.org

Ehrlich, H. L. (2002). *Geomicrobiology* (4th ed. pp. 220-224). New York: Marcel Dekker, Inc.

Garrison investigation Board (1997), *Water Quality Report.* Garrison division study, report to the international Joint Commission; US-Canada, Windsor Ontario

Grenne G. R., and Thomas P. R., (1993). *Rainwater quality from different roof Catchment. Water Science Technology*. Volume 28. pp 290-299

Griffith, M. B., J. M. Lazorchak, and Herlihy, A.T. (2004*)."Relationships among exceedances of metals criteria, the results of ambient bioassays, and community metrics in mining impacted streams."* Environmental Toxicology and Chemistry 23(7): pp.1786-1795.

Hilson, G. (2001). *A Contextual Review of the Ghanaian SSM industry* (pp. 2-30). Mining, Minerals and Sustainable Development.

IPCS (2001b) *Arsenic and arsenic compounds*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 224).

ITDG, (2001).*Country Assessment Report*. The World Bank, AFTU. Retrieved from http://www.natural-resources.org/minerals/smscalemining/definitions.htm on [10th October, 2012]

JECFA (2000). *Summary and conclusions of the fifty-fifth meeting, Geneva, 6-15 June 2000*. Geneva,World Health Organization, Joint FAO/WHO Expert Committee on Food Additives.

Kuma, J. S. and Tetteh, G. M. (2004), "Hydrochemical evaluation of surface waters in the Tarkwa gold mining district, Ghana", *90th Anniversary International Conference of the Geological Survey of Ghana, Accra*, 24-27 February, 2004

Kuma, J. S., Younger, P. L. and Bowell, R. J. (2002), *"Hydrogeological Framework for Assessing the Possible Environmental Impacts of Large-Scale Gold Mines". Conference jointly organised by Hydrogeological Group of the Geological*

Society of London and the Applied Mineralogy Group of the Mineralogical Society, British Geological Survey, *Key worth*, 15th February 2001.

Lodenius, L. and Malm, O. (1998). *Mercury in the Amazon*. Rev. Environ Contam. Toxicol. 152: 25-52.

Lombe, W. C. (2003). *Small scale mining and the environment: Bloom beyond the doom and gloom (11th ed. Pp. 95-96).* Accra: Journal of Cleaner

McClure, R. and Schneider, A. (2001). *The Seattle Post Intelligencer: More than a century of mining has left the West deeply scarred*.

Ntengwe, F. W. (2006). *Pollutant Loads and Water Quality in Streams of Heavily Populated and Industrialized Towns.* Physics and Chemistry of the Earth, 31:832-839.

Ntibrey, B.K. (2001). *SSM of Precious Minerals in Ghana- A Strategy to Improve Environmental Performance*. M.Sc. Thesis, School of Mines, Institute of Mining and Mineral Engineering, Kwame Nkrumah University of Science and Technology.

Obuasi Municipal Assembly Medium Terms Development Plan (2006). *Profile of Obuasi*. Obuasi, Town and Country Planning Department.

Owens, P.N., Batalla, R.J., Collins, A.J., Gomez, B., Hicks, D.M., Horowitz, A.J., and Trustrum, N.A. (2005). *"Fine-grained sediment in river systems: environmental significance and management issues."* River Research and Applications 21:693-717.

Project Underground (2000). *Gold Mining in Ghana Destroys Livelihoods, Health and the Environment.* Drill bits and Tailings, 22 Dec., Vol.5, No. 19 Retrieved on [10th October, 2012] from http://www.moles.org/ProjectUnderground/drillbits/5_19/4.html.

Ravengai, S., Love, D., Gratwicke, B., Mandingaisa, O. and Owen, R. J. S. (2005). *Impact of iron duke pyrite mine on water chemistry and aquatic life- Mazowe Valley* (2nd ed. pp. 219-228). Zimbabwe: Water SA.

Rozkowski, A. and Rozkowski, J. (1994). *Impact of Mine Waters on River Water Quality in the Upper Silesian Coal Basin*. Fifth International Mine Congress, Nottingham 18-23 September, Pp.811-821.

Shoko, D.S.M. and Love, D. (2005). *Gold panning legislation in Zimbabwe - what potentials for sustainable management of river resources* in*:* Mathew, K. and Nhapi, I. (Eds.) *Water and Wastewater Management for Development Countries* (pp. 499-512). London: IWA Publishing.

Shymamala, R., Shanthi, M. And Latitha, P. (2008). *Physicochemical analysis of Boerwell water samples of Telungupalayam Area in Coimbatore District,* Tamilnadu, India.E-Journal of Chemistry Vol 5, No.4, pp924-929.

Skousen, J., Politan, K., Hilton, T., and Meek, A. (1990). *Acid mine drainage treatment systems: chemicals and costs.* Green Lands, 20(4): 31-37.

Ullrich, S. M., Tanton, T. W. and Abdrashitova, S. A. (2001). *Mercury in the Aquatic Environment: A Review of Factors Affecting Methylation*. Crit. Rev. Environ. Sci. Technol. 31 (3): 241-293.

WHO (2003). *pH in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/12).

WHO (2003a). *Nitrate and nitrite in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization.

WHO (2003b). *Sulfate in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization

WHO (2003c). *Lead in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization.

WHO (2003d). *Manganese in drinking-water.* Background document for preparation of WHO Guidelines for drinking-water quality. Geneva, World Health Organization

WHO (2003e). Mercury in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality. Geneva, World Health Organization

WHO (2003f). Arsenic drinking water. Background document for preparation of WHO Guidelines for drinking-water quality. Geneva, World Health Organization

WHO (2006). Guideline value for drinking water quality. Geneva, World Health Organization

World Bank Group (2001). Retrieved on [10th October, 2012] from http://www.world bank.org/html/fpd/mining/key/artisanal/artisanal/html

World Health Organization (2006). *Guidelines for Drinking-Water Quality: Incorporating First Addendum.* Vol. 1, Recommendations. - 3rd Ed.